A mafic dike system in the vicinity of Mitchell, Oregon, and its bearing on the timing of Clarno-John Day volcanism and early Oligocene deformation in central Oregon

by Edward M. Taylor, Department of Geology, Oregon State University, Corvallis, Oregon 97331

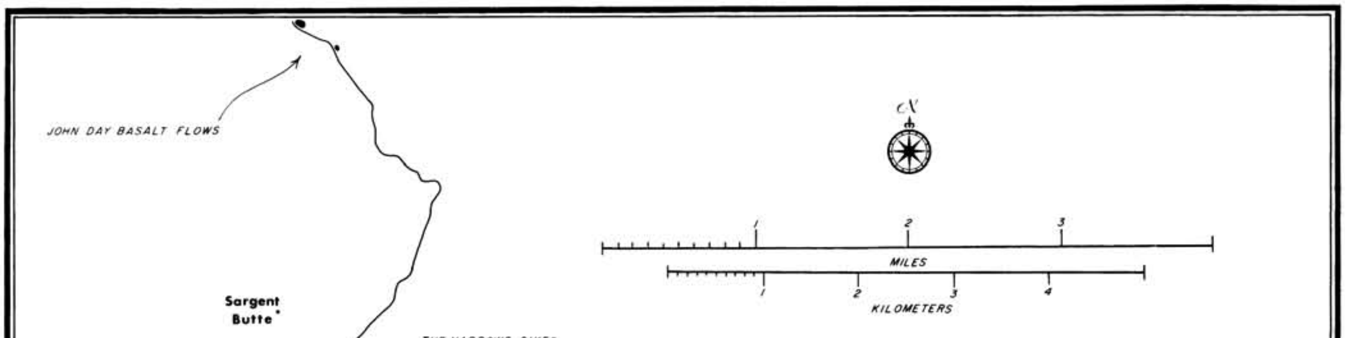
INTRODUCTION

A system of west-northwest-trending basaltic dikes crops out in the vicinity of Mitchell, Oregon. The dikes are exposed best in the central part of the northeast-southwest-trending Mitchell anticline, where they have intruded Cretaceous marine sedimentary rocks of the Gable Creek and Hudspeth Formations. The dikes also have penetrated the overlying volcanic rocks of the Clarno Formation on both limbs of the anticline and were probably associated with basaltic lava flows of the lower John Day Formation. Parts of this dike system appear on a published geologic map of the Mitchell quadrangle and have been designated "Airport dikes," "Nelson Creek dikes," and "Keyes Creek dikes" (Oles and Enlows, 1971).

The mafic dike system has been traced over an area approximately 9 mi long and 2 mi wide in which the dikes are arranged in groups of subparallel segments (Figure 1). Individual segments range in length from 1 mi to a few tens of feet and are commonly offset from each other along trend. Adjacent segments locally taper to thin edges at their extremities, or they are joined, nearly at right angles, by short connective dikes. Most of the dike segments are 15-20 ft wide; their width at a few localities where bulbous protrusions extend into incompetent rocks is as much as 110 ft. In contrast, some dikes apparently were unable to invade competent rock; they terminate or bifurcate just below thick resistant strata or preexistent sills.

Elongate depressions are produced by erosion of dikes that cut resistant strata (Figure 2). Elsewhere, as in soft mudstones of the Hudspeth Formation, low ridges mark the positions of dikes (Figure 3). Volcanic mudflow deposits of the

Figure 1. Distribution of high Fe-Ti tholeiitic basalt dikes of late Oligocene age in the vicinity of Mitchell, Oregon. Heavy solid lines represent dike outcrops; dotted lines represent inferred positions of covered dikes.



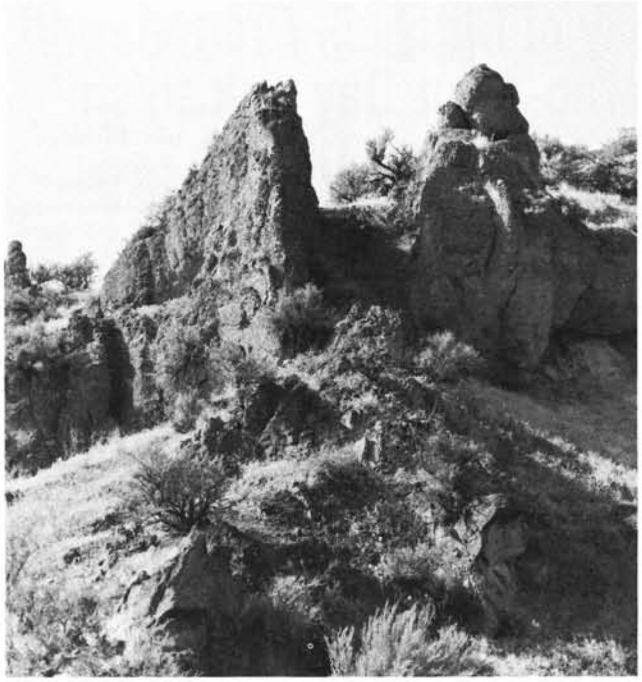


Figure 2. Mafic dike in negative relief. Country rock is erosionally resistant conglomerate of the Gable Creek Formation, 3.8 mi west of Mitchell.

Clarno Formation have been so indurated in close proximity to the dikes that double walls of erosionally resistant mudflow can be found standing in relief along dike margins.

The margins of dikes consist of very fine-grained, black, devitrified glass in a chilled zone up to 2 ft wide. Dike interiors are gray where fresh, uniformly coarse grained, and commonly display crude columnar jointing (Figure 4). Weathering of dike rocks is always more advanced in the interior than at the margins and produces a dark-brown, ferruginous soil.

PETROGRAPHY

In the dike margins, thin tablets of plagioclase (An_{55}) make up 3-4 percent of the rock and are never more than 0.5 mm long. They are surrounded by grains of pyroxene and magnetite approximately 0.001 mm in diameter which form a very fine-grained intergranular texture with microlites of plagioclase. Thin films of brown glass still exist in the freshest samples. A green isotropic clay mineral, probably a complex chlorite interlayered with other phyllosilicates replacing traces of olivine, occurs in euhedral patches up to 0.5 mm in diameter (Figure 5A).

The zone of transition between the fine-grained margins and the coarse-grained interior of dikes is only 7-10 in. wide (Figure 6). Within this zone, elongate crystals of clinopyroxene and plagioclase are suspended in a fine groundmass and become larger and more abundant toward the interior. Near the inner boundary of the transition zone, the groundmass is represented by small, fine-grained patches of late-crystallizing

Figure 3. Mafic dike in positive relief. Country rock is easily eroded mudstone of the Hudspeth Formation, 2.8 mi west of Mitchell.

Figure 4. Columnar jointing in the Keyes Creek dike adjacent to U.S. Highway 26. Hat rests upon contact with volcanic mudflow deposits of the Clarno Formation.

feldspar, largely altered to smectite (Figure 5B).

Wherever the width of dikes exceeds 10-12 ft, the interior is texturally hypidiomorphic-granular, consisting of plagioclase, monoclinic pyroxene, and opaque oxides up to 1.5 mm in length (Figure 5C). Plagioclase of composition An$_{50-60}$ makes up 75 percent of the dike rocks. The pyroxene is a dusky augite with a 2V of 45-48° and commonly constitutes 18-20 percent of the rock. The opaque oxide, which is titanomagnetite in the fine-grained margin, becomes a coarse-grained skeletal and dendritic admixture of ilmenite and magnetite in the interior.

Alteration of dike rocks by deuteric processes and weathering has converted all olivine to green chloritic minerals. In varying degrees, pyroxene is altered to highly birefringent yellow and orange smectite, ilmenite and magnetite are altered to leucoxene and hematite, and plagioclase is replaced by carbonate. In Table 1, the chemical effects of alteration are revealed by the contrast between column 3, an average of two very fresh samples from dike margins, and column 4, an average of seven altered samples from dike interiors. Altered dike rocks have lost Fe and Mg but gained Ca and an unspecified quantity of H_2O and CO_2.

Rocks of the mafic dike system in the Mitchell area are low-alumina tholeiites enriched in Fe and Ti. They are distinct from Mitchell-area basaltic flows and dikes of the Clarno Formation in which the Al, Ca, and Mg content is much greater and the Fe and Ti content is much smaller (Taylor, unpublished data). Major-element composition of the dikes is also distinct from basalts of the Picture Gorge Formation in the Mitchell area because the dikes contain much more Fe and Ti. The closest compositional match to the mafic dike system is

*Table 1. Major-element composition of mafic dikes near Mitchell, Oregon**

	(1)	(2)	(3)	(4)	(5)
SiO_2	51.3	51.8	51.6	52.0	47.74
Al_2O_3	12.8	13.4	13.1	13.7	15.27
FeO	15.6	14.5	15.1	14.1	15.2
CaO	7.8	8.5	8.2	8.6	7.57
MgO	5.4	4.0	4.7	3.5	4.70
K_2O	0.65	0.50	0.60	0.75	1.46
Na_2O	3.1	3.1	3.1	3.0	3.48
TiO_2	3.10	3.00	3.05	3.00	3.33
Total	99.75	98.80	99.45	98.65	98.75

(1) Fresh marginal glass from Keyes Creek dike, 500 ft north of south corner secs. 31 and 32, T. 11 S., R. 22 E.

(2) Fresh marginal glass from east end of Mill Creek dike, 4,400 ft elevation, NW¼ sec. 9, T. 12 S., R. 22 E.

(3) Average of (1) and (2).

(4) Average of seven slightly altered rocks from dike interiors, representing all dike groups.

(5) Basaltic lava from lower John Day Formation, 6 mi northwest of Mitchell, 700 ft west of intersection of secs. 4, 5, 8, and 9, T. 11 S., R. 21 E. Recast H_2O-free from Hay (1962).

* Analyses (1)-(4) by XRF and AAS. Total Fe as FeO. H_2O and CO_2 not included because samples were fused before analysis.

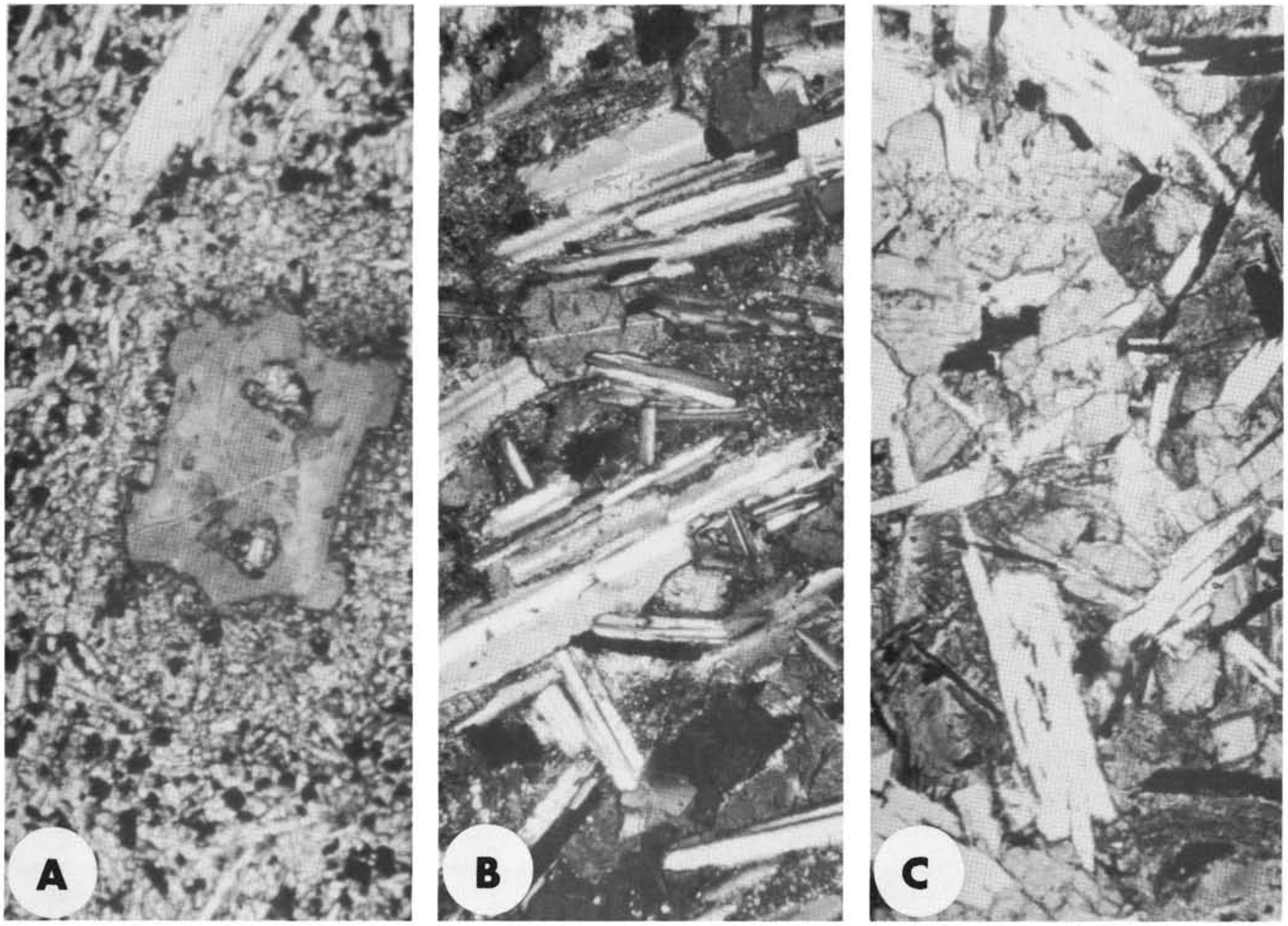


Figure 5. Photomicrographs of dike rocks in which each field width is 0.2 mm. (A) Fine-grained margin consisting of sparse olivine altered to clay (center) surrounded by microlites of feldspar and granules of pyroxene, titanomagnetite, and glass. (B) Transition zone of coarse feldspar, monoclinic pyroxene, blades of intergrown magnetite and ilmenite, and patches of fine groundmass. Crossed polars. (C) Coarse hypidimorphic-granular interior. Same minerals as (B).

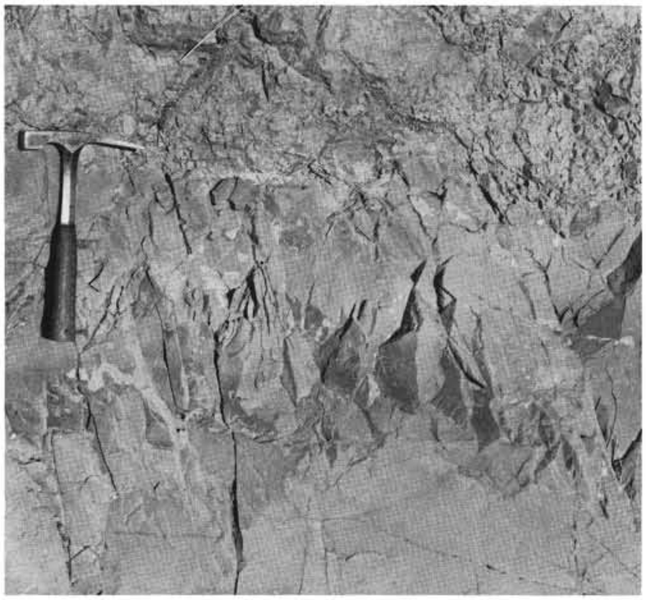


Figure 6. Transition zone from fine-grained, close-fractured margin (below head of hammer) to coarse-grained interior of mafic dike (above head of hammer).

with basaltic lavas in the lower part of the John Day Formation northwest of Mitchell (Figure 1). The John Day lavas lack phenocrysts and contain high Fe and Ti (Table 1, column 5). It is not suggested that the mafic dike system was the direct source of these particular John Day lavas, because the dikes are high-Si, low-K tholeiites while the lavas are low in Si and high in K, transitional to alkali basalts (Robinson, 1969).

CONCLUSIONS AND SPECULATIONS

Emplacement of the dikes

An obvious feature in need of resolution is the rather peculiar distribution of the dikes. Within the overall west-northwest trend, the dikes occur in distinct groups that are successively offset en echelon in a left-lateral sense. For example, Nelson Creek dikes seem to be offset from Mill Creek dikes, and a similar pattern is exhibited by Gable Creek, The Narrows, Airport, and Keyes Creek dikes (Figure 1). On a smaller scale, the same pattern can be seen between the individual offset segments of each dike group.

Although it has been reported that "dikes generally occupy preexiting faults" and some dike segments have been shown on geologic maps to be offset by strike-slip faults (Oles and Enlows, 1971, map and explanation), detailed study of the dikes and surrounding country rock has failed to confirm these relationships. Many faults of varying extent and displacement occur in the vicinity of dikes but not one has been found to be coincident with a dike. Slickensided fractures have been found within dike rocks at two localities; displacement of only a few feet is indicated. Where extremities of dikes are exposed, they are seen to taper to thin edges rather than blunt, faulted terminations. Moreover, adjacent segments often overlap in parallel alignment far beyond the positions of possible cross faults.

The Keyes Creek and Nelson Creek dikes have been described as parts of a single dike that has been offset 22,000 ft by right-lateral slip along the Mitchell fault (Oles and Enlows, 1971, p. 48, 54, 59). This interpretation must be reconsidered, because the eastern 1 mi of the Keyes Creek dike cuts across the Mitchell fault (Figure 1). Segments of the dike lie in the crush zone of the fault and display no evidence of disruption or reorientation. If the Nelson Creek dikes are correctly projected to the Mitchell fault, an offset of 28,000 ft is indicated. This is more than twice the right-lateral displacement of the Mitchell fault, as demonstrated by offset of the axis of the Mitchell anticline (Wilkinson and Oles, 1968). It is my conclusion that the mafic dike system in the Mitchell area has not been significantly displaced by later faulting of any kind. In particular, right-lateral movement along the Mitchell fault preceded dike emplacement.

The dike segments are not randomly located; in both position and orientation their emplacement appears to have been systematically controlled. It is especially significant that the dikes, with one exception, seem to have avoided the trace of the Mitchell fault and many other faults that are parallel to it. What could have localized the dikes? This question can be readily answered if it is assumed that the dikes were emplaced after most of the right-lateral movement had occurred on the Mitchell fault but before the responsible conditions of stress had died out. The magma would have found paths of least resistance along gash fractures at acute angles to the Mitchell fault, while passage of magma into the fault zone itself would have been hindered. Gash fracture control of the dikes was proposed by Oles and Enlows (1971, p. 59), but they also emphasized dike emplacement prior to right-lateral faulting and presumably prior to development of gash fractures.

A new emphasis should be placed upon the nearly equivalent age of the dike system and the Mitchell fault. If a deep-seated body of mafic, nonporphyritic, fluid magma, elongate in a west-northwest direction, was intersected by a zone of right-lateral disruption of the crust along the Mitchell fault, the magma could have penetrated gash fractures and produced the pattern of dikes now seen in the Mitchell area. Indeed, without this combination of tectonic pressures and avenues of escape, the dense magma might never have reached shallow crustal levels or poured over the surface.

Age of the dikes

K-Ar ages of the Nelson Creek dikes and Airport dikes were reported to be 29.4 ± 0.6 and 33.4 ± 1.3 m.y., respectively (Enlows and Parker, 1972). However, the dikes were probably formed at the same time. It is unlikely that, in this small area, many separate magmas of nearly identical major-element composition and extent of crystallization would penetrate to the same crustal level in response to apparently identical conditions of stress and adopt the same paleomagnetic polarity over a span of four million years. Because the dikes show a much closer compositional relationship to lavas of the John Day Formation than to any known rocks of the Clarno Formation, and because the age (31.5 m.y.) of John Day mafic lavas only 3 mi northwest of the dikes (Evernden and others, 1964) matches the average age (31.4 m.y.) of dikes reported by Enlows and Parker, I conclude that 31.5 m.y. is the best currently available estimate of the age of the mafic dike system in the Mitchell area.

Clarno-John Day boundary problem

Enlows and Parker (1972) placed the dikes within the "indicated span of Clarno igneous activity in the Mitchell quadrangle" which lasted "from about 46 million years before pres-

Table 2. K-Ar ages from upper Clarno and lower John Day Formations in the vicinity of Mitchell, Painted Hills, and Clarno Bridge

Age (m.y.)	Material	Location	Stratigraphic position	Reference
29.3 ± 0.5 29.4 ± 0.6	Whole rock	1 mi SE of Mitchell	Nelson Creek dikes	Enlows and Parker, 1972
31.1	Sanidine	Painted Hills	Tuff bed 165 ft above base of John Day Formation	Evernden and others, 1964
31.5	Whole rock	Between Mitchell and Painted Hills	Basalt lava in lower red John Day Formation	Evernden and others, 1964
32.0	Sanidine	1 mi E of Clarno Bridge	Altered tuff at base of John Day Formation	Evernden and James, 1964
30.1 ± 4.7 35.6 ± 3.4	Whole rock	4.5 mi E of Mitchell	Andesite lava, "upper Clarno"	Enlows and Parker, 1972
33.3 ± 1.2 33.5 ± 1.3	Whole rock	1.5 mi NW of Mitchell	Airport dikes	Enlows and Parker, 1972
34.0	Plagioclase	2 mi NE of Clarno Bridge	"Nut Beds" at top of Clarno Formation	Evernden and James, 1964
36.4 ± 1.1	Sanidine	2.2 mi SW of Ashwood	"Member A" at base of John Day Formation	Swanson and Robinson, 1968
36.5 ± 0.9	Sanidine	1.5 mi SW of Painted Hills	Crystal tuff near top of Clarno Formation	Evernden and others, 1964
37.5	Whole rock	Between Mitchell and Painted Hills	Andesite lava near top of Clarno Formation	Evernden and others, 1964

ent to 30 million years before present" and "was immediately succeeded by the deposition of the extensive volcaniclastic sediments of the John Day Formation" (p. 105 and Table 1). This interpretation was supported by an average age of 32.8 m.y. for a Clarno lava sample (KFO-901) collected 4.5 mi east of Mitchell.* In opposition to this interpretation was the 36-m.y. age of a widespread welded ash-flow sheet in "member A" at the base of the John Day Formation (Swanson and Robinson, 1968). Table 2 lists published K-Ar ages of Clarno and John Day rocks pertinent to this boundary problem. Much discussion in recent years has centered upon the possibility of simultaneous Clarno and John Day volcanism in central Oregon.

Inconsistencies between published radiometric ages and known stratigraphic relationships can be removed by reconsideration of three K-Ar determinations. "Member A" (36.4 m.y.) at the base of the John Day Formation overlies bedded John Day tuff (32.0 m.y.) and bedded Clarno tuff (34.0 m.y.) at Clarno Bridge (Evernden and James, 1964; Evernden and others, 1964). These bedded tuffs have been altered to bentonitic clay, and, as suggested by Swanson and Robinson (1968), their feldspars could have lost argon, giving rise to younger ages. The basal ash-flow tuff of "member A," in contrast, is a relatively fresh unit, and its age is probably more reliably estimated. The age of the "upper Clarno" andesite lava (KFO-901) from Mitchell (av. 32.8 m.y.) is erroneous because, in my opinion, it belongs stratigraphically in the lower Clarno Formation. An unpublished K-Ar age of 48.9 ± 5.2 m.y. (Enlows, Robinson, and McKee, personal communication) has been obtained on hornblende separated from another andesite flow in a nearly equivalent stratigraphic position, 3.4 mi northeast of Mitchell. In addition, volcanic mudflow deposits at approximately the same stratigraphic level as the nearby 48.9-m.y. hornblende andesite lava have been intruded by the mafic rocks of Marshall Butte. The average of two Marshall Butte age measurements is 44.9 m.y. (Enlows and Parker, 1972). It is my conclusion that in the vicinity of Mitchell, Painted Hills, and Clarno Bridge, deposition of the Clarno Formation ceased and was rapidly followed by deposition of the John Day Formation approximately 36 million years ago.

Early Oligocene deformation

The lower ash-flow tuff of "member A" at the base of the John Day Formation appears to have spread across the trace of the Blue Mountain anticline eastward to within 13 mi of Mitchell (Robinson, 1975). Most of the later John Day ash-flow tuffs were prevented from spreading that far to the east by a topographic barrier coincident with the Blue Mountain anticline (Robinson, 1966). Uplift of the Blue Mountain anticline probably produced the topographic barrier after much of the lower John Day Formation had been deposited. These relationships are compatible with an episode of northwest-southeast compressional deformation of sufficient intensity to produce broad folds and strike-slip faults and to release relatively small volumes of deep-seated mafic magmas to the surface during early Oligocene time in north-central Oregon.

The obvious magmatic distinctions between Clarno and John Day volcanism developed independently from, and some five million years prior to, the onset of crustal deformation that produced folds in John Day rocks. It is suggested that lower John Day tuffs will be found resting conformably on upper Clarno rocks in some localities and that an angular unconformity will be recognized between lowermost John Day tuffs and overlying John Day tuffs where preservation and exposure permit careful measurement. In similar fashion, strike-slip movement on the Mitchell fault probably displaced lower John Day tuffs but not overlying members of the John Day Formation.

ACKNOWLEDGEMENTS

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* It should be recorded that the location of KFO-901 is given incorrectly by Enlows and Parker; it was taken from the summit of hill 4703, in the SW ¼ of sec. 35, T. 11 S., R. 21 E. (K.F. Oles, personal communication).

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Howard C. Brooks, Resident Geologist

Grants Pass Field Office: 312 S.E. "H" Street, Grants Pass 97526, phone (503) 476-2496.
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COVER PHOTO

Mafic dike of John Day Formation cutting Cretaceous marine mudstones of the Hudspeth Formation along Gable Creek in the Mitchell quadrangle, Oregon. The article beginning on the next page discusses these dikes.

New index of Oregon topo maps available from USGS

A new index showing areas of the State of Oregon covered by 1,091 published topographic maps is now available upon request from the U.S. Geological Survey (USGS).

By showing the shape and elevation of the terrain and delineating a wide range of natural and manmade features, standard USGS topographic quadrangle maps are valuable records of the land surface for engineers, scientists, planners, and others concerned with the nation's resources. The maps also are popular with hikers, hunters, campers, and other open-air enthusiasts as "silent guides" to the outdoors. The USGS annually distributes more than 10.5 million copies of its 45,000 published "topo" maps.

The Oregon index includes a map of the state showing areas covered by each of the available 7½-minute and 15-minute quadrangle maps. The text on the back of the index lists other maps of Oregon published by the Survey, such as maps of the entire state, rivers and creeks, reservoirs and damsites, and Crater Lake National Park.

More than 85 percent of Oregon has now been covered by quadrangle maps. The 7½-minute maps are at a scale of 1:24,000 (1 in. equals 2,000 ft) and the 15-minute quadrangle maps are at a scale of 1:62,500 (1 in. equals about 1 mi).

USGS-published maps of Oregon are deposited and available for inspection at nine reference libraries in the state—in Ashland, Bend, Corvallis, Eugene, Klamath Falls, La Grande, Monmouth, Portland, and Salem. The index also lists commercial outlets in Oregon, California, Idaho and Washington where many of the maps may be purchased, including the Portland office of the Oregon Department of Geology and Mineral Industries.

Copies of the "Index to Topographic Maps of Oregon" are available free from USGS Public Inquiries Offices in Menlo Park, Calif. (Building 3, 345 Middlefield Rd.); San Francisco (504 Custom House, 555 Battery St.); Los Angeles (7638 Federal Building, 300 North Los Angeles St.) and Spokane, Wash. (678 U.S. Court House, West 920 Riverside Ave.). ☐

Mine reclamation fees increase

The 1981 Oregon Legislative Assembly passed House Bill 2220 increasing the fees (provided in ORS 517.800) for mining reclamation. The bill was signed by the Governor and became effective upon signature July 2, 1981.

The application fee for a new site is $390, and the annual renewal fee is $290. The increase is designed to maintain the self-sufficiency of the Mined Land Reclamation Program through the 1981-1983 biennium. This program, intended to restore surface mined land to a continuing useful purpose, is 90 percent funded by the industry it regulates.

The new fees are now effective for all new mining site applications. Renewal fees are effective August 1981. ☐

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