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# Are Cenozoic topaz rhyolites the erupted equivalents of Proterozoic rapakivi granites? Examples from the western United States and Finland

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## Abstract

Eruptions of topaz rhyolites are a distinctive part of the late Cenozoic magmatic history of western North America. As many as 30 different eruptive centers have been identified in the western United States that range in age from 50 to 0.06 Ma. These rhyolite lavas are characteristically enriched in fluorine (0.2 to 2 wt.% in glass) and lithophile trace elements, such as Be, Li, Rb, Cs, Ga, Y, Nb, and Ta. REE patterns are typically flat with large negative Eu anomalies; negative Nb–Ta anomalies are small or nonexistent; and F/Cl ratios in glasses are high (>3). These features, together with high Fe/Mg ratios and usually low $fO_2$, set them apart from subduction-related (I-type) silicic rocks. The rhyolites are metaluminous to only slightly peraluminous, lack indicator minerals of strongly peraluminous magmas, and have low P and B contents; these features set them apart from S-type silicic magmas. Instead, topaz rhyolites have the major and trace element, mineralogic, and isotopic characteristics of aluminous A-type or within-plate granites. Topaz rhyolites were formed during regional extension, lithospheric thinning, and high heat flow.

Topaz rhyolites of the western United States crystallized under subsolvus conditions, and have quartz, sanidine, and Na-plagioclase as the principal phenocrysts. Fluorite is a common magmatic accessory, but magmatic topaz occurs only in a few complexes; both are mineralogical indicators of F-enrichment. Many also crystallized at relatively low $fO_2$ (near QFM) and contain mafic silicate minerals with high Fe/(Fe+Mg) ratios. Some crystallized at higher oxygen fugacities and are dominated by magnetite and have titanite as an accessory mineral. Post-eruption vapor-phase minerals include topaz, garnet, red Fe–Mn-rich beryl, bixbyite, pseudobrookite, and hematite. They are genetically related to deposits of Be, Mo, F, U, and Sn. Topaz rhyolites erupted contemporaneously with a variety of other igneous rocks, but most typically they form bimodal associations with basalt or basaltic andesite and are unrelated to large collapse calderas.

In their composition and mineralogy, topaz rhyolites are similar to the evolved members of rapakivi granite complexes, especially those of Proterozoic age in southern Finland. This suggests similarity in origin and lessons learned from these rocks may help us better understand the origins of their more ancient counterparts. For example, all topaz rhyolites in western North America seem to be intrinsically related to extension following a regional period of subduction-related volcanism. Cratonized Precambrian crust is found beneath almost all of them as well. Trace element models, Sr–Nd isotopic data, and geologic associations indicate that topaz rhyolites probably form by fractional crystallization of silicic magma which originated by small degrees of melting of hybridized continental crust containing a significant juvenile mantle component not derived from a subduction zone (i.e., intrusions of within-plate mafic magma). The Sr and Nd isotopic compositions of the topaz rhyolites lie between the fields of contemporaneous mafic magmas and older calc-alkaline dacites and rhyolites. Intraplate mafic magmas and their derivatives appear

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to have lodged in the crust and were then re-melted by subsequent injections of mafic magma. In turn, the mafic mantle-derived magma probably formed as a result of decompression related to lithospheric extension *or* to convective-flow driven by the foundering of a subducting lithospheric plate. Although significant uncertainty remains, we suggest that topaz rhyolites (and by extension rapakivi granites) are probably not simply melts of mid-crustal granodiorites, nor are they derived solely from felsic crust that was previously dehydrated or from which melt had been extracted as proposed in earlier papers.

*Keywords:* Topaz rhyolite; Cenozoic; Rapakivi granite; Proterozoic; Fluorine; A-type; Anorogenic

## 1. Introduction

Topaz in rhyolitic lavas was first discovered in 1859 in western Utah and reported in the scientific literature by Simpson (1876). Since then, topaz-bearing rhyolitic lavas have been identified in much of western United States (Christiansen et al., 1983), Mexico (Huspeni et al., 1984), the Yukon Territory of Canada (Sinclair, 1986), eastern Russia and Mongolia (Kovalenko and Kovalenko, 1984). Topaz-bearing rhyolite dikes of Proterozoic age have also been found in southern Finland (Haapala, 1977) and central Arizona (Kortemeier and Burt, 1988). Christiansen et al. (1986) concluded that topaz rhyolite lavas from the western United States are generally similar to some A-type granites. This report summarizes the characteristics of Cenozoic topaz rhyolites–emphasizing new data from the Wah Wah Mountains of southwestern Utah–and compares them to Proterozoic rapakivi granites of the Fennoscandian shield (Fig. 1). Southern Finland is the type locality of these unique anorogenic granitic rocks, which Haapala and Rämö (1992) have redefined as A-type granites with rapakivi texture. Once the similarities between Cenozoic topaz rhyolites and Proterozoic rapakivi granites are clear, we consider a new model for the origin of topaz rhyolites and its implications for the petrogenesis of rapakivi granites in particular and A-type granites in general.

## 2. Methods of study

New geochemical data in this paper are presented for rhyolite lavas from in and near the Wah Wah Mountains of southwestern Utah (Fig. 2). Major and trace element compositions were collected by X-ray fluorescence spectrometry at Brigham Young University. Analyses of international materials for 31 elements can be found at http://www.geology.byu.edu/faculty/ehc/. Elemental and isotopic compositions of other topaz rhyolites and for Finnish rapakivi granites are taken from the references cited below.

New Sr, Nd, and Pb isotope compositions were measured on a GV Instruments Sector 54 thermal ionization mass spectrometer (TIMS) at the University of Wisconsin–Madison Radiogenic Isotope Laboratory following standard procedures (e.g., Johnson and Thompson, 1991). Samples were crushed in a steel jaw crusher and powdered in an agate ball mill. For Sr and Nd, 50 mg aliquots of whole-rock powders were spiked with $^{84}$Sr- and $^{150}$Nd-enriched tracers and dissolved in a mixture of HF and $HNO_3$, the elements were then separated using standard ion-exchange chromatography. Total procedural blanks were $<0.1$ ng for both Sr and Nd, which are negligible. For Pb isotope ratios, 100 mg aliquots of whole-rock powder were dissolved in a mixture of HF and $HNO_3$, and Pb was separated using HBr and HCl on an ion-exchange column. Total procedural blanks for Pb were also negligible at $<2$ ng. Both Sr and Nd isotope compositions were exponentially corrected for mass fractionation using $^{86}Sr/^{88}Sr=0.1194$ and $^{146}Nd/^{144}Nd=0.7219$, respectively. Within-run errors in measured $^{87}Sr/^{86}Sr$ ratios for dynamic analyses are determined as ±2 standard error (2SE) using $n=120$ (number of measured ratios). The $^{87}Sr/^{86}Sr$ ratio measured for NBS-987 during this study was $0.710265\pm8$ (2SE, $n=13$). Neodymium was measured as $NdO^+$ and is presented as εNd values relative to present day CHUR, taken to be equal to BCR-1, measured during the analytical session as $0.512636\pm5$ (2SE). Within-run errors in measured $^{143}Nd/^{144}Nd$ ratios for dynamic analyses are reported as 2SE where $n=150$ (number of measured ratios). Twelve analyses of an internal Ames Nd standard yielded a $^{143}Nd/^{144}Nd$ ratio and precision of $0.511977\pm3$ (2SE). Lead isotope ratios were corrected for mass fractionation by +0.14% per atomic mass unit based on fourteen analyses of NBS-981 (±0.005%; 2SE) and NBS-982 (±0.008%; 2SE) standards.

## 3. Distribution and ages

### *3.1. Distribution of topaz rhyolites in western United States*

Topaz rhyolites are widespread in western North America (Fig. 1) and have been found as far north as