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Correction: (Y/N) N *Corrected No.* 0 *Corrected By Number:* 0

Administrative Record: (Y/N) Y

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(4) 57002 Fine: don't believe a word of it! Steve

New evidence for the age of the youngest eruptions in the Valles caldera, New Mexico

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ABSTRACT

New geochronologic data provide evidence for an age of about 50 to 60 ka for the youngest volcanic eruptions within the Valles caldera, New Mexico—an age that is significantly younger than most previous age determinations. Thermoluminescence age estimates for buried soils beneath the El Cajete pumice, a key stratigraphic marker in the region, range from 48 to 61 ka, and ^{14}C analyses of burnt logs within volcanic surge beds near the El Cajete vent yield similar ages of 50 to >58 ka. These data conflict with fission-track, $^{40}Ar/^{39}Ar$, and K-Ar ages of 130 to >200 ka, but are supported by recent analyses by electron spin resonance. The results of this study reinforce the need to apply a variety of dating methods when evaluating the age of young volcanic events and support the hypothesis that the El Cajete eruptions were part of a new cycle of volcanic activity in the Valles caldera after an exceptionally long period of quiescence of ~460 ka. The new age constraints also suggest a previously unrecognized link between cycles of volcanism and pulses of hydrothermal activity in the caldera, such that hydrothermal outflow appears to decrease significantly following completion of eruptive cycles.

INTRODUCTION

The Jemez Mountains of New Mexico have been the site of the largest Quaternary volcanic eruptions in the southwestern United States, which produced the early Pleistocene Bandelier Tuff in two separate eruptive sequences, totaling about 600 km^3, and resulted in formation of the Toledo and Valles calderas (Smith and Bailey, 1966). Eruptions within the younger Valles caldera (Fig. 1) have continued episodically through the Quaternary, and the most recent volcanic cycle produced the temporally and spatially related El Cajete pumice, Battleship Rock ignimbrite, Banco Bonito lava, and VC-1 rhyolite (Bailey et al., 1969; Goff et al., 1986; Self et al., 1988, 1991). The El Cajete pumice is a widespread stratigraphic marker in areas east, southeast, and south of the caldera, and accurate knowledge of its age is critical for an evaluation of seismic hazards and landscape stability in a part of the Rio Grande rift that includes the Los Alamos National Laboratory and nearby communities. In addition, the age of these eruptions has important implications for understanding cycles of volcanism in the Valles caldera (Spell and Harrison, 1993), relations between volcanism and hydrothermal activity (Goff and Shevenell, 1987), and volcanic hazards in the region (Wolff and Gardner, 1995).

In this paper we present new thermoluminescence (TL) and radiocarbon age constraints that, in combination with recent analyses by electron spin resonance (ESR) (Toyoda et al., 1995), indicate an age for the El Cajete eruptions of about 50 to 60 ka. This age is significantly younger than previous fission-track, $^{40}Ar/^{39}Ar$, and K-Ar dates of 130 to >200 ka, and the disparity in age estimates reinforces the need to apply a variety of dating methods when evaluating the age of young volcanic events. These results support the hypothesis of Wolff and Gardner (1995) that the eruptions were part of a new cycle of volcanic activity after an exceptionally long period of quiescence; the results also suggest a close temporal correspondence between cycles of volcanism and pulses of hydrothermal activity in the caldera.

PREVIOUS AGE CONSTRAINTS

Despite many attempts to date the El Cajete pumice and associated units with a variety of methods, no agreement on their age has been reached. An initial radiocarbon date of >42 ka from charcoal within El Cajete deposits in the Valles caldera was presented by Bailey et al. (1969), providing a minimum limiting age, and they also suggested that the fresh morphology of the Banco Bonito lava flow indicated a probable age of 100 ka or less. A maximum limiting age of about 520 ka is provided by $^{40}Ar/^{39}Ar$ analyses of the underlying South Mountain Rhyolite (Spell and Harrison, 1993). Fission-track ages on zircon crystals from the El Cajete pumice and the Battleship Rock ignimbrite range from 130 to 180 ka (Marvin and Dobson, 1979; Miyachi et al., 1985). A similar age of about 151 ka obtained by uranium-series disequilibrium was reported by Self et al. (1988), although Self et al. (1991) later retracted this date. K-Ar and $^{40}Ar/^{39}Ar$ analyses on biotite and plagioclase crystals from the pumice and related units have yielded ages of 205 to 1300 ka (Goff et al., 1986, 1989; Self et al., 1991; Spell and Harrison, 1993), but these at least in part reflect xenocrystic contamination, and all of these ages may be too old. Recent ESR analyses of quartz phenocryst from the El Cajete pumice and the Battleship Rock ignimbrite suggest a significantly younger age of 45 to 73 ka (Toyoda et al., 1995).

COPAR MINE STUDY SITE

Samples for radiocarbon analysis were collected in 1992 and 1993 from fresh exposures of the El Cajete pumice at the Copar pumice mine in the Valles caldera, about 1.5 km southeast of the vent (Fig. 1). At the Copar mine, the lower 7 m of Plinian de-

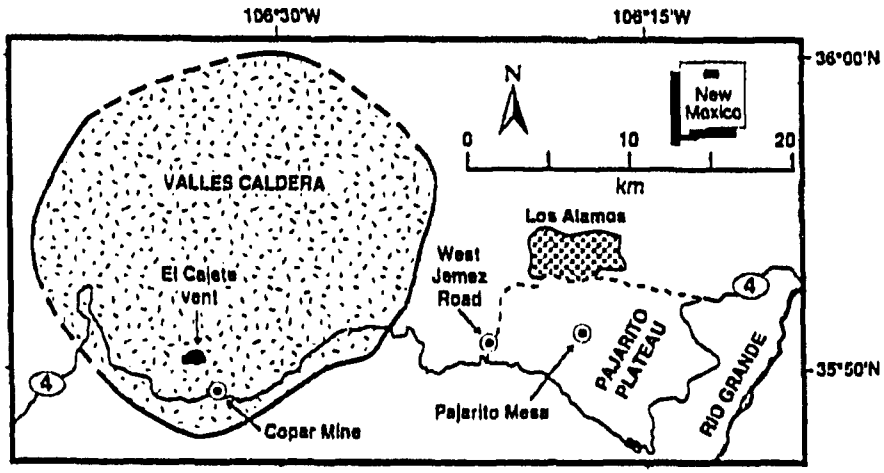

Figure 1. Location map showing study sites and El Cajete vent.

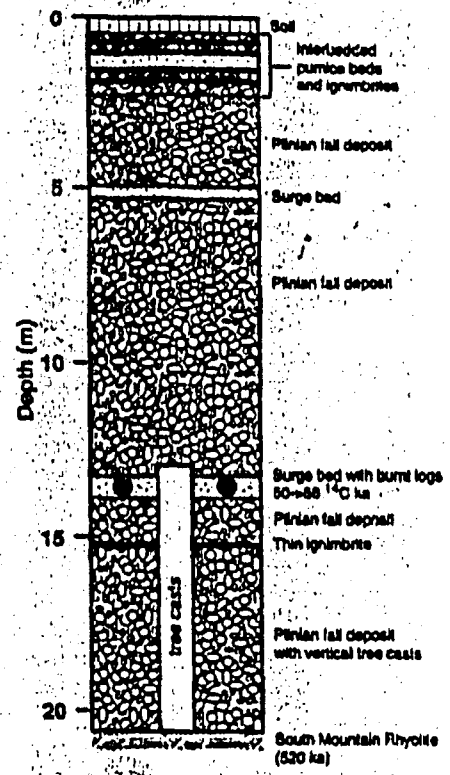

Figure 2. Stratigraphic section at Copar pumice mine, showing location of charcoal (black circles) within surge beds sampled for ^{14}C analysis (Table 1).

posits contain common vertical tree casts, up to 40 cm in diameter, that record the burial of a montane forest by the pumice (Fig. 2). A break in the Plinian eruptions is represented by a surge bed, 0.1–1.2 m thick, that contains abundant subhorizontal casts with burnt trees up to 30 cm in diameter, recording the shearing off of exposed tree tops by a volcanic blast. Because of the rapid burial of these trees by at least 13 m of additional pumice, their recent exposure by enlargement of the mine, and the lack of visible root penetration to this depth, they constitute ideal samples for constraining the age of the eruptions.

Radiocarbon Analyses. Four large samples of charcoal (65 to 270 g before pretreatment) were submitted to the Quaternary Isotope Laboratory, University of Washington, for high-precision ^{14}C analysis with extended count times. The samples were pretreated with successive hot alkali and hot acid soaks to remove humic acids and carbonate, and beta emissions were counted for at least four days. The samples yielded ages ranging from 50.1 ± 1.3 to >58 ka (Table 1). Because these ages are very close to the limit of conventional ^{14}C dating and contamination with very small amounts of modern carbon would yield erroneous "finite" ages, these analyses suggest an age of >58 ^{14}C ka

TABLE 1. RADIOCARBON DATES FOR CHARCOAL FROM EL CAJETE PUMICE

Field no.	Lab. no.*	Radiocarbon date (yr B.P.)	$\delta^{13}C$ (‰)	Pretreated mass (g)
RP-1	QL-4629	>58 000	-22.3	16.5
RP-25	QL-4645	50 100 ± 1300	-22.1	17.2
RP-47	QL-4727	57 200	-21.7 + 4100 - 2700	19.2
RP-51	QL-4728	>54 100	-22.1	19.8

* QL is Quaternary Isotope Laboratory, Seattle, Washington.

for the El Cajete pumice, although the possibility of a finite age cannot be ruled out. In addition, there is the possibility that one or more of the dated samples were from trees that had been dead for some time before the eruptions, which could provide dates that are too old.

PAJARITO PLATEAU STUDY SITES

The El Cajete pumice forms a discontinuous cover on the Pajarito Plateau, 18 to 35 km east of the volcanic vent (Fig. 1). Samples of soils that were buried by the pumice were collected for TL analyses from two trenches excavated as part of paleoseismic investigations (Kolbe et al., 1994; Wong et al., 1995). The TL signal for many terrestrial sediments is often sufficiently reduced after extended exposure to sunlight (>8 h) to accurately reflect the time since burial. Numerous studies have shown that the fine-grained component (4–11 μm) of buried A horizons and distal colluvium is amenable to TL dating and yields age estimates in agreement with ^{14}C control (Huntley et al., 1983; Forman et al., 1989, 1991; Berger and Mahaney, 1990; Forman and Maat, 1990).

At the Pajarito Mesa trench site, the sampled soil is 1.35 m deep below a gently sloping mesa top (1.2° slope), where up to 0.85 m of pumice lies beneath deposits dated at 0 to 30 ^{14}C ka (Fig. 3A; Kolbe et al., 1994; Reneau et al., 1995). The buried soil is a silt loam that probably represents a mixture of eolian and sheetwash deposits, and an analogous modern surface soil was also sampled to test for resetting of the TL signal in this environment.

At the West Jemez Road trench site, the sampled soil is 1.7 m deep below a distal colluvial slope (12° slope) at the base of the Pajarito fault scarp, and up to 1.2 m of pumice occurs beneath colluvium dated at 1 to 5 ^{14}C ka (Fig. 3B; Wong et al., 1995). The uppermost part of the buried soil is also a silt loam that may represent a reworked eolian deposit, and it overlies a poorly sorted, gravelly colluvial deposit with minimal soil development. An additional sample was collected from the lower part of this colluvial deposit as a check on the reliability of the analyses.

Thermoluminescence Analyses. TL chronometric methods employed in this study are similar to those described in Forman et al. (1993), in which the polymineral fine-grained fraction (4–11 μm) is isolated for analysis by the total- and partial-bleach methods (Table 2). In this study, all samples were analyzed by measuring blue TL emissions, which previous studies have indicated yield finite age estimates (Balescu and Lamothe, 1992). Prior to TL analysis, all samples were preheated for 48 h at 124 °C to remove an unstable TL component associated with anomalous fading. Additional storage of irradiated samples for at least 30 days and subsequent measurements showed no measurable (>5%) diminution in TL emissions, indicating a time-significant signal.

The environmental dose rate during the burial period was estimated by integrating the varying gamma and beta doses for the sampled soils and the overlying El Cajete pumice (Table 2). The largest uncertainty in the dose rate is the estimation of long-term average moisture content in the sampled deposits, which is complicated at our study sites by variations in deposit texture and Quaternary climatic fluctuations. On the basis of available data on moisture content and soil density on the Pajarito Plateau and the probability that late Pleistocene climates were wetter than today (Thompson et al., 1993), an estimate of 25 ± 10 wt% water is used for samples below the pumice bed to encompass the possible ranges in average moisture content. Because this estimate incorporates the high porosity of the pumice and the possibility of water being perched above the underlying buried soil, it most likely errs on the high side and provides a conservative overestimate of TL age. Drier conditions are inferred for the surface soil at Pajarito Mesa (10 ± 3 wt%) because of prolonged periods of surface desiccation under the modern semiarid climate.

Analyses of four samples from the buried soils provide age estimates of 48 ± 5 to 61 ± 5 TL ka (Table 2), overlapping at the 2σ level at 51 to 58 ka. Several tests support the accuracy of these analyses. First, no anomalous fading of the TL signal was observed after 30 days of storage of the samples, and the natural and laboratory signals thus appear to be stable. Second, the modern soil at Pajarito Mesa yielded a TL age estimate of [illegible]–3.5 ka (Table 2), indicating only a small [illegible]nant TL signal in the surface soils or [illegible]rhaps recent erosion that exposed older

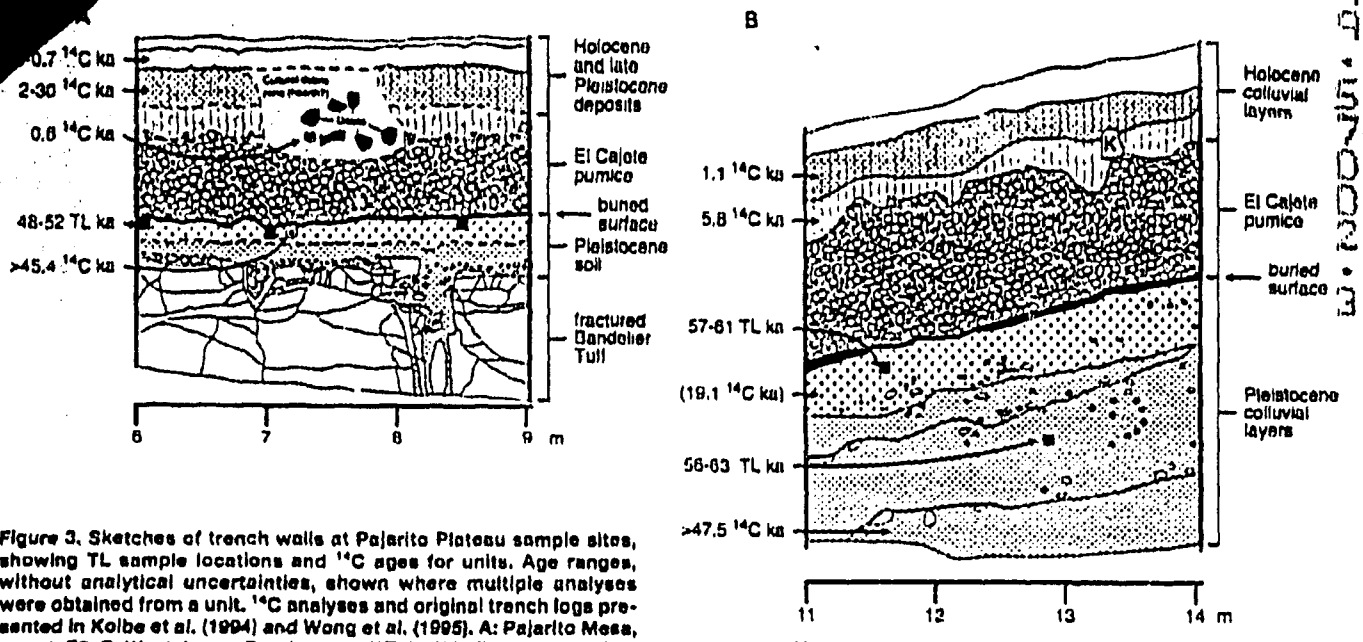

Figure 3. Sketches of trench walls at Pajarito Plateau sample sites, showing TL sample locations and ^{14}C ages for units. Age ranges, without analytical uncertainties, shown where multiple analyses were obtained from a unit. ^{14}C analyses and original trench logs presented in Kolbe et al. (1994) and Wong et al. (1995). A: Pajarito Mesa, trench E8. B: West Jemez Road, trench WTT1; K indicates krotovina; anomalous 19.1 ^{14}C ka analysis from beneath El Cajete pumice is probably due to contamination of sample or deposit with young carbon (e.g., burnt root or transport down an animal burrow). No vertical exaggeration.

TABLE 2. THERMOLUMINESCENCE DATA AND AGE ESTIMATES CONSTRAINING THE AGE OF THE EL CAJETE PUMICE

Laboratory sample number	Sediment type	Equivalent dose method*	Light exposure (hours)†	Temperature range (°C)§	Equivalent dose (grays)	Estimated water content (wt%)	Dose rate (grays/ka)#	TL age estimate (ka)**
West Jemez Road, Water Tanks Trench 1								
OTL-464	Distal Colluvium	Total Bleach	16 sun	250-400	253.30 ± 5.02	25 ± 10	4.47 ± 0.34	57 ± 5
		Partial Bleach	1 sun	250-400	272.40 ± 3.39	25 ± 10	4.47 ± 0.34	61 ± 5
OTL-465	Distal Colluvium	Total Bleach	16 sun	280-400	259.80 ± 13.89	25 ± 10	4.64 ± 0.33	56 ± 6
		Partial Bleach	1 sun	280-400	290.40 ± 51.92	25 ± 10	4.64 ± 0.33	63 ± 10
Pajarito Mesa, Trench E8								
OTL-517	*Surface Av*	Total Bleach	*16 sun*	*260-400*	13.59 ± 0.16	10 ± 3	4.53 ± 0.30	3.0 ± 0.5
		Total Bleach	8 UV		16.32 ± 0.16	10 ± 3	4.53 ± 0.30	3.5 ± 0.5
OTL-528	Buried Av	Total Bleach	8 UV	250-360	197.24 ± 3.89	25 ± 10	4.10 ± 0.33	48 ± 5
OTL-516	Buried Av	Total Bleach	8 UV	250-360	242.90 ± 5.58	25 ± 10	4.76 ± 0.36	51 ± 5
OTL-515	Buried Av	Total Bleach	8 UV	250-360	217.50 ± 4.18	25 ± 10	4.18 ± 0.33	52 ± 5

* All TL measurements were made with a Corning 5/58 and HA-3 filters in front of the photomultiplier tube. Samples were preheated to 124 °C for 48 h prior to analysis.

† Hours of light exposure to define residual level. "Sun" is natural sunlight in Columbus, Ohio. UV is light exposure from 275 W General Electric ultraviolet "sunlamp."

§ Temperature range used to calculate equivalent dose.

\# Dose rates were calculated using values of K, Th, and U analyzed at the Ohio State University and the estimated water content. For samples from major stratigraphic contacts, the radionuclide contents from the overlying pumice and underlying soil were averaged.

** All errors are at 1σ and calculated by averaging the errors across the temperature range.

deposits. However, the potential inherited age is well within 1σ errors for the older analyses and thus would have negligible effect on accuracy. Third, total-bleach and partial-bleach analyses of the West Jemez Road samples are statistically the same at 1σ (Table 2), and this concordancy further attests to the completeness of solar resetting of these sediments prior to burial. Finally, the sampled lower colluvial deposit at West Jemez Road yielded TL ages of 56 to 63 ka (Table 2, Fig. 3B), similar to the results for the overlying samples and supporting the internal consistency of these analyses.

DISCUSSION

The TL age estimates of about 48 to 61 ka from soils buried by the El Cajete pumice (Table 2) agree well with recent ESR analyses indicating ages of 45 to 72 ka (Toyoda et al., 1995). The TL analyses are typically younger than ^{14}C analyses of up to >58 ka, although at the 2σ level the TL analyses indicate possible ages as high as 58 to 71 ka, and any apparent age differences may not be significant. Notably, potential uncertainties in the TL analyses such as incomplete resetting of the TL signal would tend to provide overestimates of sample age, and our use of a broad range of water content provides a realistic age range. The TL analyses thus indicate an age of ~50 to 60 ka and suggest that the analyzed charcoal samples

from El Cajete deposits are near the upper age limit of high-precision ^{14}C dating. Possible minor differences between the TL and ^{14}C analyses may be due in part to uncertainties in the ^{14}C time scale, such as those resulting from atmospheric variations in ^{14}C production rates over time (e.g., Mazaud et al., 1991), or the partial dating of standing snags that had died before the eruptions.

The combined TL, ^{14}C, and ESR analyses indicate an age for the El Cajete pumice and related units that is significantly younger than previous analyses (130 to >200 ka) by fission-track, $^{40}Ar/^{39}Ar$, and K-Ar. However, the young age is consistent with available geomorphic evidence on the Pajarito Plateau. Stratigraphic relations and ^{14}C dating at Pajarito Mesa (Fig. 3A; Kolbe et al., 1994; Reneau et al., 1995), and elsewhere on the Pajarito Plateau, have not revealed significant "radiocarbon-dead" depositional events after eruption of the El Cajete pumice, suggesting that relatively little time elapsed before the period normally amenable to ^{14}C dating (40–45 ka). The $^{40}Ar/^{39}Ar$ and K-Ar ages are probably too old because of the analysis of xenocrysts or because the presence of excess argon (Goff et al., 1989; Self et al., 1991; Spell and Harrison, 1993; Wolff and Gardner, 1995) and the age disparity also suggest that complete annealing of fission tracks did not occur. The results of this study thus reinforce the need for the application of multiple dating methods to substantiate the ages of young (<200 ka) volcanic events.

The age of about 50 to 60 ka for the El Cajete pumice supports a hypothesis that these eruptions were part of a new cycle of volcanism after an exceptionally long period of quiescence of ~460 ka (Wolff and Gardner, 1995). Furthermore, the revised age suggests a previously unrecognized link between volcanic cycles and hydrothermal activity in the Valles caldera. Uranium-series dating of travertine at Soda Dam, a site of hydrothermal outflow from the caldera 19 km southwest of the El Cajete vent, indicates that deposition of travertine has been episodic through the Quaternary (Goff and Shevenell, 1987). There is apparently a close temporal correspondence between the El Cajete eruptions and the termination of a pulse of travertine deposition (uranium-series age of ~58 ± 3 ka), suggesting reduced hydrothermal activity following completion of the eruptive cycle. Notably, the termination of the last prior pulse of travertine deposition (~480 ± 55 ka) is also similar to the age of the last prior eruptions in the caldera (South Mountain Rhyolite, $^{40}Ar/^{39}Ar$ age of 521 ± 4 ka; Spell and Harrison, 1993), further supporting a temporal relation between volcanic and hydrothermal cycles. Finally, if such a link exists in the Valles caldera, then the renewed travertine deposition at Soda Dam at ~5 ka reported by Goff and Shevenell (1987) could indicate Holocene injection of magma beneath the caldera as a prelude to a new volcanic cycle.

ACKNOWLEDGMENTS

Supported by the U.S. Department of Energy through the Los Alamos National Laboratory Seismic Hazards and Environmental Restoration programs. Mark Hemphill-Haley, Tom Kolbe, Susan Olig, and Ivan Wong with Woodward-Clyde Federal Services and Keith Kelson with William Lettis and Associates were instrumental in the paleoseismic investigations. We thank Wayne Brown, Copar Mine, for access; Kevin Reid, Paula Watt, and Brad Wilcox for moisture content and soil density data; Minze Stuiver for discussions concerning the ^{14}C analyses; and Fraser Goff, Eric McDonald, Hank Mullins, Steve Wells, and an anonymous reviewer for helpful reviews.

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Manuscript received May 2, 1995
Revised manuscript received September 29, 1995
Manuscript accepted October 10, 1995