Geof. Int. Vol. 20-3, 1981, pp. 177-202.

METAMORPHIC BELTS OF SOUTHERN MEXICO AND THEIR TECTONIC SIGNIFICANCE

F. ORTEGA-GUTIERREZ*

RESUMEN

Los terrenos cristalinos del sur de México son subdivididos en los siguientes complejos: Oaxaqueño (Proterozoico medio), Acatlán (Paleozoico), Xolapa y "Tierra Caliente" (¿Paleozoico?-Mesozoico).

El primero consiste en gneises bandeados de la facies de granulita, con una parte basal de ortogneis anortosítico gabroide y una parte superior de paragneises calcáreos, pelíticos y cuarzo-feldespáticos, que incluyen varios intervalos de charnockita. La edad, deformación, estratigrafía y metamorfismo del Complejo Oaxaqueño son interpretados en términos de un ciclo tectónico grenvilliano. El complejo Acatlán polimetamórfico consiste en dos partes: (1) Una placa parautóctona formada por migmatita en la base, esquistos pelíticos y psamíticos con gabros diferenciados en la parte media, y metasedimentos cuarzosos sin carbonatos en la parte superior. (2) Una placa alóctona formada por rocas ofiolíticas eclogitizadas, junto con abundantes granitoides milonitizados, todo ello cubierto por metasedimentos flyschoides e inmaduros. El Complejo Acatlán se interpreta en términos de un ciclo Wilson del Paleozoico, relacionado con la apertura y cierre de un océano pre-Atlántico, mejor conocido como Iapetus en el sistema orogénico Apalachiano-Caledoniano.

Los complejos metamórficos Xolapa y "Tierra Caliente", de edad probablemente mesozoica, parecen representar respectivamente las partes infracortical (raíz) y supracortical de arcos magmáticos y cuencas sedimentarias asociadas, que se desarrollaron en respuesta a una subducción pacífica principalmente durante la fase mesozoica del régimen tectónico Cordillerano.

La construcción geológica gradual del sur de México se atribuye así a los regímenes tectónicos Grenvilliano, Apalachiano y Cordillerano, cada uno de los cuales dejó su inconfundible rúbrica en las rocas descritas brevemente en este trabajo.

* *Instituto de Geología, UNAM, 04510, México, D.F.*

ABSTRACT

Crystalline terranes of southern Mexico are subdivided into middle Proterozoic Oaxacan, Paleozoic Acatlán and Paleozoic(?)-Mesozoic Xolapa and "Tierra Caliente" complexes. The former consists of granulite facies banded gneisses, with a basal part of anorthosite-gabbro orthogneiss and an upper part of calcareous, pelitic and quartzo-feldspathic paragneisses, including several intervals of charnockite. The age, deformation, stratigraphic and metamorphic characteristics of the Oaxacan Complex are interpreted in terms of a Grenvillian tectonic cycle. The polymetamorphic Acatlán Complex consists of two parts: (1) a parautochtonous plate formed by migmatite at the base, pelitic and psammitic schist with layered metagabbro in the middle, and carbonate-free quartzose metasediments in the upper part. (2) An allochtonous plate formed by eclogitized ophiolitic rocks, together with abundant mylonitized granitoids, all covered by immature flyshoid metasediments. The Acatlán Complex is interpreted in terms of a Paleozoic Wilson cycle, related to the opening and closure of a pre-Atlantic ocean or Iapetus of the Appalachian-Caledonian orogenic system.

The Xolapa and "Tierra Caliente" metamorphic complexes, of most probable Mesozoic age, appear to represent respectively the polydeformed, infracrustal (roots) and supracrustal parts of magmatic arcs and related sedimentary basins, that developed in response to Pacific subduction mainly during the Mesozoic phase of the Cordilleran tectonic regime.

The geologic, gradual building of southern Mexico is thus attributed to the Grenvillian, Appalachian and Cordilleran tectonic regimes, each one of which left its unmistakable signature in the rocks briefly described in this paper.

INTRODUCTION

Geologically, southern Mexico probably is one of the most complex regions of the world. The crystalline rocks that constitute the local "basement" to the Phanerozoic sedimentary and volcanic sequences have recorded Precambrian through Mesozoic, and even Tertiary intense geological events. In addition, the paleogeography of this area has been a major problem for the Mesozoic reconstruction of Pangea eversince the work of Bullard and others (1965). And yet, eventhough there is a great need for detailed descriptions of these terranes, little progress in this direction has been achieved in the last two decades. The present paper thus aims at filling part of this gap in the understanding of the tectonic evolution of southern Mexico.

The following descriptions and preliminary tectonic interpretation of the principal metamorphic belts of southern Mexico, hopefully will provide a sounder geologic framework that may support or improve the evolutionary paleogeographic models of southern Mexico.

SUBDIVISION OF THE METAMORPHIC BELTS OF SOUTHERN MEXICO

Since the present author first attempted (Ortega-Gutiérrez, 1976) a three fold subdivision of the crystalline complexes of southern Mexico, continued research in the area (Ortega-Gutiérrez, 1981; Campa-Uranga, 1978; de Csema and Fries, in press; Carfantan, in press; Elías-Herrera, 1981) has permitted to increase to at least six the number of these belts (Fig. 1). However, because the writer is familiar only with four of these complexes (Oaxacan, Acatlán, Xolapa and "Tierra Caliente"), only these will be treated here. Their main geometric, lithological, structural, metamorphic, tectonic and geochronological characteristics known today are summarized in Table 1.

OAXACAN COMPLEX

Distribution and lithology.

This metamorphic belt is the oldest known (middle Proterozoic) in southern Mexico. Its absolute age (*ca.* 900-1100 m.a.) was established by K-Ar dating of pegmatitic micas (Fries *et al.*, 1962; Fries and Rincón-Orta, 1965) and by U-Pb isotopic studies of zircon from pegmatite and gneiss (Anderson and Silver, 1981; Ortega-Gutiérrez *et al.*, 1977). The most distinctive features of this belt are the granulite grade of metamorphism and the presence of large bodies of massive anorthosite.

The Oaxacan Complex (Fig. 1) trends northwesterly in the central part of the State of Oaxaca, defining a belt 50-100 km wide which is exposed continuously from southern Puebla to about 25 km inland from the Pacific coast opposite Puerto Angel. In the type area of central Oaxaca (Ortega-Gutiérrez, in preparation) it is more than 10 km thick and composed of two main parts; a basal suite of a layered anorthosite complex and an upper sequence of psammo-pelitic and calcareous gneisses and granulites, including several intervals of orthogneissic charnockitic to syenitic banded gneisses.

A simplified geologic map of the Oaxacan Complex as exposed between Oaxaca and Nochixtlán is presented in Fig. 2. The map includes a mylonite formation that marks the eastern limit of the complex, and a Paleozoic(?) intrusive granite. The anorthosite massif constitutes the apparent structural base of the Oaxacan Complex in this area. It is a body that had an inferred area of exposure of more than 400 km^2 (30 x 15 km), but was divided in two parts by the granite intrusion the lead-alpha date of which is 240 ± 30 m.a. (Fries *et al.*, 1966). The anorthosite has an intermediate composition, its main mineral being *andesine* with microcline, hypersthene, Fe/Ti ore, quartz, apatite and occasionally biotite as accesories. The relict megacrystic-ophitic texture apparent in various parts of the body demonstrates its magmatic origin.

A shell of related layered orthogneisses covers the anorthosite, reaching a maxim-

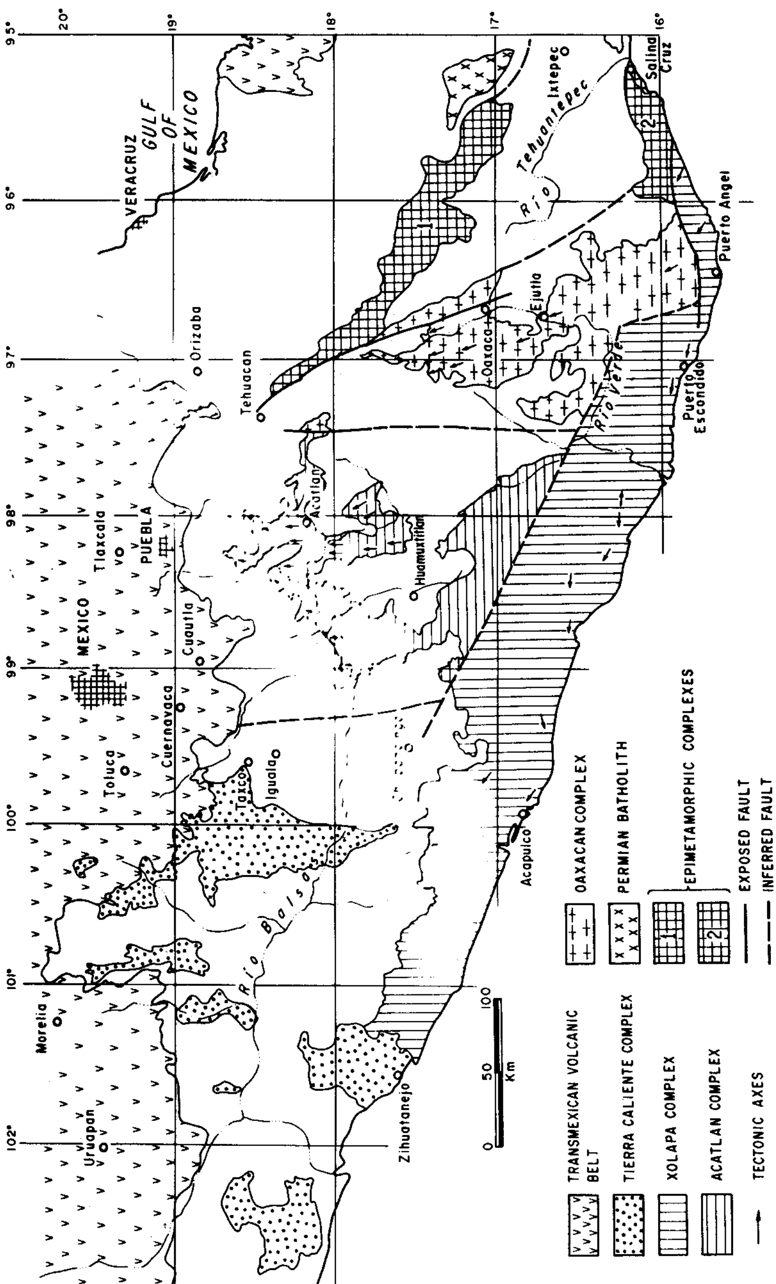

Fig. 1. Geologic map showing the distribution of crystalline terranes in southern Mexico.

MAIN FEATURES	OAXACAN	ACATLAN	XOLAPA	TIERRA CALIENTE
AGE	MIDDLE PROTEROZOIC	EARLY PALEOZOIC	PALEOZOIC-MESOZOIC?	MESOZOIC-PALEOZOIC ?
MIN. LENGTH	270 Km	270 Km	500 Km	250 Km
MAX. WIDTH	100 Km	170 Km	75 Km	100 Km
MIN. THICKNESS	17 Km	15 Km	10 Km	4 Km
APROX. AREA EXPOSED	10,000 Km^2	10,000 Km^2	20,000 Km^2	7,000 Km^2
SED. PROTOLITH	PLATFORM TYPE	PASSIVE CONTINENTAL MARGIN - OCEANIC	ISLAND ARC ?	ISLAND ARC
IGNEOUS PROTOLITH	THOLEITIC-ALKALIC	OPHIOLITIC	CALC-ALKALIC	CALC-ALKALIC
DOMINANT. DEF. STYLE	MONOPHASE	POLYPHASE	MONOPHASE ?	POLYPHASE
MAIN MET. FACIES	GRANULITE	PLURIFACIAL	AMPHIBOLITE	GREENSCHIST
MET. FACIES SERIES	MESOBARIC	POLYBARIC	HYPOBARIC	HYPOBARIC
SYNTECT. MYLONITES	UNKNOWN	ABUNDANT	RARE	RARE
MIGMATITES	RARE	RARE	ABUNDANT	UNKNOWN
SIALIC BASEMENT	UNEXPOSED	REWORKED ? IN PART OCEANIC	SIALIC ?	GRANITIC?
OROGENIC STYLE	ENSIALIC ?	WILSON CYCLE	CONTINENTAL MARGIN	CONTINENTAL MARGIN
MAIN ECONOMIC METALLIC MINERALS	Ti-P-Fe U-Th-Zr	LARGELY UNEXPLORED POTENTIAL Cu, Fe, Co, Ni	UNEXPLORED	MASSIVE AND VEIN POLYMETALLIC SULFIDES
STRUCTURAL PROVINCE	GRENVILLIAN	APPALACHIAN - CALEDONIAN	CORDILLERAN	CORDILLERAN

Table 1. Main crystalline terranes of southern Mexico and their principal geological characteristics.

um thickness of 2,000 m and a minimum of about 100 m. These gneisses are interbanded with the upper part of the anorthosite and vary in composition from ultramafic to ultrafelsic. Bands, lenses and irregular bodies of nelsonite (ilmenite/magnetite-apatite rock) and apatite-ilmenite-rich gneisses form the lower part of the orthogneissic shell, whereas gabbroic to granitic garnetiferous rocks dominate in the upper part. The bluish or violet color of quartz in these rocks is very distinctive.

The overlying paragneisses apparently were intruded by the anorthositic complex before the granulite facies metamorphism. This is borne out by the sharpness of the contact, presence of dikes passing from the anorthositic massif into the paragneisses, and by the absence of evidence indicating former contact relations such as tectonic or sedimentary.

Several formations can be distinguished in the paragneissic sequence, but they can be grouped in two units: the basal part is formed predominantly by calcium-rich banded gneisses that include widespread marble and scapolite-rich calc-silicate. Abundant, both graphite-rich and graphite-free granitic gneisses of unclear origin occur closely associated with the calcic units. The overlying unit includes distinctive pelitic gneisses rich in garnet, sillimanite, biotite, perthite and sometimes spinel. Several intervals of charnockitic banded gneisses occur in this upper part (Fig. 2).

Structure.

The entire Oaxacan Complex bears the imprint of a pervasive deformation represented by banding and foliation. These two features are parallel except in a few places, where their oblique intersection suggests structural complications. Later folding parallel to previous fold axes deformed banding and foliation. The dominant structural trend is NNW which is the constant direction of a penetrative *b lineation* (parallel to fold axes) with shallow to moderate plunge (*cf.* Kesler and Heath, 1970a). Local deviation of this lineation is normally due to rotational faulting or to diapiric(?) late movement of the anorthositic massif. The early folding style is one of extreme amplitude and isoclinal.

Later folding is open to closed in profile and with vertical to subhorizontal axial planes. The mylonitic formation shown in Fig. 2 has an apparent Oaxacan Complex protolith, but the age of the mylonitization is unknown and could be as young as Mesozoic. For this reason this pervasive deformation and retrogressive metamorphism of the Oaxacan Complex is left out of its Precambrian context.

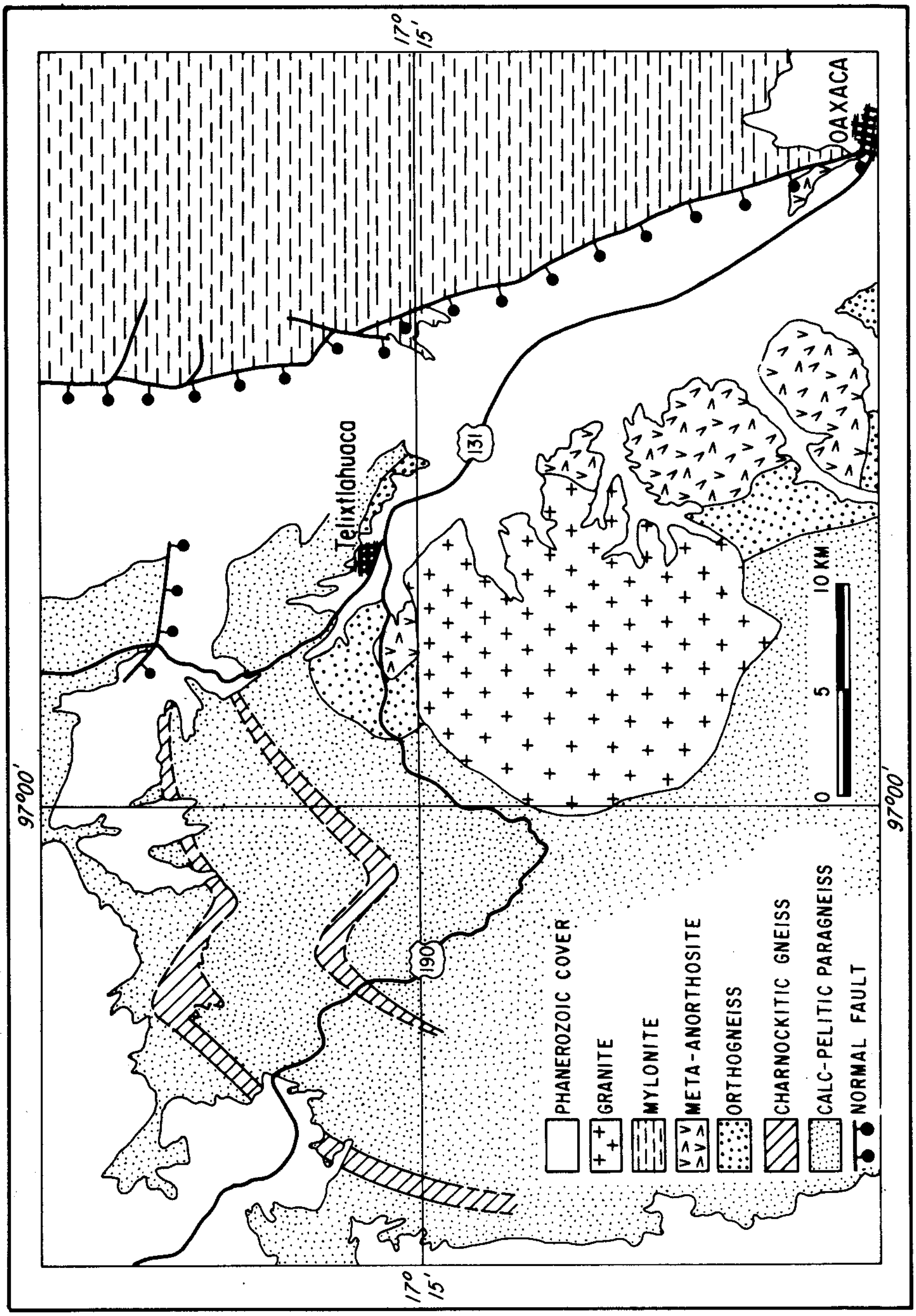

Fig. 2. Simplified geology of the Oaxacan Complex in its type-area of Central Oaxaca.

Metamorphism

Despite the apparent polyphase deformation of the Oaxacan Complex, only one penetrative metamorphism can be identified in the mineral assemblages of most lithologies. This metamorphism reached the granulite facies under temperatures and pressures prevailing in the lower crust.

The metamorphic recrystallization, as deduced from the textural-structural relations in outcrop and thin section, accompanied the folding events that produced both banding and foliation. This metamorphism also affected the massive and homogeneous anorthositic body, the original megacrystic structure of which was mostly replaced by a granoblastic, fine-grained metamorphic texture. Some rutile was formed from original ilmenite, while the rest of the igneous minerals (plagioclase, pyroxenes, and apatite) remained stable but recrystallized. The granulite assemblages of the gabbroic orthogneisses surrounding the anorthosite include abundant garnet and hypersthene, as well as minor clinopyroxene and spinel, suggesting intermediate pressure of formation (5-8 kb) at high temperatures (700-800^{o}C). The marbles and calc-silicates are characterized by assemblages rich in carbonates, scapolite, clinopyroxene, forsterite and wollastonite. The assemblage quartz-feldspar-garnet-sillimanite is widespread in the pelitic gneisses, again suggesting intermediate pressures of formation outside the stability field of the high-pressure aluminous silicate polymorph kyanite. Cordierite, on the other hand, is extremely rare.

Tectonic significance

The age and lithologies of the Oaxacan Complex are similar to those in vast areas of the Grenville Province and the Adirondack Mountains of the Canadian Shield. This correlation originally proposed by Fries *et al.* (1962) seems indeed valid, considering that widespread outcrops of "grenvillian" rocks exist along the entire Appalachian Province (King, 1959) and continue south into Mexico, where they come to surface in the States of Tamaulipas (Novillo Gneiss) and Hidalgo (Huiznopala Gneiss) (Fig. 3). The nature of these rocks in Mexico (Fries and Rincón-Orta, 1965; Ortega-Gutiérrez, 1978a) is similar to the Oaxacan Complex, and they seem to be connected beneath the Transmexican Volcanic Belt. This apparent continuity of the Precambrian complexes of eastern and southern Mexico would preclude important displacements across the Transmexican Volcanic Belt as proposed, for example, by Gastil and Jensky (1973).

The original supracrustal rocks of the Oaxacan Complex were rich in mature, anorogenic sediments, including some possible evaporites (Ortega-Gutiérrez, 1982) and apparently lacked in graywacke-andesite lithotectonic associations. This may be

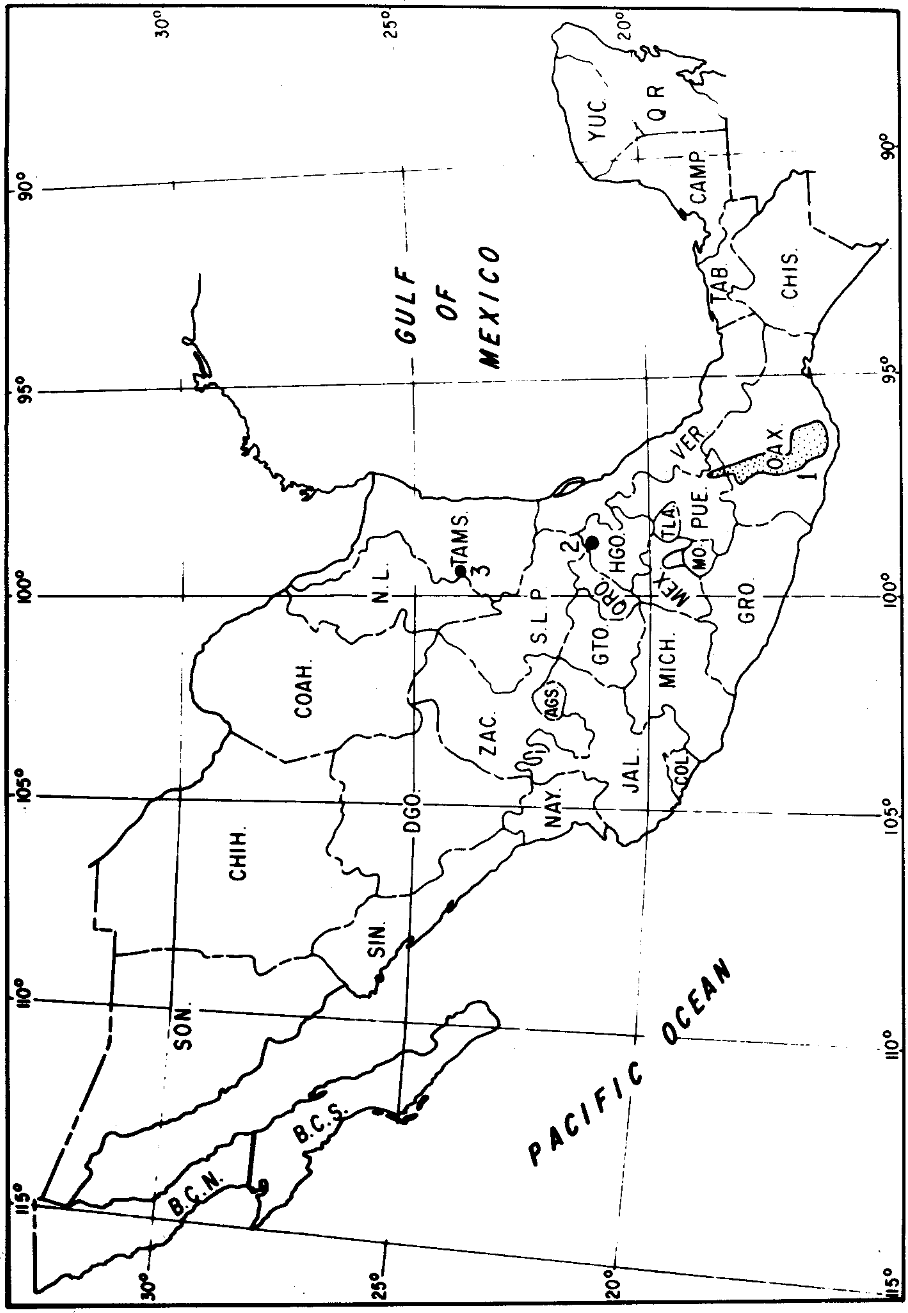

Fig. 3. "Grenvillian" outcrops in southern and eastern Mexico. 1. Oaxacan Complex. 2. Huiznopala Gneiss. 3. Novillo Gneiss.

interpreted in terms of an original continental rift or marine platform environment of deposition, that was later invaded by gabbroic-anorthositic magmas at deep levels in the crust.

The deformation and metamorphism following or accompanying this magmatic event could have been caused by the emplacement at great depth of these mantle-derived magmas or, perhaps as suggested by Dewey and Burke (1973) for the classical Grenville Province, by a mechanism of continental collision and nappe thickening of the crust. However, the deeply eroded nature and limited exposure of the Oaxacan Complex make rather difficult its tectonic interpretation.

Perhaps the most significant structural feature of the Oaxacan Complex is the presence of wide mylonitic belts at the contacts with the adjacent crystalline belts. About 40 km south of Tehuacán, the western limit of the Oaxacan Complex is exposed as a vertical shear zone more than 300 m wide that separates the latter from the Paleozoic Acatlán Complex. This fault has been interpreted (Ortega-Gutiérrez, 1978b) as one with a history of repeated movements at least since the Paleozoic. The eastern limit of the Oaxacan Complex is the Oaxaca Fault, a N-S trending complex fault zone formed by a belt of mylonitic rocks several tens of kilometers wide that apparently dips to the west, beneath the Oaxacan Complex. Its southern limit against the Xolapa Complex is exposed about 30 km north of Pochutla, State of Oaxaca. This limit is also marked by a belt of mylonitic linear tectonite several kilometers wide, the structural geometry of which implies an overthrusted position of the Xolapa Complex above the Oaxacan Complex.

Another important aspect of the geology and tectonics of the Oaxacan Complex is in reference to its "European" paleogeographic position during the Cambrian-Ordovician, as deduced from the nature of the trilobite fauna found in the Tremadocian Tiñu Formation that unconformably overlies the Oaxacan Complex (Pantoja-Alor and Robison, 1967; Pantoja-Alor, 1970). The Ollenid Province (Whittington and Hughes, 1974), existing as a unit at that time, is now widely separated and exposed in areas including western South America, North Africa, Oaxaca, Nova Scotia, Eastern Newfoundland, Western Europe, the Urals and Central Asia. The present position of the Oaxacan Complex in the American Continent on one hand, and its correlation with the Grenville Province of North America on the other, imply the operation of a Wilson cycle in the Paleozoic and the extinction of a correspondant ocean, the vestiges of which are indeed present in southern Mexico forming part of the Acatlán Complex as described below.

Finally, it should be pointed out that the mylonitic belts fringing on three sides the Oaxacan Complex represent intense shear movements of still unknown age, magnitude and sense, the rotational effects of which will have to be considered when paleomagnetic techniques are applied in the area for the analysis of its past tectonic displacements.

ACATLAN COMPLEX

Geometry, lithologies and age

This crystalline terrane (Fig. 1) extends for some 200 km west of the Oaxacan Complex, and southerly from the Transmexican Volcanic Belt to within 60 km from the Pacific coast. It is the most complex of all metamorphic belts of southern Mexico. It comprises a pile of rocks more than 15 km thick that consists of a contrasting suite of petrographic types, varying from slate to migmatite, granite to ultramylonite, and gabbro to eclogite, including a tectonized ophiolite. This complex has been formally named Acatlán Complex (Ortega-Gutiérrez, 1978c) and subdi vided into two lithostratigraphic subgroups: Petlalcingo and Acateco. The former is considered a parautochtonous assemblage of clastic metasediments, uncertain metavolcanic rocks and a few intrusions of mafic-ultramafic composition. This assemblage was metamorphosed on several occasions to become schists and migmatites. The Acateco subgroup, by contrast, constitutes an allochtonous plate overlapping the former (lower) subgroup for a minimum distance of more than 100 km along a folded previously horizontal contact. It is composed of three formal lithostratigraphic units: (1) metaophiolite (Xayacatlán Formation), (2) mylonitized granitoids (Esperanza Granitoids) and (3) a coarsely clastic unit (Tecomate Formation) that was unconformably deposited over the other two units, apparently before movement of the nappe sheet took place. Consequently it is also deformed and metamorphosed.

Since a detailed stratigraphic description of the Acatlán Complex is already published (Ortega-Gutiérrez, 1978c), only a brief summary of the extremely varied petrography of these rocks is presented here. The Petlalcingo Subgroup consists of three units, Magdalena Migmatite in the bottom, Chazumba Formation in the middle, and Cosoltepec Formation on top. The migmatite forms the lowest exposed levels of the Acatlán Complex; it is of quartzo-feldspathic-calcareous-pelitic composition. The neosomatic (anatexitic) component is granitic to granodioritic, whereas the paleosome (protolith) was probably a succession of calcareous shales, sandstone, shale and dolomite. The overlying Chazumba Formation is composed of quartzose biotite schist and impure quartzite enclosing a metagabbroic layered complex of small size. The Cosoltepec Formation is lithologically diverse. Interlayered amphibolite-quartzite forms the basal parts, two-mica garnet schist dominates in the middle, and quartzose phyllites and quartzites compose the upper and more characteristic part of this unit.

The Acateco (allochtonous) Subgroup consists at the base of a polymetamorphic and dismembered ophiolite (Xayacatlán Formation) consisting of completely serpentinized and mylonitized peridotite, layered metagabbro and siliceous, ironrich metasediments interlayered with eclogitized, probably metabasaltic rocks.

The ophiolitic rocks are overlain by the Esperanza Granitoids, a suite of mylonitized and metamorphosed granitoids which in certain areas are intimately mixed with greenstones of the ophiolitic Xayacatlán Formation. The granitoids form a cataclastic complex composed of numerous bands of recrystallized mylonite-ultramylonite-protomylonite, the former granitic nature of which can be recognized only by ubiquitous pegmatite and because in rare areas of low strain, the granitic character is obvious.

The upper part of the allochtonous plate is represented by a low grade, metamorphosed clastic unit (Tecomate Formation) consisting of psammite-metaconglomerate, and marmorized limestone with crinoid or cistoid fragments. It overlies with an apparent unconformity the Esperanza Granitoids; the unconformity is, however, obliterated by post-depositional deformation and metamorphism.

Within the Acatlán Complex the author (Ortega-Gutiérrez, 1978c) has included a deformed trondhjemitic pluton (Totoltepec Stock) and a swarm of undeformed granitic, aplitic, and pegmatitic sills and dikes (San Miguel Dykes). A lead-alpha date in the sodic pluton suggests an Ordovician age (Fries *et al.*, 1970), whereas Rb-Sr dates in the San Miguel Dykes (M. Ruiz-Castellanos, personal communication) suggest a Triassic age.

The age of the Acatlán Complex is Paleozoic; paleontologic, stratigraphic and radiometric data (see Ortega-Gutiérrez, 1978c, for a summary) support this age assignment. More recent isotopic data (de Cserna *et al.*, 1980; M. Ruiz-Castellanos, personal communication) have identified "Taconian" and "Acadian" phases of deformation-metamorphism in the geologic history of the Acatlán Complex.

Structure

Four regional phases of deformation affected the Acatlán Complex probably in pre-Carboniferous time. Additional, less penetrative phases of deformation were probably related to orogenic movements in late Paleozoic, Jurassic and Cretaceous-Tertiary times. The two earlier phases of deformation imprinted the foliated structure to the Acatlán Complex and its characteristic isoclinal microfolding. These phases apparently were not coaxial. The present axial direction of the second folding varies due to younger deformation from NW, N and to NE. A third deformation phase was coaxial with the second, but along a subvertical axial plane cleavage that transected and locally transposed the earlier foliations. The N-S predominant structural grain shown today by the Acatlán Complex in its type area is the product of this folding phase. The fourth phase is represented by kink bands and cross folds of open to closed geometry, and was not accompanied by any axial plane foliation or metamorphism, at least in the observed upper structural levels of the Acatlán Complex.

The polyphase deformational style of the Acatlán Complex resulted in an extremely intricate structural geometry with the abundant generation of fold interference patterns, including the four classes recognized by Ramsay (1967, p. 531) in similar orogenic terranes. Flattening and stretching of the Acatlán Complex rocks are clearly expressed by rodding, mullion, boudinage, deformed pebbles and tension gashes, whereas intense and repeated shearing is demonstrated by the syntectonic rotation of garnets and extreme thinning of the microfold limbs, or complete detachment of their hinges. The constant, northward plunge of regional folding and lineation in the Acatlán Complex, probably points in the local direction of crustal thickening.

Metamorphism

If the structure of the Acatlán Complex is difficult to unravel, its metamorphic evolution is even more complex, for besides the syntectonic metamorphism corresponding to each penetrative deformation (3 phases), two additional metamorphic events under static conditions occurred following the first and the third foldings. To make things even more complex, it seems that in part very different metamorphic histories were registered in the parautochtonous and allochtonous plates forming the Acatlán Complex.

The tectonic superposition of these two plates even reversed the metamorphic isograds, locally, for example bringing ophiolitic rocks of the eclogite facies on top of metasediments of the low greenschist facies. The metamorphic history of the lower plate is dominated by a single, protracted metamorphic event, the thermal culmination of which occurred when all penetrative deformation had ended. The volume affected by this event has the form of a dome (Ortega-Gutiérrez, 1975), the isograd pattern of which indicates a paleogeothermal gradient of the order of 40°C/km. In the core of this dome, the rocks were migmatized under upper amphibolite facies, whereas the higher points of the thermal structure (biotite-chlorite isograd) invaded the ophiolitic allochton.

In contrast, a minimum of four discrete metamorphic events characterizes the upper, allochtonous plate. The most distinctive metamorphism developed under high pressure and low to moderate temperature, most probably within an active

Cambro-Ordovician(?) subduction zone. This is supported by the petrologic characteristics of the eclogitized rocks, that were classified (Ortega-Gutiérrez, 1974) in Group C of Coleman and others (1965), on the basis of thermochemical calculations and the presence in them of rare glaucophane and ubiquitous barroisite. Intense retrogression in the greenschist facies occurred during transport of these rocks over the continental edge and later, during subsequent deformation related to the third folding episode.

Tectonic significance

The Acatlán Complex bears indisputable evidence of a geologic evolution related to the opening and closing (Wilson cycle) of a Paleozoic ocean basin. Elsewhere this ocean has been called Proto-Atlantic (Wilson, 1966) and Iapetus (Harland and Gayer, 1972). The described lithologies, structures and petrology of the Acatlán Complex can be ordered sequentially: the Petlalcingo Subgroup can be considered as deposits related to a passive continental margin, probably located along the paleoamerican side of that Paleozoic ocean. The ophiolitic Xayacatlán Formation of the Acateco Subgroup represents the vestiges of this ocean in southern Mexico. Its subsequent high pressure metamorphism reflects transport into a main subduction zone, where Iapetus and related seas were eventually consumed. The closing stages and final collision of the continental masses (Paleoamerica and Paleoeuroafrica) was neatly registered by the advance of the ophiolitic nappe over the American continental margin. The consequent tectonic thickening of the crust then resulted in the intense metamorphic reworking of the basement and its cover; both were buried under the edge of the leading eastern continent. The migmatization of the Petlalcingo Subgroup and the third folding episode can be related to the final suturing (Devonian?)of the two continental masses formerly separated by an ocean.

This evolutionary orogenic model for the Acatlán Complex leaves, however, some important problems unsolved. One such problem is the apparent absence of late Paleozoic strata in the entire cover of the Acatlán Complex. The yet poor timing of the principal tectonothermic stages of this crystalline belt, therefore, provides ample space for speculation regarding the precise time of final penetrative deformation of the Acatlán Complex during the Paleozoic. The oldest unconformable sequence deposited over this belt is composed of marine sediments and continental red beds of Early to Middle Jurassic age.

However, in the Los Reyes Metzontla-San Luis Atolpotitlán area, located some 40 km south of Tehuacán in the State of Puebla, late Paleozoic continental and marine sedimentary rocks (Matzitzi Formation) occur together with Precambrian gneisses of the Oaxacan Complex, and mylonitic schists and granitoids of the Acatlán Complex. Unfortunately, whereas the contact relations between that last two units are clearly known as a high-angle shear zone, the tectonostratigraphic relations of the Paleozoic Matzitzi Formation with either of the two crystalline terranes are not, in the writer's opinion, definitely established. Most studies in the area, however, favor the Matzitzi-Acatlán Complex contact of this region as a major unconformity (Hernández-Estévez, 1980), despite the total absence in the basal conglomerate of Matzitzi Formation of clastic elements washed from the Acatlán or Oaxacan Complexes.

XOLAPA COMPLEX

This crystalline terrane, eventhough is the most extensive of the four principal belts of southern Mexico, is the least known. After its formal definition and description in its type area between El Ocotito and Acapulco, Guerrero, more than 15 years ago by de Cserna (1965), very little additional information on the geology of the Xolapa Complex is available (Klesse, 1968; Kesler, 1973; de Cserna *et al.,* 1974a; Guerrero *et al.*, 1978).

The following account on the geology of the Xolapa Complex is thus very preliminary, based mainly on information obtained during several reconnaissance traverses made by the writer in the last years.

Distribution, lithology and age

The Xolapa Complex defines a WNW-trending belt more than 600 km long and 50-150 km wide which runs parallel to the Pacific continental margin. The predominant rocks are middle an upper amphibolite facies migmatites, gneisses and schists, in that order of abundance. Lower grade rocks, however, were included in the original definition. These lithologies were later intruded by bodies of approximately granite to granodiorite composition and Mesozoic and Tertiary ages. It is interesting to point out that a very detailed study in a small area at Puerto Escondido, Oaxaca (Sánchez-Rubio, 1972), however, demonstrated the gradational nature that exists among most of these units, including some of the younger intrusive granites.

In many places, swarms of mafic dikes and pegmatitic veins exhibit not only a synplutonic behavior relative to the enclosing granite or gneiss, but they may become an integral part of the banded migmatitic structure.

The Xolapa Complex, thus, could be interpreted in terms of a continuous plutonic evolutionary process due to the wholesale ascent, passage and emplacement of subcrustal magmas and the consequent fusion and migmatization of the local crust.

The section along the Mexico-Acapulco Highway south of Tierra Colorada, as pointed out already by de Csema (1965), exposes gneiss and migmatite, but thick beds of marble and amphibolite are also characteristic. The gneiss units are of biotite granodiorite or homblende-biotite diorite composition and commonly exhibit inclusions, some of which are clearly metasedimentary xenoliths.

A rather spectacular outcrop of aluminous migmatite is present at La Venta, near Acapulco. Here extremely abundant crystals of sillimanite up to 10 cm long together with cordierite, biotite and rare, relict kyanite constitute most of the rock. This suggests that the rock is a *restite* left out as the refractory product of intense anatexis of pelitic sediments. Similar rocks are present in other places.

A second section across the Xolapa Complex east of Acapulco, on the road Tierra Colorada-Ayutla-San Marcos, consists predominantly of granitic orthogneisses and banded migmatite. A few intervals of sillimanite-cordierite-rutile-biotite pelitic metasediment occur isolated in the quartzo-feldsphatic units. The presence of a gabbroic layered intrusion could belong to or be intrusive into the Xolapa Complex.

Between Pinotepa Nacional and Putla, the Xolapa Complex is formed mostly by migmatite, with intrusions of undeformed, tabular granitoids. The section along Puerto Escondido to Oaxaca is also formed predominantly by migmatite, part of which is metasedimentary because the common presence of marble. Between Puerto Escondido and Puerto Angel in the State of Oaxaca, the gneissic rocks of the Xolapa Complex altemate with several undeformed plutons of granitic-dioritic composition. The most narrow section some 30 km across the Xolapa Complex is exposed between Puerto Angel and Pochutla. Here it consists of calcium-rich migmatite, banded gneiss, biotite schist, some marble and intrusive granitoids. Finally, along the coast from Puerto Angel to Salina Cruz, the Xolapa Complex crops out intermittently between large intrusive granitoids and Late Cretaceous flysch (J. C. Carfantan, personal communication).

The age of the Xolapa Complex has been an elusive problem despite many efforts to date the sequence by isotopic-radiometric methods (de Csema *et al.*, 1962; de Csema *et al.*, 1974a; Halpern *et al.*, 1974; Guerrero-García *et al.*, 1978) and by geological inference (de Csema, 1965; Kesler and Heath, 1970b; Ortega-Gutiérrez, 1976). So far, a spread of ages from the Cambrian to the Tertiary has been obtained by radiometric dating, whereas Precambrian or Paleozoic ages have been proposed based on geological correlation and stratigraphic (apparent) position.

Structure

Lack of mapping of the Xolapa Complex permits here only to point out some broad generalizations. Gneissic foliation is the dominant structural feature of the

Xolapa Complex, and its regional direction, contrary to common belief, is roughly parallel to the Pacific margin (*i.e.* WNW). The dip of this foliation may be either to the SW or NE. Lineations also trend parallel to the coast (Kesler, 1973) and are more common in the orthogneisses defined by mineral alignment. Plunge ranges from moderate to steep. Evidence of polyphase, penetrative deformation is rarely apparent along the traverses made, but this may be due to poor detailed observations and obliteration by the last distorsions.

The intersecting structural trends of the gneissic and schistose components of the Xolapa Complex at its type-locality (de Csema, 1965, p. 49) is, in the writer's opinion more apparent than real, and probably due to insufficient structural measurements, for a lot more of these are needed to characterize the complex structural geometry of this terrane.

Another important structural observation is the not uncommon presence of mylonitic shear zones in the orthogneisses, which suggests a syntectonic mode of emplacement of the latter.

Metamorphism and tectonic significance

Mineral assemblages in calcareous (with wollastonite), mafic (with cummingtonite) and pelitic (with cordierite-sillimanite-andalusite) rocks, characterize the Xolapa Complex as a low pressure/high temperature belt, typical of the Circum-pacific orogenic regions. The unpaired nature of the Xolapa Complex (oceanic crust is immediately exposed to the south) is certainly due to truncation of the continental margin of southern Mexico (de Csema, 1967; Karig *et al.*, 1978). It is interpreted here that the missing high pressure/low temperature belt has been displaced laterally (*i.e.* towards Central America or Baja California) or subhorizontally beneath the structural frame of the Sierra Madre del Sur. The low P/T Xolapa Complex, with its abundant migmatite, deformed granitic-dioritic-gabbroic bodies and the myriads of mafic-to-felsic dikes and veins, probably represents the exposed roots of an ancient volcanic arc (*cf.* Halpern *et al.*, 1974) supported at least in part by continental lithosphere. Strontium isotopic data in the Xolapa Complex (Halpern *et al.*, 1974), support this view.

This tectonic interpretation is compatible with a mainly Mesozoic age for the Xolapa Complex, which is, therefore, visualized as the orogenic expression of oceanic lithosphere subduction related to a Circumpacific tectonic regime.

"TIERRA CALIENTE COMPLEX"

Distribution, lithology and age

The metamorphic rocks exposed mainly in the southern slopes of the Balsas River Basin and beyond the southern limits of the Transmexican Volcanic Belt (Fig. 1), have been mapped with several formal or informal names: Taxco Schist (Fries, 1960), Taxco Viejo Greenstone (Fries, 1960), Ayotusco Formation (Díaz, in press) and "the volcano-sedimentary metamorphic sequence of Teloloapan-Ixtapan de la Sal" (Campa-Uranga *et al.*, 1974). Although lithologies may be of different origin (*i.e.* igneous and sedimentary) and could be separated by profound unconformities (*cf.* Flores, 1936, p. 1014; Elías-Herrera, 1981; Parga-Pérez, 1981; de Cserna, 1978, and in press), or fundamental faults, they exhibit some unifying characteristics, such as the low grade of metamorphism, "eugeosynclinal" aspect and an apparent structural simplicity. For these reasons here a common name is used to refer to all these rocks as a complex, until better geochronology and mapping establish their true geological relationships. The informal name "Tierra Caliente" complex ("hot land complex") has been chosen because it is exposed mainly within a region where hot climate prevails. This belt, as shown in Fig. 1, comprises rocks of different ages including some Cretaceous, which have not been separated from the more thoroughly reconstituted terranes.

Similar lithologies, however, seem to be present in southern Mexico at Ixcuinatoyac, Guerrero (Klesse, 1968), Petatlán, Guerrero (de Cserna *et al.*, 1978), Arteaga, Michoacán (Múgica, 1980) and Tzitzio-Huetamo, Michoacán (Mauvois *et al.*, 1976). Further correlations with the low-grade metamorphic rocks of Guanajuato (Guiza, 1949) and Zacatecas (Burckhardt and Scalia, 1906; McGehee, 1976) in central and northern Mexico are not warranted at this stage in view of the still rather poor dating of all these terranes.

The low grade of metamorphism that in general affected the "Tierra Caliente" complex makes simple the identification of its original rocks. They comprise a sequence of interbedded sedimentary and volcanic units. The former are predominantly shale and tuffaceous graywacke, and among the volcanics andesitic rocks and felsites predominate.

Regarding the age or ages involved in the evolution of this complex very little is known. In the original definition of the Taxco Schist and Taxco Viejo Greenstone (Fries, 1960), a Paleozoic age was tentatively assigned to the former and a Triassic one to the latter. The finding of ammonites within a volcano-sedimentary sequence at Ixtapan de la Sal, State of Mexico, and its correlation with the Taxco Schist, and Taxco Viejo Greenstone (Campa-Uranga *et al.*, 1974) led these authors to suggest younger Jurassic-Cretaceous ages for the entire sequence. Similarly, Aptian ammonites were found in a mildly metamorphosed sequence at Campo-Morado, Gue-

IY

rrero (Burckhardt, 1930, p. 158) as well as Jurassic (de Cserna, 1978, p. 10) within the outcropping area of the "Tierra Caliente" complex. However, radiometric dating (lead-alpha) of a meta-rhyolite bed within the Taxco Schist (de Cserna *et al.*, 1974b) gave a Precambrian grenvillian age (1110 ± 120 m.y.). Further investigation by Campa-Uranga (1978) insisted on assigning a Jurassic-Cretaceous age to the entire "Tierra Caliente" complex on the basis of alleged biostratigraphic dating. On the other hand, de Cserna (1978) included part of these metamorphic rocks under the heading of Precambrian (?)-Paleozoic, and Elías-Herrera (1981) and Parga-Pérez (1981) added important field geological evidence that pre-Jurassic basement is involved in the tectonic evolution of the "Tierra Caliente" complex. Finally, late Paleozoic radiometric data are available from units comparable to the "Tierra Caliente" complex exposed in Petatlán, Guerrero (de Cserna *et al.*, 1978) and Arteaga, Michoacán (Múgica, 1980, personal communication) in southern Mexico. It is concluded here from these rather scattered data that the "Tierra Caliente" complex represents a composite orogenic terrane, the tectonothermic evolution of which was probably initiated in the upper half of the Paleozoic and continued well into the Cretaceous.

Metamorphism

Until recently the grade of metamorphism of these rocks was generally set in the chlorite zone of the greenschist facies (Fries, 1960; Díaz, in press; Campa-Uranga *et al.*, 1974; Colorado-Liévano, 1979), and locally in the prehnite-pumpellyite facies (Díaz-García, in press). The recent discovery, however, of an area with amphibolite facies rocks in the "Tierra Caliente" complex between Tejupilco and Zacazonapan, State of Mexico (Elías-Herrera, 1981 and Parga-Pérez, 1981), for the first time permitted the local petrotectonic characterization of the baric type of regional or orogenic metamorphism that affected this complex. Presence of cordierite and rapid succession of isograds in that area suggest high geothermal gradients typical of the low pressure/high temperature belts (*cf.* Miyashiro, 1961, 1972, 1973; Zwart, 1967). On the other hand, the reported presence of minerals such as *pumpellyite* and *phengite* (Díaz-García, in press) and the recent finding of *piedmontite* and *stilpnomelane*(?) by this writter in the Taxco Viejo Greenstone, together suggest the existence of rocks affected by a high pressure/low temperature metamorphism, probably in relation to a trench subduction tectonic regime, contemporaneous with the arc magmatism and sedimentation which most of the "Tierra Caliente" complex represents.

The metamorphic evolution of the lower structural levels of the "Tierra Caliente" complex is, however, polytectonic. The detailed study of Elías-Herrera (1981) demonstrated the effects of four phases of intense metamorphism, the third one of which reached the amphibolite facies under static conditions. The earlier two phases were syntectonic with intense shear isoclinal folding, and in the greenschist facies. The fourth phase was retrogressive.

Structure

The structure of the "Tierra Caliente" complex is very poorly known. Its polyphase deformation was first pointed out by Fries (1960) and later corroborated by Campa-Uranga and others (1974), Campa-Uranga (1978), Colorado-Liévano (1979), Elías-Herrera (1981), Parga-Pérez (1981) and de Cserna and Fries (in press). However, the geometry and kinematics of the up to four phases of folding and the generation of two distinguishable penetrative foliations, have not been determined in detail. Axial directions such as NE or N-S for the first and third foldings respectively have been mentioned (Colorado-Liévano, 1979), but a NW direction for the third folding has been locally established by detailed mapping (Elías-Herrera, 1981; Parga-Pérez, 1981). Probably the most significant fact about the structural geometry of the "Tierra Caliente" complex is the prevailing low angle inclinations of its regional foliation. This, strongly suggests the existence of large scale recumbent folds or nappes corresponding to the first and second episodes of deformation. The dominant direction of tectonic transport or polarity, though essential to the understanding of the tectonic history of the "Tierra Caliente" complex, has not been determined.

Tectonic significance

Geologic features of the "Tierra Caliente" complex, such as abundance of siliceous and andesitic volcanics, graywackes and black shale, baric types of metamorphism, intense polyphase deformation and a most probable Mesozoic age, strongly suggest, if not demonstrate, the Pacific tectonic affinities of this complex (see also Campa-Uranga *et al.*, 1974; Campa-Uranga, 1978). However, the unsuspected complexities in metamorphic history and deformation found recently by Elías-Herrera (1981) and Parga-Pérez (1981) in the Tejupilco and Zacazonapan areas, merit strong consideration for a possible earlier initiation of sedimentary and tectonic activity during the Paleozoic (de Cserna, 1978; and in press). More specifically, perhaps a most significant tectonic feature of the "Tierra Caliente" complex refers to its metamorphic framework. The very high geothermal gradients (70-100^{o} C/km) determined in the Tejupilco-Zacazonapan area (Elías-Herrera, 1981; Parga-Pérez, 1981) are not compatible with the stability conditions naturally and experimentally known for assemblages with pumpellyite, piedmontite, phengite and stilpnomelane(?), which locally characterize the upper structural levels of the "Tierra Caliente" complex. This could be explained more easily by the structural superposition of two different terranes as suggested by de Csema (1971, p. 103-104), one belonging to the oceanic-trench association (Taxco Viejo Greenstone) and the other to the marginal sea-island arc environment (Taxco Schist and related lithologies). The lithologic descriptions of the Taxco Viejo Greenstone (Fries, 1960; Díaz-García, in press), however, are difficult to reconcile with an open oceanic environment of deposition, since they resemble those of an island arc-marginal sea association.

The presence of mafic and ultramafic suboceanic igneous rocks within the "Tierra Caliente" complex (de Csema, in preparation; García-Calderón, 1978, p. 159), including pelagic siliceous sediments, lends support to a complex juxtaposition of open ocean, and island arc environments, which have not been separated in current mapping of the area.

It is clear that until better dating (both isotopic and biostratigraphic) is achieved for the "Tierra Caliente" complex, and its detailed stratigraphy, structure and petrology are determined, this metamorphic terrane will continue to be an enigma in the geological constitution of southern Mexico.

CONCLUSIONS

The distribution, ages, and geological characteristics of the metamorphic terranes of southern Mexico, including their contact relations, which are consistently tectonic, substantiate the introductory statement of this article about the unique geological complexity of southern Mexico. The paleogeographic position of each of the crystalline terranes in a space-time continuum is a task that should involve not only the collection of critical samples to measure their ages and paleomagnetism but, first of all, their detailed mapping and study, with emphasis on structure and petrology.

At the present time, the Precambrian and early Paleozoic ages of the Oaxacan and Acatlán complexes respectively are established beyond any reasonable doubt. These complexes represent two geological cycles which seem to be of very different nature. The Precambrian, or Oaxacan regime, developed most probably as an intracratonic basin that was tectonically thickened and metamorphosed by the massive introduction of anorthosite-gabbroic magmas ascending from the mantle. The Acatlán Complex, on the contrary, resulted from a Paleozoic Wilson cycle, related to the existence and extinction of a pre-Atlantic Ocean that elsewhere (*i.e.* Appalachian-Caledonian orogenic systems) is known as Iapetus. The present contact relations between the Oaxacan and Acatlán complexes mark the suture of the collided paleo-continents. The late Paleozoic evolution of southern Mexico is practically unknown because of the paucity of exposed rocks of this age.

During the Mesozoic, the crystalline record shows an entirely different tectonic position (*i.e.* Pacific) of southern Mexico. The still undated, but most probably Mesozoic Xolapa and "Tierra Caliente" complexes, represent immature clastic sedimentation, explosive calc-alkalic contemporaneous volcanism and contrasted metamorphic regimes, typical of the Circumpacific orogenic belts, the origin of which is bound to the continuous and predominantly eastward subduction of the Pacific ocean floor beneath the leading edge of the American continent.

BIBLIOGRAPHY

ANDERSON, T. H. and L. T. SILVER, 1971. Age of granulite metamorphism during the Oaxacan orogeny, Mexico. *Geol. Soc. Amer., Abstracts with Programs, 3,* 492.

BULLARD, E. C., J. E. EVERETT, and A. G. SMITH, 1965. The fit of the continents around the Atlantic. *Roy. Soc. London Philos. Trans. Ser. A, 258,* 41-51.

BURCKHARDT, Ch., 1930. Etude synthétique sur le Mésozoïque mexicain. *Soc. Paleont. Suisse, Mem., 49-50,* 280 p.

BURCKHARDT, Ch. and S. SCALIA, 1906. Géologie des environs de Zacatecas. Congr. Geol. Internal. X, Guía. Exc. 16, 26 p.

CAMPA-URANGA, M. F., 1978. La evolución tectónica de Tierra Caliente, Guerrero. *Bol. Soc. Geol. Mex., 39,* 2, 52-64.

CAMPA-URANGA, M. F., M. CAMPOS, R. FLORES, and R. OVIEDO, 1974 (1975). La secuencia mesozoica volcánica-sedimentaria metamorfizada de Ixtapan de la Sal, Méx.-Teloloapan, Gro. *Bol. Soc. Geol. Mex. 35,* 7-28.

CARFANTAN, J. C., 1982. Evolución estructural del sureste de México: Paleogeografía e historia tectónica de las zonas internas mesozoicas. México, D.F., Univ. Nal. Autón. Méx., Inst. Geología, Symposium Evolución Tectónica de México, 19-22 Nov., 1979, Memoria (in press).

COLEMAN, R. G., D. E. LEE, L. B. BEATTY, and W. W. BRANNOCK, 1965. Eclogites and eclogites: their differences and similarities. *Geol. Soc. Amer. Bull., 76,* 483-508.

COLORADO-LIEVANO, D., 1979. Etude d'une partie de la ceinture metamorphique (Mesozoïque) du sud du Mexique (Etats de Mexico et Guerrero). Paris, France, l'Université Pierre et Marie Curie (Paris VI), Docteur-Ingénieur Thesis, 128 p. (unpublished).

CSERNA, Z. de, 1965. Reconocimiento geológico de la Sierra Madre del Sur de México, entre Chilpancingo y Acapulco, Estado de Guerrero. Univ. Nal. Autón. México, *Inst. Geología, Bol. 62,* 77 p.

——— 1967 (1969). Tectonic framework of southern Mexico and its bearing on the problem of continental drift. *Bol. Soc. Geol. Mex., 30,* 159-168.

22

——— 1971. Mesozoic sedimentation, magmatic activity and deformation in northern Mexico, *in* The geologic framework of the Chihuahua tectonic belt, K. Seewald and D. Sundeen, eds., *Midland, West Texas. Geol. Soc.*, 99-117.

——— 1978. Notas sobre la geología de la región comprendida entre Iguala, Ciudad Altamirano y Temascaltepec, Estados de Guerrero y México. Soc. Geol. Mex. Libro-guía de la excursión geológica a Tierra Caliente, Estados de Guerrero y México, 1-25.

CSERNA, Z. de, E. SCHMITTER-VILLADA, P. E. DAMON, D. E. LIVINGSTON, and L. J. KULP, 1962. Edades isotópicas de rocas metamórficas del centro y sur de Guerrero y de una monzonita cuarcífera de Sinaloa. Univ. Nal. Autón. México *Inst. Geologia, Bol. 64,* 71.84.

CSERNA, Z. de, C. FRIES, Jr., C. RINCON-ORTA, J. SOLORIO-MUNGUIA, and E. SCHMITTER-VILLADA, E., 1974a. Nuevos datos geocronométricos paleozoicos del sur de México. *Bol. Asoc. Mex. Geol. Petroleros, 26,* 195-204.

CSERNA, Z. de, C. FRIES, Jr., C. RINCON-ORTA, H. WESTLEY, J. SOLORIO-MUNGUIA, and E. SCHMITTER-VILLADA, 1974b. Edad Precámbrica tardía del Esquisto Taxco, Estado de Guerrero. *Bol. Asoc. Mex. Geol. Petroleros, 26,* 183-193.

CSERNA, Z. de, R. L. ARMSTRONG, C. YAÑEZ-GARCIA, and J. SOLORIO-MUNGUIA, 1978. Rocas metavolcánicas e intrusivos relacionados paleozoicos de la región de Petatlán, Estado de Guerrero. Univ. Nal. Autón. México, *Inst. Geología, Revista, 2,* 1-7.

CSERNA, Z. de, and C. FRIES, Jr., 1982. Hoja Taxco, 1:100,000, con Resumen de la geología de la Hoja Taxco, Estados de Guerrero, México y Morelos. Univ. Nal. Autón. México, Inst. Geología, Carta Geológica de México, serie 1:100,000.

DEWEY, J. F. and K. C. A. BURKE, 1973. Tibetan, Variscan, and Precambrian basement reactivation: products of continental collision. *Jour. Geol., 81,* 683-692.

DIAZ-GARCIA, V., 1980. Las rocas metamórficas de la región de Zacualpan, Estado de México. Univ. Nal. Autón. México, *Inst. Geología, Revista, 4* (in press).

ELIAS-HERRERA, M., 1981. Geología del Area Almoloya de las Granadas-San Lucas del Maíz, Municipio de Tejupilco, Estado de México. Univ. Nal. Autón. México, Fac. Ciencias, Tesis de Maestría, 177 p. (inédita).

FLORES, T., 1936. Los cuerpos de pirita cuprífera de Campo Morado, Estado de Guerrero, México. *Internal. Geol. Cong., Washington Report, 101,* 1013-1027.

FRIES, C., Jr., 1960. Geología del Estado de Morelos y de partes adyacentes de México y Guerrero, región central-meridiomal de México. Univ. Nal. Autón. México, *Inst. Geologia, Bol., 60,* 236 p.

FRIES, C., Jr., E. SCHMITTER, P. E. DAMON, and D. E. LIVINGSTON, 1962. Rocas precámbricas de edad grenvilliana de la parte central de Oaxaca en el sur de México. Univ. Nal. Autón. México, *Inst. Geologia, Bol., 64,* 45-53.

FRIES, C., Jr., and C. RINCON-ORTA, 1965. Nuevas aportaciones geocronológicas y técnicas empleadas en el laboratorio de geocronología. Univ. Nal. Autón. México, *Inst. Geología, Bol., 73,* 57-133.

FRIES, C., Jr., C. J. SCHLAEPFER, and C. RINCON-ORTA, 1966. Nuevos datos geocronológicos del Complejo Oaxaqueño. *Soc. Geol. Mex., Bol., 29,* 1, 59-66.

FRIES, C., Jr., C. RINCON-ORTA, J. SOLORIO-MUNGUIA, E. SCHMITTER-VILLADA and Z. de CSERNA, 1970. Una edad radiométrica ordovícica de Totoltepec, Estado de Puebla. *Soc. Geol. Mex. Libro Guía de la Excursión México-Oaxaca,* 164-166.

GARCIA-CALDERON, J., 1978. Asbestos de México. *Bol. Soc. Geol. Mex., 39,* 2, 154-161.

GASTIL, R. G., and W. JENSKY, 1973. Evidence for strike-slip displacement beneath the Transmexican Volcanic Belt. *Stanford Univ. Publ. in Geol. Sci., 13,* 171-180.

GUERRERO-GARCIA, J. C., L. T. SILVER, and T. H. ANDERSON, 1978. (1980). Estudios geocronológicos en el Complejo Xolapa. *Bol. Soc. Geol. Mex., 39,* 22-23.

GUIZA, R., 1949. Estudio geológico del Distrito minero de Guanajuato. *Inst. Nal. Inv. Recursos Minerales, Bol. 22,* 75 p.

HALPERN, M., J. C. GUERRERO-GARCIA, and M. RUIZ-CASTELLANOS, 1974. Rb-Sr dates of igneous and metamorphic rocks from southeastern and central Mexico: a progress report. *Un. Geof. Mex., Reunión Anual, México, D. F., Resúmenes,* 30-31.

HARLAND, W. B., and R. A. GAYER, 1972. The Arctic Caledonides and earlier oceans. *Geol. Magazine, 109,* 289-314.

HERNANDEZ-ESTEVEZ, S., 1980. Tramo: Puebla, Tehuacán, Zapotitlán Salinas, Los Reyes Metzontla y San Francisco Xochiltepec, Puebla. Soc. Geol. Mex., *Libro-Guía de la Excursión geológica al borde noroeste de la Paleopenínsula de Oaxaca (sureste del Estado de Puebla),* p. 3-11.

KARIG, D. E., R. K. CARDWELL, G. F. MOORE, and D. G. MOORE, 1978. Late Cenozoic subduction and continental margin truncation along the northern Middle America Trench. *Geol. Soc. Amer. Bull., 89,* 265-276.

KESLER, S. E., 1973. Basement rock structural trends in southern Mexico. *Geol. Soc. Amer. Bull., 84,* 1059-1064.

KESLER, S. E. and S. A. HEATH, 1970a. Structural trends in the southernmost North American Precambrian, Oaxaca, Mexico. *Geol. Soc. Amer. Bull., 81,* 2471-2476.

——— 1970b. Structural evidence for Precambrian rocks in the Xolapa Complex, Guerrero, Mexico. *Geol. Soc. Amer. Abstr. with Programs, 2,* p.287.

KING, P. B., 1959. The evolution of North America: New Jersey. Princeton Univ. Press, 189 p.

KLESSE, E., 1968 (1970). Geology of the El Ocotito-Ixcuinatoyac region and of

La Dicha stratiform sulphide deposit, State of Guerrero. *Bol. Soc. Geol. Mex., 31,* 107-140.

MAUVOIS, R., A. DEMANT, and L. SILVA-MORA, 1976. Estructuras terciarias en la base del Eje Neovolcánico (ejemplo de la depresión Tzitzio-Huetamo, Estado de Michoacán). III Congr. Latinoamericano de Geol., Acapulco, México, Resúmenes, p. 87.

McGEHEE, R. V., 1976. Las rocas metamórficas del Arroyo de La Pimienta, Zacatecas, Zac. *Bol. Soc. Geol. Mex., 37,* 1-10.

MIYASHIRO, A., 1961. Evolution of metamorphic belts. *Jour. Petrology, 2,* 277-311.

——— 1972. Metamorphism and related magmatism in plate tectonics. *Am. Jour. Sci., 272,* 629-656.

——— 1973. Metamorphism and metamorphic belts. London, George Allen & Unwin, 492 p.

MUGICA, R. M., 1980. Determinación de edades por el método de Potasio-Argón de rocas ígneas intrusivas y metamórficas del área de Arteaga, suroeste del Estado de Michoacán, México. Soc. Geol. Mex., V Convención Geológica Nacional, Resúmenes, p. 84.

ORTEGA-GUTIERREZ, F., 1974 (1975). Nota preliminar sobre las eclogitas de Acatlán, Puebla. *Bol. Soc. Geol. Mex., 35,* 1-6.

——— 1975. The pre-Mesozoic geology of the Acatlán area, south Mexico. Leeds, England, Univ. of Leeds, Ph. D. Thesis, 166 p. (unpublished).

ORTEGA-GUTIERREZ, F., 1976. Los complejos metamórficos del sur de México y su significado tectónico. III Congr. Latinoamericano de Geol. Acapulco, México, Resúmenes, p. 101.

——— 1978a. El Gneis Novillo y rocas metamórficas asociadas en los cañones del Novillo y de La Peregrina, área de Ciudad Victoria, Tamaulipas. Univ. Nal. Autón. México, *Inst. Geología, Revista, 2,* 19-30.

——— 1978b. Geología del contacto entre la Formación Acatlán paleozoica y el Complejo Oaxaqueño precámbrico, al oriente de Acatlán, Estado de Puebla. *Bol. Soc. Geol. Mex., 39,* 27-28.

——— 1978c. Estratigrafía del Complejo Acatlán en la Mixteca Baja, Estados de Puebla y Oaxaca. Univ. Nal. Autón. México, *Inst. Geología, Revista, 2,* 112-131.

——— 1981. Deep orogenic belts of southern Mexico. *Geol. Soc. Amer., Abstr. with Programs, 13,* p.99.

——— 1982. Evidences of Precambrian evaporites in the Oaxacan granulite Complex of southern Mexico. Univ. Nal. Autón. México. *Inst. Geología, IGCP Joint Mtg. Projects 157 and 160, Developments and interactions of Precambrian lithosphere, biosphere, and atmosphere, Abstracts, p. 27.*

ORTEGA-GUTIERREZ, F., ANDERSON, T. H. and SILVER, L. T., 1977. Lithologies and geochronology of the Precambrian craton of southern Mexico. *Geol. Soc. Amer., Abstr. with Programs, 9,* 1121-1122.

PANTOJA-ALOR, J., 1970. Rocas sedimentarias paleozoicas de la región centro-septentrional de Oaxaca. *Soc. Geol. Mex., Libro-Guía de la Excursión México-Oaxaca, p. 67-84.*

PANTOJA-ALOR, J. and R. A. ROBISON, 1967. Paleozoic sedimentary rocks in Oaxaca. *Science, 157,* 1033-1035.

PARGA-PEREZ, J. J., 1981. Geología y metalogénesis del yacimiento estratiforme de sulfuros masivos de Tizapa, Zacazonapan, Estado de México. *Minero-Noticias, México, n.62, año 5,* 43-59.

RAMSAY, J. G., 1967. Folding and fracturing of rocks. New York, McGraw-Hill, 568 p.

SANCHEZ-RUBIO, G., 1972. Las migmatitas de Puerto Escondido, Oaxaca. Univ. Nal. Autón. México. Fac. Ingeniería, Tesis Profesional, 47 p. (inédita).

WHITTINGTON, H. B. and C. P. HUGHES, 1974. Geography and faunal provinces in the Tremadoc Epoch, *in* Ross, C. A. (Ed.), Paleogeographic provinces and provinciality. *Soc. Econ. Paleontol. and Mineral., Spec. Publ. 21,* 203-218.

WILSON, J. T., 1966. Did the Atlantic close and then reopen? *Nature, 211,* 676-681.

ZWART, H. J., 1967. The duality of orogenic belts. *Geologie en Mijnbouw, 46e(8),* 283-309.

(Received Oct. 19, 1981)
(Accepted Feb. 25, 1982)