# A petrographic and geochemical study of High Cascades Pliocene volcanics across the Klamath River, south-central Oregon

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## INTRODUCTION

Careful study of volcanic rocks from the High Cascades in south-central Oregon offers an opportunity to better understand both local and regional magmatic processes within this range. Subduction of the Juan de Fuca plate beneath the North American plate originally created the Cascades Range magmatic arc, and regional tendencies have greatly influenced its composition during the past 18 million years. Changes in converging plate velocities (Priest, 1990), accompanied by rotation of the southern portion of the arc (Wells, 1990) and the impingement of the Basin and Range extensional regime to the southeast (Guffanti and Weaver, 1988) produced extension throughout the southern portion of the range. This regional extension, compounded with thinning of the North American plate, initiated normal faulting and north-south trending grabens throughout the High Cascades (Guffanti and Weaver, 1988). Mantle-derived magma exploited these rifts, especially along the weaker boundary between ancient accreted magmatic arcs and the North American Archean craton (Hart and Carlson, 1987). This new stress direction thus changed the character of magmatism in the High Cascades by creating easier paths for magma to take on its way to the surface. Because of this opportunity for relatively rapid ascent, volcanism in the High Cascades includes basaltic and bimodal magmatism, in addition to arc-related, andesitic activity (Hart and Carlson, 1987).

To better understand these volcanic products, an investigation of a small section of the High Cascades between Mount McLoughlin and Mount Shasta was conducted through the W. M. Keck Foundation in Geology during summer, 1995. Eight square miles spanning across the Klamath River in south-central Oregon were mapped, and rock samples were collected for analysis. The main goals of this study include creating an accurate geologic map of the area, describing petrographic and geochemical variations within and between units, and suggesting trends of magma evolution. Processes creating these trends must also be considered within the larger tectonic setting of the High Cascades.

## VOLCANIC STRATIGRAPHY AND PETROGRAPHY

Field observations and K/Ar dating, supported by petrographic and geochemical analyses, were used to determine the local stratigraphy of the study area (Figure 1). Eight units were distinguished, although poor outcrop quality abundant vegetation often prevented thorough sampling of each. Despite these difficulties, the following units were named and described.

The oldest unit in the area is Boyle Ash Cone Pyroclastic Material. Exposures of this layer have been severely reworked by surficial processes, since parts of the unit appear to have remained uncovered for millions of years. Due to its well-cemented, almost lithified character, this unit lithologically approaches a conglomerate classification. Bright yellow matrix-like clumps of ash and lapilli hold together clasts which range in size from pebbles to small boulders. Both air fall and pyroclastic flow material may be present. Based on sample correlation between outcrops, the source of this material is the Boyle Ash Cone, located approximately two miles northwest of the most distal exposures of pyroclastic material. Samples were too heterogeneous and altered to be analyzed geochemically.

The next youngest stratigraphic unit is the Hayden Mountain Basaltic Andesite (HMBA). K/Ar data shows this unit to be 3.7 ± 0.1 Ma, the oldest lava flow in the area. Most samples of this unit are basaltic andesites, three have low enough $SiO_2$ to be considered basalts according to the Le Bas classification (Figure 2). Hand samples appear light gray and contain 5% olivine phenocrysts (1-2 mm) and 10% plagioclase, including 1-2 mm phenocrysts. Some of the olivines are altered to iddingsite. Glomeroporphyritic clumps of olivine and plagioclase occur as well, and few orthopyroxene phenocrysts (<1 mm) have been identified. Petrographically, HMBA contains 60-65% plagioclase phenocrysts, which are often zoned, indicating a change in equilibrium between solid and liquid phases at the time of crystallization.

Buck Mountain Basalt (BMB), dated at 2.8 ± 0.2 Ma, is the next unit overlying HMBA. Hand sample, geochemical and petrographic analyses of BMB reveals virtually identical chemistry to that of the less mafic HMBA. The contact between these units is therefore based on field relations, which were unfortunately further complicated by extensive faulting. Samples from BMB contain about 7% olivine, slightly more than those from HMBA. Petrography reveals plagioclase as the most abundant phenocryst, followed by olivine and phenocrysts of clinopyroxene.

The next youngest unit in the study area is Chase Mountain Basaltic Andesite (CMBA), dated at 2.5 ± 0.07 Ma. This unit is by far the most extensive in the area, occurring on both sides of the Klamath River and covering nearly everything east of it (Figure 1). Interestingly, olivine content seems to decrease gradually from northern to southern flows. Flows near the southern border of the area are closer to the unit's vent, Chase Mountain, which is located approximately one mile to the south. Northern flows are more mafic, containing 5% iddingsitized olivine phenocrysts (1-2 mm), while southern flows have less than 1% olivine. Glomeroporphyritic clumps of olivine and plagioclase (2 mm) occur frequently throughout CMBA. Orthopyroxene is rare in hand samples and does not exceed 1 mm. Plagioclase also plays an important role as the most abundant phenocryst in is unit. Like HMBA samples, CMBA contains zoned plagioclase, indicative of a shifting equilibrium at the time of crystallization.

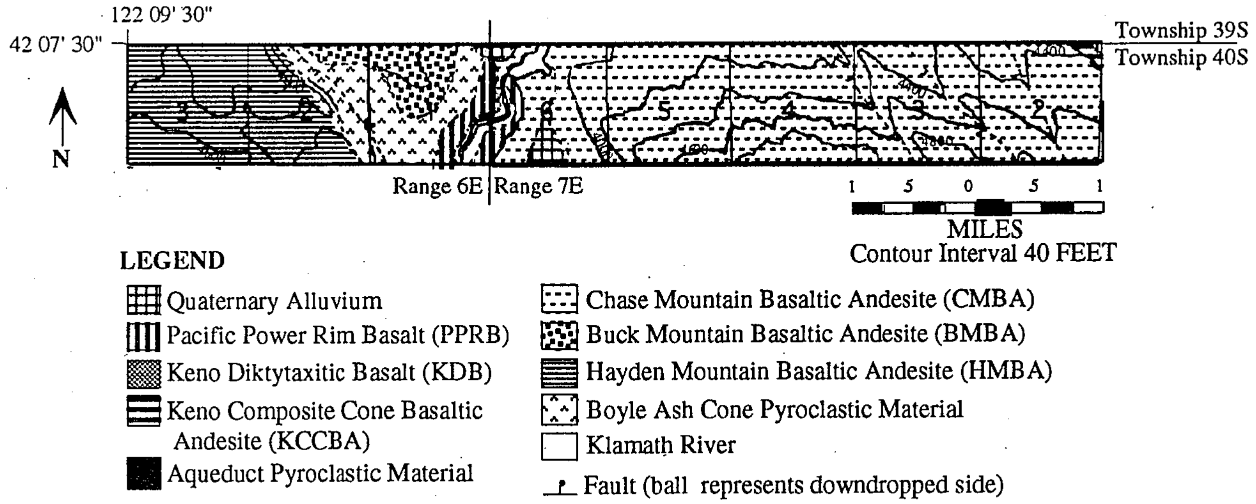
The Aqueduct Pyroclastic Material, outcropping on both sides of the Klamath River (shown as small black lines along the north-south trending stretch of the river in Figure 1), follows as the next youngest unit. Sandwiched between two flows, this pyroclastic unit contains both air fall and block-and-ash flow material within its nearly four meter thickness. Its age must fall between 2.5 ± 0.07 and 1.9 ± 0.3 Ma, the ages of underlying CMBA and overlying Pacific Power Rim Basalt flows. Given these confining ages, the source of these pyroclastics is likely the Aqueduct Basalt, an exogenous dome on the west side of the river, south of the area, which was dated at 2.4 ± 0.1 Ma.

In the farthest sixteenth of a mile of the northeast corner of the study area, (Figure 1), two units are exposed. The older is the Keno Composite Cone Basaltic Andesite, (KCCBA), a small flow from the cone approximately half a mile to the northwest. Like many of the basaltic andesites throughout the area, this unit is also difficult to distinguish. Hand samples are light gray with about 4% visible olivine. Thin sections show about 65% plagioclase as the most abundant phenocryst.

The second of the units in the far northeast corner of the study area is the Keno Diktytaxitic Basalt (KDB), a high-alumina olivine basalt (HAOT). Dated at 2.0 ± 0.3 Ma, this mafic unit is one of the youngest, despite its position relatively low in the river canyon exposures. The apparent discrepancy between its age and stratigraphic position compared to other units may be the result of inverted topography. KDB likely flowed downhill quickly into areas of lower topography because of relatively low viscosity, a flow characteristic common to basalts (Wilson 1989). The source of this unit was likely fissure eruptions, evidenced by faulting along the river throughout the extent of KDB. The abundant diktytaxitic plagioclase gives hand samples a sparkly appearance. Due to poor outcrop quality in the limited extent of KDB within the study area, no samples were collected for petrographic and geochemical analysis. Results from north of my section were used instead.

Appearing at the top of the stratigraphic column, Pacific Power Rim Basalt (PPRB), is the youngest lava, dated at 1.9 ± 0.3 Ma. It outcrops in a small northeast-southwest trending flow along both sides of the Klamath River. Dark in appearance, this unit contains nearly 6% olivine. In thin section, abundant plagioclase phenocrysts reveals a similar pattern as other flows in the study area. The source of this unit are likely the exogenous domes along the east side of the Klamath River, which match closely geochemically.

Figure 1. Map of study area



## GEOCHEMICAL ANALYSIS

Twenty-seven samples from HMBA, CMBA, BMB and PPRB were analyzed at Franklin and Marshall College using X-ray flourescence to determine major and trace elements, FeO titrations and loss on ignition. Data from additional samples of these units outside of the study area were also used to characterize KDB and KCCBA. The results reveal several interesting possibilities for magma evolution within each unit.

Three units can be classified as basaltic andesites according to the TAS classification established by Le Bas, et al., (1986), as shown in Figure 2. The remaining three are basalts, with KDB falling in the HAOT range of the calc-alkaline-tholeiitic plot. Beyond placing units in these compositional categories, geochemistry also provided evidence that fractional crystallization has affected the magma sources of the calc-alkaline units, (all except KDB). The minerals involved were likely the most abundant phenocrysts in each of these units: plagioclase ± olivine ± clinopyroxene ± titanomagnetite. Accordingly, the quantities of highly compatible elements that are easily incorporated into the crystal lattices of these minerals vary, in some cases illustrating liquid lines of descent of these units.

Plagioclase fractionation can be seen in Figure 3, a plot of Sr versus Mg. Sr, which commonly occupies the divalent cation position of plagioclase (Smith, 1983), shows increasing levels as Mg content increases in the calc-alkaline unit, CMBA. This trend suggests that early flows of CMBA may have included abundant amounts of plagioclase, which were segregated from the rest of the magma. As these phenocrysts formed, they incorporated constituent elements, such as Sr, into their structures, depleting the remaining melt of these elements. Later removal of plagioclase phenocrysts from the magma chamber created a shift in composition of the remaining magma. Similarly, since Mg increases with Sr, phenocrysts of olivine may have fractionally crystallized along with plagioclase. Other evidence suggesting that olivine was involved in fractional crystallization can be seen in Figure 4. This linearly decreasing trend of Ni versus Cr, two elements that commonly substitute for Mg in olivine crystals, is further evidence that this mineral was removed from the magma chamber, depleting the remaining melt of these compatible elements. Petrography also confirms this possibility, since relatively abundant percentages of both plagioclase and olivine exists in CMBA.

When considered in the context of a fractionally crystallizing magma chamber, the increase in mafic minerals further away from the vent may offer even more insight into the evolution of CMBA. If olivine and plagioclase were fractionally crystallizing out of the melt, then more mafic flows, containing greater amounts of these minerals, may represent older flows from Chase Mountain. Generally, early eruptions from volcanoes stay close to the source, gradually building a slope as additional flows continue to accumulate on its flanks. Later activity, flowing down these increased slopes, tend to reach greater distances from the vent before cooling and becoming too viscous to continue. Since evidence of fractional crystallization suggests that more mafic flows are actually older than more felsic ones, the apparent pattern of CMBA eruptions contrasts this general model. This dilemma may be at least partly resolved by considering that viscosity increases as flows become more felsic. Higher viscosity may have prevented later CMBA flows from reaching the distances of their mafic antecedents. Another hypothesis is that the amount of material erupted from Chase Mountain may have decreased in time, so that later flows lacked the volume to continue farther down the flanks. CMBA likely experienced both of these conditions.

Geochemical trends from other units also indicate that fractional crystallization influenced magma evolution. Similar to CMBA, plots of Cr versus Ni reveal that olivine was involved in this process to some degree in all units (Figure 4). Despite the obvious influence of fractional crystallization, however, the effects of other processes must also be considered. Evidence from a spider diagram (after Pearce, et al., 1977) presents the possibility that crustal contamination also took place (Figure 5). Troughs of Nb and Th levels indicate that magmas may have interacted with country rock before or during their ascent to the surface (Wilson, 1989). Representative samples from HMBA and BMB show dips for both of these elements, while the other calc-alkaline units only show dips for Nb. Still, the amount of variation within the geochemistry of all these units can not be totally accounted for by fractional crystallization and crustal contamination. PPRB, for example, as the youngest flow in the area, should be the most evolved. On the contrary, it falls on the less evolved end of the spectrum, near the HAOT (Figure 4). An explanation for this younger, more parental-like magma is that the chamber was recharged with mantle-derived material. Magma replenishment or magma mixing may be another important process in these units.

## CONCLUSIONS

Magma evolution throughout the area, therefore, likely involved complex combinations of fractional crystallization, crustal contamination and magma mixing. These processes may be considered in the context of the tectonic setting as well. The parental HAOT reflects the recent change in volcanism within the High Cascades, caused by regional extension. More felsic calc-alkaline units are typical of arc-activity, which often involves crustal contamination and fractional crystallization processes. Magma from these units likely ponded beneath thicker crustal blocks, continually erupting material that had been gradually evolving throughout the active life of the chamber.

Figure 2. Total Alkali vs. Silica Classification (after Le Bas, et al., 1986).

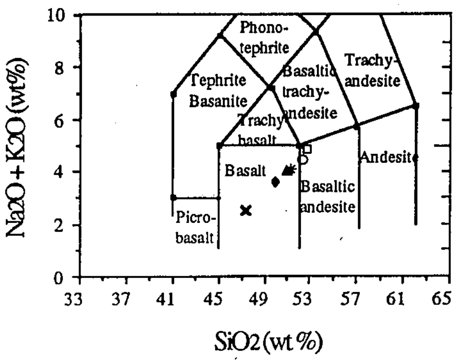


Figure 4. Ni vs. Cr

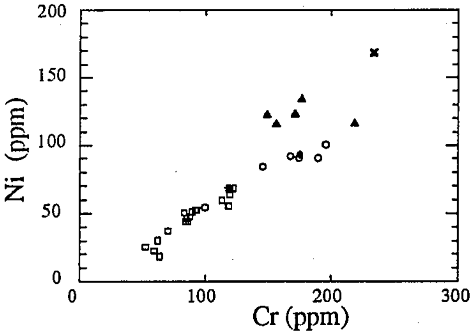
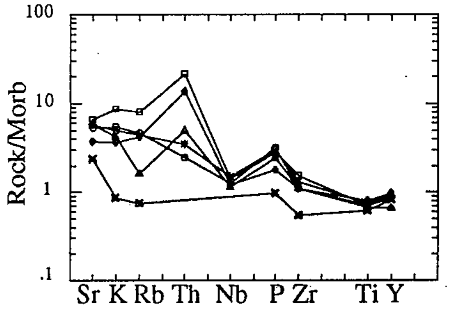


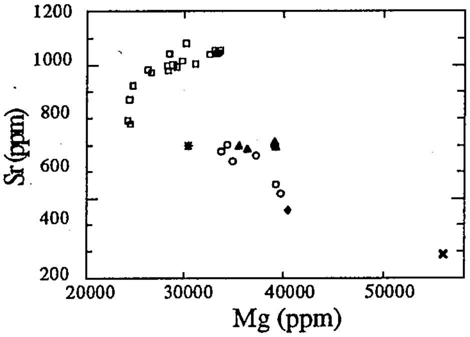
Figure 5. Spider Diagram (after Pearce, et al., 1977).



**Explanation of symbols:**

- ○ Hayden Mountain Basaltic Andesite (HMBA)
- ◆ Buck Mountain Basaltic (BMB)
- □ Chase Mountain Basaltic Andesite (CMBA)
- * Keno Composite Cone Basaltic Andesite (KCCBA)
- × Keno Diktytaxitic Basalt (KDB)
- ▲ Pacific Power Rim Basalt (PPRB)

Figure 3. Sr vs. Mg



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