Revista Mexicana de Ciencias Geológicas, v. 26, núm. 1, 2009, p. 133-142

Carboniferous tholeiitic dikes in the Salada unit, Acatlán Complex, southern Mexico: a record of extension on the western margin of Pangea

Miguel Morales-Gámez[1,2*], J. Duncan Keppie[3], and Jaroslav Dostal[4]

[1]Posgrado en Ciencias de la Tierra, Instituto de Geología, Universidad Nacional Autónoma de México,
Ciudad Universitaria, Del. Coyoacán, 04510 México D.F., Mexico.
[2]Present address: Instituto Tecnológico Superior de Tacámbaro, Departamento de Ingeniería Geológica,
Av. Tecnológico #201, Zona El Gigante. 61650 Tacámbaro, Mich., Mexico.
[3]Departamento de Geología Regional, Instituto de Geología, Universidad Nacional Autónoma de México,
Ciudad Universitaria, Del. Coyoacán, 04510 México D.F., Mexico.
[4]Department of Geology, St. Mary's University, 923 Robie Street, Halifax, Nova Scotia, Canada B3H 3C3.
** mglmsgz@gmail.com*

ABSTRACT

A suite of mafic dikes intrudes polydeformed, greenschist facies, metapsammites and metapelites of the Salada unit in the eastern part of the Acatlán Complex, southern Mexico. The age of the dikes is constrained by the youngest detrital zircon in the Salada host rocks (352±3 Ma) and the Early Permian age of the overlying Tecomate formation, which is devoid of such dikes. The mafic rocks are generally composed of amphibole, chlorite, feldspar, epidote and accessory opaque minerals. Their chemistry resembles rift-related tholeiites with ~50 wt.% SiO_2 and Mg# ~0.40–0.60. Their chondrite-normalized REE patterns resemble N-type MORB with (La/Sm)n mostly ~0.5–0.6, and their mantle-normalized patterns are relatively flat with no negative Nb anomaly and a low Th/La ratio indicating the absence of both subduction-related fluids and crustal contamination. Their chemistry resembles N-type MORB. Their intrusive relationships with the continentally-derived clastic rocks suggests that they were emplaced in thin continental crust. Shallow-water, Mississippian fauna in the adjacent Oaxaquia terrane, with Mid-Continent (USA) affinities, indicate that Pangea had already amalgamated by this time. In this context, the tholeiitic dikes are inferred to have formed during extension on the western margin of Pangea that was synchronous with extrusion of high-pressure rocks above an active subduction zone.

Key words: Acatlán Complex, geochemistry, Pangea, Carboniferous, Mexico.

RESUMEN

Se estudia una serie de diques máficos que intruyen metapelitas y metapsamitas polideformadas de la unidad Salada y que se hallan en condiciones metamórficas de esquistos verdes. Esta unidad aflora en el sector oriental del complejo Acatlán, en el sur de México. La edad de los diques está limitada por los circones detríticos más jóvenes de las rocas de caja de la unidad Salada (352±3 Ma) y por la edad del Pérmico Temprano de la formación Tecomate sobreyaciente, en la cual no se ha hallado ese tipo de diques. Los diques máficos están compuestos generalmente por anfíbol, clorita, feldespato, epidota y minerales opacos. Su composición geoquímica los clasifica como rocas toleíticas originadas por extensión (rift) con contenidos de sílice en torno al 50% en peso y Mg# entre 40 y 60. Los espectros de tierras *raras normalizados a valores condríticos indican que son de tipo N-MORB con (La/Sm)m entre 05 y 0.6, mientras que los espectros normalizados a valores del manto son planos, no presentan anomalía de Nb y tienen una baja relación de Th/La, lo que indica la ausencia tanto de fluidos derivados de procesos de subducción como de contaminación cortical. Su similitud con rocas de tipo N-MORB y su relación de intrusión en rocas clásticas de afinidad continental sugiere que estos diques se emplazaron en una corteza continental adelgazada. La presencia de fauna misisipiense de aguas someras, con afinidad al Mid-Continent (EUA), en el colindante terreno de Oaxaquia indica que Pangea pudo estar amalgamada entonces. De esta manera, se puede inferir que los diques toleíticos se formaron debido a la extensión en el margen occidental de Pangea, que fue coetánea con la exhumación de rocas de alta presión en un ambiente de margen activa.*

Palabras clave: Complejo Acatlán, geoquímica, Pangea, Carbonífero, Mexico.

INTRODUCTION

The mafic dikes that form the topic of this paper occur in the Xayacatlán area within the eastern part of the Acatlán Complex, Mixteca terrane (Figure 1). They intrude metapsammites and metapelites that were polydeformed under greenschist facies conditions. They were previously assigned to the Cosoltepec Formation, which was interpreted as a Cambro-Ordovician accretionary prism by Ortega-Gutiérrez *et al.* (1999, and references therein). However, the presence of Devonian detrital zircons (youngest detrital zircon age of ~376 Ma or ~410 Ma youngest population) in the type Cosoltepec Formation led Talavera-Mendoza *et al.* (2005) and Vega-Granillo *et al.* (2007) to suggest that the Cosoltepec Formation was deposited as a Devono-Carboniferous passive margin bordering Gondwana and that it was subsequently caught in the collision zone between Gondwana and Laurentia during the amalgamation of Pangea. On the other hand, Keppie *et al.* (2008a, and references therein) have proposed that the Mixteca terrane lay on the active western margin of Gondwana during the Carboniferous. In an attempt to shed light on the Late Paleozoic tectonic setting of the Mixteca terrane, we present geochemical data for some Carboniferous mafic dikes in the eastern part of the Acatlán Complex.

GEOLOGICAL SETTING

The Acatlán Complex (Mixteca terrane) is bounded on three sides by faults and shear zones (Figure 1a): 1) along its eastern side the north-trending, Permian, dextral Caltepec fault zone separates it from the ~1 Ga Oaxacan Complex (Elias-Herrera and Ortega-Gutiérrez, 2002), which forms the basement of the Oaxacan (Oaxaquia) terrane (Keppie, 2004); 2) to the south, the east-west, Cenozoic, dextral La Venta-Chacalapa Fault (Tolson, 2007; Solari *et al.*, 2007) juxtaposes it against the Xolapa terrane; and 3) to the west, the NNE-trending, late Mesozoic-early Cenozoic, westerly-vergent Papalutla thrust places the Acatlán Complex on top of the Cretaceous Morelos platform (Cerca *et al.*, 2007). The northern boundary of the Mixteca terrane is obscured by overlain Mesozoic-Cenozoic rocks of the Mixteca terrrane cover and the Trans-Mexican Volcanic Belt (Gómez-Tuena *et al.*, 2007) (Figure 1a). The geological history of the eastern Acatlán Complex has recently been summarized by Keppie *et al.* (2008a) as follows (Figure 2):

1) Ordovician deposition of rift-passive margin clastic rocks and intrusion of a rift-related, bimodal suite of igneous rocks;

2) latest Devonian-Carboniferous, polyphase deformation attributed to rapid exhumation of the high pressure (HP) rocks that was synchronous with deposition of sedimentary rocks, including the Salada unit; Mississippian eclogite facies (HP) metamorphism and polyphase deformation;

3) Early Permian intrusion of arc-related plutons into periarc sedimentary rocks (including the Tecomate formation) synchronous with low grade polyphase deformation; and

4) Late Permian-Triassic deposition of the siliciclastic rocks (Chazumba and Magdalena units) in a foredeep in front of S-vergent thrusts; and

5) Jurassic migmatization associated with polyphase deformation of the Chazumba and Magdalena units.

Remapping of the Xayacatlán area has distinguished three greenschist facies, clastic units (Figure 3), from west to east (Morales-Gámez *et al.*, 2008): 1) the Ordovician Huerta unit composed of polydefomed metapsammites and metapelites; 2) the pre-450 Ma Amate unit consisting of polydeformed meta-arkoses and metapelites; and 3) the Carboniferous Salada unit made up of metapsammites and metapelites cut by mafic dikes. An older limit for the age of the mafic dikes that intrude the Salada unit is provided by the 352±3 Ma age of the youngest detrital zircon (Morales-Gámez *et al.*, 2008). These dikes do not occur in the overlying, Lower Permian Tecomate formation. A reconnaissance of the geochemical characteristics of mafic rocks associated with the greenschist facies clastic rocks revealed that they are predominantly tholeiitic MORB-type rocks associated with minor alkalic varieties of uncertain age (Keppie *et al.*

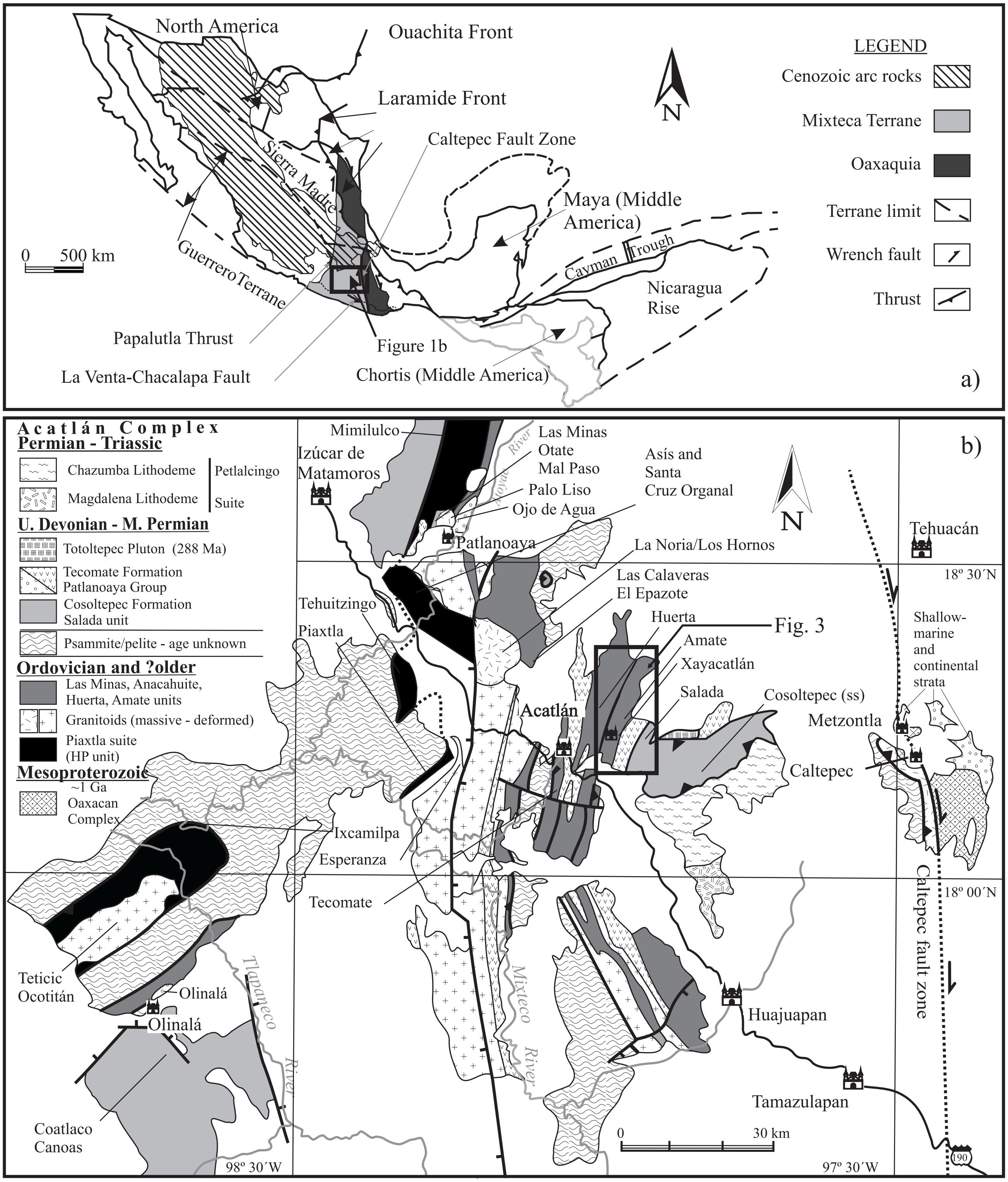

Figure 1. Location of the Xayacatlán map shown on (a) terrane map of Middle America (modified after Keppie, 2004), and (b) geological map of the Acatlán Complex (modified after Keppie *et al.*, 2008a).

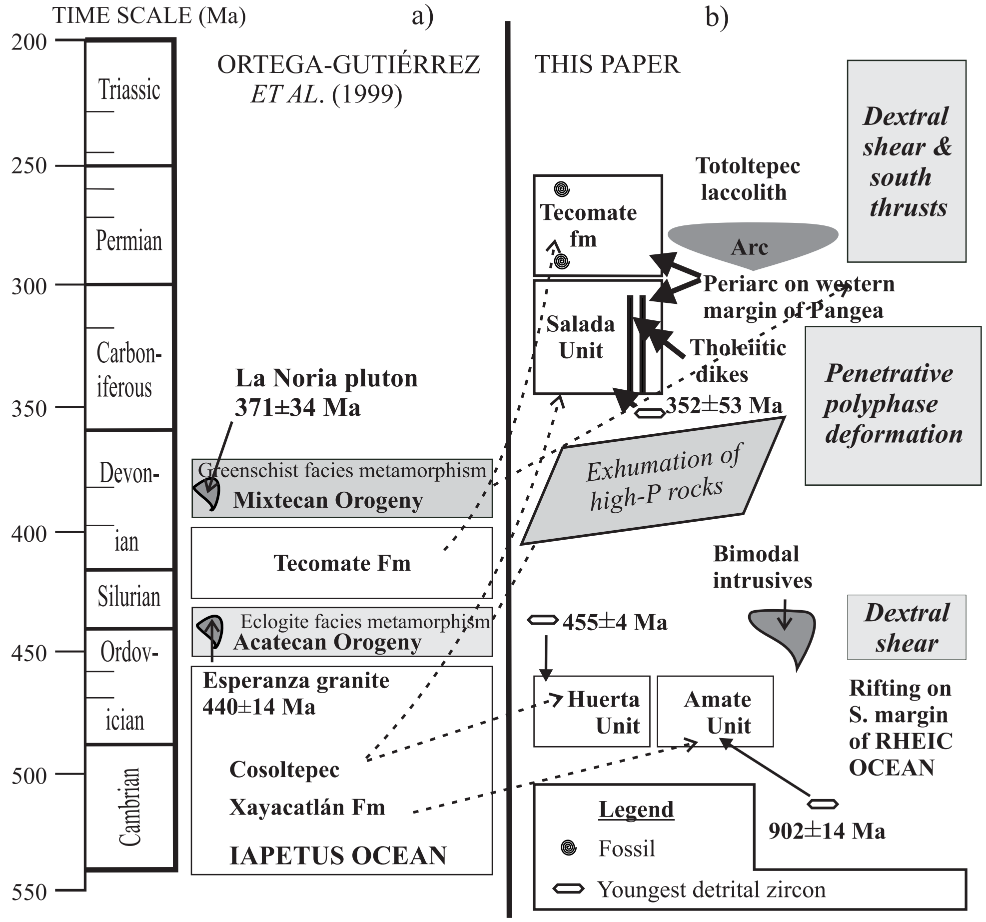

Figure 2. Time and space diagram showing the geological record of the Xayacatlán area (after Morales-Gámez *et al.*, 2008).

2007). Further research has indicated that the clastic rocks can be assigned to, at least, two different ages: Ordovician (Huerta and Amate units and correaltives) and Carboniferous (Salada unit and correlatives)(Keppie *et al.*, 2008a; Ramos-Arias *et al.*, 2008; Morales-Gámez *et al.*, 2008; Grodzicki *et al.*, 2008; Hinojosa-Prieto *et al.*, 2008). Mafic dikes and flows associated with the Ordovician clastic rocks appear to be continental rift tholeiites formed in a rift-passive margin environment (Keppie *et al.*, 2008b). The Carboniferous mafic pillow lavas in the western Acatlán Complex also have within-plate tholeiitic affinities (Grodzicki *et al.*, 2008). In order to determine the tectonic environment during the Carboniferous (passive or active margin), the geochemistry of mafic dikes that intrude the Salada unit was undertaken and is presented in this paper.

PETROGRAPHY

Nine geochemical samples of the Salada Unit were collected in the northern part of the area, and one sample from the south (Figure 3). All the samples are from different NNE-trending mafic dikes and display the same structural history as the host rocks. In places, the dikes cut the bedding in the host rocks. In thin section the mafic rocks are composed of amphibole, chlorite, feldspar, epidote and accessory opaque minerals. The metasedimentary rocks are made up of quartz, muscovite, chlorite and accessory opaque minerals. These mineral associations indicate metamorphism under greenschist facies conditions. The fact that the amphiboles are aligned indicates that this metamorphism was synchronous with deformation.

GEOCHEMISTRY

Ten samples were analyzed for major and some trace elements (Rb, Sr, Ba, Ga, Zr, Y, Nb, V, Ni, Co and Cr) by X-ray fluorescence spectrometry in the Department of Earth Sciences of University of Ottawa, Canada. Eight representative samples were selected from this set for analysis of other trace elements (rare-earth elements [REE], Th, Nb, Ta, Zr and Hf) by ICP-MS at the Department of Earth Sciences, Memorial University of Newfoundland. The analytical error of the trace element determinations is 2–10 % and <2% for major elements. Where available, ICP-MS data were preferred because of their better quality at low concentration levels.

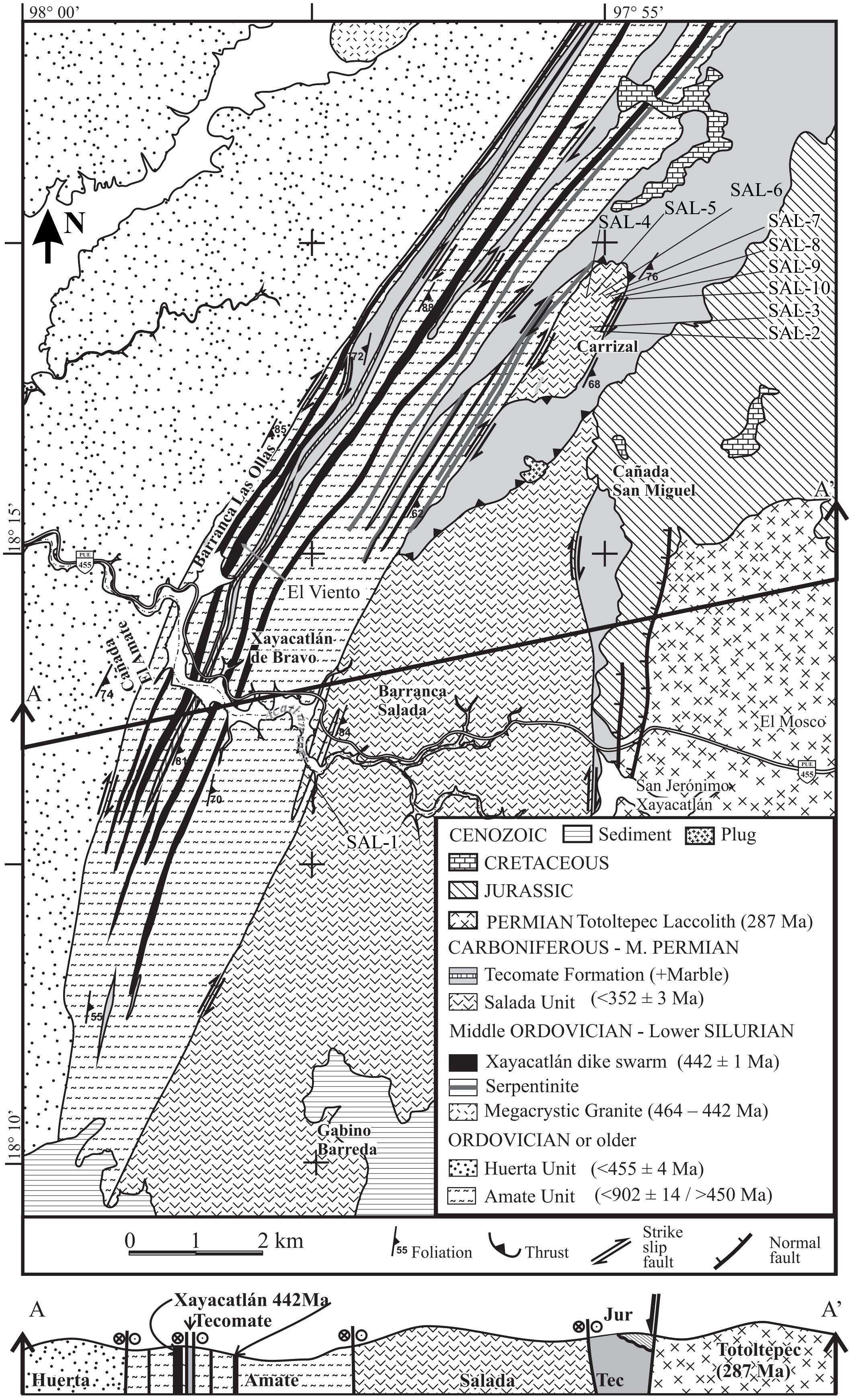

Figure 3. Geological map of the Xayacatlán area showing locations of mafic dikes sampled for geochemistry.

Table 1. Geochemical data for mafic dikes cutting the Salada unit, Acatlán Complex, southern Mexico.

Sample	**SAL-1**	**SAL-2**	**SAL-3**	**SAL-4**	**SAL-5**	**SAL-6**	**SAL-7**	**SAL-8**	**SAL-9**	**SAL-10**
Long.	97°57’39”	97°55’29”	97°55’28	97°55’11”	97°55’03”	97°55’00”	97°54’54”	97°54’51”	97°54’48”	97°54’46”
Lat.	18°13’16”	18°16’44”	18°16’44	18°17’04”	18°17’05”	18°17’06”	18°17’02”	18°17’02”	18°17’04”	18°17’05”
SiO_2 (wt.%)	47.66	45.39	45.34	44.93	46.28	43.67	46.50	45.27	47.44	49.21
TiO_2	0.99	1.59	1.31	2.43	1.23	1.48	1.49	2.06	1.44	1.24
Al_2O_3	16.40	14.96	12.94	14.86	15.03	15.44	14.58	11.66	13.62	13.47
$Fe_2O_3^T$	10.33	12.03	10.25	13.28	11.47	11.56	12.01	13.61	13.30	12.21
MnO	0.16	0.19	0.19	0.20	0.18	0.29	0.21	0.23	0.19	0.18
MgO	6.63	8.86	5.54	6.51	8.66	7.79	8.31	4.54	7.59	7.84
CaO	9.93	8.03	13.31	11.06	8.01	9.01	10.49	11.09	9.35	8.63
Na_2O	3.07	2.64	2.89	1.13	1.80	1.78	2.03	3.16	2.75	2.77
K_2O	0.02	0.10	0.25	0.04	0.17	0.39	0.14	0.13	0.08	0.19
P_2O_5	0.08	0.13	0.12	0.22	0.10	0.12	0.11	0.33	0.13	0.11
LOI	4.10	6.00	7.30	5.40	7.40	9.20	3.50	8.00	4.70	4.40
Total	99.37	99.92	99.44	100.06	100.32	100.73	99.37	100.08	100.59	100.25
Mg#	0.56	0.59	0.52	0.49	0.60	0.57	0.58	0.40	0.53	0.56
Cr (ppm)	234	360	167	261	221	126	244	43	170	175
Ni	98	84	78	62	122	98	99	20	90	66
Co	44	45	41	40	47	49	49	46	55	50
V	251	321	275	400	275	290	304	325	359	333
Zn	72	88	74	93	85	97	90	114	100	91
Rb	3	6	13	5	12	19	9	10	8	15
Ba	32	32	39	26	39	55	37	56	66	45
Sr	371	148	153	226	119	166	190	76	123	97
Ga	16	17	14	19	14	17	16	15	16	14
Ta	0.28	0.14	0.10	0.24	0.08	-	0.14	-	0.22	0.21
Nb	4.2	2.4	1.8	4.4	1.5	-	2.1	-	4.0	3.4
Hf	1.66	2.46	1.87	4.45	1.82	-	2.45	-	2.11	1.71
Zr	64	98	75	117	68	91	93	152	82	70
Y	17	29	24	48	22	38	29	46	25	23
Th	0.27	0.17	0.17	0.53	0.08	-	0.10	-	0.19	0.16
La	3.29	2.95	2.37	5.44	2.05	-	2.59	-	2.82	2.41
Ce	7.77	9.32	6.86	16.33	6.15	-	8.16	-	7.94	6.79
Pr	1.25	1.66	1.25	2.86	1.10	-	1.49	-	1.33	1.20
Nd	6.51	9.29	7.20	15.78	6.22	-	8.71	-	7.54	6.74
Sm	2.10	3.11	2.45	5.23	2.19	-	2.90	-	2.58	2.34
Eu	0.83	1.21	0.92	1.77	0.83	-	1.18	-	0.96	0.87
Gd	2.86	4.58	3.73	7.52	3.55	-	4.61	-	4.09	3.71
Tb	0.51	0.84	0.67	1.34	0.63	-	0.82	-	0.78	0.68
Dy	3.46	5.78	4.64	9.18	4.36	-	5.76	-	5.30	4.80
Ho	0.67	1.19	0.96	1.93	0.87	-	1.20	-	1.04	0.94
Er	2.04	3.53	2.89	5.73	2.65	-	3.48	-	3.06	2.74
Tm	0.286	0.514	0.422	0.823	0.399	-	0.502	-	0.449	0.413
Yb	1.99	3.37	2.83	5.41	2.60	-	3.29	-	3.10	2.72
Lu	0.284	0.472	0.394	0.761	0.357	-	0.452	-	0.479	0.425

$Fe_2O_3^T$ = total Fe as Fe_2O_3; Mg# = Mg/(Mg+Fe^T).

Analytical results for these rocks are presented in Table 1. The major and trace element compositions of these rocks are similar to those of modern volcanic rocks. This suggests that the rocks are the metamorphic equivalents of such rocks and that they retain, to a large degree, their magmatic composition. Unlike sedimentary rocks, they have high Cr/Th (>400) and low Th/La (<0.1) ratios (Rollinson, 1993), and according to a procedure of Leake (1964), they resemble metamorphosed basalts. The rocks have a composition corresponding to subalkaline basalts (Figure 4) with SiO_2 (volatile-free basis) ranging between 47.5 and 51.5 wt. % and Mg# (=Mg/Mg+Fe_{tot}) between 0.40 and 0.60, and display tholeiitic characteristics (Figure 5). According to their normative compositions, the rocks are mostly olivine-normative tholeiites. Cr and Ti abundances are typical of rift-related tholeiites (Figure 6). The chondrite-normalized REE patterns of most of the rocks show a minor depletion of light REE (Figure 7) and their patterns

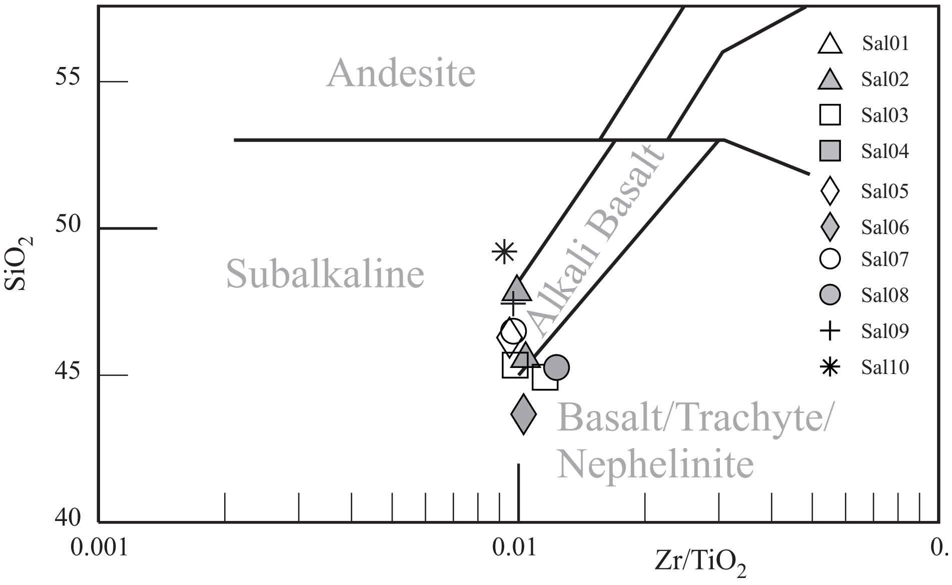

Figure 4. Geochemical data for the Salada mafic dikes plotted on the Zr/TiO_2 versus SiO_2 (wt.%) diagram of Winchester and Floyd (1977). Abbreviations: Sub-AB: subalkaline basalt; AB: alkaline basalt; TrAn: trachyandesite; Bas: basanite; Trach: trachyte; Neph: nephelinite.

are similar to N-type MORB with $(La/Sm)_n$ mostly ~0.5–0.6. The absolute concentration of REE varies slightly but the shape of the patterns remains the same: these variations are consistent with low-pressure fractional crystallization. The mantle-normalized trace element patterns of the rocks (Figure 8) are relatively flat without a Nb depletion relative to La and Th suggesting that the rocks have not been modified by subduction-related fluids and that the rocks were not significantly contaminated by crustal material. The absence of a Nb anomaly and a low Th/La ratio suggest an asthenospheric source without any suprasubduction imprint or crustal contamination. The high Ti and Cr content also rules out formation in an arc environment. The rocks resemble N-type MORB. The geochemical characteristics suggest that the rocks are either rift-related oceanic basalts or continental tholeiite emplaced in rather thin crust without significant crustal contamination: the latter is most likely as the mafic dikes intrude continentally-derived clastic rocks.

DISCUSSION

The Carboniferous, rift-related tholeiitic dikes in the Xatacatlán area may be correlated with within-plate, rift-related tholeiitic pillow basalts interbedded with clastic metasedimentary rocks (Coatlaco unit) in the western part of the Acatlán Complex, which have yielded a 357 ± 35 Ma detrital zircon age (Grodzicki *et al.*, 2008). Deposition of the Salada and Coatlaco units was also contemporaneous with deposition of the Patlanoaya Group, which, in turn, was synchronous with exhumation and deformation of high-pressure rocks (Ramos-Arias *et al.*, 2008), and the earliest deformation of the Salada unit (Morales-Gámez *et al.*, in press). This deformation has been related to extrusion of the high-pressure rocks into the upper plate above an active subduction zone (Keppie *et al.*, 2008a).

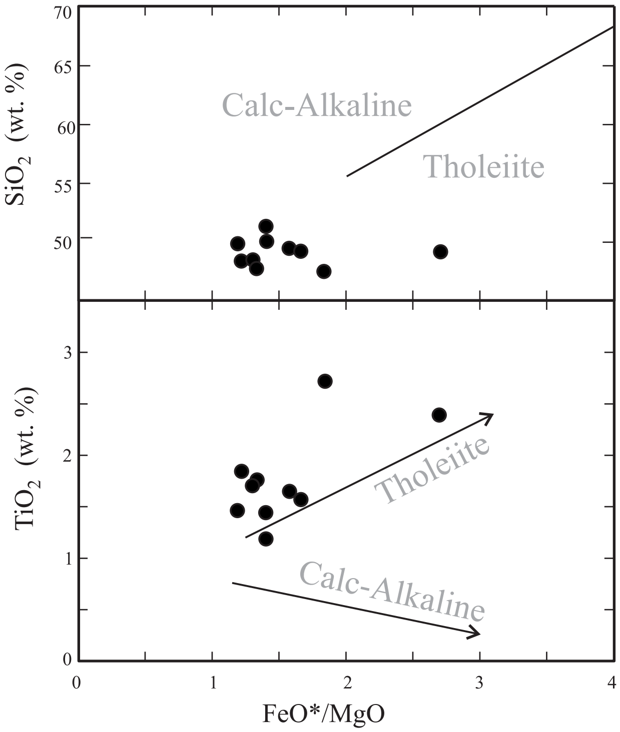

Figure 5. (a) FeO*/MgO versus TiO_2 (wt%) and (b) FeO*/MgO versus SiO_2 for Salada dikes. The lines showing calc-alkaline and tholeiitic trends are after Miyashiro (1974). FeO* = total Fe as FeO.

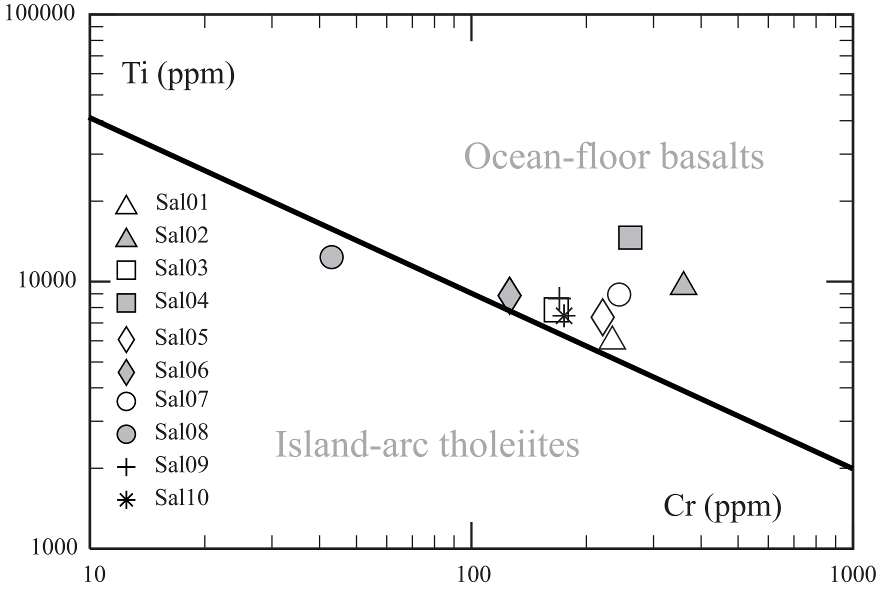

Figure 6. Geochemical data for the Salada mafic dikes plotted on the Cr (ppm) versus Ti (ppm) diagram of Pearce (1975) showing the compositional fields for island arc tholeiites and within-plate basalts (including mid-ocean ridge basalts).

Talavera-Mendoza *et al.* (2005) and Vega-Granillo *et al.* (2007) place the Mixteca terrane in the collisional suture zone between southern Laurentia and Gondwana (Figure 9a). That this collision had already taken place by the Mississippian is suggested by the presence of shallow water Mid-Continent (USA) fauna in the Santiago Formation that lies above the ~1 Ga Oaxacan Complex in the adjacent Oaxaquia terrane (Navarro-Santillan *et al.*, 2002). Although the presence of Carboniferous, within-plate, rift-related tholeiites could be explained by gravitational collapse of a collisional orogen, it is inconsistent with paleomagnetic data, which indicate that, in the Permian, the Mixteca terrane lay roughly at its present position relative to Laurentia (Alva-Valdivia *et al.*, 2002). The latter position places the Mixteca terrane on the Pacific margin of Pangea (Figure 9b). On the other hand, Carboniferous rift-related tholeiites synchronous with deformation, and extrusion of high-pressure rocks in an active margin setting, is more consistent with a location along the western margin of Pangea, well south of the Laurentia-Gondwana suture zone (Figure 9b) (Elias-Herrera and Ortega-Gutiérrez, 2002; Keppie *et al.*, 2008a).

ACKNOWLEDGMENTS

We would like to acknowledge a PAPIIT grant (IN100108-3) and a CONACyT grant (CB-2005-1: 24894) to JDK and a NSERC discovery grant to JDS that facilitated the fieldwork and chemical analyses. CONACyT contributed to studies for MMG. We are grateful to Dr. J.B. Murphy for detailed reviews that have allowed for improvement of the manuscript.

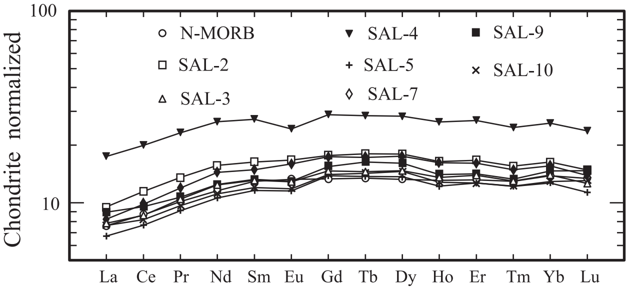

Figure 7. Chondrite-normalized REE abundances in the Salada mafic dikes and N-type MORB of Sun and McDonough (1989). Normalizing values are after Sun and McDonough (1989).

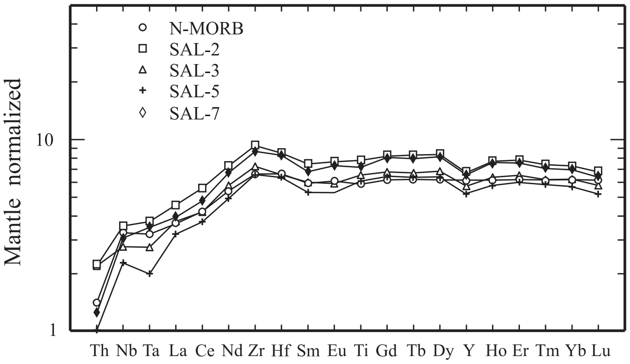

Figure 8. Geochemical data for the Salada mafic dikes and N-type MORB plotted on the mantle-normalized trace element diagram (Sun and McDonough, 1989). Normalizing values after Sun and McDonough (1989).

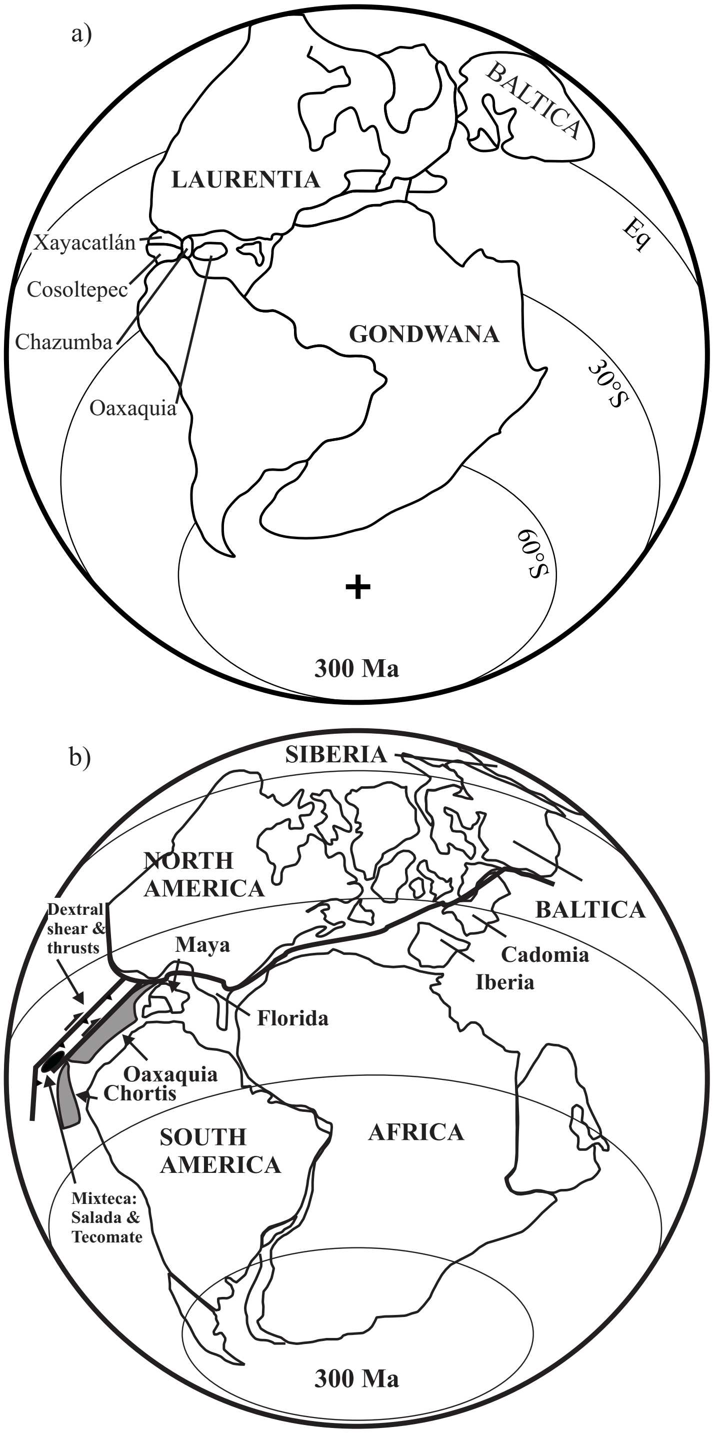

Figure 9. Permo-Carboniferous reconstructions: (a) after Talavera-Mendoza *et al.* (2005) and Vega-Granillo *et al.* (2007), and (b) modified from Keppie *et al.* (2008a).

REFERENCES

Alva-Valdivia, L.M., Goguitchaichvli, A., Grajales, M., Flores de Dios, A., Urrutia-Fucugauchi, J., Rosales C., Morales, J., 2002, Further constraints for Permo-Carboniferous magnetostratigraphy: case study of the sedimentary sequence from San Salvador-Patlanoaya (Mexico): Compte Rendus Geoscience, 334, 1-7.

Cerca, M., Ferrari, L., Lopez, M., Martiny, B. Iriondo, A., 2007, Late Cretaceous shortening and early Tertiary shearing in the central Sierra Madre del Sur, southern Mexico: Insights into the evolution of the Caribbean-North American plate interaction: Tectonics, 26, TC3007, doi:10.1029/2006TC001981.

Elías-Herrera, M., Ortega-Gutiérrez, F., 2002, Caltepec fault zone: an Early Permian dextral transpressional boundary between the Proterozoic

Oaxacan and Paleozoic Acatlán complexes, southern Mexico, and regional implications: Tectonics, 21(3), 10.1029/200TC001278.

Gómez-Tuena, A., Langmuir, C.H., Goldstein, S.L., Straub, S.M., Ortega-Gutiérrez, F., 2007, Geochemical evidence for slab-melting in the Trans-Mexican Volcanic Belt: Journal of Petrology, 48(3), 537–562.

Grodzicki, K.R., Nance, J.D., Keppie, J.D., Dostal, J., Murphy, J.B., 2008, Structural, geochemical and geochronological analysis of metasedimentary and metavolcanic rocks of the Coatlaco area, Acatlán Complex, southern Mexico: Tectonophysics. doi:10.1016/j.tecto.2008.01.016.

Hinojosa-Prieto, H.R., Nance, R.D., Keppie, J.D., Dostal, J.V., Ortega-Rivera, A., Lee, J.K.W., 2008, Ordovician and Late Paleozoic-Early Mesozoic tectonothermal history of the La Noria area, northern Acatlán Complex, southern Mexico: Record of convergence in the Rheic and paleo-Pacific Oceans: Tectonophysics. doi: 10.1016/j.tecto.2008.06.002

Keppie, J.D., 2004, Terranes of Mexico revisited: a 1.3 billion year odyssey: International Geology Review, 46, 765-794.

Keppie, J.D., Dostal, J., and Elias-Herrera, M., 2007, Ordovician-Devonian oceanic basalts in the Cosoltepec Formation, Acatlán Complex, Mixteca terrane, southern Mexico: vestiges of the Rheic Ocean, *in* Linnemann, U., Kraft, P., Nance, R.D., Zulauf, G. (eds.), The Geology of Peri-Gondwana: Geological Society of America, Special Paper 423, 477-487.

Keppie, J.D., Dostal, J., Murphy, J.B., Nance, R.D., 2008a, Synthesis and tectonic interpretation of the westernmost Paleozoic Variscan orogen in southern Mexico: from rifted Rheic margin to active Pacific margin: Tectonophysics, doi:10.1016/j.tecto.2008.01.012.

Keppie, J.D., Dostal, J., Miller, B.V., Ramos-Arias, M.A., Morales-Gámez, M., Nance, R.D., Murphy, J.B., Ortega-Rivera, A., Lee, J.W.K., Housh, T., Cooper, P., 2008b, Ordovician-earliest Silurian rift tholeiites in the Acatlán Complex, southern Mexico: evidence of rifting on the southern margin of the Rheic Ocean: Tectonophysics, doi:10.1016/j.tecto.2008.01.010.

Leake, B.E., 1964, The chemical distinction between ortho- and para-amphibolites: Journal of Petrology, 5, 238-254.

Miyashiro, A., 1974, Volcanic rock series in island arcs and active continental margins: American Journal of Science, 274, 321–355.

Morales-Gámez, M., Keppie, J. D., Norman, M., 2008, Ordovician-Silurian rift-passive margin on the Mexican margin of the Rheic Ocean overlain by Permian periarc rocks: evidence from the Acatlán Complex, southern Mexico: Tectonophysics. doi:10.1016/j.tecto.2008.01.014.

Morales-Gámez, M., Keppie, J.D., Ortega-Rivera, A., Lee, J.W.K., in press, Paleozoic structures in the Xayacatlán area, Acatlán Complex, southern Mexico: transtensional rift- and subduction-related deformation along the margin of Oaxaquia: International Geology Review.

Navarro-Santillan, D., Sour-Tovar, F., Centeno-García E., 2002, Lower Mississippian (Osagean) brachiopods from the Santiago Formation, Oaxaca, Mexico: stratigraphic and tectonic implications: Journal of South American Earth Sciences, 15(3), 327-336.

Ortega-Gutiérrez, F., Elías-Herrera, M., Reyes-Salas, M., Macías-Romo, C., López, R., 1999, Late Ordovician-Early Silurian continental collision orogeny in southern Mexico and its bearing on Gondwana-Laurentia connections: Geology, 27, 719-722.

Pearce, J. A., 1975, Basalt geochemistry used to investigate past tectonic settings on Cyprus: Tectonophysics, 25, 41-67.

Ramos-Arias, M.A., Keppie, J.D., Ortega-Rivera, A., Lee, J.W.K., 2008, Extensional late Paleozoic deformation on the western margin of Pangea, Patlanoaya area, Acatlán Complex, southern Mexico: Tectonophysics, 448, 60-78.

Rollinson, H. R., 1993, Using Geochemical Data: Evaluation, Presentation, Interpretation: Longman, UK, 352 p.

Solari, L. A., Torres-de León, R., Hernández-Pineda, G., Solé, J., Solís-Pichardo, G., Hernández-Treviño, T., 2007, Tectonic significance of Cretaceous-Tertiary magmatic and structural evolution of the northern margin of the Xolapa Complex, Tierra Colorada area, southern Mexico: Geological Society of America Bulletin, 119, 1265–1279.

Sun, S. S., McDonough, W.F., 1989, Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes, *in* Saunders, A.D., Norry, M.J. (eds.), Magmatism in the Ocean Basins: Geological Society of London, Special Publication 42, 313-345.

Talavera-Mendoza, O., Ruiz, J., Gehrels, G. E., Meza-Figueroa, D.M., Vega-Granillo, R., 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, 235, 682-699.

Tolson, G., 2007, The Chacalapa fault, southern Oaxaca, Mexico, *in* Alaniz-Álvarez, S.A., Nieto-Samaniego, Á.F. (eds.), Geology of Mexico: Celebrating the Centenary of the Geological Society of Mexico: Geological Society of America, Special Paper 422, 343-357, doi: 10.1130/2007.2422(12).

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

Winchester, J.A., Floyd, P.A., 1977, Geochemical discrimination of different magma series and their differentiation products using immobile elements: Chemical Geology, 20, 325-343.

Manuscript received: July 31, 2008
Corrected manuscript received: September 16, 2008
Manuscript accepted: October 20, 2008