Pressure-temperature-time evolution of high-pressure rocks of the Acatlán Complex (southern Mexico): Implications for the evolution of the Iapetus and Rheic Oceans: Reply

Ricardo Vega-Granillo[1,†], Oscar Talavera-Mendoza[2], Diana Meza-Figueroa[1], Joaquin Ruiz[3], Margarita López-Martínez[4], and George E. Gehrels[3]

[1]*Departamento de Geología, Universidad de Sonora, Rosales y Encinas S/N, Hermosillo, Sonora 83000, México*

[2]*Unidad Académica de Ciencias de la Tierra, Universidad Autónoma de Guerrero, A.P. 197, Taxco, Guerrero 40200, México*

[3]*Department of Geosciences, University of Arizona, Tucson, Arizona 85721, USA*

[4]*Departamento de Geología, Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE), Km 107 Carr, Tijuana-Ensenada, Ensenada, Baja California, México*

We thank Keppie et al. (2008) for their comment that allows us to expand the discussion on the geology and metamorphic evolution of the Acatlán Complex of southern Mexico. In our paper (Vega-Granillo et al., 2007), we provide geologic, petrologic, thermobarometric, and geochronologic evidence of three distinctive high-pressure (HP) metamorphic events of Early Ordovician, Late Ordovician–Silurian, and Silurian ages overprinting the Acatlán Complex; these events affect three different lithological suites, under contrasting pressure-temperature (P-T) conditions. This new concept differs from the classical idea proposed by Ortega-Gutiérrez (1978), who considered a single HP metamorphic event in the Acatlán Complex affecting diverse lithologies; this concept is endorsed by Keppie et al. (2008). The comment by Keppie et al. (2008) is basically focused on geochronologic data and disregards other critical evidence such as field relationships and petrologic or thermobarometric constraints, which support our interpretations. Keppie et al. (2008), following the stratigraphic scheme of Ortega-Gutiérrez et al. (1999), merge the Xayacatlán and Esperanza granitoids units into the Piaxtla Group just based on the HP overprinting metamorphism. Consequently, they regard it as unnecessary to specify which unit they are referring to—determined age or geologic relationship; therefore, they ambiguously mention to the lithological units or events overprinting them by their geographic location. However, Talavera-Mendoza et al. (2005) indicate that the Piaxtla Group is actually composed of four genetically unrelated units (Xayacatlán, Ixcamilpa, Esperanza, and Tecolapa), proving artificial the merger as a single group. In the following sections, we answer each aspect discussed by Keppie et al. (2008) in their comment.

ONE OR THREE HP METAMORPHIC EVENTS IN THE ACATLÁN COMPLEX?

Three distinct HP metamorphic events are defined in the Acatlán Complex by field relationships and petrologic and thermobarometric determinations along with U-Pb and $^{40}Ar/^{39}Ar$ geochronologic data. In the Olinalá area, in southern Acatlán, lower P (~350–450 °C; ~3–5 kbar) metabasites of the El Rodeo suite are thrust over medium-temperature (~490–610 °C; ~12–13 kbar) eclogitic rocks of the Xayacatlán suite. The contrasting P-T conditions indicate metamorphism in both suites occurred before their tectonic juxtaposition. The thrust fault is intruded by granites of 476 ± 8 Ma (U-Pb, zircon; Talavera-Mendoza et al., 2005). In the same area, eclogitic rocks of the Xayacatlán suite are intruded by post-eclogitic leucogranites of 478–471 Ma (U-Pb, zircon; Talavera-Mendoza et al., 2005). The same relationship occurs at Mimilulco and Piaxtla, where granites of 461 ± 9 Ma and 474 ± 16 Ma (U-Pb, zircon; Talavera-Mendoza et al., 2005) intrude Xayacatlán eclogitic rocks. None of the intruding granites bear evidence of HP metamorphism, but they do show evidence of local dynamic metamorphism under greenschist- to amphibolite-facies conditions (Vega-Granillo, 2006). At Mimilulco, the Middle Ordovician leucogranite transects the eclogitic foliation and engulfs xenoliths of Xayacatlán eclogitic rocks (Fig. 1A). This geologic and geochronologic evidence indicates that eclogitic metamorphism in the Xayacatlán suite occurred before leucogranite intrusion ~478–461 Ma.

The youngest detrital zircon cluster in blueschists (200–390 °C; 6–9 kbar) (Vega-Granillo et al., 2007) of the Ixcamilpa suite has a peak of ca. 477 Ma (U-Pb, zircon; Talavera-Mendoza et al., 2005) indicating a maximum Early Ordovician depositional age. As indicated above, the age of eclogitic metamorphism in the Xayacatlán suite predates that age. Accordingly, the eclogite metamorphism of Xayacatlán and the blueschist metamorphism of Ixcamilpa are unrelated. In our paper, we clearly stated that the ages for deposition and blueschist metamorphism in Ixcamilpa are bracketed between ca. 477 Ma, the age of the youngest detrital zircon cluster, and the 323 ± 6 Ma $^{40}Ar/^{39}Ar$ age yielded by phengite of that suite. However, we indicate that the absence of detrital zircons of Silurian and Devonian age would suggest a Late Ordovician depositional age. As correctly argued by Keppie et al. (2008), the absence of such zircons can be due to other factors than an undeveloped source. A depositional age for the Ixcamilpa suite younger than Late Ordovician is therefore feasible. However, the younger depositional age reinforces our conclusion that rocks of the Ixcamilpa suite are unrelated to those of the Xayacatlán suite, and that HP events affecting both suites must occur at different times.

The Esperanza granitoids in central Acatlán yield 442–440 Ma ages (U-Pb, zircon; Ortega-Gutiérrez et al., 1999; Talavera-Mendoza et al., 2005; Vega-Granillo et al., 2007), and consequently, they are younger than eclogitic metamorphism of the Xayacatlán suite (<478 Ma). Esperanza typical granitoids intrude a sedimentary sequence whose deposit age cannot be better constrained than 719–440 Ma (Vega-Granillo et al., 2007). Granites and sediments are intruded by mafic dikes of unknown age. Then,

[†]E-mail: rvega@ciencias.uson.mx

GSA Bulletin; September/October 2009; v. 121; no. 9/10; p. 1460–1464; doi: 10.1130/B26514.1; 1 figure.

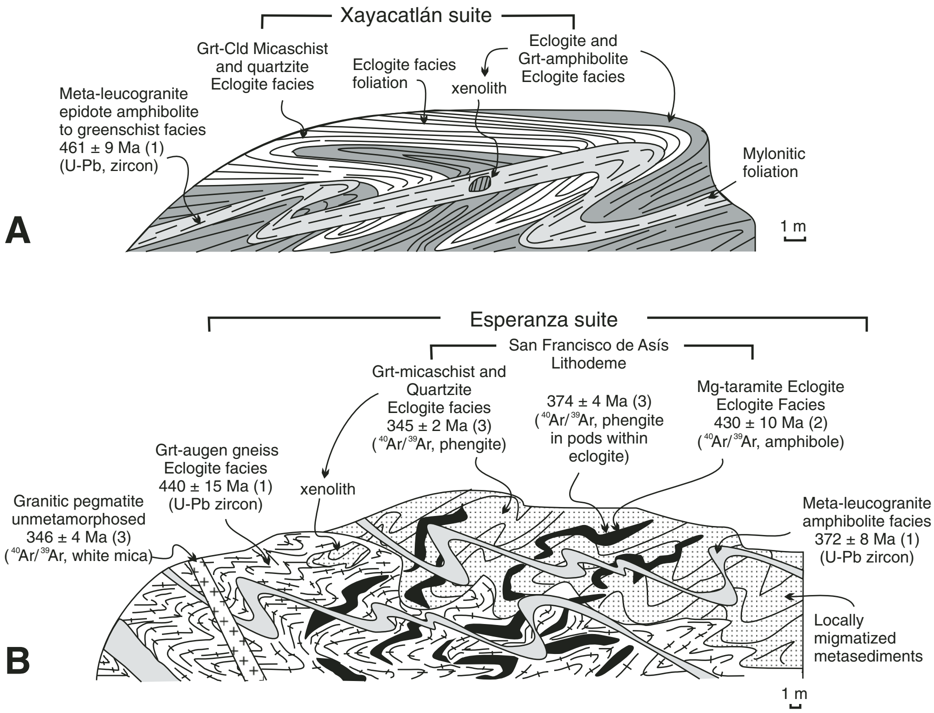

Figure 1. (A) Cartoon displaying the geologic relationships in the Xayacatlán Suite. (1) Interpreted as magmatic age (Talavera-Mendoza et al., 2005); Grt—garnet, Cld—chloritoid. (B) Cartoon displaying the geologic relationships in the Esperanza suite. (1) Interpreted as magmatic ages; (2) interpreted as the eclogite-facies metamorphism age; (3) interpreted as cooling ages (all ages in (B) from Vega-Granillo et al., 2007).

granites, sediments, and mafic dikes underwent a high-temperature (~730–830 °C; 15–17 kbar) eclogite-facies metamorphism (Vega-Granillo et al., 2007), which transformed these rocks into high-grade gneisses, quartz-feldspar schists, quartzites, garnet mica schists, and eclogites. These lithologies make up the Esperanza suite. Subsequently, the Esperanza suite rocks were intruded by post-eclogitic muscovite leucogranite (Fig. 1B) yielding a crystallization age of 372 ± 8 Ma (U-Pb zircon; Vega-Granillo et al., 2007). Accordingly, the age of the HP metamorphism in the Esperanza rocks is restricted by the Lower Silurian 442–440 Ma crystallization age of the Esperanza granitoids and the Late Devonian 372 ± 8 Ma age of post-eclogitic leucogranite. As a consequence, eclogitic metamorphism in the Esperanza suite cannot be related to the Early Ordovician eclogitic metamorphism of the Xayacatlán rocks. On the other hand, in the Ixcamilpa suite, the lithology and geologic setting have an oceanic affinity, in contrast to those of the Esperanza suite, which are continental (De la Cruz-Vargas, 2004; Murphy et al., 2006). Furthermore, the detrital zircon age plot of the Ixcamilpa suite has a pattern clearly different from those of the Xayacatlán and Esperanza suites (Talavera-Mendoza et al., 2005, 2006; Murphy et al., 2006; Vega-Granillo et al., 2007), suggesting they were deposited in different basins. Additionally, the obtained P-T path for the Ixcamilpa suite corresponds to simple subduction, whereas the P-T path for the Esperanza suite corresponds to continental collision (Vega-Granillo et al., 2007). Therefore, the blueschist event in the Ixcamilpa suite and the eclogitic event in the Esperanza suite cannot be the same whether or not they could be coeval.

Keppie et al. (2008) propose a single HP metamorphic event of Mississippian age based on a single concordant, U-Pb age of 346 ± 3 Ma 98 (Middleton et al., 2007) obtained from zircon overgrowths in eclogite. They mention U-Pb zircon ages from decompression migmatites yielding similar ages (~347–330 Ma) (Middleton et al., 2007) and a phengite age yielding a $^{40}Ar/^{39}Ar$ plateau of 351 ± 2 Ma interpreted as the cooling through ~350 °C (Murphy et al., 2006). They do not find evidence of older thermal events. Even though all ages cited by Keppie et al. (2008) were obtained in the San Francisco de Asis area (part of our Esperanza suite) in the central region, they interpreted these ages as dating the HP metamorphism in the whole Acatlán Complex (Xayacatlán, Ixcamilpa, and Esperanza) regardless of the differences indicated previously.

The proposal of a single HP metamorphic event of Mississippian age affecting all HP suites of Acatlán requires substantiation. It is well known that in the Patlanoaya region, in central Acatlán, both HP and low-pressure (LP) metamorphic rocks are overlain by a sedimentary unit named the Patlanoaya Formation, which contains fossils of Late Devonian (Famennian, 374.5–359.2 Ma according to Gradstein et al., 2004) to Early Permian (Guadalupian) age (Brunner, 1987; Vachard et al., 2000; Vachard and Flores de Dios, 2002). Near the base of the Patlanoaya Formation there are more than 50 m of basal conglomerate, and there is no evidence of tectonic shearing affecting the contact. The oldest fossils are mostly older than the age proposed by Keppie et al. (2008) for their HP metamorphic event in the Acatlán (~353–341 Ma). According to our thermobarometric data, HP metamorphism in the central band of Acatlán (Esperanza suite) occurred at ~15–17 kbar corresponding to ~50–60 km depth (Vega-Granillo et al., 2007). Evidently, deposition of the Late Devonian and Lower Mississippian Patlanoaya beds and eclogitic metamorphism cannot occur simultaneously. Patlanoaya strata partially overlying the HP rocks necessarily imply their previous exhumation; consequently, the HP metamorphism in central Acatlán must have occurred before Late Devonian. In our view, the ages of post-eclogitic leucogranite 372 ± 8 Ma (U-Pb zircon; Vega-Granillo et al., 2007), leucocratic pods in eclogite 374 ± 2 Ma (Ar-Ar phengite; Vega-Granillo et al., 2007), as well as the dates of zircon overgrowths in eclogite obtained by Middleton et al. (2007), date the migmatization event succeeding the eclogitic event not the eclogitic event itself.

GEOCHRONOLOGY

Keppie et al. (2008) challenge some of our $^{40}Ar/^{39}Ar$ ages, particularly those yielding older ages than their own. Amphibole in eclogite from the Esperanza suite yields an isochron age of 430 ± 5 Ma, which we regard as the age of the eclogitic metamorphism in that suite. In the first instance, amphibole older age can be explained by its higher closure temperature in relation to the white mica (e.g., Geyh and Schleicher, 1990). Keppie et al. (2008) argue that the isochron of the eclogite (sample RAC-201) includes points that force the correlation line and that the high-temperature fraction in one of the experiments yielding an age of 526 ± 12 Ma is evidence of excess argon and that, consequently, the plateau age obtained with the other fractions is invalid. However, the difference observed on the amphibole age spectra is an artifact of the heating schedule, because the diagram concentrates results from two different techniques (Fig. 8F in Vega-Granillo et al., 2007). A six-step experiment conducted on the multigrain sample heated with the Ta-furnace gave an integrated age of 438.7 ± 6 Ma defined by four fractions representing up to 90% of released ^{39}Ar. Other two-step results obtained through a single-grain, laser fusion experiment yielded an integrated age of ~419 ± 5 Ma. A third, three-step, single-grain, laser fusion experiment gave two plateaus of ~418 ± 4 and ~315 ± 4 Ma, suggesting the possibility of two thermal events. All but the first fraction of each experiment were combined to define the isochron age of 430 ± 5 Ma, with $(^{40}Ar/^{36}Ar)_i$ = 332 ± 20, which is our best age estimate for the amphibole (complete argon results are in the GSA Data Repository of Vega-Granillo et al., 2007). This age is concordant within uncertainty with a 418 ± 18 Ma, U-Pb monazite age obtained by Ortega-Gutiérrez et al. (1999) from the Esperanza gneiss regarded as recording the eclogitic metamorphism.

Large (~2 cm) phengite crystals are conspicuous in some eclogites from Santa Cruz Organal, where they crystallize into 6- to 10-cm-wide veins and pods. Two experiments on that phengite yielded identical and simple $^{40}Ar/^{39}Ar$ spectra with an integrated age of 374 ± 2 Ma. That age is in agreement with the Late Devonian 372 ± 8 Ma age (U-Pb zircon; Vega-Granillo et al., 2007) of leucogranite transecting the eclogitic body. Keppie et al. (2008) suggest that this age may imply excess argon because other of our and their $^{40}Ar/^{39}Ar$ ages of phengites yielded younger ages. However, $^{40}Ar/^{39}Ar$ spectra are very simple and do not show evidence of excess argon (some detailed notes on the Ar geochronology are included in the GSA Data Repository).

The Esperanza suite and the Late Devonian leucogranite are transected by an undeformed and unmetamorphosed granitic pegmatite. The large (>2 cm) white mica crystals from this pegmatite yielded a $^{40}Ar/^{39}Ar$ isochron age of 346 ± 4 Ma (Early Mississippian). The isochron age was calculated with 35 combined fractions of three laser step-heating experiments and one bulk sample analysis. That age is also challenged by Keppie et al. (2008), who adduce excess argon. However, we do not find evidence of excess argon in the correlation diagram from that pegmatite; sample RAC-188 (GSA Data Repository of Vega-Granillo et al., 2007).

Excess argon has been interpreted in amphiboles and phengites from some HP terrains yielding anomalously older ages, whereas independent evidence (geologic and/or geochronologic) proves a younger age of metamorphism (e.g., Arnaud and Kelley, 1995; El-Shazly et al., 2001). With the evidence presented by Keppie et al. (2008), such a process in the Acatlán Complex remains tentative. Scaillet (1998) stated that excess argon is not an ineluctable feature of HP–ultrahigh-pressure (UHP) metamorphism, and that in some cases the interpretation of excess argon can prevent alternative geologic interpretations. Furthermore, factors other than excess argon have been proposed to explain geologically meaningful older $^{40}Ar/^{39}Ar$ ages in metamorphic HP minerals (Maurel et al., 2003). For example, some rocks, blocks, or parts of a sequence, can avoid Ar resetting when the lack of penetrative deformation reduces hydrothermal circulation and diminishes diffusion in minerals. Another possible reason to preserve older ages can be the grain size (Maurel et al., 2003). The Ar is released from minerals through diffusion, and diffusion is easier and more complete in smaller size grains than in larger grains. Thus, the 2-cm crystals of phengite yielding the Late Devonian (374 ± 2 Ma) age could retain that older age because of their size without excess Ar being involved.

SOME IMPORTANT REMARKS

In their comment, Keppie et al. (2008) misinterpreted some of our statements. They mentioned for example that evidence of an Ordovician–Silurian HP metamorphism in Santa Cruz Organal remains tentative. In our work, we do not propose such an age for the HP metamorphism in that locality. In this zone we proposed a Silurian (~430–418 Ma) age for the HP metamorphism imposed only over the Esperanza suite. However, a pre–478 Ma age for the eclogitic metamorphism is proposed for the Xayacatlán suite, in western Acatlán.

Keppie et al. (2008) also mentioned that we proposed an orogenic tectonic setting for the Esperanza granitoids. The geochemistry of the Esperanza granitoids is out of the scope of our paper, and we do not assign the Esperanza granitoids to a particular tectonic setting. In fact, we do not regard the mafic dikes of the Esperanza suite (San Francisco de Asis lithodeme) of Ordovician age as suggested by Keppie et al. (2008), because they transect the Lower Silurian Esperanza gneiss of 440 ± 15 Ma (Vega-Granillo et al., 2007), and consequently must be younger.

Finally, Keppie et al. (2008) indicate that we interpreted the Esperanza granitoids as decompression melts following HP metamorphism. The Esperanza granitoids unit as originally defined by Ortega-Gutiérrez (1978) is actually composed of four distinct and unrelated plutonic suites (Talavera-Mendoza et al., 2005): (1) a 1165–1043 Ma plutonic suite referred to as the Tecolapa suite; (2) a 478–461 Ma magmatism postdating eclogitic metamorphism in the Xayacatlán suite; (3) a 442–441 Ma plutonic suite forming part of the Esperanza suite (as defined in Vega-Granillo et al., 2007) in central Acatlán; and (4) a ca. 371 Ma (Yañez et al., 1991; Vega-Granillo et al., 2007) magmatism that includes the La Noria pluton and leucogranites intruding the Esperanza suite in central Acatlán. The 478–461 Ma rocks intrude exclusively the Xayacatlán suite, postdating its eclogitic metamorphism. Only the Late Devonian leucogranite intruding the eclogitic rocks of the Esperanza suite is regarded by us as decompression melts. We did not find evidence of Lower Silurian granitoids intruding the Xayacatlán suite, and we never considered the Lower Silurian granitoids in the central band as decompression melts as suggested by Keppie et al. (2008).

TECTONIC MODEL

Arguing the existence of a single HP metamorphic event of Mississippian age based on a few U/Pb and $^{40}Ar/^{39}Ar$ ages and some paleomagnetic data, Keppie et al. (2008) confront our tectonic model. In a previous section we demonstrated that the development of a HP metamorphism of Mississippian age synchronously with sedimentation of Patlanoaya strata over the same HP rocks is simply untenable. Moreover, a single HP metamorphism cannot explain the field relationships of HP rocks and associated plutonic rocks, as well as petrologic and thermobarometric differences presented in our paper (Vega-Granillo et al., 2007), information that was neglected in the Keppie et al. (2008) comment.

Paleomagnetic studies in the Acatlán Complex have produced contrasting results and varied models (e.g., Fang et al., 1989; Böhnel, 1999; Alva-Valdivia et al., 2002). Quantification of the displacement critically depends upon the ages of the magnetizations and resolutions of the structural attitudes. The Acatlán Complex is polydeformed with some lithologies experiencing two or three phases of isoclinal folding (Vega-Granillo, 2006). Except for some work on microtectonics of small areas (e.g., Weber et al. 1997; Malone et al., 2002), the nature, kinematics, and age of the deformation in Acatlán is just beginning to be studied in detail. Even the Permian beds overlying the Acatlán Complex are folded and locally dynamically metamorphosed (Vega-Granillo, 2006). Based on Alva-Valdivia et al. (2002), Keppie et al. (2008) argue that paleomagnetic data for Permian rocks indicate a latitudinal position relative to North America similar to its present location, contradicting our paleogeographic model for that time. However, Alva-Valdivia et al. (2002) recognized that "… our dataset is not sufficiently robust to enable constraints about the tectonic evolution of the studied area." Furthermore, the most accepted paleogeographic reconstructions of Pangea during the Permian place South America overlapping most of southern Mexico, implying an allochtonous origin for terranes of that region (Pindell and Dewey, 1982; Pindell, 1985, 1994; Handschy et al., 1987; Pindell and Kennan, 2001). In their study on the Acatlán area, Fang et al. (1989) mention evidence of displacement of the Acatlán terrane relative to North America but point out that the ages of the magnetizations and resolutions of the structural attitudes are not well constrained. Thus, from our point of view, Keppie et al. (2008) do not provide robust geochronologic or paleomagnetic evidence to dismiss our tectonic model for the Acatlán Complex.

CONCLUDING REMARKS

Deciphering the tectonic evolution of polymetamorphosed orogens such as the Acatlán Complex using exclusively a geochronologic approach can lead to an overinterpretation of the ages. The ages must be consistent with other lines of evidence such as geologic relationships, stratigraphy, petrology, geochemistry, thermobarometry, and microtectonics, in order to reduce misinterpretations. Studies of small areas of complex terrains are necessary to define critical geologic aspects and to acquire well-controlled geochronologic, geochemical, and structural data. However, some prudence must be taken in extrapolating data and interpretations to different areas, particularly if discrepancies in the geologic record exist.

Our interpretation concerning the existence of three separate HP events in the Acatlán Complex is a more comprehensive model to explain its metamorphic evolution because it is consistent with all sorts of available data. As detailed in our paper, a set of HP metamorphic events, of similar age, affecting analogous petrotectonic assemblages, under comparable P-T conditions, has been described in the Appalachian-Caledonian chain, where they are related to the closure of the Iapetus Ocean (e.g., Jamieson, 1990; McKerrow et al., 2000; Miller et al., 2000; Van Staal, 1994, 2007; Shervais et al., 2003). In view of the available evidence, the correlation of the Acatlán Complex with the Appalachian-Caledonian orogen remains the best hypothesis. The model proposing a single Mississippian HP event affecting all the HP suites of the Acatlán Complex is an oversimplification and requires fundamental explanations about the geologic relationships of the Acatlán Complex and its sedimentary cover.

ACKNOWLEDGMENTS

This work was supported by a Consejo Nacional de Ciencia y Tecnología (CONACYT) grant (J32549-T) to DMF and two National Science Foundation grants (EAR-9708361 and EAR-9628150) to GG and JR.

REFERENCES CITED

Alva-Valdivia, L.M., Goguitchaichvli, A., Grajales, M., Flores de Dios, A., Urrutia-Fucugauchi, J., Rosales, C., and Morales, J., 2002, Further constraints for Permo-Carboniferous magnetostratigraphy: Case study of the sedimentary sequence from San Salvador-Patlanoaya (Mexico): Comptes Rendus Geoscience, v. 334, p. 1–7, doi: 10.1016/S1631-0713(02)01821-7.

Arnaud, N.O., and Kelley, S., 1995, Evidence for excess Ar during high pressure metamorphism in the Dora-Maira (western Alps, Italy), using a ultra-violet laser ablation microprobe $^{40}Ar/^{39}Ar$ technique: Contributions to Mineralogy and Petrology, v. 121, p. 1–11, doi: 10.1007/s004100050086.

Böhnel, H., 1999, Paleomagnetic study of Jurassic and Cretaceous from the Mixteca terrane (Mexico): Journal of South American Earth Sciences, v. 12, p. 87–93, doi: 10.1016/S0895-9811(99)00038-3.

Brunner, P., 1987, Microfacies y microfósiles de las rocas carbonatadas del Paleozoico de San Salvador Patlanoaya, Puebla, México: Revista de la Sociedad Mexicana de Paleontología, v. 1, p. 98–124.

De la Cruz-Vargas, J.C., 2004, Geoquímica de esquistos azules y eclogitoides del Complejo Acatlán: Evidencia de una zona de subducción del Paleozoico en el Sur de México [M.S. thesis]: Hermosillo, Universidad de Sonora, 88 p.

El-Shazly, A.E., Broecker, M.S., Hacker, B.R., and Calvert, A.T., 2001, Formation and exhumation of blueschists and eclogites from NE Oman: New constraints from Rb-Sr and $^{40}Ar/^{39}Ar$ dating: Journal of Metamorphic Geology, v. 19, p. 233–248, doi: 10.1046/j.1525-1314.2001.00309.x.

Fang, W., Van der Voo, R., Molina-Garza, R., Moran-Zenteno, D., and Urrutia-Fucugachi, J., 1989, Paleomagnetism of the Acatlán terrane, southern México: Evidence for terrane rotation: Earth and Planetary Science Letters, v. 94, p. 131–142, doi: 10.1016/0012-821X(89)90089-7.

Geyh, M.A., and Schleicher, H., 1990, Absolute age determinations: Berlin, Springer-Verlag, 503 p.

Gradstein, F.M., Ogg, J.G., and Smith, A.G., eds., 2004, A Geologic Time Scale Cambridge, Cambridge University Press, 589 p.

Handschy, J.W., Keller, G.R., and Smith, K.J., 1987, The Ouachita system in northern Mexico: Tectonics, v. 6, p. 323–330, doi: 10.1029/TC006i003p00323.

Jamieson, R.A., 1990, Metamorphism of an early Paleozoic continental margin, western Baie Verte Peninsula Newfoundland: Journal of Metamorphic Geology, v. 8, p. 269–288, doi: 10.1111/j.1525-1314.1990.tb00473.x.

Keppie, J.D., Nance, R.D., Murphy, J.B., Miller, B.V., Dostal, J., and Ortega-Rivera, A., 2008, Comment on paper by Vega-Granillo et al., 2007, Pressure-temperature-time evolution of high-pressure rocks of the Acatlán Complex (southern Mexico): Implications for the evolution of the Iapetus and Rheic Oceans: Geological Society of America Bulletin, v. 119, p. 1249–1264.

McKerrow, W.S., Mac Niocaill, C., and Dewey, J.F., 2000, The Caledonian Orogeny redefined: The Geological Society of London, v. 157, no. 6, p. 1149–1154.

Malone, J.R., Nance, R.D., Keppie, J.D., and Dostal, J., 2002, Deformational history of part of the Acatlán Complex: Late Ordovician–Early Permian orogenesis in southern Mexico: Journal of South American Earth Sciences, v. 15, p. 511–524, doi: 10.1016/S0895-9811(02)00080-9.

Maurel, O., and Monié, P.P., Respaut, J.P., Leyreloup, A.F., and Maluski, H., 2003, Pre-metamorphic $^{40}Ar/^{39}Ar$ and U–Pb ages in HP metagranitoids from the Hercynian belt (France): Chemical Geology, v. 193, p. 195-214.

Middleton, M., Keppie, J.D., Murphy, J.B., Miller, B.V., and Nance, R.D., 2007, P-T-t constraints on exhumation following subduction in the Rheic Ocean: Eclogitic Asis Lithodeme, Piaxtle Suite, Acatlán Complex, southern Mexico, *in* Linnemann, U., Nance, R.D., Zulaf, G., and Kraft, P., eds., The Geology of Peri-Gondwana: The Avalonian–Cadomian Belt, Adjoining Cratons and the Rheic Ocean: Geological Society of America, Special Paper, v. 423, p. 489–509.

Miller, B.V., Stewart, K.G., Miller, C.F., and Thomas, C.W., 2000, U-Pb ages from the Bakersville Eclogite: Taconian eclogite metamorphism followed by Acadian and Alleghanian cooling: Geological Society of America Abstracts with Programs, v. 32, no. 2, p. A-62.

Murphy, J.B., Keppie, J.D., Nance, R.D., Miller, B.V., Dostal, J., Middleton, M., Fernández-Suarez, J., Jeffries, T.E., and Storey, C.D., 2006, Geochemistry and U-Pb protolith ages of eclogitic rocks of the Asís Lithodeme, Piaxtla Suite, Acatlán Complex, southern Mexico: Tectonothermal activity along the southern margin of the Rheic Ocean: The Geological Society of London, v. 163, p. 683–695, doi: 10.1144/0016-764905-108.

Ortega-Gutiérrez, F., 1978, Estratigrafía del Complejo Acatlán en la Mixteca Baja, Estados de Puebla y Oaxaca: Revista Insituto de Geología, Universidad Nacional Autónoma de México, v. 2, no. 2, p. 112–131.

Ortega-Gutiérrez, F., Elías-Herrera, M., Macías-Romo, C., and López, R., 1999, Late Ordovician-Early Silurian continental collisional orogeny in southern Mexico and its bearing on Gondwana-Laurentia connections: Geology, v. 27, p. 719–722, doi: 10.1130/0091-7613(1999)027<0719:LOESCC>2.3.CO;2.

Pindell, J.L., 1985, Alleghenian reconstruction and the subsequent evolution of the Gulf of Mexico, Bahamas, and proto-Caribbean Sea: Tectonics, v. 4, p. 1–39, doi: 10.1029/TC004i001p00001.

Pindell, J.L., 1994, Evolution of the Gulf of Mexico and the Caribbean, *in* Donovan, S.K., and Jackson, T.A., eds., Caribbean Geology: An Introduction: Kingston, University West Indies Publishers' Association, p. 13–39.

Pindell, J.L., and Dewey, J.F., 1982, Permo-Triassic reconstruction of western Pangea and the evolution of the Gulf of Mexico/Caribbean region: Tectonics, v. 1, p. 179–211, doi: 10.1029/TC001i002p00179.

Pindell, J.L., and Kennan, L., 2001, Kinematic evolution of the Gulf of Mexico and Caribbean, *in* Fillon, R., et al., eds., Transactions of the Gulf Coast Section Society of Economic Paleontologists and Mineralogists (GCSSEPM) 21st Annual Bob F. Perkins Research Conference, Petroleum Systems of Deep-Water Basins: Houston, Texas, p. 193–220.

Scaillet, S., 1998, K-Ar ($^{40}Ar/^{39}Ar$) Geochronology of ultrahigh pressure rocks, *in* Hacker, B.R., and Liou, J.G., eds., When Continents Collide: Geodynamics and Geochemistry of Ultrahigh-pressure Rocks: Netherlands, Kluwer Academic Publishers, p. 161–201.

Shervais, J.W., Dennis, A.J., McGee, J.J., and Secor, D., 2003, Deep in the heart of Dixie: Pre-Alleghanian eclogite and high-P granulite metamorphism in the Carolina terrane, South Carolina, USA: Journal of Metamorphic Geology, v. 21, p. 65–80, doi: 10.1046/j.1525-1314.2003.00416.x.

Talavera-Mendoza, O., Ruiz, J., Gehrels, G.E., Meza-Figueroa, D.M., Vega-Granillo, R., and Campa-Uranga, M.F., 2005, U-Pb geochronology of the Acatlán Complex and implications for the Paleozoic paleogeography and tectonic evolution of southern Mexico: Earth and Planetary Science Letters, v. 235, p. 682–699, doi: 10.1016/j.epsl.2005.04.013.

Talavera-Mendoza, O., Ruiz, J., Gehrels, G.E., Meza-Figueroa, D., Vega-Granillo, R., and Valencia, V., 2006, U-Pb geochronology of the Acatlán Complex and implications for the Paleozoic paleogeography and tectonic evolution of southern Mexico: Earth and Planetary Science Letters, v. 245, p. 476–480, doi: 10.1016/j.epsl.2006.03.017.

Vachard, D.A., and Flores de Dios, A., 2002, Discovery of latest Devonian/earliest Mississippian microfossils in San Salvador Patlanoaya (Puebla, México): Biogeographic and geodynamic consequences: Comptes Rendus Geoscience, v. 334, p. 1095–1101, doi: 10.1016/S1631-0713(02)01851-5.

Vachard, D., Flores de Dios, A., Buitrón, B.E., and Grajales, M., 2000, Biostratigraphie par fusilines des calcaires Carboniferes et Permienes de San Salvador Patlanoaya (Puebla, Mexique): Geobios, v. 33, p. 5–33, doi: 10.1016/S0016-6995(00)80145-X.

Van Staal, C.R., 1994, Brunswick subduction complex in the Canadian Appalachians: Record of the Late Ordovician to Late Silurian collision between Laurentia and the Gander margin of Avalon: Tectonics, v. 13, p. 946–962, doi: 10.1029/93TC03604.

Van Staal, C.R., 2007, Pre-Carboniferous metallogeny of the Canadian Appalachians, *in* Goodfellow, W.D., ed., Mineral deposits of Canada: A synthesis of major deposit-types, district metallogeny, the evolution of geological provinces, and exploration method: Mineral Deposit Division, Geological Association of Canada, Special Publication 5, p. 793–818.

Vega-Granillo, R., 2006, Petrología, termobarometría y análisis estructural en la región NW del Complejo Acatlán, Puebla, México: Implicaciones tectónicas [Ph.D. thesis]: México, Universidad Nacional Autónoma de México, 344 p.

Vega-Granillo, R., Talavera-Mendoza, O., Meza-Figueroa, D., Ruiz, J., Gehrels, G.E., López-Martínez, M., and De la Cruz-Vargas, J.C., 2007, Pressure-temperature-time evolution of high-pressure rocks of the Acatlán Complex (southern Mexico): Implications for the evolution of the Iapetus and Rheic Oceans: Geological Society of America Bulletin, v. 119, p. 1249–1264, doi: 10.1130/B226031.1.

Weber, B., Meschede, M., Ratschbacher, L., and Frisch, W., 1997, Structure and kinematic history of the Acatlán Complex in the Nuevos Horizontes—San Bernardo region, Puebla: Geofisica International, v. 36, no. 2, p. 63–76.

Yañez, P., Ruiz, J., Patchett, P.J., Ortega-Gutiérrez, F., and Gehrels, G.E., 1991, Isotopic studies of the Acatlán complex, southern Mexico: Implications for Paleozoic North American tectonics: Geological Society of America Bulletin, v. 103, p. 817–828, doi: 10.1130/0016-7606(1991)103<0817:ISOTAC>2.3.CO;2.

Manuscript Received 16 July 2008
Revised Manuscript Received 24 November 2008
Manuscript Accepted 28 April 2009

Printed in the USA