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MAJOR- AND TRACE-ELEMENT ANALYSES OF STEENS BASALT, SOUTHEASTERN OREGON

By

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INTRODUCTION

This report presents major- and trace-element analyses of 85 lava flows and dikes collected from the Steens Basalt at Steens Mountain, Oregon (fig. 1). The 16.6-Ma Steens Basalt is a laterally continuous unit of lava flows exposed throughout much of southeastern Oregon (fig. 2) (Fuller, 1931; Walker, 1960; Walker and Repenning, 1965; Greene and others, 1972; Carlson and Hart, 1983a; Hart and Carlson, 1985; Mankinen and others, 1987). The basalt is exposed in a major basin-range fault scarp that provides almost 2000 m of local relief above the Alvord Desert, revealing one of the thickest single exposures of Tertiary basalt in the world. The section records a change in magnetic polarity from reversed at the base to normal polarity at the top, with a long transitional period between the two (Watkins, 1965), and may have been erupted in a brief episode only a few thousand to a few tens thousands of years long. The basalt unconformably overlies Oligocene and early Miocene lava flows and ash-flow tuffs that range from basaltic andesite to biotite rhyolite in composition (Fuller, 1931; Walker, 1979). It underlies a capping stage of platy andesite lava flows that are compositionally related to the Steens Basalt.

More than 100 individual flows form the Steens Basalt. Flows vary from 1 to 10 m, and average 5 m, thick. A maximum thickness of approximately 920 m was determined from the geologic maps of Minor and others (1987a, 1987b).

Possible feeders for the Steens Basalt are vertical dikes exposed in the Steens Mountain escarpment (Fuller, 1931; Minor and others, 1987a, 1987b). The dikes are chiefly of normal polarity (Mankinen and others, 1987), and samples collected during this study are compositionally equivalent to the upper flows of the sequence (table 1, nos. JS-42 and -62).

Steens Mountain represents the remains of a shield volcano that may have been 80 to 100 km in diameter (Mankinen and others, 1985). The central vent, defined by a circular magnetic anomaly, is located near the crest of the mountain (Rytuba, 1988). The original extent of Steens and Steens-like flows is estimated to have been between 25,000 and 50,000 km^2 (Carlson and Hart, 1983a; Carlson and Hart, 1987; Mankinen and others, 1987). Steens-like flows are petrographically and compositionally similar to late Steens Basalt flows but are isotopically distinct and are slightly younger. They may have been included with Steens Basalt in earlier reconnaissance studies attempting to define the eastern extent of the basalt.

Data from Mankinen and others (1987) suggest that the Steens Basalt and equivalents were erupted initially during a reversed-polarity stage from vents dispersed over a broad area of southeast Oregon and northwest Nevada. The vents became progressively more localized until the final normal-polarity stage, when eruption was confined to a single large shield volcano.

By correlating many exposures of Steens and Steens-like sequences, Mankinen and others (1987) constructed a fence diagram showing that (1) pre-Steens topography was irregular, with local relief of as much as 1000 m, (2) the lowermost reversely magnetized flows of Steens Basalt maintained a maximum thickness of 400-500 m throughout the area, (3) the greatest thickness of transition-polarity Steens Basalt occurs along a south trend southward from Steens Mountain, suggesting that the source vents were in this general vicinity, and (4) the section of normal-polarity flows of Steens Basalt is thickest at Steens Mountain and thins westward and southward from there indicating a single centralized vent. Mankinen and others (1987) also noted that platy basaltic andesite flows, compositionally similar to those that marked the final eruptive period of Steens Mountain, began to erupt earlier 65 km south of Steens Mountain, near the Oregon-Nevada border, during the reversed-polarity time interval; they continued into the normal-polarity interval.

METHODS

Sampling on the east-facing side of Steens Mountain began at the base of the basalt flows above a sequence of altered calc-alkaline lava flows and ash-flow tuffs. Forty two samples were collected on the ridge between Little Alvord Creek and Pike Creek, (fig. 3; sec. 7, T. 34

S., R. 34 E.). Steep cliffs and dense brush discouraged further ascent, so the last sample was collected at 7600 ft elevation. The next transect began at 7600 ft in the canyon west of the north-south-trending ridge that separates Alvord Desert from Wildhorse Canyon (sec. 2, T. 34 S., R. 33 E.). Projecting the dips, we estimate that the flow sequence continued in Wildhorse Canyon at about the 7200 ft elevation. However, talus-covered exposures down the canyon precluded our beginning the second transect down dip from the site of sample 42; thus we were unable to collect an overlapping sequence and assume that some flows were missed. Our apparent meander up Wildhorse Canyon (from secs. 2 and 1, T. 34 S., R. 33 E., to secs. 35, 26, 25, and 36, T. 33 S., R. 33 E. in order of sample number) was due to extrapolating superposition of flows on the basis of lateral continuity.

An attempt was made to sample every flow. However, highly weathered flows or talus-mantled slopes lacking outcrop were not sampled. We estimate that at least 60 percent of the flows from the entire Steens Basalt sequence were sampled. Appendix 1 includes brief descriptions and thicknesses of sections not analyzed. The freshest material was chosen and cleaned of weathered surfaces in the field. Brief hand-sample and outcrop descriptions are in Appendix 1.

Whole-rock chemical compositions were obtained using an automated Rigaku 3370 spectrometer at the GeoAnalytical Laboratory, Washington State University, Pullman. Sample preparation and analytical procedures are detailed by Johnson and others (in press). Each sample was analyzed for 27 major and trace elements, and the data were normalized on a volatile-free basis. The analytical precision is reported to be less than 1percent for major elements and less than 5-10 percent for most trace elements. Rock powders were processed using 2:1 dilution fused beads; duplicate beads were produced for several samples to check analytical precision and reproducibility of results.

PETROGRAPHY, CHEMISTRY, AGE, AND MAGNETIC POLARITY

Steens Basalt varies from aphanitic to diktytaxitic to coarsely porphyritic with plagioclase megacrysts 1 to 4 cm long forming up to 30 percent of the mode. Thin zones of some thick flows contain cumulate plagioclase to 50 percent of the mode, buat they were avoided and attempts were made to collect representative samples within a flow unit. Unlike thick packages of members of the Columbia River Basalt Group, which are petrographically monotonous from flow to flow, the Steens Basalt shows marked variation among flows. Coarsely plagioclase-phyric flows are commonly interbedded with flows of olivine basalt free of plagioclase phenocrysts (Appendix 1), probably reflecting pulses of magmatism.

Chemical analyses of multiple flows of Steens Basalt show them to be chiefly olivine tholeiite that ranges in composition from 48 to 54 percent SiO_2 (fig. 4; table 1). In the study area, the unit varies from more primitive alkali olivine basalt at the base to more evolved tholeiite toward the top of the section. Although some compositional variation can be found between petrographically different flows, grouping by mineralogy is inconsistent. For example, samples 34-41 (JS-22-29; table 1) cannot be clearly distinguished by chemistry as being either plagioclase or olivine rich. No attempt was made to sample intra-flow variation, which can differ by as much as 1-25 percent plagioclase phenocrysts. Although variations in major- and trace-elements have long been recognized and related to mineralogic differences (Gunn and Watkins, 1970), compositional change from base to top has been largely ignored. This study shows increasing incompatible element concentrations, and decreasing compatible element content, from base to top (figs. 5 and 6). The lower flows show remarkable trace-element homogeneity, whereas the upper flows have increasing compositional scatter (fig. 6). A few elements, such as Cu (fig. 6), exhibit no regular pattern. Rare earth- (REE) and trace-element patterns throughout the sequence are similar to each other, with no systematic relationship with respect to silica content (figs. 7 and 8). The Steens Basalt generally conforms to the typical continental flood-basalt pattern for all REE (Philpotts, 1990). MORB-normalized trace elements have similar profiles throughout the basalt sequence.

No thin sections were prepared for this study. Thin section work by C.T. Harper (Baksi and others, 1967) and Mankinen and others (1987) shows that the basalt contains, on average, 60 percent feldspar (An_{65-75}), 20 percent ophitic Ca-rich augite, 8 to 10 percent olivine, and 8 percent Fe-Ti oxides. Also locally present is apatite, glass, chlorophaeite, and zeolites (Avent, 1970). Olivine is usually somewhat altered.

The Steens Basalt is middle Miocene in age. Recent work by Swisher and others (1990) on samples collected from the base and top of the basalt section yielded ages of 16.58 ± 0.05 Ma and 16.59 ± 0.02 Ma, determined using $^{40}Ar/^{39}Ar$ laser fusion of coarse plagioclase crystals. Lack of sedimentary interbeds and obvious horizons of erosion or weathering indicates a relatively rapid emplacement of the entire sequence. Gunn and Watkins (1970) proposed that the lower and upper limits on the time taken for the entire sequence to accumulate could be as little as 2000 or as much as 50,000 years, respectively. A previously determined 14.8-Ma K-Ar age from a capping flow north of Steens Mountain (Hart and Carlson, 1985) is from a petrographically similar rock that is stratigraphically separated from the Steens Basalt by a thin layer of the 15 Ma tuff of Oregon Canyon (Rytuba and McKee, 1984; Sherrod and others, 1989; Johnson, 1995).

The Steens Basalt is contemporaneous with much of the Columbia River Basalt Group (CRBG; fig. 2) of northeastern Oregon, eastern Washington, and western Idaho (Walker, 1969; Watkins and Baksi, 1974; Hart and others, 1989). Recent mapping between Steens Mountain and the recognized southern margin of the CRBG at Farewell Bend on the Oregon-Idaho border shows a nearly continuous band of CRBG-like tholeiite as much as 600 m thick between previously recognized outcrop areas of the two units (Ferns, 1993; Lees, 1994; Hooper and others, 1995; Binger, 1997, Johnson and others, 1998). One such sequence, the basalt of Malheur Gorge, previously known as the Unnamed Igneous Complex of Kittleman and others (1967), is divided by Lees (1994) into the lower Pole Creek, upper Pole Creek, and Birch Creek formations from base to top, respectively, on the basis of chemistry. The lowest exposed flows, the lower Pole Creek, are compositionally similar to the more primitive lower reversely polarized flows of the Steens Basalt (Binger, 1997). Lees (1994) and Binger (1997) note the similarity between the upper Pole Creek and Birch Creek formations and the Imnaha and Grande Ronde Basalt, respectively, both members of the CRBG. Although the upper tholeiitic flows of Steens Basalt have some similarities with the more evolved Birch Creek and Grande Ronde Basalts, they are compositionally distinct (Binger, 1997). Regionally, the change up section from the more primitive lower Steens Basalt-type composition at the base to CRBG compositions at the top appears to be accompanied by an increase in Imnaha and Grande Ronde types toward the north (Hooper and others, 1995).

The Steens Basalt records a geomagnetic polarity reversal from reversed- to normal-magnetization directions (Watkins, 1965; Baksi and others, 1967; Mankinen and others, 1987). The detailed work of Mankinen and others (1987) indicates that the magnetostratigraphy consists of three segments: a thicker lower sequence of reversed polarity, a 150-m-thick middle sequence of transitional polarity, and an upper sequence of normal polarity. Although the location of the transition in our sampled sequence is not known precisely, proximity of the sampling area to that of the geomagnetic transects indicates that the normal-polarity flows probably occupy the upper 350 m (~1148 feet) of the 920-m section. The sudden scatter in composition of samples above map number 44 might begin at about the polarity change, but no polarity measurements were made during this study.

An experimental study of plagioclase-hosted melt inclusions in the Steens Basalt (Johnson and others, 1995) suggests that, unlike plagioclase-hosted melt inclusions from many oceanic basalts, the inclusions analyzed in sample JS-5 exhibit a narrow range of composition and are more evolved than the host rock. Evidence derived from petrography, mineral chemistry, and phase-equilibria modeling supports the contention that the trapped magma formed late in the petrologic history of the system, and that the phenocrysts crystallized in a shallow (1 to 3 kbar) well-mixed system. Homogeneity of the melt inclusions and of the basalt of the lower Steens section suggests the presence of a middle to upper crustal magma chamber.

Sr and Nd isotope analyses by Carlson and Hart (1983a) indicate the Steens Basalt and underlying andesite were derived from a depleted mantle source ($^{87}Sr/^{86}Sr$ 0.70366-0.70385, and ε_{Nd} +4.2-6.9). Carlson and Hart (1983b) and Hart and Carlson (1987) propose that the parental Steens Basalt was subjected to contamination by a crustal material that was predominantly Cenozoic in age and consisted only of the extrusive rocks and their reworked products that were produced as a magmatic arc migrated across southern Oregon and northern Nevada. This mafic crustal material was only slightly more evolved isotopically than the primary magmas themselves. In contrast, the isotopic signature of the"Steens type" basalt indicates derivation from enriched mantle sources ($^{87}Sr/^{86}Sr$ 0.7052-0.7056, and ε_{Nd} -2.2 to -3.1) (Carlson, 1984).

References Cited

Anders, E., and Ebihara, M., 1982, Solar-system abundances of the elements: Geochimica et Cosmochimica Acta, v. 46, p. 2363-2380.

Avent, J.C., 1965, Cenozoic stratigraphy and structure of Pueblo Mountains region, Oregon-Nevada: Seattle,Univeristy of Washington, Ph.D. dissertation, 119 p.

Baksi, A.K., York, D., and Watkins, N.D., 1967, Age of the Steens Mountain geomagnetic polarity transition: Journal of Geophysical Research, v. 72, no. 24, p. 6299-6308.

Binger, G.B., 1997, The volcanic stratigraphy of the Juntura region, eastern Oregon: Pullman, Washington State University, M.S. thesis, 206 p.

Carlson, R.W., and Hart, W.K., 1983a, Areal extent and isotope geochemistry of the Steens Mountain flood basalt, southeastern Oregon [abs.]: Eos (American Geophysical Union, Transactions), v. 64, no. 18, p. 338.

——1983b, Geochemical study of the Steens Mountain flood basalt: Carnegie Institution of Washington Yearbook 82, p. 475-481.

——1985, Regional extent and significance of Steens Mountain-type basalts in the northern Great Basin [abs]: Geological Society of America Abstracts with Programs, v. 17 no. 4, p. 212.

——1987, Crustal genesis on the Oregon Plateau: Journal of Geophysical Research, v. 92, p. 6,191-6,206.

Ferns, M.L., Brooks, H.C., Evans, J.G., and Cummings, M.L., 1993, Geologic map of the Vale 30- x 60-minute quadrangle, Malheur County, Oregon, and Owyhee County, Idaho: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-77, scale 1:100,000.

Fuller, R.E., 1931, The geomorphology and volcanic sequence of Steens Mountain in southeastern Oregon: University of Washington Publications in Geology, v.3, no. 1, 130 p.

Goldstein, M.A., Strangway, D.W., and Larson, E.E., 1969, Paleomagnetism of a Miocene transition zone in southeastern Oregon: Earth and Planetary Science Letters, v. 7, p. 231-239.

Greene, R.C., Walker, G.W., and Corcoran, R.E., 1972, Geologic map of the Burns quadrangle, Oregon: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-680, scale 1:250,000.

Gunn, B.M., and Watkins, N.D., 1970, Geochemistry of the Steens Mountain Basalts, Oregon: Geological Society of America Bulletin, v. 81, no. 5, p. 1,497-1,516.

Hart, W.K., and Carlson, R.W., 1985, Distribution and geochronology of Steens Mountain-type basalts from the northwestern Great Basin: Isochron/West, no. 43, p. 5-10.

——1987, Tectonic controls on magma genesis and evolution in the northwestern United States: Journal of Volcanology and Geothermal Research, v. 32, p. 119-135.

Hart, W.K., Carlson, R.W., and Mosher, S.A., 1989, Petrogenesis of the Pueblo Mountains basalt, southeastern Oregon and northern Nevada, in Reidel, S.R., and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, p. 367-378.

Hooper, P.R., Hawkesworth, C.J., Lees, K.R., Francis, M., Johnson, J.A., and Binger, G.B., 1995, The southern extension of the Columbia River Basalts: tectonic implications [abs.]: Geological Society of America Cordilleran Section, v. 28, no. 5.

Johnson, D.M., Hooper, P.R., and Conrey, R.M., XRF Analysis of rocks and minerals for major and trace elements on a single low dilution li-tetraborate fused bead: Advances in X-Ray Analysis, v.41, in press

Johnson, J.A., 1995, Geologic evolution of the Duck Creek Butte eruptive center, High Lava Plains, southeastern Oregon: Corvallis, Oregon State University, M.S. thesis, 151 p.

Johnson, J.A., Hooper, P.R., Hawkesworth, C.J., and Binger, G.B., 1998, Geologic map of the Stemler Ridge quadrangle, Malheur County, Southeastern Oregon: U.S. Geological Survey Miscellaneous Field Studies Map, OF 98-105, scale 1:24,000.

Johnson, J.A., Nielsen, R.A., and Fisk, M., 1995, Plagioclase-hosted melt inclusions in the Steens Basalt, southeastern Oregon: Petrologica, v. 4, no. 3, p. 267-273.

Kittleman, L.R., Green, A.R., Haddock, G.H., Hagood, A.R., Johnson, A.M., McMurray, J.M., Russell, R.G., and Weeden, D.A., 1967, Geologic map of the Owyhee region, Malheur County, Oregon: University of Oregon Museum of Natural History Bulletin 8, scale 1:125,000.

LeBas, M.J., and Streckeisen, A., 1991, The IUSG systematics of igneous rocks: Journal of the Geological Society of London, v. 148, part 5, p. 825-833.

Lees, K.R., 1994, Magmatic and tectonic changes through time in the Neogene volcanic rocks of the Vale area, Oregon, northwestern U.S.A.: Milton Keynes, United Kingdom, Open University Ph.D. dissertation, 284 p.

Mankinen, E.A., Prevot, Michel, Gromme, C.S., and Coe, R.S., 1985, The Steens Mountain (Oregon) geomagnetic polarity transition, 1. Directional history, duration of episodes, and rock magnetism; Journal of Geophysical Research, v. 90, no. B12, p. 10,393-10,416.

Mankinen, E.A., Larson, E.E., Gromme, C.S., Prevot, Michel, and Coe, R.S., 1987, The Steens Mountain (Oregon) geomagnetic polarity transition, 3. Its regional significance; Journal of Geophysical Research, v. 92, no. B8, p. 8057-8076

Minor, S.A., Rytuba, J.J., Goeldner, C.A., and Tegtmeyer, K.J., 1987a, Geologic map of the Alvord Hot Springs quadrangle, Harney County, Oregon: U.S. Geological Survey Miscellaneous Field Studies Map MF-1916, scale 1:24,000.

Minor, S.A., Rytuba, J.J., Meulen, D.B., Grubensky, M.J., and Tegtmeyer, K.J., 1987b, Geologic map of the Wildhorse Lake quadrangle, Harney County, Oregon: U.S. Geological Survey Miscellaneous Field Studies Map MF-1915, scale 1:24,000.

Philpotts, A.R., 1990, Principles of Igneous and Metamorphic Petrology: Englewood Cliffs, New Jersey, Prentice Hall, 498 p.

Rytuba, JJ., 1988, Volcanism, extionsional tectonics, and epithermal mineralization in the Northern Basin and Range Province, California, Nevada, Oregon, and Idaho: U.S. Geological Survey Circular 1035, p. 59-62.

Rytuba, J.J., and McKee, E.H., 1984, Peralkaline ash-flow tuffs and calderas of the McDermitt volcanic field, southeast Oregon and north central Nevada: Journal of Geophysical Research, v. 89, no. B10, p. 8,616-8,628.

Sherrod, D.R., Minor, S.A., and Vercoutere, T.L., 1989, Geologic map of the Sheepshead Mountains, Harney and Malheur Counties, Oregon: U.S. Geological Survey Miscellaneous Field Studies Map MF-2079, scale 1:50,000.

Sun, S.-s., and McDonough, W.F., 1989,Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes: *in* Saunders, A.D. and Norry, J.J. (eds), Magmatism in the Ocean Basins, Geological Society Special Publication, no. 42, p. 313-345.

Swisher, C.C., Ach, J.A., and Hart, W.K., 1990, Laser fusion 40Ar/39Ar dating of the type Steens Mountain Basalt, southeastern Oregon, and the age of the Steens geomagnetic polarity transition [abs.]: Eos (American Geophysical Union Transactions), v. 71, no. 43, p. 1296.

Walker, G.W., 1960, Age and correlation of some unnamed volcanic rocks in south-central Oregon: U.S. Geological Survey Professional Paper 400B, p. B298-B300.

——1969, Geology of the High Lava Plains province: in Weissenborn, A.E., (ed.).Mineral and Water Resources of Oregon, State of Oregon Department of Geology and Mineral Industries Bulletin 64, p. 77-79.

——1979, Revisions to the Cenozoic stratigraphy of Harney Basin, southeastern Oregon: U.S. Geological Survey Bulletin 1475, 35 p.

Walker, G.W., and Repenning, C.A., 1965, Reconnaissance geologic map of the Adel quadrangle, Lake, Harney, and Malheur Counties, Oregon: U.S. Geological Survey Miscellaneous Investigations Map I-446, scale 1:250,000.

Watkins, N.D., 1965, Paleomagnetism of the Columbia plateaus: Journal of Geophysical Research, v. 70, no. 6, p. 1379-1406.

Watkins, N.D., and Baksi, A.K., 1974, Magnetostratigraphy and oroclinal folding of the Columbia River, Steens, and Owyhee Basalts in Oregon, Washington, and Idaho: American Journal of Science, v. 274, p. 148-189.

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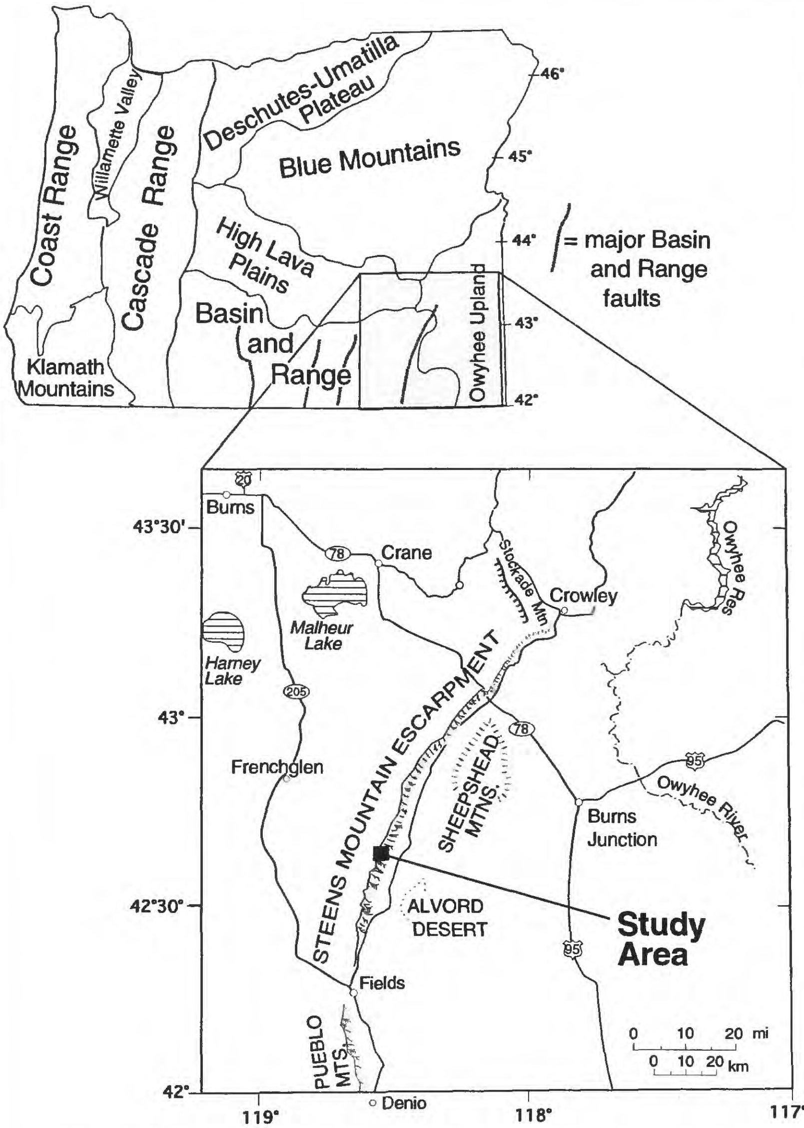

Figure 1: Physiographic provinces of Oregon with inset location map and local geographic names.

Figure 2: Map showing approximate extent of Steens Basalt and Columbia River Basalt Group (CRBG) (from Carlson and Hart, 1983 and Mankinen and others, 1985). Small pale-shaded areas indicate approximate boundaries of thick sections of basalt of Malheur Gorge and related rocks that are similar in age to the CRBG and Steens Basalt (Kittleman and others, 1965; Ferns and others, 1991). The lower part of the basalt of Malheur Gorge is chemically equivalent to the lower Steens Basalt, and the middle and upper parts are equivalent to the Imnaha and Grande Ronde Basalts of the CRBG (Binger, 1997).

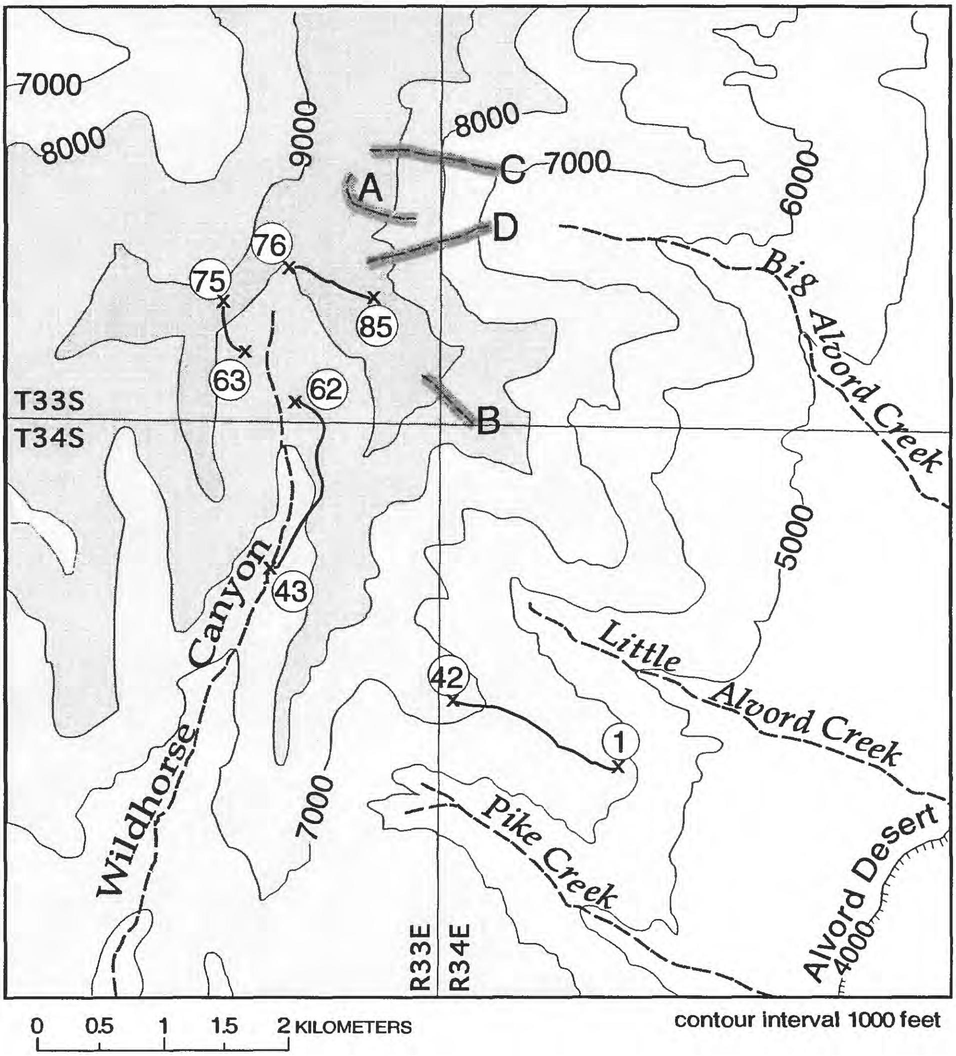

Figure 3: Map showing locations of sections sampled on Steens Mountain. Map numbers refer to samples in table 1 and figure 5; these are not the sample numbers (listed in table 1) which are not sequential. Number 1 is the base of the sequence, and 85 is the top. Transects A and B show the approximate locations sampled for paleomagnetism by Mankinen and others (1985); C and D are the transects of Goldstein and others (1969).

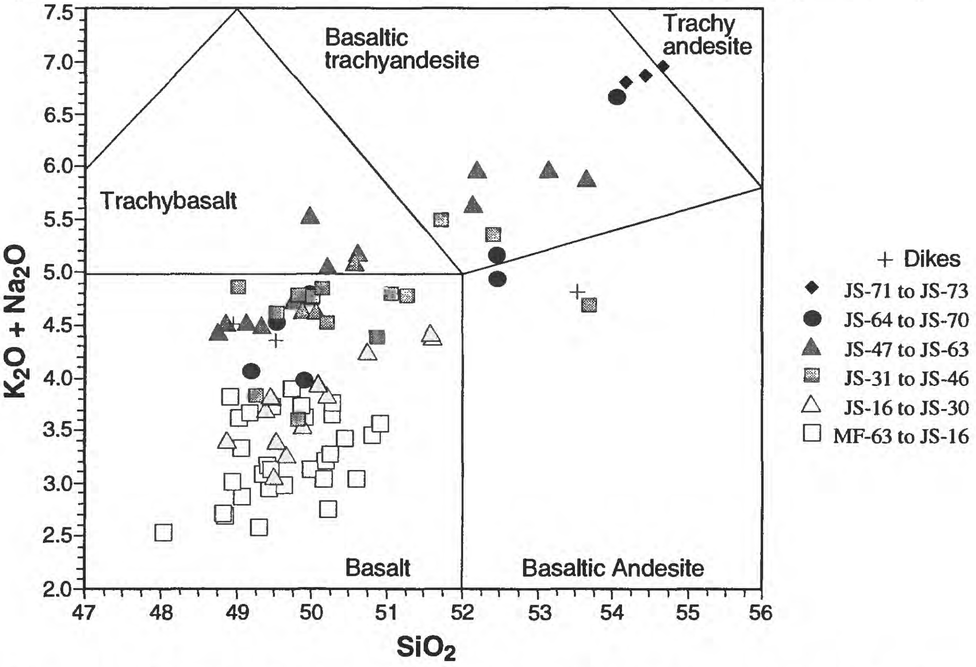

Figure 4: Chemical analyses of rocks from Steens Mountain plotted on total alkali-silica diagram of Le Bas and Streckeisen (1991). MF-63 is the base of section, and JS-73 is from the top of Steens Mountain.

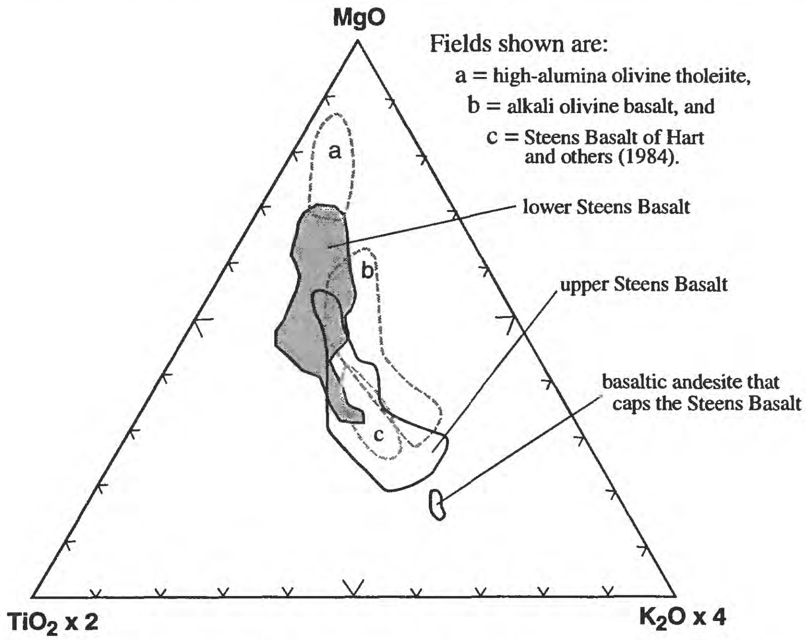

Figure 5: MgO-TiO_2-K_2O ternary plot showing the fields for some basalt and basaltic andesite of southeast Oregon. Dashed lines enclose fields of high-alumina olivine tholeiite, alkali olivine basalt, and Steens Basalt of Hart and others (1984). Lower Steens Basalt includes all samples stratigraphically lower than JS-30; upper Steens Basalt includes all samples from JS-31 to JS-70. Capping basaltic andesite includes samples JS-71 to JS-73.

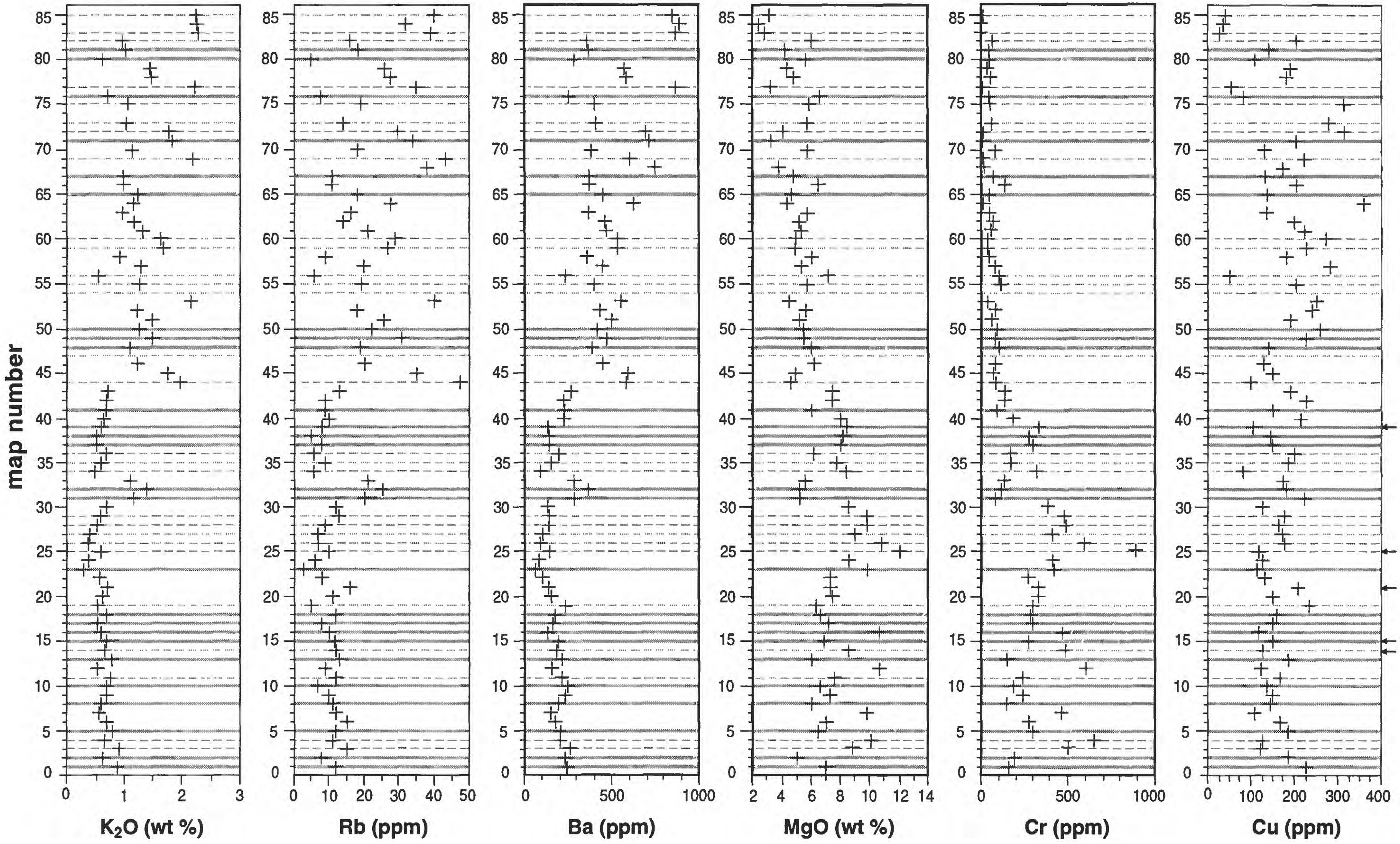

Figure 6: Major- and trace-element concentrations as a function of stratigraphic position. Map numbers refer to table 1. Number 1 is the base of the sequence, and numbers 83 through 85 are late-stage basaltic andesite lava flows. Dikes (47, 54, and 74) are not plotted. Gray horizontal line indicates samples with more than 10 percent plagioclase phenocrysts; dashed line indicates absense of plagioclase as a phenocryst phase; arrow at right indicates more than 10 percent olivine phenocrysts. Phenocryst abundances are at bottom of table 1.

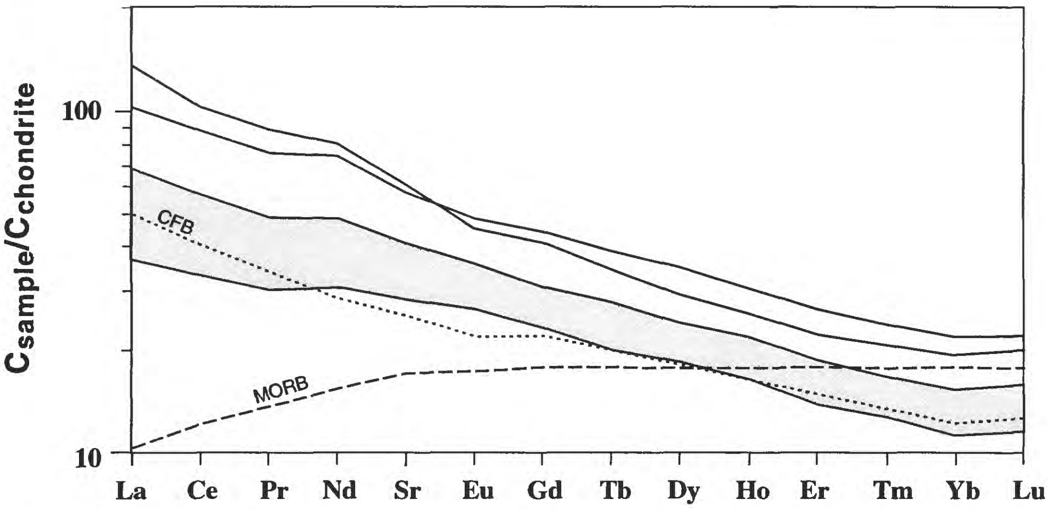

Figure 7: Chondrite-normalized plot of rare-earth element abundances. Shaded area encloses Steens Basalt analyses, and solid lines are the capping basaltic andesite. The dashed lines show patterns for typical continental flood basalt (CFB, short dashed) and mid-ocean ridge basalt (MORB, long dashed) (Philpotts, 1990). Chondrite values from Anders and Ebihara (1982)

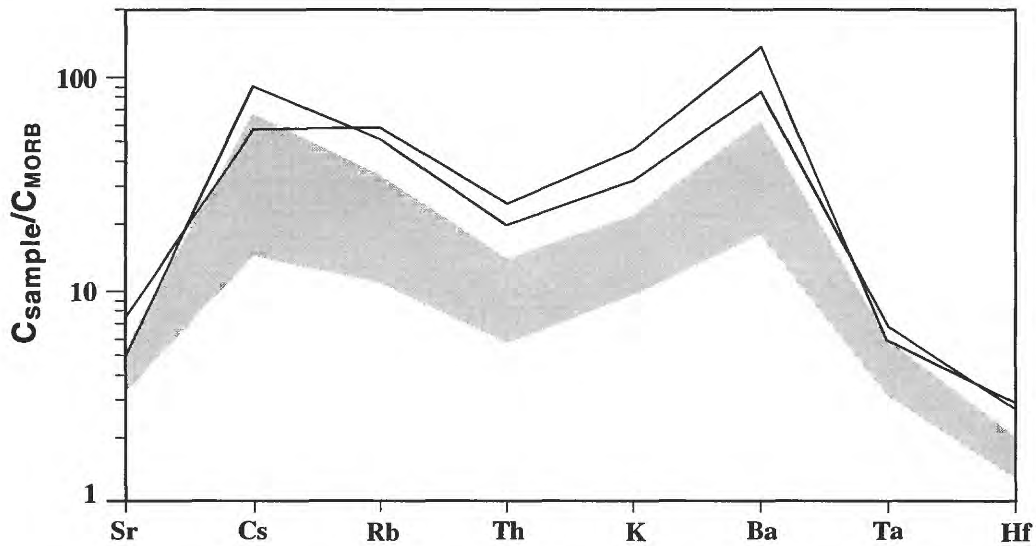

Figure 8: MORB-normalized plot of trace elements of samples analyzed by ICP-MS. Shaded area encloses Steens Basalt analyses, and solid lines are the capping basaltic andesite. There is no systematic relationship between silica content and trace-element abundance. MORB values from Sun and McDonough (1989).

Table 1: Xrf and ICP-MS analyses of Steens Basalt and capping basaltic andesite. Elevations from 7 1/2 minute topographic map and regularly calibrated altimeter.

map no.	1	2	3	4	5	6	7	8	9
sample #	MF94-63	MF94-64	MF 94-65	MF 94-66	MF 94-67	MF 94-68	MF 94-69	JS-001	MF 94-70
elevation	6480'	6545'	6550'	6552'	6670'	6800'	6810'	6750	6790'
Major elements normalized to 100 (wt. %) with original oxide total									
SiO_2	49.71	49.85	49.45	49.34	50.24	50.90	49.43	50.26	49.88
Al_2O_3	16.27	18.39	14.71	14.32	14.77	16.09	14.77	17.74	18.11
TiO_2	2.22	2.09	2.03	1.81	2.32	1.96	1.81	2.00	1.97
FeO*	11.19	9.84	11.49	11.06	11.81	9.76	10.37	9.73	9.53
MnO	0.17	0.16	0.18	0.18	0.18	0.17	0.17	0.12	0.16
CaO	9.26	10.62	9.18	9.88	10.23	10.32	10.28	9.99	10.42
MgO	6.96	5.03	8.89	10.09	6.51	7.01	9.82	6.10	6.01
K_2O	0.88	0.60	0.89	0.64	0.79	0.69	0.56	0.77	0.59
Na_2O	3.02	3.14	2.85	2.45	2.87	2.87	2.58	2.99	3.04
P_2O_5	0.31	0.29	0.33	0.23	0.28	0.23	0.21	0.29	0.29
	99.70	99.81	100.10	100.11	99.90	99.55	99.66	99.92	99.92
Trace-element analyses by XRF (ppm)									
Ni	112	101	215	261	94	134	248	110	107
Cr	160	189	500	650	296	274	463	146	153
Sc	27	25	27	30	36	28	28	25	28
V	338	296	289	311	347	324	298	302	311
Ba	243	238	263	203	205	175	148	211	196
Rb	12	8	15	11	12	15	12	13	11
Sr	432	476	399	327	346	309	300	450	486
Zr	161	150	151	132	165	138	127	143	140
Y	30	27	28	26	31	29	26	26	25
Nb	14.4	12.7	13.8	10.4	12.8	10.9	10.9	11.2	11.5
Ga	20	22	22	18	22	20	18	21	20
Cu	†226	†185	104	129	†185	†166	109	†188	147
Zn	91	88	92	90	91	85	83	85	87
Pb	1	3	1	3	1	0	1	0	2
La	13	12	8	14	10	4	0	2	0
Ce	33	43	34	20	29	29	29	47	22
Th	1	0	2	1	1	4	1	2	2
Trace-element analyses by ICP-MS (ppm)									
La	15.00	--	16.07	--	--	--	--	--	--
Ce	34.21	--	35.08	--	--	--	--	--	--
Pr	4.68	--	4.59	--	--	--	--	--	--
Nd	22.31	--	21.51	--	--	--	--	--	--
Sm	6.30	--	6.05	--	--	--	--	--	--
Eu	2.07	--	2.02	--	--	--	--	--	--
Gd	6.16	--	6.00	--	--	--	--	--	--
Tb	1.02	--	0.96	--	--	--	--	--	--
Dy	6.07	--	5.76	--	--	--	--	--	--
Ho	1.16	--	1.13	--	--	--	--	--	--
Er	2.91	--	2.82	--	--	--	--	--	--
Tm	0.41	--	0.39	--	--	--	--	--	--
Yb	2.43	--	2.29	--	--	--	--	--	--
Lu	0.36	--	0.35	--	--	--	--	--	--
Ba	267	--	268	--	--	--	--	--	--
Th	1.18	--	1.47	--	--	--	--	--	--
Y	29.61	--	28.81	--	--	--	--	--	--
Hf	4.15	--	3.96	--	--	--	--	--	--
Ta	0.69	--	0.72	--	--	--	--	--	--
Nb	10.83	--	11.10	--	--	--	--	--	--
U	0.39	--	0.46	--	--	--	--	--	--
Pb	3.02	--	3.24	--	--	--	--	--	--
Cs	0.11	--	0.26	--	--	--	--	--	--
% of phenocrysts present in sample collected for analysis.									
plagiocl.	**	**	**	**	**	**	**	30-40	**
olivine	**	**	**	**	**	**	**	0	**

Major elements are normalized on a volatile-free basis with total Fe is expressed as FeO.

† denotes values >120% of highest standard.

** percentages not available for MF94-series samples)

Data from Binger (1997), GeoAnalytical Lab., Washington State University, Pullman, WA.

(Table 1 cont.)

map no.	10	11	12	13	14	15	16	17	18	19
sample #	MF 94-71A	MF 94-71B	MF 94-71C	MF 94-72	JS-2	JS-3	JS-4	JS-5	JS-6	JS-7
elevation	6840'	6840'	6790'	6890'	6940'	6960'	6980'	6985'	6995'	7010'
Major elements normalized to 100 (wt. %) with original oxide total										
SiO_2	49.01	48.91	49.15	49.42	50.15	50.78	49.06	49.40	50.42	49.06
Al_2O_3	15.51	16.55	15.34	14.22	14.66	16.16	14.35	16.84	16.44	14.89
TiO_2	2.23	2.22	2.23	1.67	1.94	1.98	1.79	1.92	2.04	†2.66
FeO*	11.66	11.24	11.41	10.72	10.63	9.94	10.89	10.38	9.96	12.82
MnO	0.18	0.18	0.19	0.18	0.18	0.17	0.18	0.17	0.17	0.20
CaO	10.16	10.13	10.21	9.92	10.60	10.33	9.99	10.78	10.65	10.43
MgO	7.31	6.64	7.52	10.72	8.57	6.93	10.66	7.12	6.66	6.29
K_2O	0.69	0.69	0.74	0.51	0.66	0.68	0.57	0.50	0.67	0.53
Na_2O	2.94	3.14	2.93	2.44	2.39	2.78	2.31	2.67	2.76	2.81
P_2O_5	0.30	0.31	0.30	0.21	0.23	0.23	0.21	0.22	0.23	0.31
	100.81	100.07	99.74	100.23	99.34	99.29	99.72	99.65	99.81	99.65
Trace-element analyses by XRF (ppm)										
Ni	119	112	126	240	176	137	285	146	120	85
Cr	238	160	241	606	489	278	461	292	281	296
Sc	32	27	40	36	25	24	24	24	25	34
V	376	338	381	290	323	321	291	294	322	374
Ba	238	243	216	150	187	189	136	167	178	235
Rb	10	12	12	9	12	12	10	8	12	5
Sr	407	432	408	340	330	310	314	378	360	347
Zr	148	161	149	117	138	140	126	138	140	183
Y	30	30	29	23	26	28	25	26	28	36
Nb	11.4	14.4	11.2	10.4	10.4	11.0	9.7	10.8	11.2	14.9
Ga	20	20	19	19	22	20	19	23	23	24
Cu	149	†226	†169	121	126	†150	116	148	†161	†234
Zn	101	91	103	86	89	84	87	81	85	99
Pb	3	1	0	0	0	2	4	0	4	0
La	9	13	3	14	0	16	6	5	11	20
Ce	22	33	37	25	30	28	30	32	35	56
Th	1	1	5	3	1	3	1	0	1	4
Trace-element analyses by ICP-MS (ppm)										
La	--	15.00	--	--	--	--	--	--	--	--
Ce	--	34.21	--	--	--	--	--	--	--	--
Pr	--	4.68	--	--	--	--	--	--	--	--
Nd	--	22.31	--	--	--	--	--	--	--	--
Sm	--	6.30	--	--	--	--	--	--	--	--
Eu	--	2.07	--	--	--	--	--	--	--	--
Gd	--	6.16	--	--	--	--	--	--	--	--
Tb	--	1.02	--	--	--	--	--	--	--	--
Dy	--	6.07	--	--	--	--	--	--	--	--
Ho	--	1.16	--	--	--	--	--	--	--	--
Er	--	2.91	--	--	--	--	--	--	--	--
Tm	--	0.41	--	--	--	--	--	--	--	--
Yb	--	2.43	--	--	--	--	--	--	--	--
Lu	--	0.36	--	--	--	--	--	--	--	--
Ba	--	267	--	--	--	--	--	--	--	--
Th	--	1.18	--	--	--	--	--	--	--	--
Y	--	29.61	--	--	--	--	--	--	--	--
Hf	--	4.15	--	--	--	--	--	--	--	--
Ta	--	0.69	--	--	--	--	--	--	--	--
Nb	--		--	--	--	--	--	--	--	--
U	--	0.39	--	--	--	--	--	--	--	--
Pb	--	3.02	--	--	--	--	--	--	--	--
Cs	--	0.11	--	--	--	--	--	--	--	--
% of phenocrysts present in sample collected for analysis.										
plagiocl.	**	0	**	**	0	15	10	20-30	10-15	0
olivine	**	0	**	**	5-10	10-12	10-15	<5	1-2	0

Major elements are normalized on a volatile-free basis with total Fe is expressed as FeO.

† denotes values >120% of highest standard.

** percentages not available for MF94-series samples)

Data from Binger (1997), GeoAnalytical Lab., Washington State University, Pullman, WA.

(Table 1 cont.)

map no.	20	21	22	23	24	25	26	27	28	29	30
sample #	JS-8	JS-9	JS-10	JS-11	JS-12	JS-13	JS-14	JS-15	JS-16	JS-17	JS-18
elevation	7020'	7025'	7050'	7060'	7065'	7080'	7090'	7120'	7130'	7200'	7235'
	Major elements normalized to 100 (wt. %) with original oxide total										
SiO_2	49.97	50.16	48.93	48.03	48.83	48.82	49.29	50.21	49.61	50.57	50.23
Al_2O_3	14.76	14.92	14.71	15.79	15.16	13.39	14.36	15.06	14.87	14.82	15.26
TiO_2	2.24	2.20	2.49	1.80	2.03	1.72	1.63	1.73	1.83	1.82	1.83
FeO*	11.20	11.15	11.99	10.96	10.95	11.34	10.68	10.12	10.21	9.55	10.13
MnO	0.18	0.17	0.19	0.17	0.18	0.19	0.18	0.18	0.17	0.17	0.16
CaO	10.83	10.63	11.08	10.74	11.36	9.60	10.37	10.82	10.24	10.05	10.30
MgO	7.43	7.31	7.33	9.79	8.58	12.02	10.74	8.94	9.87	9.76	8.61
K_2O	0.61	0.70	0.54	0.28	0.36	0.57	0.37	0.39	0.53	0.59	0.68
Na_2O	2.52	2.52	2.48	2.26	2.33	2.14	2.22	2.36	2.45	2.46	2.60
P_2O_5	0.26	0.25	0.26	0.18	0.21	0.21	0.17	0.19	0.23	0.21	0.21
	99.75	99.95	99.19	100.10	99.78	99.87	99.72	100.00	100.32	100.76	100.71
	Trace-element analyses by XRF (ppm)										
Ni	113	120	120	261	164	345	280	188	260	261	196
Cr	330	329	276	424	407	890	592	404	484	474	385
Sc	34	35	33	26	35	31	27	31	27	29	34
V	366	362	390	302	351	299	293	320	303	293	300
Ba	148	143	106	66	77	138	92	105	147	139	131
Rb	11	16	8	3	6	10	7	7	9	13	12
Sr	336	337	322	302	285	301	243	257	303	296	303
Zr	154	154	165	122	134	123	109	115	129	125	128
Y	30	31	32	25	28	24	23	26	26	25	26
Nb	12.2	12.4	15.4	10.4	12.5	9.7	8.8	8.9	10.7	11.2	10.9
Ga	19	22	20	19	18	18	20	19	21	17	18
Cu	149	†207	132	113	127	118	†176	†173	†162	†179	125
Zn	91	95	99	86	88	88	90	90	85	82	84
Pb	2	2	1	0	0	2	1	2	0	2	1
La	23	3	11	5	16	9	7	4	19	6	16
Ce	40	33	50	28	27	17	13	27	43	37	44
Th	1	3	2	3	1	3	2	1	1	1	0
	Trace-element analyses by ICP-MS (ppm)										
La	13.29	--	--	--	--	--	--	--	--	--	10.92
Ce	30.50	--	--	--	--	--	--	--	--	--	24.57
Pr	4.10	--	--	--	--	--	--	--	--	--	3.38
Nd	19.54	--	--	--	--	--	--	--	--	--	16.66
Sm	5.74	--	--	--	--	--	--	--	--	--	4.81
Eu	1.98	--	--	--	--	--	--	--	--	--	1.69
Gd	6.32	--	--	--	--	--	--	--	--	--	5.43
Tb	1.04	--	--	--	--	--	--	--	--	--	0.90
Dy	6.18	--	--	--	--	--	--	--	--	--	5.41
Ho	1.25	--	--	--	--	--	--	--	--	--	1.06
Er	3.10	--	--	--	--	--	--	--	--	--	2.71
Tm	0.43	--	--	--	--	--	--	--	--	--	0.37
Yb	2.53	--	--	--	--	--	--	--	--	--	2.27
Lu	0.38	--	--	--	--	--	--	--	--	--	0.33
Ba	171	--	--	--	--	--	--	--	--	--	162
Th	1.42	--	--	--	--	--	--	--	--	--	1.09
Y	29.96	--	--	--	--	--	--	--	--	--	27.02
Hf	4.13	--	--	--	--	--	--	--	--	--	3.51
Ta	0.66	--	--	--	--	--	--	--	--	--	0.56
Nb	9.92	--	--	--	--	--	--	--	--	--	8.49
U	0.38	--	--	--	--	--	--	--	--	--	0.39
Pb	2.81	--	--	--	--	--	--	--	--	--	2.43
Cs	0.47	--	--	--	--	--	--	--	--	--	0.26
	% of phenocrysts present in sample collected for analysis.										
plagiocl.	<3	<5	sp	10	sp	0	0	0	0	0	3
olivine	3-5	15	sp	1-2	0	15	0	<2	2-3	7	7

Major elements are normalized on a volatile-free basis with total Fe is expressed as FeO.

† denotes values >120% of highest standard.

** percentages not available for MF94-series samples)

Data from Binger (1997), GeoAnalytical Lab., Washington State University, Pullman, WA.

(Table 1 cont.)

map no.	31	32	33	34	35	36	37	38	39	40
sample #	JS-19	JS-20	JS-21	JS-22	JS-23	JS-24	JS-25	JS-26	JS-27	JS-28
elevation	7260'	7280'	7350'	7380'	7420'	7470'	7500'	7550'	7560'	7600'
Major elements normalized to 100 (wt. %) with original oxide total										
SiO_2	51.56	51.57	50.72	49.49	49.86	50.19	48.87	49.50	49.66	49.37
Al_2O_3	15.32	14.69	14.73	16.13	16.28	15.02	15.84	15.88	16.65	15.95
TiO_2	†2.77	†2.72	†2.72	1.84	1.98	2.64	2.09	2.01	1.63	1.89
FeO*	11.02	12.01	12.02	10.16	10.45	11.51	11.22	10.61	9.62	11.56
MnO	0.19	0.20	0.20	0.17	0.17	0.20	0.18	0.18	0.17	0.18
CaO	9.19	8.81	9.27	10.50	9.76	10.07	10.16	10.01	10.39	9.02
MgO	5.15	5.22	5.68	8.44	7.73	6.23	7.99	8.16	8.41	8.05
K_2O	1.17	1.38	1.09	0.48	0.59	0.68	0.53	0.52	0.59	0.64
Na_2O	3.25	3.01	3.17	2.58	2.96	3.17	2.89	2.89	2.68	3.06
P_2O_5	0.38	0.39	0.39	0.19	0.23	0.31	0.24	0.25	0.21	0.28
	100.59	100.19	100.47	101.03	100.76	100.56	100.79	100.82	100.91	100.52
Trace-element analyses by XRF (ppm)										
Ni	57	50	59	192	158	75	163	162	179	125
Cr	76	108	132	321	167	176	297	269	333	177
Sc	31	29	34	31	27	36	30	27	28	27
V	390	377	406	309	294	412	354	337	296	336
Ba	287	363	286	89	149	197	140	139	129	223
Rb	20	25	21	6	9	6	8	5	8	10
Sr	390	379	374	342	380	360	370	391	402	448
Zr	189	198	190	120	131	169	133	125	109	125
Y	35	38	38	25	25	34	27	26	23	24
Nb	15.7	18	14.9	9.4	10.9	13.2	10.1	9.6	8.1	7.1
Ga	24	21	22	21	21	20	22	22	20	22
Cu	†223	†184	†171	84	†186	†200	148	147	103	†214
Zn	107	113	110	82	88	110	96	96	84	102
Pb	1	4	2	0	2	2	0	0	1	0
La	14	24	6	6	7	11	11	14	17	0
Ce	55	67	51	26	32	49	37	42	22	31
Th	0	3	5	1	1	1	3	1	0	3
Trace-element analyses by ICP-MS (ppm)										
La	--	--	--	8.82	--	--	10.39	--	8.93	11.01
Ce	--	--	--	20.38	--	--	24.14	--	20.65	25.58
Pr	--	--	--	2.92	--	--	3.35	--	2.94	3.51
Nd	--	--	--	14.68	--	--	16.45	--	14.36	17.15
Sm	--	--	--	4.32	--	--	4.87	--	4.31	4.83
Eu	--	--	--	1.58	--	--	1.72	--	1.55	1.66
Gd	--	--	--	4.99	--	--	5.39	--	4.86	5.11
Tb	--	--	--	0.79	--	--	0.89	--	0.76	0.82
Dy	--	--	--	4.91	--	--	5.28	--	4.73	4.90
Ho	--	--	--	0.97	--	--	1.06	--	0.95	0.96
Er	--	--	--	2.45	--	--	2.70	--	2.32	2.53
Tm	--	--	--	0.33	--	--	0.37	--	0.33	0.35
Yb	--	--	--	1.95	--	--	2.20	--	1.95	2.05
Lu	--	--	--	0.31	--	--	0.34	--	0.30	0.32
Ba	--	--	--	115	--	--	161	--	150	213
Th	--	--	--	0.70	--	--	0.72	--	0.68	0.77
Y	--	--	--	24.62	--	--	27.65	--	23.16	25.34
Hf	--	--	--	3.06	--	--	3.33	--	2.75	3.14
Ta	--	--	--	0.46	--	--	0.50	--	0.42	0.48
Nb	--	--	--	6.88	--	--	7.71	--	6.24	7.26
U	--	--	--	0.24	--	--	0.24	--	0.25	0.29
Pb	--	--	--	1.70	--	--	1.87	--	1.81	2.17
Cs	--	--	--	0.13	--	--	0.10	--	0.16	0.20
% of phenocrysts present in sample collected for analysis.										
plagiocl.	15	10-15	3-4	0	0	0	15-30	10-12	15-20	<1
olivine	2	2	3-5	7	3-5	sp	1	4-7	8-12	0

Major elements are normalized on a volatile-free basis with total Fe is expressed as FeO.

† denotes values >120% of highest standard.

** percentages not available for MF94-series samples)

Data from Binger (1997), GeoAnalytical Lab., Washington State University, Pullman, WA.

(Table 1 cont.)

map no.	41	42	43	44	45	46	47	48	49	50	51
sample #	JS-29	JS-30	JS-31	JS-32	JS-33	JS-34	JS-35	JS-36	JS-37	JS-38	JS-39
elevation	7600'	7600'	7580'	7615'	7640'	7700'	7750'	7750'	7770'	7820'	7850'
	Major elements normalized to 100 (wt. %) with original oxide total										
SiO_2	50.07	49.44	49.25	53.67	52.39	51.05	49.51	50.19	51.26	50.00	50.13
Al_2O_3	17.39	15.15	16.56	16.30	15.98	16.19	15.54	16.08	15.10	15.41	14.26
TiO_2	2.03	2.24	1.94	1.78	2.09	2.01	†2.76	2.10	2.63	2.52	†3.25
FeO*	10.24	12.07	11.09	9.52	10.55	10.59	12.45	11.45	11.71	12.22	12.94
MnO	0.17	0.20	0.19	0.16	0.19	0.19	0.19	0.19	0.19	0.20	0.22
CaO	9.82	9.27	9.70	7.85	8.10	8.76	8.67	9.16	8.13	8.99	8.27
MgO	6.05	7.50	7.53	4.67	4.88	6.17	6.06	6.06	5.43	5.56	5.22
K_2O	0.67	0.69	0.72	1.96	1.75	1.21	1.36	1.10	1.50	1.26	1.46
Na_2O	3.27	3.14	2.74	3.61	3.59	3.43	3.00	3.29	3.52	3.39	3.65
P_2O_5	0.30	0.30	0.29	0.48	0.48	0.40	0.46	0.37	0.52	0.46	0.60
	101.17	100.74	99.02	100.18	100.20	100.47	100.33	100.49	100.57	99.90	100.38
	Trace-element analyses by XRF (ppm)										
Ni	82	103	116	63	50	79	98	79	69	58	46
Cr	86	141	137	84	66	76	80	107	84	95	58
Sc	27	32	32	22	20	24	25	28	32	29	34
V	329	408	320	250	307	298	379	323	346	342	480
Ba	224	228	262	584	593	444	383	386	473	415	497
Rb	9	9	13	47	35	20	29	19	31	22	26
Sr	490	430	568	517	508	464	429	466	409	454	414
Zr	134	138	130	181	183	157	197	156	211	190	223
Y	27	29	28	29	32	61	37	32	43	37	45
Nb	9.9	9.3	7.2	13.8	13.6	11.6	13.2	10.3	14.8	13.0	16.9
Ga	23	21	19	21	24	19	25	20	23	21	25
Cu	148	†227	†189	99	149	129	†307	139	†226	†260	†192
Zn	101	107	95	92	98	105	†132	102	†120	†114	†137
Pb	0	3	0	4	4	2	4	3	3	2	4
La	22	13	17	5	37	30	17	12	25	11	22
Ce	39	36	40	50	56	36	58	65	52	49	80
Th	0	3	1	4	4	4	4	3	6	3	5
	Trace-element analyses by ICP-MS (ppm)										
La	--	12.23	--	--	--	--	--	16.26	--	--	--
Ce	--	28.41	--	--	--	--	--	34.88	--	--	--
Pr	--	3.93	--	--	--	--	--	4.69	--	--	--
Nd	--	19.30	--	--	--	--	--	22.55	--	--	--
Sm	--	5.46	--	--	--	--	--	6.00	--	--	--
Eu	--	1.90	--	--	--	--	--	2.02	--	--	--
Gd	--	5.77	--	--	--	--	--	6.19	--	--	--
Tb	--	0.93	--	--	--	--	--	1.02	--	--	--
Dy	--	5.56	--	--	--	--	--	6.08	--	--	--
Ho	--	1.08	--	--	--	--	--	1.20	--	--	--
Er	--	2.86	--	--	--	--	--	3.07	--	--	--
Tm	--	0.39	--	--	--	--	--	0.43	--	--	--
Yb	--	2.33	--	--	--	--	--	2.62	--	--	--
Lu	--	0.35	--	--	--	--	--	0.41	--	--	--
Ba	--	233	--	--	--	--	--	383	--	--	--
Th	--	0.85	--	--	--	--	--	1.64	--	--	--
Y	--	29.16	--	--	--	--	--	31.74	--	--	--
Hf	--	3.51	--	--	--	--	--	3.95	--	--	--
Ta	--	0.50	--	--	--	--	--	0.59	--	--	--
Nb	--	8.00	--	--	--	--	--	9.24	--	--	--
U	--	0.30	--	--	--	--	--	0.65	--	--	--
Pb	--	2.42	--	--	--	--	--	4.09	--	--	--
Cs	--	0.11	--	--	--	--	--	0.29	--	--	--
	% of phenocrysts present in sample collected for analysis.										
plagiocl.	15-25	<1	2-5	0	1-2	<1	0	10	7-12	7-10	3-5
olivine	3-4	0	0	0	<1	0	0	0	0	1	0

Major elements are normalized on a volatile-free basis with total Fe is expressed as FeO.

† denotes values >120% of highest standard.

** percentages not available for MF94-series samples)

Data from Binger (1997), GeoAnalytical Lab., Washington State University, Pullman, WA.

(Table 1 cont.)

map no.	52	53	54	55	56	57	58	59	60	61	62
sample #	JS-40	JS-41	JS-42	JS-43	JS-44	JS-45	JS-46	JS-47	JS-48	JS-49	JS-50
elevation	7980'	8120'	8100'	8220'	8390'	8440'	8520'	8540'	8550'	8560'	8580'
	Major elements normalized to 100 (wt. %) with original oxide total										
SiO_2	49.01	51.71	48.94	50.85	49.81	49.81	49.52	50.55	50.59	49.95	49.76
Al_2O_3	14.86	15.52	15.15	15.73	15.93	14.70	16.99	14.56	14.47	15.23	14.89
TiO_2	†2.94	2.61	†2.68	2.13	1.91	†2.78	1.98	†2.94	†2.95	†2.78	†2.83
FeO*	13.35	11.41	13.48	11.13	10.99	12.98	11.63	12.91	12.95	12.51	13.02
MnO	0.21	0.20	0.20	0.18	0.18	0.21	0.18	0.21	0.21	0.21	0.21
CaO	8.62	8.01	8.42	9.47	10.11	8.83	8.64	8.24	8.17	8.67	8.79
MgO	5.66	4.46	6.15	5.73	7.17	5.36	6.09	4.91	4.90	5.38	5.27
K_2O	1.22	2.16	1.34	1.25	0.56	1.28	0.89	1.67	1.63	1.33	1.17
Na_2O	3.58	3.34	3.18	3.14	3.05	3.52	3.73	3.42	3.55	3.44	3.57
P_2O_5	0.55	0.60	0.46	0.40	0.30	0.53	0.34	0.57	0.58	0.51	0.48
	100.55	99.75	100.44	100.76	100.70	100.49	100.59	99.90	100.21	100.26	100.75
	Trace-element analyses by XRF (ppm)										
Ni	61	30	95	60	90	51	106	41	42	55	50
Cr	85	39	78	118	97	82	49	31	33	54	64
Sc	32	30	33	30	28	34	24	36	35	36	36
V	422	342	373	344	260	402	305	448	419	445	†459
Ba	430	550	403	402	238	449	355	526	529	466	456
Rb	18	40	25	19	6	20	9	27	29	21	14
Sr	461	472	425	491	502	439	692	452	448	479	472
Zr	205	218	196	158	137	206	137	215	216	197	191
Y	40	42	38	31	27	42	27	44	43	39	50
Nb	16.1	16.3	13.6	11.8	12.9	15.1	9.2	14.6	16	13.9	14.0
Ga	25	22	25	20	20	23	20	24	24	23	24
Cu	†240	†251	†281	†205	52	†281	†184	†225	†272	†222	†201
Zn	†128	†122	†123	103	103	†126	105	†130	†130	†124	†125
Pb	7	6	1	4	1	1	3	5	7	4	4
La	13	32	13	11	16	35	6	21	20	12	30
Ce	50	70	50	53	53	71	52	63	56	59	71
Th	5	3	4	2	1	3	1	3	3	4	0
	Trace-element analyses by ICP-MS (ppm)										
La	--	--	--	--	--	--	--	--	24.31	--	--
Ce	--	--	--	--	--	--	--	--	53.78	--	--
Pr	--	--	--	--	--	--	--	--	7.25	--	--
Nd	--	--	--	--	--	--	--	--	34.43	--	--
Sm	--	--	--	--	--	--	--	--	9.01	--	--
Eu	--	--	--	--	--	--	--	--	2.80	--	--
Gd	--	--	--	--	--	--	--	--	9.17	--	--
Tb	--	--	--	--	--	--	--	--	1.47	--	--
Dy	--	--	--	--	--	--	--	--	8.92	--	--
Ho	--	--	--	--	--	--	--	--	1.74	--	--
Er	--	--	--	--	--	--	--	--	4.43	--	--
Tm	--	--	--	--	--	--	--	--	0.62	--	--
Yb	--	--	--	--	--	--	--	--	3.76	--	--
Lu	--	--	--	--	--	--	--	--	0.57	--	--
Ba	--	--	--	--	--	--	--	--	530	--	--
Th	--	--	--	--	--	--	--	--	2.43	--	--
Y	--	--	--	--	--	--	--	--	46.71	--	--
Hf	--	--	--	--	--	--	--	--	5.69	--	--
Ta	--	--	--	--	--	--	--	--	0.89	--	--
Nb	--	--	--	--	--	--	--	--	14.29	--	--
U	--	--	--	--	--	--	--	--	0.96	--	--
Pb	--	--	--	--	--	--	--	--	6.37	--	--
Cs	--	--	--	--	--	--	--	--	0.64	--	--
	% of phenocrysts present in sample collected for analysis.										
plagiocl.	5	3-5	0	0	0	5-7	3	0	0	?	?
olivine	sp	0	0	0	0	sp	0	0	0		

Major elements are normalized on a volatile-free basis with total Fe is expressed as FeO.

† denotes values >120% of highest standard.

** percentages not available for MF94-series samples)

Data from Binger (1997), GeoAnalytical Lab., Washington State University, Pullman, WA.

(Table 1 cont.)

map no.	63	64	65	66	67	68	69	70	71	72	73	74
sample #	JS-51	JS-52	JS-53	JS-54	JS-55	JS-56	JS-57	JS-58	JS-59	JS-60	JS-61	JS-62
elevation	8560'	8600'	8690'	8730'	8780'	8790'	8850'	8980'	9070'	9140'	9240'	9200'
	Major elements normalized to 100 (wt. %) with original oxide total											
SiO_2	49.12	49.97	50.19	48.75	50.03	53.14	53.62	49.86	52.17	52.14	48.85	53.51
Al_2O_3	16.10	14.37	17.15	16.37	18.25	15.62	15.12	16.82	16.25	15.33	16.31	13.51
TiO_2	2.29	3.19	2.54	2.40	2.19	2.60	2.35	2.05	†2.82	†2.66	2.56	2.46
FeO*	12.73	13.95	11.22	12.03	10.38	10.91	11.27	12.09	11.63	12.06	12.96	13.09
MnO	0.19	0.22	0.19	0.20	0.16	0.18	0.18	0.18	0.20	0.20	0.19	0.20
CaO	8.89	7.80	8.61	9.02	9.26	7.10	6.94	8.27	7.14	7.36	8.45	7.90
MgO	5.76	4.30	4.58	6.39	4.73	3.84	4.17	5.72	3.19	4.03	5.75	4.16
K_2O	0.96	1.71	1.22	0.96	0.95	2.11	2.16	1.12	1.85	1.77	1.03	1.46
Na_2O	3.56	3.82	3.82	3.47	3.66	3.85	3.71	3.53	4.11	3.87	3.49	3.37
P_2O_5	0.38	†0.68	0.48	0.42	0.40	†0.65	0.48	0.38	†0.65	0.59	0.42	0.35
	100.97	100.15	100.86	100.09	100.66	100.56	100.88	101.09	100.45	100.54	100.87	100.40
	Trace-element analyses by XRF (ppm)											
Ni	101	26	56	129	83	25	27	83	25	33	102	22
Cr	45	13	48	135	69	9	13	76	13	9	66	59
Sc	32	30	24	27	22	23	21	19	33	33	31	35
V	387	402	364	343	314	294	347	336	297	359	347	411
Ba	369	619	447	366	369	745	600	409	711	691	413	664
Rb	16	28	18	11	11	38	43	18	34	30	14	46
Sr	510	445	526	499	563	478	432	535	497	492	472	403
Zr	191	251	187	166	158	245	231	158	241	214	181	176
Y	51	52	53	54	55	56	57	31	42	45	46	41
Nb	10.0	19.0	12.0	12.0	10.0	19.0	16.0	10.6	17.4	16.1	12.2	10.6
Ga	21	22	23	23	23	21		23	25	22	25	23
Cu	137	†360	137	†204	133	†171	†223	130	†203	†312	†279	†250
Zn	109	†139	114	114	98	†125	†122	109	†130	†131	†125	†125
Pb	0	2	3	4	2	7	8	4	5	6	3	6
La	25	22	20	4	22	33	15	20	18	35	28	15
Ce	34	76	51	36	54	65	64	49	67	69	56	41
Th	0	6	2	2	2	6	5	1	1	5	3	3
	Trace-element analyses by ICP-MS (ppm)											
La	--	--	--	--	--	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--	--	--	--	--	--
Pr	--	--	--	--	--	--	--	--	--	--	--	--
Nd	--	--	--	--	--	--	--	--	--	--	--	--
Sm	--	--	--	--	--	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--	--	--	--	--	--
Gd	--	--	--	--	--	--	--	--	--	--	--	--
Tb	--	--	--	--	--	--	--	--	--	--	--	--
Dy	--	--	--	--	--	--	--	--	--	--	--	--
Ho	--	--	--	--	--	--	--	--	--	--	--	--
Er	--	--	--	--	--	--	--	--	--	--	--	--
Tm	--	--	--	--	--	--	--	--	--	--	--	--
Yb	--	--	--	--	--	--	--	--	--	--	--	--
Lu	--	--	--	--	--	--	--	--	--	--	--	--
Ba	--	--	--	--	--	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--	--	--	--	--	--
Y	--	--	--	--	--	--	--	--	--	--	--	--
Hf	--	--	--	--	--	--	--	--	--	--	--	--
Ta	--	--	--	--	--	--	--	--	--	--	--	--
Nb	--	--	--	--	--	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--	--	--	--	--	--
Pb	--	--	--	--	--	--	--	--	--	--	--	--
Cs	--	--	--	--	--	--	--	--	--	--	--	--
	% of phenocrysts present in sample collected for analysis.											
plagiocl.	sp	2-3	12-20	1-2	15-25	1-2		2	10-20	0	0	0
olivine	0	0	0	0	0	0	0	<1	0	sp	0	0

Major elements are normalized on a volatile-free basis with total Fe is expressed as FeO.

† denotes values >120% of highest standard.

** percentages not available for MF94-series samples)

Data from Binger (1997), GeoAnalytical Lab., Washington State University, Pullman, WA.

(Table 1 cont.)

map no.	75	76	77	78	79	80	81	82	83	84	85
sample #	JS-63	JS-64	JS-65	JS-66	JS-67	JS-68	JS-69	JS-70	JS-71	JS-72	JS-73
elevation	9320'	9320'	9340'	9400'	9500'	9550'	9600'	9630'	9640'	9720'	9700'
	Major elements normalized to 100 (wt. %) with original oxide total										
SiO_2	49.33	49.17	54.04	52.46	52.42	49.89	49.96	49.52	54.66	54.41	54.17
Al_2O_3	16.05	17.47	15.88	16.08	15.19	18.79	18.04	16.24	15.77	16.26	15.95
TiO_2	2.54	1.93	2.32	2.24	2.43	1.63	2.51	2.31	2.46	2.36	2.34
FeO*	12.81	11.06	10.55	11.08	12.19	10.25	11.37	12.07	10.48	10.86	10.82
MnO	0.19	0.17	0.18	0.17	0.18	0.15	0.18	0.18	0.18	0.17	0.18
CaO	8.28	9.27	6.45	7.83	7.62	9.52	8.56	8.68	5.79	5.91	5.80
MgO	5.89	6.57	3.19	4.80	4.40	5.57	4.20	6.07	2.82	2.36	3.15
K_2O	1.05	0.71	2.21	1.49	1.45	0.62	1.04	0.96	2.29	2.27	2.27
Na_2O	3.44	3.36	4.45	3.46	3.72	3.36	3.75	3.58	4.67	4.60	4.54
P_2O_5	0.42	0.29	†0.74	0.39	0.41	0.23	0.40	0.38	†0.88	†0.80	†0.78
	100.64	100.51	100.23	100.01	100.02	100.97	100.89	100.63	100.16	99.69	99.99
	Trace-element analyses by XRF (ppm)										
Ni	111	146	8	55	41	93	49	112	0	6	4
Cr	64	46	7	56	33	46	48	67	2	5	9
Sc	31	21	22	29	30	28	29	30	25	28	24
V	341	293	253	313	369	261	337	322	248	273	250
Ba	393	258	872	578	570	284	370	358	867	889	843
Rb	19	8	35	28	26	5	18	16	39	32	40
Sr	480	585	644	482	466	534	504	472	674	665	652
Zr	181	132	219	183	172	115	175	166	219	229	223
Y	36	25	37	35	33	24	30	33	38	38	32
Nb	13.3	8.5	14.3	11.3	11.8	7	13.1	12.1	15	15.4	14.6
Ga	22	20	19	22	24	18	†28	22	22	24	23
Cu	†314	83	56	†184	†189	111	143	†205	25	38	41
Zn	†121	99	†127	113	116	90	108	111	†124	†127	116
Pb	2	1	5	7	3	4	5	2	9	7	6
La	21	9	30	10	17	22	10	5	30	28	40
Ce	58	35	69	39	47	32	48	50	73	80	64
Th	3	3	2	5	3	1	2	0	2	2	4
	Trace-element analyses by ICP-MS (ppm)										
La	--	--	--	--	--	--	--	--	--	32.04	--
Ce	--	--	--	--	--	--	--	--	--	63.23	--
Pr	--	--	--	--	--	--	--	--	--	8.36	--
Nd	--	--	--	--	--	--	--	--	--	37.34	--
Sm	--	--	--	--	--	--	--	--	--	9.31	--
Eu	--	--	--	--	--	--	--	--	--	2.63	--
Gd	--	--	--	--	--	--	--	--	--	8.60	--
Tb	--	--	--	--	--	--	--	--	--	1.30	--
Dy	--	--	--	--	--	--	--	--	--	7.43	--
Ho	--	--	--	--	--	--	--	--	--	1.46	--
Er	--	--	--	--	--	--	--	--	--	3.68	--
Tm	--	--	--	--	--	--	--	--	--	0.53	--
Yb	--	--	--	--	--	--	--	--	--	3.30	--
Lu	--	--	--	--	--	--	--	--	--	0.51	--
Ba	--	--	--	--	--	--	--	--	--	846	--
Th	--	--	--	--	--	--	--	--	--	2.99	--
Y	--	--	--	--	--	--	--	--	--	40.14	--
Hf	--	--	--	--	--	--	--	--	--	5.79	--
Ta	--	--	--	--	--	--	--	--	--	0.77	--
Nb	--	--	--	--	--	--	--	--	--	13.23	--
U	--	--	--	--	--	--	--	--	--	1.05	--
Pb	--	--	--	--	--	--	--	--	--	8.48	--
Cs	--	--	--	--	--	--	--	--	--	0.39	--
	% of phenocrysts present in sample collected for analysis.										
plagiocl.	0	10-15	0	5	1	8-12	15-20	0	0	<1	0
olivine	0	0	0	sp	<0.5	sp	1	0	0	0	0

Major elements are normalized on a volatile-free basis with total Fe is expressed as FeO.

† denotes values >120% of highest standard.

** percentages not available for MF94-series samples)

Data from Binger (1997), GeoAnalytical Lab., Washington State University, Pullman, WA.

Appendix 1

Sample descriptions

Map #	Sample	Elevation	Description
			(Begin traverse on ridge between Little Alvord Creek and Pike Creek. MF-series samples are from initial reconnaissance and lack the field notes of JS-series. Most MF-samples have abundant plagioclase megacrysts. Dikes are marked with ** after sample number.)
1	MF94-63	6480	Base of section; first flow above the rhyolite unit. Abundant coarse plagioclase phenocrysts. Sample from top of flow.
2	MF94-64	6545	From center of group of coarsely plagioclase-phyric flows with red oxidized tops.
3	MF94-65	6550	Relatively aphyric to sparsely plagioclase-phyric flow.
4	MF94-66	6552	Same location as MF94-65.
5	MF94-67	6670	Thick flows with coarse plagioclase phenocrysts.
6	MF94-68	6800	No notes.
7	MF94-69	6822	Top of discrete hill.
8	JS-001	6750	Unit forms a sandy saddle with obscure outcrop. Greenish grusy outcrop is parallel to slope on west side of saddle. 30-40 percent coarse-grained fresh to yellowish plagioclase, 1-2 cm across. Sparse olivine. Groundmass appears to be coarse-grained clinopyroxene (ophitic?). Weathered surface has odd greenish-gray metallic appearance.
9	MF94-70	6790	Lowest cliff west of saddle. No notes.
10	MF94-71a	6840	Coarsely plagioclase-porphyritic flow floored by quenched aphyric base (see MF94-71b).
11	MF94-71b	"	Aphyric base of MF94-71a.
12	MF94-71c	6850	Olivine basalt
13	MF94-72	6890	10-m-thick fine-grained olivine basalt with no plagioclase phenocrysts.
		6920	Phenocrysts include 3-5 percent plagioclase and sparse olivine. Fine-grained rock with 20 percent vesicles, secondary quartz in voids, ubiquitous iron staining, and brecciated base. No analysis.
14	JS-2	6940	5-10 percent euhedral to anhedral olivine to 2 mm across, altering to iddingsite. No plagioclase phenocrysts. Fine-grained groundmass. Abundant white alteration (zeolite?). 2-m-thick flow grades from brick-red brecciated base to massive interior to vesicular top. Sample collected from fresher less-vesicular, less olivine-rich part of top.
15	JS-3	6960	15 percent plagioclase to 4 cm long, commonly as glomerocrysts; 10-12 percent fresh to partly iddingsitized olivine to 3 mm across. Fine-grained groundmass; abundant secondary zeolite and quartz in voids. 3-m-thick flow grades rapidly from non-vesicular plagioclase-phyric base to vesicular top with sparse plagioclase. Sample collected from flow top.
16	JS-4	6980	10 percent plagioclase to 0.75 cm long; 10-15 percent anhedral olivine altering to iddingsite. Fine-grained groundmass; white secondary mineralization. Lower 4 m has narrow sheeted non-vesicular areas, but cliffs prevented sample collection.

17	JS-5	6985	20-30 percent relatively fresh plagioclase to 1.5 cm long; less than 5 percent olivine to 2 mm across. Glomerocrysts of plagioclase and olivine common. Fine-grained green and reddish speckled groundmass. Secondary "cauliflower" mineral in voids. Sample collected 1 m above oxidized vesicular base.
18	JS-6	6995	10-15 percent narrow laths of plagioclase to 1.5 cm long, occurs chiefly as radial splays impressive on flat weathered surfaces. Olivine in groundmass as well as in the radial clots. Fine-grained oxidized groundmass. 3-m-thick massive outcrop.
19	JS-7	7010	Sample collected from aphyric layer of a 2-m-thick section of alternating thin plagioclase-phyric and aphyric layers. All flows composed of red, white, and green fine-grained groundmass (plag, ol, cpx?) unless noted. Looks like flow segregation, but may represent multiple thin flows. From base to top of section: 1 m sparse olivine phenocrysts, vesicular, no plagioclase 0.6 m fine-grained rock with radial splays of plagioclase (20-25 percent) with lesser olivine 0.15 m aphyric to sparsely olivine phyric 0.1 m abundant radial splays of plagioclase in fine-grained groundmass 0.3 m grades from aphyric up to 20-25 percent radial splays of plagioclase. 1 m aphyric, vesicular, with pods (elongate inclusions) of radially splayed plagioclase . Continues like this for ≈7 m more, terminates at narrow pinnacle. No fresh plagioclase-phyric. Sample collected ≈1.75 m from base. Vesicles have secondary alteration
20	JS-8	7020	1-3 percent fresh plagioclase to 3 cm long chiefly in radial splays. 3-5 percent fresh to partly iddingsitized olivine to 1 mm across. Secondary vug filling (quartz & zeolite?). Collected from vesicular base of 4-m-thick flow
21	JS-9	7025	1-m-long, 20-cm-thick, pod of olivine basalt lens in middle of flow of JS-8 with no break in the thicker flow. Less than 5 percent plagioclase to 3 mm long. 15 percent fresh to partly iddingsitized olivine. Zeolite(?) in voids and dispersed throughout.
		7040	No sample collected from 2-m-thick vesicular flow that gets more plagioclase phyric up section. Very small outcrop on ridge.
22	JS-10	7050	Sparse olivine and plagioclase phenocrysts in a fine-grained gray groundmass. 1-2-m-thick vesicular flow. Quartz and zeolite (?) as secondary mineralization.
23	JS-11	7060	10 percent plagioclase to 1 cm with independent phenocrysts more numerous than radial glomerocrysts. Radial glomerocrysts of plagioclase and olivine.Fine grained grayish groundmass with abundant seriate olivine. 2-m-thick rounded outcrop, difficult to get good sample.
24	JS-12	7065	Fine-grained rock with sparse plagioclase altering to sericite(?). 3-m-thick vesicular flow with oxidized brecciated top. Sample collected from quenched base. Upper part of flow (not collected) has ≈3 percent plagioclase to 0.5 cm.
25	JS-13	7080	15 percent olivine (altering to iddingsite), to 1 mm across; plagioclase obscured by white secondary minerals (zeolite?). Fine-grained massive non-vesicular flow. Top of unit brecciated (\`a\`a flow top?). More than 6-m-thick, base not exposed. Sample from lowest exposure.

26	JS-14	7090	Diktytaxitic, fine-grained basalt with olivine and milk-colored plagioclase in groundmass. 3-m-thick flow, angular partings, rubbly top.
27	JS-15	7120	Less than 2 percent fresh to iddingsitized olivine to 1 mm across. Fine grained, with gray to partially altered groundmass. Milky-white intergranular mineral (plagioclase?). Sample from base of 8-m-thick unit that varies from vesicular to massive to brecciated (`a`a flow?).
28	JS-16	7130	Top of unit JS-15. 2-3 percent olivine to 3 mm across. No plagioclase phenocrysts. Fine-grained, gray groundmass with some iron staining.
29	JS-17	7200	7 percent olivine to 1.5 mm diameter with iddingsitized rims. Fine-grained groundmass. Unit thickness 3 m. Overlies 5-m-thick vesicular unit (not sampled) and overlain by more than 10 m of brecciated and vesicular flows (not sampled).
30	JS-18	7235	3 percent plagioclase 3-20 mm long; 7 percent olivine 0.5-1.5 mm across. Diktytaxitic. Unit is 3-4 m thick. Sample is fairly fresh.
		7250	3-m-thick highly weathered plagioclase-phyric flow. No sample taken.
31	JS-19	7260	15 percent plagioclase phenocrysts to 2 cm long (mostly 0.5-1 cm). Radial glomerocrysts of large plagioclase have olivine between the laths. Two percent fresh pale-green olivine phenocrysts to 2 mm diameter. Very fine-grained groundmass. Flow is 7 m thick and grades to less plagioclase toward top. Top is brecciated (`a`a). Sampled collected 2 m from base.
32	JS-20	7280	10-15 percent altered plagioclase phenocrysts to 2 cm long. Two percent olivine, 1 mm diameter. Very fine-grained groundmass. Flow is 4 m thick and grades from 20 percent plagioclase at base to 5 percent at top. Sample collected in center of flow. Rock is altered.
		7300	20-m-thick interval of highly weathered flows with abundant coarse plagioclase phenocrysts. No sample taken.
33	JS-21	7350	3-4 percent plagioclase phenocrysts 0.5-1 cm long; 3-5 percent olivine, 1 mm diameter. Very fine-grained groundmass, finely speckled with olivine. Flow is 6 m thick, and has quenched aphyric base and grades up to percentages noted above. Sample collected from aphyric base.
34	JS-22	7380	7 percent olivine, 0.5-1 mm across. No plagioclase as phenocryst phase. Fine-grained and diktytaxitic. Flow is 6 m thick, not graded. Fairly fresh sample collected from massive center, 1 m up from red oxidized, quenched base.
35	JS-23	7420	3-5 percent olivine to 2 mm across, almost completely altered to iddingsite. No plagioclase phenocrysts. Fine-grained diktytaxitic groundmass with abundant disseminated Fe-Ti oxides. Groundmass plagioclase ubiquitously altered chalky white. Flow is 7 m thick, base not exposed. Sample collected from top of lower 1/3.
36	JS-24	7470	Fine-grained and diktytaxitic lava with sparse small olivine altered to iddingsite. Unit composed of several flows with unclear contacts; 7 m total thickness. Entire unit has abundant vesicles and Fe-oxide staining and acicular white minerals (zeolite?) in voids. Angular fresh-looking outcrop in contrast to more common rounded weathering surfaces.
37	JS-25	7500	15-30 percent randomly oriented seriate fresh plagioclase to 3 cm long, many speckled with black inclusions. Occurs chiefly as glomerocrysts with olivine. Fine-grained, finely vesicular groundmass. Flow is 5 m thick, base and top not exposed. Not graded.

38	JS-26	7550	10-12 percent randomly oriented, seriate fresh plagioclase, to 2 cm long; 4-7 percent euhedral to subhedral olivine to 1.5 mm. Very fine-grained groundmass. Base and top not exposed, but unit is composed of discontinuous outcrop more than 15 m thick; fairly fresh sample collected from 2-m-thick exposure.
39	JS-27	7560	15-20 percent seriate plagioclase to 3 cm long; 8-12 percent fresh olivine to 1.5 mm across. Fine grained, diktytaxitic, finely vesicular groundmass with chalky coating in voids. Flow is greater than 2 m thick, top not exposed. Sample from center. Rock is fairly fresh.
40	JS-28	7600	Less than 1 percent phenocrysts of plagioclase laths 2-3 mm long; 1 percent olivine microphenocrysts. Very fine-grained sparsely vesicular groundmass with chalky coating in voids. This is a thin (8-20 cm) "stringer" of phenocryst-poor segregated melt sandwiched between plagioclase-phyric flows (see JS-29 and -30). Lower contact is completely free of phenocrysts, however upper 1 cm has plagioclase from the host rock "floating" near the contact.
41	JS-29	7600	15-25 percent plagioclase to 2.5 cm with pinkish color; some have very fine-grained mafic inclusions; 3-4 percent iddingsitized olivine 0.5-1.5 mm across. Fine-grained groundmass. Flow is more than 5 m thick, base not exposed and top of hill is eroded. See samples JS-28 and -30 for flow segregation.
42	JS-30	7600	Aphanitic. Flow segregation similar to JS-28 but from different part of flow JS-29. Multiple bands of this darker fine-grained rock are intercalated in the porphyritic host flow, JS-29.

(End of Pike Creek traverse. Begin Wildhorse Canyon traverse.)

43	JS-31	7580	2-5 percent yellow blocky plagioclase 2-10 mm across. Very fine-grained, multicolored altered groundmass. Flow is 15-20 m thick but base not exposed. Fairly fresh sample from top. Plagioclase decreases upward but the base of the outcrop is more weathered.
44	JS-32	7615	Sparse acicular microphenocrysts of plagioclase and honey-colored minerals (2 mm across; opx?) in an aphanitic groundmass. Unit is 4 m thick; angular outcrop. Thin (mm-scale) stringers of secondary honey-colored mineralization present throughout. Fairly fresh.
45	JS-33	7640	Less than 2 percent plagioclase to 5 mm long; less than 1 percent olivine microphenocrysts. Sparse glomerocrysts of plagioclase and olivine. Fine-grained groundmass with clinopyroxene. Weathered surface is metallic-black slightly raised speckles on brick- to brown-orange groundmass (ophimottled, produced by abrupt transitions between ophitic and intergranular textures). Fairly fresh rock.
46	JS-34	7700	Less than 1 percent plagioclase to 2 cm long (base of thick flow has up to 10 percent euhedral to subhedral blocky plagioclase, but is too altered for good sample); no olivine seen. Fine grained groundmass. Unit is over 30 m thick. Sample taken from fairly fresh, plagioclase-poor upper part. Ophimottled (like JS-33).
47	JS-35**	7750	Aphanitic dike (N7E trending, 0.6 m wide). Glassy quenched contact.
48	JS-36	7750	10 percent plagioclase, 0.5-2 cm long. Fine-grained and diktytaxitic flow. Unit is 4 m thick with vesicle pipes near base.
49	JS-37	7770	7-12 percent plagioclase 1-5 cm, in sub horizontal orientation; no olivine as phenocrysts. Fine grained with plagioclase, pyroxene, olivine, and Fe-

Ti oxides visible in groundmass. Unit is 10 m thick and is subtly graded with fewer plagioclase at base.

50 JS-38 7820 7-10 percent plagioclase, 0.5-4 cm long (large crystals have inclusions); 1 percent olivine, 0.5-2 mm across (rare to 5 mm). Fine-grained and diktytaxitic groundmass. Angular (see JS-24) 10-m-thick flow with pipe vesicles at base, and vesicular top. Collected 0.3 m from base.

51 JS-39 7850 3-5 percent plagioclase 0.5-3 cm long in horizontal orientation. Fine-grained diktytaxitic groundmass. Flow is 5 m thick. Surface is ophimottled (like JS-33)

7900 30 m of flows similar to JS-39, but highly weathered. No sample taken

52 JS-40 7980 5 percent plagioclase, 1-3 cm long; sparse olivine. Graded with flow segregations of greater/lesser plagioclase. Fine-grained, diktytaxitic, finely vesicular groundmass, with some clay alteration. Sample collected 2 m from base.

8000 30 m of crumbly, highly weathered rocks. No sample taken.

53 JS-41 8120 3-5 percent randomly oriented plagioclase, 0.5 to 2 cm long. Graded with more plagioclase toward top. No olivine. Very fine-grained to glassy groundmass with fine needles of clear plagioclase and 3 percent vesicles. Rock has flat, steel-gray luster. Flow is 4 m thick; sample collected in center.

54 JS-42** 8100 Very fine grained aphyric dike with plagioclase and olivine in groundmass (out of elevation sequence; north trending; 2 m wide.)

55 JS-43 8220 Aphyric. Very fine-grained, slightly diktytaxitic groundmass with finely disseminated mafic phase altered to red specks. Flow is 4 m thick. Vesicular base and top. Fairly fresh sample.

8300 40-m section of highly weathered, crumbly plagioclase-rich flows. No sample taken.

56 JS-44 8390 Aphyric very fine-grained non-vesicular diktytaxitic groundmass with some iron staining. Flow is 10 m thick and forms an angular outcrop with some ophimottling (see JS-33).

57 JS-45 8440 5-7 percent seriate plagioclase to 2.5 cm (plagioclase phenocrysts are horizontal and swirl with flow foliation); sparse olivine, 1 mm. Fine-grained to very fine-grained finely vesicular groundmass with clear plagioclase needles in the finer-grained part, and blocky plagioclase and ophitic clinopyroxene in coarser part. Unit has 6 m of basal breccia, 4 m of massive plagioclase phyric central portion, and 2 m of upper breccia (`a`a flow).

58 JS-46 8520 3 percent plagioclase 0.5-1 cm; sparse at base of flow. No olivine. Fine-grained diktytaxitic groundmass with disseminated oxidized mafics. Flow is more than 7 m thick and grades upward into brecciated spires (`a`a flow).

[Flows above this to 8540' are brecciated and highly weathered. No fresh sample.

(Transect moves to next cliffs to north)

59	JS-47	8540	Aphyric, fine-grained vesicular slightly diktytaxitic lava flow. 2 m thick.
60	JS-48	8550	Aphyric fine-grained diktytaxitic massive lava flow. 2 m thick; sample from 0.25 m from base. The only vesicles are present as basal pipes.
61	JS-49	8560	no description written
62	JS-50	8580	no description written

(Transect moves to WNW wall of upper end of Wildhorse Canyon.)

63	JS-51	8650	Aphyric to sparsely plagioclase phyric, fine grained, and diktytaxitic. Multiple flows total 8 m thick. Entire unit is highly weathered.
		8580	10-m-thick bold rounded plagioclase-phyric outcrop (12-15% to 3 cm long). Crumbles to weathered bits. No sample taken.
64	JS-52	8600	2-3 percent plagioclase, 0.2 to 0.5 cm in a fine grained groundmass. Flow is 4 m thick with some Fe oxidation.
65	JS-53	8690	12-20 percent plagioclase phenocrysts, 1-3 cm long. Parallel alignment of plagioclase, with preferential parting of rock parallel to plagioclase. Fine grained groundmass. 15-m-thick flow with vesicular top; outcrop highly weathered and rounded. All samples crumble to less than 4-cm diameter blocks. Sample collected 7 m from base.
66	JS-54	8730	1-2 percent plagioclase phenocrysts; no plagioclase at top of flow. Fine-grained diktytaxitic groundmass, denser at base. 2.5-m-thick flow with 1/2-m-thick vesicular upper part forms an angular outcrop. Fairly fresh sample collected 1 m up from base.
67	JS-55	8780	15-25 percent plagioclase, 1-4 cm long. Base has 5 percent plagioclase to 5 cm long. Flow is 12 m thick with local variation in plagioclase abundance. Fine grained groundmass.
68	JS-56	8790	1-2 percent plagioclase 0.25-1 cm long; base has 2 percent plagioclase as large as 3 cm. Fine-grained groundmass. Large vesicles increase up section, 2 m above base to the top. Base has green clay interspersed throughout and crumbles to greenish sand. Flow is 5 m thick; sample collected 1.5 m from base.
69	JS-57	8850	Aphyric fine grained rock with oxidized vesicular brecciated base. Flow is more than 4 m thick, top not exposed. Sample collected 1.5 m from base.
70	JS-58	8980	2 percent plagioclase to 2 cm long; mostly less than 1 cm; less than 1 percent olivine to 1.5 mm. Fine-grained diktytaxitic groundmass. Flow is more than 6 m thick.
71	JS-59	9070	10-20 percent plagioclase to 2 cm long; brown staining on fractured surfaces. Fine-grained groundmass. Flow is more than 15 m thick, top not exposed. Sample collected 3 m from base.
72	JS-60	9140	Fine-grained, non-vesicular rock with sparse olivine and no plagioclase. Angular outcrop is platy with parallel horizontal partings. Fairly fresh sample.
73	JS-61	9240	Aphyric fine-grained weakly diktytaxitic rock composed of plagioclase, clinopyroxene, and red oxidized mafic phase. Some alteration clays apparent. Flow is more than 6 m thick; top eroded.

74	JS-62**	9200	Aphanitic dike with fine clear plagioclase needles. Trends N30W through saddle below JS-61. Fresh sample.
		9300	4-m-thick plagioclase-phyric (15 percent) flow. Might be up-slope equivalent of JS-60. No sample taken
75	JS-63	9320	Aphyric flow similar to JS-61, but not diktytaxitic. Platy partings parallel to hill slope. Basal part is red oxidized, highly vesicular agglutinate (`a`a?). Flow is 3 m thick; top eroded.
76	JS-64	9330	10-15 percent seriate anhedral plagioclase to 1.5 cm across; weakly graded. Fine grained groundmass with plagioclase and clinopyroxene. Abundant pale-green clay. Flow is 4 m thick. Vesicle pipes in lower 1.5 m. Agglutinated basal breccia (`a`a?) is aphyric and may be the upper part of JS-63 separated by a talus-mantled slope. 3 paleomag drill holes found in dense center of flow.
77	JS-65	9340	Aphyric fine-grained rock with plagioclase, clinopyroxene, and red oxidized mafic phase. Flow is 2-3 m thick and weathers to 5-10-cm-thick blocky plates. Slope former.
78	JS-66	9400	5 percent randomly oriented plagioclase to 1 cm, most is 0.3-0.5 cm; plagioclase is weathering out leaving voids. Rare olivine, 2 mm. Fine-grained groundmass. Unit has reddish hue relative to other units. 3-m-thick flow has vesicular top and vesicular, oxidized, and weathered brecciated base.
79	JS-67	9500	1 percent plagioclase, 2-4 mm (not cm); less than 0.5 percent olivine 0.5-1 mm, altering to iddingsite. Fine grained groundmass.
80	JS-68	9550	8-12 percent seriate plagioclase to 1 cm long, weathering out leaving voids; sparse olivine, less than 1 mm across. Fine-grained groundmass with 1 percent large vesicles. Ubiquitous dusty alteration. Flow is 6 m thick. Sample collected near center.
81	JS-69	9600	15-20 percent randomly oriented plagioclase to 1 cm, most is ~0.5 cm. 1 percent olivine 0.25-1.5 mm. Fine-grained groundmass with "oatmeal"-like texture of network plagioclase. Flow is more than 4 m thick and not graded.
82	JS-70	9630	Aphyric finely vesicular rock with a very fine-grained incipiently diktytaxitic groundmass. Blue-gray rock forms platy outcrop with ~5-cm-thick partings. Fresh sample.
83	JS-71	9640	Aphyric with aphanitic groundmass. Massive outcrop has yellow clay in ubiquitous parallel foliation partings. Overlies oxidized vesicular flow breccia.
		~9690	Discontinuous highly weathered plagioclase-phyric flow. Not sampled.
84	JS-72	9720	Less than 1 percent plagioclase, 3 mm long. Aphanitic groundmass with finely disseminated Fe-Ti oxides. Weathers to platy clay-altered slabs. Burgundy-gray swirls through portions of outcrop. Base is vesicular. Unit is 2-6 m thick; top eroded.
85	JS-73	9700	Aphyric very fine grained clay-altered rock. Flow is 4 m thick with oxidized, vesicular base.