THE VOLCANIC ROCKS OF MOUNT PERSIS: AN EOCENE CONTINENTAL ARC THAT CONTAINS ADAKITIC MAGMAS

Paper No. 154-14

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ABSTRACT

The volcanic rocks of Mount Persis (Tabor et al., 1993), western Cascades, Washington, consist of flows, with lesser tuff, tuff breccia, lahar deposits, and interbedded sedimentary rocks. Published ages from the Mt. Persis are Eocene (~38 to 47 Ma). Several USGS STATEMAP studies have provided new age and chemical data for this formation. New U-Pb LA-ICP-MS zircon ages from two Mt. Persis tuffs are 36 ± 2.3 Ma & 43.7 ± 1.0 Ma. Both tuffs contain Mesozoic and Precambrian age zircons. Compositions for 64 samples analyzed for whole rock major and trace element geochemistry range from basalt to rhyolite with most samples being andesite or dacite. Lower Si samples are magnesian while samples with high Si are ferroan. About two thirds of the Mt. Persis samples are metaluminous, while about one third are peraluminous. The peraluminous samples tend to have higher Si. Samples are medium-K calc-alkaline with lower Si values transitional to tholeiitic. 7 samples, however, are transitional to E-MORB and 12 other samples have Si, Sr, and Y that indicate they are adakitic. These adakitic rocks also have high Al and Na, and low Yb.

The geochemistry and U-Pb ages suggest the Mt. Persis originated from a continental magmatic arc source that spanned ~36-48 Ma. The high Si peraluminous samples and xenocrystic zircons suggest assimilation occurred as this magmatic system evolved. Mapping suggests that several intrusive centers occur for the Mt. Persis (including the 39-42 Ma Youngs Creek igneous complex and 47 Ma Fuller Mt. Plug). The adakitic and E-MORB affinities found in the Mt. Persis are rare in other ancestral Cascades magmatism of similar age. However, Eocene forearc magmatism that is interpreted to have formed by slab windows resulting from subducting ridges occurs through the Cordillera (e.g., 37-42 Ma Grays River volcanics). A combination of adakitic and enriched MORB magmas that exist with transitional tholeiitic-calc-alkaline magmatism occurs in arcs that sit above subducting oceanic ridges. We suggest that the volcanic rocks of the Mt. Persis formed in a continental arc setting; and, typical continental arc magmas of the Mt. Persis mixed with magma generated by a subducted oceanic ridge that may have been generated at the Kula-Farallon boundary.

INTRODUCTION

- du Bray and John (2011) suggest that the ancestral Cascades arc during the Eocene (45 to 36 Ma) was primarily located in Washington State, tholeiitic to calc-alkaline, and basaltic to andesitic. They suggest that the tectonic setting for the Eocene ancestral Cascades magmatism was a continental arc that was influenced by a slab window. However, they indicate that adakitic compositions are rare.
- Early to middle Eocene forearc volcanism occurred currently with the ancestral Cascades arc in Washington State (see Chan et al., 2012, for a review). These forearc magmas are interpreted to have compositional ranges from within-plate to mid-ocean ridge basalts and could have formed as a result of ridge subduction.
- The volcanic rocks of Mount Persis (Tabor et al., 1993, 2000) are arc rocks that may reveal a link between Eocene arc and forearc magmatism due to its mixture of arc and non-arc compositions.
- The volcanic rocks of Mount Persis (Tabor et al., 1993, 2000) consist of interbedded andesitic to basaltic flows with lesser andesitic to rhyolitic tuff, tuffaceous breccia, volcanic and tuffaceous sandstone and siltstone, lahar deposits, volcanic conglomerate, shale, siltstone, and coal.
- Tabor et al. (1993) assigned an Eocene age to the volcanic rocks of Mount Persis based on K-Ar hornblende age of *ca.* 38 Ma and an apatite fission-track age of *ca.* 47 Ma.

METHODS

- Samples for this project occurred during 5 U.S. Geological Survey (USGS) National Cooperative Geologic Mapping Program projects (Dragovich et al., 2009, 2010, 2011, 2012, 2013). Detailed methodology for geochemistry and U-Pb age dating can be found in these reports.
- Whole rock major and trace element geochemistry for 64 Mount Persis samples was completed using X-ray fluorescence and inductively coupled plasma source mass spectrometer at the GeoAnalytical Laboratory at Washington State University. See Knaack et al. (1994) and Johnson et al. (1991) for precision, accuracy, and methods.
- Zircons for this study were analyzed for U and Pb isotopes using laser ablation inductively coupled mass spectrometry (LA-ICP-MS) at the University of Alberta Radiogenic Isotope Facility (RIF). A full description of the analytical approach is reported in Simonetti and others (2005).

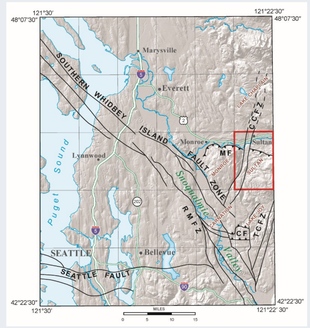

FIGURE 1

Regional tectonic map of the central Puget Lowland and Cascade foothills showing the Sultan 7.5-minute quadrangle in red (Dragovich et al., 2013). CCFZ = Cheery Creek fault zone; CF = Carnation fault; MF = Monroe fault; RMFZ = Rattlesnake Mountain fault zone; TCFZ = Tokul Creek fault zone. Current mapping projects the CCFZ north-northeast to the northernmost part of the Sultan quadrangle, and may project into the Lake Chaplain quadrangle. The TCFZ is similar to the CCFZ and likely a left-lateral fault zone conjugate to the Southern Whidbey Island fault zone.

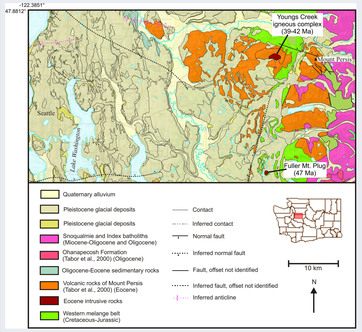

FIGURE 2

Simplified geologic map displaying the extent of the *ca.* 36-48 Ma volcanic rocks of Mount Persis (Tabor et al., 1993). Also displayed are Eocene intrusive rocks (i.e., Youngs Creek intrusive complex and Fuller Mountain Plug). Faults from figure 1 are omitted in order to simplify the map. Map created using the Washington State Department of Natural Resources Interactive Geological map (https://fortress.wa.gov/dnr/geology/?Theme=wigm)

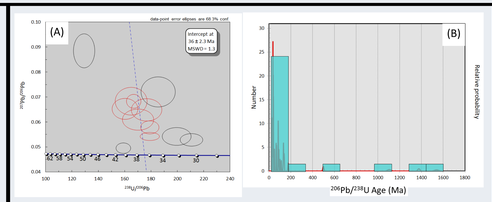

FIGURE 3

U-Pb zircon age data from a Mount Persis devitrified tuff in the Snoqualmie quadrangle (sample 08-55D). A) Concordia diagram. The 7 red error ellipses are used to calculate the intercept age. B) Relative probability density plot for 29 zircons. Note the Mesozoic and Precambrian age zircons. See Dragovich et al. (2009) for more details.

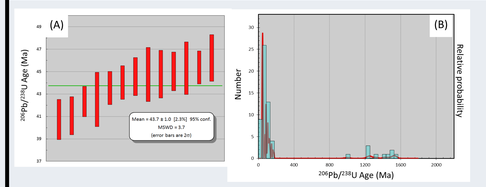

FIGURE 4

U-Pb zircon age data from a Mount Persis tuff in the Monroe quadrangle (sample 10-40Y). A) Weighted average diagram for 13 zircons from this sample. B) Relative probability density plot for 54 zircons from sample 10-40Y. Note the Mesozoic and Precambrian age zircons. See Dragovich et al. (2011) for more details.

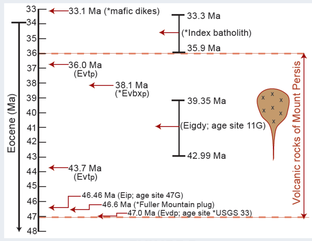

FIGURE 5

Summary of ages for the Mount Persis (Tabor et al., 1993; Dragovich et al., 2009, 2011, 2013). Also displayed are the ages for Eocene intrusive rocks (39-42 Ma Youngs Creek intrusive complex [11G], *ca.* 47 Ma Fuller Mountain Plug, and the *ca.* 46.5 Ma Drunken Charlie Lake intrusive complex [47G]) that are interpreted to be intrusive centers for the Mount Persis (Tabor et al., 1993; Dragovich et al., 2013). Also displayed are the ages for the Index batholith - which intrudes the volcanic rocks of Mount Persis (Tabor et al., 1993, and references within).

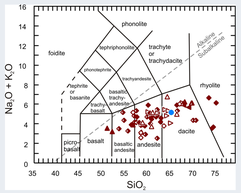

FIGURE 6

Total alkali vs. silica diagram for Mount Persis samples (in red), intrusive rocks (red diamonds), and a granodiorite from the Youngs Creek intrusive complex (in blue) (La Maître et al., 2002).

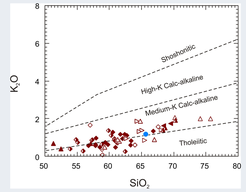

FIGURE 7

K_2O vs. SiO_2 diagram for Mount Persis samples (in red), intrusive rocks (red diamonds), and a granodiorite from the Youngs Creek intrusive complex (in blue). K-fields from Le Maître et al. (2002) shoshonitic field from Rollinson (1993).

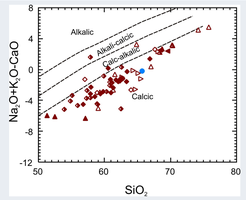

FIGURE 8

$Na_2O + K_2O$ - CaO vs. SiO_2 diagram for Mount Persis samples (in red), intrusive rocks (red diamonds), and a granodiorite from the Youngs Creek intrusive complex (in blue) (Frost et al., 2001).

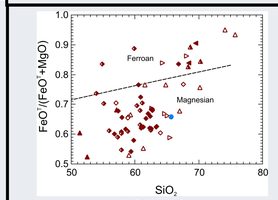

FIGURE 9

$FeO^T/ FeO^T + MgO)$ vs. SiO_2 diagram for Mount Persis samples (in red), intrusive rocks (red diamonds), and a granodiorite from the Youngs Creek intrusive complex (in blue) (Frost et al., 2001). FeO^T = FeO total.

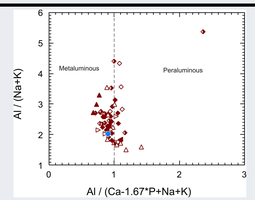

FIGURE 10

Molecular Al /(Na + K) vs. Al/(Ca - 1.67 P + Na + K) diagram for Mount Persis samples (in red) and a granodiorite from the Youngs Creek intrusive complex (in blue) (Zen, 1988; Frost et al., 2001).

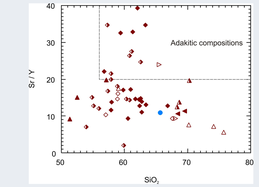

FIGURE 11

Sr/Y vs. SiO_2 diagram for Mount Persis samples (in red), intrusive rocks (red diamonds), and a granodiorite from the Youngs Creek intrusive complex (in blue). Field for adakitic compositions defined by Richards & Kerrich (2007).

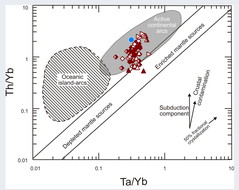

FIGURE 12

Th/Yb vs. Ta/Yb diagram for Mount Persis samples (in red), intrusive rocks (red diamonds), and a granodiorite from the Youngs Creek intrusive complex (in blue) (Pearce, 1982).

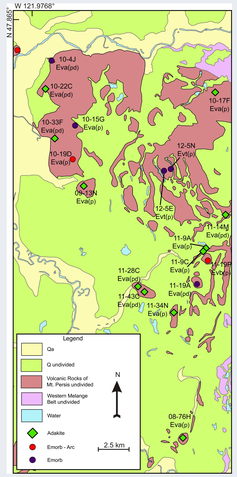

FIGURE 13

Geologic map displaying the distribution of the adakitic, enriched mid-ocean ridge basalt (E-MORB), and transitional E-MORB & calc-alkaline geochemical affinities.

DISCUSSION

- Ages for the Mt. Persis are Eocene and range between 36 - 47 Ma (Fig. 3, 4, & 5) (Tabor et al., 1993; Dragovich et al., 2009 & 2011). Mount Persis tuffs contain Mesozoic and Precambrian age zircons (Fig. 3 & 4).
- 39-42 Ma Youngs Creek intrusive complex, *ca.* 47 Ma Fuller Mountain Plug, and the *ca.* 46.5 Ma Drunken Charlie Lake intrusive complex are intrusive rocks that overlap the Mount Persis in age (Fig. 5) (Tabor et al., 1993; Dragovich et al., 2013).
- Mount Persis samples are primarily andesite to dacite, tholeiitic to medium-K calc-alkaline, calcic, magnesian, and metaluminous (Fig. 6 to 10); however, they are range from basalt to rhyolite, are transitional to ferroan, and include peraluminous samples (Fig. 6, 9, 10)
- Although only a few samples were analyzed, the Youngs Creek and Drunken Charlie Lake intrusive centers are geochemically similar to the Mount Persis (Fig. 5 - 12).
- 12 Mount Persis samples have adakitic compositions (Fig. 11). These samples also have high SiO_2, Al_2O_3, Na_2O, & Sr and low Y & Yb.
- The Mount Persis samples have elevated Th/Yb, and Ta/Yb ratios (Fig. 12). 2 samples plot in the mantle array on figure 12 while 5 others are transitional between mantle and arc affinities.

CONCLUSIONS

- The volcanic rocks of Mount Persis are the eruptive product of an Eocene continental arc that spanned between 36 & 47 Ma (Fig. 3 - 12).
- Based on age and geochemical affinities we suggest the Eocene Fuller Mountain Plug, Youngs Creek intrusive complex, and Drunken Charlie Lake intrusive complex are intrusive centers for the volcanic rocks of Mount Persis (Fig. 4 - 12).
- Mesozoic and Precambrian age xenocrystic zircons from two tuffs (Fig. 3 & 4) and peraluminous geochemical affinities in samples with higher SiO_2 (Fig. 10) suggest assimilation occurred as this magmatic system evolved.
- The adakitic and E-MORB geochemical affinities in arc magmas can be produced by slab windows which resulted from subducting oceanic ridges (Defant & Drummond, 1990; Thorkelson & Breitsprecher, 2005). The adakitic and E-MORB affinities in the Mt. Persis (Fig. 11 & 12) are widely distributed (Fig. 13) and suggested to be the product of this Eocene continental arc positioned above or near a slab window (Thorkelson & Breitsprecher, 2005).
- Adakitic and E-MORB affinities found in the Mt. Persis are rare in other ancestral Cascades magmatism of similar age (du Bray and John, 2011); however, the 37 - 42 Ma Grays River volcanics have been interpreted to represent forearc magmatism generated by a slab window. These two magmatic units may have formed from the same ridge subduction event.

SELECTED REFERENCES

- Chan, C.F., Tepper, J.H., Nelson, B.K., 2012, Petrology of the Grays River volcanics, southwest Washington: plume-influenced slab window magmatism in the Cascadia forearc: Geol. Soc. Am. Bull., v. 124, p. 1324-1338.
- Dragovich et al., 2009, Geologic map of the Snoqualmie 7.5-minute quadrangle, King County, Washington: Wa. Div. of Geo. & Earth Res., Geo. Map GM-75,, 2 sheets, 35 p.
- Dragovich et al., 2010, Geologic map of the Carnation 7.5-minute quadrangle, King County, Washington: Wa. Div. of Geo. & Earth Res., OFR 2010-01, 1 sheet, 21 p.
- Dragovich et al., 2011, Geologic map of the Monroe 7.5-minute quadrangle, King & Snohomish County Washington: Wa. Div. of Geo. & Earth Res., OFR 2011-01, 1 sheet, 24 p.
- Dragovich et al., 2012, Geologic map of the Lake Joy 7.5-minute quadrangle, King County, Washington: Wa. Div. of Geo. & Earth Res., Geo. Map Ser. 2012-01, 2 sheets, 79 p.
- Dragovich et al., 2013, Geologic map of the Sultan 7.5-minute quadrangle, King & Snohomish county, Washington : Wa. Div. of Geo. & Earth Res., Geo. Map Ser. 2013-0X, 2 sheets, in print.
- du Bray, E.A., John, D.A., 2011, Petrologic, tectonic, and metallogenic evolution of the Ancestral Cascades magmatic arc, Washington, Oregon, and northern California: Geosphere, v. 7, p. 1102-1133.
- Frost et al., 2001, A geochemical classification for granitic rocks: J. Petrol., v. 42, p. 2033-2048.
- Richards, J.P., Kerrich, R., 2007, Adakite-like rocks: their diverse origins and questionable role in metallogenesis: Econ. Geol., v. 102, p. 537-576.
- Tabor, R.W., et al., 1993, Geologic map of the Skykomish River 30- by 60 minute quadrangle, Washington: USGS, Map I-1963, 1 sheet, 67 p.
- Thorkelson, D.J., Breitsprecher, K., 2005, Partial melting of slab window margins: genesis of adakitic and non-adakitic magmas: Lithos, v. 79, p. 25-41.

ACKNOWLEDGEMENTS

This research was funded in part by the USGS National Cooperative Geologic Mapping Program under awards no. 08HQAG0104, G09AC00178, G10AC00363, G11AC20236, & G12AC20234. We would like to thank the numerous people that helped the authors conduct the field research and interpretations for these funded studies. Their names can be found as coauthors in Dragovich et al. (2009, 2010, 2011, 2012, & 2013).