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RHYOLITES IN THE GILLIES HILL-WOODTICK HILL AREA

BEAVER COUNTY, UTAH

by

S. H. Evans, Jr., and T. A. Steven

Abstract

The rhyolite of Gillies Hill forms a cluster of rounded hills between Beaver basin and Cove Fort basin in southwest-central Utah. These rocks were erupted as a series of viscous lava flows, volcanic domes, and minor pyroclastic rocks from centers localized along and near the main fault separating the volcanic rocks in the Marysvale volcanic field to the east from the batholithic intrusive rocks in the Mineral Mountains to the west. Faulting began some time in middle Miocene time before eruption of the rhyolite of Gillies Hill, and continued episodically to Pleistocene time. Potassium-argon dating indicates that the rhyolite of Gillies Hill formed from a rapid sequence of eruptions about 9.1 m.y. ago.

The rhyolite of Gillies Hill comprises an older high-silica suite (SiO_2>75 percent) consisting of numerous short stubby flows, and a younger low-silica suite ($SiO_2 \cong 70$ percent) represented by a single very large volcanic dome. The high-silica suite is believed to have formed by eruptions from the top of a compositionally zoned magma chamber. The younger low-silica suite either came from a separate magma chamber, or from a significantly different level within the same magma chamber. The close proximity of sources for both suites suggests eruptions from different levels within a single source chamber, perhaps from different vertically stacked convection cells as has recently been proposed by McBirney and Noyes (1979), McBirney (1980), Chen and Turner (1980), Irvine (1980), and Rice (1981).

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An assemblage of rhyolite lava flows, volcanic domes, and minor pyroclastic rocks, here called the rhyolite of Gillies Hill, forms a cluster of rounded hills adjacent to Interstate Highway 15 at the north end of Beaver basin in southwest-central Utah (figs. 1 and 2). These rocks belong to the silicic end member of the bimodal basalt-rhyolite suite that was errupted widely in the Basin-Range province during later Cenozoic time (Christiansen and Lipman, 1972). The rhyolite of Gillies Hill has been virtually ignored

Figures 1 and 2.--NEAR HERE

until quite recently, and indeed, the State geologic map (Hintze, 1963) shows the area to be underlain largely by Tertiary basin-fill sedimentary rocks. Haugh (1978) published a reconnaissance geologic map and report of the area in which he recognized the rhyolites as remnants of lava flows and domes of Cenozoic age and called attention to their presence. The present authors investigated the area independently; Evans studied the geochemistry and geochronology of the rhyolites as part of a research program at the University of Utah focussing on geothermal energy, whereas Steven mapped the area geologically as part of a regional study by the U.S. Geological Survey to assess the mineral resource potential of the Richfield 1^{o}x 2^{o} quadrangle.

An understanding of the geology, age, and geochemistry of the rhyolite of Gillies Hill is important for several reasons beyond merely filling a local gap in knowledge. The area is only a few kilometers southwest of the Cove

Fort-Sulphurdale KGRA, and about 20 km east of the Roosevelt KGRA. If these rhyolites were sufficiently young, a geothermal potential might exist. In addition, work in adjacent mountains has shown that multiple episodes of mineralization took place within the surrounding volcanic terrane (Steven and others, 1978a, 1978b, 1979) and that rhyolite centers in particular tend to have uranium and possibly molybdenum deposits associated with them (Cunningham and Steven, 1979a; Steven and others, 1979a). Beaver basin to the south is currently the focus of intense exploration interest for possible roll-front or sedimentary trap uranium deposits that may have been fed from rhyolite sources in the adjacent mountains (Cunningham and Steven, 1979; Steven and others, 1980). Although the rhyolite of Gillies Hill has proven too old (9.1 m.y.) to have modern geothermal significance, a relationship may exist between the rhyolite and potential mineral deposits in or near the adjacent basins.

Geologic setting

The rhyolite of Gillies Hill occupies an area between two highly contrasting igneous terranes--the Marysvale volcanic field in the Tushar Mountains to the east, and batholithic intrusives in the Mineral Mountains to the west (fig. 1). The two terranes represent different manifestations of the same middle to late Tertiary igneous episodes, juxtaposed by late Cenozoic Basin-Range faulting. Erosion has cut deeply into the highly uplifted Mineral Mountains block, whereas remnants of the youngest volcanic units are still preserved in places on the west slope of the Tushar Mountains. Although many faults are involved, the structure across which the main change in rock types takes place is nowhere exposed; in part it is buried by basin-fill sedimentary deposits, and in part by the rhyolite of Gillies Hill whose main source vents appear to have been localized along and near this major fault.

The Tushar Mountains east of the Gillies Hill-Woodtick Hill area consist of two main volcanic assemblages, the older Bullion Canyon Volcanics and the younger Mount Belknap Volcanics. The Bullion Canyon Volcanics consists largely of intermediate-composition lava flows and volcanic breccia comprising coalescing stratovolcanoes, with interlayered ash-flow tuff units (Steven and others, 1979). These rocks were erupted over a period of time ranging from before 30 m.y. ago (pre-Needles Range Formation) to about 22 m.y. ago. Exposed Bullion Canyon rocks just east of the Gillies Hill-Woodtick Hill area consist largely of 27-m.y.-old Three Creeks Tuff Member, a very crystal-rich quartz latitic ash-flow tuff, and overlying thick, coarsely porphyritic rhyodacitic lava flows. These rocks are cut by 24-23 m.y.-old monzonitic to latitic intrusions that in part pass upward into lava flows in the upper part of the Bullion Canyon assemblage. The intrusions are overlain unconformably by 22-m.y.-old Osiris Tuff.

West of the Gillies Hill-Woodtick Hill area (fig. 2), Bullion Canyon rocks are intensely propylitized intermediate-composition lava flows and breccias. Although some of the higher flows in this succession are coarsely porphyritic like those in the upper part of the main volcanic pile in the Tushar Mountains to the east, the base rests unconformably on Paleozoic sedimentary rocks, suggesting that perhaps only the lower part of the Bullion Canyon may be represented. Presently available data do no permit establishing--or eliminating--any correlations between these different areas of exposure.

In the Tushar Mountains the Bullion Canyon Volcanics is overlain by highly silicic lava flows and ash-flow tuff of the 21-14 m.y.-old Mount Belknap Volcanics. Those Mount Belknap rocks exposed nearest the Gillies Hill-Woodtick Hill area are in or adjacent to the Mount Belknap caldera, which subsided in response to catastrophic eruption of the Joe Lott Tuff Member about 19 m.y. ago (Cunningham and Steven, 1979c). Intracaldera fill in the Mount Belknap caldera consists in part of densely welded ash-flow tuff closely similar to that in the Joe Lott Tuff Member, and in part of thick, flow-layered rhyolite flows and volcanic domes that accumulated above vents along the southern and western segments of the ring fracture zone of the caldera (Cunningham and Steven, 1979b). The Joe Lott Tuff Member extended widely over low areas adjacent to the Mount Belknap caldera, and may once have covered the Gillies Hill-Woodtick Hill area; if so, it had been removed by erosion before the rhyolite of Gillies Hill was erupted in late Miocene time.

The Bullion Canyon Volcanics west of Gillies and Woodtick Hills (fig. 2) are cut by some of the oldest intrusive rocks in the batholithic assemblage of the Mineral Mountains. The oldest of these intrusive rocks is a strongly porphyritic gabbro(?) that may represent a local border phase of the younger more equigranular monzonite to syenite body that cuts both the gabbro(?) and the propylitized volcanics. These relatively low-silica rocks may correlate with similar low-silica monzonitic (latitic) intrusions on the west flank of the Tushar Mountains 8 to 18 km to the east and northeast. A few kilometers west of the area of figure 2, the monzonite-syenite pluton is cut by a coarsely crystalline quartz-bearing (25 percent or more) granite or quartz monzonite that is part of a relatively siliceous assemblage that forms most of the Mineral Mountains batholithic complex (Sibbett and Nielson, 1980). If the correlation of the older low-silica gabbro(?)-monzonite-syenite assemblage with the 24-23-m.y.-old monzonite intrusions in the Tushar Mountains is valid, it is possible that the quartz-rich granite-quartz monzonite batholithic rocks may correlate in a broad sense with the highly siliceous Mount Belknap Volcanics in the Tushar Mountains. Preliminary radiometric dating results tend to confirm this suggestion (S. H. Evans, unpublished data).

Both the low-silica and high-silica intrusive rocks in the northern Mineral Mountains are cut by late felsite dikes. Some of these dikes extend into the west-central part of the area of figure 2 where they cut the gabbroic pluton, the monzonite-syenite pluton, and the propylitized Bullion Canyon Volcanics. These late felsite dikes may be related to the rhyolite of Gillies Hill, and preliminary radiometric dating results tend to confirm this suggestion (S. H. Evans, unpublished data).

The Gillies Hill-Woodtick Hill area was extensively faulted after the Bullion Canyon Volcanics, and perhaps after the Mount Belknap Volcanics, accumulated. At this time a rough fault-block topography formed, with the structural basins penecontemporaneously filled by gravelly, sandy, and silty fluviatile sedimentary rocks. The only evidence for the presence of these early basin-fill sediments in the Gillies Hill-Woodtick Hill area is in secs. 21 and 22 near the northern margin of the area of figure 2 where tan gravelly silt is poorly exposed on low slopes beneath the basal vitrophyre of a rhyolite lava flow. Some of the cobbles consist of the gabbro(?) and monzonite-syenite now exposed in the western part of the area of figure 2, which indicates that erosion had cut down to the levels of these intrusive bodies by middle Miocene time.

Shortly before 9 m.y. ago, the rhyolite of Gillies Hill was erupted, probably along a major Basin-Range fault zone. The extrusions were chiefly viscous flow-layered rhyolite domes and flows ranging in size from fairly small domes such as Cedar Knoll (fig. 2) near the southeast end of the assemblage, to a large elongate dome that extends from the north flank of Gillies Hill, through Woodtick Hill nearly to the north end of the area shown on figure 2. One coherent unit of soft zeolitically altered ash-flow tuff accumulated in a valley along the western side of the rhyolite pile (fig. 2). At least four dome-flow units are recognized, and possibly as many as three or four times that number exist. We do not agree with many of the dome (flow) centers shown by Haugh (1978), who apparently was influenced strongly by present topography in which original volcanic morphology has been greatly modified by late Cenozoic faulting and erosion.

The rhyolite of Gillies Hill was largely covered by upper Cenozoic basin-fill deposits, which have been variably stripped to the present degree of exposure. These younger deposits have been studied by Machette and others (1980) and Steven and others (1980), and will not be discussed here. The unit QTa on figure 2 lumps these basin-fill deposits with younger pediment gravels, fanglomerates, stream alluvium and colluvium.

Pleistocene basalt flows cover the northern and northwestern parts of the mapped area (fig. 2). These basalts range in age from approximately 1.0 to 0.3 m.y. (Best and others, 1980). Except insofar as they provide evidence for age of faulting, these basalt flows have no relevance to this report and will not be discussed further.

Structural setting

The rhyolite of Gillies Hill forms an elongate volcanic pile (fig. 2) alined north-south along the trend of a buried fault that juxtaposes plutonic rocks in the Mineral Mountains block with volcanic rocks in the Tushar Mountains block. Geophysical evidence (Cook and others, 1980) indicates this major fault, and geologic evidence points toward middle Miocene as the time of its main displacement. Later faulting along the same general trend has broken the rhyolite of Gillies Hill into elongate blocks. The young faulting apparently took place over an extended period of time from late Miocene to Pleistocene.

Numerous late Cenozoic faults between the high Mineral Mountains to the west and the Gillies Hill-Woodtick Hill area step irregularly downward to the east. However, batholithic rocks or contact-metamorphosed Paleozoic sedimentary rocks predominate (fig. 2), and those intermediate-composition volcanic rocks that do occur are adjacent to the plutonic rocks and are intensely propylitized and locally hornfelsed. The whole area west of the rhyolite of Gillies Hill thus shows definite affinities to the Mineral Mountains structural block.

The east flank of the rhyolite of Gillies Hill is covered by younger basin-fill sedimentary rocks and other surficial deposits, but 2.5 km farther east the lower west flank of the Tushar Mountains consists of thick intermediate-composition lava flows in the middle and upper parts of the Bullion Canyon Volcanics. These flows dip gently westward off the tilted Tushar Mountain fault block, and are essential parts of the major Marysvale volcanic field.

A recent gravity study by Cook, Serpa, and Pe (1980, fig. 5) shows the covered area between the Mineral Mountains and Tushar Mountains structural blocks to be underlain by a gravity low believed to represent a graben (the Beaver-Cove Fort graben of Cook and others, 1980) filled with low-density basin-fill sediments. The western margin of this graben is marked by a steep gravity gradient that trends almost due north directly under the area covered by the rhyolite of Gillies Hill. Inasmuch as this rhyolite unit consists of thick local flows and flow domes that were fed by underlying vents, the accumulation seems to have been localized above a major structural break. This relationship also was recognized by Cook, Serpa, and Pe (1980, p. 30). The steep gravity gradient is interrupted by a minor gravity high in the vicinity of Gillies Hill and Woodtick Hill, suggesting that the rhyolite had its principal source in this area.

Recurrent fault movement in the Gillies Hill-Woodtick Hill area is indicated by many independent bits of evidence. The map pattern (fig. 2) suggests that some of the westernmost faults may have had very early movement, before intrusion of the gabbro(?) and monzonite-syenite plutons; this suggestion may be illusory, however, as exposures are too poor to establish with certainty that the faults do not extend northward into the intrusive bodies.

The rhyolite of Gillies Hill rests directly on older Bullion Canyon Volcanics west of Gillies Hill and Woodtick Hill, but overlies basin-fill sedimentary rocks to the north (fig. 2) and presumably to the east where the rhyolites extend out over the gravity low marking the Beaver-Cove Fort graben of Cook and others (1980). This dates major fault displacement as younger than the Bullion Canyon Volcanics and older than the late Miocene rhyolite of Gillies Hill.

Northerly trending faults parallel the underlying gravity gradient along the west side of the Beaver-Cove Fort graben of Cook and others (1980), and probably reflect renewed movement on the buried fault zone. Most displacement apparently was fairly early as erosion has largely removed or obscured the original fault-block topography. More recent movement is indicated by low scarps cutting Pleistocene basalt flows in the northern part of figure 2, and by other scarps cutting Pleistocene alluvial deposits elsewhere.

Geochronology

Five samples from the rhyolite of Gillies Hill were dated radiometrically to determine the age of volcanic activity and to establish the geologic relations with adjacent igneous terrains. In particular, the suggestion by Haugh (1978) that the rhyolites may have been erupted as recently as the Quaternary needed to be checked because of the potential for geothermal resources. Analytical data are given in table 1; sample locations are shown on figure 2.

Samples 77-3, 77-7, 77-8, 79-1 are all from what has turned out to be a single large volcanic dome that extends from the north flank of Gillies Hill northward through Woodtick Hill to the north end of the area shown on figure 2. This is the youngest major flow unit in the rhyolite of Gillies Hill. Another sample (77-6) was collected from the basal vitrophyre of a small dome called Cedar Knoll (fig. 2); this dome appears to have resulted from one of the older eruptions of the rhyolite of Gillies Hill. Standard techniques for the K-Ar method were used, the details of which are given in Evans and others (1980). It is evident that samples 77-6, 77-7, and 79-1 are concordant, but samples 77-3 and 77-8 are not. Both discordant samples are from the same large volcanic dome as the concordant samples 77-7 and 79-1. The concordant samples are from the youngest major flow unit and one of the oldest units in the rhyolite of Gillies Hill.

Some simple statistical tests were conducted to determine the cause of the variability in the data. Whereas the standard error of the ages is 12.5 percent, the standard error of potassium values is only 4.6 percent, suggesting that the major error lies in the argon data. An isochron (fig. 3) of the potassium and argon data for the concordant samples 77-6, 77-7, and 79-1, with $^{40}Ar/^{36}Ar$ plotted as the ordinate and $^{40}K/^{36}Ar$ as the abscissa, yields an age of 9.13 m.y. with an intercept of 297 on the ordinate, a $^{40}Ar/^{36}Ar$ value very near the accepted one for atmospheric argon of 295.5. If data from both concordant and discordant samples are included, the isochron (dashed line) shows an apparent age of 9.28 m.y. and an intercept of 277 on the ordinate. This intercept is clearly in error and indicates that samples 77-3 and 77-8 have lost argon. Petrographic examination shows that the biotite in the discordant samples is generally oxidized, in contrast with the fresh biotite in the concordant samples, which probably accounts for the loss in argon.

Inasmuch as the concordant samples came from both old and young flow units within the rhyolite of Gillies Hill, it is concluded that the related volcanic activity took place within a very short period of time about 9.1 m.y. ago.

Petrography

In addition to the samples collected for radiometric dating, others were taken to determine the petrographic and chemical diversity of the rhyolite of Gillies Hill. Sample locations are shown on figure 2, and modal analyses in Table 2. Modes were not determined on samples 80-5 and 80-6, which were taken from the same location as 77-3. Sample 77-5, a zeolitized tuff consisting largely of quartz and clinoptilolite, also was not counted.

Chemical analyses (see following section) show that the rhyolite of Gillies Hill clearly forms a high-silica suite (SiO_2>75 percent) represented by all but the youngest flow-dome in the unit, and a low-silica suite (SiO_2≅70 percent) represented by the single large volcanic dome at the top of the unit.

Stubby flows and domes of the high-silica suite are exposed in three lobate areas that extend outward from the Gillies Hill-Woodtick Hill topographic high. Six samples taken from outcrops (samples 77-1, 77-2, 77-6, 80-1, 80-4, and 80-7) range from 12-25 percent in phenocryst content, and show variations in relative abundances of the different minerals (table 1). The phenocrysts consist of euhedral quartz crystals (5-10 percent) ranging from 0.5-2 mm across; euhedral to subhedral sanidine crystals (3-77 percent), 0.25-0.75 mm long; subhedral plagioclase laths (oligoclase) 0.5-2 mm long; euhedral biotite flakes and books ranging from very small to 0.75 mm across (samples 77-1, 77-2, 77-6, and 80-7 only); and traces of hornblende (sample 80-1), sphene, and iron oxides. The groundmasses of samples 80-1 and 80-4 are completely devitrified, but the groundmasses of the other high-silica samples remain glassy.

The low-silica suite is represented by a single large volcanic dome that extends northward from Gillies Hill, through Woodtick Hill, and on to the two erosional remnants at the northern end of the mapped area (fig. 2). Six samples were taken from this unit, 77-3, 77-7, 77-8, 79-1, 80-5, and 80-6. Thin sections of these samples are virtually indistinguishable except for minor variations in abundance of phenocryst minerals and oxidation of biotite. All samples are flow layered with a linear fabric shown by parallel alinement of plagioclase laths. The flow contains abundant euhedral phenocrysts of andesine (11-16 percent) that range from 0.25-1 mm long. Euhedral grains of biotite (3-4 percent) are as large as 0.75 mm across, and sparse hornblende (0-1 percent) also is present. In samples 77-3 and 77-8 the biotite is oxidized and mantled by iron oxides, whereas in samples 77-7 and 79-1 the biotite is fresh. This contrast probably accounts for the discordant K-Ar ages obtained on biotite from the oxidized samples, compared to the concordant ages obtained on biotite from the unoxidized samples (see preceding section). The groundmass of this unit is completely devitrified and consists of a felted mass of feldspar microlites.

The large volcanic dome comprising the low-silica suite appears to have had a source somewhere east or northeast of Gillies Hill inasmuch as an outcrop a few meters east of sample location 77-3 shows steeply dipping (85° W.) north-striking flow-layered rhyolite with a 20 cm glassy selvage cutting sharply up across a ridge crest. The material intruded by the steeply dipping rhyolite is not exposed; it may be autoclastic debris marginal to the same low-silica flow, or it may be older material in the rhyolite of Gillies Hill. In either case, the steep glassy selvage probably is some manifestation of the vent that fed the young low-silica volcanic dome. Although this dome is everywhere younger than rocks of the high-silica suite, the time span of eruptions of all rocks in the rhyolite of Gillies Hill appears to have been small, inasmuch as early and late flows in the sequence have identical K-Ar ages, within analytical uncertainty.

The petrography of the rhyolite of Gillies Hill shows some similarities to other nearby late Miocene rhyolites, especially the 7.5-m.y.-old rhyolite of Corral Canyon on the west side of the Mineral Mountains (Lipman and others, 1978; S. H. Evans, unpublished data), and another 7.5- m.y.-old rhyolite from a local center near the SW corner of Beaver Basin (S. H. Evans, unpublished data). These occurrences may be remnants of what was once a much more extensive area of rhyotitic volcanism in late Miocene time.

Chemistry

Major elements

Chemical analyses and CIPW norms of selected samples from the rhyolite of Gillies Hill are given in table 3, along with the analytical techniques used. These analyses have been recalculated on an anhydrous basis to 100 percent in order to remove the effect of variable water content and to allow for a more meaningful comparison of major element chemistry. With the exception of sample 79-1, all the samples are corundum normative and are readily divisible into a high-silica suite (SiO_2>75 percent) and a low-silica suite ($SiO_2 \cong 70$ percent). Sample 77-5 is of a highly silicified and zeolitized ash-flow tuff, and will not be discussed further.

The low-silica suite is represented by six samples from a single volcanic dome that is the youngest eruptive unit in the rhyolite of Gillies Hill.

These samples (77-3, 77-7, 77-8, 79-1, 80-5, and 80-6) are virtually indistinguishable from one another by their major element chemistry (table 3). Of particular interest is the silica content between 70 and 71 percent, and the alumina content greater than 15 percent. Minor variations are present in Na_2O and CaO, as shown by normative compositions, but these are not reflected by modal variations in plagioclase (see table 2). The low-silica suite of the rhyolite of Gillies Hill is unique among late Cenozoic rhyolite centers of the nearby region in that no other center has lavas that combine the relatively low silica values with such high alumina values. In the Twin Peaks area, 30-35 km to the north, rhyolite domes and flows with silica contents as low as 72 percent are present (Crecraft and others, 1981), but alumina contents do not exceed 13.5 percent. These lavas were erupted significantly later (2.7-2.3 m.y. ago) than the rhyolite of Gillies Hill. In another area of silicic volcanism nearby in the central Mineral Mountains, only high-silica rhyolites were erupted (Lipman and others, 1978). Again, these lavas are significantly younger (0.8-0.5 m.y.) than those of Gillies Hill.

The high-silica suite consists of stubby flows and domes probably erupted from individual vents. This group is composed of rocks with chemistries similar to other rhyolites of the bimodal suite of the Basin-Range province. Silica content ranges between 75 and 77 percent, and alumina between 12.5 and 14 percent. Magnesia content is low and variable, although in general it is higher than in other, more evolved rhyolites from nearby centers (Lipman and others, 1978; Crecraft and others, 1981). Soda values range from 3.5 to 4.1 percent and potash values from 4.7 to 5.3; these ranges are also typical for younger nearby rhyolites from the Mineral Mountains and Twin Peaks area (Lipman and others, 1978; Crecraft and others, 1981).

Trace elements

Table 4 shows contents of selected trace elements determined using X-ray fluorescence techniques. In order to ascertain if any systematic variations in trace elements are present, values were plotted against rubidium, an incompatible element used here as a monitor of magmatic evolution (fig. 4).

As is evident from figure 4, some striking patterns emerge. For the low-silica suite samples (filled boxes) from a single volcanic dome unit, unexpected variations are noted in samples whose petrography and major element chemistry are so uniform. Lead varies from 0 to 75 ppm, Zr shows a positive correlation with rubidium, as do Sr, Y, Th, and Nb. More fieldwork will be required to determine, if possible, the precise location and configuration of the source vent and the relative time-space positions of the samples within the volcanic dome unit. Only if such data can be determined will it be possible to relate the trace-element variations in this low-silica suite to the chemical geometry of the source magma chamber.

Trace-element variations among the samples from the high-silica suite (fig. 4, filled circles), show variations similar to other rhyolite centers in the Basin-Range province. With the exception of Zr, the high-silica suite shows systematic linear variations with degree of enrichment of rubidium, i.e., degree of evolution. For Zr there seems to be a linear negative correlation of all but the most evolved sample (77-6) for which the trend reverses. This sample also differs from the other by having marked relative enrichment in Rb.

Discussion

The field, geochronologic, and chemical data presented herein indicate that the rhyolite of Gillies Hill shows both similarities and differences to trends shown in other rhyolite centers in western United States. The high-silica suite shows evolutionary patterns characteristic of silicic lavas erupted from compositionally zoned magma chambers, but field evidence is insufficient at present to establish firmly whether trace-element patterns evolved with time or reflect geologically instantaneous sampling of magma. Several different lava flow units are represented by the data, so evolution with time is permissable; the flows, however, could have been erupted in very rapid succession, which would have minimized the influence of time.

In the trace element patterns developed in the Bishop Tuff from eastern California, Hildreth (1979) shows enrichments and depletions similar to those in the rhyolite of Gillies Hill, but the Bishop Tuff formed from a geologically instantaneous eruption and thus reflects chemical variations within the source magma chamber at one point in time. In the Bandelier Tuff in New mexico (Smith, 1979), on the other hand, the Nb data indicate cyclic regeneration of a zoned magma chamber which was tapped periodically as the magma evolved.

The overlying low-silica suite is quite distinct chemically from the earlier flows in the rhyolite of Gillies Hill. This chemical discontinuity suggests either a different magma chamber, or eruption from significantly different levels within the same magma chamber. Trace-element variations within the low-silica suite also suggest that subtle chemical gradients existed within its source magma.

It is tempting to visualize the high-silica suite as representing eruptions from the top of a compositonally zoned magma chamber. Sample 77-6 from the Cedar Knoll dome near the base of the rhyolite of Gillies Hill is strongly enriched in incompatible elements, notably uranium and rubidium; from its stratigraphic position it should have been erupted from the highly evolved top of the magma chamber. As the silicic portion of the chamber was drawn down, less evolved material was erupted, with the least evolved being represented by samples 80-1 or 80-4.

Recent studies by McBirney and Noyes (1979), McBirney (1980), Chen and Turner (1980), Irvine (1980), and Rice (1981) have suggested that stacked convection cells with contrasting chemical compositions may exist within single magma chambers. Modelling experiments, particularly those of Chen and Turner (1980), have simulated magma chambers in which a vertically stacked cellular structure is developed when vertical gradients in temperature and composition exist simultaneously in a liquid. The distinctive low-silica suite overlying the high-silica suite thus may have come from the lower of two compositionally zoned cells, the uppermost one of which was exhausted by eruption of the earlier high-silica suite. Whereas the upper cell was strongly zoned in composition and may have been dynamically stable, the lower cell was much more uniform, except for subtle gradients in trace-element contents, and may have been mixed by convection (McBirney, 1980, p. 366-368). The rate of convective overturn would have had to be slow enough not to erase the gradients in trace elements but still be rapid enough to homogenize the major elements. The rhyolite of Gillies Hill could have attained the compositonal variations noted by rapid eruption from such a cellularly zoned magma chamber, by episodic eruption from different levels within either a singly or a multiply zoned magma chamber, or by some combination.

A more detailed study of the eruptive sequence and petrochemistry of the rhyolite of Gillies Hill is obviously in order to see if any of these alternatives can be substantiated. The time factor is particularly critical, but present geochronologic data probably cannot be refined sufficiently to be definitive. Establishing an accurate detailed sequence of eruptive units within the older, high-silica suite will be difficult because of poor exposures, although a general sequence probably can be determined. Abundant chemical data, particularly of trace elements, including rare-earth elements, would be especially helpful. Contributions from all these approaches will be necessary to advance beyond the broad speculations offered above.

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References

Best, M. G., McKee, E. H., and Damon, P. E., 1980, Space-time-composition patterns of late Cenozoic mafic volcanism, southwestern Utah and adjoining areas: American Journal of Science, v. 280, p. 1035-1050.

Carmichael, I. S. E., Hampel, J., and Jack, R. N., 1968, Analytical data on the USGS standard rocks: Chemical Geology, v. 3, p. 59-64.

Chen, C. F., and Turner, J. S., 1980, Crystallization in a double-diffusive system: Journal of Geophysical Research, v. 85, 85, p. 2573-593.

Christiansen, R. L., and Lipman, P. W., 1972, Cenozoic volcanism and plate tectonic evolution of the western United States--[Pt.] II, late Cenozoic: Royal Society London Philosophical Transactions, series A, v. 271, no. 1213, p. 249-284.

Cook, K. L., Serpa, L. F., and Pe, Win, 1980, Detailed gravity and aeromagnetic surveys of the Cove Fort-Sulphurdale KGRA and vicinity, Millard and Beaver Counties, Utah: University of Utah, Department of Geology and Geophysics Topical Report 78-1701.a.5.2 (available from U.S. Department of Energy as Report No. DOE/ET/28392-30).

Crecraft, H. R., Nash, W. P., and Evans, S. H., Jr., 1981, Late Cenozoic volcanism at Twin Peaks, Utah, part 1: Geology and petrology: Journal of Geophysical Research, in press.

Cunningham, C. G., and Steven, T. A., 1979a, Uranium in the Central Mining Area, Marysvale district, west-central Utah: U.S. Geological Survey Miscellaneous Investigations Map MI-1177.

______1979b, Environments favorable for the occurrence of uranium within the Mount Belknap caldera, Beaver Valley, and Sevier River Valley, west-central Utah: U.S. Geological Survey Open-File Report 79-434, 15 p.

Cunningham, C. G., and Steven, T. A., 1979c, Mount Belknap and Red Hills calderas and associated rocks, Marysvale volcanic field, west-central Utah: U.S. Geological Survey Bulletin 1468, 34 p.

Evans, S. H., Jr., Crecraft, H. R., and Nash, W. P., 1980, K/Ar ages of silicic volcanism in the Twin Peaks/Cove Creek Dome area, south-western Utah: Isochron/West, no. 28, p. 21-24.

Haugh, G., 1978, A preliminary geologic map of the Wildcat Creek area, eastern Beaver County, Utah: Utah Geology, v. 5, no. 1, p. 33-36.

Hildreth, W., 1979, The Bishop tuff--Evidence for the origin of compositional zonation in silicic magma chambers, in Chapin, C. E., and Elston, W. E., eds., Ash-flow tuffs: Geological Society of America Special Paper 180, p. 43-76.

Hintze, L. F., 1963, Geologic map of southwestern Utah: Department of Geology; Brigham Young University, 1:250,000.

Irvine, T. N., 1980, Experimental modeling of convection in interlayered intrusions: Annual report of the director Geophysical laboratory, Carnegie Institution of Washington Year Book 79, p. 247-256.

Lipman, P. W., Rowley, P. D., Mehnert, H., Evans, S. H., Jr., Nash, W. P., and Brown, F. H., 1978, Pleistocene rhyolite of the Mineral Mountains, Utah--Geothermal and archeological significance: Journal of Research, U.S. Geological Survey, v. 6, no. 1, p. 133-147.

Machette, M. N., and Steven, T. A., 1981, Preliminary geologic map of the northwest quarter of the Beaver quadrangle, Beaver County, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-________.

McBirney, A. R., 1980, Mixing and unmixing of magmas: Journal of Volcanology and Geothermal Research, v. 7, p. 357-371.

McBirney, A. R., and Noyes, R. M., 1979, Crystallization and layering of the Skaergaard intrusion: Journal of Petrology, v. 20, pt. 3, p. 487-554.

Mehnert, H. H., Rowley, P. D., and Lipman, P. W., 1978, K-Ar ages and geothermal implications of young rhyolites in west-central Utah Isochron/West, no. 21, p. 3-7.

Norrish, K., and Hutton, J. T., 1969, An accurate X-ray spectrographic method for the analysis of a wide range of geological samples: Geochemica et Cosmochemica Acta, v. 33, p. 431-453.

Rice, A., 1981, Convective fractionation: A mechanism to provide cryptic zoning (Macrosegregation), layering, crescumulates, banded tuffs and explosive volcanism in igneous processes: Journal of Geophysical Research, v. 87, no. B1, p. 405-417.

Sibbett, B. S., and Nielson, D. L., 1980, Geology of the central Mineral Mountains, Beaver County, Utah: Earth Science Laboratory, University of Utah Research Institute, Salt Lake City, Utah.

Smith, R. L., 1979, Ash-flow magmatism, in Chapin, C. E., and Elston, W., E., eds. Ash Flow Tuffs: Geological Society of America Special Paper 180, p. 5-280.

Steven, T. A., Cunningham, C. G., and Machette, M. N., 1980, Integrated uranium systems in the Marysvale volcanic field, west-central Utah: U.S. Geological Survey Open-File Report 80-524, 39 p.

Steven, T. A., Cunningham, C. G., and Rowley, P. D., 1978, Geology and mineralization in the Marysvale mining area, west-central Utah, in Shawe, D. R., and Rowley, P. D., eds., International association on genesis of ore deposits, Guidebook to mineral deposits of southwestern Utah: Utah Geological Association Publication 7, p. 67-70.

Steven, T. A., Cunningham, C. G., Naeser, C. W., and Mehnert, H. H., 1979, Revised stratigraphy and radiomentric ages of volcanic rocks and mineral deposits in the Marysvale area, west-central Utah: U.S. Geological Survey Bulletin 1469, 40 p.

Steven, T. A., Cunningham, C. G., Naeser, C. W., Mehnert, H. H., and Ludwig, K. R., 1978, Multiple ages of mineralization in the Marysvale area, west-central Utah (abs): International Association on the Genesis of Ore Deposits, Synposium, 1978, Programs and Abstracts.

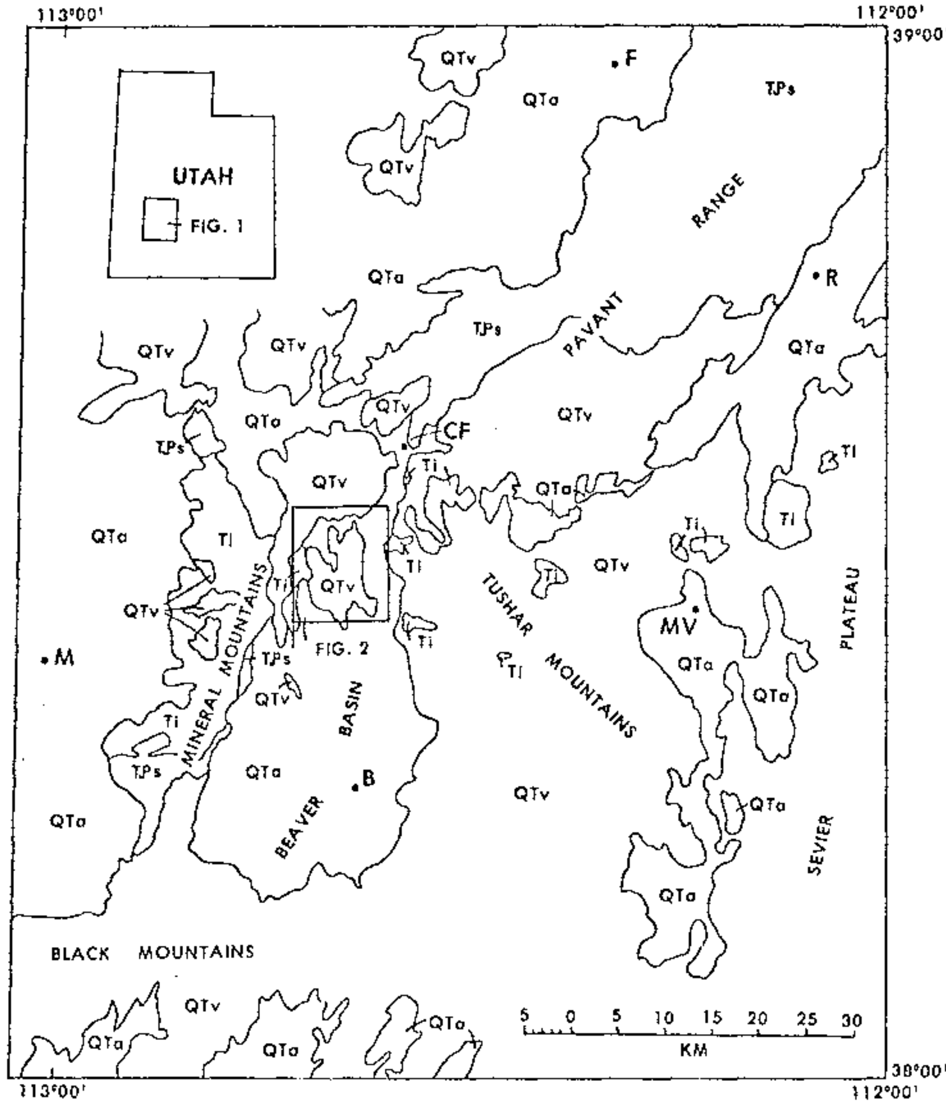

Figure 1. Geologic map of south west-central Utah showing location of figure 2. TPs, undivided Tertiary to Paleozoic sedimentary rocks; QTv, undivided Quaternary and Tertiary volcanic rocks; QTa, undivided Quaternary and Tertiary alluvial rocks; Ti, undivided Tertiary intrusive rocks. F, Fillmore; CF, Cove Fort; B, Beaver; R, Richfield; MV, Marysvale

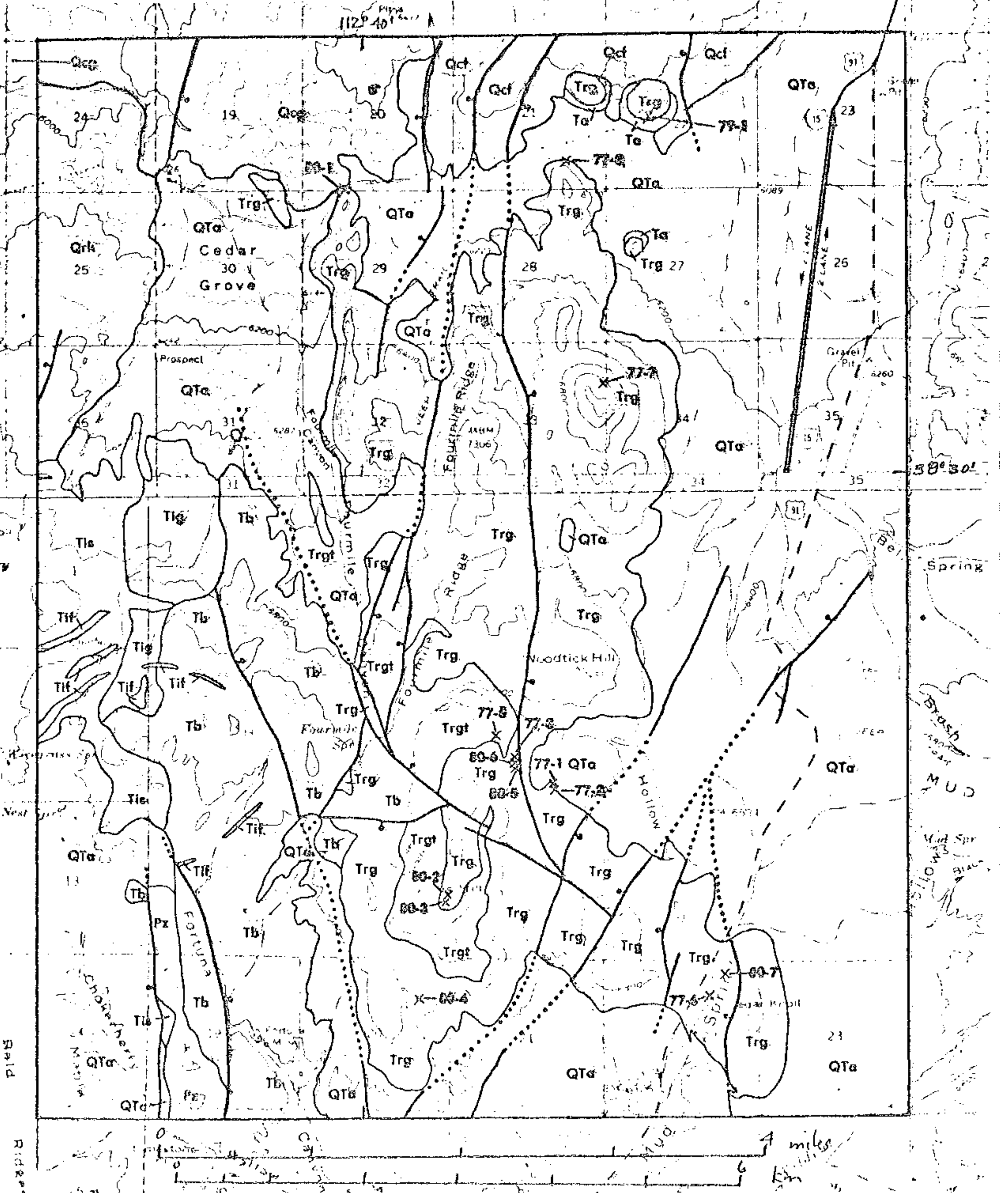

Figure 2: Geologic map of the Gillies Hill - Woodtick Hill area

EXPLANATION

QTa

Alluvial deposits younger than rhyolite of Gillies Hill

Qcg

Basaltic andesite of Cedar Grove

Qcf

Basaltic andesite of Cove Fort

Qrk

Basaltic andesite of Red Knoll

Trg | Trgt

Rhyolite of Gillies Hill

Trg - lava flows and volcanic dome

Trgt - ash-flow tuff

Tif

Felsite dike

Probably equivalent to rhyolite of Gillies Hill

Ta

Alluvial deposits older than rhyolite of Gillies Hill

Tis

Monzonite-syenite pluton

Tig

Gabbro? pluton

Tb

Bullion Canyon Volcanics

Pz

Paleozoic sedimentary rocks

———

Geologic contact

———•••

Fault

Bar and ball on downthrown side; dotted where covered

x — 77-3

Sample locality

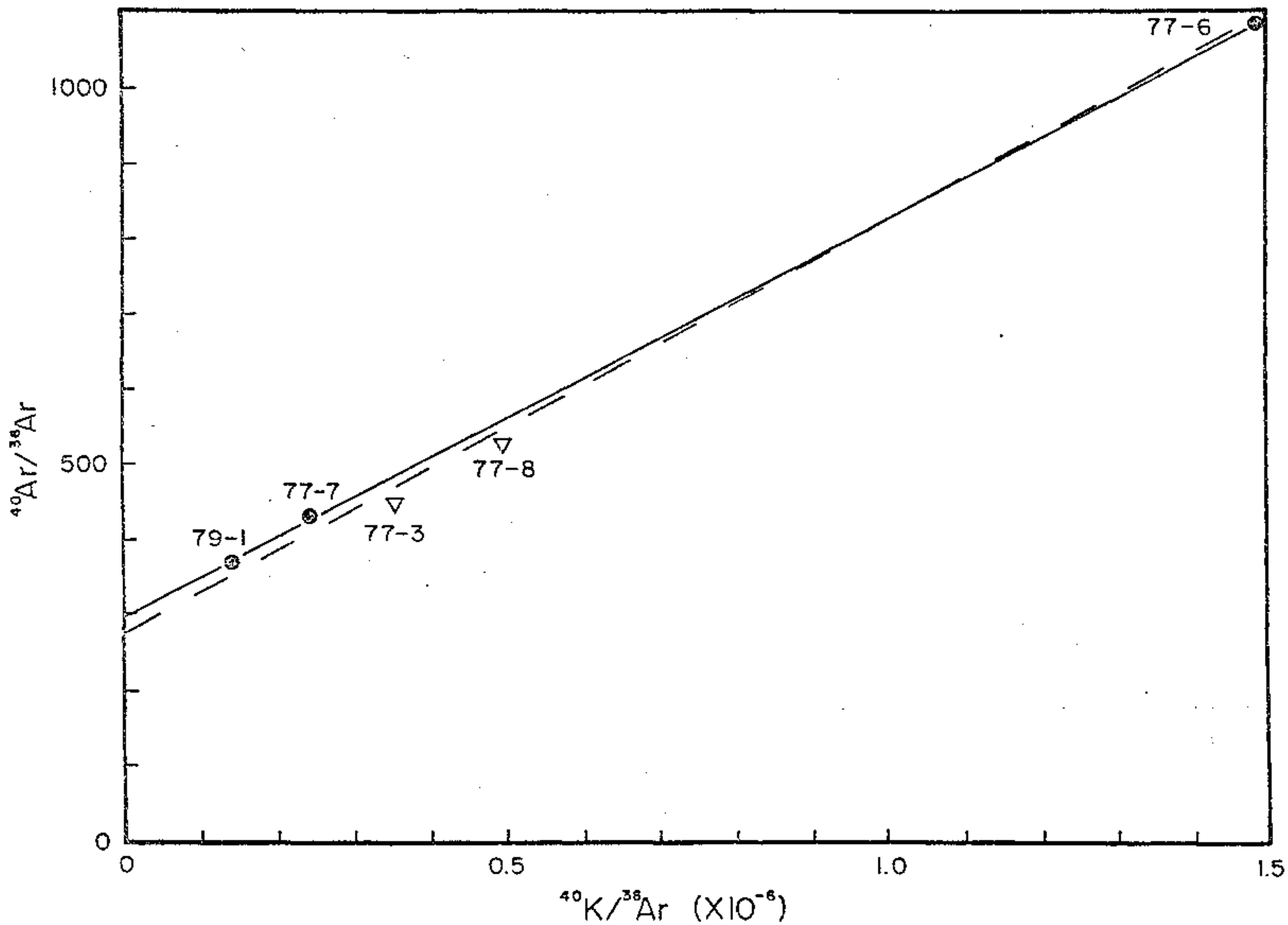

Figure 3. Potassium/argon isochrons of the rhyolite of Gillies Hill. Filled circles lie on the isochron, open triangles are discordant points. Solid isochron has an age of 9.13 m.y. and an intercept of 297; dashed isochron has an age of 9.28 m.y. and an intercept of 277

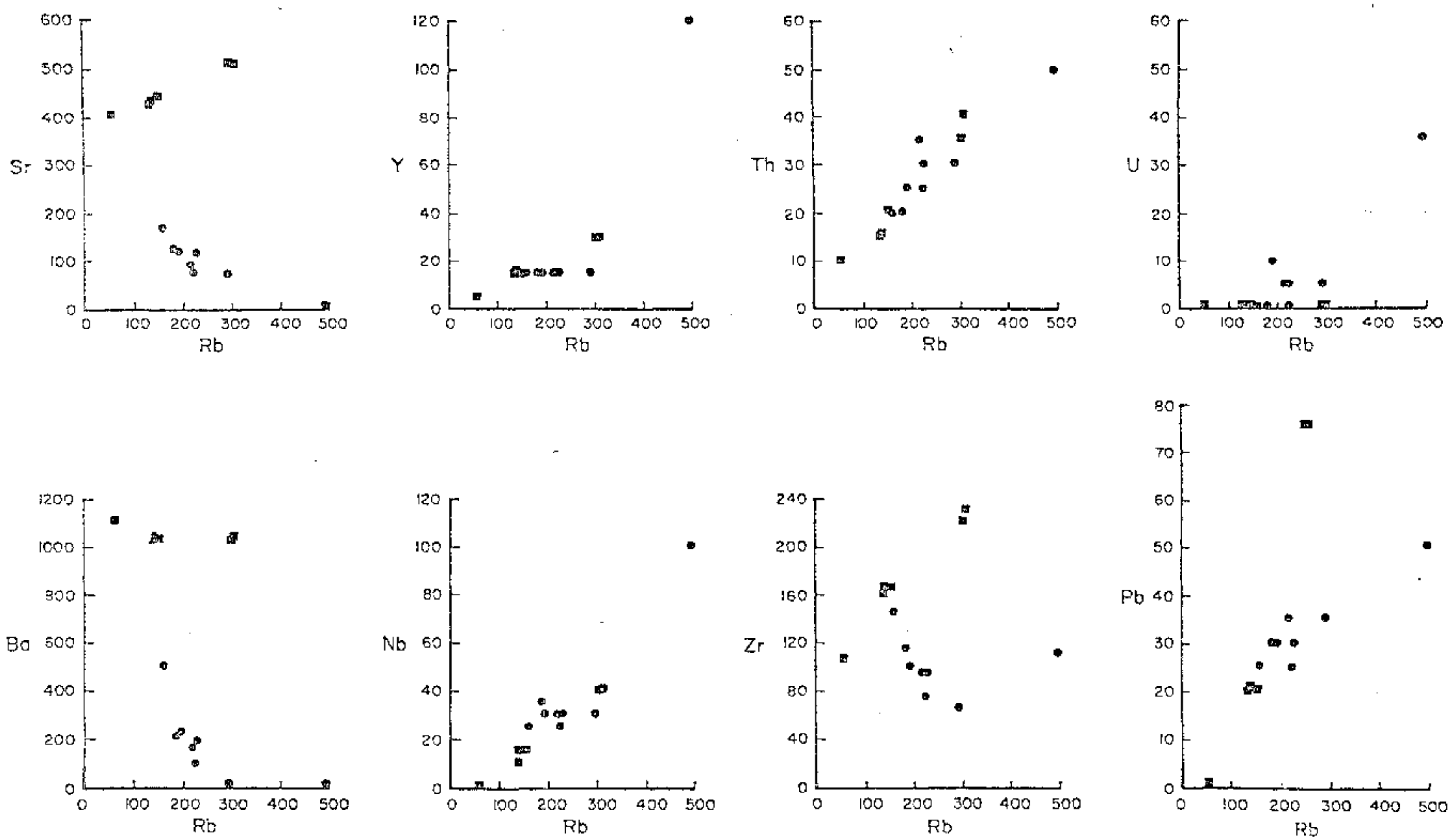

Figure 4 Plots of trace element variations versus rubidium concentration. Filled boxes are samples from the low silica suite; filled circles are samples from the high silica suite

Table 1. Radiometric ages of the rhyolite of Gillies Hill

Sample No.	Material Dated	Weight (gms).	%K	Moles/gm Ar^{40}_{Rad} ($X10^{11}$)	$\%Ar^{40}_{atm}$	Age (M.Y.) $\pm 1\sigma$
77-3	Biotite	0.93724	6.41	7.747	67	6.96 ± 0.35
77-6	Sanidine	0.70982	8.61	13.672	28	9.13 ± 0.31
77-7	Biotite	0.86234	6.78	10.869	68	9.22 ± 0.46
77-8	Biotite	0.85650	7.01	9.758	57	8.01 ± 0.32
79-1	Biotite	0.81178	7.11	11.266	80	9.11 ± 0.64

Constant Used:

$\lambda_\beta = 4.962 \times 10^{-10}$/yr.

$\lambda_\varepsilon = 0.581 \times 10^{-10}$/yr.

$K^{40}/K_{Tot.} = 1.167 \times 10^{-4}$ Mole/Mole

Table 2. Modal analyses of the rhyolite of Gillies Hill

	Low-Silica Suite				High-Silica Suite						
										Cedar Knoll	
Sample number	77 -3	77 -7	77 -8	79 -1	77 -1	77 -2	80 -1	80 -3	80 -4	77 -6	80 -7
Mineral											
Quartz	-	-	-	-	2.4	2.7	5.0	9.9	4.8	9.4	5.8
Sanidine	-	-	-	-	5.9	5.3	6.6	2.7	3.8	4.5	4.3
Plagioclase	16.1	15.3	11.1	14.4	6.6	4.7	12.3	5.3	3.0	4.4	1.2
Biotite	3.9	2.9	2.7	4.1	1.8	2.5	1.1	0.4	0.6	0.3	0.3
Hornblende	-	1.0	0.7	0.3	0.2	0.1	0.1	-	-	-	-
Sphene	-	-	-	-	0.1	-	-	0.1	-	0.1	-
Oxides	-	0.2	0.4	0.2	-	-	0.6	0.3	0.1	0.1	0.4
Glass	-	-	-	-	83.0	84.7	-	81.3	-	81.2	88.0
Groundmass	80.0	80.6	85.1	81.0	-	-	74.3	-	87.7	-	-
SUM	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Modes based on 1,000 points counted per thin section

Chemical Analyses and CIPW Norms of the Rhyolite of Gillies Hill

	Low-Silica Suite						High-Silica Suite								Zeolitic Tuff
													Cedar Knoll		
	77-3	77-7	77-8	79-1	80-5	80-6	77-1	77-2	80-1	80-2	80-3	80-4	77-6	80-7	77-5
SiO_2	70.5	70.0	70.7	70.0	70.7	70.8	76.1	76.8	75.1	77.2	75.9	75.2	76.9	77.7	79.6
TiO_2	0.36	0.40	0.39	0.35	0.36	0.36	0.19	0.15	0.27	0.07	0.15	0.27	0.06	0.10	0.16
Al_2O_3	15.4	15.3	15.1	15.2	15.4	15.2	12.9	12.7	13.1	12.5	14.0	13.6	12.7	12.7	11.9
Fe_2O_3	2.09	1.49	2.16	1.87	2.08	2.02	0.75	0.75	1.24	0.16	0.56	1.18	0.36	0.35	0.97
FeO*	0.53	1.34	0.55	0.64	0.53	0.53	0.53	0.31	0.34	0.39	0.36	0.37	0.55	0.33	0.11
MnO	0.06	0.06	0.05	0.04	0.04	0.04	0.06	0.06	0.05	0.05	0.06	0.06	0.06	0.06	0.05
MgO	0.56	0.59	0.57	0.73	0.54	0.52	0.28	0.17	0.50	0.30	0.38	0.30	0.10	0.17	0.75
CaO	2.27	2.79	2.26	3.18	2.23	2.39	0.80	0.66	0.87	0.94	0.92	0.64	0.44	0.51	2.93
Na_2O†	3.61	3.43	3.38	3.43	3.49	3.50	3.52	3.53	3.55	3.01	2.64	3.77	4.11	3.29	1.26
K_2O†	4.45	4.48	4.70	4.44	4.45	4.47	4.83	4.87	4.91	5.31	5.11	4.56	4.73	4.78	2.25
P_2O_5	0.13	0.15	0.14	0.11	0.15	0.15	0.03	0.01	0.06	0.01	n.d.	0.05	n.d.	n.d.	0.03

*Determined by ammonium meta vanadate titration, S. H. Evans analyst (Carmichael and others, 1968).
†Determined by flame photometry, J. Mason analyst.
n.d. - not detected
All other oxides determined by X-ray fluorescence spectrometry, F. H. Brown and J. Mason analysts.
Analyses matrix corrected using procedure of Norrish and Hutton (1969)

CIPW Norms, Weight percent

	77-3	77-7	77-8	79-1	80-5	80-6	77-1	77-2	80-1	80-2	80-3	80-4	77-6	80-7	77-5
Q	27.1	26.2	27.8	25.9	28.5	27.9	35.0	36.0	33.2	36.8	38.4	34.1	33.5	38.8	56.3
C	0.82	0.10	0.68	-	1.19	0.61	0.50	0.45	0.55	0.09	2.41	1.45	0.02	1.16	2.14
or	26.4	26.5	27.8	26.2	26.3	26.4	28.5	28.9	29.0	31.4	30.2	27.0	28.0	28.3	13.3
ab	30.6	29.0	28.6	29.0	29.2	29.6	29.8	29.9	30.0	25.5	22.3	31.9	34.8	27.8	10.7
an	10.4	12.9	10.3	13.0	10.1	10.9	3.77	3.21	3.92	4.60	4.56	2.85	2.18	2.53	14.3
hy	1.39	2.15	1.42	1.06	1.34	1.30	0.85	0.42	1.25	1.31	1.01	0.75	0.97	0.69	1.87
di	-	-	-	1.63	-	-	-	-	-	-	-	-	-	-	-
mt	0.85	2.16	0.81	1.15	0.80	0.80	1.09	0.76	0.48	0.23	0.81	0.61	0.52	0.51	0.05
il	0.68	0.76	0.74	0.68	0.68	0.68	0.36	0.28	0.51	0.13	0.28	0.51	0.11	0.19	0.30
hm	1.50	-	1.60	1.08	1.53	1.47	-	-	0.91	-	-	0.76	-	-	0.93
ap	0.31	0.36	0.33	0.26	0.36	0.36	0.07	0.02	0.14	0.02	-	0.12	-	-	0.07

Norms calculated on a volatile-free basis

Table 4. Trace elements analyses of the rhyolite of Gillies Hill

	Low-Silica Suite						High-Silica Suite								Zeolitic Tuff
													Cedar Knoll		
	77-3	77-7	77-8	79-1	80-5	80-6	77-1	77-2	80-1	80-2	80-3	80-4	77-6	80-7	77-5
Ba	1030	1105	1035	1020	1045	1030	230	160	490	5	190	205	n.d.	90	175
Nb	15	n.d.	40	35	15	10	30	30	25	30	30	35	105	25	25
Pb	20	n.d.	75	75	20	20	30	35	25	35	30	30	50	25	35
Rb	145	55	305	300	135	135	190	215	155	290	225	180	495	220	100
Sr	440	405	515	515	425	435	120	95	170	75	220	125	n.d.	75	645
Th	20	20	40	35	15	15	30	35	20	30	30	20	50	25	30
U	<2	<2	5	<2	<2	<2	10	5	<2	5	<2	<2	35	5	<2
Y	15	5	30	30	15	15	15	15	15	15	15	15	120	15	10
Zr	165	105	230	220	160	165	100	95	145	65	95	115	110	75	85
Th/U	-	-	8	-	-	-	3	7	-	6	-	-	1.4	5	-

n.d. not detected.

F. H. Brown, J. Mason analysts.