Geology and Petrology of the Topsy Grade-Grenada Butte Corridor, Klamath River Gorge, Southern Oregon

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GEOLOGIC SETTING

Volcanism in the Pacific Northwest commenced as a result of subduction of the Farallon Plate beneath the North American Plate between 43 and 39 Ma. High Cascade volcanism along the eastern margin of Cascadia superseded West Cascade volcanism 9 million years ago (Hammond, 1989). In southern Oregon, High Cascade volcanism is connected with the reorientation and detachment of the Gorda North subducting plate from the Juan de Fuca plate. The surface expression of volcanism depicts a narrow arc that is approximately 50 km wide. The High Cascade arc in southern Oregon is a result of multiple tectonic processes. Guffanti and Weaver (1988) believe that the subduction component of arc volcanism in northern California and southern Oregon may be waning because the oceanic plate is shortening and becoming more buoyant and resistant to subduction. This is reflected by the onset of back-arc spreading which has been responsible for geologically recent extension within the arc. The migration of a back-arc into the Cascade arc may actually be an impingement of the northwest trending Basin and Range province (Guffanti and Weaver, 1988).

In my field area, development of the Basin and Range structure appears to be incomplete. The field area is an 8 square mile transect at the southern most part of the Cascades Keck project, and northern edge of the Pomona College field area. It is located near the California-Oregon border, north of Secret Spring Volcano and south of Hamaker Mountain. Lavas from the area reflect an extensional terrain that is as young as 1.1 Ma. The presence of high alumina olivine tholeiite (HAOT) with both a back-arc and Basin and Range signature, challenges Guffanti and Weaver's assertion that Basin and Range volcanism ceased 5 million years ago in southern Oregon and subduction is the only principle source of magmatism. In fact, the HAOT lavas originate from intra-arc vents that lie along Basin and Range type extensional faults. Hammond (1989) says that arc related volcanism beginning 9 Ma, has gradually subsided with extensional volcanism dominating the arc terrain. Extensional volcanism in the High Cascades is complicated and may be the result of a combination of factors, including, the obliquity of the subducting slab, an increase in the spreading rate of the Basin and Range into the Cascade arc, or a decrease in the convergence rate between the Juan de Fuca and North American plates as a result of the migrating Mendocino triple junction.

Within the 8 mile transect there are seven different units of lava, ranging from upper Miocene calc-alkaline basalts to Quaternary HAOTs. The Klamath gorge exposes a convenient cross-section of the strata, showing the majority of these units.

The west wall of the canyon is dominated by a series of horizontal olivine phyric lava flows (Klamath Canyon Olivine Phyric Basalt, Tvbo). Flows exposed lower in the section are approximately 7.4 Ma and the lavas at the top are closer to 6.0 Ma. There is no obvious source for these flows. In the southwest corner of the field area, just below the west rim of the canyon, there is a flow that may correlate to the Topsy Plagioclase-rich, HAOT lavas that are found on the east wall.

On the east side of the Klamath river the exposed geology in the wall is much more complicated. Along the Topsy Grade the lavas consist of two distinct units of calc-alkaline basalt located lower in the section, with HAOT flows lying on top and adjacent to them. The oldest of the calc-alkaline lavas on the east wall correlates with the 6.0 Ma flows of Tvbo on the west wall. The younger, superjacent calc-alkaline unit (Aqueduct Basalt, Tvba) is conspicuous along the Topsy Grade Road and can be traced to a well preserved dome-like structure with large vertical plates or cooling joints. The lavas of this unit are truncated by a series of younger HAOT flows. The older HAOT lavas (Topsy Plagioclase-rich Basalt, Tvbt) are distinguished by an abundance of large plagioclase phenocrysts. Younger HAOT lavas include Keno Diktytaxitic Basalt, Tvbk (2.4 Ma), Chicken Hills Plagioclase Porphyry Basalt, Tvbsp (1.2 Ma), and Chicken Hills Rim Basalt, Tvbr (1.1 Ma). The source of the HAOT lavas is the Chicken Hills, which are 5.4 km to the northeast. The Chicken Hills are a series of three, steep-sided shield volcanoes that line up along a northwest, southeast normal fault and are responsible for four variations of HAOT lava, seen throughout most of the 1995 Keck study region. East of the Chicken Hills and along the northeast boundary of the field area lies Grenada Butte. Grenada Butte is an older volcanic source with basaltic andesite lavas (Grenada Butte Basaltic Andesite, Tvbag) that are approximately 6.2 Ma.

ANALYTICAL METHODS

Thin sections were made for thirty rocks and analyzed under a petrographic microscope. Geochemical data was developed at Franklin & Marshall College using XRF, ICP, and Iron Titration methods. XRF data complied with standards showing very little error. Dr. Stan Mertzman obtained K-AR and INAA data.

PETROGRAPHY

There are two distinct units of calc-alkaline basalts. The older unit (Tvbo) is a holocrystalline, olivine phyric basalt with crystal aggregates of olivine, plagioclase, and augite. The fine-grained plagioclase crystals are acicular and form subophitic intergrowths with augite. Larger plagioclase crystals can be seen in the older flows of Tvbo. Olivine is present as subhedral, fine to medium-grained crystals with intergranular and poikilitic (small inclusions of magnetite) textures. Much of the olivine has altered to iddingsite. Augite crystals are the only pyroxenes in these basalts and are present as fine-grained crystals forming the groundmass with olivine, plagioclase and magnetite. The younger calc-alkaline lava (Tvba) is similar to Tvbo, but it is more aphyric and lacks the abundance of crystal aggregates. Tvba is distinguished by its trachytic texture and acicular plagioclase crystals.

There are four distinct units of HAOT. The difference between HAOT and calc-alkaline lavas is apparent from comparative geochemical data, but there are obvious petrological distinctions as well. In general the HAOT lavas have an abundance of plagioclase and olivine with conspicuous glomeroporphyritic clots. These lavas are holocrystalline, diktytaxitic and porphyritic with the exception of Tvbk. Tvbk is a nonporphyritic, prototypical high alumina olivine tholeiite. Olivine is present as fine-grained, subhedral, intergranular crystals. Plagioclase crystals form laths and a subophitic texture with augite. Tvbk does not have the same glomeroporphyritic texture that the other high alumina olivine tholeiite units possess.

Tvbr has an abundance of olivine and plagioclase phenocrysts. Tvbsp is very similar, but the plagioclase crystals are larger and the characteristic glomeroporphyritic texture is even more conspicuous. The diktytaxitic texture is pronounced in this unit with plagioclase crystals protruding into vesicles. Tvbt has less olivine phenocrysts than the Tvbr and Tvbsp, but is distinguished by its large, acicular plagioclase crystals. In all three of these lavas, olivine forms intergranular crystals as well as glomeroporphyritic aggregates. Diktytaxitic textures still persist, and ophitic textures are as prevalent as subophitic textures. Augite crystals are not solely in the groundmass, but can be identified as phenocrysts the size of some of the olivine phenocrysts.

There is only one unit of basaltic andesite. Tvbag is primarily plagioclase dominant with few microphenocrysts of olivine.

GEOCHEMISTRY

The calc-alkaline basalts and the high alumina olivine tholeiites vary in geochemistry. They are both subalkaline lavas, but the HAOT lavas fit into the "Low K" category, whereas the calc-alkaline are "Medium K" lavas. In comparison with HAOT, the calc-alkaline lavas have considerably lower percentages of MgO, and CaO; and higher percentages of P2O5, Na2O, and K2O. The calc-alkaline lavas also have a greater abundance of incompatible or large ion lithophile elements (Rb, Sr, K).

The geochemical data for the HAOT lavas is very similar to comparative geochemistry of mid-ocean-ridge basalts (MORB) and back-arc-basin basalts (BABB) (Hart, Aronson, and Mertzman, 1984). Similar to MORB and BABB lavas, the HAOT lavas are LILE-depleted (Rb, Sr, K) and depleted in other incompatible minerals such as Nb and Zr, and Ti. HAOT lavas are enriched in MgO, CaO and Ni, varying from the Tvbk unit to the Tvbt unit. The diktytaxitic variety has an especially primitive mantle signature, with abundances of MgO and Nickel (9.15% and 178.50 ppm), and a dearth of Rb, Sr, K, Nb, Zr, and TiO2. Although the HAOT lavas from the field area are similar to MORB and BABB, they have much higher abundances of Sr (see Table 1.). Strontium percentages for MORB and BABB are 118 ppm and 214 ppm, respectively (Hart, Aronson, and Mertzman, 1984).

DISCUSSION

Comparing the geochemistry between my calc-alkaline and HAOT lavas, suggests that the calc-alkaline basalts have more of a subduction slab component whereas the HAOT lavas are derived higher in the mantle wedge with minimal crustal interaction. This is compatible with the study of Bacon (1989), who also suggests that different degrees in partial melting and high-pressure fractionation contribute to the difference between calc-alkaline and HAOT lavas.

From the LILE values, it is evident that the HAOT lavas have been disgorged as a result of extensional processes similar to those associated with back-arc spreading. The HAOT flows come from the Chicken Hills, which lies on top of

a northwest, southeast trending fault. The four different flows from the Chicken Hills, may depict a set of magma pulses from a common deep source. The initial extrusions from the Chicken Hills were a series of flows of Tvbt. There is an obvious liquid line of descent represented from older to younger flows of Tvbt. The early flows of Tvbt are primitive, but fractionated with an abundance of olivine phenocrysts and 7.37% MgO, whereas the younger flows have less olivine phenocrysts and 6.38% MgO.

The superjacent Tvbk unit plainly represents a new batch of primitive magma with a high MgO content of 9.27%. There are no phenocrysts in this high magnesia lava, suggesting that the magma must have been very hot and risen quite quickly from its source region. Consequently the younger Tvbsp and Tvbr may represent an aliquot of magma drawn from the center of the same reservoir supplying the eruptions of Tvbk, or more likely given the extensional setting, a separate batch of melt altogether. In either case, evidence of fractionation in both the early and later flows exists in the form of glomeroporphyritic aggregates in Tvbsp and Tvbr, that were possibly stirred up from the bottoms of the magma columns during eruptions.

TABLE 1. AVERAGE MAJOR- AND TRACE-ELEMENT DATA

	Tvbaq	Tvbo	Tvba	Tvbt	Tvbk	Tvbsp	Tvbr
SiO2	52.42	50.58	50.56	49.36	47.84	48.95	48.73
TiO2	1.09	1.49	1.19	1.07	0.91	1.15	1.40
Al2O3	18.31	17.11	17.40	18.17	17.34	17.51	16.85
Fe2O3	5.46	3.97	4.07	4.47	2.16	4.22	2.93
FeO	3.62	6.34	5.85	5.39	7.30	5.71	7.30
MnO	0.14	0.17	0.16	0.16	0.17	0.16	0.17
MgO	4.31	5.21	5.83	6.86	9.15	7.27	7.87
CaO	8.21	8.28	8.71	10.23	11.25	10.35	10.12
Na2O	3.80	3.69	3.56	3.09	2.40	2.96	2.86
K2O	0.97	1.06	0.89	0.29	0.13	0.29	0.37
P2O5	0.37	0.53	0.42	0.15	0.06	0.18	0.25
LOI	0.61	1.33	1.20	1.13	1.30	1.06	1.04
Total	99.31	99.65	99.84	100.36	99.98	99.79	99.88
Rb	9.70	10.88	8.10	2.48	1.55	3.38	4.03
Sr	893.00	795.80	850.60	571.83	285.00	617.50	517.80
Zr	66.00	124.80	82.40	53.67	46.00	74.25	104.00
Nb	2.60	7.38	3.94	1.07	0.11	2.78	4.90
N	54.00	82.20	95.00	116.00	178.50	112.50	127.83

CONCLUSION

The east wall of the Klamath River, in the southern most section of the Keck field area, provides evidence for a transition between subduction related volcanism and extensional volcanism. The unconformity between the youngest calc-alkaline flow of Aqueduct Basalt and the oldest HAOT flow (Topsy Plagioclase-rich Basalt) may serve as a boundary for the transition in tectonic processes. Consequently, the onset of faulting in this region probably took place less than 6.0 Ma.

The age of the Klamath river is a little more speculative, but correlating flows across river suggests that the river is younger than the youngest lava flow in the area (1.1 Ma) and that it must have cut down along the contact of the Tvbo unit on the west rim and the four different HAOT flows on the east rim.

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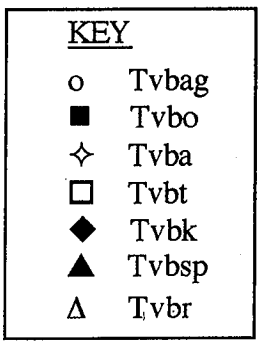
Mertzman, 1996 personal communication.



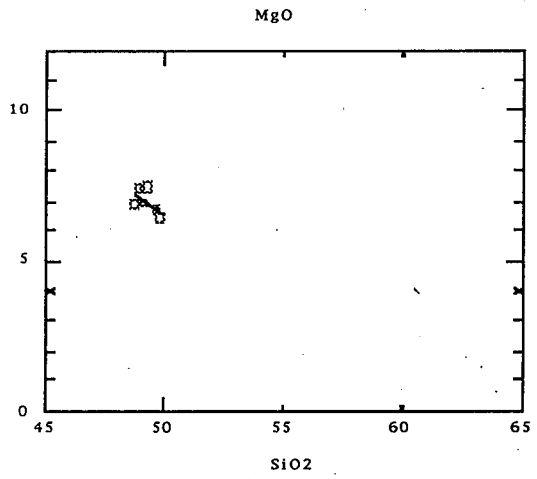


Figure 1. Plot of wt.% MgO vs. wt.% SiO2, showing fractional crystalization of Tvbt.

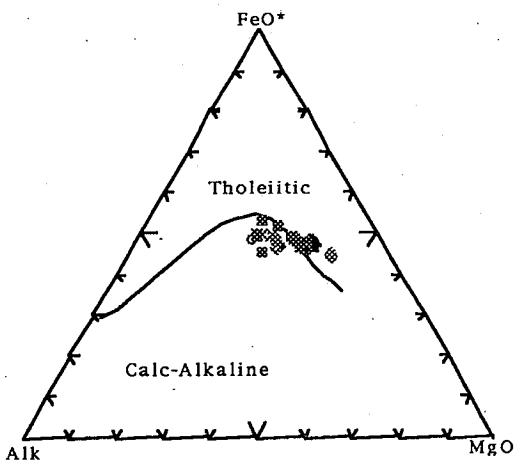


Figure 2. AFM diagram showing Calc-alkaline and Tholeiitic distribution of my 30 rocks.

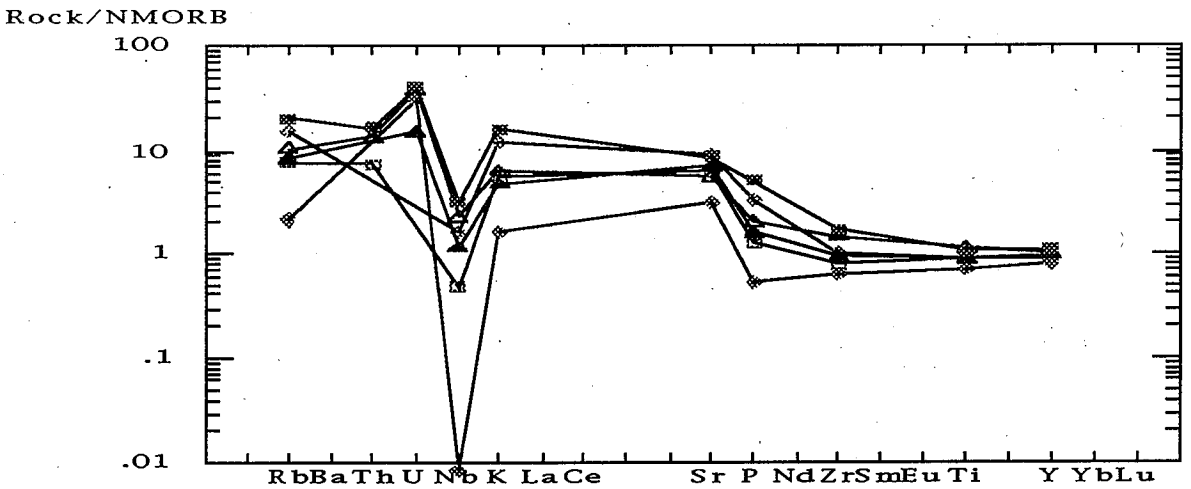


Figure 3. MORB-normalized trace element variation diagram for LILE-depleted HAOTs and the more enriched Calc-alkaline lavas.