PERMIAN BASIC VOLCANISM ON THE NW MARGIN OF GONDWANA IN THE GUACAMAYA FORMATION, CIUDAD VICTORIA BLOCK, TAMAULIPAS, MEXICO

Blanca Sughey Apolinar-Morales[1,*], Juan Alonso Ramírez-Fernández[2], Uwe Jenchen[2] & Yolanda Pichardo-Barrón[2]

[1] *Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE), Departamento de Geología, Ensenada, B.C., México*

[2] *Universidad Autónoma de Nuevo León, Facultad de Ciencias de la Tierra, Linares, N.L. México*

* sughey@cicese.edu.mx

Resumen

El presente trabajo se centra en el estudio de unidades epiclásticas de la Formación Guacamaya del Pérmico, del Grupo Tamatán, del Bloque Cd. Victoria, que representa el basamento en el Anticlinorio Huizachal-Peregrina. Los resultados sugieren que corrientes de turbidez en aguas profundas, transportaron los epiclastos volcánicos contenidos en las capas siliciclásticas. Su firma geoquímica indica una composición intermedia-básica relacionada a un arco insular, activo durante el cierre océano Réico, previo al ensamble de Pangea. Esta unidad es correlacionable con las turbiditas y lavas de la Formación Tuzancoa expuestas en el estado de Hidalgo. Esto, permite proponer la existencia de un arco insular perigondwánico del Pérmico, no descrito hasta ahora.

Palabras clave

Pérmico, Formación Guacamaya, Arco insular, Bloque Ciudad Victoria

Abstract

The present work focuses on the study of epiclastic units of the Permian Guacamaya Formation from the Tamatán Group, Cd. Victoria Block, representing the basement in the Huizachal-Peregrina Anticlinorium. The results suggest that deep-sea turbidity currents transported volcanic epiclasts included in the siliciclastic strata. Their geochemical signature indicates an intermediate-basic composition related to an island arc, active during the closure of the Rheic Ocean before the assembly of Pangea. This unit is correlatable with the turbidites and lavas of the Tuzancoa Formation exposed in the Hidalgo state. With these results, we propose the existence of a Permian perigondwanan island arc, just now described.

Keywords

Permian, Guacamaya Formation, Island arc, Ciudad Victoria Block

Apolinar-Morales, B.S., Ramírez-Fernández, J.A., Jenchen, U. & Yolanda Pichardo-Barrón, Y. (2023): Permian Basic Volcanism on the NW margin of Gondwana in the Guacamaya Formation, Ciudad Victoria Block, Tamaulipas, Mexico. – en: Montalvo Arrieta, J.C., Ramírez Fernández, J.A., Aguilar-Madera, C.G., Jenchen, U., Salinas Jasso, J.A., Velasco-Tapia, F. & Navarro-de León, I. (eds.): Número especial en conmemoración del 90° Aniversario de la Universidad Autónoma de Nuevo León y del 40° Aniversario de la Facultad de Ciencias de la Tierra. – Actas de la Facultad de Ciencias de la Tierra, UANL, Linares, **9 (2023)**: 1-7.

Introduction

The basement of northwestern Mexico consists of Precambrian and Paleozoic units, which have a significant affinity to the northwest margin of Gondwana. In this group of basement units of the Sierra Madre Oriental, described as Ciudad Victoria Block by Ramírez-Fernández et al. (2021), igneous bodies related to the development of magmatic arcs stand out. The present work focuses on the Paleozoic Tamatán basin (Alemán-Gallardo et al., 2019a; Casas-Peña et al., 2021), which has been interpreted as a retro-arc type basin located in northern Oaxaquia along the NW margin of Gondwana before the closure of the Rheic ocean and the assembly of Pangea (Casas-Peña et al., 2021). The Ordovician to Permian Tamatán Group, is made up by (1) Cañón de Caballeros Formation (Silurian), (2) Vicente Guerrero Formation (Mississippian), (3) Aserradero Rhyolite (Mississippian), (4) Del Monte Formation (Pennsylvanian), and (4) Guacamaya Formation (Permian).

Although the Tamatán Group has been previously described (Casas-Peña et al., 2021), the origin of the Guacamaya Formation epiclasts and their possible correlation with contemporaneous volcanic units (e.g Tuzancoa Formation) was unknown. In order to interpret the evolution of the different stages of perigondwanic and precollisional continental arcs preserved of the Ciudad Victoria Block, the main objective of this research is to postulate a geodynamic model that explains their origin, supported by the petrographic and geochemical data.

Geological setting

The Huizachal-Peregrina Anticlinorium is a major Laramidic structure of the Sierra Madre Oriental located west of Ciudad Victoria, Tamaulipas. The pre-Mesozoic outcrops exposed in its eroded core are found along the Caballeros, Peregrina, and Novillo Canyons, which cut perpendicular to the main axis of the NNW-SSE oriented fold and comprise four main units:

Precambian basement

The Novillo metamorphic complex (Alemán-Gallardo et al., 2019b) represents the oldest basal unit of the Sierra Madre Oriental. It has been divided into a meta-igneous and a meta-sedimentary unit according to its geochemical and modal compositions. Both units have been interpreted as part of Oaxaquia, later metamorphosed into granulite facies, related to the Rodinia assemblage, during the collision of Baltica against Amazonia (0.99-0.97 Ga) (Cameron et al., 2004; Alemán-Gallardo et al., 2019b).

Paleozoic basement

The Ordovician Peregrina Tonalite is exposed along the Novillo, Peregrina, and the Caballeros canyons and has been dated at 449 ± 3 Ma (Alemán-Gallardo et al., 2019b). It is an arc-related pluton. Granites of a comparable age located in the southern Maya block attest that the Famatinian Magmatic Arc in South America was extended into Mexico (Chew et al., 2007) forming the Peregrina-Mochonian Famatinian Arc (Estrada-Carmona et al., 2012; González-Guzmán, 2016; Alemán-Gallardo et al., 2019b).

The Carboniferous Granjeno metamorphic complex corresponds to a lithodeme exposed in the Novillo, Peregrina, and Caballeros canyons, constituted by meta-sedimentary, meta-igneous, and ultramafic bodies metamorphosed under greenschist conditions (Carrillo-Bravo, 1961; Torres-Sánchez et al., 2016). It includes a tectonically emplaced body, described as Victoria Serpentinite (Alemán-Gallardo, 2012). The metamorphism is dated at 300 Ma (Dowe et al., 2005) and is associated with an accretionary prism, formerly located along the active margin of NW Gondwana (Dickinson & Lawton, 2001; Barboza-Gudiño et al., 2011; Torres-Sánchez et al., 2015).

The Silurian to Permian siliciclastic Tamatan Group (Alemán-Gallardo et al., 2019a; Casas-Peña et al., 2021) includes the Silurian Cañon de Caballeros Formation, the Mississippian Vicente Guerrero Formation, the Mississippian Aserradero Rhyolite, the Pennsylvanian Del Monte Formation, and the Permian Guacamaya Formation. These units were deposited or emitted in a Paleozoic retro-arc basin between Oaxaquia and continental Gondwana. It is important to note that Aserradero Rhyolite represents an early pre-collisional episode of Mexico's Carboniferous to Permian magmatic arc (Ramírez-Fernández et al., 2021).

Results

Field work

The Guacamaya Formation is exposed in the Huizachal-Peregrina Anticlinorium along the Caballeros and Peregrina canyons. However, in later are exposed the best-preserved outcrops. Based on field observations, it is interpreted as a turbiditic deposit, classified into three different facies: (1) Siliciclastic facies composed of shales and sandstones that occasionally present ripples and incomplete Bouma sequences (2) Volcaniclastic facies consisting of conglomerate horizons with angular to subangular dark clast of ~1 to 10 cm in diameter, and (3) A calcareous facies constituted by limestone.

Petrography

The detrital rocks of the Guacamaya Formation are classified as litho-quartz-feldspathic with subrounded to subangular grains, showing point compaction between them. In addition, bioclasts (e.g., fusulinids, pelecypods, gastropods, and bryozoans) allowed assigning a Lower Permian age. On the other hand, epiclasts are represented by up to 2 mm volcanic glass shards generated by magma fragmentation (Figure 1).

Geochemistry

Geochemical analysis was performed only on the Guacamaya Formation epiclasts. Major elements were analyzed by inductively coupled plasma optical emission spectrometry (ICP-OES) and trace elements by inductively coupled plasma mass spectrometry (ICP-MS) at the Actlabs Laboratories, Ontario, Canada. The results were compared with those from the sandstones of the same formation (Casas-Peña, 2021), as well as the volcanic rocks of the Tuzancoa Formation (Rosales-Lagarde et al., 2005).

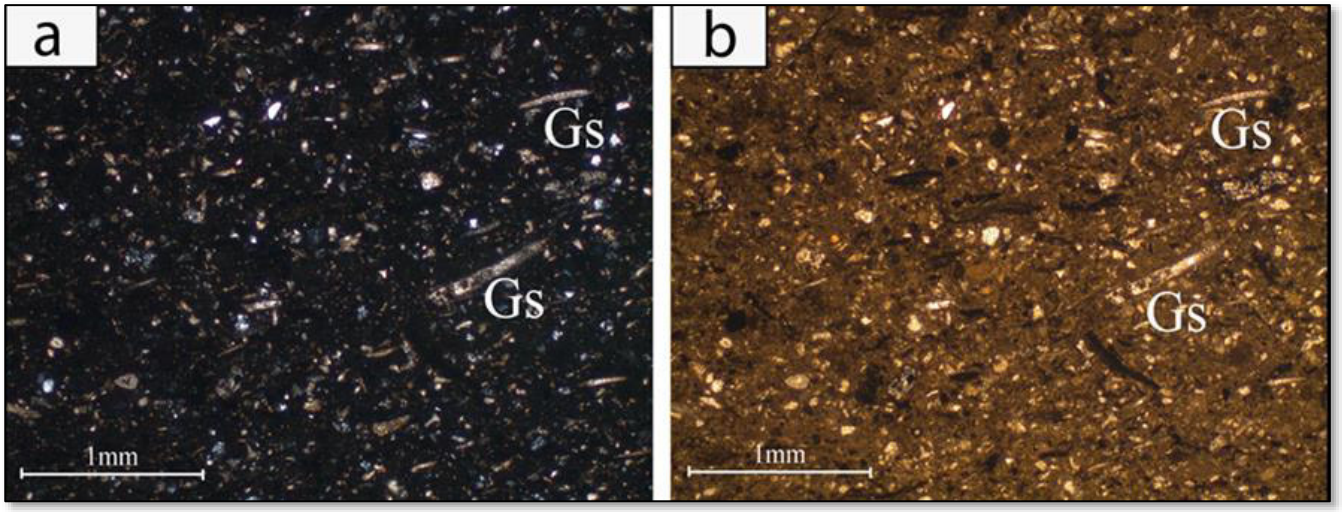

Figure 1: Microphotographs of eplicasts of the Guacamaya Formation: (a) Glass shard texture under NX and (b) under NII.

Mineralogical and lithological classification

The predominance of quartz-rich sediments, as shown in the petrological classification, is reflected in their geochemistry. These samples are enriched in SiO_2 (72-76 wt%) and depleted in Al_2O_3 (11-16 wt%), allowing grouping them in the psammites field in classification diagrams. These values agree with those reported by Pettijohn et al. (1987) for this rock type (SiO_2 >68 wt% and Al_2O_3 >14 wt%).

Weathering and diagenesis

The results of the weathering analysis indicate low values for CIA (chemical index alteration) from 6 to 23% and a PIA (plagioclase index alteration) from 5 to 30%. In addition, the samples' ICV (index of compositional variability) shows high values, with an average of 0.9. These results indicate a lower maturity and weathering in the sedimentary rocks.

Provenance and tectonic setting

Trace element geochemistry allows decoding the physical and chemical processes involved in the evolution of magmatic rocks and thus permits postulating a tectonic environment. From the Ti/Nb and SiO_2/K_2O ratios, it is possible to discriminate the source area of a given rock (Jenchen, 2018). The analyzed samples display a Ti/Nb average ratio of 1013 and a SiO_2/K_2O average ratio of 32, suggesting an intermediate to basic composition (Figure 2a). According to the Th-Sc-Zr/10 ternary diagram proposed by Bhatia & Crook (1986) the analyzed samples display an oceanic island arc affinity (Figure2b).

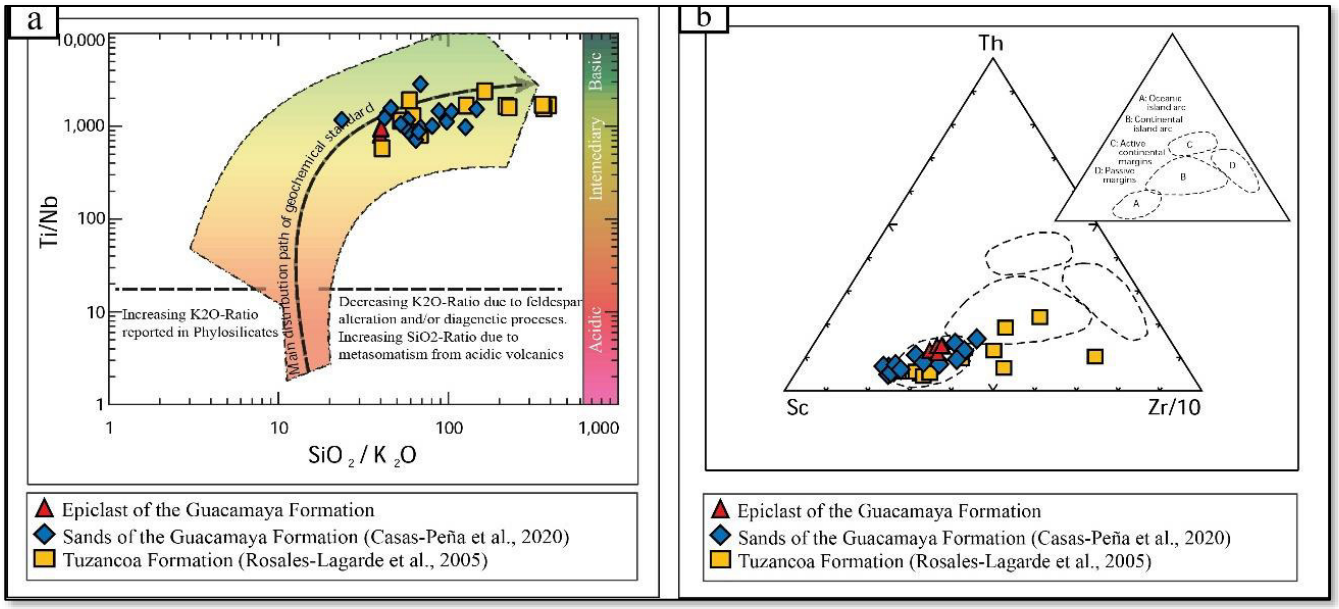

Figure 2: Source area discrimination diagrams comparing Permian volcaniclasts of the Tuzancoa Formation (Rosales-Lagarde et al., 2005), sandstones of Guacamaya Formation (Casas-Peña et al., 2021) and epiclast of the Guacamaya Formation (samples from the study area): a) SiO_2/K_2O-Ti/Nb diagram (Jenchen, 2018), b) Th-Sc-Zr/10 ternary diagram.

Incompatible element concentrations were normalized to the upper continental crust average data from Taylor & McLennan (1985). Data from the analyzed samples: Guacamaya Formation epiclasts, volcaniclasts of the Tuzancoa Formation (Rosales-Lagarde et al., 2005), and sandstones of the Guacamaya Fm. (Casas-Peña et al., 2021) reflect a depletion in HFSE (Figure 3). Nb is the element with the most pronounced negative anomalies, which have been commonly interpreted as an indicator of rocks related to magmatic arcs and/or continental crust (Baier et al., 2008).

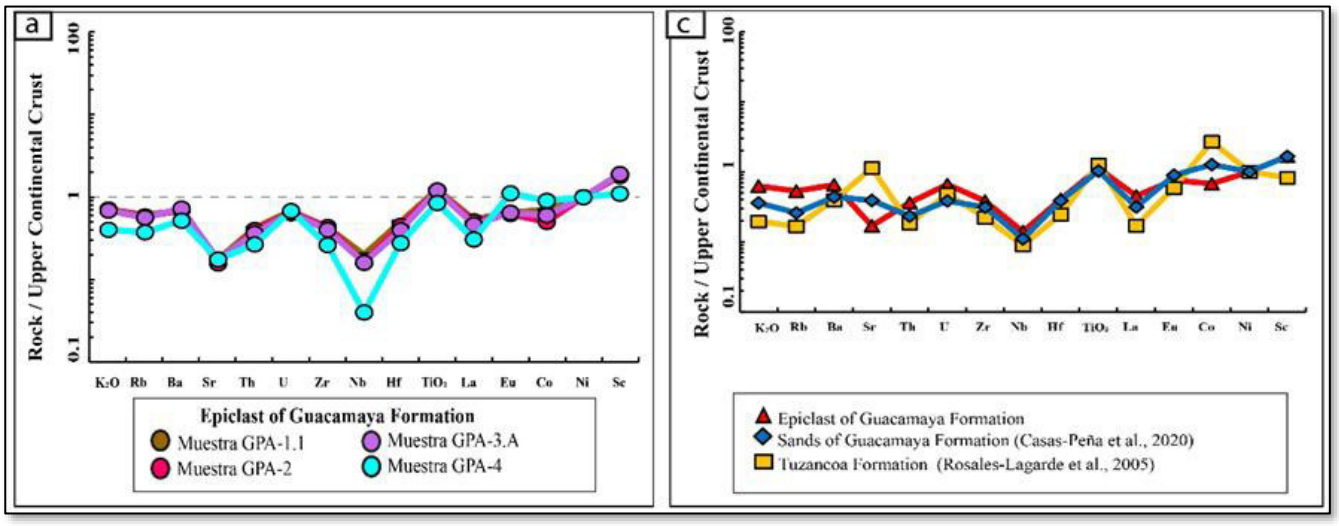

Figure 3: Trace element and rare earth element normalized diagrams (Taylor & McLennan, 1985): (a) Guacamaya Formation epiclasts (this work), (b) Average values of the samples of this work and from other Permian formations: Tuzancoa Formation volcaniclasts (Rosales-Lagarde et al., 2005) and Guacamaya Formation sandstones (Casas-Peña et al., 2021).

Discussion

Tectonic implication for the Guacamaya Formation

The Guacamaya Formation has been interpreted as a Lower Permian (Cisuralian) deep-water turbiditic deposit with evidence of volcanic activity. The geochemical signatures of the epiclasts indicate an intermediate-basic compositional source related to the Carboniferous-Triassic magmatic arc. The oldest evidence of this arc is represented by the Aserradero Rhyolite lithodeme dated with ~348 Ma (Ramírez-Fernández et al., 2021).

Evidence of volcanic activity is correlatable with that reported in the Tuzancoa Formation of the Huayacocotla Anticlinorium in Hidalgo. These rocks have been deposited near volcanic edifices, indicated by abundant lava flows intercalated with volcaniclastic rocks, where the dominant transport mechanism was turbiditic and detrital flows (Rosales-Lagarde et al., 2005).

According to published models and our new data, both the Guacamaya Formation in Ciudad Victoria and the Tuzancoa Formation volcaniclastics and lava flows are interpreted to have originated from a Permian Island arc, not previously described. This arc, developed on the northwestern margin of Gondwana, displays intermediate-basic melts, being probably related to the eastward subduction of the oceanic plate beneath Gondwana during the diachronic closure of the Rheic Ocean and before its collision with Laurentia to form Pangea. This arc may have developed in a region peripheral to the Oaxacan block to be subsequently accreted (Figure 4).

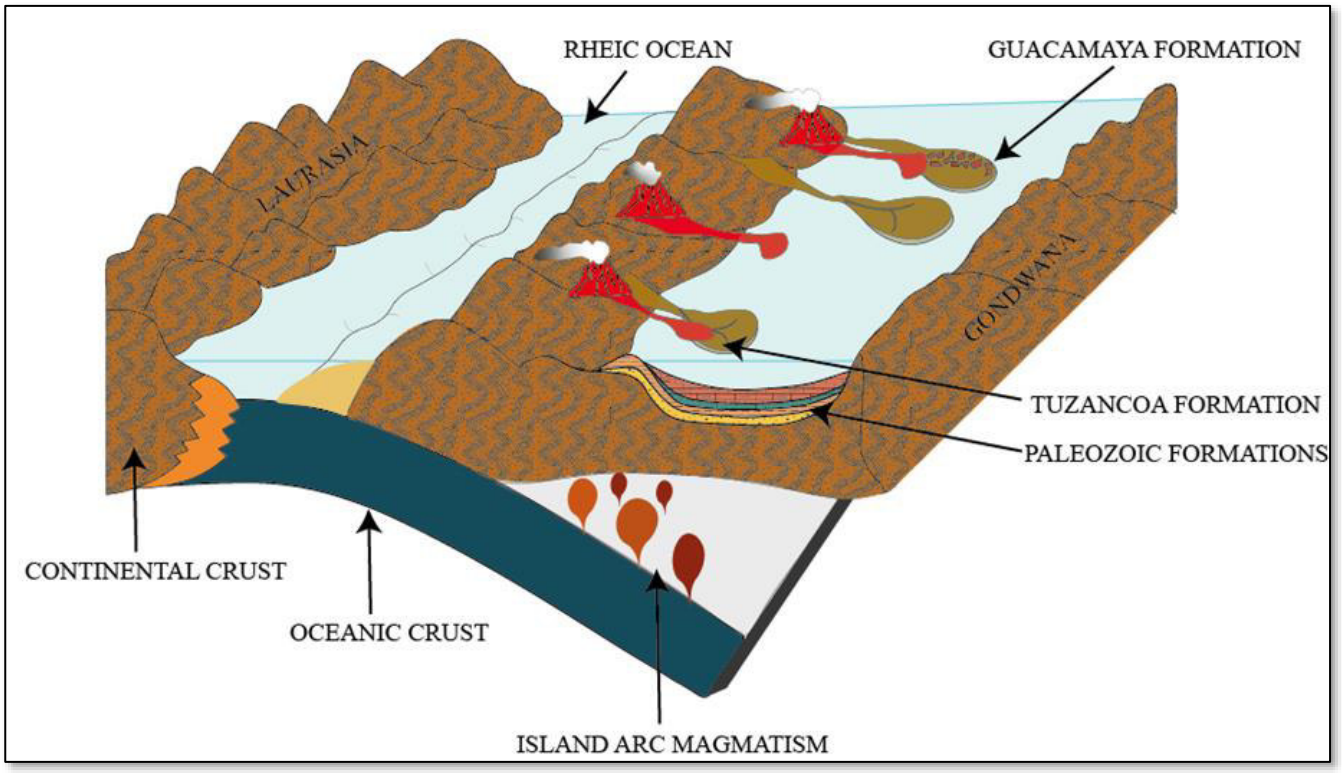

Figure 4: Paleogeographic schematic model for the Lower Permian. During this time, an island arc developed on NW margin of Gondwana, a product of the eastward subduction of the oceanic plate beneath Gondwana, during the diachronous closure of the Rheic ocean. At the same time, the turbidites of Guacamaya Formation were deposited in the most distal part of submarine lobes, when they received reworked volcanic input. The Tuzancoa Formation has been interpreted as a source proximal deposit with lava flows and volcaniclasts.

During that time, the Ciudad Victoria Block experienced some tectonic events, such as the uplift and obduction of the accretionary prism that may have caused the Granjeno Complex and the final stage of the Tamatán Group retroarc basin where it was closed and strongly deformed (Casas-Peña et al., 2021) because of the diachronous collision of Laurencia against Gondwana. This orogenic event is regionally referred to as the Ouachita-Marathon-Sonora; locally, we propose to refer to it as the Ciudad Victoria Sector.

Conclusions

According to our present study observations, the Guacamaya Formation corresponds to a turbiditic deposit composed of rhythmic intercalations of sandstones, shales, and occasionally limestone layers. In some parts, conglomerate layers with visible dark clasts are intercalated. It is important point out that:

According to field observations, three main facies have been documented: (a) siliciclastic facies, (b) volcaniclastic facies, and (c) calcareous facies. Remarkably, the volcaniclastic facies observed in the middle and upper part of the section, allow us to redefine this unit as a deep-water volcaniclastic turbiditic deposit.

Petrographic analysis indicates that the litho-quartz feldspathic sandstones contain a mixture of sources with mafic to felsic components. Their guide fossil content also allowed them to assign a Lower Permian age.

Volcanic clasts present evidence of reworking, transport, and resedimentation, allowing them to be classified as epiclasts.

The major and trace element concentration in the epiclasts indicate an affinity to an island arc, with an intermediate to basic composition, correlating to the Tuzancoa Formation, exposed in the Hidalgo state.

The model postulated in this work indicates the possible existence of a Permian island arc not described until now. It is proposed that this arc developed on the northwest margin of Gondwana, with basic to intermediate compositions. Furthermore, it is related to the eastward subduction of the oceanic plate beneath Gondwana during the diachronic closure of the Rheic Ocean before to its collision with Laurentia to finally form Pangea during Triassic times.

References

Alemán-Gallardo E.A. (2012): Remanentes del piso oceánico en la secuencia Paleozoica metamorfizada de la margen NW de Gondwana en el estado de Tamaulipas, NE de México: Serpentinita Victoria. – B.Sc. thesis, Facultad de Ciencias de la Tierra, Universidad Autónoma de Nuevo León, Linares, N.L.

Alemán-Gallardo, E.A., Ramírez Fernández, J.A., Rodríguez Díaz, A., Velasco-Tapia, F., Jenchen, U., Cruz-Gámez, E., Navarro-de León, I., De Leon-Barragán, L., (2019a): Evidence for an Ordovician continental arc in the pre-Mesozoic basement of the Huizachal-Peregrina Anticlinorium, Sierra Madre Oriental, Mexico: the Peregrina Tonalite. – Mineralogy and Petrology, **113**: 433-562. https://doi.org/10.1007/s00710-019-00660-4

Alemán-Gallardo, E.A., Ramírez-Fernández, J.A., Weber, B., Velasco-Tapia, F., Casas-Peña, J.M. (2019b): Novillo Metamorphic Complex, Huizachal-Peregrina Anticlinorium, Tamaulipas, Mexico: Characterization and development based on whole-rock geochemistry and Nd-isotopic ratios. – Journal of South American Earth Sciences, **96(102382)**: 1-17. https://doi.org/10.1016/j.jsames.2019.102382

Baier, J., Audétat, A., Keppler, H. (2008): The origin of the negative niobium tantalum anomaly in subduction zone magmas. – Earth and Planetary Science Letters, **267**: 290-300.

Barboza-Gudiño, J.R., Ramírez-Fernández, J.A., Torres-Sánchez, S.A., Valencia, V.A. (2011): Geocronología de circones detríticos de diferentes localidades del Esquisto Granjeno en el Noreste de México. – Boletín de la Sociedad Geológica Mexicana, **63**: 201-216.

Bhatia, M.R., Crook, K.A.W. (1986): Trace element characteristics of graywackes and tectonic setting discrimination of sedimentary basins. – Contributions to Mineralogy and Petrology, **92**: 181-193.

Cameron, K.L., López, R., Ortega-Gutiérrez, F., Solari, L.A., Keppie, J.D., Schulze, C. (2004): U-Pb geochronology and Pb isotopic compositions of leached feldspars: constraints on the origin and evolution of Grenville rocks from Eastern and southern Mexico. – Geological Society of America Memoirs, 197, pp 755-769.Carrillo-Bravo, J. (1961): Geología del Anticlinorio Huizachal-Peregrina al NW de Cd. Victoria,Tamaulipas. – Boletín de la Asociación Mexicana de Geólogos Petroleros, **13**: 1-98.

Casas-Peña, J.M., Ramírez Fernández, J.A., Velasco-Tapia, F., Alemán Gallardo, E.A., Augustsson, C., Weber, B., Frei, D., Jenchen, U. (2021): Provenance and tectonic setting of the Paleozoic Tamatán Group, NE Mexico: Implications for the closure of the Rheic Ocean. – Gondwana Research, **91**: 205-230. https://doi.org/10.1016/j.gr.2020.12.012

Chew, D.M., Schaltegger, U., Košler, J., Whitehouse, M.J., Gutjahr, M., Spikings, R.A., Aleksandar Mišković, A. (2007): U-Pb geochronologic evidence for the evolution of the Gondwanan margin of the north-central Andes. – Geological Society of America Bulletin, **119**: 697-711. https://doi.org/10.1130/B26080.1

Dickinson, W.R., Lawton, T.F. (2001): Carboniferous to Cretaceous assembly and fragmentation of Mexico. – Geological Society of America Bulletin, **113**: 1142–1160.

Dowe, D.S., Nance, R.D., Keppie, J.D., Cameron, K.L., Ortega-Rivera, A., Ortega-Gutierrez, F., Lee, J.W.K. (2005): Deformational history of the Granjeno schist, Ciudad

Victoria,Mexico: constraints on the closure of the Rheic Ocean? – International Geology Reviews, **47**: 920-937.

Estrada-Carmona, J., Weber, B., Martens, U., López-Martínez, M. (2012): Petrogenesis of Ordovician magmatic rocks in the southern Chiapas Massif Complex: relations with the early Palaeozoic magmatic belts of northwestern Gondwana. – International Geology Reviews, **54**: 1918-1943.

González-Guzmán R. (2016): Estudio petrogenético del basamento cristalino de la porción sureste del Macizo de Chiapas: Implicaciones tectónicas del Bloque Maya Sur. – Ph.D. thesis, División de Ciencias de la Tierra, Centro de Investigación Científica y de Estudios Superiores de Ensenada, Ensenada, B.C.

Pettijohn, F. J., Potter, P. E., Siever, R. (1987): Introduction and source materials. – Sand and sandstone, Springer, New York, N.Y.

Ramírez-Fernández J.A., Alemán-Gallardo, E.A., Cruz-Castillo, D., Velasco-Tapia, F., Jenchen, U., Becchio, R., De León-Barragán, L., Casas-Peña, J.M. (2021): Early Mississippian precollisional, peri-Gondwanan volcanic arc in NE-Mexico: Aserradero Rhyolite from Ciudad Victoria, Tamaulipas. – International Journal of Earth Sciences, **110**: 2435-2463. https://doi.org/10.1007/s00531-021-01992-3

Rosales-Lagarde, L., Centeno-García, E., Dostal, J., Sour-Tovar, F., Ochoa- Camarillo, H., Quiroz-Barroso, S. (2005): The Tuzancoa Formation: Evidence of an Early Permian Submarine Continental Arc in East-Central Mexico. – International Geology Review, **47**: 901-919. https://doi.org/0020-6814/05/822/901-19

Taylor, S.R., McLennan, S.M. (1985): The Continental Crust: Its Composition and Evolution. – Blackwell Scientific Publications, London, U.K.

Torres-Sánchez, S.A., Augustsson, C., Barboza-Gudiño. J.R., Jenchen, U., Ramírez-Fernández, J.A., Abratis, M., Schersten, A. (2015): Magmatic source and metamorphic grade of metavolcanic rocks from the Granjeno Schist: was northeastern Mexico a part of Pangaea? – Geological Journal, **51**: 845-863. https://doi.org/10.1002/gj.2702