# THE PETROGRAPHY AND GEOCHEMISTRY OF LAVAS ON THE SOUTHWEST FLANK OF MT. McLOUGHLIN, SOUTHERN OREGON

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**Introduction**

Mt. McLoughlin is a composite volcano in the southern region of the High Cascade volcanic arc 55 km south of Crater Lake, Oregon. In an attempt to understand the petrogenesis of the Mt. McLoughlin lavas, a detailed study was undertaken on a 15 $km^2$ area on the southwest flank of Mt. McLoughlin. Fieldwork distinguished five units based on dominant phenocryst assemblages. The texture and mineralogy of the different flows were determined by thin-section analysis. Major and selected trace element data were determined using X-ray fluorescence and inductively coupled plasma spectroscopies. These data characterize the flows as basaltic-andesites to andesites of a calc-alkaline nature and place some constraints on the development of a magma chamber beneath Mt. McLoughlin.

**Field Description**

Figure 1 is a simplified stratigraphic column of the flows mapped in the area. The Olivine-hornblende flow is very limited in outcrop and appears to be overlain by Rye Spring material. The Ol-hbld unit is easily distinguished in hand specimen by the presence of hornblende phenocrysts.

The Rye Spring and Rye Spring Prime flows are parts of two shield-like structures, each measuring approximately one kilometer in diameter. These flows are characterized in outcrop by remarkably tough brown boulders which, once broken, show iddingsitized olivine phenocrysts in a fine-grained groundmass. Samples from the two flows are virtually identical in hand specimen and are differentiated in the field mainly by association with the respective shields.

The youngest two units, Olivine-phyric and 2-px Andesite, cover 75 percent of the study area and are easily distinguishable from the other units by their lack of weathering and vegetation. These two units are distinguished from one another on the basis of grain size and phenocryst assemblage. The Olivine-phyric unit is fine-grained with olivine phenocrysts measuring 3 cm, while the 2-px Andesite is a coarse-grained unit with cumulophyric clots of ortho- and clinopyroxene. Within this study area, the 2-px Andesite flows appear to lie stratigraphically on top of the Olivine-phyric flows. However, in the area immediately to the southeast, the opposite seems to be true. The Mt. McLoughlin 2-px Andesite and Olivine-phyric units are thus believed to be coeval. Two relatively young episodes of volcanism are included in the 2-px Andesite unit. They are referred to as the Big Young Flow and South Squaw Flow. The Big Young Flow is a large blocky flow that can be traced to a deflated vent measuring 75 m in diameter. The South Squaw Flow emanates from South Squaw Tip, one of two prominent parasitic cones on Mt. McLoughlin.

**Figure 1.** Stratigraphic column of lavas studied

| | | | |
|---|---|---|---|
| CENOZOIC | Quaternary | Olivine-phyric | 2-px Andesite ( incl. BYF + SSF) |
| | Tertiary | Rye Spring[a] | Rye Spring Prime[b] |
| | | Olivine-hornblende[c] | |

[a]K-Ar date: 6.06 ± 0.01 Ma (Mertzman, unpublished data)
[b]K-Ar date: 6.43 ± 0.10 Ma (Mertzman, unpublished data)
[c]K-Ar date: 5.62 ± 0.09 Ma ? (Mertzman, unpublished data)

BYF = Big Young Flow
SSF = South Squaw Flow

**Petrography**

Petrographic analysis of 35 thin sections reveals that all of the samples are either andesites or basaltic-andesites comprised principally of plagioclase with lesser amounts of pyroxene, olivine, hypersthene, apatite, and opaque oxides. However, the 5 flows exhibit some unique characteristics, sufficient to distinguish them in thin section as well as in the field.

The Ol-hbld unit contains 20 modal percent phenocrysts: approximately 70% pseudomorphs of hornblende, 20% iddingsitized olivine, and 10% plagioclase, sometimes glomeroporphyritic. The trachytic groundmass consists of about 90% plagioclase and 10% olivine and pyroxene. The pseudomorphs of hornblende vary from complete resorption with reaction rims of clinopyroxene to pyroxene cores with opaque mantles. The stable association of olivine and hornblende places some constraints on the depth of the magma chamber in the Mt. McLoughlin area.

The Rye Spring flows are characteristically equigranular with a fine-grained groundmass consisting of about 80% trachytic plagioclase and nearly equal amounts of pyroxene and olivine making up the remainder. The Rye Spring flows have a characteristic 3-5 modal percent phenocryst olivine content that has been slightly altered to iddingsite. Opaque oxides and apatite are more concentrated in the Rye Spring and Rye Spring Prime flows than in the other lavas studied. Rye Spring Prime is less equigranular than Rye Spring and has an altered groundmass, but otherwise appears identical to Rye Spring in thin section.

The Olivine-phyric flows (clearly distinct in thin section from the 2-px andesite) are composed almost entirely of equigranular plagioclase microlites displaying distinct trachytic texture with infrequent clinopyroxene and olivine phenocrysts. These flows have small amounts of hypersthene, pyroxene, and olivine in the groundmass.

The 2-px Andesite flows are porphyritic, containing about 45 modal percent phenocrysts; glomeroporphyritic plagioclase accounts for 90% of the phenocrysts, and cumulophyritic clots of olivine, pyroxene, and plagioclase comprise the rest. The groundmass is relatively coarse and consists of 90% plagioclase and 10% hypersthene, pyroxene, and olivine.

**Geochemistry**

Twenty-one samples were analyzed for both major and trace elements using X-ray fluorescence and inductively coupled plasma techniques (Table 1). Using criteria of Irvine and Baragar (1971, *in* Philpotts 1989), an AFM diagram suggests that all the flows studied are calc-alkaline (Fig. 3). A Harker variation diagram of wt. % $Na_2O$ + $K_2O$ vs. wt. % $SiO_2$, based on that of Cox and others (1979), characterizes the flows as basaltic-andesite to andesite (Fig. 4).

**Discussion**

The geochemical data suggest that all of the units are genetically related. The petrographic and geochemical data can be partly interpreted to have resulted from increasing $SiO_2$ in the late stages of crystallization of an evolving magma chamber. Given that the variation in $SiO_2$ for these flows is only 5%, differentiation trends based on $SiO_2$ are difficult to discern. As can be seen in Table 1 and Figure 2, $TiO_2$, $Fe_2O_3$, and $P_2O_5$ behave similarly and decline as $SiO_2$ rises. $Al_2O_3$, in contrast, increases with $SiO_2$, as does, to a lesser extent, MgO. These trends follow a general pattern described by Mertzman and Gooding (1988) of increasing $SiO_2$, $Al_2O_3$, CaO, and Sr and decreasing Total Fe (expressed as $Fe_2O_3$), $TiO_2$, $P_2O_5$, $K_2O$, Rb, Zr, and Ba as a function of decreasing age. Plagioclase fractionation would explain the decline in CaO, Sr, and Ba in progressively younger flows. The high $Fe_2O_3$ and $TiO_2$ compared to the low MgO in Ol-hbld, Rye Spring and Rye Spring Prime flows correlates to the abundance of iron-titanium oxides in these older flows. The presence of apatite explains the high $P_2O_5$ in the Rye Spring and Rye Spring Prime flows. High MgO and Cr values for a xenolith in the South Squaw Flow (BX) indicate that it was crystallized from a primitive magma.

The presence of hornblende in the Ol-hbld flow is unique to the Mt. McLoughlin area. Experiments performed by Yoder and Tilley (1962) show that olivine and amphibole stably coexist with basaltic liquids at pressures above 12,000 bars, corresponding to depths of more than 45 km. Devolatilization during eruptive activity could cause such a drop in water pressure to create the disequilibrium that resulted in pseudomorphs of hornblende in the Ol-hbld unit.

**References cited**

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TABLE 1. Major and Trace Element Compositions of Lava Flows from Mt. McLoughlin Area of Southern Oregon

| | 2-px Andesite | | | | BYF | SSF | BX | Olivine-phyric | | | | | | | Rye Spring | | | | Rye Spr. Prime | | Ol-hbld |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spec. | 91-26 | 91-82 | 91-95 | 91-89 | 91-99 | 91-69 | 91-65 | 91-93 | 91-96 | 91-20 | 91-90 | 91-81 | 91-63 | 91-97 | 91-77a | 91-77b | 91-31 | 91-44 | 91-85 | 91-98 | 91-100 |
| SiO2 | 54.70 | 55.21 | 54.44 | 54.91 | 53.73 | 56.42 | 53.02 | 54.95 | 55.86 | 55.91 | 54.62 | 54.75 | 55.90 | 56.59 | 54.44 | 53.86 | 52.26 | 51.43 | 55.59 | 54.75 | 55.72 |
| TiO2 | 0.77 | 0.77 | 0.77 | 0.77 | 0.81 | 0.79 | 1.13 | 0.91 | 0.89 | 0.87 | 0.94 | 0.90 | 0.88 | 0.87 | 1.09 | 1.05 | 1.19 | 1.25 | 1.01 | 1.04 | 0.84 |
| Al2O3 | 19.84 | 18.91 | 19.65 | 20.73 | 19.63 | 19.48 | 16.78 | 17.96 | 18.12 | 18.52 | 18.06 | 18.77 | 18.20 | 18.13 | 18.20 | 18.39 | 18.07 | 17.97 | 17.86 | 18.46 | 18.48 |
| Fe2O3* | 2.87 | 2.18 | 1.83 | 2.21 | 2.69 | 2.42 | 2.82 | 2.43 | 2.17 | 2.29 | 2.25 | 1.92 | 2.78 | 1.60 | 3.39 | 2.90 | 3.34 | 3.26 | 3.55 | 3.72 | 3.55 |
| FeO | 3.81 | 4.82 | 4.82 | 4.17 | 4.52 | 4.33 | 5.50 | 4.79 | 4.81 | 4.77 | 5.09 | 5.15 | 4.15 | 5.18 | 4.82 | 5.11 | 5.20 | 6.38 | 4.18 | 4.38 | 3.94 |
| MnO | 0.11 | 0.11 | 0.10 | 0.10 | 0.11 | 0.12 | 0.13 | 0.12 | 0.12 | 0.12 | 0.13 | 0.12 | 0.12 | 0.12 | 0.14 | 0.14 | 0.17 | 0.17 | 0.13 | 0.14 | 0.13 |
| MgO | 4.36 | 4.72 | 4.67 | 3.40 | 4.72 | 3.68 | 7.73 | 5.69 | 4.46 | 4.35 | 5.65 | 5.12 | 4.43 | 4.52 | 3.76 | 3.82 | 4.18 | 5.05 | 3.59 | 3.80 | 3.78 |
| CaO | 8.16 | 8.05 | 8.27 | 7.60 | 8.28 | 7.48 | 8.25 | 7.70 | 7.75 | 7.59 | 7.56 | 7.66 | 7.71 | 7.63 | 7.79 | 7.72 | 7.78 | 8.44 | 7.03 | 7.36 | 7.30 |
| Na2O | 3.76 | 4.06 | 3.92 | 4.02 | 3.61 | 4.06 | 3.77 | 3.70 | 3.72 | 3.63 | 3.45 | 3.48 | 3.46 | 3.60 | 4.14 | 4.04 | 3.81 | 3.74 | 4.02 | 3.99 | 3.94 |
| K2O | 0.77 | 0.77 | 0.76 | 0.83 | 0.63 | 0.85 | 0.41 | 0.97 | 1.12 | 1.05 | 0.90 | 0.95 | 1.20 | 1.14 | 1.24 | 1.21 | 1.19 | 1.20 | 1.49 | 1.31 | 1.22 |
| P2O5 | 0.12 | 0.14 | 0.12 | 0.14 | 0.14 | 0.14 | 0.28 | 0.26 | 0.24 | 0.24 | 0.25 | 0.25 | 0.25 | 0.24 | 0.52 | 0.53 | 0.62 | 0.57 | 0.52 | 0.52 | 0.36 |
| LOI | 1.18 | 0.55 | 0.81 | 1.01 | 1.30 | 0.42 | 0.61 | 0.99 | 0.96 | 1.16 | 1.30 | 1.15 | 0.96 | 0.88 | 0.76 | 1.07 | 1.76 | 0.81 | 1.08 | 0.97 | 0.93 |
| TOTAL | 100.44 | 100.28 | 100.15 | 99.88 | 100.16 | 100.19 | 100.43 | 100.46 | 100.21 | 100.50 | 100.19 | 100.20 | 100.06 | 100.50 | 100.29 | 99.85 | 99.56 | 100.26 | 100.06 | 100.44 | 100.18 |
| Rb | 8 | 7 | 7 | 8 | 14 | 9 | 4 | 14 | 22 | 17 | 15 | 16 | 20 | 17 | 11 | 13 | 12 | 8 | 12 | 12 | 14 |
| Sr | 832 | 820 | 831 | 877 | 865 | 884 | 660 | 697 | 679 | 691 | 715 | 663 | 677 | 663 | 889 | 837 | 753 | 849 | 964 | 999 | 892 |
| Ba | 240 | 229 | 217 | 234 | 297 | 247 | 308 | 439 | 473 | 448 | 471 | 465 | 463 | 456 | 514 | 501 | 596 | 537 | 650 | 694 | 457 |
| Y | 14 | 13 | 13 | 13 | 15 | 14 | 24 | 19 | 19 | 19 | 19 | 20 | 19 | 20 | 23 | 26 | 29 | 36 | 22 | 25 | 30 |
| Zr | 65 | 78 | 42 | 67 | 75 | 68 | 146 | 133 | 133 | 124 | 132 | 130 | 124 | 125 | 121 | 121 | 128 | 135 | 131 | 132 | 101 |
| V | 175 | 185 | 184 | 163 | 176 | 167 | 168 | 164 | 175 | 166 | 166 | 175 | 174 | 170 | 196 | 192 | 210 | 215 | 163 | 167 | 169 |
| Ni | 38 | 50 | 41 | 30 | 57 | 29 | 168 | 111 | 44 | 52 | 106 | 89 | 44 | 47 | 18 | 24 | 41 | 44 | 29 | 31 | 27 |
| Cr | 35 | 37 | 31 | 10 | 27 | 9 | 252 | 164 | 77 | 61 | 122 | 102 | 79 | 80 | 36 | 29 | 50 | 61 | 32 | 31 | 40 |
| Be | 1.2 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.4 | 1.5 | 1.5 | 1.5 | 1.4 | 1.5 | 1.5 | 1.8 | 1.7 | 1.9 | 1.7 | 1.7 | 1.7 | 1.7 |
| Co | 24 | 25 | 24 | 21 | 26 | 22 | 36 | 24 | 21 | 22 | 30 | 23 | 22 | 22 | 25 | 24 | 28 | 33 | 24 | 24 | 23 |
| Sc | 19 | 19 | 19 | 16 | 20 | 17 | 22 | 19 | 20 | 19 | 19 | 20 | 20 | 19 | 20 | 20 | 21 | 23 | 17 | 17 | 16 |
| La | 8 | 7 | 8 | 9 | 10 | 9 | 15 | 17 | 17 | 17 | 18 | 17 | 16 | 16 | 20 | 23 | 24 | 23 | 23 | 24 | 23 |
| Ce | 16 | 15 | 17 | 18 | 19 | 16 | 31 | 33 | 31 | 32 | 33 | 30 | 33 | 35 | 44 | 44 | 46 | 45 | 46 | 48 | 40 |
| Yb | 0.9 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 1.5 | 1.5 | 1.4 | 1.3 | 1.6 | 1.4 | 1.5 | 1.4 | 1.7 | 1.8 | 2.4 | 2.0 | 1.6 | 1.6 | 2.2 |

Fe2O3* = total Fe

LOI = loss on ignition

BYF= Big Young Flow

SSF= South Squaw Flow

BX= Xenolith in South Squaw Flow

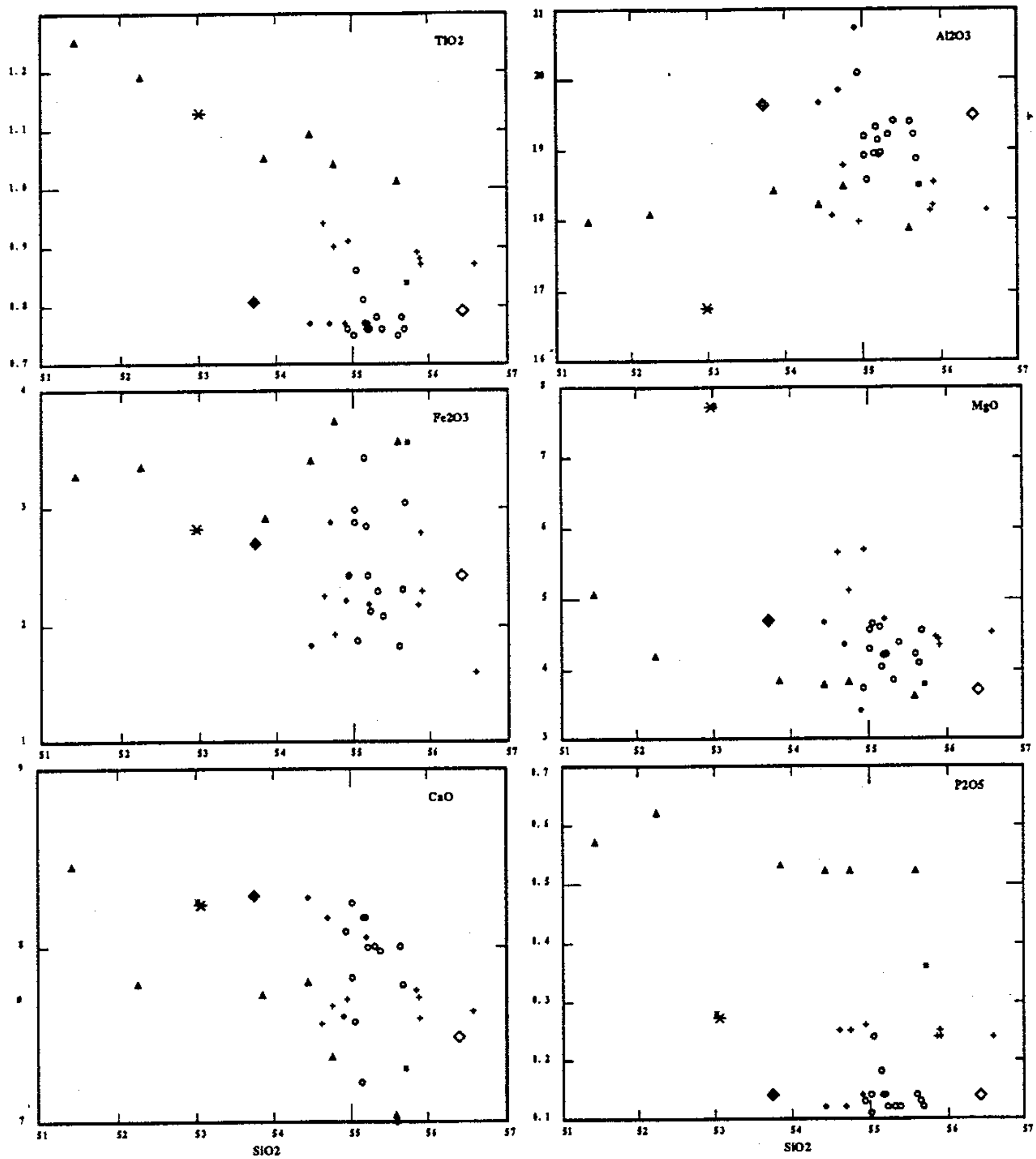


**Figure 2.** Harker diagram comparing concentrations of intermediate composition McLoughlin Summit (open circles) (Mertzman and Gooding, 1988), 2-px Andesite (small solid diamonds), Big Young Flow (large solid diamonds), South Squaw Flow (open diamond), Xenolith in South Squaw Flow (asterisk), Olivine-phyric (crosses), Rye Spring (solid triangles), Rye Spring Prime (open triangles), and Ol-hbld (open square).