Multiproxy provenance study of the Chivillas Formation: A record of the Middle Jurassic to Early Cretaceous geodynamic evolution of southeastern Mexico

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Abstract

The Middle Jurassic to Early Cretaceous tectonic configuration of southeastern Mexico was controlled by a transtensional regime associated with the final stage of the opening of the Gulf of Mexico. During this period, sedimentary basins were established within central and southern Mexico, which include detrital successions derived mostly from different igneous and metamorphic basement units, and also from Jurassic or older sedimentary successions. One of these basins is the Cuicateco, whose Early Cretaceous sedimentation is represented by the Chivillas Formation. The Chivillas Formation is made up of siliciclastic turbidites, volcanoclastic deposits, and volcanic rocks. Both the paleontological record and detrital zircon geochronology constrain the maximum age of deposition to the Early Cretaceous.

A provenance analysis was performed using U-Pb data from detrital zircon and apatite grains, as well as apatite geochemistry, and fission track analysis. The new detrital zircon and apatite U-Pb geochronology data of the Chivillas Formation allows identifying three main source areas: Early Neoproterozoic, Permian-Carboniferous, and Early Cretaceous. Trace element concentrations in the detrital apatite reveal that the Grenvillian grains have Sr content correlated with negative Eu anomalies. Also, the REE concentrations in the Grenvillian grains is higher than in the Permian-Carboniferous grains. The relative mechanical instability of apatite suggests nearby sources, such as the metamorphic rocks of the Grenvillian Oaxacan Complex, the igneous rocks belonging to the Permian-Carboniferous magmatic arc, and those belonging to Early Cretaceous magmatic arc, which was developed along the Pacific margin of Mexico. Apatite fission track analyses indicate that the Chivillas Formation was exhumed quickly during the middle Eocene, and thermal modeling indicates that exhumation lasted 7 Ma. This exhumation post-dated the contractional Laramide event and is probably associated with the reactivation of the Oaxaca fault, one of the most prominent discontinuities in southern Mexico, which acted as an extensional structure during the Cenozoic.

Introduction

The sediment and development of sedimentary basins accumulation is an important process that records the paleogeographic environment and the tectonic evolution of the source areas. In southern Mexico, the accumulation of sediments in an extensional environment with synchronous magmatic activity has been reported in the Cuicateco basin, whose Early Cretaceous sedimentation is represented by Chivillas Formation.

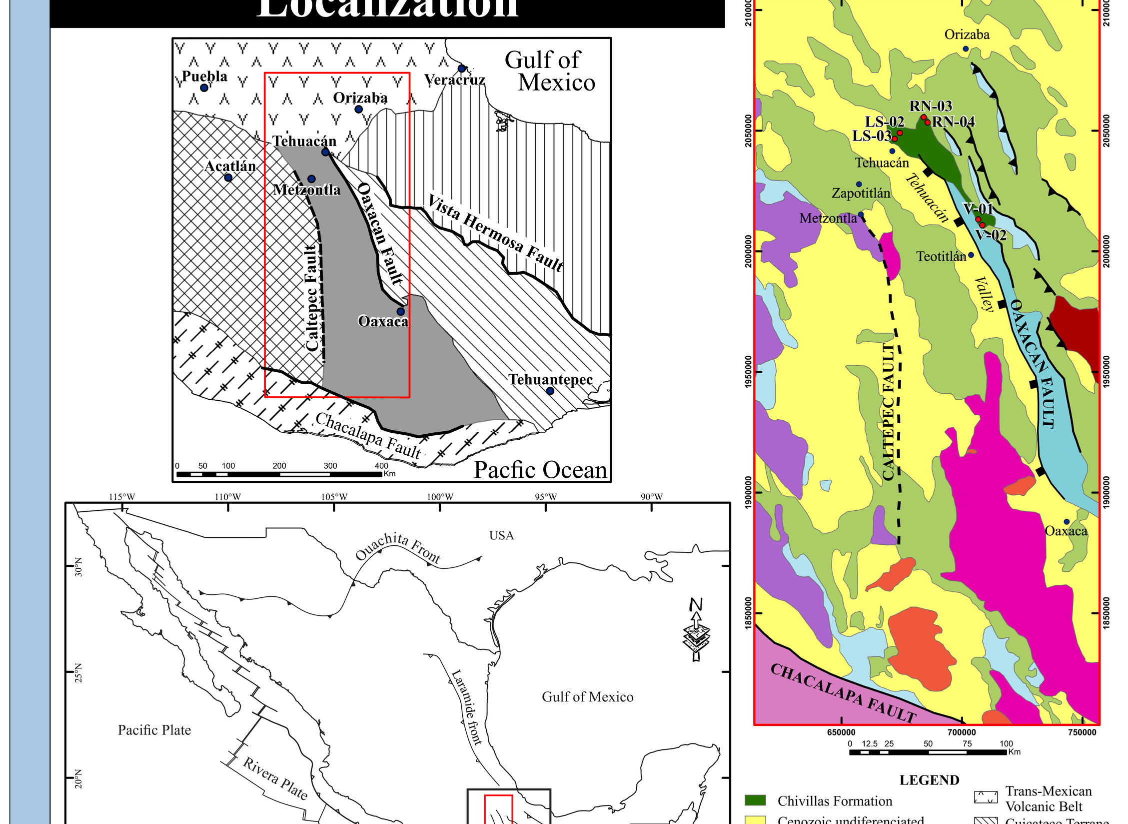
Sandstone provenance studies of Chivillas Formation identified a mixed-source provenance, including the igneous and metamorphic basement and older sedimentary sequences of central and southern Mexico (Mendoza-Rosales et al., 2013).

However, the provenance studies that integrate petrography and detrital zircon geochronology in some cases does not provide a good restriction of the source, since most clastic sequences represent a mixture derived from several types of rocks.

To identify the paleography of the basement blocks from southern Mexico during the Chivillas Formation sedimentation and elucidate the sedimentary source provenance, we applied a multi-technique study.

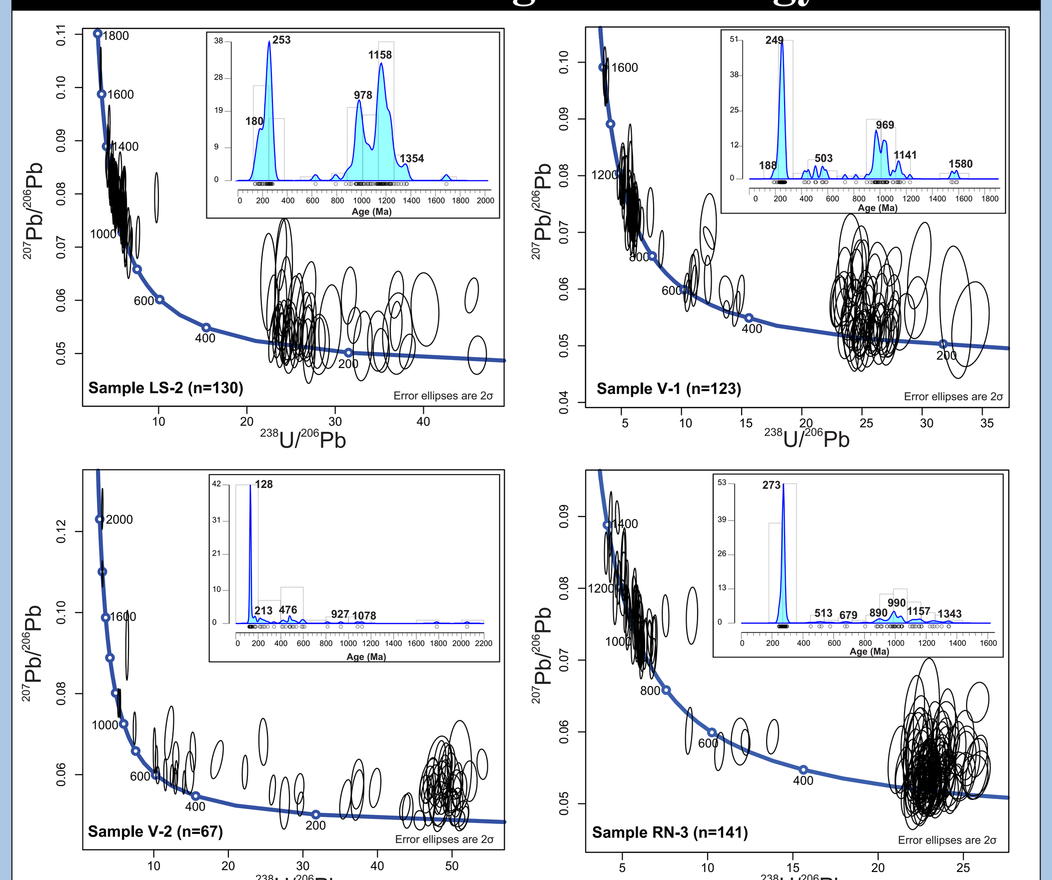
In this work U-Pb geochronology of detrital zircon and apatite grains were integrated with multiple trace-element geochemical analysis of detrital apatite. Besides, apatite fission-track analyses were performed with the aim to identify the thermal history of the Cuicateco basin.

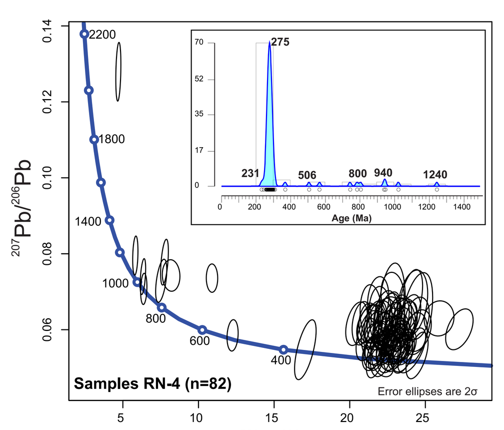
Localization



Generalized map of Mexico with the principal tectonic structures. The insets represent a detail of the tectonostratigraphic terranes of southern Mexico (Sedlock et al., 1993) and a generalized geologic map with the location of the Chivillas Formation and the analyzed samples.

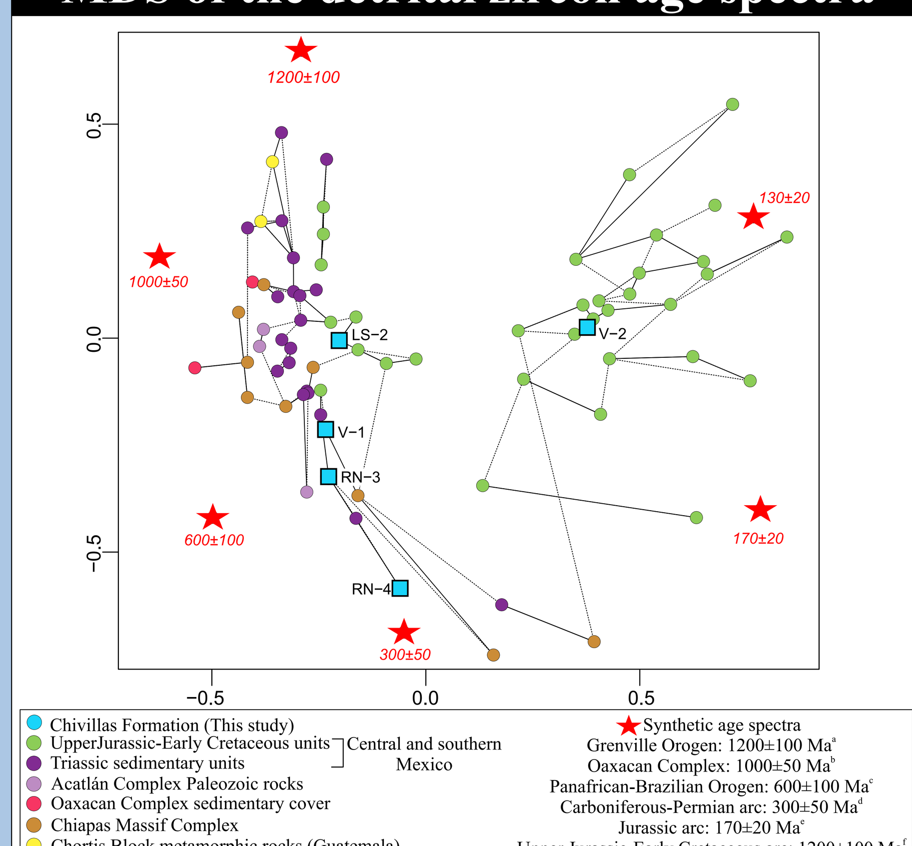
U-Pb zircon geochronology





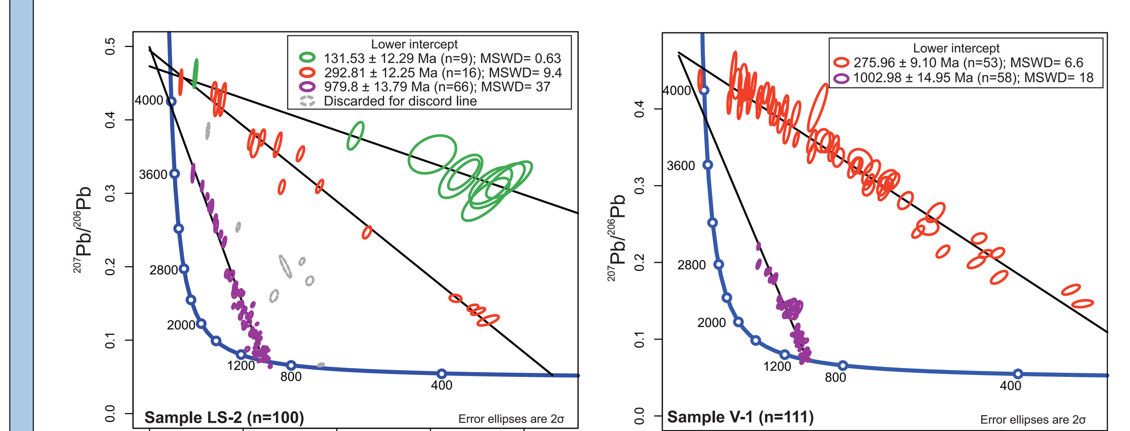
Tera-Wasserburg concordia diagrams of the samples analyzed of the Chivillas Formation and belonging to the localities reported in the geologic map. The boxes represent the Kernel Density Estimator plot (KDE) for detrital zircon data.

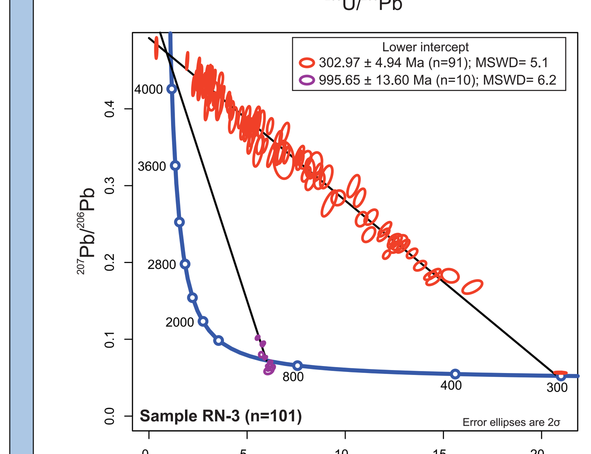
MDS of the detrital zircon age spectra



Non-metric multidimensional scaling diagram (MDS) of the Chivillas Formation and other sedimentary and metasedimentary samples of the central and southern Mexico and Guatemala. Closest neighbors of the Chivillas sandstone are Upper Jurassic-Early Cretaceous units, Triassic sedimentary units, the Acatlán Complex samples, and Chiapas Massif Complex samples. The Chivillas samples plot closer to the Grenville, Carboniferous-Permian and Upper Jurassic-Early Cretaceous synthetic samples, indicating a stronger precursor of such ages.

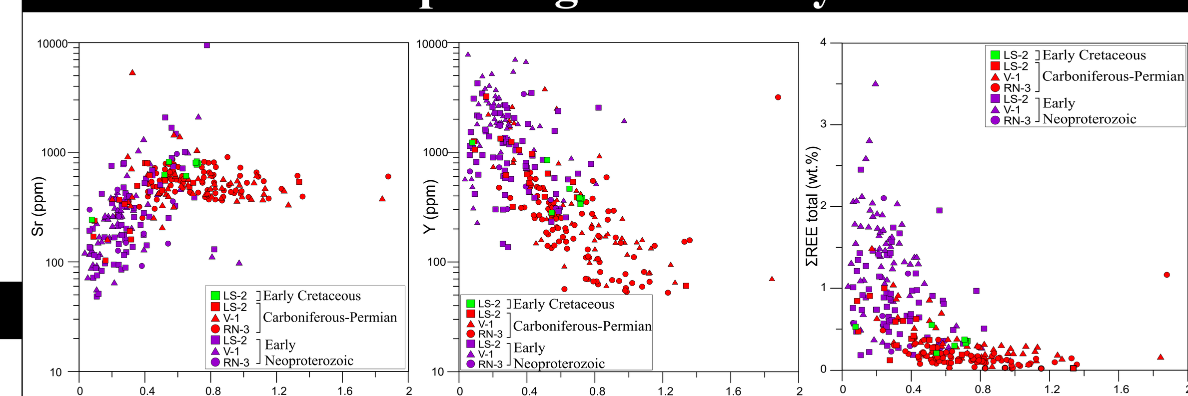
U-Pb apatite geochronology





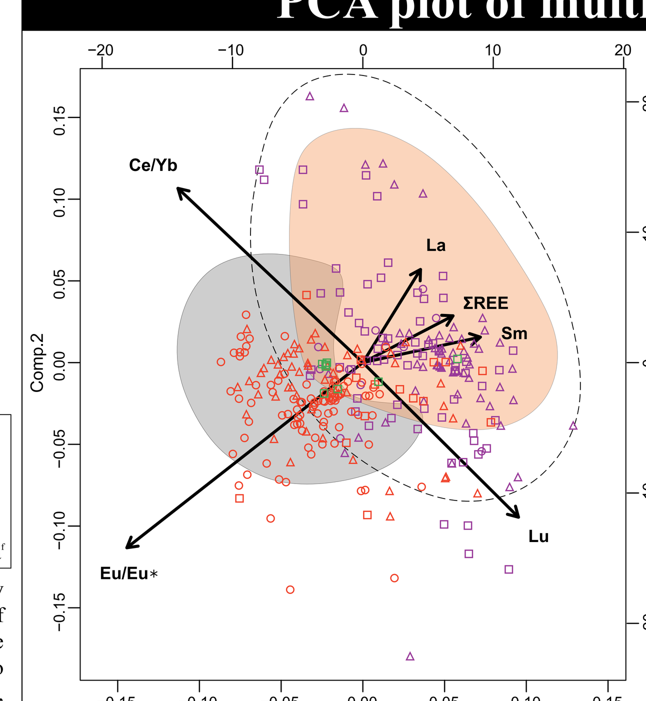
LA-ICPMS apatite U-Pb ages of three detrital samples belonging to the Chivillas Formation. Mostly are discordant, but can be interpreted as representing detritus belonging to the Grenvillian basement (ca. 1,000 Ma; violet ellipses), Carboniferous-Permian magmatism (red ellipses), and of the Early Cretaceous arc (green ellipses).

Apatite geochemistry



Apatite compositions from all the studied samples of the Chivillas Formation. The geochemistry behavior of the Sr (ppm), Y (ppm), ΣREE total (wt.%) and Eu anomaly (Eu/Eu*) is similar to in-situ high-grade metamorphic and felsic to intermediate-mafic apatite analyses from the literature (e.g., Henrichs et al., 2018; O´Sullivan et al., 2018; Tang et al., 2012; Morton and Yaxley 2007).

PCA plot of multi-element data



Early Cretaceous:
- LS-2

Carboniferous-Permian:
- LS-2
- V-1
- RN-3

Early Neoproterozoic:
- LS-2
- V-1
- RN-3

Northern Oaxacan Complex
Includes apatite of metasediments, melanosomes, migmatites and granulites (Internal data of Isotopic studies laboratory (LEI) of the UNAM; n=87)

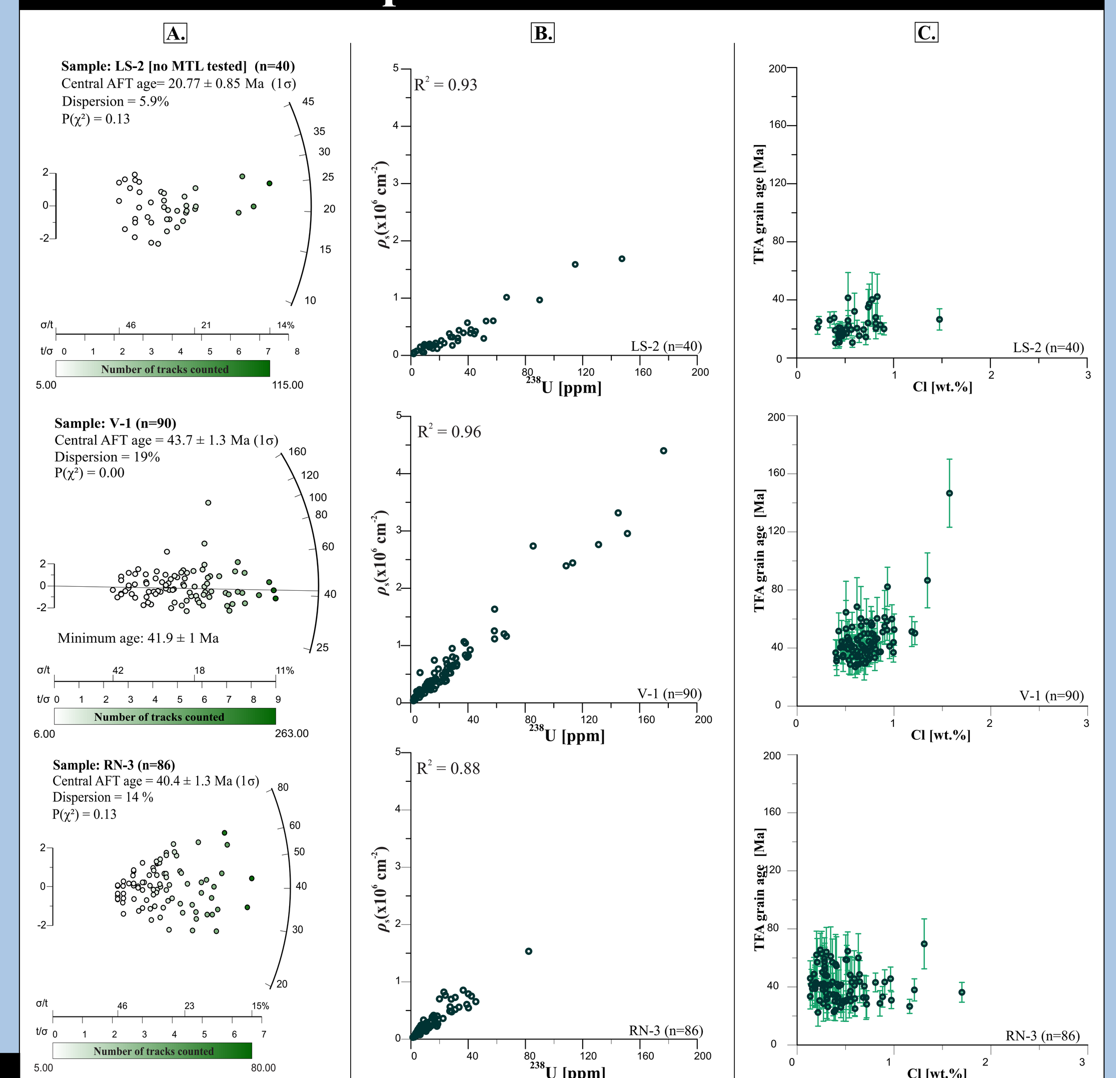
Permian magmatism
Includes apatite of Etla granite and Sosola rhyolite (Internal data of Isotopic studies laboratory; n=45)

Matzitzi Formation
Includes apatite of ABM-02 and ABM-05 samples of Bedoya Mejía, 2018; (n=80)

Principal Component Analysis of multi-element data from Chivillas Formation apatite compared to apatite fields that represent to the Oaxacan Complex, the Permian magmatism, and the Matzitzi Formation (whose main sediment sources are to the Oaxacan Complex and Upper Paleozoic igneous rocks; Bedoya Mejía, 2018).

The Early Neoproterozoic apatite is "pulled" toward ΣREE, La and Sm vectors, and "repelled" by Eu/Eu* vector. The Carboniferous-Permian apatite is "push" toward the Eu/Eu* vector and "repelled" by ΣREE, La and Sm vectors.

Apatite fission track



Detailed apatite fission-Track (AFT) results.

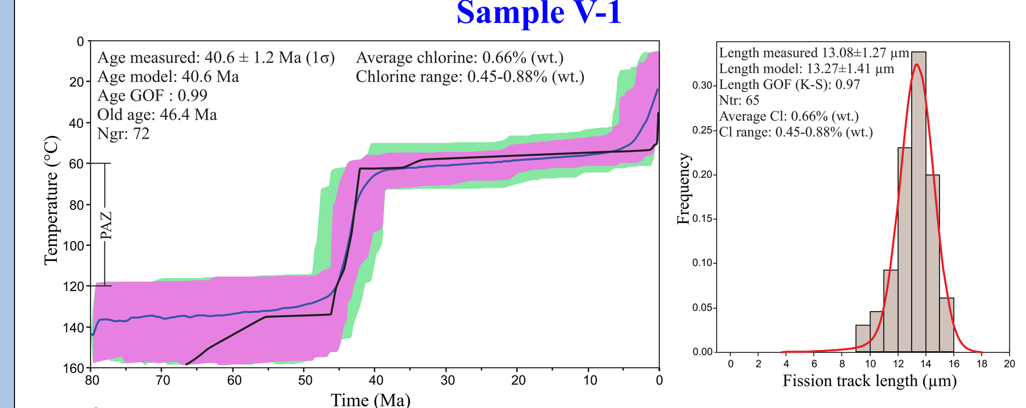
A. Radial plots; n: number of apatites dated, $P(\chi^2)$: chi-squared test, MTL: mean track length.

B. ^{238}U vs ρ_s plot (ρ_s: spontaneous track density; i.e., analogue to isochron).

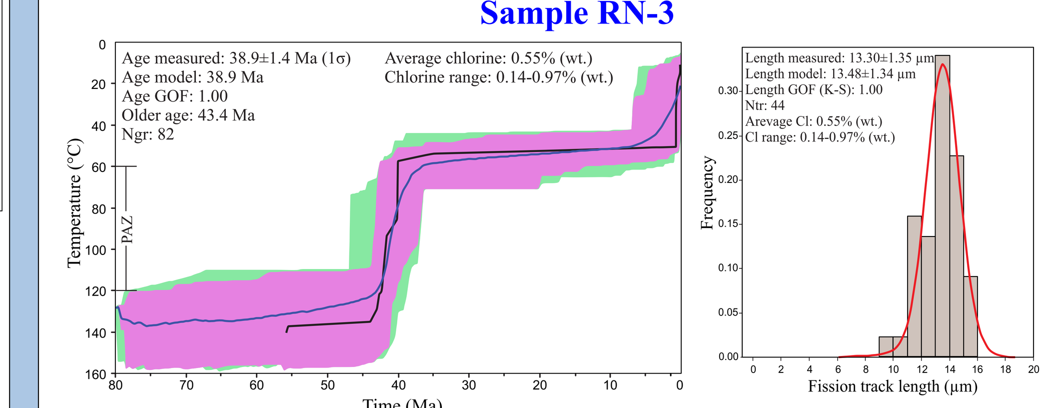
C. Single-grain AFT ages vs Chlorine contents.

Time-temperature (T-t) thermal model

Sample V-1

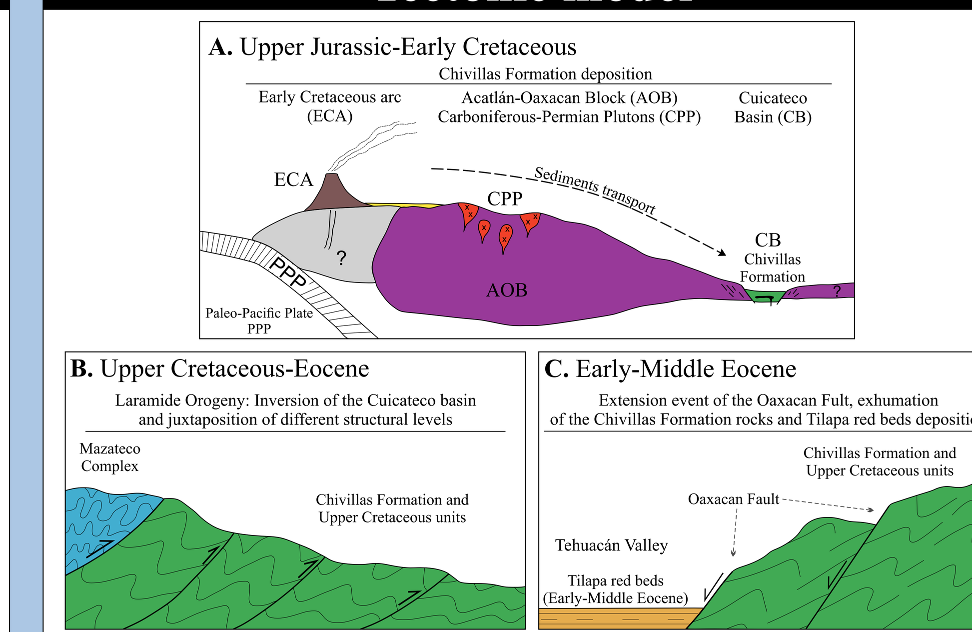


Sample RN-3



Time-Temperature modeling performed using HeFTy (Ketcham, 2005) and based on the annealing model of Ketcham et al. (2007). PAZ: partial annealing zone; Ngr: number of grains dated; Ntr: number of confined track lengths measured; Age GOF: goodness-of-fit between the measuredand model ages; GOF (K-S): goodness-of-fit between the measured and model track lengths.

Tectonic model



A. Upper Jurassic - Early Cretaceous paleogeographic reconstruction of southern Mexico during the Chivillas Formation sedimentation. B. Upper Cretaceous - Eocene reconstruction of the Cuicateco basin inversion during the Laramide Orogeny. C. Early - Middle Eocene reconstruction of the Chivillas Formation exhumation during the extensional event of the Oaxacan Fault and Tilapa red beds synchronic deposition. Based on Ángeles-Moreno, 2006; Nieto-Samaniego et al., 2006; Dávalos-Álvarez et al., 2007; Ortega-Flores et al., 2016; Sierra-Rojas et al., 2016.

Conclusions

- By integrating the geochronology and geochemistry data of the studied mineral phases and considering that the apatite mechanical properties restrict the sedimentary provenance to nearby sources, this research demonstrates that the provenance sources of the sedimentary first cycle of Chivillas Formation belong to Grenvillian Oaxacan Complex metamorphic rocks, the felsic to intermediate-mafic igneous rocks belonging to the Carboniferous-Permian magmatic arc, and those belonging to Early Cretaceous magmatic arc.
- This suggests that the Acatlán-Oaxacan block was a basement high during the Early Cretaceous, and the detrital apatite register its exposition and denudation.
- Apatite fission-track analyses indicate that the Chivillas Formation exhumed quickly during the Middle Eocene synchronic with the Tilapa red beds sedimentation. Both processes were influenced by the extensional activity of the Oaxacan Fault.

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Analytical parameters

Laser

Resonetics Resolution M050
ArF excimer 193 nm
Zircon: spot 23 μm

Apatite: spot 60 μm
Fluence: ca. 6 J/cm²
Gasses: 350 ml/min He + 4.5 ml/min N²

ICP-MS

Thermo ICap Qc quadrupole
Ablation time: 30 s
Total each analysis: 58 s
Tuning parameters: NIST 610; ^{238}U ca. 3000 cps/ppm; U/Th=1; ThO/Th <1%

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