VOLCANIC HAZARD STUDIES FOR THE YUCCA MOUNTAIN PROJECT

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ABSTRACT

Volcanic hazard studies are ongoing to evaluate the risk of future volcanism with respect to siting of a repository for disposal of high-level radioactive waste at the Yucca Mountain site. Seven Quaternary basaltic volcanic centers are located between 8 and 47 km from the outer boundary of the exploration block. The conditional probability of disruption of a repository by future basaltic volcanism is bounded by the range of 10-8 to 10-10 yr-1. These bounds are currently being reexamined based on new developments in the understanding of the evolution of small volume, basaltic volcanic centers including: 1) Many of the volcanic centers exhibit brief periods of eruptive activity separated by longer periods of inactivity. 2) The centers may be active for time spans exceeding 105 yrs, 3) There is a decline in the volume of eruptions of the centers through time, and 4) Small volume eruptions occurred at two of the Quaternary centers during latest Pleistocene or Holocene. We classify the basalt centers as polycyclic, and distinguish them from polygenetic volcanoes. Polycyclic volcanism is characterized by small volume, episodic eruptions of magma of uniform composition over time spans of 103 to 105 yrs. Magma eruption rates are low and the time between eruptions exceeds the cooling time of the magma volumes.

Future rates of volcanic activity can be forecast for the Yucca Mountain region using a plot of cumulative magma volume of Quaternary eruptive events versus time. The curve fitted to this plot decreases in slope with time, consistent with a waning in rates of volcanic activity. Curve slope segments yield magma eruption rates that range from 130 to 66 $m^3 yr^{-1}$. Two scenarios are possible for future volcanic activity in the Yucca Mountain region: 1) Recurrence of small volume eruptions at one or both of the youngest volcanic centers in the region. These are anticipated events (recurrence times of 1.5 to 15 ka) but there are virtually no consequences of such events at the Yucca Mountain site. 2) Formation of a new volcanic center. This is an unanticipated event that falls within the range of previously calculated probability bounds. The important constraints are the structural controls of sites of future volcanic activity. A new volcanic center is unlikely to occur at Yucca Mountain. This is based on the time-space patterns of volcanic activity and the infrequent occurrence of basalt centers in mountain range interiors.

INTRODUCTION

Volcanism represents one of a number of geologic processes that could affect the long-term safety of isolation of high-level radioactive waste at the Yucca Mountain site. Volcanism studies are required for site characterization activities for two reasons:

1. Five Quaternary volcanic centers are present within a 25 km radius circle centered on the Yucca Mountain exploration block (Fig. 1). Basaltic volcanism must be viewed as an anticipated geologic process during the isolation period of high-level, radioactive waste (10 ka).

2. Volcanism potentially represents a catastrophic process. The penetration of a repository by ascending basalt magma followed by surface eruption, could lead to immediate release of waste radionuclides to the accessible environment.

The purpose of this paper is to provide a summary of the past work and current strategy for characterizing and defining the risk posed by future volcanism for the Yucca Mountain site. We briefly review past study results and identify areas of development of new concepts for volcanism studies. These new concepts, which were driven by the detailed requirements for understanding the nature and history of volcanism in the site area, have contributed to advances in the basic understanding of the processes of basaltic volcanism. These advances include: 1) A combination of field mapping, geomorphic and soils analysis techniques with conventional chronology studies can be used to recognize and resolve the chronology of young (2 ka) volcanic events, 2) Small volume basalt centers may have complex eruptive histories (polycyclic activity) with episodic eruptions over periods exceeding 105 yrs, and 3) Predictions of future basaltic volcanic activity can be quantified by combining detailed chronology studies with determinations of magma eruption volumes.

This paper provides a brief overview of three topics and their impact on volcanic hazard assessment for the Yucca Mountain site: 1) Evolution of long-lived basalt centers, 2) Polycyclic volcanism and 3) Volcanic hazard investigations for the Yucca Mountain Project.

PAST WORK

Volcanic hazard studies for the Yucca Mountain site have been described in a number of publications (1,2,3,4). The most probable type of future volcanism in the area is basaltic volcanism. There have been three episodes of basaltic volcanic activity in the Yucca Mountain region during the

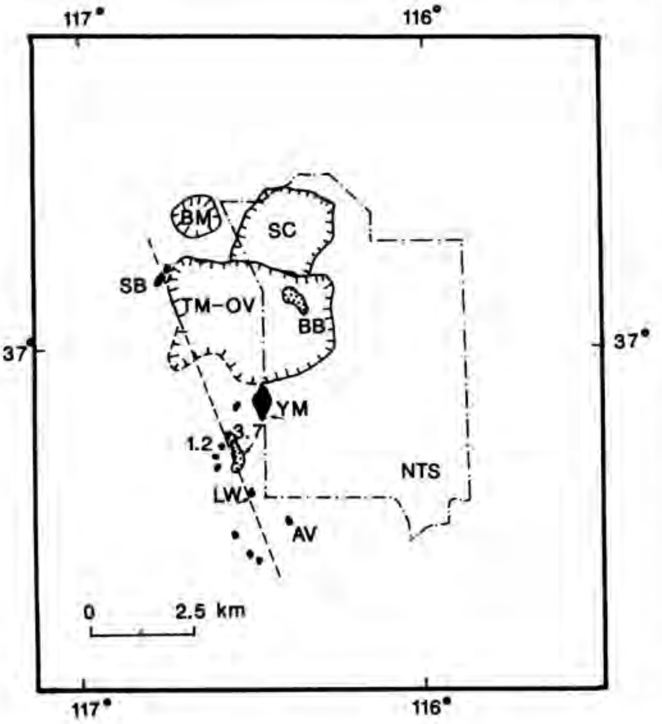

Fig. 1. Genealized map of the distribution of post 4 Ma basaltic volcanic rocks of the Yucca Mountain region. AV: aeromagnetic anomaly sites of the Amargosa Valley (4); BB: 2.8 Ma basalt of Buckboard Mesa; LW: Lathrop Wells volcanic center, SB: basalt centers of Sleeping Butte; 1.2: 1.2 Ma volcanic centers of western Crater Flat; 3.7: 3.7 Ma volcanic centers of southeast Crater Flat, YM: exploration block for the repository site at Yucca Mountain; TM:OV: Timber Mountain-Oasis Valley caldera complex; SC: Silent Canyon caldera complex; BM: Black Mountain caldera complex.

last 12 Ma. These episodes include:

1. Large volume basaltic volcanism that was temporally and spatially associated with the waning stage of the Timber Mountain-Oasis Valley caldera complex (5,6). The age of this activity is about 12 to 8.5 Ma.
2. Small volume basaltic activity that was restricted to the northeast part of the Yucca Mountain region. The age of this activity is 9 to 6.5 Ma.
3. Small volume basaltic activity that was restricted to the central and southeast parts of the Yucca Mountain region. The age of this activity is 3.7 Ma to Late Pleistocene or Holocene.

The basalt compositions of the two youngest episodes are predominantly alkalic (3,4,7). Major petrologic types include straddle-type hawaiite, hypersthene hawaiite and basaltic andesite (4,7). Eruption activity from the basaltic volcanic centers was predominantly Strombolian. These eruptions were characterized by formation of scoria cones and associated small volume, blocky aa lava flows. Episodes of hydrovolcanic activity have been identified at three volcanic centers (4,8). The probability of a volcanic event occurring and directly disrupting a repository at Yucca Mountain is 10^{-8} to 10^{-10} yr^{-1} (2).

NEW DEVELOPMENTS

Evolution of Basaltic Volcanic Centers

A standard approach to studying the evolution of continental basaltic volcanic centers is to sample and analyze the lava flows. The assumption is made, and has been made for many years of past geological research, that these centers formed during short duration eruptive events (activity on the time scale of days, months, or at most years). Sampling of the lava flows should therefore provide adequate representation of the composition and age of eruptive events.

Initial K-Ar age determinations of lava flow samples from the youngest volcanic center, the Lathrop Wells center (Fig. 1), yielded an apparent age of about 270 ka (9). It was assumed that this age represented the time of all volcanic events. One inconsistency with this interpretation is the degree of preservation of the main scoria cone: the cone slopes and the geometric form of the cone are virtually unmodified by erosion. However, in conflict with these observations, a K-Ar age determination of 230 ka was obtained for a bomb collected from the summit crater of the scoria cone. A second inconsistency is the apparent anomalous old ages and variability in K-Ar age determinations obtained for the Lathrop Wells volcanic center (9,10).

We chose, starting in late 1986, to further investigate the Lathrop Wells volcanic center to test the possibility that the scoria cone and the lava flow units from the center could differ significantly in age. The following lines of evidence indicate that the scoria cone is significantly younger than the lava units and the center had a complex, long history of volcanic activity:

1. New geologic mapping of the volcanic center at a scale of 1:4000 indicates that there were at least four major eruption cycles (11). Three spatially separate fissure systems formed prior to the development of the main scoria cone and associated satellite cones. These fissures are marked by slightly to markedly degraded scoria mounds and spatter ramparts. The fissures vented small volume, blocky aa lava flows from multiple sources along the length of the fissures.
2. The limited geomorphic modification of the main scoria cone is consistent with a young cone age (12). Geomorphic features indicative of a young age include cone slopes near the angle of repose (29 degrees), the scarcity of rilling and mass wasting features, and the absence of a cone apron. An additional feature is the very weak horizon development of surface soil on the scoria cone slopes. Wells et al (12) present evidence that indicates

the Lathrop Well scoria cone is similar in cone geomorphology and soil development to the youngest cone of the Cima volcanic field, California. This cone has been dated at about 15 ka using a variety of direct and indirect dating techniques. Thus by comparison, the youngest scoria cone eruptions at Lathrop Wells are probably latest Pleistocene to Holocene (12). The major unknowns in calibrating the age of the scoria eruptions are the rates of soil formation on basaltic scoria and the rates of erosional degradation in an area of high eolian flux.

3. Stratigraphic sections measured in quarry exposures on the south flank of the scoria cone show a complex sequence of buried soils, primary and reworked tephra, and eolian deposits (12). The exact stratigraphic position of these units is uncertain. However they appear to occur between tephra erupted from the young scoria cone and the oldest fissure system. The complexity of the stratigraphic section and the presence of soils between tephra units require a significant hiatus between volcanic events.
4. Different paleomagnetic pole positions have been measured for lava flows of the younger two fissure systems and for scoria deposits of the oldest fissure system. These data are consistent with a significant age difference between volcanic units. A current inconsistency that has not been resolved is the pole position obtained for bombs exposed in the summit of the main scoria cone. This position matches the pole position of the older fissure unit.
5. Studies of rock varnish accreted on lava surfaces adjacent to the Lathrop Wells scoria cone have revealed the presence of exotic Cr-bearing, iron-titanium oxide phenocrysts in the varnish. These phenocrysts occur in the uppermost layers of the varnish suggesting introduction during the latest stages of varnish formation. The euhedral grain morphology of the phenocrysts indicates the material was not part of the eolian influx from the Amargosa Valley (13). A likely source of the phenocrysts in the varnish is deposition from a recent scoria fall event, most probably associated with the final cone-forming eruptions of the main scoria cone.

K-Ar age determinations were obtained for five sample sites from lava flow units of the Lathrop Wells center (14). The interpretation of these age determinations has proven problematic. Our present conclusions from these data include: 1) The lavas are younger than the previously reported age of 270 ka, 2) Assuming the lavas are divided into two units, based on the field mapping, geomorphic and paleomagnetic information described above, the older lava flow sequence yields a K-Ar age of 214 ka (arithmetic mean, $n=4$) or 157 ka (weighted average, $n=4$). The younger flow sequences yields a K-Ar age of 125 ka (arithmetic mean, $n=12$) or 137 (weighted average, $n=12$). 3) The lava flow ages are not statistically different in age (F test) unless one sample site from the younger lava unit is discarded. This site appears anomalous and yields a K-Ar age of 480 ka (arithmetic mean, $n=3$) or 450 ka (weighted average, $n=3$). It is identified as an outlier on a probability plot of percent radiogenic Ar versus age. 4) The geomorphic preservation of the younger lavas and their stratigraphic position relative to the modern alluvial surfaces suggest they could be significantly younger than 100 ka. Further work is underway to attempt to resolve the K-Ar ages of the lava flow units.

Polycyclic Volcanism

Detailed studies are underway at two other Quaternary volcanic centers, the basalt of Sleeping Butte, located 47 km northwest of Yucca Mountain. The basalt of Sleeping Butte consists of two small volume, basaltic centers spaced approximately 5 km apart. Lava flows from the centers have been dated previously at 285 ka. Preliminary evaluations of the eruption history and the geomorphic and soil characteristics of volcanic deposits of this center indicate that both exhibit a complex, long duration eruptive history similar to the Lathrop Wells center. Thus three of the seven Quaternary volcanic centers in the Yucca Mountain region show intermittent eruptive behavior over long time spans.

We make an important distinction between polycyclic and polygenetic volcanism. Polygenetic behavior is characterized by intermittent eruptions over time spans of 105 to 106 yrs. The volume of eruptions range from <1 to $>10\,\mathrm{km}^3$ and there may be significant variations in the composition of the magmas, reflecting the range of magmatic processes operating in a shallow chamber(s). Wadge (15) noted that polygenetic volcanoes require a four-component magma supply system, one element of which is a sub-volcanic reservoir. The development of this type of system requires a maintained magma supply rate. Fedotov (16) argued that the required magma supply rate to develop and maintain a crustal magma reservoir is dependent on the magma composition and the geothermal gradient. He estimated that magma supply rates on the order of $10^7\ \mathrm{m}^3\ \mathrm{yr}^{-1}$ are required to maintain intermittent or continuous basaltic volcanism in a continental setting. We use the term polycyclic to refer to small volume, ($>1\mathrm{km}^3$) volcanic centers that exhibit intermittent volcanic activity where the time separation between volcanic events exceeds the maximum calculated cooling times for the volume of erupted magma (10^2 to 10^3 yrs). The magma supply rates for these centers are small ($<10^5\ \mathrm{m}^3\ \mathrm{yr}^{-1}$) and there is limited variation in the composition of the magmas. These centers have previously been classified as monogenetic volcanoes.

Prior to this work, the possibility of polycyclic volcanic activity at small volume basaltic centers was considered unlikely for several reasons: 1) Strombolian eruptions are inferred, based largely on observations of historic eruptions, to form in single eruption cycles. Wood (17) estimated that the average duration of a monogenetic basalt eruption is about 30 days. 2) The small volume of the basalt centers of the Yucca Mountain region (km3) make it unlikely that magma in feeder systems beneath the volcanoes could be preserved for significant lengths of time. The cooling times of these volumes of magma, assuming tabular feeder systems, are far shorter than the repose periods between eruptions. 3) The volume of magma erupted in the Yucca Mountain region during the Quaternary ($0.5\ \mathrm{km}^3$) is insufficient to maintain a crustal magma chamber. 4) The long time between eruptions requires generation of separate magma pulses that are erupted at nearly identical vents. This type of behavior may be possible at high cone density volcanic fields like the Lunar Crater volcanic field. It is not expected at the small volume, spatially isolated basalt centers of the Yucca Mountain region.

The magma eruption rates during the Quaternary for the basalt centers of the Yucca Mountain area are about 2 x 10^2 m^3 yr^{-1}. Multiple eruptive events would not be expected with such low eruption rates. However the following general characteristics have been recognized for the three studied Quaternary volcanoes of the Yucca Mountain region:

1. Multiple eruptions from closely spaced volcanic vents.
2. Brief periods of episodic eruptive activity separated by long periods of inactivity (10^3 to 10^5 yrs).
3. The time span of activity at individual centers exceeds 10^5 yrs.
4. There is an increase in the ratio of scoria/lava through the eruption sequence implying an increase in the volatile content of the magma. Terminal eruptions of the polycyclic centers are entirely pyroclastic.
5. A decreased eruption volume through the polycyclic sequence. Initial eruptions tend to have volumes of about 10^6 to 10^7 m^3. Final eruptions may have volumes of less than 10^6 m^3.

The frequency of occurrence of polycyclic activity at small volume volcanic centers has not been established. All three of the carefully studied Quaternary volcanic centers in the Yucca Mountain region exhibit polycyclic behavior. Brief examination of the four 1.2 Ma volcanic centers in Crater Flat using the field mapping, geomorphic and soil techniques indicate that these centers may exhibit polycyclic behavior. Geomorphic studies of individual centers in the Cima volcanic field show that some of the centers exhibit polycyclic behavior (18). We conclude, from studies in progress, that polycyclic eruptive behavior is a common but not necessarily ubiquitous feature of small volume basaltic volcanic centers of the southern Great Basin. It is a sufficiently common volcanic process, that it must be considered in volcanic hazard studies for the Yucca Mountain site.

An important question for understanding the evolution of polycyclic volcanic centers is the origin of the individual magma pulses. As noted above, the small volume, spatially isolated volcanic centers are probably not derived from periodic tapping of a crustal magma chamber. However, Serpa et al., (19) describe a mid-crustal reflecting zone (15 km depth) about 3 to 5 km thick beneath southern Death Valley. This zone is connected by a low angle fault system to a Quaternary scoria cone. They suggest the reflecting zone could be a magma body that fed magma to the surface along the low angle fault system. We tentatively conclude that shallow chambers are unlikely to exist in this geologic setting of Yucca Mountain because of the extremely low flux of basaltic magma during the Quaternary. Geophysical studies have been proposed for the characterization program to investigate the possible existence of crustal magma chambers

Two petrologic models are possible for the origin of the magmas of the small volume basalt centers: 1) Derivation by periodic tapping of a deep magma reservoir, possibly at the crust-mantle interface, and 2) Production during separate episodes of mantle melting. Geochemical studies are underway to obtain data to test these models. Lava and scoria samples have been collected systematically from volcanic units from each eruptive cycle. Studies of the major and trace element geochemical composition of the lava and scoria units should discriminate the two petrogenetic models. In either case, an extremely significant outgrowth of the polycyclic concept is the impact on petrologic studies of small volume volcanic centers. Past studies have focused preferentially on lava samples of the centers. Because of this biased sampling, the complete magma cycles of these centers have not been adequately studied.

VOLCANIC HAZARD INVESTIGATIONS

The volcanic hazard assessment for the Yucca Mountain site is based on combining the results of geologic, geochemical and geophysical investigations with risk assessment, where risk is defined as a product of probability and consequence analysis (20). The probability part of this assessment has been emphasized in site evaluations (9).

The probability of disruption of a repository by future volcanism is formulated as a conditional probability:

$$Pr = [E2 \text{ given } E1]$$

where E1 is the rate of volcanic activity and E2 is the probability of intersection of a repository by magma, given E1. This probability is expressed mathematically as (2):

$$Pr[\text{no disruptive event before time } t] = \exp^{(-rtp)}$$

where **r** is the rate of volcanic activity and **p** is the probability that a volcanic event disrupts the repository. The **r** is the most difficult parameter to bound for these calculations. The preferred technique is to define r through evaluations of magma eruption rates. Crowe et al (2) obtained magma eruption rates using a plot of magma volume versus time. A magma volume/time plot was constructed using age and volume data for the volcanic centers of the Yucca Mountain region. A regression curve was fitted to the data ($r = 0.80$) and the slope is equal to the magma eruption rate (210 m^3 yr^{-1}).

Probability calculations provide a numerical definition of the potential for volcanic disruption of a high-level waste repository. Studies have shown an exaggerated risk of nuclear technology including aspects of waste disposal in the public domain (21). Probability calculations are one means of communicating risk assessment perspectives to the public.

Consequence analysis, expressed as radiological release levels at the surface, have been completed for scenario of rising basaltic magma penetrating a repository at Yucca Mountain and erupting at the surface (22). However, there were numerous assumptions required for these calculations. The most critical include the geometry of intersection of magma in feeder dikes with stored radioactive waste, the mechanisms of incorporation of waste in the magma, the physical and chemical interaction between waste and magma and the dispersal mechanisms of waste in a surface volcanic eruption. The potential range of radiological releases obtained through varying the parameters of these assumptions are large. The resulting uncertainty may make consequence analysis of limited value in assessing the risk of direct intersection of a repository by basaltic magma.

A critical question for assessing volcanic hazards for the Yucca Mountain site is how the probability bounds are affected by the revised chronology of volcanic eruptions and the polycyclic behavior of individual centers? Revised data for the chronology of the volcanic centers were used to reconstruct the magma volume/time plot using the following assumptions: 1) The oldest lava flows at the Lathrop Wells center are 214 ka, the younger lava flows are 30 ka, the age of the last cone forming eruption is 10 ka, 2) The age of the lava flows at south Sleeping Butte center is 285 ka, there were two major cone forming events, one at 200 ka and the second at 100 ka and 3) The age of the lava flows at north Sleeping Butte center is 285 ka, the youngest cone forming event is 10 ka. Regression analysis using these revised volcanic ages yield nearly identical magma eruption rates and regression fit parameters as the previous calculations.

What is the significance of the lack of change in the calculated magma eruption rate for the probability analysis? Is the analysis insensitive to variations in the age of volcanic events? Or is the magma volume/time behavior of the volcanic centers sufficiently well described that new data do not result in changes in the eruption rate? Data from well studied volcanic fields in Hawaii provide insight into these questions.

Shaw (23) has shown that eruption rates at Kilauea and Mauna Loa volcano vary between 0.01 and 0.1 km^3 yr^{-1}; both volcanoes exhibit historic eruption rates of about 0.025 km^3 yr-1. Shaw suggests that there is an approximate steady state established in the Hawaiian volcanic systems between the rate of magma supply in a volcanic system and the surface eruption rate. The probable control of this steady state is the balance established between the stress field of the region and the rate of magma supply to the chamber beneath the centers. He further notes, based on evaluations of the cumulative erupted magma volumes and time, a self-similarity developed in the scale of observations (23). Steady state relationships can be established for the behavior of individual volcanic vents, growth of major volcanic centers, growth of individual islands of the Hawaiian islands, and long term growth of the Hawaiian-Emperor volcanic chain.

Can a magma volume/time curve be used to forecast future volcanic events for the Yucca Mountain region? We suggest that this can be done if two cases are satisfied: 1) The magma volume data must be obtained for a recognized volcanic province where there is consistency in the processes controlling generation, ascent and eruption of magma. This is satisfied for the Yucca Mountain region by examination of the time-space behavior of volcanic activity. All Quaternary volcanic activity in the region is concentrated in a narrow northwest-trending zone that extends from the Amargosa Valley on the south to northwest of Beatty (Fig 1). Eruption volume/time behavior is evaluated for the volcanic history of this volcano-tectonic zone. 2) The chronology of volcanic activity must be carefully established for individual units of the volcanic centers. This work is in progress for the Yucca Mountain area using detailed field mapping (1:5000 scale), K-Ar age determinations, rock varnish calibration and geomorphic and soils studies. Additionally, geochronology procedures using solid source mass spectrometry measurements of the U-Th decay series of volcanic units and ^{3}He/^{4}He ratios of surface volcanic rocks are being applied to the Yucca Mountain volcanic centers (24).

Figure 2 is a plot of cumulative magma volume versus time for the volcanic centers of the Yucca Mountain region. Two important relationships are established from this plot: 1) The slope of the curve fitted to the data decreases upward. This is consistent with previous suggestions (25,2) that the rate of volcanic activity is waning in the Yucca Mountain region. It contrasts markedly with the cumulative magma volume/time for active volcanic systems (Hawaii (23), and Coso volcanic field (26) which have an uniform slope. 2) The tangent or first derivative of curve slope segments yields the magma eruption rate for the Yucca Mountain volcanic province. This slope declines from about 130 m^3 yr^{-1} to 66 m^3 yr^{-1} for the time interval of Figure 2.

The parameter of the probability calculation is derived using the following equation:

$$Tp = (Vm/Em)\ Te$$

where Tp is the predicted time of the next eruption, Em is the magma production rate and Te is the time of the last volcanic eruption. Em is derived from Figure 2. It varies by about a factor of 2. Te is estimated to be 10 ka based on current understanding of the chronology of the youngest volcanic activity. The most sensitive parameter is Vm. It must be evaluated through studies of the eruptive volumes of Quaternary volcanic centers in the southern Great Basin.

Risk of Future Volcanism

Two scenarios are developed for future volcanic activity in the Yucca Mountain region: 1) Recurrence of a small volume scoria eruption at either the Lathrop Wells or the younger Sleeping Butte volcanic centers and 2) The formation of a new center of basaltic volcanism.

The polycyclic patterns of eruptions at the volcanic centers suggest that renewed activity at the Lathrop Wells or Sleeping Butte would be a small volume eruption that mantled the scoria cone and adjacent area with thin tephra deposits. This type of eruption may have occurred multiple times at the Lathrop Wells and Sleeping Butte centers during late Pleistocene and Holocene. The volume of past eruptions is about 105 to 106 m^3. The time required to generate these volumes assuming a magma production rate of 66 m^3 yr^{-1} is 1.5 to 15 ka. This could be viewed as an anticipated volcanic event during the lifetime of the repository.

The consequences of a small volume eruption at existing centers are insignificant. Disruption effects would be confined to the immediate area of basalt feeder dikes beneath the cone. The Sleeping Butte center is located 47 km northwest of the exploration block. There would be no effect at Yucca Mountain from an eruption at this center. The Lathrop Wells center is located 20 km south of the

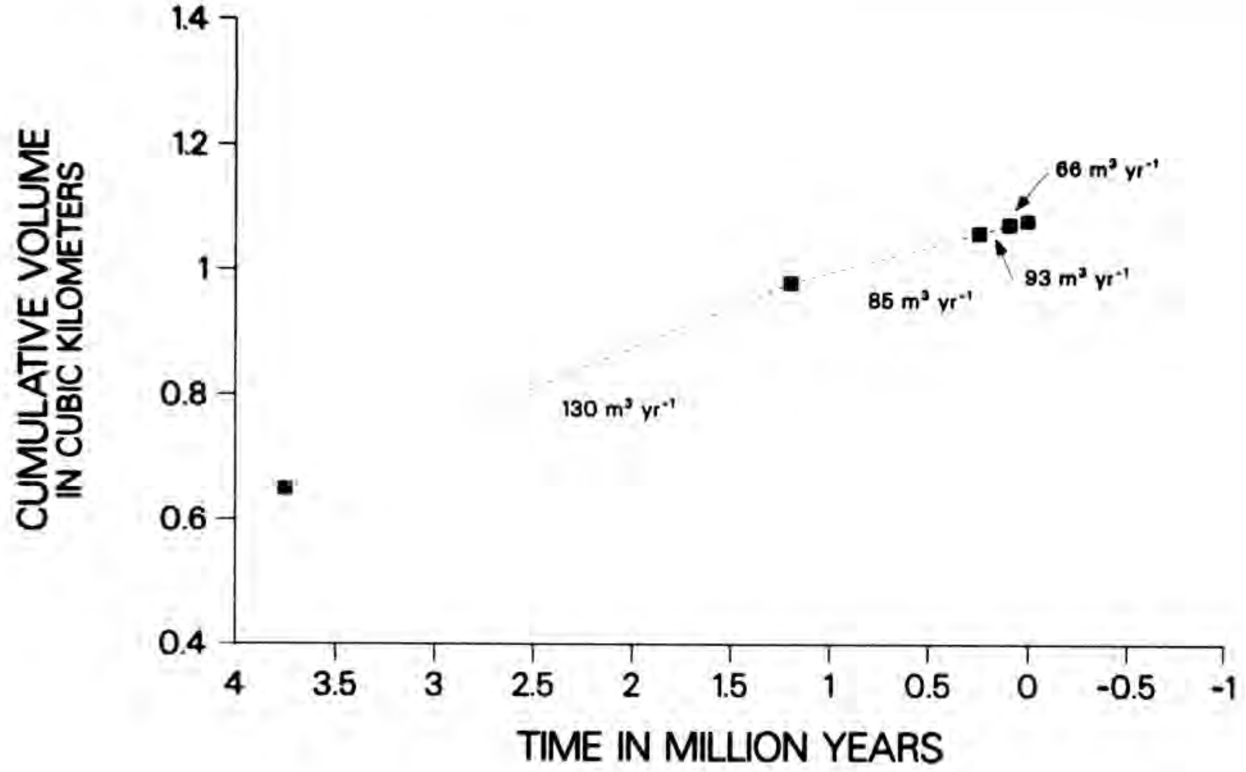

Fig. 2. Plot of cumulative magma volume versus time for volcanic centers (3.7 Ma and younger) of the Yucca Mountain region. The numbers, in m^3 yr^{-1}, are magma eruption rates for eruption intervals. They were derived graphically as the tangent to the curve slope segment. The plot illustrates two features: 1) The decline in magma eruption rates through time, 2) An apparent increase in frequency of eruptions with time.

exploration block. The primary concern with a future eruption at this center would be associated seismic activity or possible changes in the ground water table caused by intrusion of basalt along feeder dikes. Seismic activity including low magnitude earthquake swarms and accompanying volcanic tremor are common with basaltic eruptions. The significance of this activity depends on the location and magnitude of the earthquake activity. Generally, earthquake magnitudes accompanying volcanic activity are of small magnitude. They are expected to be of much smaller than the design earthquake for the repository (24). The Lathrop Wells volcanic center is located 20 km down the hydrologic gradient from the site. The ground water effects of a small volume eruption should be confined to the area of the subsurface feeder dikes. Dike widths at repository depths are about 1 to 5 meters (8). No mechanism can presently be identified for local ground water changes at the Lathrop Wells center to have any affect on the ground water setting beneath Yucca Mountain.

The second scenario for future volcanic activity is the formation of a new volcanic center. The average volume of initial eruptions at polycyclic centers in the Yucca Mountain region is about 5×10^6 m^3. Magma generation times for these events are about 70 ka. This rate falls within the range of previously calculated volcanic rates for probability calculations (2). The key parameters for predicting the significance of the second volcanic scenario are the structural controls of future sites of volcanism, the range of magma volumes associated with polycyclic eruptions, and the duration of activity at polycyclic centers. Two points are important for the structural controls of volcanism: 1) As noted previously, all Quaternary volcanic eruptions in the Yucca Mountain region are confined to a narrow northwest-trending band located southwest of Yucca Mountain (Fig 1). The two sigma error band of the geographic dispersion of the location of Quaternary centers from the center line of this zone does not intersect the exploration block of Yucca Mountain. 2) It is rare in the Quaternary volcanic record of the southern Great Basin for basaltic volcanic centers to occur in the interior of mountain ranges. The centers tend to form in alluvium-filled basins or along fault-bounded range fronts. Data on duration of activity and volumes of polycyclic eruptions are documented only at the three youngest Quaternary volcanic centers in the Yucca Mountain region. Work is in progress to obtain these data for a population of over 100 Quaternary volcanic centers in the Cima and Lunar Crater volcanic fields.

ACKNOWLEDGMENTS

This work was supported by the Yucca Mountain Project Office as part of the Civilian Radioactive Waste Management Program. This Project is managed by the US

Department of Energy, Nevada Operations Office.

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