New $^{40}Ar/^{39}Ar$ ages from the Cerocahui basin region of northern Sierra Madre Occidental, Chihuahua, Mexico: Implications for ignimbrite correlation and the timing of synextensional deposition

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Abstract

The Cerocahui basin is a half-graben located adjacent to the Copper Canyon region of the northern Sierra Madre Occidental silicic large igneous province. Previous studies in the area have identified late Oligocene alluvial and mafic-intermediate volcanic synextensional basin deposits underlain by several Oligocene silicic ignimbrite outflow sheets (Parajes formation). Age control of the study area is limited; this study presents new $^{40}Ar/^{39}Ar$ ages to further constrain depositional ages and the timing of extension.

The Chepe ignimbrite, the lowest stratigraphic unit of the Parajes formation, is exposed in a horst block on the eastern edge of the Cerocahui basin and yields an age of 34.68 ± 0.14 Ma (2σ). Previous work tentatively correlated this ignimbrite to the regionally extensive ~29.9 Ma Divisadero tuff based its stratigraphic position below younger dated rocks in the study area and its distinct crystal-rich phenocryst assemblage (~30% embayed quartz, plagioclase, biotite, hornblende, and sanidine; to 2 mm) that is similar to samples collected from the Divisadero tuff type-locality. However, the correlation of these two ignimbrites is highly unlikely based on our new age data. Instead, the Chepe ignimbrite is more likely correlated to the previously identified 34.1 ± 0.9 Ma Vista tuff, which was erupted from the Las Varas caldera ~125 km NNE of this study area. An outflow unit of the Vista tuff is identified ~70 km S of the caldera and is nearly identical in appearance to the Divisadero tuff, suggesting that this tentative correlation with the Chepe ignimbrite is plausible. The KM ignimbrite is near the stratigraphic top of the Parajes formation, with our new data yielding an age of 27.46 ± 0.30 Ma. The age of the KM ignimbrite corresponds well with previous zircon U-Pb LA ICP-MS dating from the underlying Puerto Blanco ignimbrite (27.58 ± 0.26 Ma) and from an ignimbrite near the base of the overlying Cerocahui basin deposits (28.1 ± 0.8 Ma).

A basalt lava unit that conformably caps the Cerocahui basin alluvial deposits yields an age of 23.59 ± 0.13 Ma. Based on previous work, this new age suggests a depositional rate of ~300 m/Myr in the basin near the fault margin. The basalt lava unit is relatively flat-lying and has only minor offset across the basin bounding fault, suggesting that extension in the study area was waning by ~23.6 Ma.

Geologic Setting

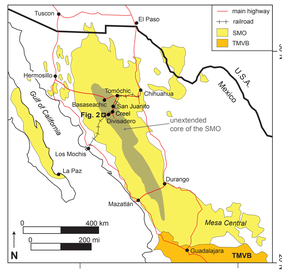


Figure 1 (above). Map of western Mexico showing the extent of the Sierra Madre Occidental (SMO) silicic large igneous province and the unextended core (gray) of the SMO (after Henry and Aranda-Gómez, 2000; Ferrari et al., 2002; Bryan et al., 2013). The location of the Cerocahui basin area is indicated by black box (Fig. 2) on the western edge of the unextended core. TMVB: Trans-Mexican Volcanic Belt.

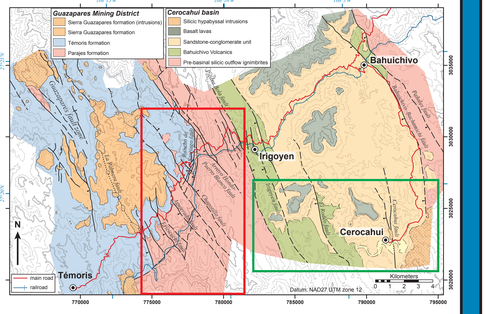
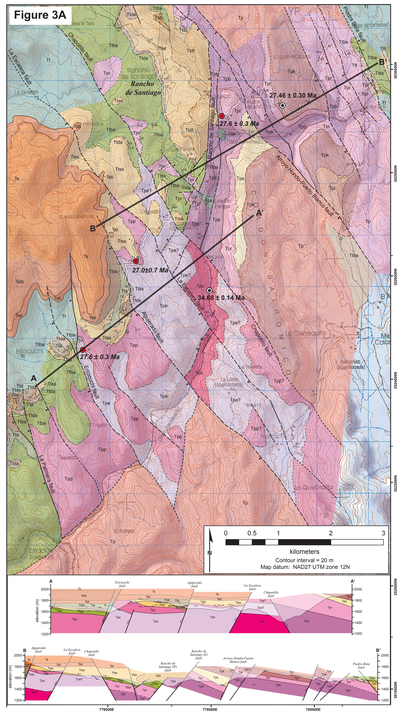


Figure 2 (above). Simplified geologic map of the Cerocahui basin and the adjacent Guazapares Mining District region to the west (after Murray et al., 2014). The red box indicates the location of Figure 3A, and the green box indicates the location of Figure 3B.

Geologic Maps



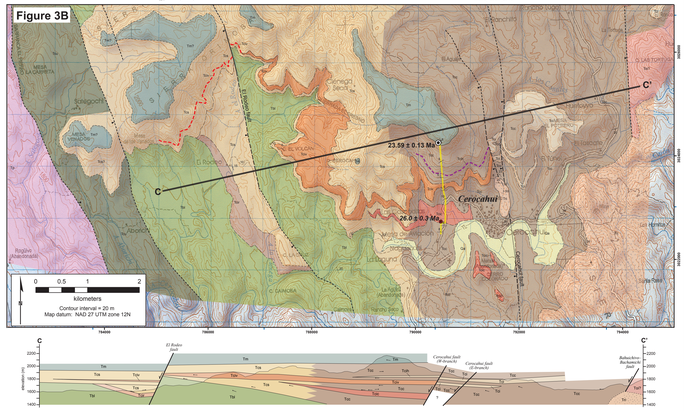


Figure 3: Geologic maps and cross sections of the Rancho de Santiago area, immediately west of the Cerocahui basin and east of the Guazapares Mining District (Fig. 3A, left), and the Cerocahui area (Fig. 3B, above). An explanation of map symbols and lithostratigraphic correlation keys is above Figure 3B. White dots indicate the locations and ages of newly dated samples by $^{40}Ar/^{39}Ar$ from this study (Table 1 & Fig. 4); red dots indicate the locations and ages of samples previously dated by zircon U-Pb LA–ICP–MS (Murray et al., 2013, 2014). Yellow line on Figure 3B indicates location of the measured stratigraphic section (Fig. 6).

$^{40}Ar/^{39}Ar$ age results

Table 1: Summary of $^{40}Ar/^{39}Ar$ results

Sample #	Map unit	Lithology	Age (Ma)	±2σ (Ma)	MSWD	Method
BM100316-3	Tm	Cerocahui basalt	23.59	0.13	0.81	Multigrain IH plateau (basalt)
BM100311-1	Tpk	KM ignimbrite	27.46	0.30	0.97	Multigrain IH plateau (sanidine)
BM100309-1	Tpc	Chepe ignimbrite	34.68	0.14	1.0	Multigrain IH plateau (sanidine)

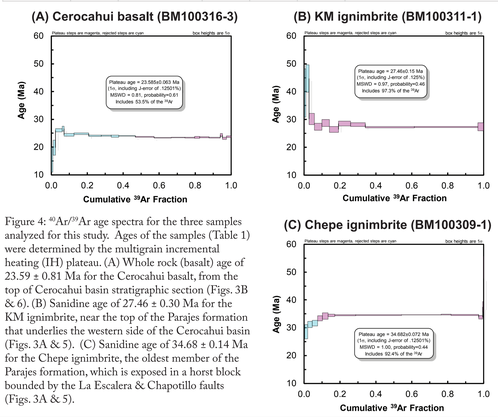
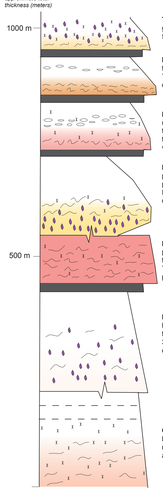


Figure 4: $^{40}Ar/^{39}Ar$ age spectra for the three samples analyzed for this study. Ages of the samples (Table 1) were determined by the multigrain incremental heating (IH) plateau. (A) Whole rock (basalt) age of 23.59 ± 0.81 Ma for the Cerocahui basalt, from the top of Cerocahui basin stratigraphic section (Figs. 3B & 6). (B) Sanidine age of 27.46 ± 0.30 Ma for the KM ignimbrite, near the top of the Parajes formation that underlies the western side of the Cerocahui basin (Figs. 3A & 5). (C) Sanidine age of 34.68 ± 0.14 Ma for the Chepe ignimbrite, the oldest member of the Parajes formation, which is exposed in a horst block bounded by the La Escalera & Chapotillo faults (Figs. 3A & 5).

Stratigraphy

Figure 5: Parajes formation generalized stratigraphy



Traza ignimbrite (Tpt): 20% phenocrysts: plagioclase, pyroxene, trace quartz; gray flamme; 30% lithic fragments (intermediate-silicic volcanic, welded tuff; to 50 mm). Basal 1 m-thick vitrophyre. Thickness: >40 m, top not exposed.

KM ignimbrite (Tpk): <5% phenocrysts: plagioclase, trace quartz; 30% gray flamme (to 30 mm); 5-10% lithic fragments (red and gray intermediate volcanic). Thickness: ~40 to 100 m. Basal 0.5 m thick black vitrophyre below ~ 10 m thick red densely welded lower portion. Weathered-out pumice lenses (to 10 cm) near top

27.46 ± 0.30 Ma

Rancho de Santiago ignimbrite (Tpr): 5-20% phenocrysts (decreasing amount upsection): plagioclase (to 3 mm), pyroxene, ± hornblende, ± quartz; 10-20% gray flamme with dark gray rims (typically to 30 mm, maximum 1 m-length); trace to 25% lithic fragments (intermediate-silicic volcanic). Thickness: ~80 to 200 m. Basal 2 m-thick vitrophyre unit. Weathered-out pumice lenses (to 25 mm) in upper middle portion of unit.

Puerto Blanco ignimbrite (Tpb): <5-20% phenocrysts (increasing amount upsection): plagioclase, biotite, with trace hornblende, pyroxene, quartz; 10-15% yellowish-white pumice fragments (to 30 mm), 5% yellow flamme (to 10 cm) in welded section; 10-40% lithic fragments (intermediate volcanic, to 50 mm), with normal coarse-tail grading and decreasing amount upsection. >190 m-thick, base not exposed

27.6 ± 0.3 Ma

Portero ignimbrite (Tpp): pink groundmass with eutaxitic texture; trace to 25% phenocrysts: plagioclase, pyroxene, ± hornblende, trace quartz; 20% dark reddish-gray flamme (to 30 cm); trace to 10% lithic fragments (intermediate volcanic; to 15 mm). Thickness: ~20 to 180 m. Basal 1 m-thick vitrophyre, top eroded. Increased amount of phenocrysts, lithic fragments, and vapor-phase alteration upsection.

Ericicuchi ignimbrite (Tpe): 5-15% phenocrysts: plagioclase, pyroxene, ± biotite, ± hornblende, trace quartz; 5-10% dark-gray flamme with orange rims (to 10 mm); trace to 10% (locally to 30%) lithic fragments (intermediate-silicic volcanic; to 2 mm, locally to 30 mm). Thickness: ~210 m. Base not exposed, or possibly located in inaccessible cliff exposures

27.6 ± 0.3 Ma
27.0 ± 0.7 Ma

Chepe ignimbrite (Tpc): 30% phenocrysts: quartz (embayed, to 5 mm), plagioclase, biotite (to 2 mm), hornblende; 15% pink-orange colored flamme. More than 140 m-thick, base not exposed. Possible multiple cooling units, or capped by either Tpe or an unidentified ignimbrite outflow sheet.

34.68 ± 0.14 Ma

Figure 5 (above): Generalized stratigraphic column describing the key characteristics of the seven distinct ignimbrites of the Parajes formation. New $^{40}Ar/^{39}Ar$ ages of the KM & Chepe ignimbrites from this study (Table 1 & Figs. 4B-C) are indicated by bold text; previous zircon U-Pb LA–ICP–MS ages of the Puerto Blanco & Ericicuchi ignimbrites dated by Murray et al. (2013) are indicated by bold italic text.

Figure 6: Cerocahui measured section

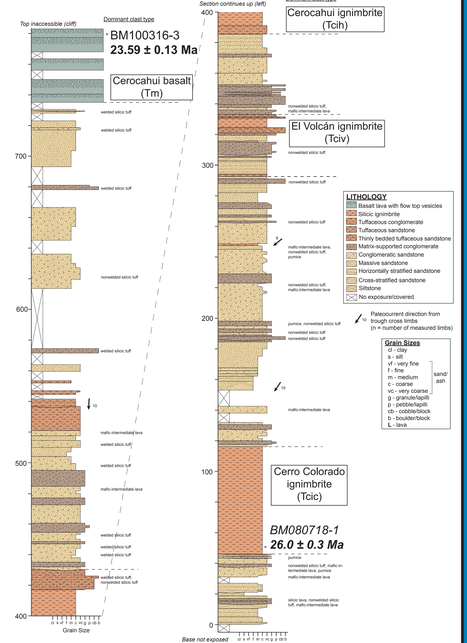


Figure 6 (right): Measured stratigraphic section of Cerocahui basin deposits in the Cerocahui village area (Fig. 3B), depicting the stratigraphic position and new $^{40}Ar/^{39}Ar$ age of the Cerocahui basalt (780 m) and the previous zircon U-Pb LA–ICP–MS age of the Cerro Colorado ignimbrite (50 m) (Murray et al., 2014). Also indicated are sedimentary facies and paleocurrent data from trough limbs. The dominant clast type (>50%) observed in conglomerates and conglomeratic sandstones are listed where recorded in the section; polymictic rocks without a single dominant clast type (<50%) are listed in order of relative abundance.

Ignimbrite Correlation

Chepe Ignimbrite

- Based on nearly identical phenocryst assemblages and stratigraphic position relative to younger dated samples, Murray et al. (2013) tentatively correlated the Chepe ignimbrite to the regional extensive 29.8 ± 0.5 Ma Divisadero tuff of Swanson et al. (2006), exposed ~45 km NE of the study area at Divisadero in the Copper Canyon region (Figs. 1 & 7).
- The new $^{40}Ar/^{39}Ar$ age of the Chepe ignimbrite from this study rejects this previous correlation, as the Divisadero tuff is ~5 Myr younger (Table 1 & Fig. 4C).
- **This study tentatively correlates the Chepe ignimbrite to the 34.1 ± 0.9 Ma Vista tuff** (Table 2) erupted from the Los Varas caldera of the Tomóchic volcanic complex (e.g., Swanson and McDowell, 1985; Wark et al, 1990), located ~120 km NNE of the study area (Figs. 1 & 7)
  - *"The Vista tuff, with its readily visible quartz, abundant feldspar, biotite, and hornblende, is nearly identical in appearance to the Divisadero tuff as seen at Copper Canyon...distinguishing between the Vista and Divisadero tuffs in the field can pose a problem."* (p. 131, Swanson et al., 2006)
  - The closest outcrops of the Vista tuff to the Cerocahui basin region are ~82 km NE near San Juanito (Figs. 1 & 7)

Table 2: Comparison of Chepe ignimbrite & Vista tuff

	Chepe ignimbrite[1]	Vista tuff[2]
Age (method)	34.68 ± 0.14 Ma ($^{40}Ar/^{39}Ar$ sanidine)	34.1 ± 0.9 Ma (K-Ar biotite, sanidine, plagioclase)
Phenocrysts	30% - abundant (>10%) plagioclase and quartz (embayed, to 5mm), biotite (to 2 mm), hornblende, sanidine, Fe-Ti oxides	to 50% - abundant (>10%) plagioclase and quartz (embayed, to 5mm), biotite, hornblende, sanidine, Fe-Ti oxides
Outcrop characteristics	Strongly welded with light red groundmass; moderate eutaxitic texture with 15% pink-orange flamme	Moderately welded with light gray groundmass, can be strongly welded and red; locally eutaxitic, with small white pumice; multiple cooling units locally

[1]Murray et al. (2013); this study

[2]Swanson and McDowell (1985); Wark et al. (1990); Swanson et al. (2006); McDowell (2007)

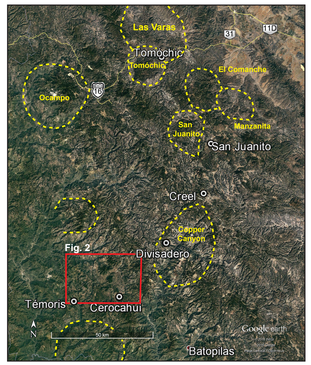


Figure 7 (above): Satellite image of the region between Tomóchic and the Cerocahui basin area (red box indicates the location of Figure 2), showing the major villages and locatities of Divisadero & Vista tuff outcrops mentioned in the text. Inferred caldera margins are shown as dashed yellow lines (locations and names after Swanson et al., 2006; Ferrari et al., 2007).

Basin Development

- The relatively flat-lying Cerocahui basalt conformably caps the gently east-to-north-dipping Cerocahui basin alluvial deposits (Figs. 3B, 6, & 8).
- Approximately 730 m of strata separates the 23.59 ± 0.13 Ma Cerocahui basalt from the 26.0 ± 0.3 Ma Cerro Colorado ignimbrite (Fig. 6), suggesting a depositional rate of ~300 m/Myr in the Cerocahui basin near the fault margin. The Cerocahui basalt has only minor offset across the basin bounding fault, suggesting that extension in the study area was active by ca. 27.5 Ma and was waning by ca. 23.6 Ma

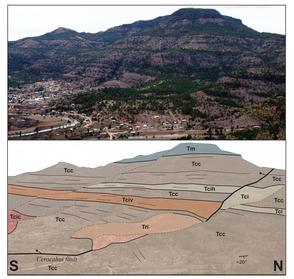


Figure 8 (above): Overview photograph and geologic interpretation of the Cerocahui basin stratigraphic section area, showing moderately E-to-N-dipping (to ~15° NE) Cerocahui basin alluvial deposits and interbedded ignimbrites below conformable near flat-lying basalt lavas (after Murray et al., 2014). See Figure 3B for symbol explanation

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