

CHEMICAL AND THERMAL EVOLUTION OF THE
TWIN PEAKS MAGMA SYSTEM, WEST CENTRAL UTAH

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ABSTRACT

A greater understanding of the evolution of shallow silicic magma systems may help interpret the thermal structure of young systems associated with geothermal resources. The Twin Peaks volcanic center of West-Central Utah is a small scale shallow silicic magma system which produced four cubic kilometers of exposed volcanics. Chemical modeling of the system's evolution indicates that two pulses of magma gave rise to two separate differentiation sequences, spanning periods of 2.7 to 2.5 m.y. and 2.43 to 2.35 m.y. A sustained heat influx from below is required to maintain the system above its solidus for periods exceeding 50,000 years. The resulting thermal gradient in the magma chamber gives rise to liquid-state differentiation which produces increasingly pronounced chemical gradients in a stagnant roof zone above the convecting bulk of the magma. A distinct pattern of chemical change, characterized by increases in SiO₂, heavy rare earths, H₂O, Na₂O, and highly charged cations, and decreases in FeO, MgO, CaO, K₂O, and light rare earth elements, results. The degree and rate of liquid-state differentiation may indicate the relative magnitude of heat flux from below, and whether heat input is continuing. Chemical changes over the first sequence, spanning about 200,000 years, was dominated by liquid-state differentiation, indicating sustained heat input. The second sequence spanned less than 100,000 years and liquid-state differentiation was considerably less pronounced, suggesting a diminishing heat influx.

Introduction

Shallow silicic magma systems are of interest because of their frequent association with geothermal resources. The Twin Peaks silicic volcanic center of west-central Utah is located within twenty-five kilometers of three known geothermal resource areas (KGRA's) including the Roosevelt Hot Springs KGRA twenty kilometers to the south. Because of this proximity and the relatively young age of the rhyolites, detailed studies of the gravity and heat flow (Carrier and Chapman, 1980), the petrology and geochemistry (Crecraft et al., 1979), and geochronology (Evans et al., 1980) have been conducted in order to: 1) determine if the Twin

Fig. 1 Generalized map of the Twin Peaks area, Utah.

Peaks volcanism is related to these KGRA's, 2) determine the size and depth of the associated magma chamber, and 3) to delineate the chemical and thermal evolution of a typical shallow level silicic magma system. This paper concerns the chemical evolution of the Twin Peaks system and compliments the study by Carrier and Chapman (1980) of the gravity and heat flow.

Geological Setting

The Twin Peaks area is located along the eastern margin of the Basin and Range Province in a region characterized by episodic basalt-rhyolite volcanism. Silicic volcanism over the last 6 m.y. has defined a generally south trending migration from the Thomas Range (6 m.y.) and Honeycomb Hills (4.7 m.y.) 120 kilometers north of the Twin Peaks area, southward to Smelter Knolls (3.4 m.y.), and to the Twin Peaks Domes (2.7 to 2.4 m.y.). Subsequent silicic volcanism

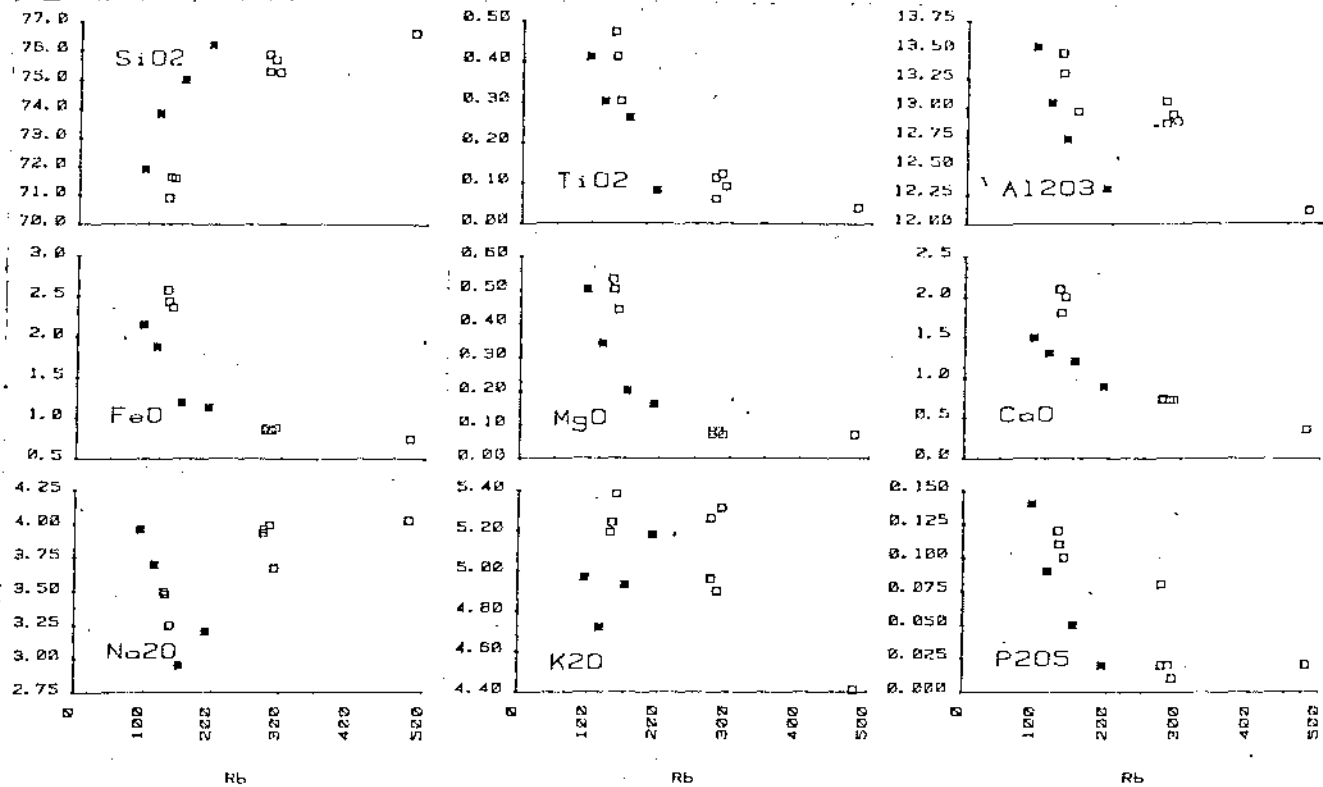


Fig. 2 Major element concentrations in the Twin Peaks rhyolites. Open squares - early sequence; closed squares - late sequence.

occurred at Roosevelt Hot Springs (0.8 - 0.5 m.y.), 20 kilometers to the south, and then at White Mountain (0.4 m.y.) 40 kilometers northeast of the Twin Peaks area (Nash et al., 1978). Generally contemporaneous basaltic volcanism has continued to within the last thousand years.

Petrology and Geochronology of the Twin Peaks Rhyolites

Silicic volcanism at Twin Peaks spanned a period from 2.74 to 2.35 m.y. and produced 4 cubic kilometers of exposed rhyolites, obsidians, and volcanoclastics (Evans et al., 1980). The distribution of volcanic rocks and their ages are given in figure 1. The *Coyote Hills rhyolite* (2.7 m.y.) was the earliest unit erupted and has an exposed volume of one cubic kilometer. This unit is the least silicic rhyolite (71% SiO₂). The *Cudahy Mine Unit* consists of two cubic kilometers of obsidians, felsites, and volcanoclastics. Obsidians have been dated at 2.4 to 2.6 m.y., although the chemical homogeneity suggests these are a single unit. Obsidians are high in silica (75.6% SiO₂). A tuff encountered in a drill hole about ten kilometers south of South Twin Peak is chemically coherent with, and believed to be cogenetic with, the Twin Peaks volcanics. It has 76.6% SiO₂ and is considered to be a highly evolved member of the Cudahy Mine Unit. The *North Twin Peak rhyolite* has been dated at 2.43 and 2.35 m.y. and has an exposed

volume of 0.4 cubic kilometers. This unit is chemically similar to the Coyote Hills rhyolite. The *Mid Dome rhyolite* located between North and South Twin Peaks has a total exposed volume of 7x10⁻⁴ cubic kilometers. It is chemically intermediate to North and South Twin Peak rhyolites. The *South Twin Peak rhyolite* comprises the 0.3 cubic kilometers of South Twin Peak and has been dated at 2.35 m.y. It contains 76.18% SiO₂.

Whole Rock Chemistry

Major element analyses are plotted against Rb in Fig. 2. Rubidium was selected because 1) it is determined with good precision and 2) for a given differentiation sequence, it is enriched by both crystal settling and liquid-state differentiation, and thus indicates the relative degree of evolution. Two generally parallel but distinct trends are apparent. The open squares represent the early trend of increasing silica (2.7 to 2.5 m.y.), consisting of the Coyote Hills, Cudahy Mine, and core samples. The closed squares represent the later trend (2.43 to 2.35 m.y.), consisting of the North Twin Peak, Mid Dome, and South Twin Peak rhyolites. Distinct but generally parallel paths are also indicated by trace elements (fig. 3), and further suggest similar mechanisms of control for each sequence. Specific differences, however, such as Lu, Mn, Y, Nb, and particularly the alkalis, attest to there

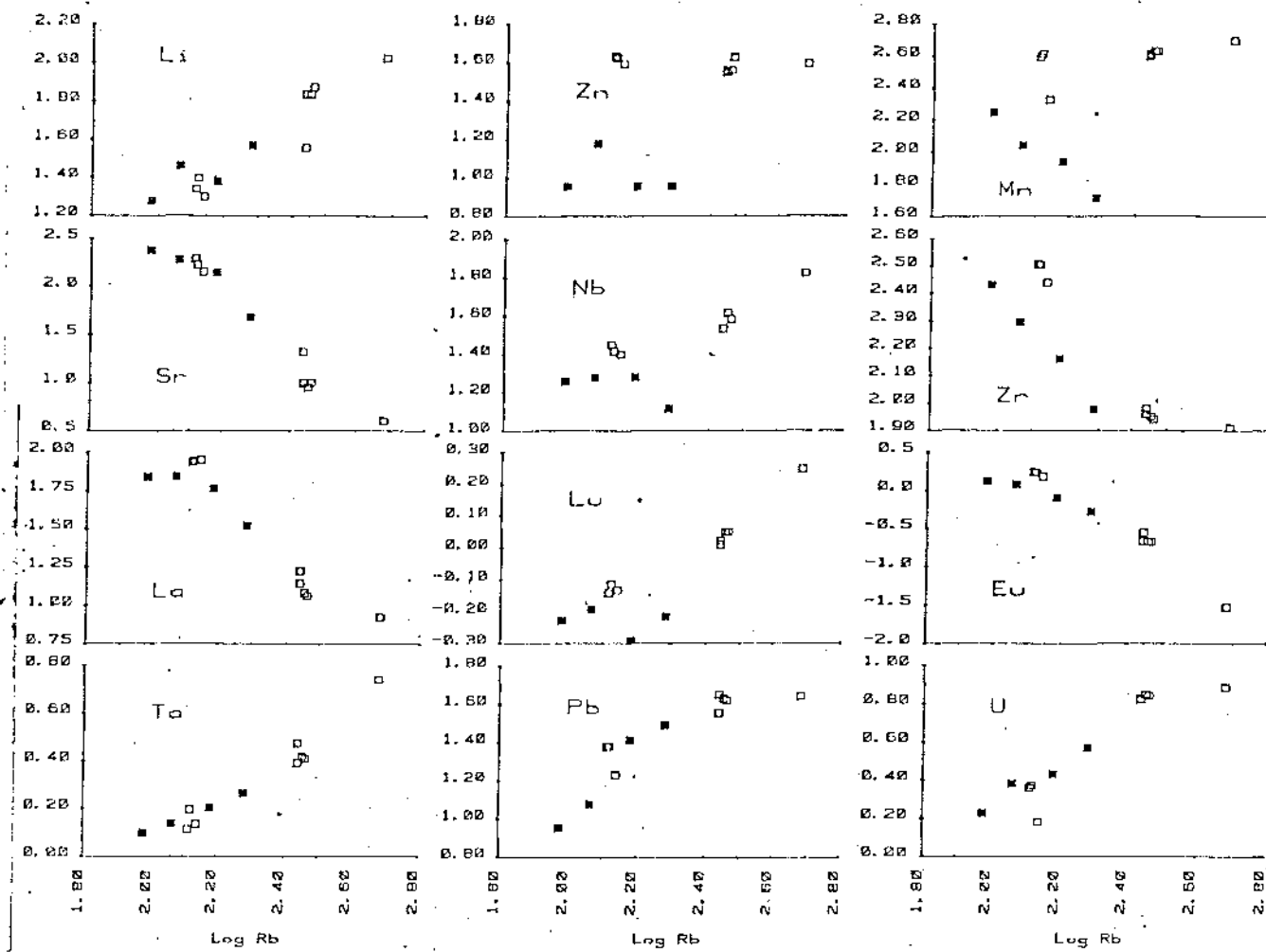


Fig. 3 Log-log plot of trace elements in the Twin Peaks rhyolite.

being contrasting mechanisms of evolution. For example in the early sequence, Na_2O increases while K_2O decreases, whereas the later sequence exhibits opposing trends.

Evolution of the Twin Peaks System

It has been demonstrated that the pattern of chemical changes between the Coyote Hills rhyolite and Cudahy Mine Unit results primarily from liquid-state differentiation in a stagnant roof zone, and that the chemical zonation in this roof zone forms in response to a thermal gradient. The density gradient resulting from the chemical zonation (primarily of water) at Twin Peaks greatly exceeds the density gradient required to arrest thermal convection. The Coyote Hills rhyolite is believed to represent the initial homogeneous and convecting magma as it was emplaced at a shallow level at a temperature of 875°C . As soon as the thermal gradient established a small but stabilizing gradient subjacent to the roof, stagnation would have permitted development of a growing zone of increasingly pronounced compositional gradients, fed by the convecting bulk of magma beneath this

zone. The tuff, represented by the core sample, is believed to have been tapped from the very top of the magma chamber prior to the eruption of the slightly deeper, less evolved obsidians. Thus, the zonation in the roof zone immediately prior to eruption of the Cudahy Mine Unit is indicated by the enrichment pattern in figure 4, determined by the concentrations of elements in the core divided by concentrations in the obsidian samples.

This pattern is very similar to the enrichment pattern for the Bishop Tuff (Hildreth, 1979) due solely to liquid state differentiation. Some characteristic features of liquid state differentiation, which are not explicable by established mechanisms such as crystal settling, are the roofward increase in heavy rare earth elements (HREE) and decrease in light rare earths (LREE), and the increase in Na_2O and decrease in K_2O . Enrichment of highly charged cations such as Th, Ta, U, and Pb and a pronounced enrichment of water and volatiles are also characteristic.

Using the pattern in figure 4 as a model for liquid state differentiation at Twin Peaks, the

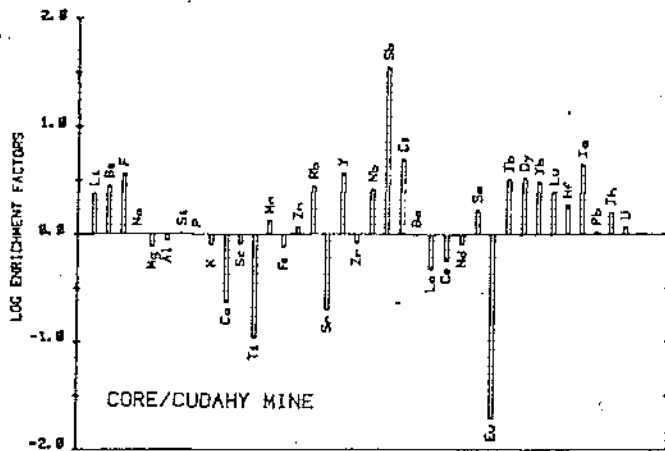


Fig. 4 Enrichment factors pattern of chemical-zonation in the Twin Peaks magma chamber.

Changes from Coyote Hills to Cudahy Mine magmas can be modeled as resulting from liquid state differentiation, with only minor crystal settling effects. Heat flow calculations predict that a magma chamber of the size and depth modeled by Carrier and Chapman (1980) would solidify in 50,000 years. Thus, a sustained heat input, probably by underplating of basalt, was necessary to maintain the heat and the thermal gradient necessary to maintain liquid state differentiation over the 200,000 year interval spanned by these two eruptions.

The second sequence initiated with the extrusion of the North Twin Peak rhyolite. This rhyolite is believed to have been a new pulse of magma from a common, lower crustal source, which then gave rise to the second differentiation sequence. Quantitative modeling indicates the chemical changes exhibited over the first part of the sequence (North Twin Peak to Mid Dome rhyolite) were produced by settling of 10% plagioclase, 3% sanidine, 2.5% augite, 1% magnetite, and .025% zircon, and only very small liquid-state effects. The dominance of crystal settling results largely from the more abundant and much larger crystals in the second sequence. The iron-titanium oxide temperature for the Mid Dome rhyolite is only 10° less than the temperature for the Coyote Hills rhyolite, erupted about 300,000 years earlier, and substantiates the need for sustained heat input. The evolution to the South Twin Peak magma again indicates liquid-state differentiation effects, which however, are less extensive than in the early sequence, and are modified by continued crystal settling. The overall shorter interval of differentiation of the second sequence and the smaller degree of liquid state differentiation indicate that the heat input into the system was considerably reduced during the second sequence.

Conclusions

Shallow silicic systems frequently give rise to one or more cycles of increasingly evolved

eruptions, which typically span periods on the order of several hundred thousand years. In large systems such as Valles, N.M. or Long Valley, Ca., these may culminate in large scale ash eruptions. In small systems such as at Twin Peaks, large volume ash deposits may be lacking. Sustained heat input is necessary to maintain these systems, and produces a very characteristic pattern of chemical change indicated in figure 4. These changes can be recognized in successive extrusions of an evolving system. The degree and rate of development of chemical gradients may indicate the relative magnitude of heat flux into the system and whether or not development or maintenance of these gradients (and therefore heat input from a deeper level) is continuing.

References

- Carrier, D. L., and Chapman, D. S., 1980, Gravity and thermal models of the Twin Peaks magma system, West-central Utah, this volume.
- Creecraft, H. R., Nash, W. P., Evans, S. H., Jr., 1979, Chemical evolution and development of compositional gradients in a silicic magma, Geol. Soc. Am. Abs. Prog. v. 11, no. 7, p. 406.
- Evans, S. H., Jr., Creecraft, H. R., and Nash, W. P., 1980, K/Ar ages of silicic volcanism in the Twin Peaks/Cove Creek Dome area, Southwestern Utah, Isochron West, 1980 (in press).
- Hildreth, E. W., 1979, The Bishop Tuff: evidence for the origin of compositional zonation in silicic magma chambers, In Ash Flow tuffs, Geol. Soc. Amer. Spec. Paper no. 180, p. 43-76.
- Nash, W. P., Turley, C., Petersen, J., and Brown, F. H., 1978, Volcanism and the regional assessment of geothermal potential in west-central Utah, Geothermal Resources Council, Transactions, v. 2, p. 475-477.