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Yucca Mountain Could Face Greater Volcanic Threat

Locating a radioactive waste repository in the United States has been the subject of over 20 years of scientific research, political wrangling, and court decisions. If a nuclear waste repository is constructed at Yucca Mountain, Nevada, 70,000 metric tons of spent nuclear fuel will be buried 300 m below the surface.

Because eight Quaternary basalt volcanoes erupted within 50 km of the proposed repository in the past million years, future volcanism is an important issue. The U.S. Department of Energy (DOE) is currently using an expert panel to evaluate current models [*Perry et al.,* 1998] and consider alternative models. This article presents an alternative model, developed independently of DOE and the expert panel, and reviews new information pertinent to volcanic hazard studies. Additionally, this article suggests that the size of the Yucca Mountain volcanic field is not presently well known.

The main implication of the alternative model is that higher recurrence rates for Yucca Mountain volcanism are possible in the future and must be factored into probability models for site disruption. This new information is timely because of the renewed interest in volcanism as a potential hazard to nuclear waste storage.

Using a probabilistic approach to hazard assessment, DOE applies the following U.S. Environmental Protection Agency (EPA) guideline. Volcanism is not an issue if there is less than one chance in 10,000 in 10,000 years of repository disruption by volcanic eruption (or less than 1.0×10^{-8} events per year). A DOE expert panel calculated the probability of magmatic disruption of the Yucca Mountain site at 1.5×10^{-8} events per year. Other calculations by the Southwest Research Institute's Center for Nuclear Waste Regulatory Analyses and the State of Nevada estimated probability as much as two orders of magnitude greater than the EPA guideline.

In 2004, the U.S. Court of Appeals ruled that the 10,000-year compliance period is an arbitrary standard and the court ordered EPA to establish a new health standard that reflects the time of maximum radioactive contamination of the environment as originally recommended by the U.S. National Academy of Sciences. Following this legal decision and a new health standard recently proposed by EPA, DOE may have to guarantee repository safety for as long as 1,000,000 years.

The Traditional Model

Traditional models for basalt volcanism near Yucca Mountain call upon partial melting of lithospheric mantle at a depth of about 60 km (reviewed by *Perry et al.,* 1998). The traditional model regards Pliocene to Quaternary basaltic volcanism as the waning phase of the southwestern Nevada volcanic field.

Volcanic hazard studies done by DOE, however, only consider volcanoes in the Yucca Mountain area and do not factor in volcanism to the northeast in the Reveille–Lunar Crater (RLC) area (Figure 1). This consideration is based on (1) isotopic ratios of neodymium and strontium that suggest that Yucca Mountain basalt has a different source than basalt in the RLC, and (2) the assumption that the Yucca Mountain field is small with no more than 20 vents and 10 km^3 of basalt while the RLC contains 100 vents and 100 km^3 of basalt; therefore, size differences preclude any linkage of the two fields.

Observations

The following observations are difficult to explain by the traditional model:

1. Basaltic volcanism near Yucca Mountain and in the RLC is episodic with the greatest number of eruptions occurring at about 4 and 1 Myr. Episodic volcanism is common in other nearby volcanic fields as is Pliocene and Quaternary volcanic activity; however, periods of maximum activity commonly do not correspond to those observed at Yucca Mountain or RLC.
2. Melting occurred at depths of 133–115 km at Crater Flat, 160 km northwest of Las Vegas, Nevada, and 162–110 km beneath the RLC [*Wang et al.,* 2002; *Smith et al.,* 2002]. Note that all melting occurred in the asthenosphere, contrary to the traditional model that requires melting of the lithospheric mantle. Several studies show that melting of lithospheric mantle late during a volcanic episode is difficult. *Harry and Leeman* [1995] recognized problems in sustaining melting of the mantle lithosphere and suggested that Quaternary basalts were derived by melting of asthenospheric mantle. Additionally, *Hawkesworth et al.* [1995] suggested that most Pliocene and Quaternary basaltic fields

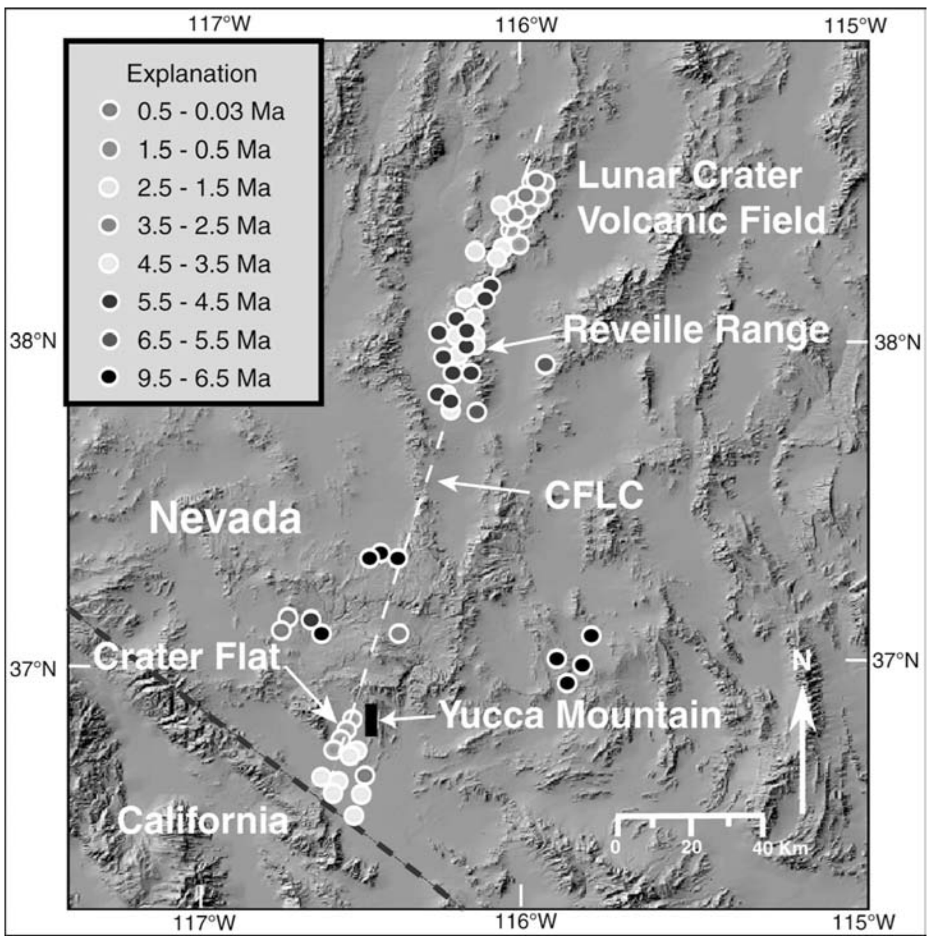

Fig. 1. Distribution of basaltic volcanoes in the Crater Flat–Lunar Crater area of central Nevada.

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were produced by melting of asthenospheric mantle.

3. Volcanoes near Yucca Mountain lie near the southern end of a belt of Pliocene-Quaternary basalt that stretches from Death Valley, California, to the RLC. Originally recognized by *Crowe and Carr* [1980] (Figure 1), the belt rarely exceeds a width of 20 km and is completely isolated from similarly aged basaltic volcanic fields in the Basin Range–Colorado Plateau transition zone to the east and the eastern front of the Sierra Nevada Range to the west.

Alternative Model

The key to understanding Yucca Mountain volcanism is knowledge of processes in the asthenosphere. Deep melting implies that hot mantle exists beneath the Yucca Mountain–RLC region [*Wang et al.*, 2002]. A mechanism to produce hot mantle is a mantle plume or hot spot. A mantle plume cannot exist in the traditional sense because (1) volcanism occurred in a narrow belt trending to the northeast nearly normal to the motion of the North American plate; (2) volcanism occurred in the same area for 11 Myr; and (3) there is no well-documented geographic or temporal migration of volcanism.

Smith et al. [2003] cite articles that document a sharp change in the thickness of the North American plate producing a west facing buttress or keel in the lithosphere. Formed by Paleozoic and Mesozoic orogeny, a lithospheric boundary (the western margin of the North American Craton) and lithospheric thinning beneath the Sierra Nevada, the buttress lies either to the west [*Jones et al.,* 1996] or east [*Zandt et al.,* 1995] of the Crater Flat–RLC area.

Mantle flow caused by the buttress results in eddies or rolls that stir up areas of mantle close to the melting temperature. Mantle caught in upward flow melts due to pressure reduction and produces basaltic magma. A mantle eddy travels with the lithosphere and results in long-lived, geographically restricted magmatism [*Humphreys et al.*, 2000]. The shape and spacing of areas of hot mantle control the geographic extent and episodic nature of volcanism. Isotopic differences between basalt near Yucca Mountain and the RLC are explained by contamination of rising magma by different composition and/or age of lithosphere.

An implication of this model is that a future peak of magmatism may occur when the next area of hot mantle is intersected by a mantle eddy caused by the lithospheric buttress.

How Large Is the Yucca Mountain Volcanic Field?

Two recent aeromagnetic surveys provide data that can be used to determine the size of the Yucca Mountain volcanic field.

(1) A high-resolution aeromagnetic survey of the Yucca Mountain area [*O'Leary et al.,* 2002] revealed 20 anomalies that may represent buried basalt volcanoes (Figure 2). This interpretation is supported by the northeast alignment of many of the anomalies and proven by drill holes that encountered basalt flows at depths of 100–400 m in alluvium. Dating buried volcanoes and inferences based on their depth of burial indicate an age from 3.8 to 11.3 Myr.

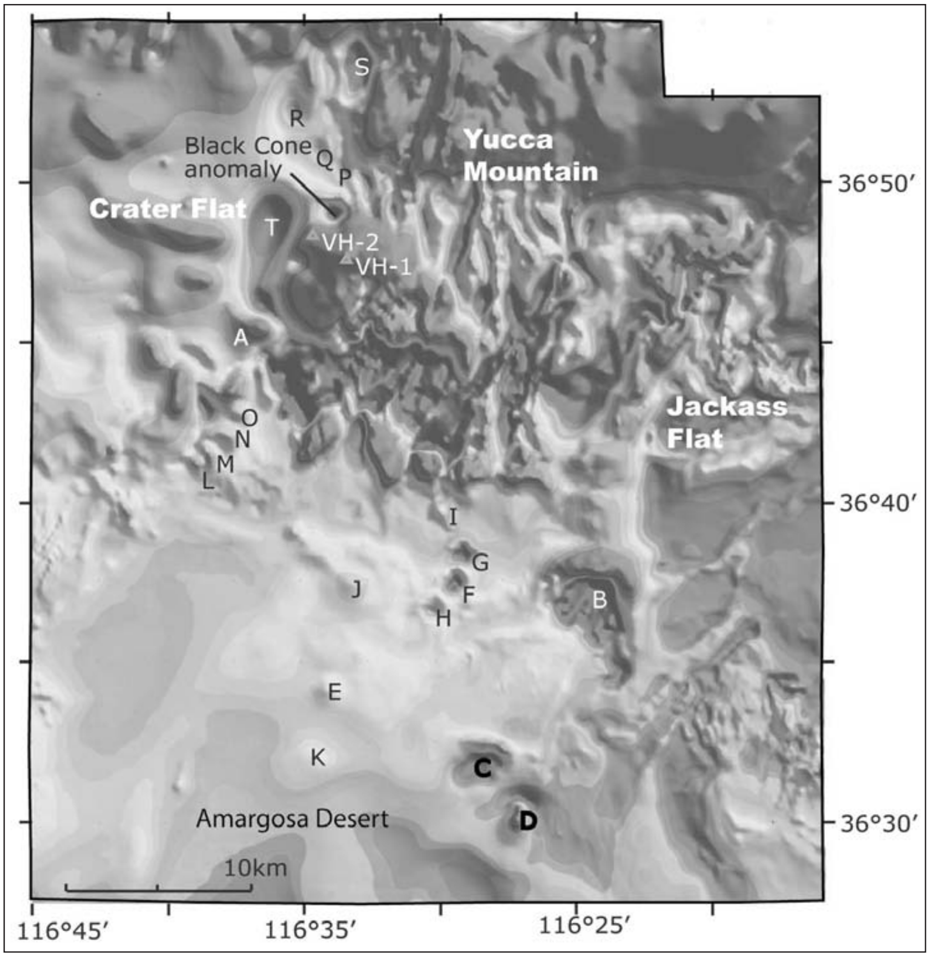

Fig. 2. Magnetic anomalies in the Crater Flat basin and northern Amargosa Desert, Nevada (from O'Leary et al. *[2002] and reproduced by permission). Shades of gray are magnetic field intensities relative to the International Geomagnetic Field; dark gray to black = negative magnetization (e.g., anomalies B and C), light gray = positive magnetization (e.g., anomalies E and J). Letters identify sites of buried volcanoes.*

(2) A high-resolution, helicopter-borne aeromagnetic survey completed by DOE in 2004 covers an area of 865 km^2 around Yucca Mountain and better defined the size and shape of many of the buried volcanoes and discovered several new anomalies [*Perry et al.,* 2004]. In late 2005, DOE plans to drill several of the anomalies revealed by this survey to determine the chemistry, age, and magnetic properties of the buried volcanoes.

These surveys do not include alluvial valleys to the west of Crater Flat or the southern part of the Amargosa Valley where additional volcanoes may be buried. Also, volcanoes may be buried in the complex terrain beneath Jackass Flat (east of Yucca Mountain) imaged by the Perry et al. 2004 survey. Although there has been much progress, the size and volume of the volcanic field near Yucca Mountain are not well known. Arguments that rule out the linkage of Yucca Mountain to RLC based on size differences are premature.

Implications

Perry et al. [2004] speculated that the 20 additional volcanic centers discovered by the aeromagnetic surveys would raise the probability of site disruption by about 40%. This number is a minimum figure because the surveys do not cover the entire area.

Volcanic recurrence rates for the RLC are as high as 12 events per million years, four times the rate calculated for the Yucca Mountain area. These figures are minimum estimates because only 70% of the volcanic centers in the RLC are dated.

A linkage between Yucca Mountain and RLC implies that higher recurrence rates may occur in the Yucca Mountain area. Adding data from future surveys of uncovered areas and higher recurrence rates may result in a probability of disruption 1–2 orders of magnitude greater than the EPA standard. A longer health standard, as ordered by the U.S. Court of Appeals, makes a disruptive event during the period of compliance even more likely.

Acknowledgments

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