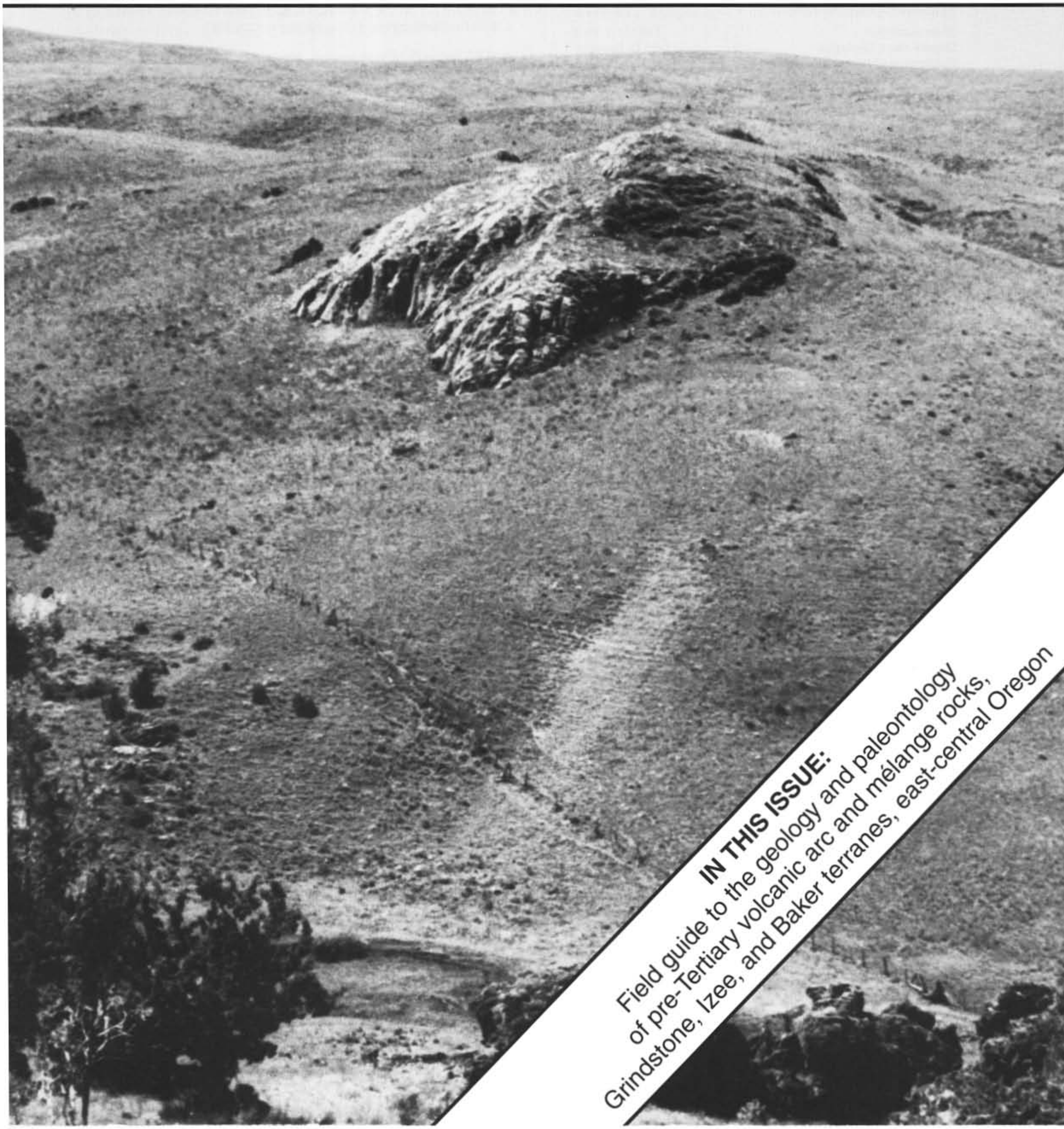
OREGON GEOLOGY

published by the
Oregon Department of Geology and Mineral Industries

VOLUME 54, NUMBER 6 NOVEMBER 1992



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Field guide to the geology and paleontology of pre-Tertiary volcanic arc and mélange rocks, Grindstone, Izee, and Baker terranes, east-central Oregon

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(ISSN 0164-3304)

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Published bimonthly in January, March, May, July, September, and November by the Oregon Department of Geology and Mineral Industries. (Volumes 1 through 40 were entitled *The Ore Bin*.)

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Information for contributors

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. If manuscript was prepared on common word-processing equipment (IBM compatible or Macintosh), a file copy on diskette should be submitted in place of one paper copy (from Macintosh systems, 3.5-inch high-density diskette 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 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*, 7th ed., 1991 or recent issues of *Oregon Geology*.) 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 the Oregon Department of Geology and Mineral Industries.

Cover photo

Large exposure of some of the oldest rock found in Oregon: Devonian limestone that was deposited somewhere nearly 400 million years ago and eventually attached to what was then the western edge of the North American continent. The location shown here, along Trout Creek in the Suplee area of east-central Oregon, is one of the stops of the field trip guide beginning on the next page.

OIL AND GAS NEWS

Drilling resumes at Mist Gas Field

During October, Nahama and Weagant Energy Company of Bakersfield, California, resumed a multi-well drilling program at the Mist Gas Field, Columbia County, Oregon. Thus far, three wells have been drilled this year: one is completed and producing gas and two are currently suspended. Drilling operations are underway at the fourth well which is the Wilson 11A-5-65, located in NW¼ sec. 5, T. 6 N., R. 5 W., Columbia County. Taylor Drilling Company, Chehalis, Washington, is the drilling contractor.

NWPA holds field symposium, announces workshop

The Northwest Petroleum Association (NWPA) held its annual field symposium at Lincoln City, Oregon, on October 11-13. The theme for the symposium was "New Exploration Concepts and Opportunities for the Pacific Northwest." Approximately 64 people attended the symposium, which covered topics of geological, geophysical, regulatory, environmental, legal, and land interests. Ray Wells, U.S. Geological Survey (USGS), and Alan Niem, Oregon State University, led an excellent field trip from Lincoln City to Tillamook to see the geology of the Oregon Coast.

For November 13, the NWPA has scheduled a meeting to include a workshop immediately following its monthly luncheon. The workshop will be on the national assessment of undiscovered oil and gas resources on the federal outer continental shelf, in state waters, and onshore. The USGS and the U.S. Marine Minerals Service will present the methodology of the assessment; at the subsequent workshop, individuals will be invited to suggest and describe hydrocarbon plays in the Pacific Northwest for possible formal designation as assessment plays. Contact Dan Wermiel at the Portland office of the Oregon Department of Geology and Mineral Industries for further information. □

Results of Santiam Pass drilling program now on open file

The Oregon Department of Geology and Mineral Industries (DOGAMI) has placed on open file the final report on results of the scientific drilling program conducted at Santiam Pass in the Cascade Range.

Geology and Geothermal Resources of the Santiam Pass Area of the Oregon Cascade Range, Deschutes, Jefferson, and Linn Counties, Oregon, edited by Brittain E. Hill.
DOGAMI Open-File Report O-92-3, 61 p., 1 map. Price $6.

This report describes in four chapters the drilling history of the Santiam Pass 77-24 well, the geologic setting of the Santiam Pass area, stratigraphy and petrology of the drill core, and the thermal results of the drilling. Appendices present descriptions and results of analytic work with surface samples, drill core sections, and thin sections. The blackline diazo map and cross section (scale 1:62,500) show geology, structure, and the locations of mountain peaks, samples used for radiometric dating, and temperature-gradient holes.

The new publication is now available at the Nature of Oregon Information Center, Suite 177, State Office Building, 800 NE Oregon Street #5, Portland, Oregon 97232-2109, phone (503) 731-4444. Orders may be charged to credit cards by mail, FAX, or phone. FAX number is (503) 731-4066. Orders under $50 require prepayment except for credit-card orders. Purchase by mail and over the counter is also possible at the DOGAMI field offices: 1831 First Street, Baker City, OR 97814, phone (503) 523-3133; and 5375 Monument Drive, Grants Pass, OR 97526, phone (503) 476-2496. □

Field guide to the geology and paleontology of pre-Tertiary volcanic arc and mélange rocks, Grindstone, Izee, and Baker terranes, east-central Oregon

by Charles D. Blome, U.S. Geological Survey, MS 919, Federal Center, Denver, CO 80225; and Merlynd K. Nestell, Department of Geology, University of Texas at Arlington, Arlington, TX 76019-0049.

This field guide was prepared for Part 1 of a field trip conducted May 13-16, 1992, in conjunction with the Cordilleran Section meeting of the Geological Society of America and entitled "Pre-Tertiary volcanic arc and mélange rocks of east-central Oregon." The first part of the field trip deals with volcaniclastic and mélange rocks in the Grindstone and Izee terranes and western part of the Baker terrane. Part 2, which deals with the pre-Tertiary sedimentary, plutonic, and ultramafic rocks in the western part of the Baker terrane, was led by Ellen Bishop and Howard Brooks, and the field guide will be published in a future issue of *Oregon Geology*.

Please note that part of the field trip entered private land and that the authors give special instructions at the beginning of the excursion itinerary. Permission to visit private land must be obtained in advance from the land owners listed in the acknowledgments. *—ed.*

INTRODUCTION

Pre-Cenozoic rocks in the Blue Mountains Province occur in a belt that trends northeast from about 15 mi south of the village of Paulina in central Oregon to near Grangeville, Idaho. Numerous inliers or windows of Paleozoic and Mesozoic (Devonian to Cretaceous) rocks in this belt are surrounded by Tertiary lavas and sedimentary rocks of continental origin (Brooks and Vallier, 1978). These inliers contain the only pre-Tertiary outcrops known between southern British Columbia and northern Washington on the north and northwestern Nevada on the south (Dickinson and Thayer, 1978). The Paleozoic inliers of the Grindstone terrane are of particular importance to Pacific Northwest geology because they are relatively unmetamorphosed (at most to zeolite grade).

This province can be described as a collage of tectonic blocks or terranes, some of which have been displaced from their original site of formation (Blome and others, 1986). Although the terrane concept (Irwin, 1972) has helped to interpret the geological relationships among the Blue Mountains structural units, the varied terminology can be confusing. A number of terrane names have been applied to the eastern Oregon units, but we use the terrane nomenclature of Silberling and others (1984, 1987), which includes, from southwest to northeast, the Grindstone, Izee, Baker, Olds Ferry, and Wallowa terranes (Figure 1). This field trip guide is an outgrowth of a study by the authors on the geology and tectonic history of the Grindstone terrane (Blome and Nestell, 1991). A complementary study is being prepared by Nestell and Blome on the paleontology and tectonic history of the Baker terrane.

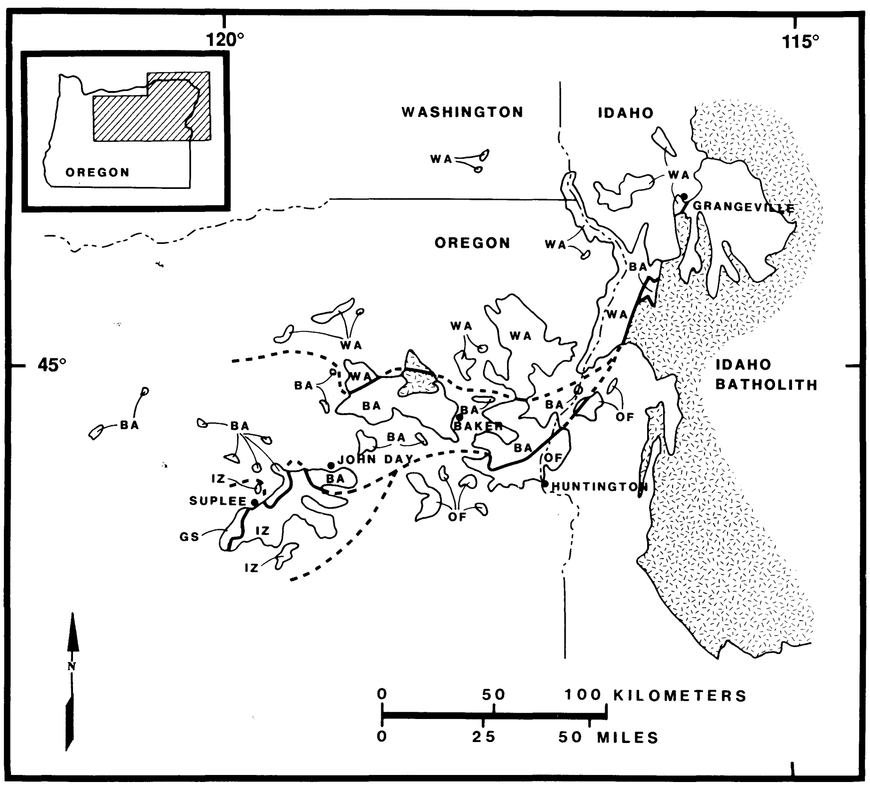

Figure 1. Distribution of pre-Tertiary rocks showing generalized terrane boundaries for the southwestern part of the Blue Mountains Province. GS = Grindstone terrane, IZ = Izee terrane, BA = Baker terrane, OF = Olds Ferry terrane, WA = Wallowa terrane. Terminology after Silberling and others (1984, 1987).

OVERVIEW

Grindstone terrane

The Grindstone terrane was first named the Paleozoic shelf terrane by Vallier and others (1977) because of the presence of shallow-water Devonian rocks. Grindstone terrane rocks were included in the mélange terrane of Dickinson and Thayer (1978), dismembered oceanic terrane by Brooks and Vallier (1978), central mélange terrane by Dickinson (1979), and oceanic/mélange terrane by Mullen and Sarewitz (1983).

The Grindstone terrane, exposed along the southwestern border of the province, contains some of the oldest rock units, including (1) Middle Devonian limestone interstratified with sandstone, chert, and argillite (unit Dl in

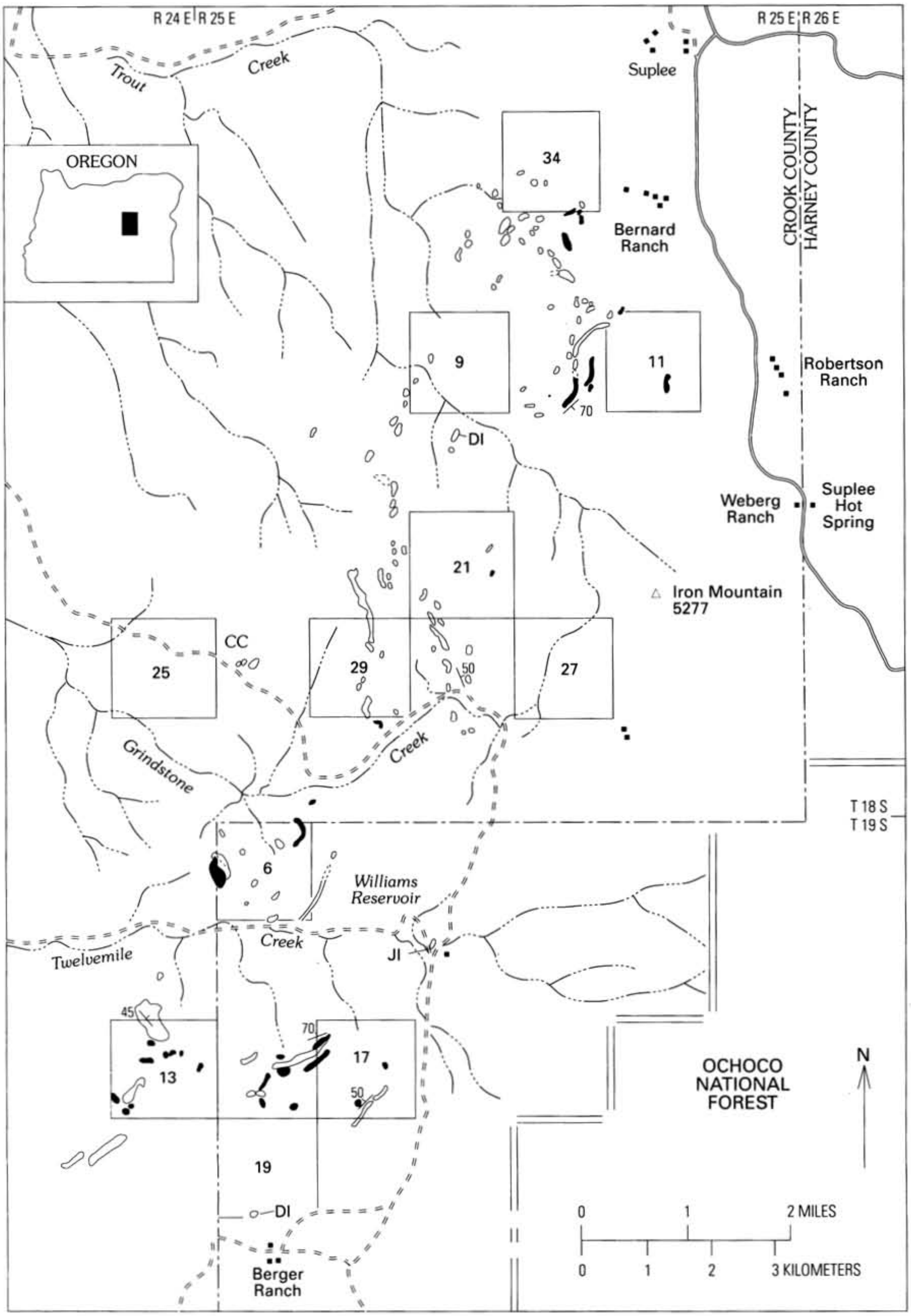

Figure 2. Distribution of Coyote Butte limestone unit (outlined areas) and unnamed chert exposures (darkened areas) (Grindstone terrane; Grindstone-Twelvemile mélange area in Figure 3). Dl = unnamed Middle Devonian limestone, CC = Coffee Creek limestone unit, Jl = unnamed Lower Jurassic limestone. Numbered squares are sections of the township/range surveying system.

Figure 2); (2) Mississippian limestone surrounded by and intermixed with calcareous and conglomeratic sandstone (originally called the Coffee Creek Formation by Merriam and Berthiaume, 1943; unit CC in Figure 2); (3) Pennsylvanian(?) mudstone, sandstone, and conglomerate (originally called the Spotted Ridge Formation by Merriam and Berthiaume, 1943) containing plant remains and minor limestone; (4) Lower Permian, partly fusulinacean-, brachiopod-, and bryozoan-bearing, volcaniclastic and dolomitic limestone (originally called the Coyote Butte Formation by Merriam and Berthiaume, 1943; outlined areas in Figure 2); (5) unnamed Permian and Lower Triassic radiolarian-bearing multicolored chert and dark mudstone (darkened areas in Figure 2); and (6) Permian and Triassic volcaniclastic sandstone and siltstone, limestone breccia, and pebble to boulder conglomerate (Blome and others, 1986; Blome and Nestell, 1991).

Izee terrane

The volcaniclastic-rich Izee terrane of Silberling and others (1984, 1987) includes the western half of the oceanic terrane of Vallier and others (1977), the western half of Dickinson's (1979) Mesozoic clastic terrane, and the western half of the fore-arc basin terrane of Brooks (1979b). The Izee terrane contains a thick, mainly flyschoid sequence of clastic sedimentary rocks, along with subordinate limestone and volcanic and volcaniclastic rocks that range in age from Late Triassic (Carnian) through Middle Jurassic (Callovian). This terrane contains Upper Triassic turbidite sequences with minor fine-grained basinal deposits that lie atop the Grindstone terrane. Rocks immediately adjacent to the Grindstone terrane in the Izee terrane consist of the chert-rich conglomerate assigned to the Begg Member of the Vester Formation, minor unnamed Lower Jurassic limestone and siltstone, and Middle Jurassic mudstone, siltstone, and sandstone that belong to the Weberg, Warm Springs, and Basey Members of the Snowshoe Formation (Dickinson and Vigrass, 1965; Blome and Nestell, 1991).

The northward-trending Poison Creek Fault divides the Upper Triassic and Lower Jurassic sedimentary rocks into two distinct stratigraphic units (Figure 3). Upper Triassic and Lower Jurassic rocks west of the fault are represented by the Vester Formation (Begg, Brisbois, and Rail Cabin Mudstone Members) and the Graylock Formation. The Rail Cabin was originally named the Rail Cabin Argillite by Dickinson and Vigrass (1965), later renamed the Rail Cabin Mudstone by Blome (1984), and most recently was reduced in rank as the Rail Cabin Member of the Vester Formation (Blome and others, 1986). Triassic and Lower Jurassic rocks east of the Poison Creek Fault include the Upper Triassic Fields Creek Formation and Laycock Graywacke and the Lower Jurassic Murderers Creek Graywacke and Keller Creek Shale. The varied biostratigraphic ages of these units are discussed by Blome and others (1986). The Triassic and Lower Jurassic units are overlain unconformably by Jurassic volcaniclastic fore-arc basin rocks of the Mowich Group and Snowshoe, Trowbridge, and Lonesome Formations (Dickinson and Vigrass, 1965; Dickinson and Thayer, 1978). Dickinson (1979) interpreted the volcaniclastic rock assemblages as mainly turbidites but stated that some shelf deposits are related to transgressive unconformities.

Baker terrane

Rock units now included in the Baker terrane of Silberling and others (1984, 1987) were originally defined as the oceanic terrane by Vallier and others (1977) because they represent structurally dismembered blocks of oceanic origin. They were also termed the dismembered oceanic terrane by Brooks and Vallier (1978) and central mélange terrane by Dickinson and Thayer (1978). Dickinson and Thayer (1978) and Dickinson (1979) considered the Miller Mountain, Frenchy Butte, and Grindstone-Twelvemile mélange areas (Figure 3) to be parts of their central mélange terrane. Silberling and others (1984, 1987) later integrated the Miller Mountain and Frenchy Butte areas into the Baker terrane.

The Baker terrane contains disrupted late Paleozoic oceanic crustal blocks, associated deep-marine sedimentary rocks of late Paleozoic and Triassic age, and tectonically mixed blocks of various rock types. Extensive zones of mélange occur in the southwestern part of the terrane, whereas more coherent rock packages exist in the

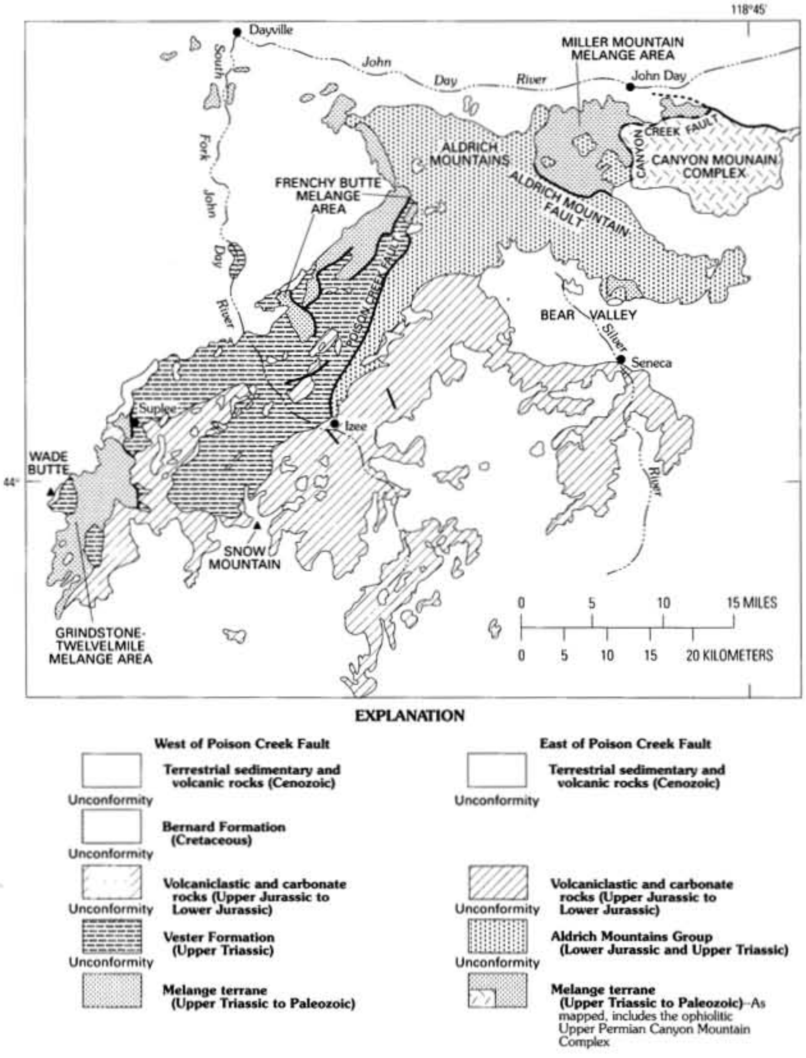

Figure 3. Generalized geologic map of the Izee and Grindstone terranes showing the location of mélange areas (modified from Dickinson and Thayer, 1978). Frenchy Butte and Miller Mountain mélange areas are now included within the Baker terrane, Grindstone-Twelvemile mélange area is considered the Grindstone terrane, and other rocks between Suplee and John Day are placed within the Izee terrane (Silberling and others, 1984, 1987).

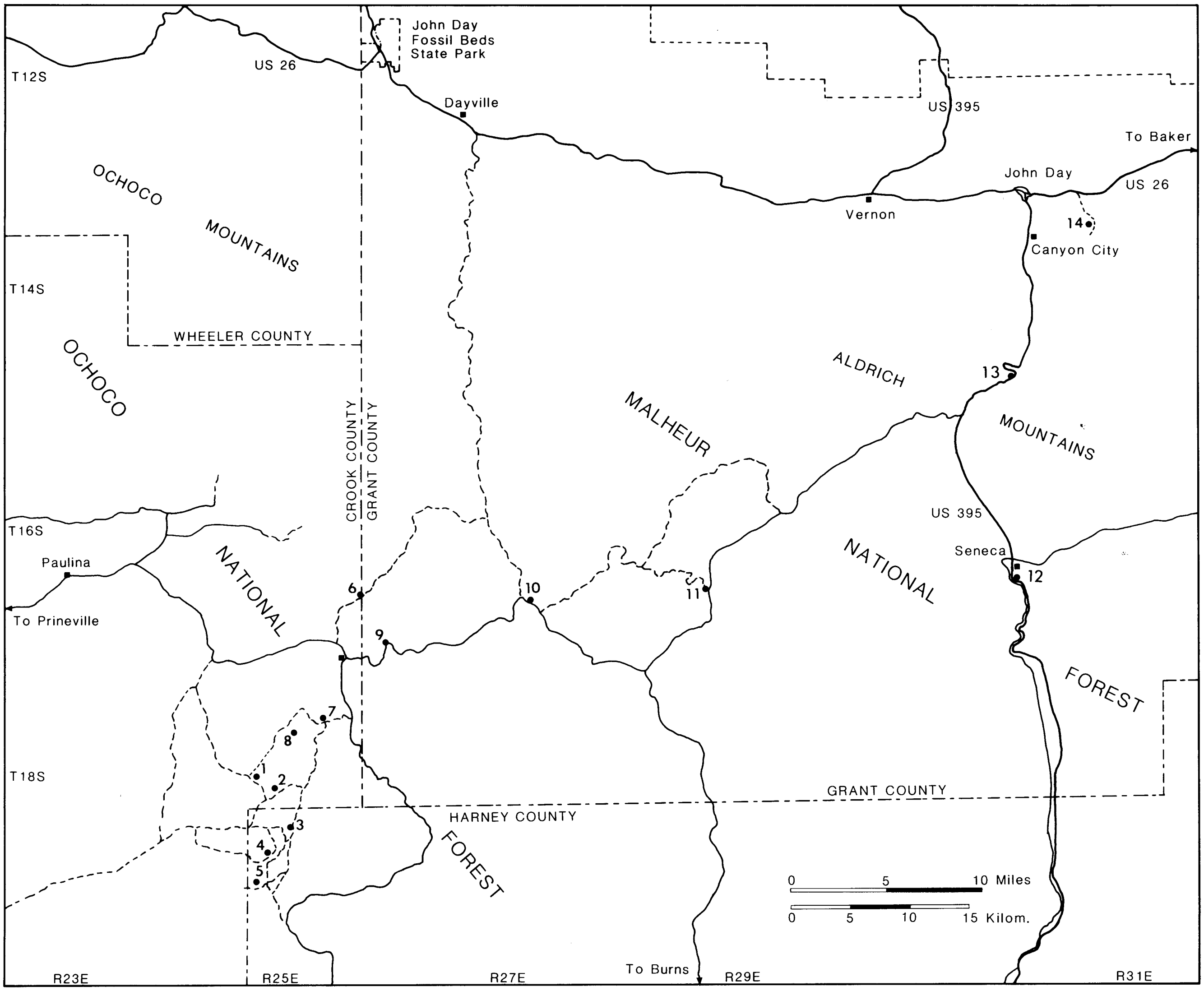

Figure 4. Map showing field trip stops for pre-Tertiary volcanic arc and mélange rocks of the Grindstone and Izee terranes and western part of the Baker terrane, east-central Oregon.

northwestern and eastern parts. Large bodies of highly deformed but lithologically coherent metamorphic and sedimentary rocks, such as the Burnt River Schist and the informally named Nelson Marble of Prostka (1967), are also present in the eastern part (Vallier and others, 1977; Silberling and others, 1984, 1987).

Blocks of serpentinite and greenstone, siliceous shale, chert, and associated metamorphosed (greenschist-grade) volcaniclastic rocks compose the Miller Mountain mélange (Figure 3). This mélange is separated from the Canyon Mountain Complex (Brown and Thayer, 1966) by the Canyon Creek Fault on the east and from the Aldrich Mountains Group of the Izee terrane by the Aldrich Mountain Fault (Figure 3). The Canyon Mountain Complex, well exposed southeast of the town of John Day (Brown and Thayer, 1966; Avé Lallemant, 1976), represents the basement rocks for the mélange (Vallier and others, 1977). Mid-Permian Tethyan fusulinaceans (verbeekinids and neoschwagerinids), and Middle (late Ladinian) to Late Triassic (early Carnian) radiolarians have been reported from limestone and chert pods, respectively, southeast of John Day on Little Dog Creek (Dickinson and Thayer, 1978; Nestell and MacLeod, 1984; Blome and others, 1986). Excellent exposures of serpentinite and pyroxenite are present a few hundred meters east of the limestone and chert outcrops.

The Frenchy Butte mélange area, located north of the town of Izee between exposures of the Fields Creek Formation (of the Aldrich Mountains Group) and the South Fork of the John Day River (Figure 3), is composed almost entirely of serpentinite and metavolcanic rocks. Although not fossiliferous, this mélange area was presumed by Dickinson and Thayer (1978) to be either Permian or Triassic in age.

Upper Paleozoic and lower Mesozoic rocks in the eastern part of the Baker terrane near Baker City, Oregon, include abundant chert, argillite, siliceous tuff, and rare coarse-grained sedimentary rocks (Vallier and others, 1977; Brooks and Vallier, 1978). Incorporated in this part of the terrane are argillite, chert, tuff, and limestone of the Elkhorn Ridge Argillite; thin-layered phyllitic quartzite, greenstone, and marble of the Burnt River Schist (Gilluly, 1937); and basalt flows and varied volcaniclastic rocks. Most of the rocks have undergone severe structural deformation and metamorphism (greenschist to rarely amphibolite facies) and in many areas are structurally intermixed with plutonic bodies.

The Baker terrane (Figure 1) is bounded on the north by Wallowa terrane Lower Permian to Middle and Upper Triassic metavolcanic and volcaniclastic rocks overlain by Upper Triassic and Lower

Jurassic carbonate rocks and clastic sequences (Silberling and others, 1984, 1987). Directly south of the Baker terrane are Upper Triassic mafic and intermediate volcanic and volcaniclastic rocks of the Huntington Formation of Brooks (1979a) in the Olds Ferry terrane (Figure 1). These are overlain by Lower Jurassic (and possibly uppermost Triassic) limestone and coarse-grained volcaniclastic rocks and Lower and Middle Jurassic sedimentary rocks of the Weatherby Formation of Brooks (1979a).

Only one locality in the generally unfossiliferous western part of the Baker terrane will be discussed in this field trip guide. Chert and limestone similar to that found in the type area of the Elkhorn Ridge Argillite in the eastern part of the Baker terrane can be found north of the Aldrich Mountains, southeast of John Day along Little Dog Creek. Here, limestone containing mid-Permian Tethyan fusulinaceans is juxtaposed with chert containing Middle and Late Triassic radiolarians (Nestell and MacLeod, 1984; Blome and others, 1986). Mélange, ophiolitic, and plutonic rocks in other parts of the Baker terrane will be discussed in connection with Part 2 of this field trip.

EXCURSION ITINERARY

Before you start

All roads and stops for this field trip guide are illustrated in Figure 4. **Stops 1-5 and 7-8 are behind locked gates on private ranches, and written permission to visit them must be obtained in advance from the property owners (see Acknowledgments).** These off-road stops are included in this guide because of their geologic uniqueness and importance to the geology and tectonics of central Oregon.

A good overview of the area can be obtained by visiting the stops that are on public land or near all-weather roads. The field trip could then begin with Stop 6 and continue with Stops 9-14. Stop 6 is on National Forest Service land but inaccessible in wet weather. At Stop 14, permission to venture off the Dog Creek road must be obtained.

The area through which this field trip passes is in a remote part of Oregon, and obvious precautions for travel should be observed. For example, gasoline and supplies in the Grindstone terrane are available only at the general store in the village of Paulina. The closest facilities in the Izee terrane and western part of the Baker terrane are in the John Day area. Reasonable caution should be taken in following the road log, as many of the unpaved roads on private ranches are impassable in wet weather (even with four-wheel drive). Stopping along roads should be done with due caution.

En route

The excursion begins in Prineville, Oregon. Travel approximately 64 mi from Prineville, Oregon, to Paulina via State Highway 380. Field trip mileage starts at the east edge of Paulina. Travel east on paved road from Paulina (Crook County Road 112) approximately 3.6 mi to Y-intersection, take the east fork and travel another 6.6 mi to turnoff (right) onto Grindstone Creek-Twelvemile Creek dirt road traveling south. Travel south-southwest past cattle pens (0.7 mi) toward basalt plateau (Grindstone Rim). Continue on dirt road approximately 1.5 mi to Y-intersection, take the left fork and head south-southeast on dirt road another 2.5 mi to the locked gate of the G.I. Ranch. **Written permission must be obtained for travel beyond this point for Stops 1-5 and 7-8** (Stop 6 is on National Forest Service land). Continue east 3.0 mi and park for Stop 1: Coffee Creek limestone unit (SE¼NW¼ sec. 30, T. 18 S., R. 25 E., Twelvemile Reservoir 7.5′ quadrangle; limestone pods with nearly vertical bedding located a short 0.1-mi hike east of dirt road).

STOP 1—COFFEE CREEK LIMESTONE UNIT, CENTRAL GRINDSTONE TERRANE

Limestone exposed on Coffee Creek, a drainage that enters Grindstone Creek south of Wade Butte, was named the Coffee Creek Formation by Merriam and Berthiaume (1943). The limestone exposures at this stop in the west-central part of the terrane (CC in Figure 2) represent their type section (Figure 5). According to Merriam and Berthiaume, typical Coffee Creek rock types include well-bedded carbonaceous limestone, muddy to sandy limestone, and calcareous sandstone; calcareous sandstone accounts for a large part of the exposures. The lower part of their section consists of sandy limestone and sandstone and grades up into argillaceous limestone.

Buddenhagen (1967) stated that he had difficulty establishing the lower and upper limits of the Coffee Creek Formation and estimating formational thickness. With the exception of the exposure in sec. 30 (CC in Figure 2), Coffee Creek exposures are small (less than 20 ft [6 m] thick) and generally restricted to the west-central part of the Grindstone terrane. The lack of mappability and traceability of the Coffee Creek exposures prompted Blome and Nestell (1991) to recommend that formal formational status be discontinued for these rocks and that the informal name "Coffee Creek limestone unit" be retained.

Merriam and Berthiaume (1943) listed corals, brachiopods, small loxonemoid gastropods, and lithistid sponge spicules from this exposure. They also stated that, because the brachiopod *Striatifera* is present, the Coffee Creek sandstones are no older than Early Carboniferous. Also present is the brachiopod *Gigantella*, whose horizon is roughly Mississippian (Visean) in age. The Coffee Creek was assigned a Late Mississippian (middle and late Meramecian and Chesterian) age by Poole and Sandberg (1977). Skinner and Wilde (1965) suggested that the Coffee Creek contained fusulinacean faunas of Early Pennsylvanian age, but fusulinaceans (*Eostaffella*) and corals (*Hexaphyllia*) collected near this locality are indicative of a Late Mississippian (Chesterian) age (Sada and Danner, 1973).

En route

Continue approximately 3.0 mi south and southeast along the same dirt road and park for Stop 2: Coyote Butte limestone unit (NW¼NW¼ sec. 33, T. 18 S., R. 25 E., Delintment Lake 7.5′ quadrangle; three large limestone blocks located on flank of ridge 0.25 mi southeast of dirt road).

STOP 2—COYOTE BUTTE LIMESTONE UNIT, CENTRAL GRINDSTONE TERRANE

The Coyote Butte limestone unit is lithologically consistent throughout much of the terrane in being coarser and crinoid- and fusulinacean-bearing in the lower parts of its exposures and finer grained and brachiopod-bearing in its upper parts. The limestone exposures strike northeast in the northern part of the terrane; the strike changes to northwest in the central part and reverts to northeast in the southern part (Figure 2). Individual beds within each exposure can dip steeply (to 75°). Some limestone blocks possess relatively uniform stratigraphy, whereas others are overturned, and some exhibit disturbed and deformed bedding. Blome and Nestell (1991) recommended that formal formational status of the Coyote Butte Formation (Merriam and Berthiaume, 1943) be discontinued because of the lack of mappability between limestone blocks and their chaotic intermixing with surrounding chert and volcaniclastic rocks; they also recommended that the informal name "Coyote Butte limestone unit" be retained.

At this locality in the central part of the terrane just north of Grindstone Creek (Figure 6), dolomitic and crinoidal limestone blocks containing limestone breccia and replacement chert crop out over several kilometers in a north-northeast trend (Figure 2). One of the limestone pods north of the road has yielded poorly preserved Early Permian conodonts (*Sweetognathus*), silicified gastropods (*Tapinotomaria*?), and poorly preserved dolomitized fusulinaceans (probably *Schwagerina*). At some localities, volcaniclastic rocks (andesitic, dacitic, and welded-tuff rock fragments) are also found in Coyote Butte fusulinacean- and bryozoan-bearing limestone, and zeolites replacing parts of fossil fragments (e.g., crinoid columnals) are common.

En route

Continue approximately 0.7 mi south and east to road cuts just west of small unnamed lake. Unnamed chert and conglomerate (questionably assigned to the Begg Member of the Vester Formation) can be observed at these road cuts. Continue 0.2 mi and turn south across earth dam and go another 3.6 mi to old Sherman ranch house. En route across the topographic high, one can see to the south the limestone exposures at Three Buttes (i.e., Coyote Butte; Figure 7). Travel approximately another 0.2 mi west and park for Stop 3: Unnamed Lower Jurassic limestone and siltstone (NE¼NE¼ sec. 8, T. 19 S., R. 25 E., Delintment Lake 7.5′ quadrangle; exposure just north of dirt road).

STOP 3—UNNAMED LOWER JURASSIC LIMESTONE AND SILTSTONE, CENTRAL GRINDSTONE TERRANE

A small exposure of limestone, shale, and siltstone (unit Jl in Figure 2; Figure 8) crops out north of Twelvemile Creek along the Grindstone-Izee terrane boundary. Buddenhagen (1967) reported that ammonites from this exposure are indicative of an Early Jurassic (Hettangian) age. Coeval siltstone-limestone exposures, assigned by Dickinson and Vigrass (1965, p. 29) to the Graylock Formation, crop out near Morgan Mountain in the adjacent Izee terrane to the northeast.

En route

From Stop 3, travel 0.6 mi south across dam to intersection. To continue field trip, take left fork heading south (right fork continues west along Twelvemile Creek and ultimately back to Paulina) and proceed another 0.6 mi to Y-intersection. Take the left fork (right fork goes to Delore Ranch) and travel 1.2 mi to T-intersection, turn right (north-northwest) and go 0.85 mi to U-shaped loop road and park for Stop 4: Coyote Butte limestone unit at Three Buttes (called Coyote Butte by Merriam and Berthiaume, 1943; S½NE¼ sec. 18, also W½NW¼ sec. 17, T. 19 S., R. 25 E., Twelvemile Reservoir 7.5′ quadrangle. The interconnected, southwest-northeast-trending Coyote Butte limestone blocks and adjacent chert are approximately a quarter-mile hike due north.

STOP 4—COYOTE BUTTE LIMESTONE UNIT AND UNNAMED CHERT, COYOTE BUTTE (THREE BUTTES), SOUTHERN GRINDSTONE TERRANE

Coyote Butte limestone unit

The Coyote Butte Formation was named by Merriam and Berthiaume (1943) for the long, prominent limestone ridge that constitutes most of Three Buttes in the southern part of the Grindstone terrane (sec. 18 in Figure 2; Figure 7). The limestone at Coyote Butte can be roughly divided into a basal light-gray, massive crinoidal, fusulinacean- and bryozoan-bearing packstone, overlain by a light-gray, medium- to thick-bedded, finer grained packstone and grainstone (Figure 9a), and an upper darker gray to yellow-brown, brachiopod-bearing argillaceous wackestone (Wardlaw and others, 1982, p. 13). According to Merriam and Berthiaume (1943), the Coyote Butte is approximately 900 ft (274 m) thick, but an exact thickness could not be determined because of poor bedding and folding.

Other significant Permian limestone exposures occur west and southwest of Coyote Butte. For example, three northerly trending limestone blocks exposed west of Three Buttes (the northeast-trending block in the southwest quarter of sec. 13, sometimes called Tucker's Butte; Figures 2 and 9b) are lithologically similar to those found at Three Buttes. Over 200 ft (60 m) of chert-grain and fine-pebble conglomerate interbedded with Coyote Butte limestone is exposed just north of Tucker's Butte on Triangulation Hill (large limestone block on the boundary of secs. 12 and 13; Figure 2). Chert commonly replaces limestone in the southwestern part of the terrane and occurs in the form of unfossiliferous, gray to black, translucent, irregular patches or pinch and swell beds.

Brachiopod, conodont, coral, and fusulinacean faunas from the Coyote Butte limestone unit are indicative of an Early Permian (late Wolfcampian to Leonardian) age (Merriam and Berthiaume, 1943; Wardlaw and others, 1982; Blome and Nestell, 1991). Merriam and Berthiaume (1943) reported earliest Permian fusulinaceans from the stratigraphically lower parts of the Coyote Butte. However, limestones collected from more than 40 localities contain similar fusulinacean faunas of late Wolfcampian to early Leonardian age (Plate 1; Blome and Nestell, 1991). The Coyote Butte fusulinacean faunas have affinities with those described from the middle part of the McCloud Limestone (Zones G and H) in the Shasta Lake area, northern California, and with those described from near Quinn River Crossing in northern Nevada (Skinner and Wilde, 1965, 1966).

Colonial corals from the Coyote Butte limestone include several species of *Heritschioides*, *Petalaxis occidentalis*, and *Thysanophyllum*? sp. (Merriam, 1942; Stevens and Rycerski, 1983). Brachiopod faunas described by Cooper (1957) from stratigraphically higher parts of the Coyote Butte are no older than latest Leonardian and may be as young as early Guadalupian. However, Waterhouse (1976) considered this fauna to be partly late Asselian in age.

Several limestone exposures (Three Buttes, Tucker's Butte, and Triangulation Hill) were sampled for conodonts and fusulinaceans by Wardlaw and others (1982). Their fusulinacean data suggest, at least in part, a Leonardian age, and the sparse conodont faunas are indicative of a Leonardian (= Artinskian; see Furnish, 1973) age for the exposures.

Unnamed chert

Siliceous rocks in the Grindstone terrane include abundant black, green, and red radiolarian chert, siliceous mudstone, and fine-grained tuff. Even though the chert exposures exhibit some lateral coherence, these rocks as a whole were never assigned a formational name and were considered part of the Carboniferous Spotted Ridge Formation according to Merriam and Berthiaume (1943). Ketner (1967) indicated that the upper part of the Coyote Butte Formation was overlain by as much as 900 ft (274 m) of chert.

Facing page, first left, then right column from the top down:

Figure 5. Coffee Creek limestone unit exposure at Stop 1 in west-central part of the Grindstone terrane (CC in Figure 2). Type section of Coffee Creek Formation of Merriam and Berthiaume (1943).

Figure 6. Typical exposures of the fusulinacean-bearing and dolomitic Coyote Butte limestone unit and unnamed chert (upper right) at Stop 2, south side of Grindstone Creek, central part of Grindstone terrane.

Figure 7. View to the south from Williams Reservoir in central part of Grindstone terrane. The three rolling hills (left of center; Three Buttes, also called Coyote Butte) are Coyote Butte limestone unit exposures seen at Stop 4. Type area of Coyote Butte Formation of Merriam and Berthiaume (1943).

Figure 8. Exposure of unnamed Lower Jurassic limestone and siltstone at Stop 3 just west of old Sherman ranch house. Scarce ammonites occur in the shales to the right of the steeply dipping limestones.

Figure 9a. Thin section of massive carbonate grainstone-packstone exposed at the northeast end of Three Buttes (Stop 4). Dark areas are cross sections of fusulinaceans, and light-colored oval areas are crinoid columnals. Field of view 8cm x 4.5cm.

Figure 9b. Exposure of steeply dipping Coyote Butte limestone unit on prominent butte to the west of Three Buttes (sometimes called Tucker's Butte; NW¼SW¼ sec. 13, T. 19 S., R. 24 E., Twelvemile Reservoir 7.5′ quadrangle). Photo taken looking south.

Figure 9c. Exposure of unnamed chert (Stop 4) located just 0.2 mi northeast of Three Buttes (loc. 5 of Blome and Reed, 1992).

Figure 10. Small pod (left side of photo) of Middle Devonian coral-bearing limestone at Stop 5; also informally referred to as the Berger Ranch limestone (Danner, 1977). Limestone pod on right side of photograph is barren of corals and conodonts and is now considered Triassic or Jurassic in age (Blome and Nestell, 1991).

Figure 5.

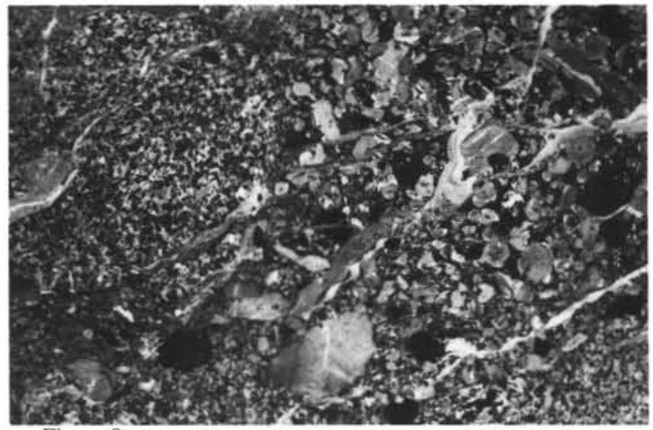

Figure 9a.

Figure 6.

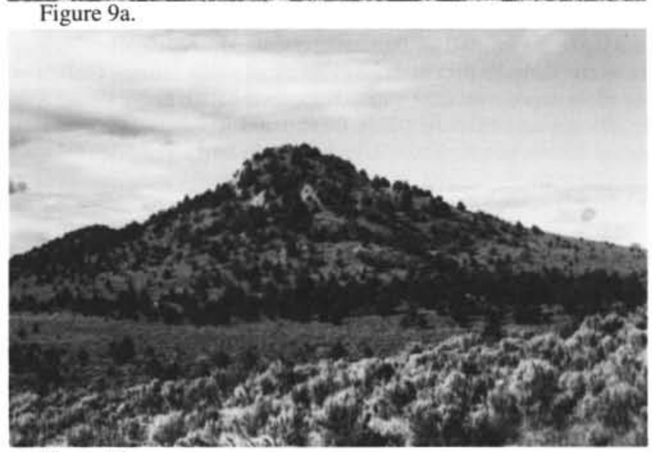

Figure 9b.

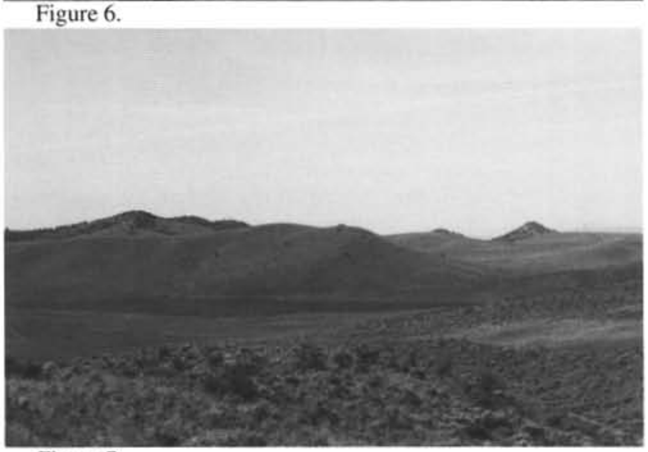

Figure 7.

Figure 9c.

Figure 8.

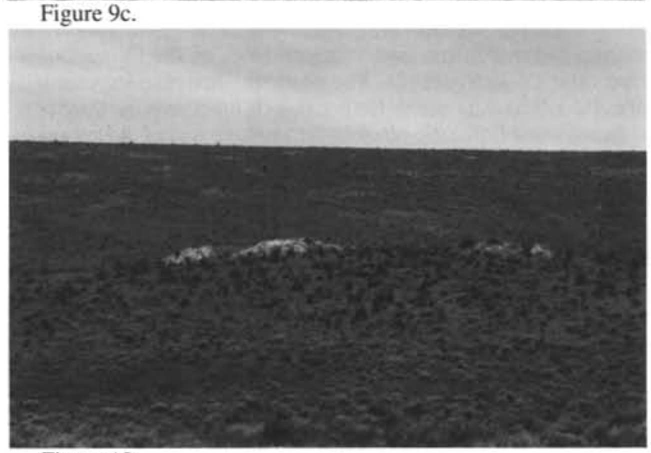

Figure 10.

Abundant chert float and small pods of chert and siliceous mudstone surround Three Buttes (i.e., Coyote Butte) but do not appear to be in depositional contact with the limestone. A red chert exposure approximately 0.2 mi northeast of the eastern extension of Coyote Butte (Figure 9c; NW¼NW¼ sec. 17, T. 19 S., R. 25 E., Twelvemile Reservoir 7.5′ quadrangle) contains radiolarian faunas assignable to the mid-Permian (upper Leonardian to lower Guadalupian) *Pseudoalbaillella globosa* Zone of Ishiga (1986; cf. Blome and Nestell, 1991; Blome and Reed, 1992). The common radiolarian taxa (Plate 2) include *Albaillella asymmetrica* Ishiga and Imoto, *Pseudotormentus kamigoriensis* De Wever and Caridroit, *Pseudoalbaillella* sp. aff. *P. globosa* Ishiga and Imoto, *Latentifistula* sp. aff. *L. crux* Nazarov and Ormiston, *Kashiwara magna* Sashida and Tonishi, and *Hegleria mammilla* (Sheng and Wang).

Blome and others (1986) demonstrated that cherts in the Grindstone terrane contain Permian (late Wolfcampian to late Guadalupian) radiolarian faunas. Additional chert collections from more than 40 localities suggest nearly continuous Grindstone chert deposition from Early Permian through Early Triassic time (Blome and Nestell, 1991; Blome and Reed, 1992). Other reported fossils besides radiolarians include Early Triassic conodonts (*Neospathodus pakistanensis* and *Ellisonia* sp.; Wardlaw and Jones, 1980).

Thinly bedded, unfossiliferous, dark-red siliceous mudstone crops out approximately 0.4 mi south of Coyote Butte (boundary between SW¼ and SE¼ sec. 18, T. 19 S., R. 25 E., Twelvemile Reservoir 7.5′ quadrangle, just north of road). It is well laminated and iron stained and lacks many of the small-scale sedimentary features (vertical and lateral graded-bedding, cross-bedding, and cut- and fill-structures) common in the dark-colored cherts.

Most of the Grindstone cherts exhibit well-developed bedding that contrasts with many of the metacherts in the adjacent Baker terrane (Figure 1). Multicolored, bedded chert has not been found in the Izee terrane (Blome, 1984; Blome and others, 1986).

En route

Backtrack to last T-intersection, turn due south, and go approximately 1.0 mi to a Y-intersection, take right (southwest) fork, go 0.5 mi to Berger Ranch buildings, and park for Stop 5. Walk approximately 0.4 mi north to fence line. The larger limestone pod immediately north of the fence represents Stop 5: Unnamed Devonian limestone (SE¼SW¼ sec. 19, T. 19 S., R. 25 E., Twelvemile Reservoir 7.5′ quadrangle).

STOP 5—UNNAMED DEVONIAN LIMESTONE NEAR THE OLD BERGER RANCH, SOUTHERN GRINDSTONE TERRANE

Among the oldest Paleozoic rocks in Oregon are two blocks of limestone in the northern and southern parts of the Grindstone terrane (unit Dl in Figure 2). The southern Devonian exposure, informally referred to as the Berger Ranch limestone by Danner (1977), is a small limestone block in the southern part of the terrane just northwest of the Berger Ranch house near the Crook and Harney Counties boundary (Figure 10, southern Dl in Figure 2).

This southernmost limestone block has yielded Middle Devonian (probably Givetian) corals, including *Heliolites* cf. *H. relectus*, *Thamnopora* sp., and *Grypophyllum* sp. (William Oliver, written communication, 1987). A smaller limestone pod that crops out just east of the southern Devonian exposure (Danner, 1977) was assigned a Triassic age by Johnson and Klapper (1978). The only other Devonian fossils known from eastern Oregon are Middle to Late Devonian conodonts (*Polygnathus* spp.) from a limestone exposure in the Baker terrane (Figure 1) to the northeast (Mullen-Morris and Wardlaw, 1986).

En route

Backtrack to the Paulina-Izee paved highway, where the Grindstone Creek-Twelvemile Creek dirt road began (Figure 4). Travel east toward Izee for 7.0 mi, turn north on the dirt road, and go 1.8 mi to the Andy Bernard Ranch. Go past ranch buildings through gate (Note: Although this is a public access road, do not attempt to travel beyond gate in wet weather!) and continue east 2.0 mi to Crook-Grant Counties boundary and park for Stop 6: Coyote Butte limestone unit, northern Grindstone terrane (near intersection of secs. 1/12 and 6/7, T. 17 S., Rs. 25 and 26 E., respectively, Suplee 7.5′ quadrangle, Figure 11a; one large and two small knobs of the Coyote Butte limestone unit located 1.6 mi northeast of ranch house; another limestone knob located 0.5 mi to the northeast, all exposed on north side of road).

STOP 6—COYOTE BUTTE LIMESTONE UNIT NEAR BERNARD RANCH, NORTHERN EDGE OF GRINDSTONE TERRANE

One large and two small fossiliferous limestone blocks crop out near the boundary between Crook and Grant Counties (Figure 11a). This locality is also equivalent to locality OR-4 of Skinner and Wilde (1966) and locality V192 of Dickinson and Vigrass (1965).

The northeasternmost limestone pod (Figures 11a and 11b; NE¼SW¼ sec. 6, T. 17 S., R. 26 E., Suplee 7.5′ quadrangle) is equivalent to locality OR-5 of Skinner and Wilde (1966) and locality V193 of Dickinson and Vigrass (1965). This exposure represents one of the few places where large blocks of Coyote Butte limestone are exposed on public property. Abundant volcaniclastic debris composed of andesitic, dacitic, and welded-tuff rock fragments and zeolites replacing parts of the fossil debris (Figure 11c) have been reported from one of the small limestone blocks (Blome and Nestell, 1991). Skinner and Wilde (1966) described Early Permian (late Wolfcampian or early Leonardian) fusulinaceans (Plate 1) from these limestone blocks.

En route

Travel west and south back to Paulina-Izee paved road, turn east, go 1.0 mi, and turn south onto paved road (Crook County Road 318) toward Robertson and Weberg Ranches. Travel south and go 3.4 mi to four-way intersection at Robertson Ranch, then turn west onto dirt road and go 1.7 mi to Y-intersection, take the left fork and proceed

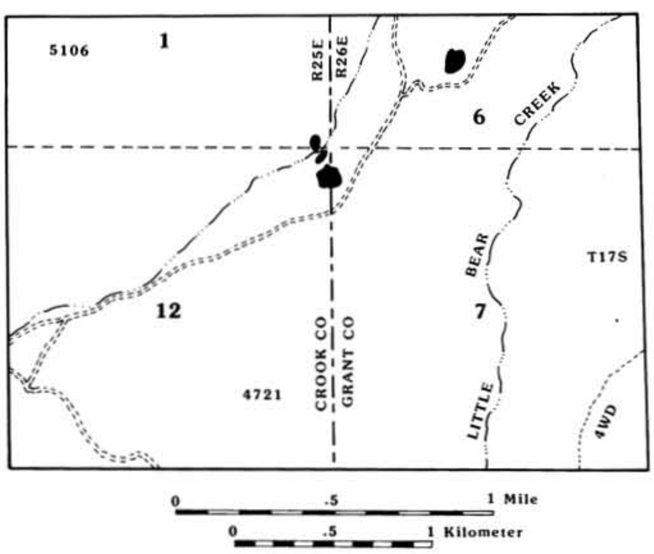

Figure 11a. Distribution of Coyote Butte limestone blocks at Stop 6 along the northern boundary of the Grindstone terrane, near boundary between Crook and Harney Counties. Large numbers identify sections of the township/range surveying system.

Figure 11b. Large pod of the Coyote Butte limestone unit at Stop 6 on forest service road northeast of the Bernard ranch.

Figure 11c. Thin section of carbonate (grainstone) from small limestone pod at Stop 6, north side of small drainage (NE corner sec. 12, T. 17 S., R. 25 E., Suplee 7.5′ quadrangle; loc. 35S-17B of Blome and Nestell, 1991). Crinoid columnal coated with bryozoan in center of photo. Field of view 2.5cm x 1.7cm.

0.5 mi to another Y-intersection, proceed on right fork (new road!) 0.3 mi, and park for Stop 7: Unnamed chert unit (SE¼NE¼ sec. 10, T. 18 S., R. 25 E., Suplee 7.5′ quadrangle). Hike approximately a quarter of a mile north to top of north-south trending ridge on east side of fence line to view unnamed red chert exposures. Conglomerate and volcaniclastic sandstone can be seen a short hike (0.4 mi) to the west along the dirt road (center of sec. 10, T. 18 S., R. 25 E., Suplee 7.5′ quadrangle).

STOP 7—UNNAMED CHERT AND BEGG MEMBER OF VESTER FORMATION, NORTHERN GRINDSTONE TERRANE

Unnamed chert

Chert is sparsely exposed in the northern part of the terrane as lenticular blocks, many of which are elongate and aligned in a general northeast-southwest-trending direction and parallel the Coyote Butte exposures (Figure 2). The chert exposures are typically nonresistant (low lying), red and black, and thickly bedded in the north near the North Fork of Trout Creek. Thin intrabeds of dark, red to black mudstone and shale represent a minor fraction of the siliceous rocks. The northern bedded chert exposures were informally referred to as the Birdsong beds by Buddenhagen (1967).

Narrow exposures of red chert are an easy hike north from an unmapped dirt road that leads west from the four-way intersection of the paved road to Suplee and the road to the Robertson Ranch (Figure 4). One exposure of red chert can be seen approximately a quarter of a mile north of the dirt road (Figures 12a and 12b). The radiolarian faunas extracted from this exposure (Plate 2) are the oldest in the Grindstone terrane (loc. 2 of Blome and Reed, 1992) and correlate with the Lower Permian (Wolfcampian) *Pseudoalbaillella lomentaria* and *Pseudoalbaillella scalprata* m. rhombothoracata Zones of Ishiga (1986). Age-diagnostic taxa include *Pseudoalbaillella scalprata* morphotype *scalprata* Ishiga and *Pseudoalbaillella scalprata* morphotype *postscalprata* Ishiga (Plate 2). Parts of this same chert trend can be traced across the ridge tops to the south-southwest (Figure 12a), and other bands can be seen approximately half a mile to the southeast.

Begg Member of Vester Formation

According to Dickinson and Thayer (1978), the Begg Member of the Vester Formation (originally Begg Formation of Dickinson and Vigrass, 1965) unconformably overlies the Paleozoic rocks of the Grindstone terrane and represents the oldest rocks in the Izee terrane. The significance of this unconformity for discriminating the Izee from the Grindstone terrane is discussed below. The Begg Member is characterized by chert-grain sandstone, chert-pebble conglomerate, volcaniclastic rocks, and sedimentary breccia, intercalated with equal or greater amounts of mudstone and siltstone.

A small road cut 0.4 mi west of the unnamed chert locality exposes conglomerate containing well-rounded, fusulinacean-bearing cobbles derived from the Coyote Butte limestone unit (center of sec. 10, T. 18 S., R. 25 E., Suplee 7.5′ quadrangle). This conglomerate has a clast composition similar to limestone-rich conglomerate exposed on Big Flat in the Izee terrane to the east (Figure 13a; loc. 46 of Blome and Nestell, 1991).

Rare exposures of volcaniclastic siltstone and sandstone of unknown age are exposed between Grindstone and Twelvemile Creeks. These exposures are generally unresistant, dark colored (gray to green), locally chert-grain rich, and exposed only in drainages and road cuts. A small exposure of volcaniclastic sandstone can be seen in the same small road cut (Figure 13b).

The precise age of the Begg Member is not known, but it has been tentatively assigned to the Carnian Stage below the late Carnian *Tropites subbulatus* Zone of Smith (1927). The basal part of the member could possibly extend down into the Middle Triassic. Both Mississippian and Permian fossils have been found in limestone and chert boulders and pebbles (Dickinson and Thayer, 1978; Blome and others, 1986). Faunal data presented in Blome and Nestell (1991) showed that most, if not all, of the conglomerate and volcaniclastic rocks scattered throughout the Grindstone terrane are assignable to the Upper Triassic Vester Formation.

En route

From Stop 7, backtrack 0.3 mi to Y-intersection, proceed southwest 1.0 mi to Y-intersection, turn right (northwest) to remains of

Figure 12a.

Figure 12b.

Figure 13a.

Figure 13b.

Figure 14a.

Figure 14b.

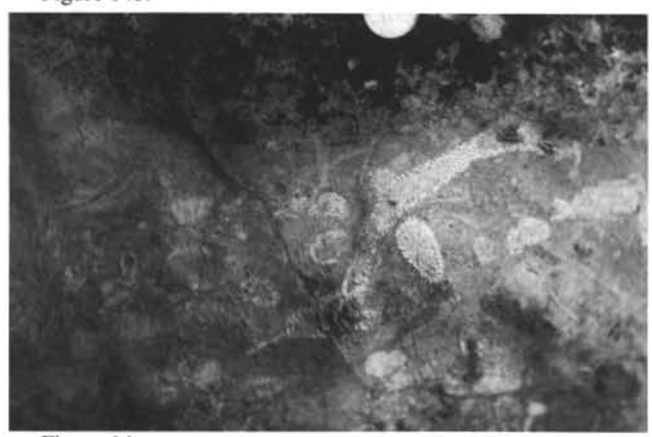

Figure 14c.

Figure 15.

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Figure 12a. Exposure of unnamed Lower Permian chert at Stop 7, northern part of the Grindstone terrane, view toward southwest (loc. 2 of Blome and Reed, 1992). Similar chert exposures crop out along the ridge tops in background of photo.

Figure 12b. Closeup of resistant chert exposure shown in foreground of Figure 12a. Photo taken facing northwest.

Figure 13a. Well-rounded cobble of fusulinacean-bearing limestone in Begg Member (Vester Formation) conglomerate on Big Flat (loc. 46 of Blome and Nestell, 1991). Conglomerates similar to this can be seen at Stop 7 in small road cuts and adjacent hill just west of the unnamed chert exposure (center of sec. 10, T. 18 S., R. 25 E., Suplee 7.5′ quadrangle).

Figure 13b. One of the rare exposures (loc. 19 of Blome and Nestell, 1991) of volcaniclastic sandstone surrounded by less resistant mudstone. Exposure along road just west of unnamed chert at Stop 7, northern Grindstone terrane (center of sec. 10, T. 18 S., R. 25 E., Suplee 7.5′ quadrangle).

Figure 14a. Large block of the coral- and conodont-bearing unnamed Middle Devonian limestone exposed at Stop 8, west side of South Fork Trout Creek, northern Grindstone terrane. View toward southwest from top of ridge containing Upper Triassic Begg Member conglomerate.

Figure 14b. East side of unnamed Middle Devonian limestone exposure at Stop 8.

Figure 14c. Closeup of unnamed Middle Devonian limestone surface, east base of exposure in Figure 14a. Large fossils in photo are corals (coin for scale).

Figure 15. Typical exposure of chert-rich Begg Member (Vester Formation) conglomerate exposed at Stop 9, just off highway northeast of Suplee, west side of four-wheel-drive road.

Birdsong Ranch (building burned), and park for Stop 8: Unnamed Devonian limestone (NE¼NW¼ sec. 16, T. 18 S., R. 25 E., Suplee 7.5′ quadrangle). Hike northwest along drainage for approximately 0.8 mi to large Devonian limestone exposure just west of the South Fork of Trout Creek. Exposures of the Coffee Creek limestone unit can be seen immediately east of drainage on lower slopes, and scattered small outcrops of the Coyote Butte limestone can be viewed to the southeast along ridge crests.

STOP 8—UNNAMED DEVONIAN LIMESTONE, NORTHERN GRINDSTONE TERRANE

Kleweno and Jeffords (1961) described the larger northern exposure of the unnamed Devonian limestone (Figures 14a and 14b; unit Dl in Figure 2) as approximately 100 ft (30 m) of highly folded, massive, cherty limestone with associated cherty breccia and sandstone overlain by chert and argillite. The contact between the limestone and chert appears gradational, but the contact with the adjacent sandstone is sharp and assumed to be unconformable. This outcrop has been informally referred to as the Birdsong limestone by Danner (1977).

The megafossil fauna from the Devonian limestone includes Middle Devonian corals (Figure 14c), stromatoporoids, and brachiopods (Kleweno and Jeffords, 1961; Danner, 1967; Sorauf, 1972; Poole and others, 1977). Additional brachiopod genera (*Schizophoria* and *Emanuella*) and conodonts of Middle Devonian (Givetian) age were also found in this limestone block (Johnson and Klapper, 1978). Savage and Amundson (1979) noted that conodonts from this locality possess a conodont color alteration index (CAI) of 3, which corresponds to a temperature range of 110°-200° C (Epstein and others, 1977). Conodonts recovered from the Permian Coyote Butte limestone unit have CAIs of 1.5-2 (50°-140° C).

En route

Backtrack to Crook County Road 318 and north to Paulina-Izee road. Turn east toward Izee, go 3.5 mi to hairpin turn, and park for Stop 9: Begg Member conglomerate, Vester Formation (central part and NE¼ sec. 20 and SW¼ sec. 17, T. 17 S., R. 26 E., Suplee 7.5′ quadrangle; conglomerate exposed on both sides of highway and just beyond locked gate east and west of dirt road).

STOP 9—BEGG MEMBER OF THE VESTER FORMATION, WESTERN IZEE TERRANE

Traveling east toward the town of Izee, one can see weathered chert-grain sandstone and chert-pebble conglomerate exposures along the highway. Large outcrops of conglomerate assigned to the Vester Formation are exposed just 0.25 mi to the north along the west side of a four-wheel-drive (private!) road (Figure 15; Dickinson and Vigrass, 1965). The high chert-pebble content of the conglomerate at this stop is typical of most Begg conglomerate exposures.

En route

Continue on Paulina-Izee road toward Izee for approximately 9.3 mi to Dayville turnoff. Continue southeastward toward Izee for another 0.9 mi and park for Stop 10: Brisbois Member of the Vester Formation (SW¼ sec. 10, T. 17 S., R. 27 E., Izee 7.5′ quadrangle; Brisbois Member exposed along the north side of highway for another 0.5 mi).

STOP 10—BRISBOIS MEMBER ROCKS, VESTER FORMATION, WESTERN IZEE TERRANE

The Brisbois Member of the Vester Formation (Dickinson and Thayer, 1978; originally the Brisbois Formation of Dickinson and Vigrass, 1965) consists of thin-bedded mudstone and siltstone and intercalated, thin-bedded, gray to black siliciclastic sandstone and sandy calcarenite. Typical Brisbois Member mudstone exposures are visible in a series of road cuts along the highway from Suplee to Izee, beginning approximately 1 mi east from the turnoff to Dayville. Faulted and folded Brisbois exposures can be viewed 1.6 mi southeast of Stop 10 along the highway to Izee (SE¼ sec. 15, T. 17 S., R. 27 E., Izee 7.5′ quadrangle; Figure 16).

Calcarenite beds of the Brisbois Member contain shallow-water brachiopod, bivalve, gastropod, and crinoid fragments. Other bivalves (*Halobia* sp.) and ammonites collected throughout this member are interpreted as being derived from displaced limestone blocks. The ammonites collected from the Brisbois are all indicative of the upper Carnian *Tropites subbulatus* Zone (Dickinson and Vigrass, 1965). Other late Carnian halobiids (*Halobia* cf. *H. ornatissima* Smith) from the upper part of the Brisbois Member were reported by Blome (1984).

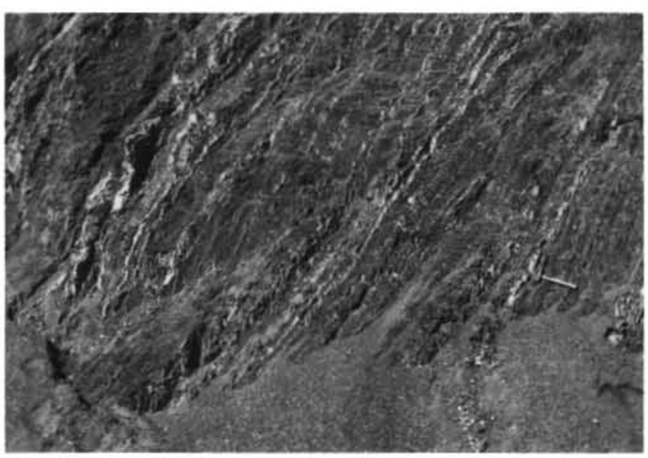

Figure 16. Faulted and folded, thin-bedded mudstone and siltstone of the Brisbois Member (Vester Formation) exposed southeast of Stop 10, approximately 2.5 mi east of turnoff to Dayville along paved highway west of Izee.

En route

From Stop 10, continue eastward for approximately 7.0 mi through Izee to Y-intersection. Take left (northeast) fork toward U.S. 395 and go for another 6.8 mi to Deer Creek Road (NFS 6730). Turn southwest onto forest service road, go 0.3 mi to sharp bend, and park for Stop 11: Snowshoe Formation (SW¼SW¼ sec. 6, T. 17 S., R. 29 E., Lewis Creek 7.5′ quadrangle; exposure just northeast of gravel road).

STOP 11—SNOWSHOE FORMATION EAST OF IZEE

The Snowshoe Formation, established by Lupher (1941) for a sequence of well-bedded siltstone and mudstone with minor sandstone, conformably overlies the Hyde Formation and underlies the Trowbridge Formation along the South Fork of the John Day River near the town of Izee (shown as Jurassic volcaniclastic rocks in Figure 3). Here the Snowshoe Formation was divided into three informal members by Dickinson and Vigrass (1965). The lower member is characterized by brown, gray, or black, thin-bedded mudstone, shale, and siltstone. It also contains ammonite impressions and the bivalve *Posidonia* on bedding partings as well as lenses of silty limestone and dark-gray carbonate concretions. The middle member contains gray to black shale and mudstone intercalated with gray to green volcaniclastic siltstone and fine-grained sandstone. The upper member is typified by thin-bedded mudstone and siltstone with thick intercalations of gray calcareous sandstone. Smith (1980) formally named the lower member the Warm Springs Member, and the middle and upper members the Schoolhouse and South Fork Members, respectively. The sedimentary structures in the coarser grained Snowshoe volcaniclastic rocks indicate deposition in midfan or suprafan lobes within slope to base-of-slope depositional settings (Blome and Nestell, 1991, p. 1292).

A typical Snowshoe Formation exposure can be seen on NFS Road 6730 just west of the intersection with State Highway 63 (Izee-John Day road) along Bunton Creek. This exposure (OR-523 of Pessagno and Blome, 1980, 1982; Pessagno, Six, and others, 1989), which is assigned to the middle member of the Snowshoe Formation (now the South Fork Member of Smith, 1980), is composed of dark-gray mudstone, interbedded graywacke, and gray micritic limestone concretions containing well-preserved silicified radiolarians (Superzone 1, Zone 1C of Pessagno, Blome, and others, 1987) assignable to the middle Bajocian *Otoites sauzei* standard ammonite zone (Imlay, 1973). This overturned section overlies the Silvies Member of the Snowshoe Formation. The underlying lower 200 ft (60 m) of the lower member (equivalent to part of the Warm Springs Member of Smith, 1980) near Izee contains late Toarcian and early Bajocian (Aalenian) ammonite faunas (Imlay, 1973). Other radiolarian faunas and ammonites from Schoolhouse Gulch, immediately north of Izee (Figure 2; Pessagno, Blome, and others, 1987), indicate that the lower part of the Warm Springs Member is assignable to the middle and upper Toarcian and that the remainder of the member is Aalenian (lower Bajocian of Imlay, 1973) and lower Bajocian (= middle Bajocian of Imlay, 1973).

En route

Return to paved road, turn left and travel 16.8 mi to U.S. 395. Turn right (south) and go 7.5 mi on U.S. 395 to town of Seneca. Continue 1.0 mi south of Seneca and park for Stop 12: Undifferentiated Snowshoe Formation (SW¼ sec. 2, T. 17 S., R. 31 E., Silvies 7.5′ quadrangle; exposed on north side of highway).

STOP 12—UNDIFFERENTIATED SNOWSHOE FORMATION, SENECA

This conspicuous exposure of Snowshoe Formation rocks (Figure 17) contains dark-gray mudstone with abundant small, radiolarian-bearing micritic limestone concretions and minor graywacke beds.

Figure 17. Dark-gray mudstone exposure (Stop 12) of undifferentiated Snowshoe Formation containing minor graywacke and ammonite- and radiolarian-bearing limestone concretions (north side of U.S. 395 just south of Seneca).

These rocks rest unconformably(?) beneath massive conglomerate and graywacke of the basal part of the Silvies Member (Snowshoe Formation). The ammonite assemblage from this locality (Pessagno, Whalen, and Yeh, 1986, p. 48) contains *Leptosphinctes* Buckman and *Megasphaeroceras rotundum* Imlay and is assignable to the upper Bajocian Rotundum Zone or its European equivalents (Pessagno, Six, and others, 1989). Well-preserved Late Bajocian radiolarian assemblages from limestone concretions (locs. OR-549A-C) have been described and illustrated by Pessagno and Blome (1980, 1982), Pessagno and Whalen (1982), and Pessagno and others (1986, 1989).

En route

Proceed north on U.S. 395 (toward John Day), go 5.3 mi to first exposures of the Laycock Graywacke, and park for Stop 13: Laycock Graywacke (SW¼ sec. 11 and N½ sec. 15, T. 15 S., R. 31 E., Canyon Mountain 7.5′ quadrangle. No photo was included due to the monotonous and repetitive nature of the graywacke exposed for several miles along U.S. 395).

STOP 13—UPPER TRIASSIC LAYCOCK GRAYWACKE

The rocks of the Aldrich Mountains Group (Fields Creek Formation, Laycock Graywacke, Murderers Creek Graywacke, and Keller Creek Shale) are restricted to the east side of the Poison Creek Fault system (Brown and Thayer, 1966). The Laycock Graywacke is composed of volcaniclastic and tuffaceous sandstone (graywacke of Brown and Thayer, 1977), shale, and conglomerate, some of which is reworked (Dickinson and Thayer, 1978). Extensive exposures of the Laycock can be studied in north-facing road cuts along U.S. 395 just south of Vance Creek (Brown and Thayer, 1977). The Late Triassic age of the Laycock is inferred by its stratigraphic position between the underlying Upper Triassic Fields Creek Formation and overlying Lower Jurassic Murderers Creek Graywacke.

En route

Continue northward approximately 12 mi to town of John Day. From the intersection of U.S. Highways 395 and 26 (center of John Day), turn east, and proceed 2.6 mi to the turnoff to Dog Creek, which makes a sharp angle back to the west. Continue south 1.3 mi on the Dog Creek road until the paved road makes a sharp turn to the right (west). Continue straight across the cattle guard, bearing to the right where the road forks, and then through the gate. Continue 0.7 mi to the road-metal pit on your left and park for Stop 14: Little Dog Creek locality, western Baker terrane (SW¼SE¼ sec. 32, T. 13 S., R. 32 E., John Day 7.5′ quadrangle; exposure on northeast side of ranch road). **Permission must be obtained to venture off the Dog Creek road.**

STOP 14—LITTLE DOG CREEK LOCALITY, WESTERN BAKER TERRANE

Chert and limestone similar to that found in the type area of the Elkhorn Ridge Argillite in the eastern part of the Baker terrane can also be found north of the Aldrich Mountains, both southeast of John Day and near the town of Mount Vernon. In the Baker terrane, limestone and chert are rarely seen in contact with one another because of tectonic disruption, but such a contact is preserved in a road-metal pit (Figures 18a and 18b) on Little Dog Creek a few miles southeast of John Day. Serpentinite and pyroxenite can also be found to the east of the pit on the east slopes of the ridge separating Little Dog and Dog Creeks. Chromite has been mined at several sites along Little Dog Creek.

Although biostratigraphic age data are very scarce from rocks in the western part of the Baker terrane, mid-Permian fusulinaceans, and Late Triassic (Carnian and Norian) radiolarians and conodonts have been recovered from the limestone and chert blocks, respectively, at the Dog Creek locality (Nestell and MacLeod, 1984; Blome and others, 1986). Mid-Permian Tethyan fusulinaceans *Neoschwagerina* cf. *N. craticulifera*, rare *Yangchenia* sp. and *Pseudodoliolina* sp. can be found in a pod of metamorphosed limestone breccia at the north end of the pit. Other Tethyan fusulinacean genera (Plate 3) found in limestone pods in this area include *Maklaya*, *Misellina*, *Nagatoella*, *Ascervoschwagerina*, and *Armenina* (Nestell, 1983). These genera have been reported only from faunas confined to the western margin of North America (Thompson and others, 1950; Bostwick and Nestell, 1966; Monger and Ross, 1971; Stevens, 1977).

Contorted and metamorphosed ribbon cherts containing poorly preserved specimens of the Late Triassic radiolarian genera *Capnodoce*, *Corum*, *Pachus*, *Renzium*, and *Xipha* (Plate 4) and the Late Triassic conodont *Epigondolella abneptus* can be seen in the road-metal pit and on the east side of the road in a small road cut (Figure 18c) between the gate and pit. Larger pods of limestone and chert can be seen on east-facing slopes and near the top of the hill to the west of Little Dog Creek (Figure 18d). Much of this limestone is altered to marble, and fossils are scarce.

The limestone pods on Little Dog Creek are of varying sizes (ranging from a few to tens of meters across) and conglomeratic in some areas, and many appear to be "imbedded" in Middle to Late Triassic radiolarian-bearing chert. Carbonate textures range from mudstone to boundstone. Fusulinaceans and algae are the dominant fossil components of the limestones and range in age from latest Wolfcampian to earliest Guadalupian. We interpret the Little Dog Creek limestones as possibly representing fragments of seamounts redeposited into a basinal setting dominated by siliceous sediments. The Little Dog Creek rocks lie on the northern margin of the Canyon

Upper left: *Figure 18a. Mid-Permian fusulinacean-bearing brecciated limestone overlying Upper Triassic radiolarian-bearing chert at Stop 14, small road-metal pit on east side of Little Dog Creek.*

Lower left: *Figure 18b. Contact (at hammer head) in road-metal pit between mid-Permian fusulinacean-bearing brecciated limestone block and Upper Triassic radiolarian-bearing chert (Stop 14).*

Upper right: *Figure 18c. Tightly folded Upper Triassic radiolarian-bearing ribbon chert exposed in east road cut just north of the road-metal pit on Little Dog Creek at Stop 14.*

Lower right: *Figure 18d. Outcrops (west of Stop 14) of mid-Permian limestone blocks containing Tethyan fusulinaceans. Photo taken looking west from ridge above Little Dog Creek (NE¼SW¼ sec. 32, T. 13 S., R. 32 E., John Day 7.5' quadrangle).*

Mountain Complex, which was accreted to North America in the Late Jurassic or Early Cretaceous. The biostratigraphic relationships of the Little Dog Creek limestone and chert to more extensive exposures in the Baker terrane to the northeast will be discussed in a forthcoming paper.

COMPARISON OF GRINDSTONE, IZEE, AND BAKER TERRANE ROCKS

Separation of the Izee and Grindstone terranes by Silberling and others (1984, 1987) was based on the absence of known conformable contacts between their rock units and lack of Paleozoic rocks in the Izee terrane, except for Paleozoic limestone clasts in Begg Member conglomerate. The presence of Begg conglomerate in both terranes indicates that the Grindstone terrane formed at least part of the basement for Izee deposition by Late Triassic time. However, the absence of discernible sedimentary contacts between all Grindstone and Izee exposures studied prevents us from reducing the two terranes to subterrane status (Blome and Nestell, 1991).

We agree with Dickinson and Thayer (1978) that uplift and erosion of Grindstone terrane rocks provided part of the detritus for Izee terrane deposition. The Grindstone terrane conglomerate is lithologically similar to the Izee terrane Begg conglomerate near Wade Butte but differs from Begg conglomerate in the central part of the Izee terrane by containing common Coffee Creek limestone detritus. The Begg conglomerate in the Izee terrane (in the Big Flat area) contains cobbles with a somewhat different Permian fusulinacean fauna (e.g., *Pseudoschwagerina* and *Polydiexodina*) and Late Triassic corals and ammonites (Blome and Nestell, 1991). These faunal contrasts between the Triassic conglomerates of the Grindstone and Izee terranes suggest that either (1) the Begg conglomerate may have had several provenances, or (2) the conglomerates may be of varying ages, with the more extensive Izee Begg Member conglomerate being younger. Other redeposited Permian faunas from conglomerate in both terranes indicate penecontemporaneous sources during Begg deposition (Blome and Nestell, 1991).

The Grindstone terrane contains Middle Devonian, Upper Mississippian, Lower Pennsylvanian, Permian, and Lower Triassic rocks according to floral and faunal (brachiopod, conodont, coral, fusulinacean, and radiolarian) evidence. These rock assemblages are all of low metamorphic (zeolite) grade based on conodonts having CAIs of 3 or less and the presence of fresh zeolite minerals in some of the limestone and volcaniclastic rocks. Furthermore, much of the limestone is unaltered. The Grindstone fusulinacean faunas are all of McCloud Limestone affinity and do not contain Tethyan forms (Blome and Nestell, 1991).

Devonian, Pennsylvanian, and Permian faunas are known from limestone and chert in the Baker terrane, but pre-Late Permian faunas are very rare (Mullen-Morris and Wardlaw, 1986). Baker limestone and chert exhibit tectonic shear fabrics, possess greenschist or higher regional metamorphic grades (conodonts with CAIs of 5 to 6), and are commonly altered to marble and metachert, respectively; the limestone also contains two types of fusulinacean faunas, those containing Tethyan forms and those related to the McCloud Limestone (Nestell, 1983; Miller, 1987; Nestell and Blome, 1988).

Scarce fusulinacean assemblages from small, metamorphosed (greenschist-grade) limestone pods in the west-central part of the Baker terrane (east of Elkhorn Ridge) are coeval with and nearly identical to Coyote Butte faunas in the Grindstone terrane. The exact timing of tectonic inclusion of these limestone blocks into the Baker terrane is difficult to ascertain because in some places, such as the Dog Creek locality and one locality on the east side of the Elkhorn Mountains, Permian fusulinacean-bearing limestone is juxtaposed with coeval or Late Triassic (Carnian to Norian) radiolarian chert blocks (Nestell and MacLeod, 1984; Blome and others, 1986; and Nestell and Blome, 1988). Chert in the Grindstone terrane contains both Permian (late Wolfcampian to Djulfian) and Early Triassic radiolarian and conodont faunas, whereas chert in the Baker terrane contains Late Permian and Late Triassic radiolarians. The presence of Permian Coyote Butte detritus in both Grindstone and Izee Triassic conglomerates and the insertion of Coyote Butte limestone outliers into the western part of the Baker terrane no earlier than Late Triassic time suggest that all three terranes were juxtaposed by the Late Triassic or Early Jurassic (Blome and others, 1986; Blome and Nestell, 1991).

DEPOSITIONAL MODELS FOR GRINDSTONE, IZEE, AND BAKER TERRANE ROCKS

One reason for the varied depositional models proposed for the Grindstone terrane (Buddenhagen, 1967; Dickinson and Thayer, 1978; Wardlaw and others, 1982) is the fact that outcrops in the terrane are scarce and in disarray. For example, the Devonian and Mississippian (Coffee Creek limestone unit) limestone blocks are widely separated from one another, yet the southernmost Devonian limestone is almost in contact with a Triassic limestone pod (Figure 2). Several of the limestone blocks exhibit random strike-dip orientations, and some have overturned lithostratigraphy and biostratigraphy. Also, many of the cherts partly enwrap the individual limestone exposures (e.g., at Three Buttes; Blome and Nestell, 1991).

Dickinson and Thayer (1978) and Dickinson (1979) implied that the Grindstone terrane is part of a large mélange belt (Baker terrane) of dismembered oceanic-crust and island-arc rocks in a tectonic matrix of deformed ocean-floor chert and argillite. The severe structural disruption was inferred to be the result of long-term subduction that lasted through Middle Triassic time. The same authors also interpreted the presence of volcaniclastic and chert-grain detritus in the calcarenites as representing deposition on volcanic edifices and partly on uplifted areas of mélange composed of deformed chert and argillite within an arc-trench gap. According to Dickinson (1979), the presence of both Tethyan and American fusulinacean faunas in his central mélange terrane indicates tectonic juxtaposition of stratal components whose depositional sites were far apart in the Paleopacific.

We do not believe that the Grindstone siliceous rocks represent subducted ocean-floor sediments as suggested by Dickinson and Thayer (1978) and Dickinson (1979) because of several lines of evidence. Typical ocean-floor rocks, such as basalt, are missing from the Grindstone rocks and are restricted to the Baker terrane to the northeast. The only Tethyan faunas within Dickinson's mélange are from rocks in the Miller Mountain mélange area (Figure 3; cf. Nestell, 1983), an area now considered to be part of the Baker terrane (Silberling and others, 1984, 1987). Grindstone limestone and chert exposures lack shear or other deformational fabrics at or near their boundaries with adjacent volcaniclastic rocks, and much of the chert exhibits sedimentary structures indicative of slope to base-of-slope paleoenvironments. Furthermore, the examination of aerial photos shows the bedding of the volcaniclastic rocks between the various limestone and chert exposures to be somewhat continuous but discordant with the boundaries of individual limestone and chert blocks (Blome and Nestell, 1991).

An alternative depositional model for the Grindstone terrane limestones (Blome and Nestell, 1991; their Figure 7a) is that they represent gravity slide and slump blocks that became detached from a carbonate shelf fringing a volcanic knoll or edifice in Permian time. These limestones were redeposited and intermixed with Permian and Lower Triassic base-of-slope to basinal chert and siliceous mudstone and uppermost Permian(?) and Triassic slope to base-of-slope volcaniclastic rocks in a fore-arc basin setting. The eroded carbonate shelf either was situated on a structural high along the trench flank of the fore-arc basin (Dickinson and Seely, 1979) or fringed the arc massif itself. We have not discounted the possibility that the older and more metamorphosed unnamed Devonian limestone became integrated with the other Grindstone rocks through structural disruption.

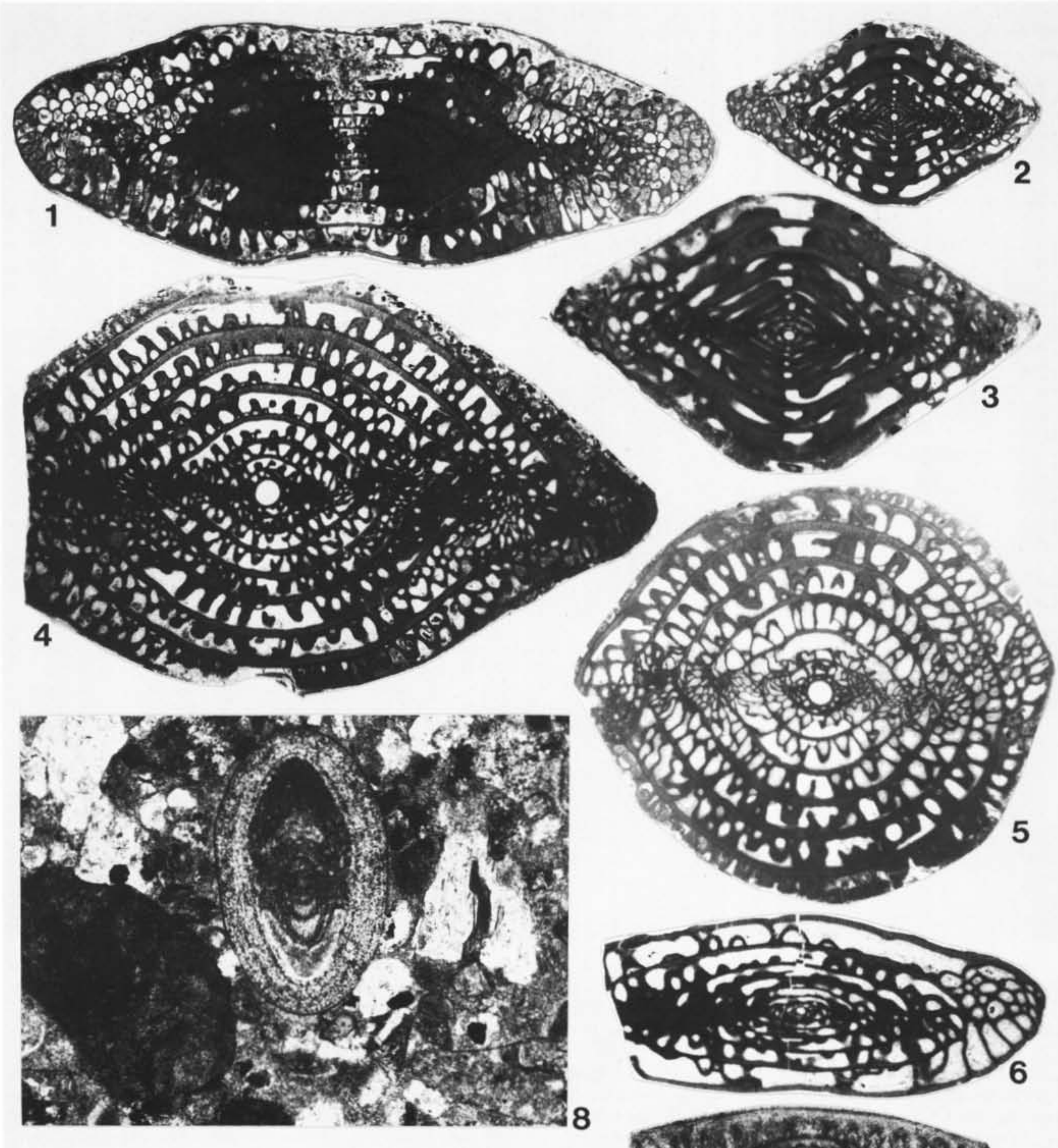

Plate 1. Fusulinaceans from the Grindstone terrane. Specimens 1-6 are reproduced from Skinner and Wilde, 1966. Specimen 7 is from the massive limestone at the east end of Three Buttes. Specimens 1-7 are all from the Coyote Butte limestone unit and are late Wolfcampian in age. Specimen 8 (coated) is Early Pennsylvanian (note the euhedral feldspar in the section) and is from a cobble in the conglomerate in the vicinity of the Coffee Creek limestone unit at Stop 1. 1. *Schwagerina amoena*, x 10; 2. *Pseudofusulinella pinguis*, x 10; 3. *Pseudofusulinella pulchella*, x 20; 4. *Schwagerina oregonensis*, x 10; 5. *Chalaroschwagerina tumentis*, x 10; 6. *Schwagerina minima*, x 20; 7. *Boultonia* sp., x 50; 8. *Nankinella* cf. *N. plummeri*, x 45.

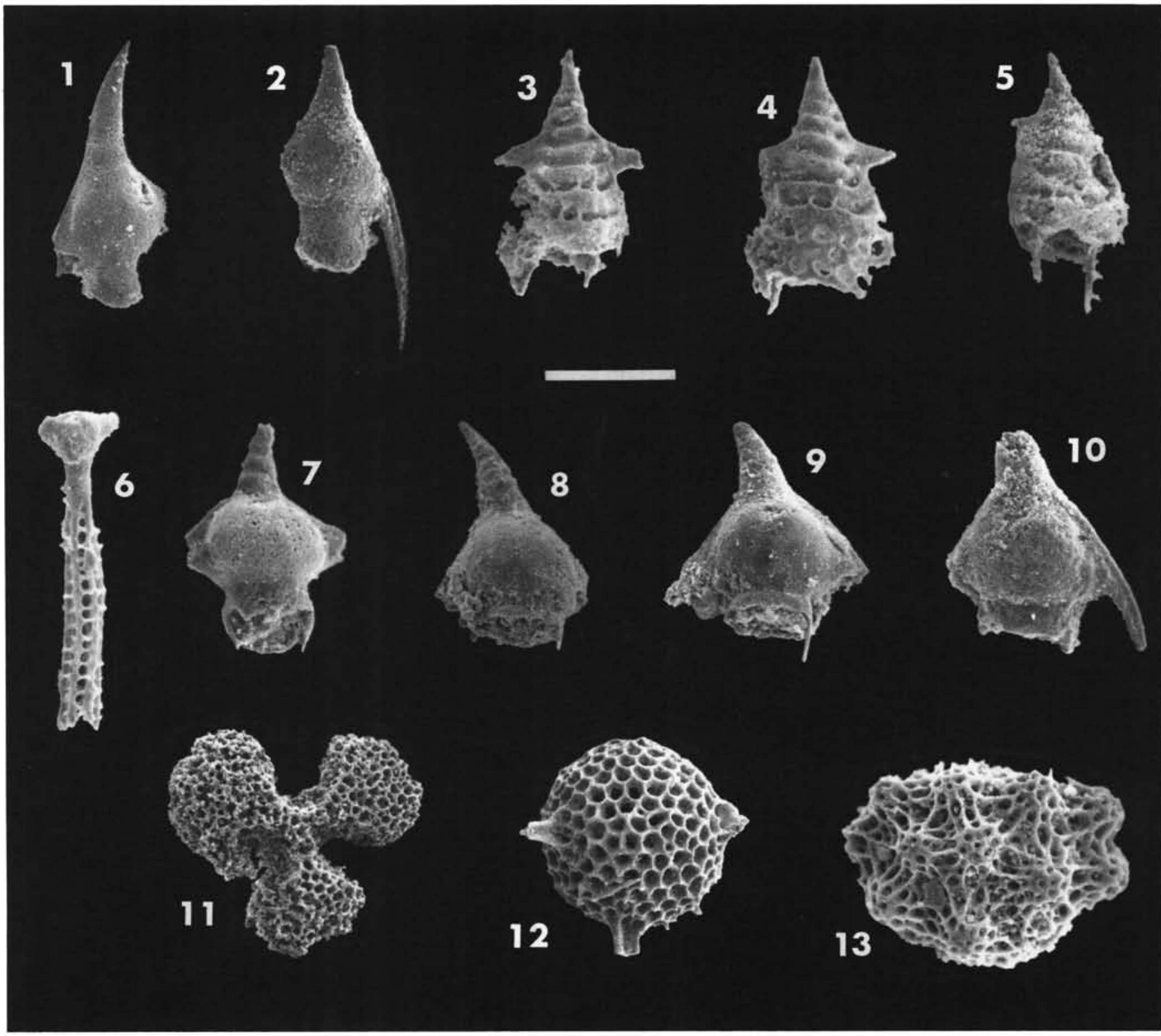

Plate 2. Permian radiolarians from unnamed chert at Stops 4 and 7. 1-2. *Pseudoalbaillella scalprata* morphotype *postscalprata*, both x 120; 3-5. *Albaillella asymmetrica*, x 160, x 200, and x 160 respectively; 6. *Pseudotormentus kamigoriensis*, x 150; 7-8. *Pseudoalbaillella* sp. aff. *P. globosa*, x 150 and x 160, respectively; 9-10. *Pseudoalbaillella scalprata* morphotype *scalprata*, x 160 and x 180, respectively; 11. *Latentifistula* sp. aff. *L. crux*, x 130; 12. *Kashiwara magna*, x 130; 13. *Hegleria mammilla* x 180. Scale bar = 2 cm.

Late Triassic to Middle Jurassic submarine-fan deposits, represented by the Begg Member of the Vester Formation, the unnamed Lower Jurassic limestone and siltstone, and the Snowshoe Formation, subsequently covered the Grindstone deposits (Blome and Nestell, 1991, their Figure 7b). These and other Izee terrane volcaniclastic rock units represent nearly continuous volcaniclastic deposition that infilled the fore-arc basin from Late Triassic through Late Jurassic time (Dickinson and Vigrass, 1965; Dickinson and Thayer, 1978; Dickinson, 1979).

The adjacent Baker terrane to the northeast is a mélange belt of dismembered oceanic crust (e.g., Canyon Mountain Complex; Thayer, 1977) and highly altered limestone, chert, and argillite (Bostwick and Koch, 1962; Vallier and others, 1977). These rocks represent tectonized fragments whose disruption reflects deformation through subduction (Dickinson, 1979; Nestell and Blome, 1988). Both Tethyan and American fusulinacean and coral faunas are found in the Baker terrane limestone.

The tectonic setting for the Grindstone and other eastern Oregon terranes is problematic. Miller (1987) theorized that the Grindstone terrane is part of the McCloud island-arc system that developed above an east-dipping late Paleozoic subduction complex (Burchfiel and Davis, 1981; Miller and Wright, 1987), that complex marginal and foreland basins separated the arc from the continental craton, and that the McCloud island-arc system occupied a back-arc position from Devonian to Permian time (Miller, 1987). However, the contrasts between McCloud Limestone and Grindstone Coyote Butte limestone faunas suggest that the Grindstone terrane and other eastern Oregon terranes may not have been directly linked to the McCloud island-arc system (Blome and Nestell, 1991).

Dickinson (1979) suggested that the Grindstone terrane rocks represent uplifted ridges of mélange (between trench and fore-arc basin) produced by east-dipping subduction in an arc-trench gap. The presence of sedimentary mélange and fore-arc basin rocks in the Grindstone and Izee terranes, respectively (Blome and Nestell,

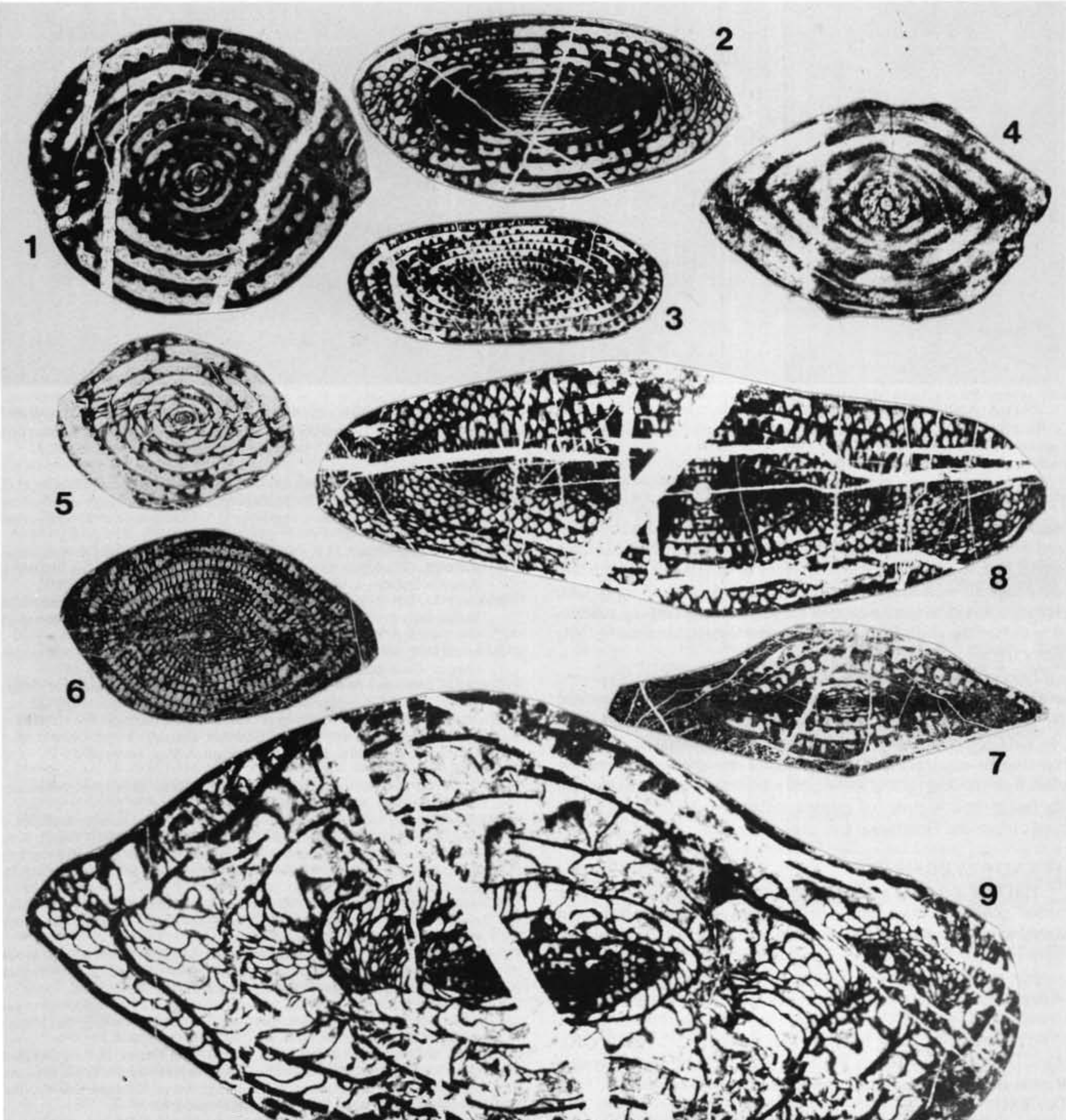

Plate 3. Middle Permian fusulinaceans from the limestone pods on Little Dog Creek. Specimens 1-7 from pods west of creek; 8, 9 from small pod east of creek and above road-metal pit. 1. *Misellina* cf. *M. claudae*, x 20; 2. *Nagatoella* cf. *N. orientis*, x 10; 3. *Pseudodoliolina* sp., x 10; 4. *Yangchenia* sp., x 20; 5. *Armenina* sp., x 10; 6. *Neoschwagerina* sp., x 10; 7. *Chusenella* sp., x 10; 8. *Parafusulina* sp., x 10; 9. *Ascervoschwagerina*(?) sp., x 10. Specimens of the genera 4, 5, and 8 have never been described from North America. Note extensive fractures in some of these forms in contrast to those from the Grindstone terrane.

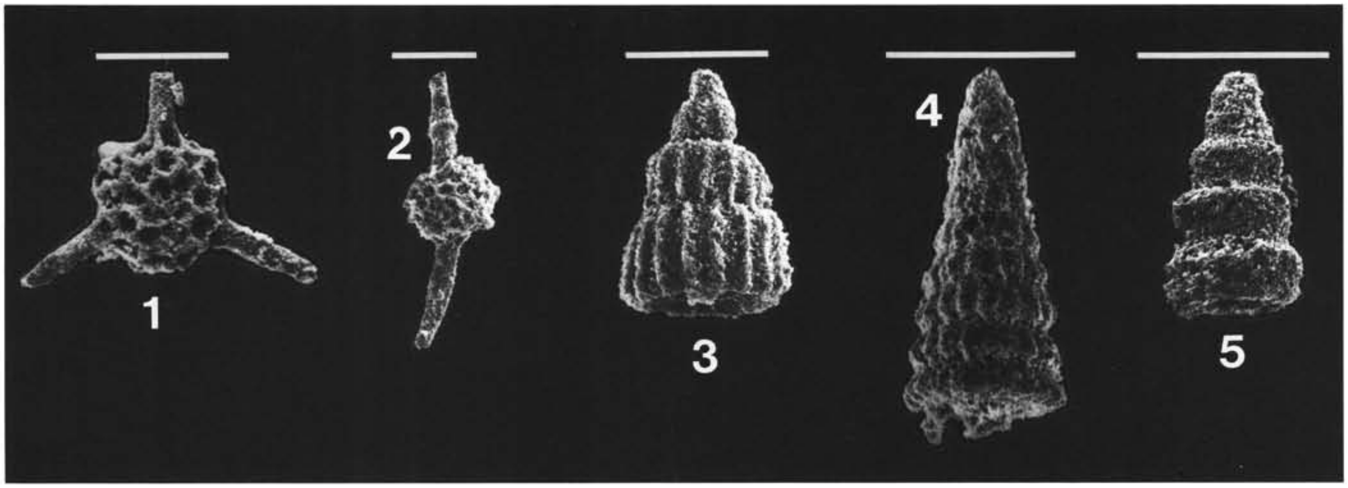

Plate 4. Radiolarians from Late Triassic chert at the Little Dog Creek road-metal pit and adjacent road cut, Stop 14. 1. *Capnodoce antiqua*; 2. *Renzium* sp.; 3. *Xipha pessagnoi*; 4. *Corum speciosum*; 5. *Pachus* sp. Scale bar for Figures 1-4 = 100 microns; bar for Figure 5 = 200 microns.

1991), support an east-dipping subduction model. However, Vallier (1992) and White and others (1992) suggested that a change in convergence direction occurred between the ancient Pacific plate and the Blue Mountains island arc during the Late Triassic. In their model, the Wallowa and Baker terranes developed as an arc/fore-arc pair with west-dipping subduction in Paleozoic to early Late Triassic (early Carnian) time, but a change to east-dipping subduction shifted the axis of volcanism in latest Triassic time to the Olds Ferry terrane.

Paleomagnetic data for the Blue Mountains island arc (Pessagno and Blome, 1986; Vallier and Brooks, 1986) indicate that it has rotated 60° clockwise since the Late Jurassic and/or Early Cretaceous (Wilson and Cox, 1980; Hillhouse and others, 1982). If rotational data for the Grindstone, Izee, and Baker terranes are applicable, counterclockwise rotation back to its original site of deposition would place the Baker oceanic crust and tectonic mélange rocks west and northwest of Izee and Grindstone fore-arc basin rocks.

ACKNOWLEDGMENTS

This field trip guide and the geological field work over a six-year period could not have been accomplished without the help and cooperation of many people. We would especially like to express our thanks to the local ranchers who extended their hospitality and support without hesitation. Among these are Lawrence and Bill Weberg (Weberg Ranch, Paulina, OR), Earl McConnell (formerly Grindstone Livestock Co., Paulina, OR), Bill Smith (G.I. Ranch Corp., Bend, OR), Chris Meyers (Meyers Ranch, Creswell, OR), Alice Delore (Delore Ranch, Paulina, OR), Andy Bernard (Bernard Ranch, Paulina, OR), and Denny Dahl (Puppy Creek Ranch, John Day, OR).

We would also like to thank Norm Silberling, Cathy Nichols, and Mark Ferns for their insightful reviews. Pat Whalen and Norm MacLeod were the first to identify radiolarians from the Little Dog Creek locality. The authors would especially like to acknowledge the pioneering fusulinacean work in eastern Oregon during the 1950s and 1960s of Dr. David Bostwick (geology professor at Oregon State University for many years).

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MINERAL EXPLORATION

MAJOR MINERAL EXPLORATION ACTIVITY

County, date	Project name, company	Project location	Metal	Status
Baker 1990	Cracker Creek Mine Bourne Mining Corp.	T. 8 S. R. 37 E.	Gold	Expl
Baker 1991	Cave Creek Nerco Exploration	Tps. 11, 12 S. R. 42 E.	Gold	App
Baker 1991	Gold Hill Golconda Resources	T. 12 S. R. 43 E.	Gold	App
Baker 1991	Gold Ridge Mine Golconda Resources	T. 12 S. R. 43 E.	Gold	Expl
Baker 1992	Pole Creek Placer Dome U.S.	T. 13 S. R. 36 E.	Gold, silver	Expl
Baker 1992	Bigelow prospect Yellow Eagle Mining	T. 7 S. R. 45 E.	Gold	Expl
Coos 1991	Seven Devils Oreg. Resources Corp.	Tps. 2, 7 S. R. 4 W.	Chromite, zircon	Expl com
Crook 1988	Bear Creek Independence Mining	Tps. 18, 19 S. R. 18 E.	Gold	Expl
Curry 1992	Mindoro Project Mindoro Corporation	T. 36 S. R. 12½ W.	Precious metals	Expl
Curry 1992*	Myers Creek Quarry Oreg. St. Highw. Div.	T. 38 S. R. 14 W.	Rock	Expl
Grant 1991	Buffalo Mine American Amex	T. 8 S. R. 35½ E.	Gold	App
Grant 1992	Quartzburg Placer Dome U.S.	T. 12 S. R. 33 E.	Precious metals	Expl
Harney 1990	Pine Creek Battle Mtn. Exploratn.	T. 20 S. R. 34 E.	Gold	Expl
Harney 1991	Flagstaff Butte Noranda Exploration	Tps. 3, 9 S. R. 37 E.	Gold	App
Harney 1992	Celatom Mine Eagle-Picher Minerals	Tps. 19, 20 S. Rs. 35-37 E.	Diatoms	App
Jackson 1991	Al Sarena Project Fischer-Watt Gold Co.	T. 31 S. R. 2 E.	Gold	App
Jackson 1992*	Janus Project Kennecott Exploration	T. 39 S. R. 4 W.	Precious metals	Expl
Josephine 1992	Eight Dollar Mountain Doug Smith	T. 38 S. R. 8 W.	Nickel	Expl
Lake 1988	Quartz Mountain Wavecrest Resources.	T. 37 S. R. 16 E.	Gold	Expl
Lake 1990	Glass Butte Galactic Services	Tps. 23, 24 S. R. 23 E.	Gold	Expl
Lake 1991	8th Drilling Series Wavecrest Resources	T. 37 S. R. 17 E.	Gold	Expl
Linn 1991	Hogg Rock Oreg. St. Highw. Div.	T. 13 S. R. 7½ E.	Rock	App
Malheur 1988	Grassy Mountain Atlas Precious Metals	T. 22 S. R. 44 E.	Gold	Expl, com
Malheur 1988	Jessie Page M.K. Gold Co.	T. 25 S. R. 43 E.	Gold	Expl
Malheur 1988	Kerby Malheur Mining	T. 15 S. R. 45 E.	Gold	Expl, com
Malheur 1989	Hope Butte Chevron Resources	T. 17 S. R. 43 E.	Gold	Expl, com
Malheur 1990	Ali/Alk Atlas Precious Metals	T. 17 S. R. 45 E.	Gold	Expl
Malheur 1990	Cow Valley Butte Cambiex USA, Inc.	T. 14 S. R. 40 E.	Gold	Veg

MAJOR MINERAL EXPLORATION ACTIVITY (continued)

County, date	Project name, company	Project location	Metal	Status
Malheur 1990	Goldfinger Site Noranda Exploration	T. 25 S. R. 45 E.	Gold	Expl
Malheur 1990	Grassy Mtn. Regional Atlas Precious Metals	T. 22 S. R. 44 E.	Gold	Veg
Malheur 1990	Katey Claims Atlas Precious Metals	Tps. 24, 25 S. Rs. 44, 46 E.	Gold	Expl
Malheur 1990	Mahogany Project Cyprus Minerals	T. 26 S. R. 46 E.	Gold	App
Malheur 1990	Racey Project Ican Minerals, Ltd.	T. 13 S. R. 41 E.	Gold	Expl
Malheur 1990	Sand Hollow Noranda Exploration	T. 24 S. R. 43 E.	Gold	Veg
Malheur 1990	Stockade Mountain BHP-Utah Internatl.	T. 26 S. Rs. 38, 39 E.	Gold	Expl
Malheur 1990	Stockade Project Phelps Dodge Mining	Tps. 25, 26 S. R. 38 E.	Gold	Expl
Malheur 1991	Bannock Atlas Precious Metals	T. 25 S. R. 45 E.	Gold	Veg
Malheur 1991	Quartz Mtn. Basin BHP-Utah Intl., Inc.	T. 24 S. R. 43 E.	Gold	App
Malheur 1991	Rhinehardt Site Atlas Precious Metals	Tps. 18, 19 S. R. 45 E.	Gold	Veg
Malheur 1991	White Mountain D.E. White Mtn. Mining	T. 18 S. R. 41 E.	Diatoms	App
Malheur 1992*	Deer Butte Atlas Precious Metals	T. 21 S. R. 45 E.	Gold	Expl
Malheur 1992	Shell Rock Butte Ronald Willden	T. 21 S. R. 44 E.	Gold, silver	App
Malheur 1992*	Swamp Creek Carlin Gold Co.	T. 25 S. R. 38 E.	Gold	Expl
Marion 1990	Bornite Project Plexus Resources	T. 8 S. R. 3 E.	Copper	App com

Explanations: Date = Date application was received or permit issued. App = application being processed. Expl = Exploration permit issued. Veg = Vegetation permit. Com = Interagency coordinating committee formed, baseline data collection started. * = New site

The announced sale of Atlas Precious Metals Grassy Mountain project to Newmont Mining Corporation was completed during the month of October.

A Draft Environmental Impact Statement for the Plexus Bornite copper mine project in Marion County should be available from the Detroit Ranger District of the Willamette National Forest by mid-November.

Questions or comments should be directed to Gary Lynch or Allen Throop in the Mined Land Reclamation Office of the Oregon Department of Geology and Mineral Industries, 1536 Queen Avenue SE, Albany, OR 97321, telephone (503) 967-2039, FAX (503) 967-2075. □

Correction

In the field trip guide "Natural hazards of the Pacific Northwest" by Charles L. Rosenfeld, an article that appeared in the July issue of *Oregon Geology*, Figure 4 on page 78 should have been attributed to Richard B. Waitt, Jr., who published it in 1985 in his paper "Case for periodic, colossal jökulhlaups from Pleistocene glacial Lake Missoula," GSA Bulletin, v. 96, no. 10, on page 1272. We apologize for the oversight. —*ed.*

New-edition *Geology of Oregon* has a new look

After we offered our readers a taste of the first chapter in the last issue of this magazine, we now take pleasure in announcing the appearance of the whole book—the all-new fourth edition of *Geology of Oregon*:

Geology of Oregon, 4th ed., 1992, by Elizabeth L. Orr, William N. Orr, and Ewart M. Baldwin, published by Kendall/Hunt Publishing Company, ISBN 0-8403-8058-5, 254 p., $25.

Over 28 years, this standard of comprehensive information on the geology of the state for both students and amateurs in the field was seen through three editions by its original author Ewart Baldwin, now emeritus professor of the University of Oregon. In the fourth edition, Baldwin now shares authorship with Elizabeth Orr, a research librarian, and her husband, William Orr of the University of Oregon Department of Geological Sciences.

The Orrs have already become known to the geologically interested public with such books as *Handbook on Oregon Plant and Animal Fossils* (1981), *Bibliography of Oregon Paleontology* (1984), and *Rivers of the West* (1985). Their contribution to *Geology of Oregon* indeed makes this an "all-new" edition—completely rewritten and 50 percent longer than the last edition.

In comparison to the previous editions, efforts have been increased to make this book useful for those without scientific and geologic training—as well as for the experts. The diversity and complexity of Oregon's geology therefore required a certain degree of generalization and simplification in presenting a great deal of "technical" information and the conclusions that have been drawn from it.

While the original organization—treating the state's physiographic provinces one by one—was retained, the approach is changed to place the emphasis on tectonics and paleoenvironments (rather than stratigraphy). The book thus reflects a significant body of information that has come to light only in recent years and uses it to present a dramatic account of how Oregon was built and changed as a part of the North American continent. A "user-friendly" look is achieved also by the addition of many three-dimensional block diagrams and drawings that reconstruct plants and animals from fossils—less technical in appearance than the usual graphic illustrations but just as informative.

A brief introductory chapter sketches in broad strokes the creation of the land that Oregon occupies today and stimulates the reader's appetite to learn more. A similarly brief chapter follows, describing the development of geological study of the state and of geologic sciences in Oregon. The sequence of chapters on individual physiographic provinces follows the pattern in which the edge of the continent moved west toward the position of today's coastline. Each of these chapters concludes with a brief list of suggested readings, while at the very end a voluminous bibliography (21 pages) provides a wealth of references. A glossary of technical terms and a subject index round off a book of which one enthusiastic early reader, Portland State University Emeritus Professor John E. Allen, wrote us that "It will be many years before a fifth edition is justifiable."

The new book is available from the regional distributors, Orr Publishers, P.O. Box 5286, Eugene, OR 97405. It can also be purchased over the counter, by mail, phone, or FAX for $25, plus $3 for mailing from the Nature of Oregon Information Center of the Oregon Department of Geology and Mineral Industries, Suite 177, 800 NE Oregon Street, Portland, Oregon 97232-2109, phone (503) 731-4444, FAX (503) 731-4066; or from the Department's field offices in Baker City, 1831 First Street, Baker City, Oregon 97814, phone (503) 523-3133, FAX (503) 523-9088; and Grants Pass, 5375 Monument Drive, Grants Pass, Oregon 97526, phone (503) 476-2496, FAX (503) 474-3158. □

THESIS ABSTRACTS

The Department maintains a collection of theses and dissertations on Oregon geology. From time to time, we print abstracts of new acquisitions that in our opinion are of general interest to our readers.

Longshore grain sorting and beach-placer formation adjacent to the Columbia River, by Zhenlin Li (Ph.D., Oregon State University, 1991), 232 p.

The formation of beach placers primarily involves processes of waves and currents that selectively sort and concentrate the valuable minerals according to their densities, sizes and shapes. Black sand placers are found on the beaches adjacent to the mouth of the Columbia River. Reviews of historical shoreline changes show that jetty construction has caused rapid beach accretion immediately adjacent to the river mouth, and thus is important to the placer development. Beach-face sand samples were collected along 70 km of shoreline north and south from the river mouth and were analyzed to determine the sorting processes responsible for the formation of this placer. It is found that heavy minerals are highly concentrated close to the Columbia River mouth, reaching 60 percent to 70 percent on the summer beach, and in excess of 90 percent during the winter. The concentration decreases systematically with longshore distance, being reduced to less than 2 percent after 20 km of longshore transport from the river mouth. The median grain sizes of principal minerals generally become finer with longshore distance, but an away-from-source coarsening is found within 5-8 km of the river mouth. These analyses indicate that the Columbia River is the major sediment source for these beaches. The sand is transported alongshore north and south away from the river mouth. Though normal grain sorting and sediment transport processes are important for most parts of the beaches, selective grain sorting and transport processes are dominant immediately adjacent to the river mouth.

Calculations of hydraulic ratios for various mineral pairs show that the longshore transportability of heavy mineral increases with its relative grain size and decreases with its density. This suggests that the heavy minerals of higher densities and finer grain sizes are less easily transported alongshore and are more concentrated close to the river mouth. Settling velocity measurements show that sorting due to contrasting settling rates could be responsible for the overall separation of the heavy minerals from the light minerals but cannot explain the separation of individual heavy minerals. Evaluations of selective entrainment stresses and bedload transport rates and results of the flume experiments show that minerals requiring higher selective entrainment stresses and with resulting lower bedload transport rates are those most concentrated in the placer deposits. This suggests that selective entrainment and differential transport sorting processes have been most important in the formation of the placer deposits adjacent to the Columbia River.

Structure and tectonics of the southern Willamette Valley, Oregon, by Erik P. Graven (M.S., Oregon State University, 1991), 119 p.

Surface geology, seismic data, petroleum exploratory well data, and water well data have been used to analyze the structural and tectonic history of the southern Willamette Valley. Tertiary strata beneath the southern Willamette Valley appear to have had an early Cascade or Clarno volcanic source to the east by the middle Eocene. The Tertiary strata have been deformed into a series of broad north-northeast-trending folds and northeast- and northwest-trending faults which initially developed under east-northeast compression during the middle Eocene and have since been rotated clockwise to their present positions. The cross-cutting pattern of subsurface faults has been complicated by reactivation during the clockwise rotation of S_1 to its present orientation of north-south. Uplift of the

Coast Range prior to emplacement of the Miocene Columbia River Basalt Group (CRBG) produced the gentle east dip of strata beneath the western edge of the Valley and beneath the CRBG in the Salem and Eola Hills.

The southern Willamette Valley is controlled by erosion of the relatively incompetent Eugene Formation following emplacement of CRBG. Neogene sediments deposited after this degradation event suggest that during the late Miocene to Pliocene the proto-Willamette River flowed east of the Salem Hills before uplift along the Waldo Hills forced its course to the west. This aggradation appears to have been caused by increased uplift of the Coast Range and/or subsidence of the Willamette Valley over the slab bend in the subducting Juan de Fuca Plate. Degradational and aggradational periods during the Pleistocene appear to have been caused by readjustment of the Willamette River system to new base levels and changes in sediment supply to the valley.

Neotectonic features in the valley include (1) the Owl Creek fault which is at least Pleistocene in age and possibly younger, (2) the Harrisburg anticline, (3) the Turner fault, and (4) deformation in the North Santiam River Basin including the Mill Creek fault. With the exception of the Owl Creek fault, the minimum age of these structures is poorly constrained but is at least post-Miocene and possibly younger.

Geology and hydrothermal mineralization in the vicinity of Rocky Top, Marion County, Oregon, by John M. Curless (M.S., Oregon State University, 1991), 111 p.

The Rocky Top area is located within the Western Cascades subprovince of Oregon, approximately 65 km east-southeast of Salem. Late Oligocene- to late Miocene-age volcanic rocks exposed within the area form an impressive 3,000-m-thick stack of calc-alkaline volcanic rocks which locally records subsequent events of tectonic deformation, magmatic intrusion, and hydrothermal mineralization. Pliocene to Pleistocene volcanic rocks in the Rocky Top area are unaltered, chemically distinct, and found as intracanyon flows into the older rocks.

Plutonic rocks of late Miocene age have been hydrothermally mineralized and are exposed as northwest-trending dikes and small stocks. Their spatial distribution as well as mineralogical, textural, and chemical features indicate that they are related to the nearby Detroit Stock. Early formed quartz diorites at Sardine Creek and Rocky Top are exposed as dikes with sharp to slightly brecciated contacts and were emplaced along pre existing northwest-trending structures. Later hornblende granodiorites, with contacts defined by well-developed intrusive breccias, are exposed as irregularly shaped northwest-elongate dikes and small stocks. Stratigraphic reconstruction from Sardine Creek to Rocky Top suggests that the later hornblende granodiorites were emplaced at a minimum depth of roughly 1 km, with the earlier quartz diorites intruding to shallower levels.

Propylitic alteration is widespread throughout the Rocky Top area and intensifies with proximity to northwest-trending structures. Potassic alteration is limited to within the Detroit Stock, where several samples contain incipient veinlets and diffuse replacement zones of hydrothermal biotite. Late-stage sericitic (sericite-quartz) and argillic (clay-quartz plusmin barite) alteration is characterized by the replacement of groundmass and phenocrysts by sericite or clay minerals, quartz, and pyrite, along with a loss of primary textures, which accompanies mild to strong bleaching of the wall rocks. Late-stage alteration is structurally controlled and overprints earlier propylitic and potassic alteration.

Zones of hydrothermal metallization are narrow and weakly developed and lack evidence of past exploration activity. Sulfide minerals occur as open-space fillings and as disseminations in the volcanic and plutonic rocks. The principal sulfide is pyrite, although sphalerite, chalcopyrite, and galena are locally abundant in small veins and disseminations associated with sericitic alteration. Sulfur isotopic compositions of these minerals range from +2.8 per mil to -3.3 per mill and average about -0.5 per mil. This relatively narrow range of delta 34S values, near 0 per mil, is suggestive of a magmatic origin of sulfur and is consistent with data obtained elsewhere from the Western Cascades. Isotopic temperature estimates from coexisting sphalerite and galena indicate that sulfide deposition occurred at 200°-220°C.

More than 80 rock-chip samples from the Rocky Top, Sardine Creek, and Detroit stock areas have been analyzed for Cu, Pb, Zn, and other trace metals. Concentrations of these metals in samples from the Rocky Top area range up to 16 ppm Ag, 16 ppb Au, 830 ppm Cu, 75 ppm Mo, 1330 ppm Pb, and 3570 ppm Pb, and 3570 ppm Zn. Threshold values dividing background and mineralized samples were determined to be 60 ppm Cu, 30 ppm Pb, and 100 ppm Zn. The relative proportions of these metals in mineralized samples depict a progressive change with increasing horizontal and vertical distance from more Cu (Zn) at the Detroit Stock, through Zn (Cu) at Sardine Creek, to Pb (Zn) at Rocky Top.

Investigation of the interrelationships between mineralization and associated plutonic rocks combined with volcanic stratigraphy, structure, and topography suggests that Rocky Top may be one of the youngest and highest level hydrothermal systems recognized in the Western Cascades. Although plutonism and hydrothermal mineralization in this area have many features in common with nearby mining districts of the Western Cascades, the absence of well-developed breccia pipes, through-going veins, and zones of intense pervasive alteration are consistent with the lack of previous mining activity or extensive exploration.

Petrogenesis of compositionally distinct silicic volcanoes in the Three Sisters region of the Oregon Cascade Range: The effects of crustal extension on the development of continental arc silicic magmatism, by Brittain Hill (Ph.D., Oregon State University, 1991), 235 p.

The Three Sisters region of the Oregon High Cascades has developed three compositionally and petrogenetically distinct silicic (i.e., SiO_2 ≥58 percent) magma systems within the last 600,000 years. These silicic systems evolved from the same High Cascade mafic magma system and developed in the same 20- x 30-km area of the arc, but did not interact. The Broken Top system (BT) evolved to 71 percent SiO_2 through a combination of plag + px + Fe-Ti oxides ± ap (PPFA) fractionation and 20-35 percent mixing of rhyolitic (74 percent SiO_2) crustal melts. In contrast, part of the Three Sisters system (3S) evolved to 66 percent SiO_2 through PPFA fractionation alone, while other parts evolved to 66 percent SiO_2 through PPFA fractionation coupled with ≥40 percent mixing of rhyolitic (≥72 percent SiO_2) crustal melts.

The 3S system was intermittently active from ≤340 ka to 2 ka. The petrogenesis of intermediate composition rocks at Middle Sister (<340 ka, >100 ka) was controlled by PPFA fractionation to ≤66 percent SiO_2. Rhyolite (72-76 percent SiO_2) was first erupted in the 3S system at ~100 ka, at the start of South Sister (SS) volcanism. Major and trace element abundances preclude derivation of 3S rhyolite through crystal fractionation but are consistent with 20-30 percent dehydration melting of mafic amphibolite. The petrogenesis of intermediate composition rocks at SS was controlled PPFA fractionation coupled with 30-40 percent rhyolitic magma mixing. However, the rhyolitic magma mixed into an essentially mafic system, which limited intermediate differentiation at SS to ≤66 percent SiO_2.

The BT system was active from ~600 ka to at least 200 ka. Major and trace element abundances preclude derivation of BT rhyolite (74 percent SiO_2) through crystal fractionation but are consistent with ~30 percent dehydration melting of older tonalitic intrusions. BT petrogenesis was controlled by PPFA fractionation accompanied by 10-20 percent mixing of rhyolitic magmas to ~63 percent SiO_2, with ~30 percent rhyolite mixing from 63-71 percent SiO_2. In contrast to the 3S system, differentiation proceeded beyond 66 percent SiO_2 because rhyolitic magma was mixed into a more evolved (~60-65 percent SiO_2) system.

The observed temporal and spatial variations in petrogenesis were not controlled by regional changes in tectonic setting, crustal thickness or crustal composition. However, small-scale changes in the magnitude of crustal extension occurred in this area, and are thought to have controlled petrogenesis by localizing mid-crustal mafic magmatism and thus crustal heat flow.

Late holocene paleoseismicity along the northern Oregon coast by Mark E. Darienzo (Ph.D,) Portland State University, 1991, 167 p.

Marsh paleoseismological studies were conducted in four bays (Necanicum, Nestucca, Siletz, and Yaquina) along the northern Oregon coast and compared with completed studies in two other bays (Netarts and Alsea). Coseismically buried peats were identified in all bays, based on (1) abrupt contacts, decreases in organic content, increases in sand content, increases in beach sand, and changes in diatom assemblages, all from the peat to the overlying sediments; (2) distinct sandy. layers and key plant macrofossils, such as *Triglochin*, above the buried peat, and (3) widespread correlation of the buried peats within the bay. The stratigraphy and the ages and depths of the top six coseismically buried peats were compared between bays. The following similarities were noted: (1) All bays recorded five burial events in the top 2.6 m within the last 2,200 years. (2) Six burial events were recorded in six bays in the top 3.0 m, except Alsea Bay (3.3 m), and all six events occurred within the last 2,600 years except Yaquina (2,780 years). (3) The depth to the top of each buried peat in the bays is consistent, falling within discrete ranges, except for the to two events at Yaquina. (4) Distinct sandy layers (tsunami-deposited) are present over the topmost buried peat in all bays except Yaquina and over the fourth in all bays except Yaquina and Nestucca. (5) Distinct tsunami-deposited sandy layers are absent over the third buried peat in Netarts, Nestucca, Siletz, Alsea, and possibly Yaquina but present at Necanicum. The evidence strongly suggests synchroneity of coseismic events between the Necanicum River and Alsea Bay (a distance of 175 km), with the exception of the second and sixth event. The sixth coseismic event would be synchronous between Alsea and Netarts, a distance of 105 km. The support for synchroneity of the second event is weak. Synchroneity of coseismic burial events on the northern Oregon coast would argue for paleomagnitudes of at least 8.1 M_w, given a minimum rupture width of 50 km and a rupture length of 105 km. The paleomagnitudes were determined via the moment magnitude equation $M_w=\frac{2}{3}\log_{10}M_o-10.7$, where M_o=shear modulus x rupture area x seismic slip. The seismic slip is estimated from a minimum recurrence interval of 300 years and.a minimum convergence rate of 3.5 cm/yr.

Geology of the Krumbo Reservoir quadrangle, southeastern Oregon, by Jenda A. Johnson (B.S., Oregon State University, 1992), 56 p.

The geology of the Krumbo Reservoir quadrangle, located on the west side of the Steens Mountain escarpment in southeastern Oregon, consists of a bimodal assemblage of Miocene olivine basalt and rhyolite ash-flow tuff characteristic of northwestern Basin and Range volcanism. The assemblage contains three major stratigraphic markers, the Steens Basalt (approximately 16 Ma), the Devine Canyon Ash-flow Tuff (approximately 9.5 Ma), and the Rattlesnake Ash-flow Tuff (approximately 6.7 Ma). Locally exposed units of limited extent are upper Miocene olivine basalt, emplaced between Devine Canyon and Rattlesnake time, and tuff and tuffaceous sedimentary rocks that underlie the Devine Canyon Ash-flow Tuff. The entire study area is underlain by the chemically homogeneous lava flows of Steens Basalt. The Steens Basalt is unconformably overlain by a sequence as thick as 30 m of tuff and tuffaceous sedimentary strata and, locally, by the Devine Canyon Ash-flow Tuff (maximum thickness 17 m). The basalt of Hog Wallow lies conformably above the Devine Canyon Ash-flow Tuff in the northern part of the map area. The Rattlesnake Ash-flow Tuff, which includes some poorly exposed tuffaceous sedimentary strata at its base, conformably overlies the Devine Canyon Ash-flow Tuff and forms the capping unit in the map area. The ash-flow tuffs form mesas and flat-topped ridges. The rhyolite ash-flow tuffs spread laterally over tens of thousands of square kilometers in southeastern Oregon.

Two different sets of faults form conspicuous escarpments in the map area: north-striking-faults that parallel Basin and Range faults and numerous closely spaced west-northwest-striking faults that parallel the Brothers Fault zone. In the map area, the Devine Canyon Ash-flow Tuff changes map pattern from sheet-forming in the northwest to lobe-forming in the southeast. The elongate erosional remnants of the Devine Canyon Ash-flow Tuff parallel the Brothers Fault zone and probably result from inverted topography as a consequence of thicker deposition of the tuff in paleodrainages. It seems likely that this zone marks the ancient change in slope from flat ground with surface water present on the northwest to better-drained ground south and southeastward. Dutch Oven, a closed depression 1.5 km in diameter, is a relict secondary hydroexplosion crater that formed when the hot Rattlesnake pyroclastic flow interacted with surface water; the resulting steam blasted through the overlying deposits leaving a large pit. At least six such pits are found in the Rattlesnake Ash-flow Tuff in this part of Harney Basin. □

Observatory needs volunteers

The USDA Forest Service, McKenzie Ranger District, of the Willamette National Forest is looking for volunteer interpreters or naturalists to serve at Dee Wright Observatory by the summit of the old McKenzie Highway (Hwy 242) in the Cascade Range.

The volunteer position is to start in June 1993, and volunteers would spend three to six hours a day, three or more days a week between July and October, at the observatory assisting visitors. A shorter time commitment would also be possible. Some knowledge of and interest in geology of the Cascades and history of Oregon would be particularly desirable. Camping in the area is not required, so that volunteers could commute from Sisters, Bend, Eugene, or the McKenzie River corridor.

Plans are to repair the observatory structure and replace interpretive signs in the near future, and volunteers would be helping to decide what information should be provided. Additional opportunities for volunteers will be to develop a guided walk for the existing paved trail through the lava beds at the site and also to serve as campground hosts at either a dispersed camp area (Scott Lake) on Highway 242 or in a campground on Highway 126.

In the Forest Service volunteer program, volunteers are signed up on a volunteer agreement that provides them with coverage for on-the-job accidents. They will be expected to provide their own transportation to the observatory. The agency will negotiate reimbursement of some expenses such as mileage, typically at a rate not exceeding $15 a day and for gasoline. Camping volunteers need to provide their own camping equipment, so owners of recreational vehicles are particularly encouraged to apply.

The agency is flexible with this proposed volunteer arrangement and invites all those who are possibly interested or have questions to call or write Pam Novitzky, Developed-Sites Manager, McKenzie Ranger District, McKenzie Bridge, OR 97413, phone (503) 822-3381. *—USFS release*

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