GEOTHERMOMETRY OF GRAPHITIC MATERIAL IN METASEDIMENTARY ROCKS OF THE SIERRA MADRE ORIENTAL, NE MEXICO: REVEALING THE LAST STAGES OF PANGEA

UASLP Universidad Autónoma de San Luis Potosí | FACULTAD DE INGENIERÍA

Torres Sánchez, Sonia Alejandra[1], Castillo Hernández, Oscar Emmanuel[1], Augustsson, Carita[2]

1) Universidad Autónoma de San Luis Potosí, Facultad de Ingenieria, San Luis Potosí, México
2) Institutt for Petroleumsteknologi,Universitetet i Stavanger, Norway

Correspon. author Sonia Alejandra Torres Sánchez sonia.torres@uaslp.mx

1) Introduction

The Sierra Madre Oriental is a long range that resulted from the deformation of Mesozoic rocks and its basement complex. Both were uplifted, shortened and transported northeastward forming a fold and thrust belt during the Laramide orogeny. Vestiges of the Mexican Paleozoic continental configuration are present in the metamorphic basement of the Sierra Madre Oriental, in northeastern Mexico. This basement unit crops out in eroded cores of laramidic structures as the Huizachal-Peregrina Anticlinorium (Novillo, Peregrina and Caballeros Canyons), Miquihuana and Bustamante Uplifts in Tamaulipas and in the Aramberri Uplift in Nuevo Leon (Fig.1). The unit known as Granjeno Schist comprises intercalations of metamorphic rocks with both sedimentary (psammite, pelite, turbidite, conglomerate, marble, black shale) and volcanic (tuff, lava flows, pillow lava and ultramafic bodies) protoliths (Torres Sánchez et al., 2016).

Several studies have discussed the provenance and metamorphism of the Granjeno Schist, but no data concernig the graphitization degree have been studied.

Organic matter preserved in the sedimentary rocks can be transformed into crystalline graphite due to metamorphism, process known as graphitization. (Bonijoly et al., 1982; Wopenka and Pasteris, 1993; Beyssac et al., 2002, 2003; Buseck and Beyssac, 2014). It is generally accepted that the degree of graphite crystallinity, or its structural order, it is determined mainly by the maximum temperature conditions experienced by the host rocks, whereas lithostatic pressure and shear strain are considered to have only minor influence on graphitization (Bonijoly et al., 1982; Wopenka and Pasteris, 1993; Bustin et al., 1995). Therefore, graphite crystallinity has been calibrated as an indicator of the peak temperatures reached during progressive metamorphism (Beyssac et al., 2002; Reitmeijer and McKinnon, 1985)

With the application of fieldwork, petrographic and Raman spectroscopy techniques, this work aims to understand the highest metamorphic degree that ocurred during the evolution of the Granjeno Schist. This can provide a better control on the conditions of the tectonic processes related with Pangea amalgamation.

The importance of this kind of studies it is that they are founded on descriptive and analytical analysis which allow to understand the geological process that took place in the ancient Earth. Honouring James Hutton, we aim to reveal geological past process throught the understanding of actual natural phenomena.

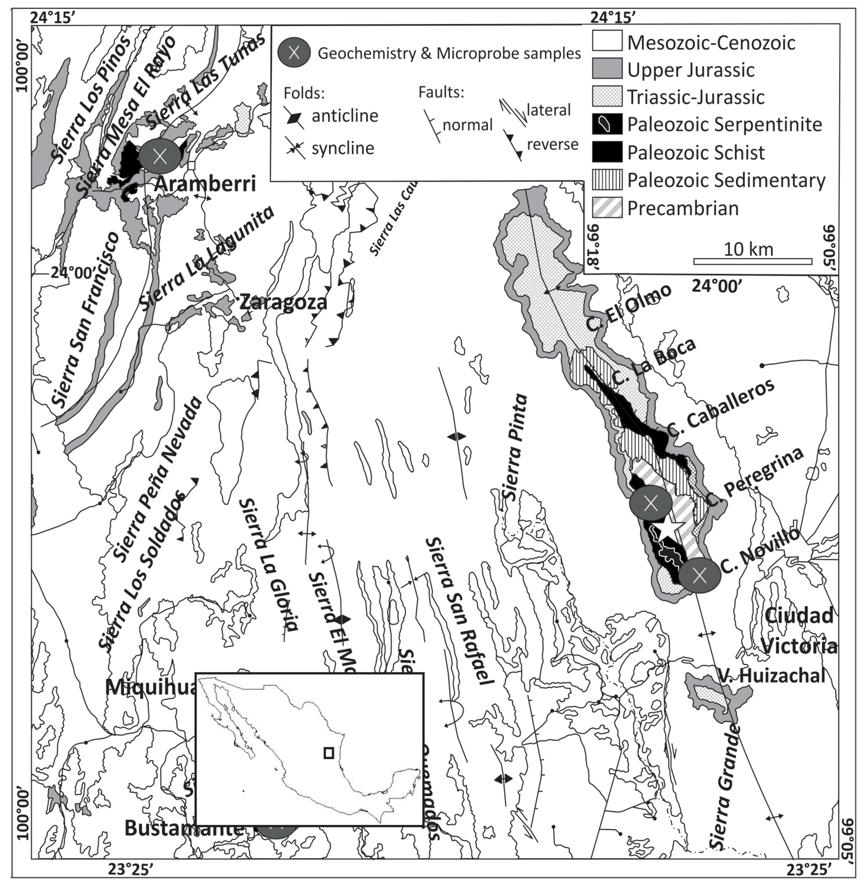

Fig.1 Study area and geological map of the Sierra Madre Oriental, Nuevo León and Tamaulipas states (after Barboza et al., 2010)

2) Macroscopic and petrographic composition

The graphitic schist consists of fine-grained, homogeneous, grayish to black layers (2 to 5 m thickness) with NW-SE-trending foliation (Fig. 2a) and crenulation structures (Figs. 2b and c). Quartz veins are commonly observed also intruding parallel to the bedding, forming isoclinal folds. The graphitic schist is stratigraphically interlayered with pelitic and psammitic schist (Fig. 2c).

The graphitic schist it is mainly composed of the metamorphic minerals white mica, chlorite, quartz, feldspar, graphite and accesory minerals as tourmaline and circon (Figs. 3a-d). The rocks have lepidoblastic texture with micaceous, graphitic and quartz-plagioclase (0.1 to 0.5 mm) sectors (Fig. 3a). It is also recognized porphyrolepidoblastic and lepidoporphyroblastic textures where the porphyroblasts consists of subhedral to euhedral albite (1 mm) commonly surrounded by acicular muscovite, chlorite, graphite, and sutured quartz bands (Fig. 3b).The feldspar porphyroblasts contain graphitic inclusions defining a foliation that is oblique to the dominant metamorphic foliation (Fig. 3b). Folds of the graphitic foliation are preserved locally in the feldspar porphyroblasts. Graphitic rocks develop crenulation cleavage indicating refolding of the main foliation (Fig. 3d).

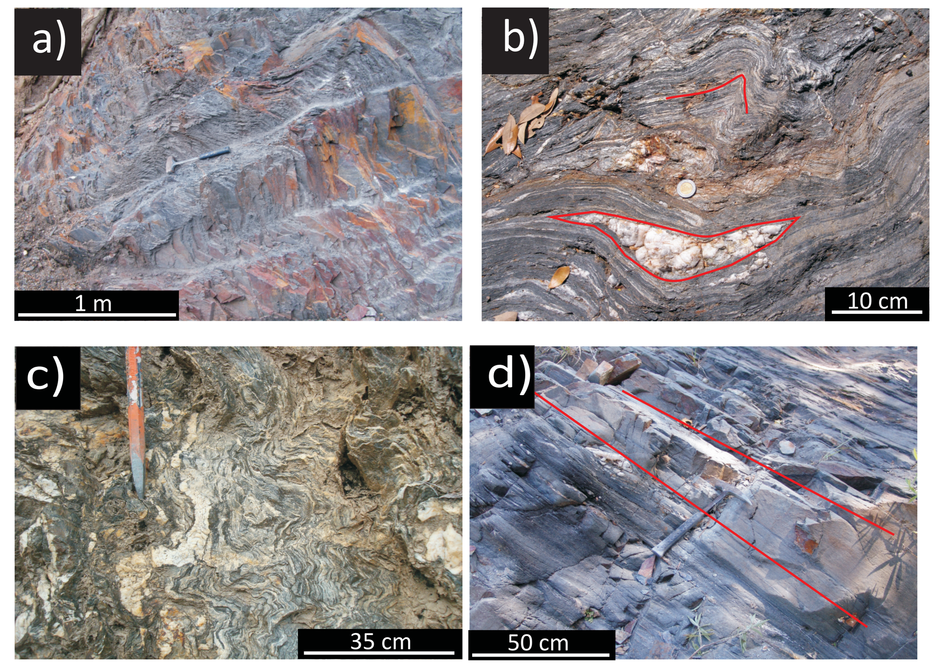

Fig. 2 a) Graphitic schist, b) quartz veins and crenulations structures in the graphitic schist, c) folded foliation in graphitic schist. d) graphitic schist interbedded with psammitic schist,

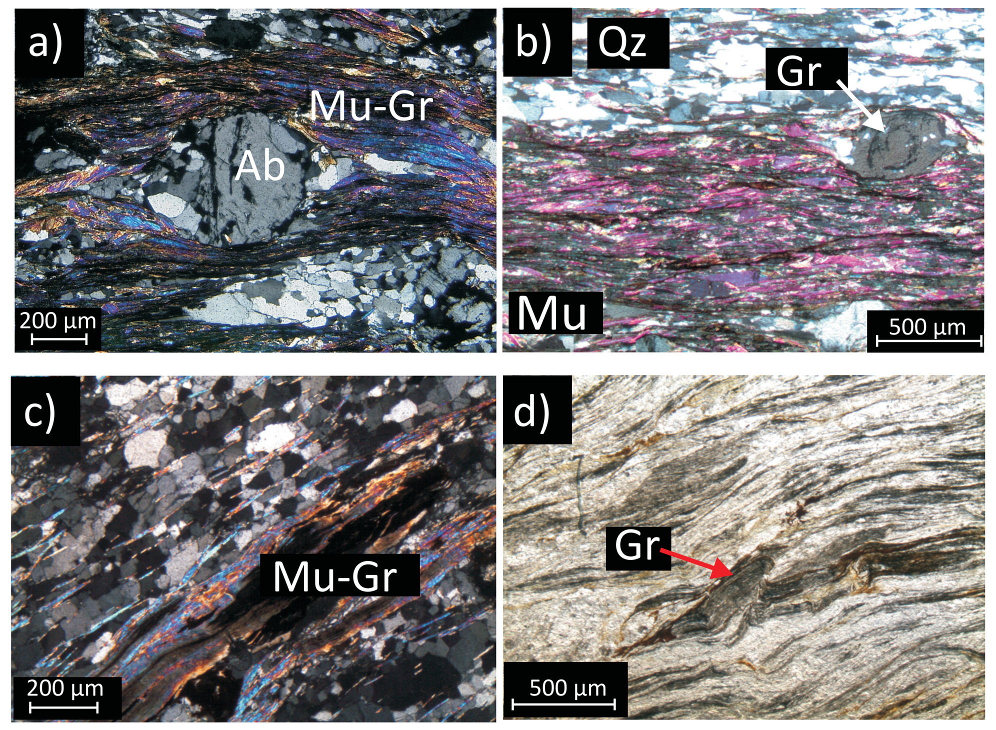

Fig. 3 a) Lepidoblastic texture with muscovite, graphite, quartz and plagioclase mineral phases, b) porphyrolepidoblastic with albite porphydoblast, c) lepidoblastic texture with quartz bands and graphite, d) graphite with crenulation cleavage.

3) Raman spectroscopy

Raman spectra of graphite were measured by an Thermo Scientific DXR (FSU Jena, Germany) with a 532 nm laser. The laser (2.0 mW) was focused on the samples with a 20× objective. The scattered light was dispersed with a 900 g mm- 1 grating. The combination of the 20× objective and 532 nm laser wavelength produced a laser spot size of approximately 1.3 μm in diameter. The spectra were calibrated using the Raman band from a silicon wafer prior to each set of measurements. For each spectrum, the area ratio was calculated ($R2 = A_{D1}/(A_G + A_{D1} + A_{D2})$, where A is the area of the peak, G band is the main high-frequency band of graphite, and D1 and D2 bands are defect bands observed in the first-order Raman spectrum of graphite) (Wopenka and Pasteris, 1993; Beyssac et al.,2002).

All the acquired spectra show typical G, D1 and D2 bands, respectively at 1580, 1350 and 1620 cm-1

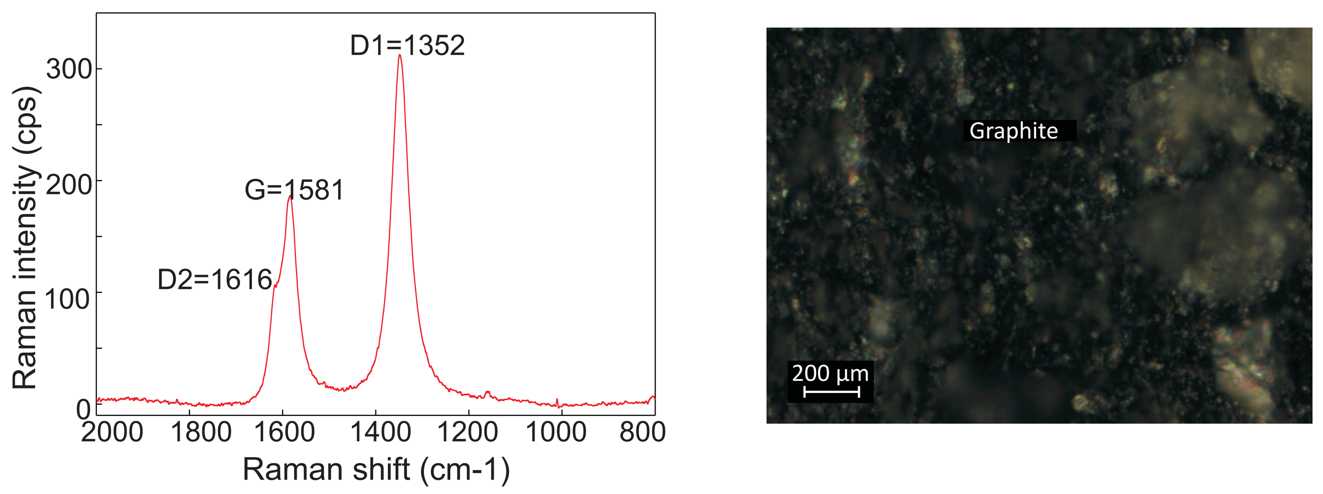

Fig. 4 Raman spectra and example of the graphite analyzed sample from the Granjeno schist

4) Metamorphism

Mineralogical assemblages of the graphitic rocks represents the lowest part of greenschist facies (Chl+Ab+Mu+Phg+Gr+Qz±Tu±Zr). The chlorite geothermometer and the presence of phengite in the metasedimentary, units as well as $^{40}Ar/^{39}Ar$ ages on metavolcanic and metaultramafic rocks indicate that the Granjeno Schist was metamorphosed under sub-greenschist to greenschist facies with temperatures ranging from 250-345°C with 2.5 kbar during Carboniferous time (330±30 Ma; Torres et al., 2016). Low I_D/I_G ratio vales of 0.54 to 2.30 are according to low grade metamorphism. According with quantitative empirical metamorphic thermometer using Raman spectroscopy data, the graphitization temperature ranges from 320°C to 430 °C

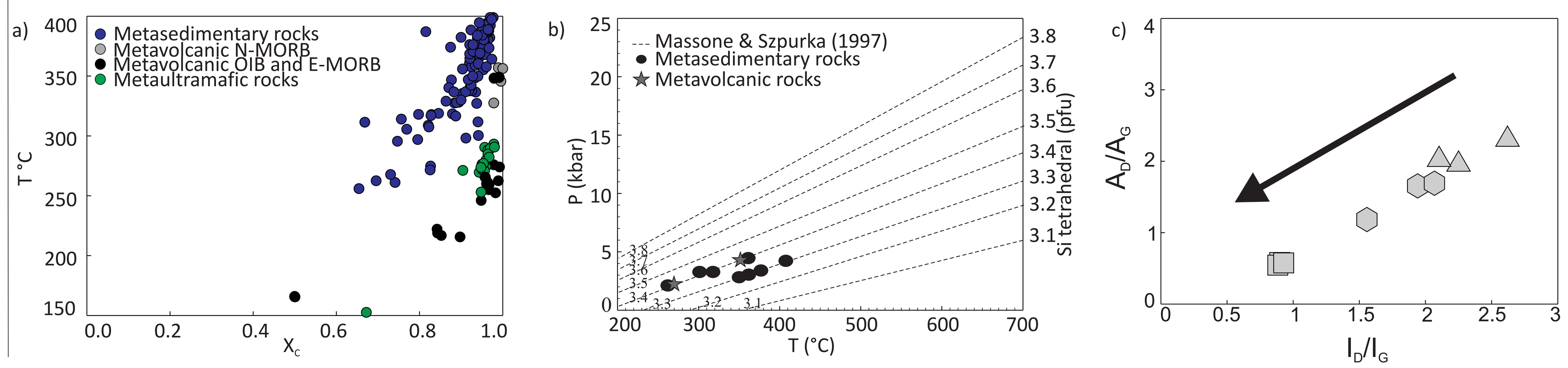

Fig. 5 a) T °C vs X_c (chlorite content) based on Cathelineau, 1988 (Torres Sánchez 2015), b) Phengite P-T diagram with Si pfu isoplets based on Massonne & Szpurka, 1997 (Torres Sánchez 2015), c) Comparison of I_D/I_G vs A_D/A_G intensities ratios of the Raman peaks based on Marshall et al., 2012

5) Conclusions

The graphitic rocks in the Granjeno Schist are pervasive throughout the whole unit, indicating a carbon-rich depositional environment in which a significant organic material was preserved. This environment could be related with the peripheria of southwest Gondwana and the deposition of the carbon rich material took place prior to the Granjeno Schist metamorphism. Lithospheric mantle slivers juxtaposed during the metamorphism of the Granjeno Schist, this is suggested by tectonic contact of the serpentinite lenses with the metavolcanic and metasedimentary rocks. The metamorphism of the Granjeno Schist represents the latest tectonics events during the closure of the Rheic Ocean and along the paleo-Pacific margin after the closure of Pangea.

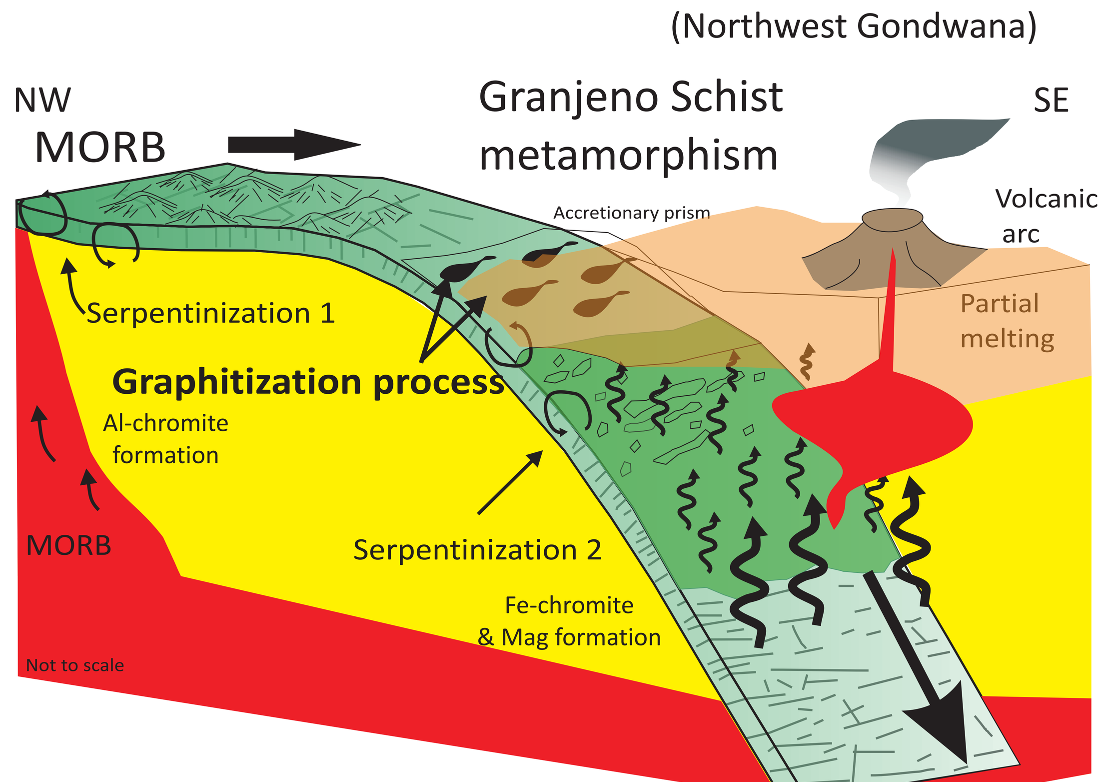

Fig. 5 Subduction model for the Granjeno Schist metamorphism during Pennsylvanian to Permian time (modified from Deschamps et al., 2013 and Torres Sánchez et al., 2017). MORB: mid-ocean ridge, Mag: magnetite.

References & Acknowledgements

Beyssac, O., Goffé, B., Chopin, C., & Rouzaud, J. N. (2002). Raman spectra of carbonaceous material in metasediments: a new geothermometer. Journal of metamorphic Geology, 20(9), 859-871.

Beyssac, O., Goffé, B., Petitet, J. P., Froigneux, E., Moreau, M., & Rouzaud, J. N. (2003). On the characterization of disordered and heterogeneous carbonaceous materials by Raman spectroscopy. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 59(10), 2267-2276.

Bonijoly, M., Oberlin, M., & Oberlin, A. (1982). A possible mechanism for natural graphite formation. International Journal of Coal Geology, 1(4), 283-312.

Buseck, P. R., & Beyssac, O. (2014). From organic matter to graphite: Graphitization. Elements, 10(6), 421-426.

Bustin, R. M., Ross, J. V., & Rouzaud, J. N. (1995). Mechanisms of graphite formation from kerogen: experimental evidence. International Journal of Coal Geology, 28(1), 1-36.

Cathelineau, M. (1988). Cation site occupancy in chlorites and illites as function of temperature. Clay minerals, 23(4), 471-85.

Deschamps, F., Godard, M., Guillot, S., & Hattori, K. (2013). Geochemistry of subduction zone serpentinites: A review. Lithos, 178, 96-127.

Marshall, A. O., Emry, J. R., & Marshall, C. P. (2012). Multiple generations of carbon in the Apex chert and implications for preservation of microfossils. Astrobiology, 12(2), 160-166.

Massonne, H. J., & Szpurka, Z. (1997). Thermodynamic properties of white micas on the basis of high-pressure experiments in the systems K2O MgO Al2O3 SiO2 H2O and K2O FeO Al3O3 SiO2 H3O. Lithos, 41(1-3), 229-250.

Rietmeijer, F. J., Mackinnon, I. D. (1985). Poorly graphitized carbon as a new cosmothermometer for primitive extraterrestrial materials. Nature, 315(6022), 733.

Torres-Sánchez, S. A., Augustsson, C., Jenchen, U., Barboza-Gudiño, J. R., Gallardo, E. A., Fernández, J. A. R., ... & Abratis, M. (2017). Petrology and geochemistry of meta-ultramafic rocks in the Paleozoic Granjeno Schist, northeastern Mexico: Remnants of Pangaea ocean floor. Open Geosciences, 9(1), 361-384.

Torres Sánchez, S.A., (2015). Implicaciones Geodinámicas Del Complejo Metamórfico Paleozoico De La Sierra Madre Oriental En El Noreste De México. Tesis Doctoral, UANL, FCT, México.

Torres Sánchez, S. A., Augustsson, C., Barboza Gudiño, J. R., Jenchen, U., Ramírez Fernández, J. A., Abratis, M., & Scherstén, A. (2016). Magmatic source and metamorphic grade of metavolcanic rocks from the Granjeno Schist: was northeastern Mexico a part of Pangaea?. Geological Journal, 51(6), 845-863.

Wopenka, B., & Pasteris, J. D. (1993). Structural characterization of kerogens to granulite-facies graphite; applicability of Raman microprobe spectroscopy. American mineralogist, 78(5-6), 533-557.

We would like to thank to ConacyT for a research stay at the Institute of Geosciences, Friedrich-Schiller University Jena, Germany, "Becas Mixtas 2012- 2013 Movilidad en el extranjero" (scholarship number 239341) and DAAD for the "Research Grant for Doctoral Candidates and Young Academics and Scientists 2013-2015" (scholarship number 57076385).