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Volcanic Episodes near Yucca Mountain as determined by paleomagnetic studies at Lathrop Wells, Crater Flat, and Sleeping Butte, Nevada

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ABSTRACT

It has been suggested that mafic volcanism in the vicinity of Yucca Mountain, Nev., is both recent (20ka) and a product of complex "polycyclic" eruptions. This pattern of volcanism, as interpreted by some workers at the Lathrop Wells volcanic complex comprises a sequence of numerous small-volume eruptions that become more tephra-producing over time. Such sequences are thought to occur over time spans as long as 100,000 years. However, paleomagnetic studies of the tephra and lava flows from mafic volcanoes near Yucca Mountain fail to find evidence of repeated eruptive activity over time spans of 10^3 to 10^5 years, even though samples have been taken that represent approximately 95% of the products of these volcanoes. Instead, the eruptions seem to have occurred as discrete episodes at each center and thus can be considered to be "monogenetic". Dates of these episodes have been obtained by the proven radiometric-geochronometer methods of K-Ar or $^{40}Ar/^{39}Ar$ dating.

INTRODUCTION

Volcanism poses a potential hazard to the proposed Yucca Mountain high-level-nuclear-waste repository that must be evaluated for the planned lifetime of the facility. Although the repository block itself is located in Miocene silicic volcanic rocks, this volcanic process is inactive and is not thought to represent a significant hazard relative to the planned lifetime of the repository (10,000 years). Conversely, mafic alkalic basalt eruptions have occurred at five nearby Basin and Range areas in the past 3.7 m.y.; the latest eruptions occurred at the Lathrop Wells volcanic center, situated only 20 km from the repository site. An evaluation is thus required of the potential for mafic volcanism in or near the repository.

Wells et al (1990) have suggested that the most recent eruptive activity at the Lathrop Wells volcanic center is very latest Pleistocene (20 ka) or Holocene in age, on the basis of its youthful morphologic appearance and weakly developed soils. Earlier eruptive events were also inferred, creating the need for a concept of "polycyclic" volcanism to explain numerous small-volume, short-duration eruptive events that occur at a single place over time spans of 10^3 to 10^5 years (Crowe et al, 1989). In addition, two basaltic cinder cones at Sleeping Butte, 47 km NW of Yucca Mountain, that are only 2.5 km apart have been described on the basis of detailed studies of geomorphic and soil characteristics to have produced five major cinder or flow eruptions in the past 285 k.y (Crowe et al, 1990). Finally, more than 25 vents, on multiple NE and NW orientations, with ages between 1.09 Ma and 786, ka have been suggested to exist on the main SW-NE volcanic trend across Crater Flat (Feuerback et al, 1990).

These interpretations of recurrent small-volume eruptions do not accord with observations of the nature of recent mafic cinder-cone volcanism. Wood (1980) reviewed all 42 known historical cinder-cone and flow eruptions worldwide and concluded that the average duration of eruptive activity is less than 30 days and that 95% are over within a year. The small overall volume of the mafic volcanic centers in the Yucca Mountain area, coupled with the estimated 30-40-km depths of origin, make it difficult to imagine a process whereby such small incremental volumes of magma would be repeatedly erupted in the same places. Moreover, the volume of erupted lava during the past 3.7 m.y. indicates a magma flux that is insufficient to maintain any high-level crustal chamber, thus requiring each successive dike to find its own path to the surface, its predecessor having frozen owing to the long repose periods between eruptions (Crowe et al, 1990).

Paleomagnetic studies of these young mafic volcanic rocks were undertaken to evaluate the rate of recurrence of eruptive activity at these centers. This work involves the collection of oriented core samples and the measurement of the direction of remanent magnetization preserved in these volcanic rocks. The preliminary conclusions of this study are as follows: (1) there is no evidence of polycylcic eruptions near Lathrop Wells or Crater Flat, (2) the volcanic rocks have not undergone tectonic deformation, and (3) my data support a simple and conventional interpretation of the history of mafic volcanism in the Yucca Mountain area.

BACKGROUND AND PROCEDURE

The geomagnetic field is not constant at the Earth's surface. Instead the local elements of the field, principally declination, inclination, and intensity, change with various periodicities. These variations, with periods ranging from 1 to 10^5 years, involve the gain or loss of tens of percent in the vectorial components of the field and are termed geomagnetic secular variations. These secular variations arise from electrical currents in the fluid core of the Earth and are commonly described in terms of dipole or nondipolar sources; the variations are a constant attribute of the geomagnetic field. At a given site in middle latitudes, the secular variation over time will cause declination changes of ±20° and inclination changes of ±25° about the average magnetic-field direction. Over sufficient time, the geomagnetic field approximates a geocentric axial dipole, giving an average magnetic-field direction with zero declination and an inclination derived from the equation

$$\tan(\text{inclination}) = 2\tan(\text{latitude}).$$

Secular variation produces rates of angular motion of the local magnetic-field direction that are generally slow but can range from less than 1° to more than 10°/century; a long term average is 4°-5°/century (Champion and Shoemaker, 1977; Mankinen et al, 1986). This variation, when viewed over time frames of hundreds of years, causes a smooth change in the local magnetic-field directions that, when plotted in stereographic projections, takes the form of large or small clockwise or counter clock-wise loops. If the secular-variation sampling interval is longer than about 200 years, the pattern of directions sampled (declination/inclination pairs) can be quite erratic and encompass virtually the entire range of possible directions. Thus, geomagnetic secular variation can be used as a timing device for assessing the duration of geologic phenomena. For example, when a lava flow is erupted and cools, it acquires a remanent magnetization parallel to the geomagnetic field. If a second flow erupts within a few months or years in the same general area, it also will acquire a remanent magnetization parallel to that of the first flow because the geomagnetic field remains nearly constant during short time intervals. But if 100 years or more had elapsed before the second flow is erupted and cools, then its paleomagnetic-field direction could be quite different because the local magnetic-field direction will generally have changed by 5° or more.

When this approach is applied to volcanic fields, for which there is ample geologic evidence (radiometric dating, compositional changes, multiple vents, unconformities, soil horizons, different erosional base levels) of eruptive activity over long periods of time, the directions of remanent magnetization vary widely. Conversely, when none of these geologic clues exist all the lava flows in a volcanic field have commonly been found to record a consistent direction (Champion and Shoemaker, 1977). Therefore, paleomagnetic studies that assess secular variation offer an ideal tool to evaluate polycyclic volcanism at the young mafic centers close to Yucca Mountain.

The sampling and measuring methods used in this study follow standard procedures (McElhinny, 1973), except that a sun compass was exclusively used for core orientation. Core samples were taken in the field by using a hand-held, gasoline-powered drill. Considering the geologic youthfulness of the volcanic units sampled and the absence of cross-sectional exposures, extra care was taken to collect material from parts of the lava flows that came to rest as fluids. All samples were progressively demagnetized in an alternating magnetic field to remove possible secondary remanent components, which arise principally from an isothermal remanence due to large current discharges from lightning.

RESULTS

A total of 755 cores from 59 sites were taken from the Lathrop Wells, Crater Flat, and Sleeping Butte volcanic centers. No paleomagnetic samples have been taken to date from the 2.7-Ma basalt of Buckboard Mesa. The sites were selected to sample both the understood stratigraphy and the areal extent of each volcanic center. The results are presented here in chronologic order, from oldest to youngest.

3.7-Ma volcanic centers in Crater Flat

The first group of volcanic centers crop out as deeply dissected cones and lava flows with locally exposed feeder dikes in the SE corner of Crater Flat. Absolute ages on these flow as determined by K-Ar or $^{40}Ar/^{39}Ar$ techniques have yet to be published, but some preliminary data were presented in Sinnock and Easterling (1983). The flows are out of grade with the alluvial surface of the basin and are buried by as much as 30 m of gravel. The flows are also faulted on a NNE trend, with displacements down to the west. Six sites were located in these flows, spread among all major outcrops, including one in an upfaulted block with at least 35 m of throw positioned on the east margin of Crater Flat. Preliminary paleomagnetic results suggest that all sites record a reversed direction of remanent magnetization, with a declination of 153° and an inclination of -67° (Fig. 1). Final magnetic cleaning may improve the comparison of the site mean directions, but the preliminary data in hand are already tightly grouped, suggesting little time duration to the eruptions forming the 3.7-Ma outcrops. The grouping also indicates no significant tectonic distortions of the floor of Crater Flat since 3.7 Ma, distortions which would disperse the mean paleomagnetic directions.

1.1-Ma volcanic centers in Crater Flat

The second group of volcanic centers consist of eroded cinder cones and surrounding lava flows that form a 12-km-long, NE-trending arc across the center of Crater Flat. The argon-based age information is unpublished for these centers but, again, has been presented in a preliminary form (Sinnock and Easterling, 1983). The flows are basically in grade with the alluvial surface of the basin and show no evidence of faulting. It was suggested on the basis of geomorphic and soil-profile data (Crowe et al, 1990) and of the identified orientation of multiple vents (Feuerback et al,

1990) that the volcanic history of these centers was complex and polycyclic. A program of paleomagnetic sampling was designed to evaluate these ideas. A total of 20 sites have been located in all five principal areas of this group, in outcrops of both lava flows and tephra. Preliminary paleomagnetic results indicate a single, reversed direction of remanent magnetization in all 20 outcrops, with a declination of 178° and an inclination of -64° (Fig. 1). Although this paleomagnetic-field direction and that of the adjacent, 3.7-Ma volcanic centers in Crater Flat are similar, they cannot be confused because they have different K-Ar ages and stratigraphic positions.

The possible time complexities of polycyclic eruptive activity or tectonic rotation caused by faulting that have been suggested for the 1.1-Ma volcanic centers at Crater Flat are effectively eliminated by these data. A compelling conclusion from the data is that a single short (approx. 100 year)-duration volcanic episode produced all five of the 1.1-Ma volcanic centers in Crater Flat.

Sleeping Butte cones

Two cinder cones and associated flows are situated 47 km NW of the Yucca Mountain area in the vicinity of Sleeping Butte. K-Ar dating on samples from these cones is unpublished, but preliminary ages fall in the range 250-300 ka (R. Fleck and B. Turrin, unpubl. data). On the basis of detailed geomorphic and soil-profile data, it has been suggested that three eruptive episodes (flows, 285 ka; cone, 200ka and 100 ka) have formed the Little Black Peak complex, whereas at least two eruptive episodes (flows, 285 ka; youngest cone, 10 ka) formed the Hidden Cone center (Crowe et al, 1990). Again, a program of paleomagnetic sampling was designed to evaluate this idea. A total of 13 sites were distributed in various flow outcrops and on the rims of the cinder cones. Preliminary data suggest that the two cones record similar, but not exactly the same, direction of remanent magnetization (Fig. 1). A small angular difference of 3° is indicated between the 351° declination, and 58° inclination, at Little Black Peak and the 345° declination, and 57° inclination, at Hidden Cone. An algorithm suggested by Bogue and Coe (1981) can be used to analyze the probability that these two directions are random samples of geomagnetic secular variation; they are so similar that the chance of their being random is only 5%. Given the close agreement of the paleomagnetic-field directions and the within-cone directional consistency, the long time gaps suggested by the polycyclic model are contradicted. The statistical argument effectively eliminates the possible interpretation that the two cones are truly separate in time. Instead, the cones and flows probably formed during a brief (approx. 100 years) interval at a K-Ar date of about 300 ka.

Lathrop Wells volcanic center

The latest mafic volcanism near Yucca Mountain consists of a cinder cone, spatter deposits, and lava flows, situated 20 km away at the Lathrop Wells volcanic center. The petrology and geology of this center have been described and mapped (Vaniman and Crowe, 1981) and more recently, reinterpreted (Crowe et al, 1988). On the basis of detailed geomorphic and soil-profile data, it has been suggested that this center also has had "at least four major eruption cycles," produced from multiple vent systems, the most recent episode at 20 ka (Wells et al, 1990; Crowe et al, 1990). A total of 27 paleomagnetic sites have been located in the variously identified tephra and lava-flow products of this center to test the model of polycyclic eruptive behavior. Preliminary results show that two distinct directions of remanent magnetization were recorded at Lathrop Wells (Turrin et al, in press) : one in "older," mantled spatter deposits (units Qs_5), and the other in "younger," unmantled lava flows (unit Ql_3) on the N and E margins (Fig. 1). The directions plotted in figure 1 for the Lathrop Wells volcanic center (Qs_1, Ql_3, Qs_5) are unlike those plotted for older volcanic centers and were obtained by averaging several mean site directions from each geologic unit. The statistical confidence in the directional distinction between units Ql_3 and Qs_5 is at the 99.98% level, although the angular difference between these two directions is only 4.7°. A statistical evaluation of this small angular difference indicates and 89% probability that the mean directions for units Qs_5 and Qs_3 are nonrandom samples of geomagnetic secular variation (Bogue and Coe, 1981).

This indication of limits on the time difference between the eruptions of units Qs_5 and Ql_3 corresponds to a statistical constraints from the argon dating that the two episodes can have been no more than 30 k.y. different in age (Turrin et al, in press; Turrin et al, 1991). Additional paleomagnetic data collected from an extended site along the rim of the supposedly young (20 ka) (Wells et al, 1990) Lathrop Wells cone also cast doubt on polycyclic eruptions there. Although this site is located in the very youngest tephra deposits on the rim, it has a mean paleomagnetic-field direction that is only 0.3° different from that of "old" unit Qs_5 spatter (Fig. 1). A statistical evaluation of this small difference indicates a chance of only 4 parts in 10,000 that the agreement could be random (Bogue and Coe, 1981). The close concurrence of these two directions, coupled with the absence of any geologic unconformity or soil horizon between the cinder-cone and spatter deposits, suggest that they represent the same eruption.

Overall, the paleomagnetic data suggest that all the eruptive products at the Lathrop Wells volcanic center were produced during two events, separated by no more than 100 years in time. Thus, in the context of geologic time, Lathrop Wells is monogenetic. K-Ar (Turrin et al, in press) and $^{40}Ar/^{39}Ar$ (Turrin et al, 1991) studies require that the date of this event is between 119 and 141 ka and cannot be as late as 20 ka. Although this date is still relatively recent for mafic volcanism so close to the proposed repository site (20 km), the order-of-magnitude increase in suggested age for the Lathrop Wells volcanic center, should have a significantly affect on the calculated probabilities of future volcanic disruption of the Yucca Mountain facility.

CONCLUSIONS

Paleomagnetic studies on the young (3.7-0.1 Ma) mafic volcanic rocks in the vicinity of Yucca Mountain indicate that the various volcanic centers were produced by episodic eruptions. The duration of eruptive activity at any one of these volcanic centers was sort (<100 years), and once eruptions were completed, they did not recur at that center. In addition, volcanic centers with similar K-Ar and $^{40}Ar/^{39}Ar$ ages can all be shown to have erupted within very brief (100 year) time spans. This observation is particularly well demonstrated at the 1-Ma volcanic centers of Crater Flat that share a single direction of remanent magnetization. Tests of polycyclic volcanism, using the paleomagnetic method, show that this not a viable explanation for the mafic volcanic episodicity near Yucca Mountain. The simple, monogenetic eruptions at these centers can be best date by using proven radiometric techniques, such as K-Ar and $^{40}Ar/^{39}Ar$ methods, on samples of the lava flows. The mean argon age of 130 ka on the Lathrop Wells volcanic center (Turrin et al, 1991) suggests that extremely recent mafic volcanism (10-20 ka) has not occurred near the Yucca Mountain repository.

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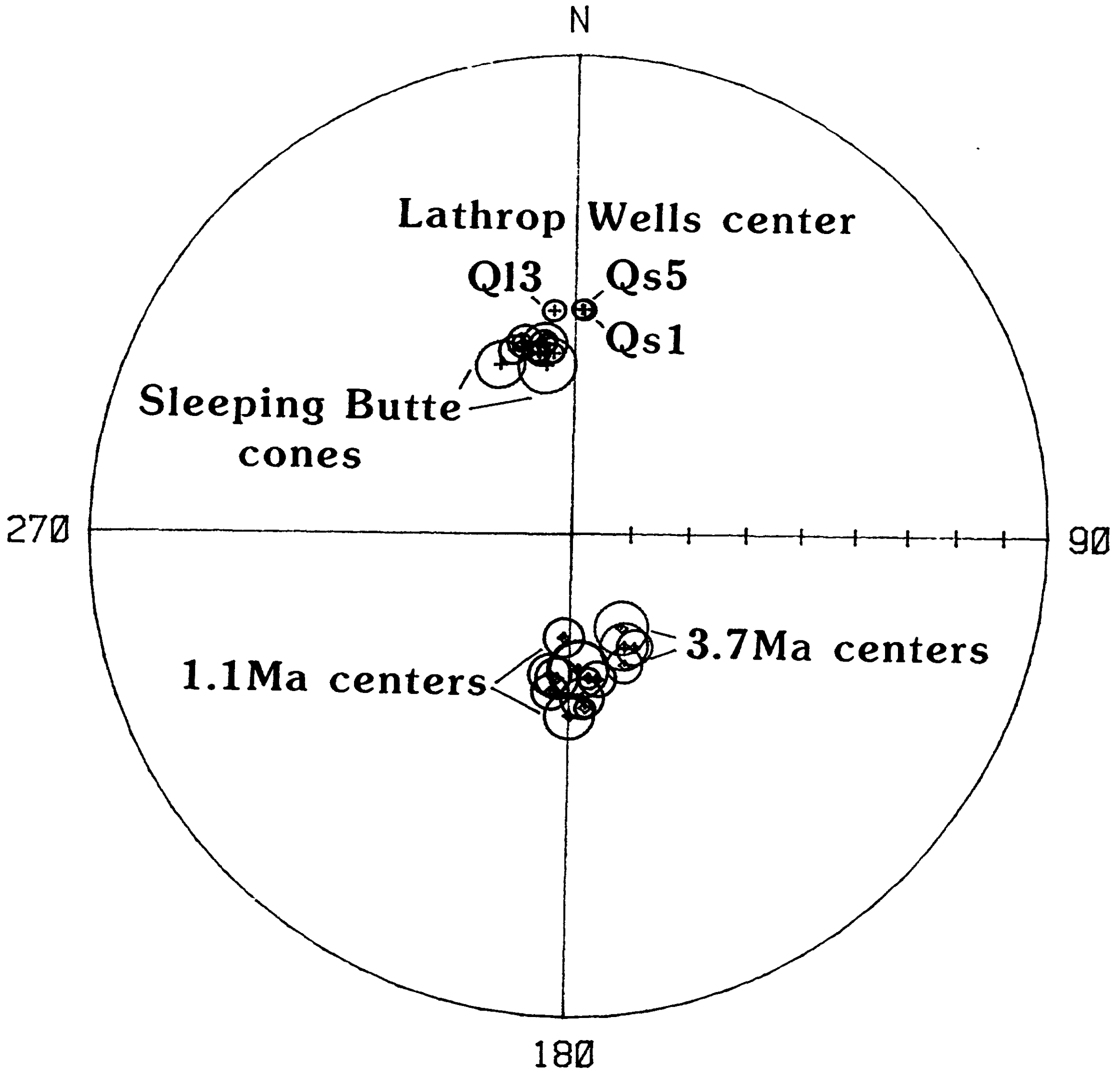
FIGURE CAPTION

FIGURE 1. Equal- Area projection showing mean directions of remanent magnetization and 95%-confidence circles for volcanic centers near Yucca Mountain. Crosses, lower hemisphere; diamonds, upper hemisphere. Mean directions for geologic units at the Lathrop Wells center are averages of mean directions for individual sites.

Note of Clarification regarding this publication

This Open-File Report is a verbatum republication of an extended abstract presented to a meeting of the American Nuclear Society in Las Vegas, NV in 1991. It has been republished at the request of the Nuclear Regulatory Commission to improve its availability to the public. It has not been altered from its original form, except to bring it into conformity with reference style for Open-File Reports, and in the updating of references which were in press.



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