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SR AND PB ISOTOPE VARIATIONS OF FELDSPARS IN THE MIDDLE TO LATE EOCENE PALM PARK FORMATION AND OREJON ANDESITE: IMPLICATIONS FOR REGIONAL VARIABILITY AND MAGMATIC SOURCE CHARACTERISTICS

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Abstract—Volcanic rocks of the Palm Park Formation, exposed in multiple locations throughout south-central New Mexico, are composed of volcanic and volcanoclastic rocks that are lithologically and compositionally variable at scales within individual exposures and between exposures at different localities. Plagioclase crystals from Palm Park volcanic rocks in these different exposures have variable Sr and Pb isotope characteristics that broadly reflect an origin from either multiple magmas and/or a changing magmatic system that becomes less radiogenic over time (i.e., from ~45 to ~39 Ma). These isotope variations constrain the evolution and sources of Palm Park volcanic rocks when magmatism related to Laramide orogenesis transitioned to magmatism associated with the ignimbrite flare-up, a poorly studied portion of the middle to late Tertiary magmatic history of southern New Mexico.

INTRODUCTION

Although the ages and sources of late Eocene, ignimbrite flare-up-related magmatism have been evaluated in south-central New Mexico (e.g., Zimmerer and McIntosh, 2013; Verplanck et al., 1999; Ramos et al., this volume), little is known about the age, duration, and sources of middle to late Eocene volcanism and volcaniclastic sedimentation that occurred just prior to the flare-up. The period marks the transition between Laramide orogenesis and ignimbrite flare-up magmatism at ~36 Ma prior to initiation of Rio Grande rifting and is reflected in the volcanic and volcaniclastic rocks of the Palm Park Formation.

The Palm Park Formation in south-central New Mexico is composed of a suite of compositionally variable volcanic rocks and volcanoclastic sedimentary rocks scattered throughout the region. The rocks are primarily andesitic and dacitic in composition, are commonly variably altered, and are difficult to stratigraphically correlate across localities. Here, Sr and Pb isotope characteristics of feldspars hosted in Palm Park lavas and tuffs are used to evaluate the magmatic sources and compositional diversity of Palm Park volcanic rocks regionally. These include ash-fall tuffs and andesitic and dacitic lavas exposed in the Organ Mountains, Doña Ana Mountains, Robledo Mountains, and Sierra de Las Uvas Mountains (Fig. 1). The isotopic characteristics of feldspars in these poorly-studied volcanic rocks constrain the nature of pre-rift volcanism (46–36 Ma, Clemons, 1979; Hawley et al., 1975) occurring during the waning stages of Laramide orogenesis and offer insights regarding other age-equivalent, pre-rift volcanic and volcaniclastic strata exposed in other parts of south-central New Mexico (e.g., in the Caballo, Potrillo, San Diego, and southern San Andres Mountains).

METHODS

Whole rocks were collected from eight individual sites (Fig. 1) from five regional Palm Park exposures including those in the Sierra de Las Uvas (Bell Top Mountain), Robledo (Apache and Faulkner Canyons), Doña Ana (Cleofas Canyon), and Organ Mountains (Fillmore Canyon). Two additional samples from the Doña Ana Mountains (Ramos et al., this volume) will also be discussed. Whole rocks were crushed and sieved. Individual feldspars, typically plagioclase crystals, were hand picked from sieve fractions. Feldspars were then etched in 10% hydrofluoric acid for 5–20 minute intervals, rinsed in distilled water, and sonicated to obtain crystals free of adhering materials. Feldspars chosen for single crystal analyses ranged from 0.1 to 3 mg.

Individual clean plagioclase crystals were dissolved using hydrofluoric, nitric, and hydrochloric acids. Strontium was purified using cation exchange chromatography and 2.5N hydrochloric acid. Lead was purified using 1N hydrobromic acid and anion exchange chromatography. Lead was analyzed using multi-collector inductively coupled plasma mass spectrometry with Pb isotopes normalized to NBS997 $^{205}Tl/^{203}Tl=0.41892$ and Sr was analyzed using thermal ionization mass spectrometry with Sr normalized to $^{86}Sr/^{88}Sr=0.1194$ at the Johnson Mass Spectrometry Laboratory at NMSU.

Age corrections for Sr and Pb isotopes used measured $^{87}Rb/^{86}Sr$ ratios and assumed U/Pb and Th/Pb ratios. Age corrections for Pb isotopes assumed U/Pb and Th/Pb ratios for plagioclase of 0.02 and 0.08, which are significantly higher than ratios determined by Wolff and Ramos (2003) for potassium feldspars. Actual U/Pb and Th/Pb ratios were not measured but even these higher ratios result in age corrections that generate only minor variations in ratios compared to overall Pb iso-

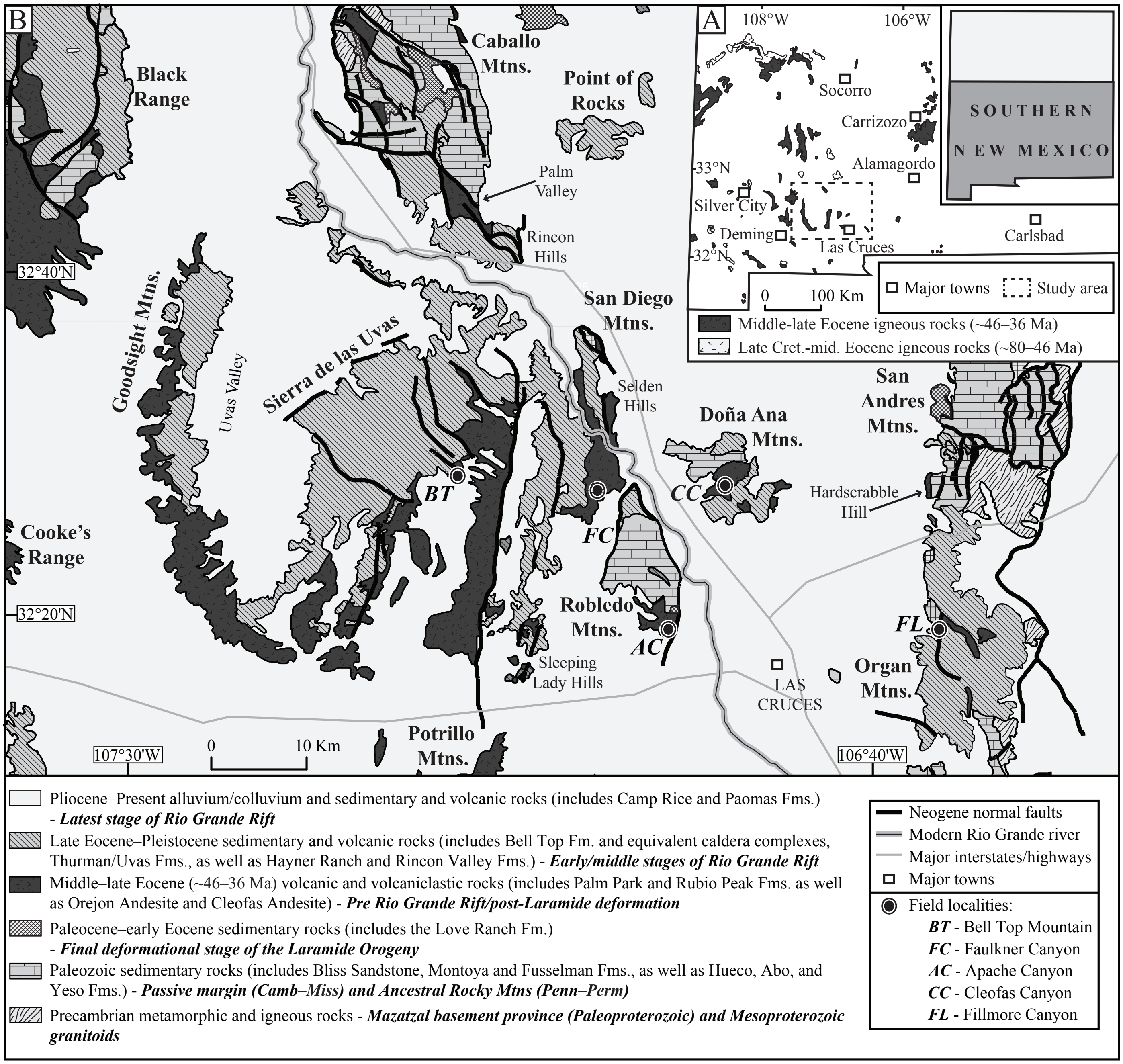

FIGURE 1. Regional map of south-central New Mexico showing sample locations of whole rocks collected for this study. Palm Park Formation tuffs were collected from Apache Canyon (Robledo Mountains) and Bell Top Mountain (Sierra de Las Uvas Mountains). Andesitic and dacitic lavas were collected from Fillmore Canyon (Organ Mountains), Cleofas Canyon (Doña Ana Mountains), and the Robledo Mountains as indicated (map modified from Creitz et al., this volume).

tope variations and do not substantially impact interpretations regarding feldspar origins.

RESULTS

Forty-eight feldspars were analyzed for Sr and Pb isotopes from a range of volcanic lithologies (Tables 1 and 2) collected from near the stratigraphic base, middle, and top of the Palm Park Formation (or equivalent rocks) throughout south-central New Mexico. Some of the oldest parts of the Palm Park Formation are marked by a light-colored ash-fall tuff (AC-02) in the Robledo Mountains (Seager et al., 2008) that contains 45.0±0.7 Ma zircons (Creitz et al., this volume). This ash-fall tuff is present in Palm Park strata but may originate from a more distal source not reflected by the same local magmatic sources as most Palm Park volcanic rocks (Fig. 2). Similarly, rocks near the top of the Palm Park Formation are marked by another ash-fall tuff (BT) that crops out in the Sierra de Las Uvas Mountains and contains 39.6±0.5 Ma zircons (Creitz et al., this volume). This tuff may also originate from distal magmatic sources (Fig. 2). Samples collected from the middle portions of the Palm Park Formation are primarily lava flows that

TABLE 1. Table showing formations, localities, sample identifiers, ages, and coordinate locations.

Formation	Palm Park	Palm Park	Palm Park	Palm Park	Palm Park	Palm Park	Palm Park	Palm Park	Palm Park	Palm Park
Location	Robledo Mtns.	Organ Mtns.	Organ Mtns.	Doña Ana Mtns.	Doña Ana Mtns.	Doña Ana Mtns.	Doña Ana Mtns.	Robledo Mtns.	Robledo Mtns.	Sierra de Las Uvas Mtns.
	Apache Canyon	Filmore Canyon	Filmore Canyon	Cleofas Canyon	Cleofas Canyon	Cleofas Canyon	Cleofas Canyon	Faulkner Canyon	Faulkner Canyon	Bell Top Mtn.
Samp. ID	PALMP-(RM/AC)-02	OREJON-(OR/FL)-02	OREJON-(OR/FL)-01	DAA	DAD	PALMP-(DA/CC)-05	PALMP-(DA/CC)-01	PALMP-(RB/FC)-01	PALMP-(RB/FC)-08	PALM-(SU/BT)-01
Age	45.0±0.7 Ma	43.8±0.4 Ma	42.8±0.5 Ma	43.12±0.19 Ma	43.31±0.05 Ma	41.6±0.7 Ma	41.3±0.7 Ma	41.0±0.6 Ma	41.0±0.6 Ma	39.6±0.5 Ma
Latitude	32.348	32.344	32.344	32.462	32.457	32.463	32.462	32.460	32.478	32.486
Longitude	-106.881	-106.584	-106.568	-106.839	-106.853	-106.844	-106.838	-106.971	-106.948	-107.120

originated from more local sources. Feldspars in Palm Park volcanics are targeted because they are both plentiful in most deposits and resistant to post-eruption alteration, a common feature of Palm Park volcanic rocks. Below, isotopic results of feldspars from lavas and tuffs from different regional sites are described from stratigraphically oldest to youngest as indicated by the ages of zircons in the individual rocks sampled (Creitz et al., this volume).

Three plagioclase crystals from an ash fall tuff containing 45.0±0.7 Ma zircons (Creitz et al., this volume) have variable Rb and Sr concentrations and Sr and Pb isotope ratios. This tuff is interbedded with volcaniclastic and gypsiferous strata that Seager et al. (2008) identified as the basal portion of the Palm Park Formation in Apache Canyon of the Robledo Mountains. It is abnormally light in color compared to most Palm Park deposits and has plagioclase crystals with relatively low Rb concentrations (~2–13 ppm), variable Sr concentrations (650–4060 ppm), and relatively unradiogenic, age-corrected $^{87}Sr/^{86}Sr$ signatures (~0.7045–0.7052) that are only minimally impacted by post-eruption decay (Fig. 3). $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ ratios of these feldspars are also unradiogenic (e.g., $^{206}Pb/^{204}Pb$: 17.19–17.22; Table 2, Figs. 3 and 4).

Four plagioclase crystals from a lava flow that contains 43.8±0.4 Ma zircons (Creitz et al., this volume) from the lower portion of the Orejon Andesite (i.e., Palm Park Formation equivalent, FC-02) in Fillmore Canyon of the Organ Mountains have elevated Rb (~460–1630) and Sr concentrations (~3450–4460), and radiogenic, age-corrected $^{87}Sr/^{86}Sr$ ratios of 0.7062 to 0.7065 (Fig. 3). Age-corrected $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ ratios of these same plagioclases are variable and highly radiogenic (e.g., $^{206}Pb/^{204}Pb$: 17.65–17.96; Figs. 3 and 4). Both Sr and Pb isotope ratios are significantly more radiogenic than plagioclase crystals from the basal, ash-fall tuff in Apache Canyon.

In contrast to plagioclase crystals from the lower portion of the Orejon Andesite in Fillmore Canyon, six plagioclase crystals from a lava flow (FC-01) from the upper portion of the Orejon Andesite, which contains 42.8±0.5 Ma zircons (Creitz et al., this volume), have lower Rb concentrations (~30–255 ppm), variable and elevated Sr concentrations (~1919–5500 ppm), and less radiogenic, age-corrected $^{87}Sr/^{86}Sr$ ratios that range from 0.7050–0.7058 (Fig. 3). Accompanying age-corrected $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ ratios of these same plagioclases are relatively uniform and unradiogenic (e.g., $^{206}Pb/^{204}Pb$: 17.51–17.53; Figs. 3 and 4). Overall, Sr and Pb isotope ratios of plagioclase crystals from lavas in the younger portions of Palm Park Formation equivalents in Fillmore Canyon are less radiogenic than those in the older portions of Palm Park Formation equivalents in the Organ Mountains.

Compared to the Organ Mountains, plagioclase crystals from each of two lavas from Cleofas Canyon in the Doña Ana Mountains are unradiogenic. The first lava (CL-05), located to the east of the second, hosts 41.6±0.7 Ma zircons. Four plagioclase crystals from this lava have low Rb concentrations (~14-19 ppm), high Sr concentrations (~1820–2150 ppm), and unradiogenic age-corrected $^{87}Sr/^{86}Sr$ (~0.7045–0.7046; Fig. 3). Accompanying age-corrected $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ ratios are generally less radiogenic than plagioclase crystals in the Organ Mountains (e.g., $^{206}Pb/^{204}Pb$ = 17.33 to 17.53; Figs. 3 and 4). Six plagioclase crystals from a second lava flow (CL-01) from Cleofas Canyon that contains 41.3±0.7 Ma zircons (Creitz et al., this volume), an age that is indistinguishable from the first lava, has plagioclase crystals with low Rb concentrations (~3–80), elevated Sr concentrations (~900 to 1160 ppm), and similarly unradiogenic, age-corrected $^{87}Sr/^{86}Sr$ ratios (~0.7045–0.7047; Fig. 3) as the first lava. Accompanying age-corrected $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ ratios are also similar to results for the first lava and unradiogenic compared to those in the Organ Mountains ($^{206}Pb/^{204}Pb$ = 17.22 to 17.45; Figs. 3 and 4). Overall, the two Cleofas Canyon lavas have plagioclases crystals with similar $^{87}Sr/^{86}Sr$, $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ that originate from lavas hosting zircons with identical ages.

Additional plagioclase crystals were analyzed from two samples in Cleofas Canyon and are included here (Ramos and Heizler, this volume). The first (DAA) has a 43.05 Ma $^{40}Ar/^{39}Ar$ age from feldspars that have low Rb concentrations (<1 ppm) and intermediate Sr concentrations (1500 ppm). These feldspars have $^{87}Sr/^{86}Sr$ ratios of 0.7033–0.7049 and $^{206}Pb/^{204}Pb$ ratios of 18.73–19.06, which are the most radiogenic Pb isotope ratios of any plagioclase crystals from the Palm Park Formation (Figs. 3 and 4). In addition, a dacite (DAD) has plagioclase crystals with low Rb concentrations (17–23 ppm) and intermediate to high Sr concentrations (1050–2150 ppm). $^{87}Sr/^{86}Sr$ ratios are similar to many other Palm Park feldspars (0.7046–0.7048; Fig. 3) and Pb isotope ratios are much less radiogenic than the first Cleofas Canyon sample ($^{206}Pb/^{204}Pb$=17.23–17.26; Figs. 3 and 4).

TABLE 2. Table showing selected trace element and isotope ratios of Palm Park Formation plagioclase crystals. Note that Sr and Pb isotope ratios are corrected for the age indicated. Sample locations are in bold and italics, and samples are in bold.

Identifier	Mineral	Age (Ma)	Crystal Wt. (mg)	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	$^{87}Sr/^{86}Sr_i$	Error (2σ)	U/Pb	Th/Pb	$^{206}Pb/^{204}Pb_i$	Error (2σ)	$^{207}Pb/^{204}Pb_i$	Error (2σ)	$^{208}Pb/^{204}Pb_i$	Error (2σ)
Sierra de Las Uvas Mtns.																	
PALMP(SU/BT)-01																	
Gr#1	Plag	39.6	0.340	-	-	0.001	0.705765	0.705763	*0.000013*	0.02	0.08	17.426	*0.016*	15.447	*0.014*	37.075	*0.034*
Gr#2	Plag	39.6	0.425	-	-	0.001	0.706869	0.706869	*0.000021*	0.02	0.08	17.289	*0.003*	15.439	*0.003*	37.884	*0.008*
Gr#3	Plag	39.6	0.320	-	-	0.001	0.705723	0.705722	*0.000011*	0.02	0.08	17.274	*0.002*	15.433	*0.002*	37.721	*0.006*
Gr#4	Plag	39.6	0.320	1	1789	0.002	0.706024	0.706023	*0.000011*	0.02	0.08	17.310	*0.002*	15.439	*0.002*	37.804	*0.004*
Gr#5	Plag	39.6	0.161	1	1297	0.001	0.706470	0.706469	*0.000013*	0.02	0.08	17.290	*0.040*	15.407	*0.032*	37.741	*0.082*
Gr#6	Plag	39.6	0.121	1	1211	0.001	0.706889	0.706888	*0.000010*	0.02	0.08	17.389	*0.008*	15.441	*0.006*	37.873	*0.016*
Robledo Mtns.																	
PALMP(RB/FC)-01																	
Pl#1	Plag	41.0	0.050	3	1997	0.001	0.704476	0.704473	*0.000010*	0.02	0.08	17.178	*0.024*	15.385	*0.020*	37.161	*0.052*
Pl#2	Plag	41.0	0.425	-	-	0.001	0.704509	0.704508	*0.000010*	0.02	0.08	17.213	*0.009*	15.428	*0.008*	37.278	*0.020*
Pl#4	Plag	41.0	0.058	1	2114	0.001	0.704468	0.704467	*0.000011*	0.02	0.08	17.235	*0.034*	15.446	*0.036*	37.325	*0.082*
Pl#6	Plag	41.0	0.320	-	-	0.001	0.704378	0.704377	*0.000013*	0.02	0.08	17.179	*0.005*	15.426	*0.005*	37.259	*0.012*
Pl#9	Plag	41.0	0.340	-	-	0.001	0.704360	0.704359	*0.000011*	0.02	0.08	17.221	*0.010*	15.435	*0.009*	37.279	*0.022*
Pl#11	Plag	41.0	0.051	1	1987	0.000	0.704537	0.704536	*0.000014*	0.02	0.08	17.147	*0.020*	15.349	*0.018*	37.080	*0.044*
Robledo Mtns.																	
PALMP(RB/FC)-08																	
Pl#1	Plag	41.0	0.205	1	2246	0.001	0.704596	0.704595	*0.000010*	0.02	0.08	17.215	*0.004*	15.422	*0.004*	37.287	*0.011*
Pl#3	Plag	41.0	0.372	1	1698	0.002	0.704712	0.704711	*0.000017*	0.02	0.08	17.330	*0.004*	15.444	*0.004*	37.574	*0.008*
Pl#4	Plag	41.0	0.331	1	2140	0.001	0.704616	0.704615	*0.000010*	0.02	0.08	17.215	*0.005*	15.417	*0.005*	37.283	*0.013*
Pl#7	Plag	41.0	0.205	2	2035	0.003	0.704682	0.704680	*0.000017*	0.02	0.08	17.215	*0.005*	15.417	*0.004*	37.285	*0.010*
Doña Ana Mtns.																	
DAD																	
Pl#4	Plag	43.1	1.680	-	-	-	-	-	-	0.01	0.08	17.249	*0.008*	15.418	*0.008*	37.461	*0.022*
Pl#5	Plag	43.1	0.390	17	1390	0.050	0.704678	0.704645	*0.000010*	-	-	-	-	-	-	-	-
Pl#7	Plag	43.1	4.470	19	2151	0.040	0.704843	0.704819	*0.000013*	0.01	0.08	17.235	*0.001*	15.413	*0.001*	37.444	*0.003*
Pl#8	Plag	43.1	0.200	23	1747	0.060	0.704727	0.704691	*0.000014*	0.01	0.08	17.263	*0.003*	15.416	*0.002*	37.472	*0.006*
Pl#9	Plag	43.1	2.490	19	1046	0.080	0.704803	0.704752	*0.000013*	0.01	0.08	17.246	*0.002*	15.413	*0.002*	37.471	*0.005*
Doña Ana Mtns.																	
PALMP(DA/CC)-01																	
Pl#1	Plag	41.3	2.572	81	895	0.262	0.704650	0.704496	*0.000010*	0.02	0.08	17.250	*0.002*	15.429	*0.002*	37.352	*0.006*
Pl#2	Plag	41.3	2.916	4	1035	0.011	0.704688	0.704681	*0.000011*	0.02	0.08	17.240	*0.001*	15.425	*0.001*	37.328	*0.004*
Pl#3	Plag	41.3	1.423	3	1018	0.009	0.704675	0.704670	*0.000011*	0.02	0.08	17.446	*0.003*	15.461	*0.003*	37.491	*0.007*
Pl#4	Plag	41.3	0.526	-	-	-	-	-	-	0.02	0.08	17.338	*0.004*	15.451	*0.003*	37.409	*0.007*
Pl#5	Plag	41.3	0.182	4	951	0.004	0.704657	0.704650	*0.000070*	0.02	0.08	17.263	*0.008*	15.432	*0.008*	37.367	*0.016*
Pl#6	Plag	41.3	0.124	5	1159	0.005	0.704625	0.704618	*0.000011*	0.02	0.08	17.226	*0.034*	15.373	*0.032*	37.229	*0.046*
Doña Ana Mtns.																	
PALMP(DA/CC)-05																	
Pl#2	Plag	41.6	0.371	19	1917	0.029	0.704583	0.704566	*0.000011*	0.02	0.08	17.530	*0.008*	15.427	*0.007*	37.576	*0.017*
Pl#3	Plag	41.6	0.720	14	1820	0.022	0.704589	0.70476	*0.000030*	0.02	0.08	17.333	*0.004*	15.442	*0.004*	37.589	*0.010*
Pl#6	Plag	41.6	0.362	16	1850	0.025	0.704630	0.704615	*0.000018*	0.02	0.08	17.375	*0.005*	15.430	*0.005*	37.617	*0.012*
Pl#8	Plag	41.6	0.437	17	2153	0.023	0.704514	0.704500	*0.000008*	0.02	0.08	17.347	*0.004*	15.443	*0.004*	37.594	*0.010*
Doña Ana Mtns.																	
DAA																	
Pl#1	Plag	43.1	1.475	0	449	0.002	0.704963	0.704962	*0.000010*	0.01	0.08	18.732	*0.002*	15.624	*0.002*	38.309	*0.006*
Pl#2	Plag	43.1	0.800	-	-	0.002	0.703603	0.703359	*0.000010*	0.01	0.08	19.035	*0.004*	15.648	*0.004*	38.475	*0.010*
Pl#3	Plag	43.1	0.900	0	449	0.002	0.704836	0.705835	*0.000011*	0.01	0.08	19.063	*0.001*	15.669	*0.001*	38.536	*0.003*
Organ Mtns.																	
OREJON(OR/FL)-01																	
Pl#1	Plag	42.8	0.372	-	-	-	-	-	-	0.02	0.08	17.519	*0.017*	15.468	*0.016*	37.786	*0.004*
Pl#4	Plag	42.8	0.046	55	2064	0.027	0.705712	0.705665	*0.000035*	0.02	0.08	17.518	*0.010*	15.453	*0.008*	37.787	*0.020*
Pl#7	Plag	42.8	0.205	-	-	-	-	-	-	0.02	0.08	17.540	*0.005*	15.453	*0.004*	37.774	*0.010*
Pl#10	Plag	42.8	0.167	255	3441	0.215	0.705132	0.705002	*0.000024*	0.02	0.08	17.532	*0.004*	15.458	*0.004*	37.780	*0.009*
Pl#12	Plag	42.8	0.331	98	5497	0.051	0.705846	0.705815	*0.000010*	0.02	0.08	17.514	*0.002*	15.462	*0.002*	37.794	*0.006*
Pl#13	Plag	42.8	0.032	30	1919	0.016	0.705481	0.705453	*0.000013*	0.02	0.08	17.527	*0.018*	15.472	*0.016*	37.837	*0.042*
Organ Mtns.																	
OREJON(OR/FL)-02																	
Pl#4	Plag	43.8	1.094	461	4166	0.321	0.706638	0.706439	*0.000010*	0.02	0.08	17.648	*0.002*	15.476	*0.002*	37.829	*0.004*
Pl#7	Plag	43.8	0.986	1632	3456	1.367	0.707018	0.706168	*0.000013*	0.02	0.08	17.955	*0.002*	15.509	*0.002*	37.927	*0.004*
Pl#9	Plag	43.8	0.264	1252	4464	0.812	0.706815	0.706310	*0.000013*	0.02	0.08	17.795	*0.018*	15.511	*0.016*	37.911	*0.038*
Pl#14	Plag	43.8	0.581	1297	3823	0.982	0.706861	0.706439	*0.000010*	0.02	0.08	17.763	*0.002*	15.486	*0.003*	37.486	*0.009*
Robledo Mtns.																	
PALMP(RM/AC)-02																	
Pl#12	Plag	45.0	0.209	13	4055	0.009	0.704985	0.704979	*0.000013*	0.02	0.08	17.222	*0.008*	15.425	*0.008*	37.425	*0.018*
Pl#1	Plag	45.0	0.119	3	773	0.003	0.705196	0.705189	*0.000017*	0.02	0.08	17.189	*0.006*	15.417	*0.004*	37.387	*0.012*
Pl#2	Plag	45.0	0.146	2	646	0.003	0.704996	0.704990	*0.000011*	0.02	0.08	17.204	*0.004*	15.417	*0.004*	37.330	*0.014*

Standards analyzed with unknowns included NBS987 (n=9) with an $^{87}Sr/^{86}Sr$ of 0.710303 and NBS981 (n=18) $^{206}Pb/^{204}Pb$=16.928 (SD=0.002), $^{207}Pb/^{204}Pb$=15.480 (SD=*0.002*), $^{208}Pb/^{204}Pb$=36.662 (SD=*0.006*) for standards with Pb concentrations similar to unknowns.

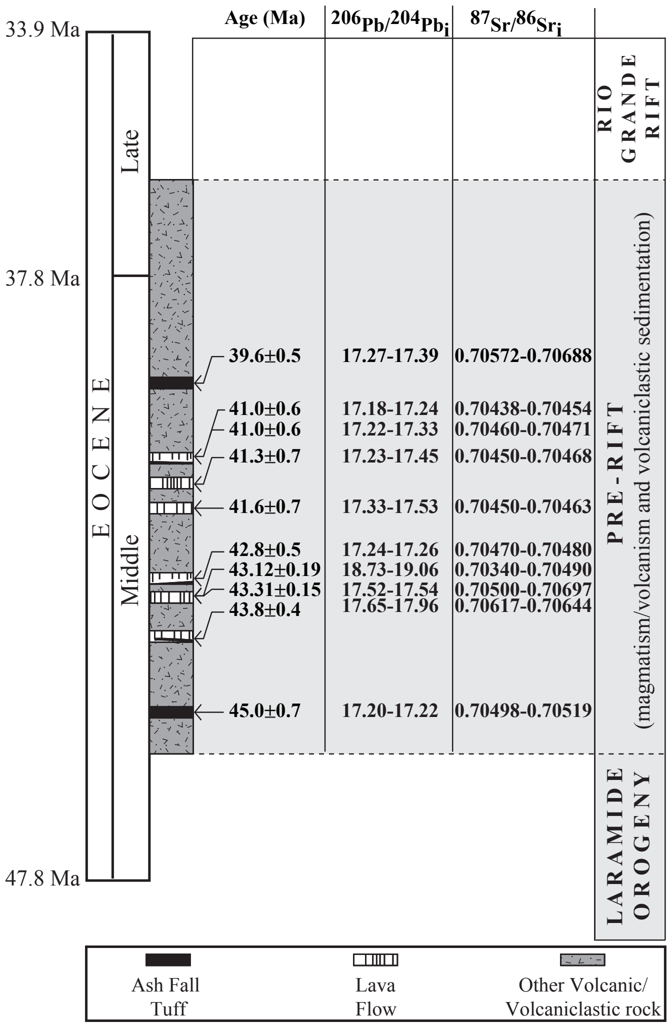

FIGURE 2. Stratigraphic column of Palm Park Formation (and age equivalent Orejon Andesite) lithologies showing zircon and $^{40}Ar/^{39}Ar$ ages and age-corrected $^{87}Sr/^{86}Sr$ and $^{206}Pb/^{204}Pb$ ratios of plagioclase crystals from andesitic and dacitic lavas, and air-fall tuffs. Ages are from Creitz et al. (this volume), Ramos et al. (this volume), and Ramos and Heizler (this volume).

In addition to feldspars from lavas from the Doña Ana and Organ Mountains, four plagioclase crystals were analyzed from two lava flows that contain zircons with identical ages of 41.0±0.6 Ma (Creitz et al., this volume) from Faulkner Canyon in the Robledo Mountains. Plagioclase crystals from the first lava flow (FC-01), collected stratigraphically up-section from the second, have low Rb concentrations (1.0–3.0 ppm) and intermediate Sr concentrations (1700–2250 ppm). Age-corrected $^{87}Sr/^{86}Sr$, $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ ratios are unradiogenic (0.7046–0.7047 and $^{206}Pb/^{204}Pb$ =17.21–17.33; Figs. 3 and 4) with Sr isotope ratios being similar to those of Palm Park feldspars in the Doña Ana Mountains although accompanying Pb isotope ratios are less radiogenic. Three plagioclase crystals from the second lava (FC-08), collected from lower in the section, also have low Rb concentrations (1–3 ppm) and high Sr concentrations (2000–2100 ppm). Age-corrected $^{87}Sr/^{86}Sr$ ratios are similarly unradiogenic (0.7044–0.7046) as are age-corrected $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ ratios (e.g., $^{206}Pb/^{204}Pb$= ~17.15–17.24; Figs. 3 and 4). In general, Sr and Pb isotope ratios of plagioclases from the two lavas in the Robledo Mountains are similar to each other. They also have similar Sr isotope characteristics to feldspars in the Doña Ana Mountains, but the Pb isotope ratios of Robledo Mountain feldspars are less radiogenic.

Lastly, three plagioclase crystals from a tuff (BT) located in the uppermost portion of the Palm Park Formation and stratigraphically below the Bell Top Formation in the Sierra de Las Uvas Mountains, that contains 39.6±0.5 Ma zircons (Creitz et al., this volume), have low Rb concentrations (~1 ppm), elevated Sr concentrations (~1200–1800 ppm), radiogenic $^{87}Sr/^{86}Sr$ ratios (0.7060–0.7069; Fig. 2), and unradiogenic $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ ratios (e.g., $^{206}Pb/^{204}Pb$ =17.29–17.39; Figs. 3 and 4). These isotopic characteristics (i.e., radiogenic Sr and unradiogenic Pb) are dissimilar to all other Palm Park feldspars and may indicate that this ash fall is unrelated to the magmatic source generating the majority of Palm Park volcanic rocks.

Overall, Palm Park Formation plagioclase crystals have rubidium, strontium, $^{87}Sr/^{86}Sr$, and $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ ratios that vary widely. There are plagioclase crystals with similar characteristics in lavas collected from the same locality (i.e., Robledo Mountains) but most are variable within specific exposures. Plagioclase crystal isotope characteristics from different localities are however different, which attests to the likely time dependent variation of these signatures.

DISCUSSION

Palm Park Formation-Orejon Andesite (Organ Mountains)

Strontium and lead isotope ratios of plagioclases from two Orejon lavas (i.e., Palm Park age equivalents) from the Organ Mountains, which have zircon ages that are nearly within analytical error (42.8±0.5 and 43.8±0.4 Ma; Creitz et al., this volume), have significantly different age-corrected $^{87}Sr/^{86}Sr$ ratios (~0.7050–0.7052 vs. ~0.7061–0.7064) with one crystal from the second lava approaching the $^{87}Sr/^{86}Sr$ ratios of the first lava (i.e., 0.7058). Age-corrected $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ ratios are also different (Figs. 2, 3 and 4) with the first lava being more radiogenic (e.g., $^{206}Pb/^{204}Pb$= ~17.69 to 17.96 vs. 17.52–17.55) than the second lava. These differences indicate that isotope ratios of plagioclase crystals from Orejon lavas in the Organ Mountains are highly variable and likely originate from different magmatic sources or involve a complex magma system where magmas with variable isotopic characteristics can be erupted almost simultaneously (i.e., <1 my). Alternatively, elevated Rb concentrations of plagioclase in both lavas, but especially for plagioclases in the OR-02 lava, may result from post-eruption alteration. In addition to Rb, Sr may also have been modified where alteration may have imparted a more radiogenic $^{87}Sr/^{86}Sr$ signature to the feldspars. This could also account for the higher $^{87}Sr/^{86}Sr$ of one of the plagioclase crystals in the second lava (~0.7058), which also has elevated Rb contents (98 ppm). Thus, we view crystal results from the second lava as suspect and likely altered. It is

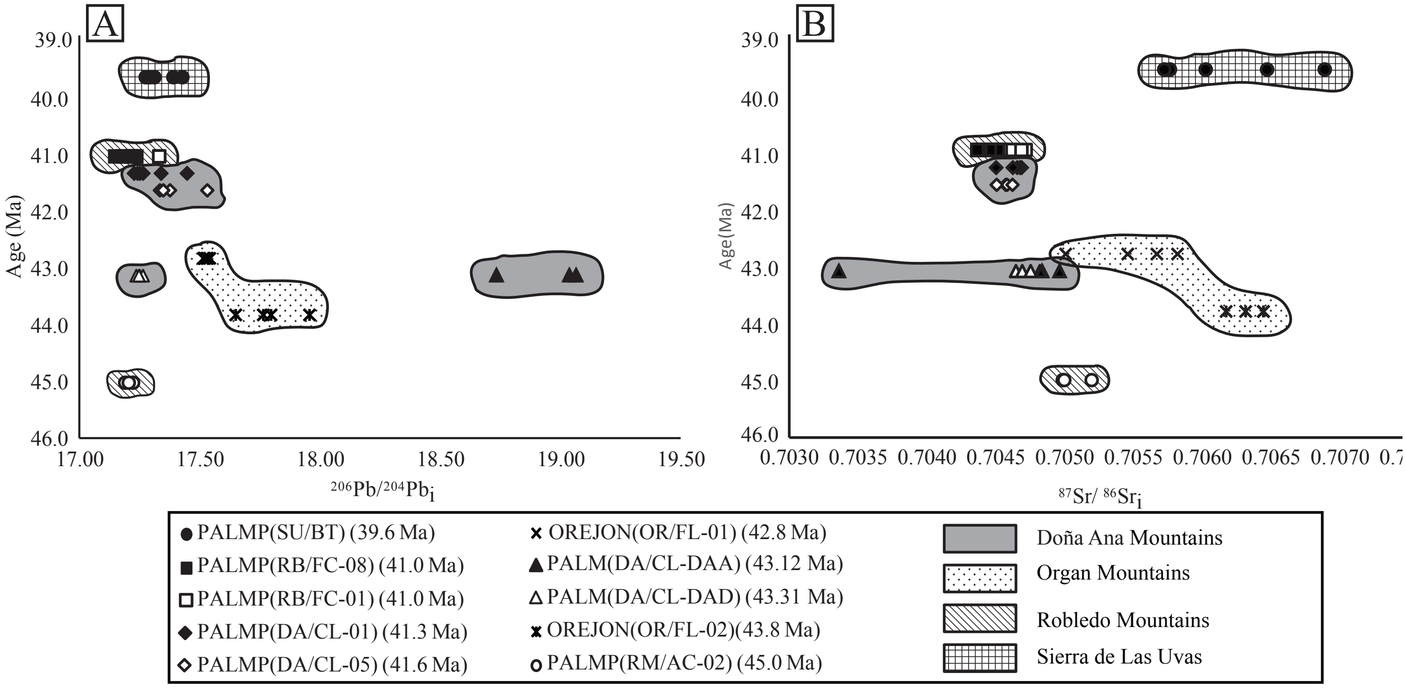

FIGURE 3. Diagrams illustrating age-corrected, plagioclase crystal **A)** $^{206}Pb/^{204}Pb$ and **B)** $^{87}Sr/^{86}Sr$ variations compared with stratigraphic age. Both diagrams illustrate the general nature of decreasing $^{87}Sr/^{86}Sr$ and $^{206}Pb/^{204}Pb$ of plagioclase with decreasing age. Note, that plagioclase crystals from 1) Apache Canyon (Robledo Mountains) have unradiogenic Pb isotopes and intermediate Sr isotope ratios while 2) crystals from Bell Top Mountain have intermediate/low Pb isotopes and radiaogenic Sr isotopes compared to the Palm Park Formation lavas of similar age.

however unclear as to what effects alteration would have on Pb isotopes. In any case, plagioclase Sr and Pb isotope variations of crystals from the second lava confirm involvement of variable andesitic Palm Park equivalent magmatism in the Organ Mountains.

Palm Park Formation (Doña Ana Mountains)

Age-corrected $^{87}Sr/^{86}Sr$ (~0.7045–0.7046) and $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ ratios (e.g., $^{206}Pb/^{204}Pb$= ~17.34 to 17.54; Figs. 2, 3 and 4) of plagioclase crystals from the two Palm Park lavas from the Doña Ana Mountains, which have zircon ages that are within error (41.3±0.7 and 41.6±0.7 Ma), are very similar. These results contrast with those of Ramos et al. (this volume) where plagioclase crystals from andesitic lava sampled from the eastern portion of Cleofas Canyon (i.e., up-canyon and east of lavas sampled here) have variable $^{87}Sr/^{86}Sr$ ratios (0.7033–0.7049) and highly radiogenic Pb isotope ratios (e.g., $^{206}Pb/^{204}Pb$= ~18.73 to 19.06), unlike any measured in this study (Figs. 2, 3, and 4). However, plagioclase crystals sampled from a dacite in the western portion (i.e., down canyon and west of lavas sampled here) of Cleofas Canyon have slightly more radiogenic $^{87}Sr/^{86}Sr$ ratios (0.7047–0.7048) and slightly less radiogenic to overlapping Pb isotope ratios (e.g., $^{206}Pb/^{204}Pb$= ~17.24 to 17.26). In addition, the andesite-hosted, plagioclase crystals with the highly radiogenic Pb isotope ratios also yielded a 43.05±0.28 $^{40}Ar/^{39}Ar$ Ma age (Ramos and Heizler, this volume), which is slightly older than the zircon ages. These age differences suggest Palm Park volcanic rocks increase in age in an eastward direction in Cleofas Canyon and that this section of the Palm Park Formation encompasses ≤2 my of geologic time.

Overall, andesitic and dacitic Palm Park lavas in the Doña Ana Mountains have variable Sr and Pb isotope signatures that must originate from different magmatic sources or involve a complex magma system where magmas with different isotopic characteristics can be erupted in a short amount of geologic time (i.e., ~2 my). In any case, Sr and Pb isotope variations of plagioclases confirm the involvement of variable andesitic and dacitic magmas associated with Palm Park volcanism in the Doña Ana Mountains.

Palm Park Formation (Robledo Mountains)

Plagioclase crystals from two Palm Park lavas from the Robledo Mountains, which have identical zircon ages (41.0±0.6 and 41.0±0.6 Ma), have similar age-corrected $^{87}Sr/^{86}Sr$ (~0.70435–0.70451) and $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ ratios (e.g., $^{206}Pb/^{204}Pb$= ~17.19 to 17.34; Figs. 2, 3, and 4). Lavas hosting these crystals are likely younger than those in the Organ and Doña Ana Mountains and may have originated from a similar, or the same, magma. In contrast to other Palm Park localities, the feldspars from the two lavas from the Robledo Mountains indicate a relatively homogenous magma source. Alternatively, and given their identical ages, these lavas may originate from the same sequence of lavas erupted at the same time. Overall, plagioclase crystals from the Robledo Mountains have uniform isotope signatures that extend ratios to less radiogenic signatures.

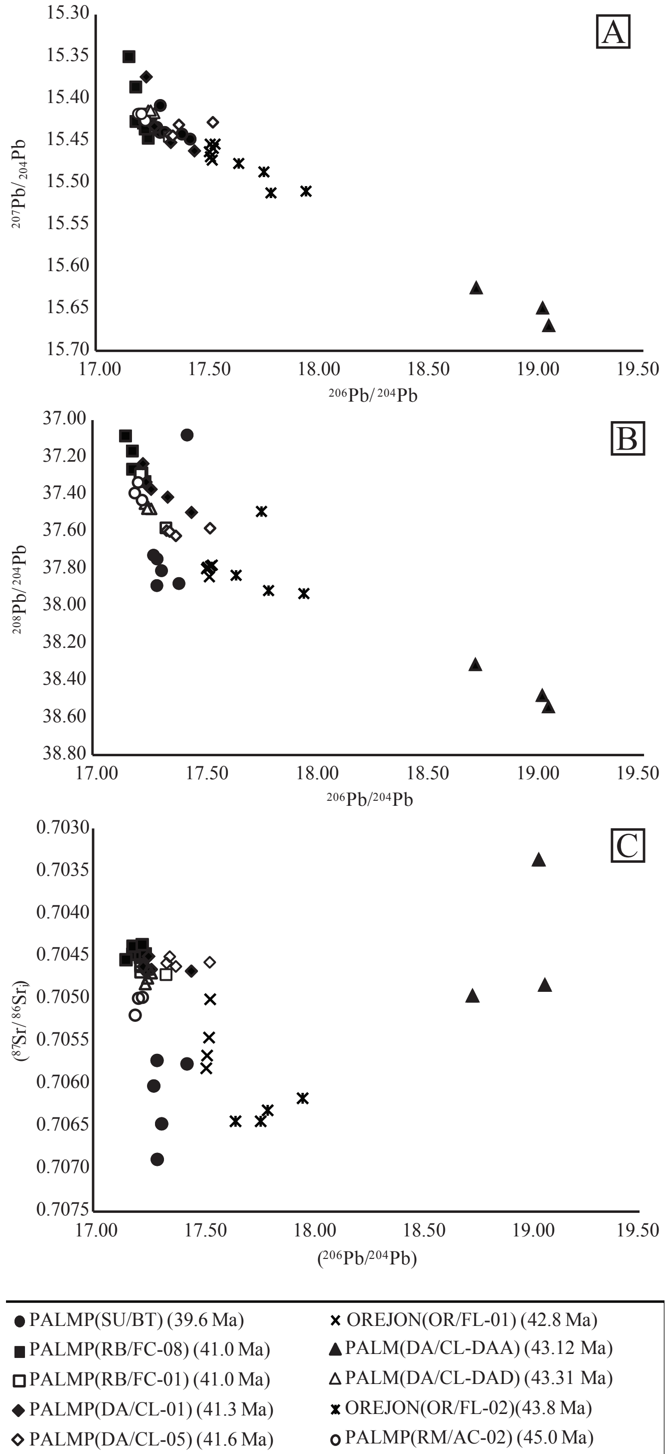

FIGURE 4. Diagrams showing age-corrected, plagioclase crystal **A**) ^{207}Pb/^{204}Pb, **B**) ^{208}Pb/^{204}Pb, and **C**) ^{87}Sr/^{86}Sr vs. ^{206}Pb/^{204}Pb variations. Note the distinct and different ^{206}Pb/^{204}Pb defined by the tuffs at near the base (AC-02) and top (BT) of the Palm Park Formation stratigraphic section.

Palm Park Formation (Sierra de Las Uvas Mountains)

Plagioclase crystals from a Palm Park tuff from the Sierra de Las Uvas Mountains, which host zircons with a 39.6±0.5 Ma age, have more radiogenic age-corrected ^{87}Sr/^{86}Sr (~0.7059–0.7068) and variable ^{206}Pb/^{204}Pb, ^{207}Pb/^{204}Pb, and ^{208}Pb/^{204}Pb ratios (e.g., ^{206}Pb/^{204}Pb= ~17.28 to 17.43; Figs 2, 3, and 4). The tuff hosting these crystals is likely the youngest of all Palm Park Formation rocks sampled although its Sr isotope crystal signatures are most similar to Orejon Andesite lavas in the Organ Mountains, which are older than ~43 Ma. Pb ratios are however less radiogenic than feldspars in the Organ Mountains, likely because the sources generating these magmas were highly variable in their Sr and Pb isotopic characters.

Palm Park Formation (Regional Characteristics)

Overall, plagioclase crystals from Palm Park Formation volcanic rocks and age equivalents in south-central New Mexico retain a range of Sr and Pb isotope characteristics originating from lavas hosting zircon crystals with ages ranging from ~45 to ~39 Ma. Presumably older (~44–43 Ma; Fig. 2) Orejon Andesite lavas from Fillmore Canyon in the Organ Mountains have plagioclase crystals that are more radiogenic in both Sr (0.7051–0.7064) and Pb (^{206}Pb/^{204}Pb=17.52–17.96) and which range to more radiogenic ^{87}Sr/^{86}Sr as a result of post-eruption alteration. These isotope characteristics are unique to crystals in Organ Mountain lavas and suggest that early-erupted, Palm Park andesitic magmas originated from relatively radiogenic mantle sources. The later appearance of andesite with less radiogenic isotope signatures in Fillmore Canyon (e.g., ^{87}Sr/^{86}Sr= 0.7051–0.7053, ^{206}Pb/^{204}Pb=17.52–17.55 in OR-01) may be consistent with a greater, less radiogenic crustal contribution rather than a different mantle origin for these signatures or the changing nature of the crust assimilated (i.e., towards materials that were less radiogenic). A single crystal with intermediate isotope characteristics in this later erupted lava may indicate some alteration similar to that reflected in crystals from the first lava. In any case, Orejon Andesite lavas in the Organ Mountains likely reflect the earliest record of Palm Park volcanic activity and earliest isotopic characteristics of the Palm Park volcanic source.

In contrast to the Organs Mountains, plagioclase crystals from Palm Park lavas from Cleofas Canyon in the Doña Ana Mountains have intermediate ages with highly variable ^{87}Sr/^{86}Sr and Pb isotope signatures, which include crystals with the most radiogenic Pb isotope characteristics. Three of four lavas sampled for plagioclase have similar Sr and Pb isotope ratios that likely reflect the general character of Palm Park volcanic rocks but clearly a highly radiogenic Pb isotope source was involved. In contrast, plagioclase crystals from the Robledo Mountains retain the least radiogenic isotope signatures in both Sr and Pb isotopes. This may result from either a different mantle source being involved in Palm Park magmatism or more likely, a greater crustal contribution or less radiogenic crust being added during magmatic ascent and differentiation.

In contrast to Palm Park lavas, air-fall tuffs found at the top (AP-02) and bottom (BT) of the stratigraphic section have very different isotope signatures as similar age Palm Park Formation lavas. Isotopic and potential compositional differences (as reflected by their lighter color) likely indicate a more distal origin for these tuffs (as compared to the accompanying lavas).

CONCLUSIONS

Volcanic rocks of the Palm Park Formation or the age equivalent Orejon Andesite, exposed in the Organ Mountains, Doña Ana Mountains, Robledo Mountains, and Sierra de Las Uvas Mountains, are mainly composed of locally-derived andesitic and dacitic rocks erupted at the time when magmatism associated with Laramide orogenesis transitioned to magmatism associated with the ignimbrite flare-up in south-central New Mexico. Feldspars from early-erupted lavas (~45–44 Ma) have more radiogenic Sr and Pb isotope ratios than those in late-erupted lavas (~41–39 Ma). Variations likely result from the involvement of different magmatic sources or sources that sequentially incorporated more less-radiogenic crust. Some of the oldest and youngest parts of the Palm Park Formation contain tuffs likely originating from more distal sources as indicated by host feldspars with different Sr and Pb isotope characteristics. Results confirm that magmatism occurring during the tectonic transition from Laramide orogenesis to that of the ignimbrite flare-up involved a range of magmas that must have originated from a complex magmatic system that involved variable magmatic sources.

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REFERENCES

Clemons, R.E., 1979, Geology of Good Sight Mountains and Uvas Valley, southwest New Mexico: New Mexico Bureau of Mines & Mineral Resources, Circular 169, 31 p.

Creitz, R.H., Hampton, B. A., Mack, G.H., and Amato, J.M., *this volume*, U-Pb Geochronology of Middle-Late Eocene Intermediate Volcanic Rocks of the Palm Park Formation and Orejon Andesite in South-central New Mexico.

Hawley, J.W., Seager, W.R., and Clemons, R.E., 1975, Third day-road log from Las Cruces to north Mesilla Valley, Cedar Hills, San Diego Mountain, and Rincon area: New Mexico Geological Society, Guidebook 26, p. 35–53.

Ramos, F.C., Askin, T., Levesque, S.M., Stevens, P., Thines, J., Farnsworth-Pinkerton, S., Lindell, S. and Richard, N., *this volume*, Sr and Pb Isotope Variations of Igneous Feldspars in the Doña Ana Mountains.

Ramos, F.C., and Heizler, M. T., *this volume*, Age Relationships of Igneous Rocks in the Doña Ana Mountains.

Seager, W.R., Kottlowski, F.E., and Hawley, J.W., 2008, Geologic Map of the Robledo Mountains and Vicinity, Dona Ana County, New Mexico: New Mexico Bureau of Geology & Mineral Resources, Open-File Report 509.

Verplanck, P. L., Farmer, G. L., McCurry, M., and Mertzman, S. A., 1999, The Chemical and Isotopic Differentiation of an Epizonal Magma Body: Organ Needle Pluton, New Mexico: Journal of Petrology, v. 40, p. 653-678.

Wolff, J.A. and Ramos, F.C., 2003, Pb isotope variations among Bandelier Tuff feldspars: no evidence for a long-lived silicic magma chamber: Geology, v. 31, p. 533-536.

Zimmerer, M.J., and McIntosh, W.C., 2013, Geochronologic evidence of upper-crustal in situ differentiation: Silicic magmatism at the Organ caldera complex, New Mexico: Geosphere, v. 9, p. 155-169.