Silver Creek caldera—The tectonically dismembered source of the Peach Spring Tuff

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ABSTRACT

Sanidine ^{40}Ar/^{39}Ar geochronology confirms that Silver Creek caldera, which straddles the eastern edge of the Colorado River extensional corridor near Oatman, Arizona (United States), is the source of the Peach Spring Tuff. Eight new dates (five from outflow, three from caldera fill) are analytically indistinguishable, and combined with the most precise previously published date give a weighted mean average age of 18.78 ± 0.02 Ma. A fragment of the caldera identified in the midst of the extensional corridor is structurally juxtaposed with mesozonal plutons of identical age. The implied extension direction (182°–225°) is compatible with abundant previously published structural data for the region.

INTRODUCTION

The Peach Spring Tuff (Arizona, United States) of Young and Brennan (1974) was originally used primarily to interpret geomorphic evolution of the Colorado Plateau and Transition zone (Fig. 1). Interest heightened when it became apparent that the ignimbrite also blanketed large areas of the Mojave Desert (Glazner et al., 1986; Buesch, 1992), indicating that a large caldera must have formed during its eruption. Based on studies of the ignimbrite's distribution and thickness (Young and Brennan, 1974; Glazner et al. 1986; Carr, 1991) and flow directions as inferred from mineral, lithic, pumice, and magnetic fabric (Buesch, 1992; Hillhouse and Wells, 1991), the source caldera was widely thought to be located near the junction of Nevada, Arizona, and California. Because much of this area had been mapped and/or explored, it was assumed that the caldera must be completely buried by basin fill.

Based on a strong petrologic similarity with Peach Spring Tuff outflow, Ferguson (2008) reinterpreted the inner part of a caldera complex mapped by Thorson (1971) near Oatman, Arizona, as intracaldera Peach Spring Tuff, and named the redefined, smaller structure Silver Creek caldera.

SILVER CREEK CALDERA

Silver Creek caldera is defined by a densely welded trachyte ignimbrite at least 450 m thick that has no preserved top or exposed bottom (Fig. 2; Figs. DR2 and DR3 in the GSA Data Repository[1]). In the southern part of the caldera, megabreccia and mesobreccia (*sensu stricto*; Lipman, 1976) occur in clast-supported, concordant lenses interpreted as avalanche breccia within gently dipping ignimbrite (Thorson, 1971; Pearthree et al., 2009). In the north, kilometer-scale mega blocks are surrounded by folded, contorted ignimbrite. Some of the blocks could be floor to the caldera fill, but others are clearly enclosed within the ignimbrite. Clasts in the breccias of granite, lacustrine carbonate, and dacite (lava, breccia, ignimbrite, and subaqueous ignimbrite) can be matched to specific units exposed in the caldera wall (Pearthree et al., 2009).

Correlation of the ignimbrite at Silver Creek with outflow Peach Spring Tuff is based on positive petrologic, geochemical, and geochronologic tests. Paleomagnetic data (R.Varga, 2010, personal commun.) indicate that the ignimbrite at Silver Creek has the same distinctive northeasterly remanence direction as densely welded Peach Spring Tuff outflow (Wells and Hillhouse, 1989). Phenocryst modes and heavy minerals in outflow Peach Spring Tuff and the ignimbrite at Silver Creek are nearly identical, dominated by blocky K-feldspar up to 6 mm, subordinate plagioclase ≤3 mm, ≤1% biotite, and minor to trace quartz, hornblende, pyroxene, sphene, zircon, and apatite. Peach Spring Tuff outflow is mostly rhyolitic (68%–76% SiO_2) and normally zoned with phenocryst content ranging between 4% and 20%, whereas intracaldera ignimbrite at Silver Creek is mostly trachytic (65%–68% SiO_2) and contains ~35% phenocrysts (Ransome, 1923; Thorson, 1971; Young and Brennan, 1974; Gusa et al., 1987; Buesch, 1993; Pamukcu et al., 2009; Carley et al., 2009). Lateral and vertical compositional zonation is common in large-volume silicic ignimbrites (e.g., Bachmann and Bergantz, 2008a), and has previously been demonstrated for Peach Spring Tuff outflow (Buesch, 1993).

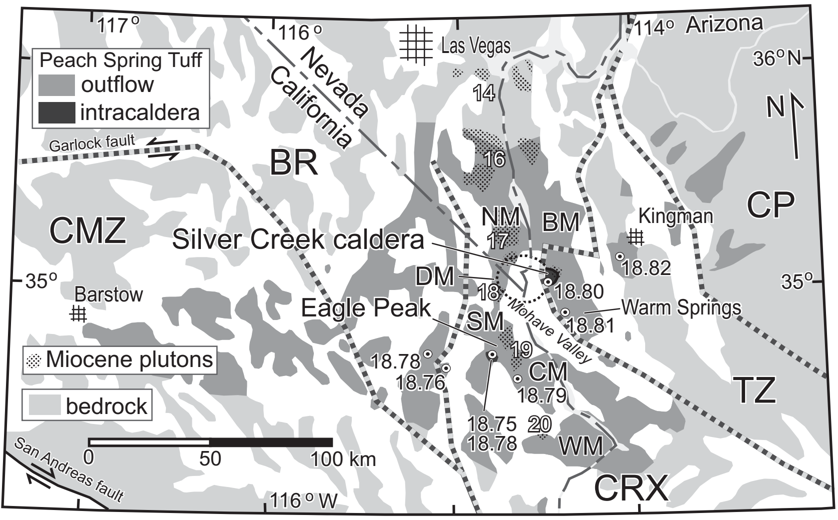

Figure 1. Map showing extent (dark gray and black) of Peach Spring Tuff (Arizona, United States) (modified slightly from Wells and Hillhouse [1989]), location and age (white numbers) of Miocene plutonic rocks which, in general, postdate the onset age of volcanism by ~2–4 m.y. (Faulds et al., 2001), and locations of eight new sanidine ^{40}Ar/^{39}Ar dates of the ignimbrite (black numbers). Hypothetical, pre-extension 26-km-diameter caldera is shown (dotted circle). Ranges: BM—Black Mountains; CM—Chemehuevi Mountains; DM—Dead Mountains; NM—Newberry Mountains; SM—Sacramento Mountains; WM—Whipple Mountains. Major tectonic provinces: CP—Colorado Plateau; TZ—Transition zone; CRX—Colorado River extensional corridor; BR—Basin and Range; CMZ—Central Mojave strike-slip zone.

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[1]GSA Data Repository item 2013009, Figures DR1–DR4 and Table DR1 (analytical data), is available online at www.geosociety.org/pubs/ft2013.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

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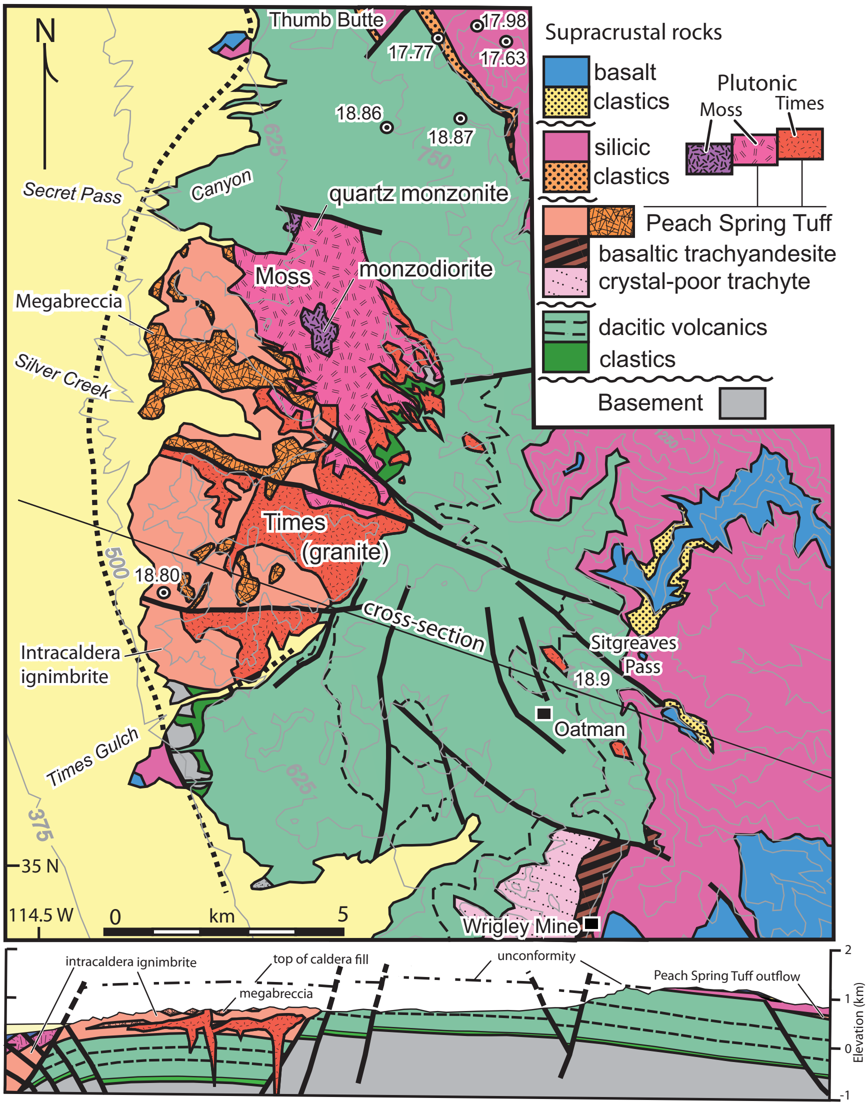

Figure 2. Simplified geology and cross section of Silver Creek caldera (Arizona, United States) showing our 18.80 Ma intracaldera date, recalculated $^{40}Ar/^{39}Ar$ dates (Ma) near Thumb Butte from Lang et al. (2008), and a K-Ar age (average of two dates) near Sitgreaves Pass from DeWitt et al. (1986). Geology from Ransome (1923), Thorson (1971), Lang et al. (2008), Pearthree et al. (2009), and new mapping. Moss—Moss Porphyry; Times—Times Porphyry.

Recent studies demonstrate that, although Silver Creek intracaldera fiamme are overall less silicic than outflow pumice and fiamme, there is significant compositional overlap (Pamukcu, 2010). A 140-m-thick Peach Spring Tuff outflow sequence at Warm Springs (Fig. 1; Fig. DR2) includes an upper zone of trachyte vitrophyre with 35% phenocrysts, identical in phenocryst abundance, composition, and mode to intracaldera ignimbrite at Silver Creek.

MEGABRECCIA NEAR EAGLE PEAK

We identify Peach Spring Tuff megabreccia 40 km southwest of Silver Creek caldera in the Sacramento Mountains, California (Fig. 1; Fig. DR4). Based on the megabreccia (Lipman, 1976; Wright and Walker, 1977), we interpret the ignimbrite as intracaldera. Located 2.25 km southwest (230°) of Eagle Peak, the megabreccia occurs as a series of 15–65 m blocks of dacite lava, granite, and lacustrine limestone clustered along an irregular, gradational contact between resistant knobs of welded ignimbrite (map unit Txlt interpreted as Peach Spring Tuff by McClelland [1984]) and a recessive, poorly to nonwelded ignimbrite mesobreccia (map unit Tlt of McClelland [1984]). The contact is, in our opinion, a cooling facies boundary within the same ignimbrite (cooling unit). Thin sections show that both rocks have the same distinctive phenocryst abundances, modes, and heavy minerals as outflow Peach Spring Tuff. The mesobreccia has a Peach Spring Tuff–compatible paleomagnetic remanence direction (J. Hillhouse, 2011, personal commun.). Strata that underlie the ignimbrite(s) northwest of Eagle Peak (Spencer and Turner, 1983) are propylitically altered dacitic volcanic and lacustrine (carbonate and volcaniclastic) rocks that overlie granitic basement. The ignimbrite's top is not preserved due either to truncation by a fault or an angular unconformity. However, it hosts a steeply southwest-dipping (50°–70°) eutaxitic foliation (over a strike-normal distance of 1100 m southwest of the megabreccia locality) that indicates it could be very thick (>800 m).

GEOCHRONOLOGY

Sanidine phenocrysts were separated from eight bulk rock samples: five from rhyolitic outflow, one from trachytic intracaldera ignimbrite at Silver Creek, and one each from the welded (megabreccia matrix) and mesobreccia ignimbrites near Eagle Peak. The samples were irradiated together with Fish Canyon Tuff sanidine monitors (28.20 Ma; Kuiper et al., 2008). Fifteen single sanidine crystals from each sample were individually fused by CO_2 laser and analyzed by the $^{40}Ar/^{39}Ar$ technique using the MAP 215–50 mass spectrometer at the New Mexico Geochronology Research Laboratory. Irradiation procedures, analytical parameters, and data are in the Data Repository. Results are summarized in Table 1 and Figure 3. Each sample yielded a unimodal, near-Gaussian distribution of single-crystal ages (Fig. DR1). Weighted mean ages for the eight samples are analytically indistinguishable, ranging from 18.75 ± 0.04 to 18.82 ± 0.05 Ma (2σ error). K/Ca ratios are also similar, ranging from 24 ± 12 to 32 ± 6, indicating consistent sanidine compositions among the eight samples. The ages and K/Ca ratios are analytically indistinguishable from two other published laser fusion $^{40}Ar/^{39}Ar$ analyses of Peach Spring Tuff sanidine (18.74 ± 0.07 Ma [Miller et al., 1998] and 18.92 ± 0.36 Ma [Nielson et al., 1990]; both ages recalculated to calibration of Kuiper et al. [2008]). In contrast to Nielson et al. (1990), we did not find evidence for anomalously old xenocrystic feldspars; these may have been removed during our mineral separation process. Because no other major similar-age ignimbrites have been reported in the vicinity, our results strongly support correlation of the trachyte ignimbrite at Silver Creek and the megabreccia-hosting ignimbrites near Eagle Peak with outflow-facies Peach Spring Tuff. Our new age determinations and the age from Miller et al. (1998) form a unimodal Gaussian distribution with a weighted mean age of 18.78 ± 0.02 Ma (MSWD = 1.14, n = 9).

DISCUSSION

Based on a minimum original caldera depth of 1.2 km (Fig. 2) and a minimum Peach Spring Tuff outflow dense rock–equivalent volume of 640 km³ (Buesch, 1992) we estimate, by assuming outflow volume is roughly equivalent to intracaldera volume (Lipman, 1984), a 26 km

TABLE 1. SUMMARY OF PEACH SPRING TUFF AGES

Sample	Facies	Latitude (° N)*	Longitude (° W)	Location	Age (Ma)	Error (2σ)
CAF-2–21546	intracaldera	35.04898	114.47539	Silver Creek Caldera, AZ	18.80	± 0.07
CAF-2–29091	intracaldera	34.76635	114.77535	Eagle Peak, CA	18.75	± 0.04
CAF-2–29111	matrix, intra-caldera breccia	34.77045	114.79514	Eagle Peak, CA	18.78	± 0.05
KINGMAN PST	outflow	35.18808	114.03686	Kingman, AZ	18.82	± 0.05
CAF-2–28792	outflow	34.59773	114.65320	Snaggletooth, CA	18.79	± 0.05
CAF-2–14735	outflow	34.89936	114.37814	Warm Springs, AZ	18.81	± 0.05
LP52D	outflow	34.63917	115.05666	Little Piute Mountains, CA	18.76	± 0.07
PT1B	outflow	34.76367	115.13567	Piute Mountains, CA	18.78	± 0.06
PST-1 (Miller et al., 1998)	outflow			Little Piute Mountains, CA	18.74	± 0.07
JN87-Ki (Nielson et al., 1990)	outflow			Kingman, AZ	18.92	± 0.36
Weighted mean age for the Peach Spring Tuff (n = 9)					18.78	± 0.02

Note: All ages relative to Fish Canyon Tuff sanidine (28.20 Ma; Kuiper et al., 2008). AZ—Arizona; CA—California.

*Latitude/longitude in NAD 83.

Published ages adjusted as follows:

PST-1 monitored using Fish Canyon Tuff sanidine, original calibration age 27.74 Ma, adjusted calibration age 28.20 Ma.

JN87-Ki monitored using Taylor Creek Rhyolite sanidine, original calibration age 27.88 Ma, adjusted calibration age 28.34 Ma.

The weighted mean age excludes the less precise age of Nielson et al. (1990).

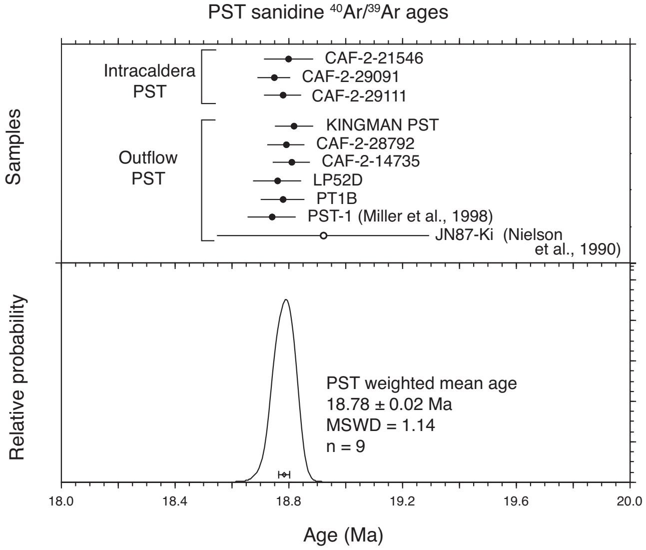

Figure 3. Summary of new and published ^{40}Ar/^{39}Ar laser-fusion ages from Peach Spring Tuff (PST) sanidine phenocrysts. Upper panel shows age determinations and 2σ errors. Lower panel shows age-probability distribution (Deino and Potts, 1992) and weighted mean age, excluding the less precise result of Nielson et al. (1990) (open symbol in upper panel). All ages are relative to Fish Canyon Tuff sanidine at 28.20 Ma (Kuiper et al., 2008).

diameter for the original caldera (Fig. 1). Assuming that the intracaldera Peach Spring Tuff outcrops near Eagle Peak could restore to anywhere within our hypothetical original caldera, the magnitude of structural extension is likely between 26 and 48 km in a direction ranging between 182° and 225° (Fig. 1). A deeper caldera fill would decrease the caldera diameter and the range of extension magnitude and direction, whereas an unusually large or odd shape might increase them, but because the eastern margin is well-defined, the range of extension direction cannot adjust to more westerly than ~225°. This is compatible with Gray et al.'s (1990) extension direction of 190°–230° from normal faults in the southern Black Mountains, the 223° slip direction on detachment faults in the Chemehuevi Mountains (John and Foster, 1993), and 210°–220° kinematics on the Sacramento Mountains detachment fault near Eagle Peak (Simpson et al., 1991). Ductile fabrics in the footwall of the detachment fault at Eagle Peak, however, give a composite direction of 240° (Campbell-Stone et al., 2000). Decoupling between footwall and hanging wall should be expected in highly extended belts, and may account for the discrepancy. An early phase of minor (~5% of the total), ~190°-oriented, dike-accommodated extension in the footwall (John and Foster, 1993; Campbell-Stone et al., 2000) might have been associated with higher magnitudes of similarly oriented extension in the hanging wall.

The petrologic uniqueness of the Peach Spring Tuff, and the fact that it represents the region's only supereruption (*sensu stricto*; Miller and Wark, 2008) might make it possible to identify Silver Creek caldera's matching, structurally subjacent plutonic complex (e.g., Bachmann and Bergantz, 2008b) and add a third dimension (depth) to our restoration. In the Sacramento Mountains, which were tilted and rapidly uplifted between ca. 20 Ma and 15 Ma, two appropriately aged mesozonal (10–15 km) intrusive suites have been identified: the ca. 19–18 Ma Sacram diorite-granite (Campbell and John, 1996); and the ca. 19 Ma Eagle Wash diorite-granodiorite-leucogranite, the granodiorite yielding U-Pb sphene and zircon ages of 18.7 ± 0.4 Ma and 18.8 ± 1.6 Ma (Pease et al., 1999). The suites are part of a northward-younging belt (Fig. 1) of west-tilted Miocene mesozonal plutons that is coincident with a gravity high (Mickus and James, 1991) and whose apex is in the southern Sacramento Mountains. Plutonic complexes in the Dead Mountains might also be related to Peach Spring Tuff magmatism. A granite–quartz diorite pluton at the north end (House et al., 2004) has yielded preliminary 18.5 Ma U-Pb zircon ages (Howard et al., 1996), and foliated granitoid in the middle of the range has yielded Early Miocene zircons (K.A. Howard, 2010, personal commun.). Plutons in the Newberry Mountains and farther north, likely too young to be related to the Peach Spring Tuff, have been matched successfully to specific eruptive sequences in supra-adjacent ca. 19–15 Ma volcanics (Bachl et al., 2001; Miller and Miller, 2002; Lang et al., 2008).

CONCLUSIONS

Petrologic, geochemical, paleomagnetic, and geochronologic tests all indicate that Silver Creek caldera is the source of the 18.8 Ma Peach Spring Tuff. A fragment of the caldera extended 40 km to the southwest is a displacement marker structurally juxtaposed with a belt of similarly aged mesozonal plutons that might represent residue of the Peach Spring Tuff supereruption.

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