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Short Note

Geochronology of Mexican mineral deposits. III: the Taxco epithermal deposits, Guerrero

José L. Farfán-Panamá[1,2], Antoni Camprubí[3,*], Eduardo González-Partida[4], Alexander Iriondo[4], Enrique Gonzalez-Torres[3,5]

[1] Unidad Académica de Ciencias de la Tierra, Universidad Autónoma de Guerrero, Ex-Hacienda de San Juan Bautista, 40323 Taxco el Viejo, Gro., México.
[2] Programa de Posgrado en Ciencias de la Tierra, Universidad Nacional Autónoma de México, Boulevard Juriquilla 3001, 76230 Querétaro, Qro., México.
[3] Instituto de Geología, Universidad Nacional Autónoma de México, Ciudad Universitaria, 04510, D.F., Mexico.
[4] Centro de Geociencias, Universidad Nacional Autónoma de México, Boulevard Juriquilla 3001, 76230 Querétaro, Qro., Mexico.
[5] Facultad de Ingeniería, Universidad Nacional Autónoma de México. Ciudad Universitaria, 04510, D.F., Mexico.

[*] camprubitaga@gmail.com

Abstract

New $^{40}Ar/^{39}Ar$ (34.96 ± 0.19 Ma) and U-Pb ages (35.44 ± 0.24 and 34.95 ± 0.37 Ma) obtained in this study for the Calavera group of dikes, which predate intermediate sulfidation epithermal mineralization in the Taxco mining district, constrain the formation of such deposits to less than 34.96 Ma (latest Eocene). These deposits might arguably have formed at ~ 33 Ma, thus coinciding in age with the La Azul fluorite deposits, within the same district. Although this age is significantly younger than previously existing estimations, the deposits at Taxco consistently cluster into a Late Eocene to Oligocene metallogenic event. Such event was closely associated with the volcanism in the northern part of the Sierra Madre del Sur, specifically to the most prominent flare-up of subduction-derived volcanism before it ceased in the region and refashioned into the Trans-Mexican Volcanic Belt.

Keywords: Taxco, Mexico, epithermal deposits, intermediate sulfidation, $^{40}Ar/^{39}Ar$ ages, U-Pb ages, zircon.

Resumen

Las nuevas edades $^{40}Ar/^{39}Ar$ (34.96 ± 0.19 Ma) y U-Pb (35.44 ± 0.24 y 34.95 ± 0.37 Ma) obtenidas en este estudio para el conjunto de diques Calavera, cuyo emplazamiento precedió al de las mineralizaciones epitermales de sulfuración intermedia del distrito minero de Taxco, constriñen la formación de dichos depósitos a menos de 34.96 Ma (Eoceno tardío). Estos depósitos pudieran haberse formado razonablemente a ~ 33 Ma, coincidiendo en edad con los depósitos de fluorita de La Azul, en el mismo distrito. Aunque esta edad es significativamente menor que las estimaciones preexistentes, los depósitos de Taxco pertenecen de forma consistente al episodio metalogenético del Eoceno tardío al Oligoceno. Dicho episodio estuvo ligado cercanamente al emplazamiento del volcanismo de la porción norte de la Sierra Madre del Sur y, específicamente, al evento de mayor envergadura del volcanismo de subducción previo al cese del volcanismo en esta región y a su reconfiguración en la Faja Volcánica Mexicana.

Palabras clave: Taxco, México, depósitos epitermales, sulfuración intermedia, edades $^{40}Ar/^{39}Ar$, edades U-Pb, circón..

1. Introduction

The Taxco district (Figure 1) is located in the northern part of the state of Guerrero and consists dominantly of polymetallic intermediate sulfidation deposits (Camprubí and Albinson, 2006, 2007) as veins and stockworks, plus replacement mantos of possible skarn genetic affinity. Only a few Au-rich veins in this district can be ascribed to the low sulfidation subtype of epithermal deposits. This district is one of the 'classical' silver mining districts in Mexico that has been extensively mined since the 16th century, although the Aztecs initiated mining in the region during the 15th century. The present mineral reserves in the Taxco district exceed 7 Mt at 91 g/t Ag, 6.83 % Zn and 1.05 % Pb (Servicio Geológico Mexicano, 2004), although its estimated historical production exceeds 30 Mt (Albinson *et al.*, 2001), and includes Ag-Zn-Pb producing mines (namely the San Antonio, Guerrero, Babilonia, Guadalupe, Golondrina, Pedregal and Hueyapa mines). The formation of these deposits is related to the hydrothermal activity associated with the magmatism of the Sierra Madre del Sur (Camprubí *et al.*, 2006; Camprubí, 2013). For succinct descriptions of the local geology, see Alaniz-Álvarez *et al.* (2002), Servicio Geológico Mexicano (2004), and Camprubí *et al.* (2006).

In this region of the Sierra Madre del Sur, Alaniz-Álvarez *et al.* (2002) and Morán-Zenteno *et al.* (2004, 2005, 2007) described a NW-SE striking tectonomagmatic alignment of volcanic centers —parallel to the present-day Pacific margin— that stretches ~ 200 km between the Cerro Purungueo intrusive and the Huautla volcanic field. This arrangement is associated with regional sinistral strike-slip and transtensive fault systems, and was postulated as a major crustal-scale discontinuity (Alaniz-Álvarez *et al.*, 2002; Morán-Zenteno *et al.*, 2004). The volcanic centers that constitute this alignment are the Cerro Purungueo intrusive (Ferrari *et al.*, 2004), the Nanchititla (Chávez-Álvarez *et al.*, 2012), Sultepec–La Goleta (Díaz-Bravo and Morán-Zenteno, 2011) and Taxco volcanic centers (Alaniz-Álvarez *et al.*, 2002), the Buenavista–Tilzapotla caldera

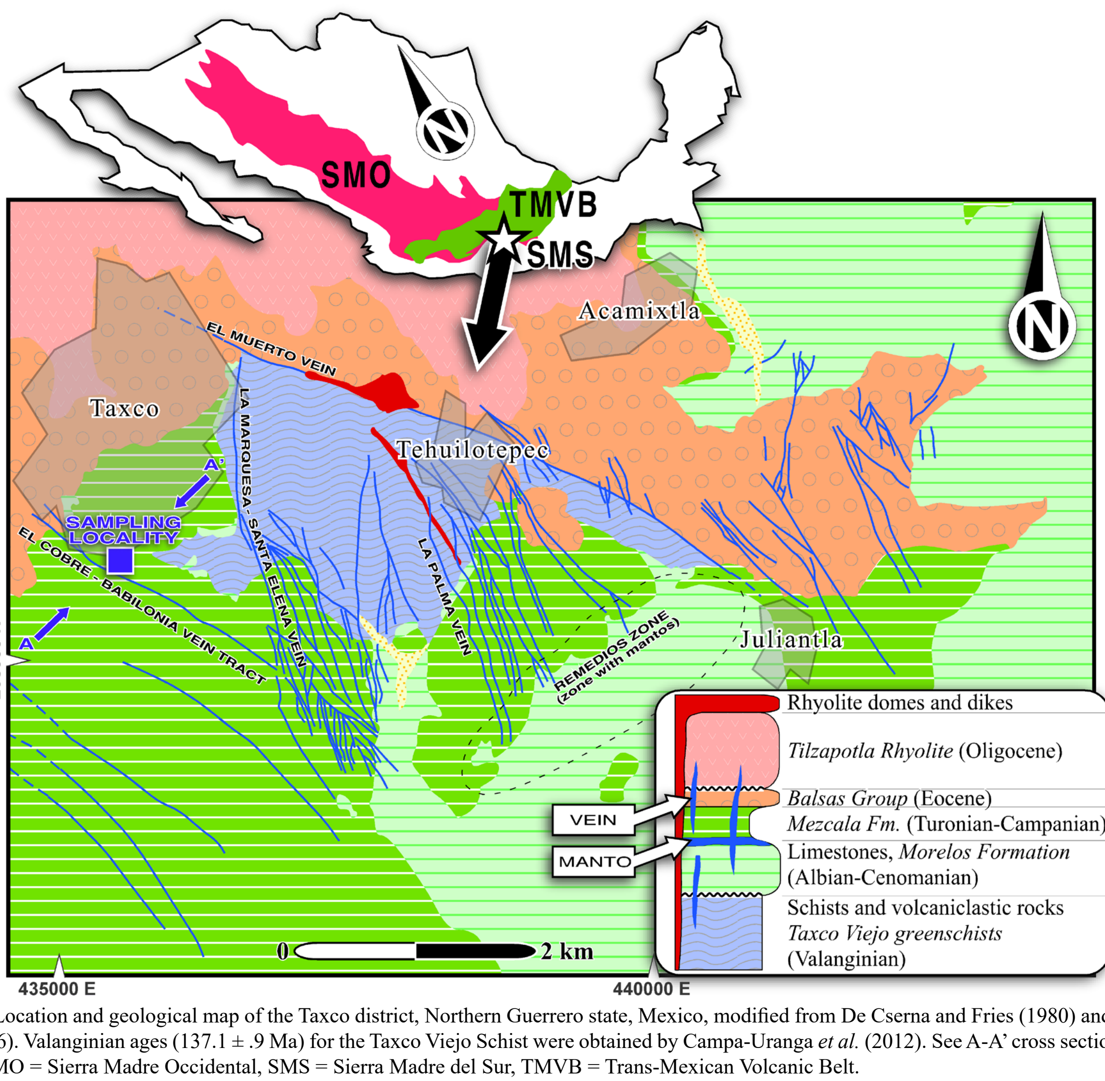

Figure 1. Location and geological map of the Taxco district, Northern Guerrero state, Mexico, modified from De Cserna and Fries (1980) and Camprubí *et al.* (2006). Valanginian ages (137.1 ± .9 Ma) for the Taxco Viejo Schist were obtained by Campa-Uranga *et al.* (2012). See A-A' cross section in Figure 2. Key: SMO = Sierra Madre Occidental, SMS = Sierra Madre del Sur, TMVB = Trans-Mexican Volcanic Belt.

(Morán-Zenteno *et al.*, 2004), and the Huautla volcanic field (González-Torres *et al.*, 2013). Most of these volcanic centers have associated epithermal (*e.g.*, Sultepec, Taxco, Huitzuco and Huautla) or skarn deposits (Buenavista de Cuéllar; see Camprubí, 2013). Alaniz-Álvarez *et al.* (2002) and Morán-Zenteno *et al.* (2004) reported late Eocene ages for the sinistral strike-slip faulting in the Taxco and Buenavista–Tilzapotla volcanic centers. Camprubí *et al.* (2003) attributed an age of 38 to 36 Ma to the intermediate sulfidation epithermal deposits at Taxco by using data from Alaniz-Álvarez *et al.* (2002). Pi *et al.* (2005) dated the La Azul fluorite deposit near the Acamixtla village between 33.0 and 30.0 Ma ([U-Th]/He in fluorite) and advocated for an epithermal model for their formation. This deposit is the only one within the Taxco mining district for which radiometric ages are available. The plausibility of the La Azul fluorite deposit as part of the epithermal type, as opposed to a Mississippi Valley Type model, was further discussed by Pi *et al.* (2006) and Tritlla and Levresse (2006).

This paper presents the first $^{40}Ar/^{39}Ar$ and U-Pb age determinations for the Calavera group of dikes, which predated the intermediate sulfidation epithermal deposits at the Taxco district (Figure 2; also see Figure 2 in Camprubí *et al.*, 2006), in order to better constrain their age.

2. Methods and results

2.1. $^{40}Ar/^{39}Ar$ analytical procedure

A pure mineral separate of potassium feldspar from a mafic dike of the Calavera group of dikes in the wallrock assemblage within the El Cobre–Babilonia vein tract (Mi Carmen ore shoot) of the Taxco district was dated by $^{40}Ar/^{39}Ar$ geochronology (Figure 3 and Table 1). Potassium feldspar crystals that ranged in size from 250 to 180 µm were separated using heavy liquids and hand picking to a purity of > 99 %. The sample was washed in acetone, alcohol, and deionized water in an ultrasonic cleaner to remove dust and then re-sieved by hand using a 180-µm sieve.

Aliquots of the potassium feldspar sample (~ 20 mg) were packaged in copper capsules and vacuum sealed into quartz tubes. The sample aliquots were then irradiated in package number KD29 for 20 hours in the central thimble facility at the TRIGA reactor (GSTR) at the U.S. Geological Survey in Denver, Colorado. The monitor mineral used in the package was Fish Canyon Tuff sanidine (FCT-3) with an age of 27.79 Ma (Kunk *et al.*, 1985; Cebula *et al.*, 1986) relative to MMhb-1 with an age of 519.4 ± 2.5 Ma (Alexander *et al.*, 1978; Dalrymple *et al.*, 1981). The type of container and the geometry of the sample and standards were similar to that described by Snee *et al.* (1988).

The potassium feldspar sample (GP-B-48) was analyzed at the U.S. Geological Survey Thermochronology lab in Denver, Colorado, using the $^{40}Ar/^{39}Ar$ step-heating method and a VG Isotopes 1200B mass spectrometer fitted with an electron multiplier. For additional information on the analytical procedure see Kunk *et al.* (2001). The analyzed sample yielded an isochron age at 34.90 ± 0.2 Ma and an average age at 34.96 ± 0.19 Ma that is hereby interpreted as the age of crystallization of the Calavera group of dikes. These analyses are displayed in Table 1 and Figure 3.

2.2. U-Pb analytical procedure

Two samples were selected for U-Pb dating in zircon separates from intrusive bodies of the Calavera dike set in the southwestern part of the Taxco district; in both cases, the samples came from dikes that formed just before epithermal mineralization. The U-Pb zircon analyses were performed at the Isotopic Studies Laboratory (LEI) at the *Centro de Geociencias* of the *Universidad Nacional Autónoma de México*. An excimer (193 nm) laser ablation system by Resonetics was attached to a quadruple Thermo-X series ICP-MS spectrometer to carry out the analyses. The system has been described by Solari *et al.* (2010) and all data have been reduced by in-house software "UPb.age" (Solari and Tanner, 2011) and plotted with the computational software "Isoplot 3.0" (Ludwig, 2003).

The analyzed samples yielded ages at 35.44 ± 0.24 (sample C-3) and 34.95 ± 0.37 Ma (sample C-5). These analyses are displayed in Table 2 and Figure 4.

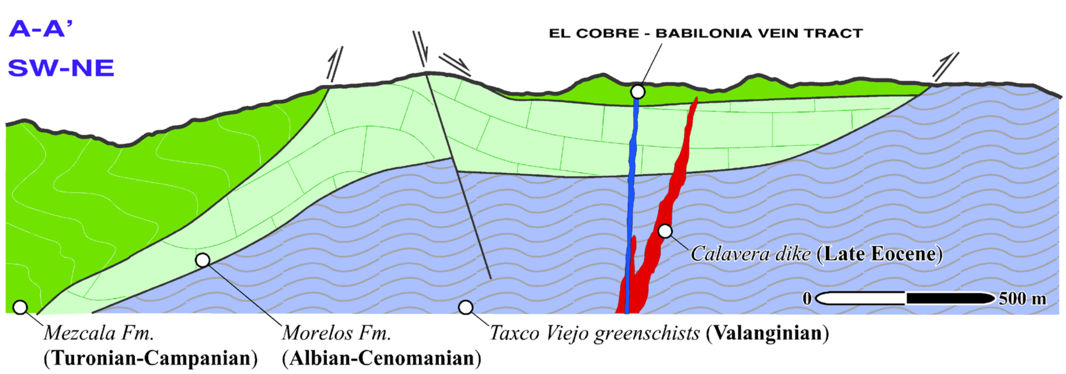

Figure 2. Representative cross section for the spatial relationship between the Calavera dike swarm and the epithermal veins that postdate it. Same legend as in Figure 1.

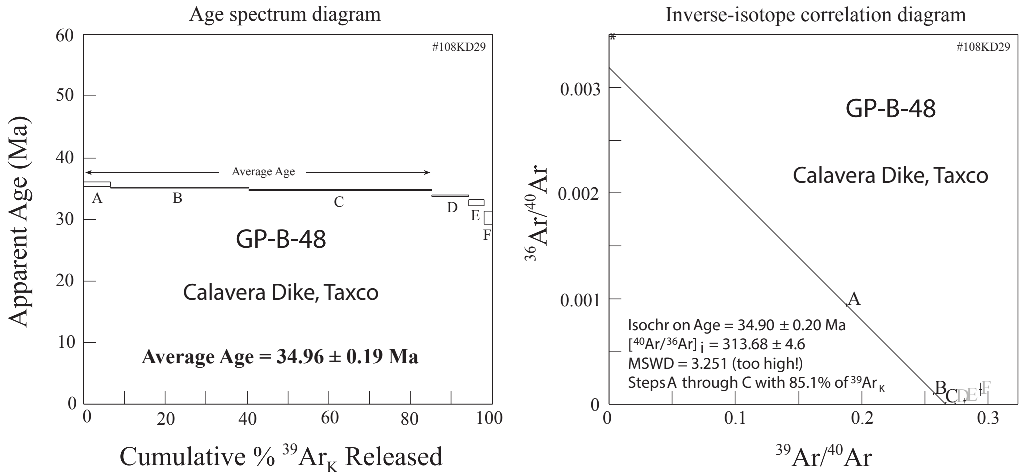

Figure 3. $^{40}Ar/^{39}Ar$ age spectrum and isochron for the GP-B-48 potassium feldspar sample from the Calavera group of dikes in the Mi Carmen ore shoot of the Taxco mining district.

Table 1. $^{40}Ar/^{39}Ar$ step-heating data for a potassium feldspar separate of the Calavera dikes from Taxco.

Step	Temp. °C	$\%^{39}Ar$ of total	Radiogenic Yield (%)	$^{39}Ar_k$ (Moles x 10^{-12})	$^{40}Ar^*/^{39}Ar_k$	Apparent K/Ca	Apparent K/Cl	Apparent Age (Ma)	Error (Ma)
GP-B-48	*Calavera dike, Taxco*	***K-feldspar***	*J = 0.005202 ± 0.50%*		*wt = 20.5 mg*	*#108KD29*			
A	750	6.6	72.2	0.07086	3.843	92	208	35.71	± 0.17
B	850	33.8	97.1	0.36375	3.781	231	3906	35.14	± 0.02
C	1000	44.7	99.6	0.48088	3.739	309	18528	34.75	± 0.03
D	1050	9.0	99.7	0.09723	3.641	190	1987	33.85	± 0.08
E	1100	3.9	98.9	0.04159	3.518	108	1033	32.72	± 0.23
F	1150	2.0	95.8	0.02115	3.259	42	695	30.33	± 0.53
Total Gas		100.0	96.9	1.07546	3.733	245	9853	34.70	
85.1% of gas on plateau-like in 750 through 1000 steps							**Average Age =**	**34.96**	**± 0.19**

Ages calculated assuming an initial $^{40}Ar/^{36}Ar$ = 295.5 ± 0.
All precision estimates are at the one sigma level of precision.
Ages of individual steps do not include error in the irradiation parameter J.
No error is calculated for the total gas age.

3. Discussion and conclusions

The $^{40}Ar/^{39}Ar$ (34.96 ± 0.19 Ma) and U-Pb ages (35.44 ± 0.24 and 34.95 ± 0.37 Ma) obtained in this study for the Calavera set of dikes that predate epithermal mineralization in the Taxco mining district, given the different closure temperatures of the dated minerals (potassium feldspar and zircon) with respect to each dating method (*e.g.*, Figure 1 in Chiaradia *et al.*, 2013), are congruent with the rapid cooling expected for a dike swarm. Also, these ages are similar to that obtained for the Acamixtla ignimbrite (35.77 ± 0.42 Ma), which belongs to the Taxco volcanic field (González-Torres *et al.*, 2013), and are younger than those obtained by Alaniz-Álvarez *et al.* (2002) for similar rocks. Therefore, epithermal deposits must be younger than 34.90 Ma. Still, the ages in this study would cluster into a Late Eocene metallogenic event in the Sierra Madre del Sur, along with the Placeres del Oro, Pinzán Morado, Las Fraguas and Huautla epithermal deposits, and the Piedra Imán and Buenavista de Cuéllar IOCG 'clan' deposits (Table 3; see also Table 1 and Figure 7 in Camprubí, 2013), all of them located in the northern Guerrero state or its vicinities. Such ages also occur between two of the volcanic episodes in the Sierra Madre del Sur (between ~ 36.5 and ~ 34.5 Ma; González-Torres *et al.*, 2013) that constitute the last relevant flare-up episode before the extinction of its subduction-derived volcanism and the rearrangement of such activity into the Trans-Mexican Volcanic Belt during the Miocene. In spite of being relatively restricted in space, especially when compared to the Oligocene flare-up of the Sierra Madre Occidental and the massive formation of associated ore deposits (see Camprubí, 2013, and references therein), this volcanic episode in the Sierra Madre del Sur makes of this region a highly prospective one for epithermal and skarn

Table 2. U-Pb determinations in zircon from the Calavera dikes from Taxco.

				CORRECTED RATIOS										CORRECTED AGES (Ma)									
	U (ppm)	Th (ppm)	Th/U	$^{207}Pb/^{206}Pb$	±1σ	$^{207}Pb/^{235}U$	±1σ	$^{206}Pb/^{238}U$	±1σ	Rho	$^{208}Pb/^{232}Th$	±1σ	% disc	$^{206}Pb/^{238}U$	±1σ	$^{207}Pb/^{235}U$	±1σ	$^{207}Pb/^{206}Pb$	±1σ	$^{208}Pb/^{232}Th$	±1σ	Best age (Ma)	±1σ
C-3 (mafic dike, Taxco) January 2011 (Mount ICGEO-21)																							
Zircon_**29**	4369	886	0.18	0.04657	0.00076	0.02973	0.00054	0.00463	0.00003	0.320	0.00148	0.00004	0	29.8	0.2	29.7	0.5	27	34	29.8	0.9	29.8	0.2
Zircon_**36**	2476	408	0.15	0.04736	0.00094	0.03113	0.00068	0.00477	0.00003	0.330	0.00152	0.00002	1	30.7	0.2	31.1	0.7	67	46	30.6	0.5	30.7	0.2
Zircon_**34**	3930	928	0.21	0.04746	0.00081	0.03314	0.00061	0.00507	0.00003	0.380	0.00165	0.00003	2	32.6	0.2	33.1	0.6	72	40	33.3	0.6	32.6	0.2
Zircon_**3**	2549	909	0.32	0.05702	0.00281	0.04090	0.00219	0.00520	0.00006	0.300	0.00162	0.00002	18	33.5	0.4	41.0	2.0	492	104	32.6	0.4	33.5	0.4
Zircon_**33**	903	257	0.26	0.04779	0.00143	0.03499	0.00109	0.00532	0.00004	0.280	0.00167	0.00005	2	34.2	0.3	35.0	1.0	89	67	34.0	1.0	34.2	0.3
Zircon_**17**	234	60	0.23	0.05275	0.00393	0.03941	0.00319	0.00542	0.00010	0.330	0.00170	0.00005	11	34.8	0.7	39.0	3.0	318	167	34.3	1.0	**34.8**	**0.7**
Zircon_**19**	439	183	0.38	0.05000	0.00249	0.03731	0.00201	0.00541	0.00006	0.260	0.00171	0.00003	6	34.8	0.4	37.0	2.0	195	108	34.5	0.7	**34.8**	**0.4**
Zircon_**9**	588	154	0.24	0.05384	0.00359	0.04029	0.00279	0.00543	0.00005	0.210	0.00170	0.00003	13	34.9	0.3	40.0	3.0	364	152	34.3	0.6	**34.9**	**0.3**
Zircon_**27**	862	247	0.26	0.05145	0.00257	0.03864	0.00204	0.00545	0.00005	0.250	0.00171	0.00003	8	35.0	0.3	38.0	2.0	261	108	34.6	0.5	**35.0**	**0.3**
Zircon_**30**	698	261	0.34	0.04982	0.00247	0.03764	0.00199	0.00548	0.00005	0.250	0.00173	0.00004	7	35.2	0.3	38.0	2.0	186	107	34.9	0.8	**35.2**	**0.3**
Zircon_**7**	188	68	0.32	0.05609	0.00570	0.04232	0.00459	0.00547	0.00010	0.270	0.00170	0.00006	16	35.2	0.6	42.0	4.0	456	225	34.0	1.0	**35.2**	**0.6**
Zircon_**18**	449	145	0.29	0.04853	0.00176	0.03672	0.00143	0.00549	0.00005	0.220	0.00174	0.00004	5	35.3	0.3	37.0	1.0	125	79	35.1	0.7	**35.3**	**0.3**
Zircon_**11**	847	204	0.22	0.04707	0.00150	0.03586	0.00123	0.00553	0.00005	0.290	0.00176	0.00007	1	35.5	0.3	36.0	1.0	53	67	35.0	1.0	**35.5**	**0.3**
Zircon_**14**	342	119	0.31	0.05366	0.00422	0.04088	0.00344	0.00553	0.00008	0.300	0.00173	0.00004	13	35.5	0.5	41.0	3.0	357	176	34.9	0.8	**35.5**	**0.5**
Zircon_**40**	757	241	0.29	0.05371	0.00166	0.04080	0.00136	0.00552	0.00007	0.370	0.00190	0.00011	13	35.5	0.4	41.0	1.0	359	70	38.0	2.0	**35.5**	**0.4**
Zircon_**16**	615	167	0.24	0.05314	0.00202	0.04031	0.00158	0.00555	0.00005	0.240	-0.00019	-0.00006	11	35.7	0.3	40.0	2.0	335	86	-3.8	-1.2	**35.7**	**0.3**
Zircon_**23**	769	332	0.39	0.05118	0.00255	0.03933	0.00207	0.00557	0.00005	0.210	0.00175	0.00002	8	35.8	0.3	39.0	2.0	249	108	35.4	0.5	**35.8**	**0.3**
Zircon_**22**	323	140	0.39	0.04608	0.00424	0.03570	0.00346	0.00562	0.00007	0.260	0.00188	0.00026	0	36.1	0.5	36.0	3.0	2	179	38.0	5.0	**36.1**	**0.5**
Zircon_**12**	327	82	0.23	0.04974	0.00261	0.03864	0.00216	0.00563	0.00007	0.240	0.00178	0.00005	5	36.2	0.5	38.0	2.0	183	117	35.9	1.0	**36.2**	**0.5**
Zircon_**8**	379	131	0.31	0.05974	0.00612	0.04642	0.00501	0.00564	0.00008	0.250	0.00174	0.00005	21	36.2	0.5	46.0	5.0	594	229	35.2	1.0	**36.2**	**0.5**
Zircon_**26**	1769	512	0.26	0.05625	0.00454	0.04392	0.00378	0.00566	0.00007	0.340	0.00176	0.00005	17	36.4	0.5	44.0	4.0	462	171	36.0	1.0	**36.4**	**0.5**
Zircon_**25**	563	209	0.33	0.05614	0.00404	0.04406	0.00330	0.00569	0.00005	0.200	0.00177	0.00003	17	36.6	0.3	44.0	3.0	458	153	35.8	0.6	36.6	0.3
Zircon_**5**	906	223	0.22	0.04991	0.00180	0.03922	0.00145	0.00571	0.00005	0.220	0.00179	0.00005	6	36.7	0.3	39.0	1.0	191	83	36.0	1.0	36.7	0.3
Zircon_**2**	551	197	0.32	0.05978	0.00718	0.04767	0.00584	0.00578	0.00007	0.120	0.00179	0.00007	21	37.2	0.5	47.0	6.0	596	255	36.0	1.0	37.2	0.5
Zircon_**10**	416	86	0.19	0.04884	0.00213	0.03963	0.00187	0.00589	0.00007	0.310	0.00186	0.00005	3	37.8	0.5	39.0	2.0	140	96	38.0	1.0	37.8	0.5
Zircon_**20**	190	63	0.30	0.04923	0.00300	0.04005	0.00258	0.00590	0.00008	0.220	0.00187	0.00009	5	37.9	0.5	40.0	3.0	159	129	38.0	2.0	37.9	0.5
Zircon_**4**	484	150	0.28	0.04662	0.00248	0.03973	0.00244	0.00618	0.00011	0.370	0.00197	0.00013	1	39.7	0.7	40.0	2.0	30	112	40.0	3.0	39.7	0.7
Zircon_**37**	663	316	0.43	0.05215	0.00130	0.14506	0.00379	0.02022	0.00015	0.300	0.00639	0.00015	7	129.0	0.9	138.0	3.0	292	57	129.0	3.0	129.0	0.9

Weighted Mean $^{206}Pb/^{238}U$ age = 35.44 ± 0.24 Ma
(n = 16; MSWD = 1.5; 2-sigma)

Table 2. (Continued) U-Pb determinations in zircon from the Calavera dikes from Taxco.

C-5 (mafic dike, Taxco) January 2011 (Mount ICGEO-21)

Zircon_**6**	6771	3203	0.42	0.06293	0.00271	0.03906	0.00174	0.00448	0.00005	0.260	0.00165	0.00007	26	28.8	0.3	39.0	2.0	706	86	33.0	1.0	28.8	0.3
Zircon_**40**	1690	426	0.23	0.04719	0.00113	0.03072	0.00078	0.00473	0.00004	0.330	0.00158	0.00004	1	30.4	0.3	30.7	0.8	59	52	31.9	0.8	30.4	0.3
Zircon_**19**	6147	1438	0.21	0.04713	0.00075	0.03163	0.00054	0.00487	0.00003	0.360	0.00162	0.00003	1	31.3	0.2	31.6	0.5	56	33	32.7	0.6	31.3	0.2
Zircon_**22**	5743	1183	0.18	0.04727	0.00076	0.03201	0.00056	0.00492	0.00003	0.400	0.00166	0.00003	1	31.6	0.2	32.0	0.6	63	34	33.5	0.6	31.6	0.2
Zircon_**30**	6786	1820	0.24	0.04831	0.00077	0.03289	0.00058	0.00494	0.00004	0.430	0.00163	0.00003	3	31.8	0.3	32.9	0.6	114	35	32.9	0.6	**31.8**	**0.3**
Zircon_**10**	2029	383	0.17	0.04735	0.00096	0.03244	0.00074	0.00497	0.00004	0.310	0.00158	0.00005	1	32.0	0.2	32.4	0.7	67	42	32.0	1.0	**32.0**	**0.2**
Zircon_**21**	2920	881	0.27	0.04667	0.00086	0.03197	0.00069	0.00497	0.00004	0.330	0.00159	0.00005	0	32.0	0.2	32.0	0.7	32	36	32.0	1.0	**32.0**	**0.2**
Zircon_**2**	2578	782	0.27	0.04667	0.00072	0.03212	0.00056	0.00499	0.00003	0.270	0.00162	0.00006	0	32.1	0.2	32.1	0.6	32	32	33.0	1.0	**32.1**	**0.2**
Zircon_**24**	4086	1026	0.22	0.04844	0.00078	0.03342	0.00058	0.00501	0.00003	0.370	0.00176	0.00004	4	32.2	0.2	33.4	0.6	121	34	35.5	0.8	**32.2**	**0.2**
Zircon_**25**	2240	666	0.27	0.04679	0.00104	0.03257	0.00082	0.00505	0.00004	0.340	0.00161	0.00006	0	32.5	0.2	32.5	0.8	39	47	32.0	1.0	**32.5**	**0.2**
Zircon_**28**	5604	1689	0.27	0.04867	0.00083	0.03394	0.00061	0.00506	0.00003	0.320	0.00164	0.00004	4	32.5	0.2	33.9	0.6	132	38	33.1	0.8	**32.5**	**0.2**
Zircon_**8**	4107	837	0.18	0.04754	0.00093	0.03310	0.00071	0.00505	0.00003	0.360	0.00160	0.00003	2	32.5	0.2	33.1	0.7	77	43	32.4	0.6	**32.5**	**0.2**
Zircon_**39**	1658	532	0.29	0.04899	0.00194	0.03460	0.00148	0.00512	0.00004	0.280	0.00162	0.00003	6	32.9	0.3	35.0	1.0	147	85	32.8	0.6	**32.9**	**0.3**
Zircon_**13**	2608	536	0.18	0.04790	0.00120	0.03389	0.00091	0.00515	0.00005	0.360	0.00174	0.00005	2	33.1	0.3	33.8	0.9	94	52	35.0	1.0	33.1	0.3
Zircon_**20**	2336	539	0.21	0.05333	0.00462	0.03794	0.00349	0.00516	0.00005	0.270	0.00163	0.00007	13	33.2	0.3	38.0	3.0	343	174	33.0	1.0	33.2	0.3
Zircon_**27**	1504	299	0.18	0.04984	0.00125	0.03543	0.00095	0.00516	0.00005	0.350	0.00164	0.00004	6	33.2	0.3	35.4	0.9	188	55	33.1	0.8	33.2	0.3
Zircon_**17**	1972	493	0.22	0.04839	0.00135	0.03507	0.00104	0.00523	0.00005	0.340	0.00179	0.00005	4	33.6	0.3	35.0	1.0	118	58	36.0	1.0	33.6	0.3
Zircon_**23**	1811	463	0.23	0.05242	0.00105	0.03770	0.00082	0.00522	0.00004	0.390	0.00173	0.00005	11	33.6	0.3	37.6	0.8	304	40	35.0	1.0	33.6	0.3
Zircon_**16**	4848	1812	0.33	0.04847	0.00121	0.03506	0.00119	0.00525	0.00007	0.660	0.00166	0.00002	4	33.7	0.4	35.0	1.0	122	52	33.6	0.4	33.7	0.4
Zircon_**9**	1508	413	0.25	0.04960	0.00163	0.03588	0.00133	0.00525	0.00005	0.370	0.00166	0.00002	6	33.7	0.3	36.0	1.0	176	72	33.5	0.4	33.7	0.3
Zircon_**35**	1510	237	0.14	0.04767	0.00143	0.03502	0.00119	0.00533	0.00007	0.390	0.00169	0.00009	2	34.2	0.5	35.0	1.0	83	65	34.0	2.0	**34.2**	**0.5**
Zircon_**14**	1283	173	0.12	0.04854	0.00121	0.03569	0.00106	0.00533	0.00006	0.450	0.00169	0.00003	5	34.3	0.4	36.0	1.0	126	52	34.1	0.7	**34.3**	**0.4**
Zircon_**18**	2169	558	0.23	0.04893	0.00122	0.03605	0.00095	0.00535	0.00004	0.330	0.00182	0.00004	4	34.4	0.3	36.0	0.9	144	52	36.8	0.8	**34.4**	**0.3**
Zircon_**26**	699	378	0.48	0.05319	0.00391	0.03968	0.00311	0.00541	0.00005	0.230	0.00170	0.00002	13	34.8	0.3	40.0	3.0	337	154	34.4	0.5	**34.8**	**0.3**
Zircon_**29**	5983	2110	0.32	0.04815	0.00072	0.03596	0.00062	0.00542	0.00005	0.500	0.00195	0.00004	3	34.8	0.3	35.9	0.6	107	33	39.4	0.8	**34.8**	**0.3**
Zircon_**15**	1769	484	0.25	0.04801	0.00106	0.03581	0.00083	0.00543	0.00004	0.300	0.00179	0.00004	2	34.9	0.3	35.7	0.8	100	46	36.1	0.8	**34.9**	**0.3**
Zircon_**5**	829	200	0.22	0.04799	0.00182	0.03627	0.00143	0.00548	0.00005	0.280	0.00180	0.00012	2	35.2	0.3	36.0	1.0	99	81	36.0	2.0	**35.2**	**0.3**
Zircon_**1**	539	154	0.26	0.04672	0.00562	0.03558	0.00463	0.00552	0.00006	0.250	0.00191	0.00041	1	35.5	0.4	36.0	5.0	35	221	39.0	8.0	**35.5**	**0.4**
Zircon_**11**	1193	306	0.23	0.04886	0.00168	0.03736	0.00152	0.00555	0.00007	0.460	0.00176	0.00004	4	35.6	0.4	37.0	1.0	141	71	35.5	0.8	**35.6**	**0.4**
Zircon_**34**	405	151	0.33	0.05108	0.00255	0.03932	0.00200	0.00560	0.00006	0.190	0.00178	0.00006	8	36.0	0.4	39.0	2.0	244	107	36.0	1.0	**36.0**	**0.4**
Zircon_**31**	430	129	0.27	0.04861	0.00291	0.03920	0.00246	0.00585	0.00007	0.210	0.00185	0.00011	4	37.6	0.4	39.0	2.0	129	126	37.0	2.0	37.6	0.4
Zircon_**4**	1920	686	0.32	0.05080	0.00240	0.04208	0.00214	0.00601	0.00006	0.260	0.00190	0.00003	8	38.6	0.4	42.0	2.0	232	101	38.3	0.5	38.6	0.4
Zircon_**12**	1159	278	0.21	0.05403	0.00308	0.04633	0.00307	0.00622	0.00012	0.450	0.00195	0.00004	13	40.0	0.8	46.0	3.0	372	114	39.4	0.7	40.0	0.8
Zircon_**3**	1237	391	0.28	0.06565	0.00236	0.08426	0.00383	0.00931	0.00016	0.590	0.00286	0.00005	27	60.0	1.0	82.0	4.0	795	71	57.8	1.0	60.0	1.0

Weighted Mean $^{206}Pb/^{238}U$ age = 32.27 ± 0.23 Ma
(n = 9; MSWD = 1.9; 2-sigma)

Weighted Mean $^{206}Pb/^{238}U$ age = 34.95 ± 0.37 Ma
(n = 10; MSWD = 2.3; 2-sigma)

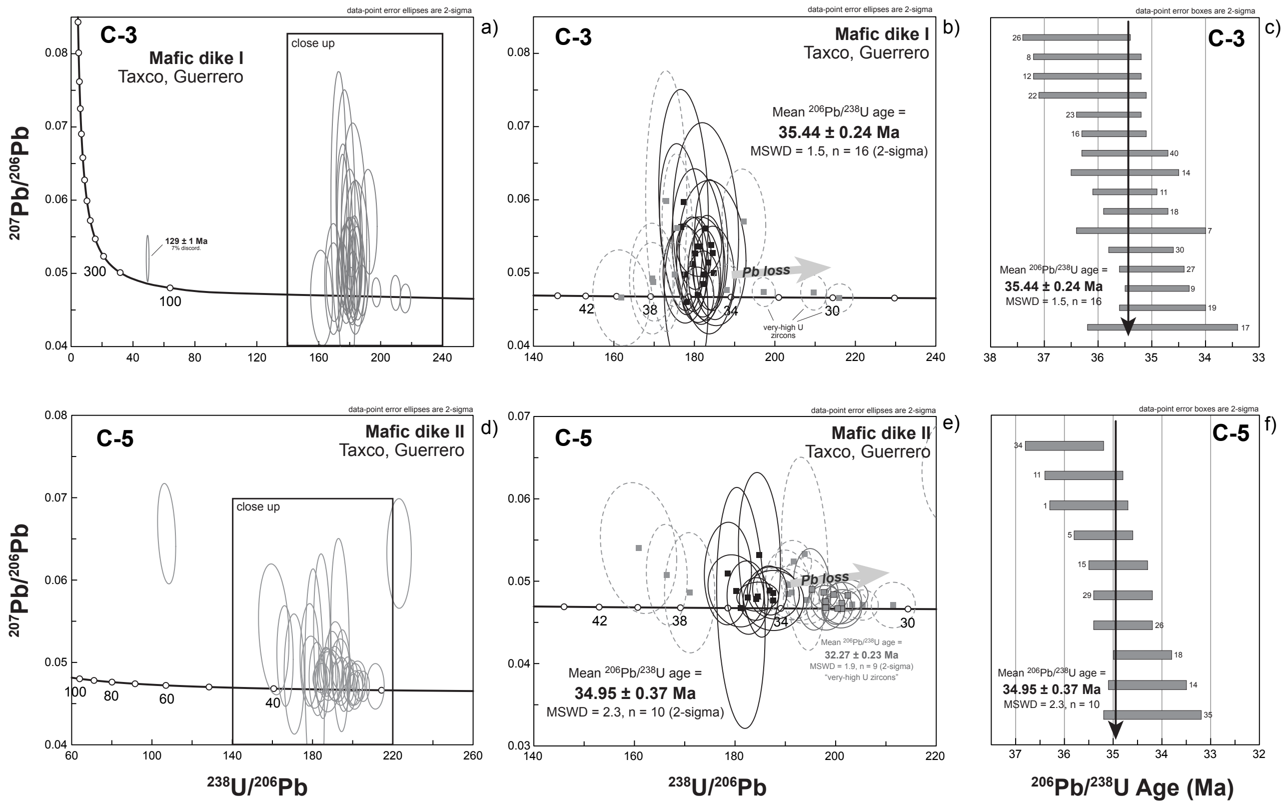

Figure 4. Tera-Wasserburg U-Pb concordia plots (a, b, d and e) and plots of weighted averages of individual $^{206}Pb/^{238}U$ ages (c and f) of analyzed zircons from two samples of the pre-epithermal mineralization Calavera group of dikes from the Taxco district. Solid-line ellipses, with black square centers, are data used for age calculations; gray-line ellipses are data excluded from age calculations due to different degrees of Pb-loss and/or zircon inheritance. All U-Pb data are plotted with 2-sigma errors and all calculated weighted mean ages are also listed at the 2-sigma level. Original U(Th)-Pb data can be found for inspection in Table 2.

Table 3. Age determinations for the Calavera group of dikes that predate the Taxco epithermal deposits, in comparison with ages of ore deposits in the northern part of the Sierra Madre del Sur, Mexico

Sample	Locality	Type of deposit	Coordinates	Method	Mineral	Age (Ma)	Sources
Real de Guadalupe		Polymetallic intermediate sulfidation epithermal deposit		K-Ar	w.r.	40.0 to 37.0	Albinson and Parrilla (1988)
Placeres del Oro, Pinzán Morado & Piedra Imán		Ag-Au low sulfidation epithermal deposits and iron oxide veins of the IOCG 'clan' (Piedra Imán)		K-Ar	w.r.	<36.6	Pantoja-Alor (1986)
C-3	Taxco	Ag-Zn-Pb intermediate sulfidation epithermal deposit	18º32'20" N	U-Pb	Zircon	35.44 ± 0.24	This study
C-5			99º33'45" W	U-Pb	Zircon	34.95 ± 0.37	
GP-B-48				$^{40}Ar/^{39}Ar$	K-feldspar	34.96 ± 0.19 (average)	
Buenavista de Cuéllar		Iron oxide skarn of the IOCG 'clan'		$^{40}Ar/^{39}Ar$	K-feldspar	35.5 to 34.7	Meza-Figueroa *et al.* (2003)
Huautla		Polymetallic intermediate sulfidation epithermal deposit		U-Pb	Zircon	34.8 to 31.4	González-Torres *et al.* (2013)
La Azul (Taxco district)		Fluorite deposit, uncertain type (epithermal or MVT)		(U-Th)/He	Fluorite	33.0 to 30.0	Pi *et al.* (2005)

deposits (either sulfide or iron oxide skarns of the IOCG 'clan') during the Late Eocene.

The volcanic centers of the previously described magmatic lineament have been interpreted as the eruptive manifestation of a progressive thermomechanical maturation of the crust, driven by sustained igneous activity that affected the region since the early Eocene. According to this idea, widespread Eocene magmatism and injection of mantle-derived melts into the crust promoted the development of a hot zone extending to upper crustal levels, and the formation of a mature intracrustal magmatic system; within this context, intermediate-siliceous compositions were produced by low-pressure fractional crystallization, crustal contamination, and anatexis (Mori *et al.*, 2012; González-Torres, 2013).

We may also examine the plausibility of the two proposed genetic affinities for the La Azul fluorite deposits in the Taxco district, as Pi *et al.* (2005, 2006) advocate for an epithermal model, whereas Tritlla and Levresse (2006) favor a Mississippi Valley Type (MVT) model instead. Firstly, fluorite is a common mineral in intermediate sulfidation epithermal deposits (Lyons, 1988; Ponce and Clark, 1988; Albinson and Rubio, 2001; Albinson *et al.*, 2001; Camprubí *et al.*, 2001; Camprubí and Albinson, 2006, 2007), including those in the Taxco district (Camprubí *et al.*, 2006). Such characteristic in deposits of different ages and localities implies that F- would have been a major ion in ore-forming solutions associated with intermediate sulfidation epithermal environments. Secondly, the ages in this paper for the Calavera group of dikes indicate that epithermal mineralization would be younger than ~ 34.96 Ma. The common knowledge indicates that the time span between the youngest volcanic or hypabyssal rocks that predate genetically linked epithermal mineralization —regardless of their state of sulfidation, or the size of the deposits— and epithermal mineralization itself is ~ 2 m.yr. in Mexican deposits (as determined in the Fresnillo, Guanajuato, Pachuca-Real del Monte, Tayoltita, and Temascaltepec districts; see Lang *et al.*, 1988; McKee *et al.*, 1992; Enríquez and Rivera, 2001; Camprubí *et al.*, 2003; Camprubí and Albinson, 2007; Velador *et al.*, 2010; Martínez-Reyes *et al.*, 2015, and references therein), whereas such gaps are significantly shorter for high sulfidation deposits (La Caridad Antigua; Valencia *et al.*, 2005, 2008). Assuming that this were the case, it would be reasonable to expect that the earliest epithermal deposits of Taxco formed at ~ 33 Ma, which coincides with the range of ages between 33.0 and 30.0 Ma determined by Pi *et al.* (2005) for the La Azul fluorite deposit. Notably, the Huautla Formation of the neighboring Huautla mining district, a heterogeneous volcanic succession that hosts hydrothermal alteration zones and epithermal veins, has a similar U-Pb age at 32.9 ± 0.6 Ma (González-Torres *et al.*, 2013). That would then imply (1) that the 'classical' polymetallic intermediate sulfidation deposits at Taxco and the small fluorite deposits nearby formed at the same time, and (2) that their formation by means of very different fluids and mineralizing processes (as of magmatic-hydrothermal and epithermal model vs. basinal brines and MVT model; see Table 3) would have been highly implausible. Therefore, from this point of view, it is likely to ascribe the La Azul fluorite deposit to the epithermal type, as postulated by Pi *et al.* (2005, 2006).

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References

Alaniz-Álvarez, S.A., Nieto-Samaniego, Á.F., Morán-Zenteno, D.J., Alba-Aldave, L., 2002, Rhyolitic volcanism in extension zone associated with strike-slip tectonics in the Taxco region, southern Mexico: Journal of Volcanology and Geothermal Research, 118, 1-14.

Albinson, T., Parrilla, L.V., 1988, Geologic, mineralogic, and fluid inclusion characteristics of polymetallic veins, Real de Guadalupe mining district, Guerrero, Mexico: Economic Geology, 83, 1975-1984.

Albinson, T., Rubio, M.A., 2001, Mineralogic and thermal structure of the Zuloaga vein, San Martín de Bolaños district, Jalisco, Mexico, *in* Albinson, T., Nelson, C.E. (eds.), New mines and discoveries in Mexico and Central America: Society of Economic Geologists Special Publication Series, 8, 115-132.

Albinson, T., Norman, D.I., Cole, D., Chomiak, B.A., 2001, Controls on formation of low-sulfidation epithermal deposits in Mexico: constraints from fluid inclusion and stable isotope data, *in* Albinson, T., Nelson, C.E. (eds.), New mines and discoveries in Mexico and Central America: Society of Economic Geologists Special Publication Series, 8, 1-32.

Alexander, E.C. Jr., Mickelson, G.M., Lanphere, M.A., 1978, Mmhb-1: a new $^{40}Ar/^{39}Ar$ dating standard, *in* Zartman, R.E. (ed.), Short papers of the fourth international conference, geochronology, cosmochronology, and isotope geology: U.S. Geological Survey Open-File Report, 78-701, 6-8.

Campa-Uranga, M.F., Torres de León, R., Iriondo, A., Premo, W.R., 2012, Caracterización geológica de los ensambles metamórficos de Taxco y Taxco el Viejo, Guerrero, México: Boletín de la Sociedad Geológica Mexicana, 64, 369-385.

Camprubí, A., 2013, Tectonic and metallogenic history of Mexico, *in* Colpron, M., Bissig, T., Rusk, B.G., Thompson, J.F.H., (eds.), Tectonics, metallogeny, and discovery: the North American Cordillera and similar accretionary settings: Society of Economic Geologists, Special Publication, 17, 201-243.

Camprubí, A., Albinson, T., 2006, Depósitos epitermales en México: actualización de su conocimiento y reclasificación empírica: Boletín de la Sociedad Geológica Mexicana, 58, 27-81.

Camprubí, A., Albinson, T., 2007, Epithermal deposits in México – an update of current knowledge, and an empirical reclassification, *in* Alaniz-Álvarez, S.A., Nieto-Samaniego, A.F. (eds.), Geology of México: Celebrating the Centenary of the Geological Society of México: The Geological Society of America Special Paper, 422, 377-415.

Camprubí, A., Canals, À., Cardellach, E., Prol-Ledesma, R.M., Rivera, R., 2001, The La Guitarra Ag-Au low-sulfidation epithermal deposit, Temascaltepec district, Mexico: vein structure, mineralogy, and sulfide-sulfosalt chemistry, *in* Albinson, T., Nelson, C.E. (eds.), New mines and discoveries in Mexico and Central America: Society of Economic Geologists Special Publication Series, 8, 133-158.

Camprubí, A., Ferrari, L., Cosca, M.A., Cardellach, E., Canals, À., 2003, Ages of epithermal deposits in Mexico: regional significance and links with the evolution of Tertiary volcanism: Economic Geology, 98, 1029-1037.

Camprubí, A., González-Partida, E., Torres-Tafolla, E., 2006, Fluid inclusion and stable isotope study of the Cobre–Babilonia polymetallic epithermal vein system, Taxco district, Guerrero, Mexico: Journal of Geochemical Exploration, 89, 33-38.

Cebula, G.T., Kunk, M.J., Mehnert, H.H., Naeser, C.W., Obradovich, J.D., Sutter, J.F., 1986, The Fish Canyon Tuff: A potential standard for the $^{40}Ar/^{39}Ar$ and fission track dating methods: Terra Cognita, 6, 140.

Chávez-Álvarez, M.J., Cerca, M., Ferrari, L., 2012, Physical and geological description of the Nanchititla dyke swarm: Revista Mexicana de Ciencias Geológicas, 29, 551-571.

Chiaradia, M., Schaltegger, U., Spikings, R., Wotzlaw, J.-F., Ovtcharova, M., 2013, How accurately can we date the duration of magmatic-hydrothermal events in porphyry systems?—An invited paper: Economic Geology, 108, 565-584.

Dalrymple, G.B., Alexander, E.C., Lanphere, M.A., Kraker, G.P., 1981, Irradiation of samples for $^{40}Ar/^{39}Ar$ dating using the Geological Survey TRIGA reactor: U.S. Geological Survey Professional Paper, 1176, 55 p.

De Cserna, Z., Fries, C., 1980, Carta Geológica de México, Hoja Taxco 14Q-h(7), Carta Geológica de México, serie de 1:100,000, México, Instituto de Geología, UNAM.

Díaz-Bravo, B.A., Morán-Zenteno, D.J., 2011, The exhumed Eocene Sultepec-Goleta Volcanic Center of southern Mexico: Record of partial collapse and ignimbritic volcanism fed by wide pyroclastic dike complexes: Bulletin of Volcanology, 73, 917-932.

Enríquez, E., Rivera, R., 2001, Timing of magmatic and hydrothermal activity at the San Dimas District, Durango, Mexico, *in* Albinson, T., Nelson, C.E. (eds.), New mines and discoveries in Mexico and Central America: Society of Economic Geologists Special Publication Series, 8, 33-38.

Ferrari, L., Cerca-Martínez, M., López-Martínez, M., Serrano-Durán, L., González-Cervantes, N., 2004, Age of formation of the Tzitzio antiform and structural control of volcanism in eastern Michoacán and western Guerrero: Geos, 24, 165.

González-Torres, E., 2013, Estratigrafía, geocronología y petrogénesis del campo volcánico de Huautla, Estados de Morelos, Puebla y Guerrero, y sus implicaciones en el origen del magmatismo silícico de la Sierra Madre del Sur: México, Programa de Posgrado en Ciencias de la Tierra, Universidad Nacional Autónoma de México, unpublished PhD dissertation, 259 p.

González-Torres, E.A., Morán-Zenteno, D.J., Mori, L., Díaz-Bravo, B., Martiny, B.M., Solé, J., 2013, Geochronology and magmatic evolution of the Huautla volcanic field: Last stages of the extinct Sierra Madre del Sur igneous province of southern Mexico: International Geology Review, 55, 1145-1161.

Kunk, M.J., Sutter, J.F., Naeser, C.W., 1985, High-precision $^{40}Ar/^{39}Ar$ ages of sanidine, biotite, hornblende, and plagioclase from the Fish Canyon tuff, San Juan volcanic field, South-central Colorado [abs.]: Geological Society of America Abstracts with Programs, 17, 636.

Kunk, M.J., Winick, J.A., Stanley, J.O., 2001, $^{40}Ar/^{39}Ar$ age-spectrum and laser fusion data for volcanic rocks in west central Colorado: U.S. Geological Survey Open-File Report, 01-472, 94 p.

Lang, B., Steinitz, G., Sawkins, F.J., Simmons, S.F., 1988, K-Ar age studies in the Fresnillo silver district, Zacatecas, Mexico: Economic Geology, 83, 1642-1646.

Ludwig, K.R., 2003, ISOPLOT, a geochronological toolkit for Microsoft Excel, Version 3.00: Berkeley Geochronology Center Special Publication, 4, 70 p.

Lyons, J.I., 1988, Geology and ore deposits of the Bolaños silver district, Jalisco, Mexico: Economic Geology, 83, 1560-1582.

Martínez-Reyes, J.J., Camprubí, A., Uysal, I.T., Iriondo, A., González-Partida, E.; Geochronology of Mexican mineral deposits. I: Veta Madre and Sierra epithermal vein systems, Guanajuato district: Boletín de la Sociedad Geológica Mexicana, submitted.

McKee, E.H., Dreier, J.E., Noble, D.C., 1992, Early Miocene hydrothermal activity at Pachuca-Real del Monte, Mexico: an example of space-time association of volcanism and epithermal Ag-Au mineralization: Economic Geology, 87, 1635-1637.

Meza-Figueroa, D., Valencia-Moreno, M., Valencia, V.A., Ochoa-Landín, L., Pérez-Segura, E., Díaz-Salgado, C., 2003, Major and trace element geochemistry and $^{40}Ar/^{39}Ar$ geochronology of Laramide plutonic rocks associated with gold-bearing Fe skarn deposits in Guerrero state, southern Mexico: Journal of South American Earth Sciences, 16, 205-217.

Morán-Zenteno, D.J., Alba-Aldave, L., Solé, J., Iriondo, A., 2004, A major resurgent caldera in southern Mexico: the source of the late Eocene Tilzapotla ignimbrite: Journal of Volcanology and Geothermal Research, 136, 97-119.

Morán-Zenteno, D.J., Cerca, M., Keppie, J.D., 2005, La evolución tectónica y magmática cenozoica del suroeste de México: avances y problemas de interpretación: Boletín de la Sociedad Geológica Mexicana, 57, 319-314.

Morán-Zenteno, D.J., Cerca, M., Keppie, J.D., 2007, The Cenozoic tectonic and magmatic evolution of southwestern México: advances and problems of interpretation, *in* Alaniz-Álvarez, S.A., Nieto-Samaniego, Á.F. (eds.), Geology of México: Celebrating the Centenary of the Geological Society of México: Geological Society of America Special Paper, 422, 71-91.

Mori, L., Morán-Zenteno, D., Martiny, B., González-Torres, E., Chapela-Lara, M., Díaz-Bravo, B., Roberge, J., 2012, Thermomechanical maturation of the continental crust and its effects on the Late Eocene-Early Oligocene volcanic record of the Sierra Madre del Sur province of southern Mexico: International Geology Review, 54, 1475–1496.

Pantoja-Alor, J., 1986, Siete edades geocronométricas cenozoicas de la cuenca media del Río Balsas, in Programas y Resúmenes del Primer Simposio de Geología Regional de México: México, D.F., Universidad Nacional Autónoma de México, Instituto de Geología, 60-61.

Pi, T., Solé, J., Taran, Y., 2005, (U–Th)/He dating of fluorite: application to the La Azul fluorspar deposit in the Taxco mining district, Mexico: Mineralium Deposita, 39, 976-982.

Pi, T., Solé, J., Taran, Y., 2006, Reply to discussion on "(U–Th)/He dating of fluorite: application to the La Azul fluorspar deposit in the Taxco mining district, Mexico" (Miner Depos 39:976-982): Mineralium Deposita, 41, 300.

Ponce, B.F., Clark, K.F., 1988, The Zacatecas mining district: a Tertiary caldera complex associated with precious and base metal mineralization: Economic Geology, 83, 1668–1682.

Servicio Geológico Mexicano, 2004, Carta geológico-minera, Taxco E14-A68, 1:50,000: Pachuca, Hidalgo, Servicio Geológico Mexicano, Secretaría de Economía.

Snee, L.W., Sutter, J.F., Kelly, W.C., 1988, Thermochronology of economic mineral deposits: Dating the stages of mineralization at Panasqueira, Portugal, by high precision 40Ar/39Ar age spectrum techniques on muscovite: Economic Geology, 83, 335–354.

Solari, L.A., Tanner, M., 2011, UPb.age, a fast data reduction script for LA-ICP-MS U-Pb geochronology: Revista Mexicana de Ciencias Geológicas, 28, 83–91.

Solari, L.A., Gómez-Tuena, A., Bernal, J.P., Pérez-Arvizu, O., Tanner, M., 2010, U-Pb zircon geochronology by an integrated LA-ICPMS microanalytical workstation: achievements in precision and accuracy: Geostandards and Geoanalytical Research, 34, 5−18.

Tritlla, J., Levresse, G., 2006, Comments on "(U–Th)/He dating of fluorite: application to the La Azul fluorspar deposit in the Taxco mining district, Mexico" by Pi et al. (Mineralium Deposita 39: 976–982): Mineralium Deposita, 41, 296–299.

Valencia, V.A., Ruiz, J., Barra, F., Gehrels, G., Ducea, M., Titley, S.R., Ochoa-Landín, L., 2005, U-Pb zircon and Re-Os molybdenite geochronology from La Caridad porphyry copper deposit: Insights for the duration of magmatism and mineralization in the Nacozari District, Sonora, Mexico: Mineralium Deposita, 40, 175-191.

Valencia, V.A., Eastoe, C., Ruiz, J., Ochoa-Landín, L., Gehrels, G., González-León, C., Barra, F., Espinoza, E., 2008, Hydrothermal evolution of the porphyry copper deposit at La Caridad, Sonora, Mexico, and the relationship with a neighboring high-sulfidation epithermal deposit: Economic Geology, 103, 473-491.

Velador, J.M., Heizler, M.T., Campbell, A.R., 2010, Timing of magmatic activity and mineralization and evidence of a long-lived hydrothermal system in the Fresnillo silver district, Mexico: constraints from $^{40}Ar/^{39}Ar$ geochronology: Economic Geology, 105, 1335-1349.

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