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## TOWARDS A REVISED GEOLOGICAL HISTORY OF THE ACATLAN COMPLEX, SOUTHERN MEXICO: TECTONIC AND PALEOGEOGRAPHIC IMPLICATIONS

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Based upon limited geochronology and poorly preserved fossils, the Acatlan Complex of southern Mexico has been inferred to comprise: (i) low-grade, Lower Paleozoic trench/forearc or miogeoclinal metasedimentary rocks (Petlalcingo Group) thrust beneath (ii) eclogitic oceanic lithospheric rocks (Piaxtla Group) during the Late Ordovician-Early Silurian, Acatecan Orogeny, unconformably overlain by (iii) Siluro-Devonian, arc-related volcanic and sedimentary rocks (Tecomate Formation), all deformed during (iv) the low-grade, Middle Devonian Mixtecan Orogeny and intruded syntectonically by a Late Devonian granitoid pluton, and unconformably overlain by (v) Late Devonian-Early Permian sediments (Patlanoaya and Matzitzi formations). Respective correlation of the Acatecan and Mixtecan orogenies with the Taconian and Acadian orogenies of the Appalachians implied that the Acatlan Complex was a vestige of the Iapetus Ocean. New U-Pb zircon analyses and fossil identifications indicate a revised sequence of events: (1) deposition of terrigenous sediments that were intruded by (2) rift-related mafic and felsic rocks during the Ordovician (~440-480 Ma); (3) polyphase deformation and eclogite facies metamorphism at 346 „b 3 Ma followed by migmatization at ~350-330 Ma associated with tectonic interleaving of the low- and high-grade units; (4) Upper Devonian-Middle Permian arc magmatism (e.g. Totoltepec pluton: 290-285 Ma) and deposition of the Tecomate Formation (containing latest Pennsylvanian-Middle Permian fossils and granite pebbles with 280-230 Ma ages) and Patlanoaya Formation (containing Upper Devonian-Lower Permian fossils); (5) Lower-Middle Permian polyphase deformation under low-grade metamorphic conditions; and (6) Middle Jurassic (174-170 Ma), plume-related, polyphase deformation, high-low grade metamorphism and bimodal magmatism. These new data indicate that the main Paleozoic tectonothermal events are Carboniferous and Permian (rather than Ordovician and Devonian) suggesting a correlation with the Variscan-Alleghanian-Ouachita orogen. These new data indicate: (i) birth and destruction of an ocean in the Ordovician and Early Carboniferous, respectively, followed by (ii) oblique convergent deformation during arc development in the Early-Middle Permian. Such a correlation is more compatible with: (i) an origin along the Amazonian-Oaxaquia margin of the Rheic Ocean (rather than Iapetus), followed by (ii) subduction of the paleo-Pacific Ocean beneath the western margin of Pangea, respectively. Jurassic subduction of the paleo-Pacific beneath western Mexico led to overriding of a plume.

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## U-PB SINGLE-CRYSTAL GEOCHRONOLOGY OF THE ACATLÁN COMPLEX: STRATIGRAPHIC AND TECTONIC IMPLICATIONS

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Single-crystal U-Pb geochronology of metasedimentary and magmatic suites of the Acatlán Complex (southern Mexico) and its late Paleozoic sedimentary cover reveals a complex geological evolution recording tectonic events from the assembly of Rodinia to the break-up of Pangea. Data for the Esperanza Granitoids indicate the existence of three major magmatic suites related to separated orogenic events: (1) A Mesoproterozoic (1165±30 to 1043±50 Ma) suite related to the Grenvillian orogeny; (2) an Early Ordovician (478±5.2 to 471±4.5 Ma) suite related to the Taconian orogeny; and, (3) a Middle to Late Ordovician (460.5±8.5 to 440±14 Ma) suite related to the Acatecan orogeny. Eclogitic rocks from the Xayacatlán Formation of Neoproterozoic-Early Ordovician age contain detrital zircons derived most probably from the southwestern North America Grenville province. U-Pb ages of detrital zircons in blueschists from the Ixcamilpa area are consistent with a Middle Ordovician depositional age and derivation from Laurentian sources including Taconian, Hudsonian and Archean rocks. The Tecomate Formation resulted to be composed of two unrelated units of contrasting age and lithology: a Neoproterozoic-Early Ordovician, arc- and rift-related volcanosedimentary unit (El Rodeo Formation) containing detrital zircons deriving from the southwestern North America Grenville province; and, an essentially sedimentary unit containing Early Permian fauna. The Cosoltepec Formation has a maximum Cambrian depositional age and contains detrital zircons consistent with derivation from South American sources including the Brasiliano, Grenvillian and the Trans-Amazonian orogens. The age of the Magdalena and Chazumba Formations is established to the Late Pennsylvanian-Early Permian, substantially younger than previously inferred, and contain detrital zircons indicating derivation from both North and South America crustal sources. The Olinalá Formation from the Late Paleozoic sedimentary cover contains detrital zircons deriving mainly from Grenvillian sources with a significant contribution of Pennsylvanian magmatic rocks.

The earliest stages of the tectonic evolution of the Acatlán Complex are tied to the evolution of Rodinia. Eclogitic and blueschists suites document plate convergence along the eastern margin of Laurentia during the Taconian and Salinian (Acatecan) orogenic pulses, whereas that volcanosedimentary rocks from El Rodeo Formation are related to a rift process during Taconian time. Overprinting by a major Acadian-age tectonothermal event is suggested by existing geochronological data, which was accompanied by the intrusion of La Noria granite at high crustal levels. Amalgamation of the Cosoltepec Formation must have occurred after Silurian most probably during Carboniferous time and was accompanied by the emplacement of the Totoltepec stock. The present tectonic setting of the Acatlán Complex was ultimately achieved by amalgamation of the Magdalena-Chazumba suite during the final stages of Pangea assembly. The Early Jurassic

tectonothermal event affecting only the Chazumba and Cosoltepec units to produce the Magdalena Migmatite is related to the break-up of Pangea and the opening of the Gulf of Mexico.

The Acatlán Complex represents a major suture zone of convergence between Laurentian and Gondwanan assemblages and mirrors the structure and evolution of the Appalachian-Caledonian Chains of North America.

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## THERMOBAROMETRY OF THE HIGH-PRESSURE METAMORPHISM IN THE ACATLÁN COMPLEX

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Blueschists, eclogites and garnet-amphibolites are part of the Xayacatlan Formation, which protoliths have oceanic affinities. Thermobarometric studies in that unit draw a clockwise path evolving from blueschist, eclogite, epidote-amphibolite to greenschist facies. Temperature conditions are typical of low-temperature eclogites associated with subduction zones and with Alpine type retrograde path. Esperanza Granitoids is a complex suite made by Grenvillian gneisses, a metamorphosed sedimentary-volcanic sequence and Early to Middle Ordovician metagranites. Metamorphic conditions indicate a temperature range from 632ºC to 800ºC with pressures as high as 16.8 Kbars. P-T data indicate an evolution from eclogite, amphibolite to epidote-amphibolite facies. Metamorphic conditions and geologic frame are typical of medium-temperature eclogites generally associated with collision between continents or microplates. A middle Ordovician age (U-Pb zircon) obtained from a granitic dyke cutting the Xayacatlan Formation, that age postdates the first high-pressure metamorphic event. A second high-pressure event occurred in the Esperanza Granitoids after or contemporaneous with 440 Ma granite intrusions, which made part of that suite. Lower Silurian to Lower Devonian ages previously reported in both units could be related with later thermal readjusts during the exhumation process. By their metamorphic, chronologic and geologic characteristics, Xayacatlán Formation may be related to the Dunnage zone in northern Appalachians and the blueschists correlated with the New Brunswick subduction complex; while Esperanza Granitoids could be compared with rocks of the Humber zone of the same orogenic region. The orogenic phases can be related with those in the Caledonian orogeny originated by the development and closure of the Iapetus Ocean.

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## NEW GEOCHRONOLOGICAL AND STRATIGRAPHIC DATA RELATED TO THE PALEOZOIC EVOLUTION OF THE HIGH-PRESSURE PIAXTLA GROUP, ACATLÁN COMPLEX, SOUTHERN MEXICO

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The eclogitic rocks (Piaxtla Group) of the Acatlán Complex, southern Mexico, have been interpreted to be pre-Devonian suture elements. The Piaxtla Group has been inferred to encompass slices of oceanic lithosphere (mafic and ultramafic bodies) and continental crust (peraluminous sediments and granitoids) trapped in a subduction zone, deeply buried, and eclogitized during continental collision (Acatecan Orogeny) by Late Ordovician time. The Acatecan Orogeny was roughly correlated with the Taconian Orogeny in the Appalachians implying that the Piaxtla Group contains remnants of the Iapetus Ocean. However, our new U-Pb zircon data for the eclogites of Piaxtla Group in the San Francisco de Ásis area, north of Tehuitzingo, and similar results (Middleton et al., 2004), seem to indicate a tectonic evolution related to the destruction of the Rheic Ocean (rather than Iapetus) during the Alleghanian-Ouachita Orogeny.

The Piaxtla Group in the San Francisco area consists of lenses and boudins of eclogites (omphacite + garnet + quartz + rutile ± phengite ± epidote/zoisite) enclosed in a polyphase-deformed kyanite-phengite-garnet schist and interlayered phengite-garnet-rutile metagranitoids (Esperanza Granitoids). Although the group is strongly affected by retrogression related to exhumation, the mineral assemblages and textural relationships in the micaceous schist and metagranitoids indicate that these rocks also underwent eclogite-facies metamorphism. The Esperanza Granitoids at its type locality yielded a U-Pb zircon age of 440±14 Ma that we interpreted as the age of the high-pressure metamorphism and the syntectonic emplacement of the granitoids during the Acatecan Orogeny. In order to date more directly the eclogitic metamorphism, single zircon grains from the eclogites of the San Francisco de Ásis area were analyzed by SHRIMP.

U-Pb SHRIMP ages for zircon rims in the eclogites of San Francisco vary from 359±2 Ma to 345±5 Ma with an average age (10 data points in different grains) of 352±2 Ma. We also obtained a zircon core age of 442±2 Ma. The dates of 352 Ma for rims and 442 Ma for the core may be interpreted as the ages of the eclogitic metamorphism and crystallization of protolith, respectively, suggesting an Alleghanian affinity. This interpretation, however, contradicts a key but overlooked stratigraphic relationship whereby clastic and fossiliferous Upper Devonian beds (Otate and Patlanoaya formations) unconformably overlie the high-pressure rocks of the Piaxtla Group near Patlanoaya. Fragments of phengite schist and detrital phengite and rutile, eclogitic minerals, are common in psammitic beds of the Otate and Patlanoaya formations. Thus, we consider that the 442 Ma age of the zircon core agrees with the Late Ordovician age for the interlayered Esperanza Granitoids, and also dates the eclogitic metamorphism in San Francisco area. The Late Ordovician age for the eclogites and the stratigraphic data reinforce the existence of a pre-

Devonian collisional event as formerly proposed. The zircon rim ages may be related to a poorly understood early Mississippian tectonothermal event that occurred during the exhumation process.

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## EL SIGNIFICADO TECTÓNICO DE LOS MINERALES PESADOS DE LA FORMACIÓN TECOMATE Y DE ALGUNAS UNIDADES INFERIORES DEL COMPLEJO ACATLÁN Y DE SU COBERTURA

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Los minerales pesados de la Formación Tecomate y análisis U-Pb por LA-ICPMS obtenidos para sus zircones detríticos en la región de Acatlán-Tehuitzingo, Puebla, junto con los minerales pesados de los Granitoides Esperanza, Formación Cosoltepec y una unidad metasedimentaria que se correlaciona con la Formación Ahuatlán del Paleozoico Inferior, discordante con respecto a los Granitoides Esperanza, sugieren una procedencia local y otra relacionada a un margen continental para los sedimentos de la Formación Tecomate. Los minerales principales identificados son zircón, apatito, turmalina, rutilo, titanita y granate, cuyas características revelan fuentes granulíticas (zircón) y rocas de alta presión metamórfica (rutilo, granate), magmáticas (apatito, turmalina, titanita), así como de granos reciclados.

Los datos U-Pb para los zircones detríticos de la Formación Tecomate se agrupan en las siguientes poblaciones: a) Cámbrico-Ordovícico (460-500 Ma), b) Mesoproterozoico (900 a 1650 Ma), c) Neoproterozoico (729 y 879 Ma) y d) una muy escasa que va de los 1620 a los 1921. Con base en las características de los minerales pesados y la edad de sus zircones la primera población tiene como fuente de aporte los metagranitos ordovícicos de los Granitoides Esperanza. Para los zircones Mesoproterozoicos su procedencia más probable es el Complejo Oaxaqueño, lo que es reforzado por la presencia de cuarzo rutilado, fragmentos de gneis granulítico y mesopertitas. El resto de las poblaciones proviene de zircones retrabajados de las unidades inferiores del Complejo Acatlán.

Por otro lado, la unidad metasedimentaria, cubierta en discordante por la Formación Tecomate, contiene minerales pesados derivados de fuentes metamórficas de alta presión expuestas en el área (rutilo rodeado de titanita, turmalina, granate y zircones zonados), algunos de ellos también presentes en la Formación Tecomate. Además, la Formación Otate, base de la cobertura paleozoica en el área de Patlanoaya, con una edad mínima del Devónico tardío y discordante con respecto al resto de las unidades inferiores del Complejo Acatlán, también contiene minerales derivados de este último, lo cual implica su exposición durante el Devónico.

Estos datos confirman la existencia de un evento de colisión predevónico (Orogenia Acateca) además del evento pérmico que afectó a la Formación Tecomate.

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## XAYACATLAN FORMATION, ACATLAN COMPLEX, SOUTHERN MEXICO: TECTONIC IMPLICATIONS

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The Xayacatlan Formation is a part of the Piaxla Group, the upper allochthonous slice of the Acatlan Complex. The formation has been interpreted as an ophiolitic sequence and the Lower Paleozoic vestige of either the Iapetus or Rheic oceans. It consists of high-grade mafic-ultramafic and interlayered pelitic and siliceous metasedimentary rocks that are structurally overlain by high-pressure metagranitoids and migmatites (Esperanza granitoids). All of these rocks are thought to have experienced eclogite facies metamorphism and polyphase deformation and were obducted during the Late Ordovician-Early Silurian Acatecan Orogeny over the Petlalcingo Group, a thick siliciclastic sequence interpreted as a para-autochthonous trench and forearc deposit, that ranges in metamorphic grade from lower greenschist to upper amphibolite facies. The Esperanza granitoids are syntectonic with respect to the emplacement of the nappe and yield a 440 „b 14 Ma age (U-Pb zircon age). This nappe pile is unconformably overlain by the volcano-sedimentary Tecomate Formation, which consists of conglomerate, sandstone, slate, within-plate mafic and felsic volcanic rocks, and limestone that contains Pennsylvanian-Early Permian conodonts. It was intruded by the 287 b 2 Ma calc-alkaline Totoltepec pluton before being strongly deformed in S-vergent thrust zones and dextral N-S shear zones within lower greenschist facies metamorphic conditions. These rocks are unconformably overlain by the Lower Permian Matzitzi Formation, which also oversteps the Oaxacan Complex.

Re-examination of the type area of the Xayacatlan Formation reveals that it consists of a mafic igneous sequence intruded at 442 „b 1 Ma (U-Pb zircon age) that underwent upper amphibolite facies metamorphism before cooling through 500-550°C by 414 b 15 Ma (40Ar/39Ar hornblende age). This was followed by a lower greenschist facies overprint that has been dated elsewhere at 288 „b 14 Ma (K-Ar muscovite age). Although generally thoroughly recrystallized, some of the amphibolites appear to preserve igneous textures. Their major and trace elements are rather similar to modern igneous rocks, suggesting that they also preserve primary compositions. The amphibolites have typical tholeiitic characteristics, and resemble continental tholeiites rather than rocks with oceanic affinities. In contrast to earlier studies, these rocks are interpreted here as part of a plutonic complex emplaced in continental crust, possibly the underlying Oaxacan Complex. The Xayacatlan Formation is thus inferred to represent an obducted slice of the continental lithosphere.

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## REVISED GEOLOGICAL HISTORY OF THE GRANJENO SCHIST, CIUDAD VICTORIA, MEXICO: CORRELATIONS WITH THE ACATLÁN COMPLEX (SOUTHERN MEXICO) AND PALEOGEOGRAPHIC IMPLICATIONS

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Exposed in the core of a NNW-trending frontal anticline of the Laramide fold-thrust belt of northeastern Mexico, the Paleozoic Granjeno Schist comprises a polydeformed assemblage of metasedimentary and metavolcaniclastic rocks and serpentinized mafic-ultramafic units inferred to represent an ophiolitic mélange and/or slices of oceanic lithosphere. The earliest deformation (D1) produced greenschist facies cleavage and folds that predate emplacement of a leucogranite at 351±54 Ma (containing xenoliths of the Granjeno) and may record obduction of this oceanic unit. Subsequent deformations (D2a-c) produced three superposed, low-grade, fabric elements that are inferred to record the progressive tectonic juxtapositioning of the Granjeno Schist against the ~1 Ga Novillo Gneiss by NNW-directed dextral shear under conditions of decreasing temperature. Cooling ages of 313±13 Ma and 300±4 Ma are considered to date the onset of dextral motion, which continued into the Permian. These events may be correlated with the Late Paleozoic events recorded in the Acatlán Complex that have recently been linked with the closing of the Rheic Ocean and the oblique subduction of the paleo-Pacific Ocean beneath western Pangea.