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Structure and kinematic history of the Acatlán Complex in the Nuevos Horizontes - San Bernardo region, Puebla

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RESUMEN

Las rocas metamórficas e ígneas del Paleozoico, que forman el basamento de la parte norte del terreno Mixteca en el sur de México, se han agrupado como el Complejo Acatlán. Seis fases de deformaciones distintas se han diferenciado por distintas facies metamórficas, grados de ductilidad y correlación temporal. La primera deformación (D1) está caracterizada por metamorfismo de alta temperatura (M1), que se sobreimpuso a eclogitas y culminó en anatexis y la intrusión de granitos. Durante esta deformación crecieron grandes micas claras y megablastos de feldespato potásico en las rocas metasedimentarias. La segunda deformación (D2) causó retrometamorfismo (diaftóresis) llegando hasta un metamorfismo de bajo grado (esquisto verde). Las micas de la M1 están conservadas como porfidoclastos dentro de la foliación S1. Durante esta deformación se han fracturado con una temperatura menor, mientras que en la foliación S2 están sustituidas por sericita. La deformación (D2) causó recristalización dinámica de cuarzo. La tercera deformación (D3) plegó el área en estructuras isoclinales y estrechas con vergencia hacia el poniente. Los sedimentos, depositados entre D2 y D3, sufrieron un metamorfismo de muy bajo grado, y tienen al igual que los granitos, intrusados durante la D3 a un nivel de la corteza superior, una foliación S3. La cuarta deformación (D4) está caracterizada por pliegues tipo "kink", una zona empinada de cizalla cataclástica y planos de estrías. Los cálculos de tensores de paleoesfuerzo dan ejes s1 y s3 subhorizontales con una dirección de s1 NE-SW. La mayor parte de las poblaciones de fallas frágiles está relacionada con la quinta deformación (D5), con ejes s1 y s3 también subhorizontales, con una dirección de s1 ENE-WSW. Fallas normales definen la sexta deformación (D6) con ejes s1 subverticales y ejes s3 subhorizontales con direcciones alrededor de N-S.

Palabras clave: Geología estructural, tectónica, análisis de deformación, Complejo Acatlán, sur de México.

ABSTRACT

Paleozoic metamorphites and magmatites forming the basement of the northern Mixteca terrane in southern Mexico define the Acatlán Complex. Six stages of deformation are defined by metamorphic facies, structural behaviour, and overprinting relationships. The first deformation (D1) is accompanied by high temperature metamorphism (M1), which overprints pre-existing eclogites (D0), and culminates in intrusions of granites. During this deformation, large crystals of mica and megablasts of potassic feldspar grew. The second deformation (D2) is indicated by diaphtoresis up to greenschist facies. Mica crystals of the M1 are preserved as relictic porphyroclasts in the S1 foliation planes. On D2 planes they were broken and substituted by sericite. D2 caused elongation and recrystallization of quartz. During the third deformation (D3) the Acatl‡n Complex was

folded into W-vergent, tight to isoclinal folds. Sediments deposited between D2 and D3 were metamorphosed by very low grade metamorphism during D3. As the granites intruded into an upper crustal level, they show S3 foliation. The fourth deformation phase is characterized by kinkfolds, cataclastic shearzones, and faults with slickensides. Calculations of the paleostress tensors yielded subhorizontal s1- and s3-axis indicating NE-SW orientation of s1. Most of the fault populations belong to the fifth deformation (D5) with subhorizontal s1- and s3-axis with ESE-WNW s1 direction. Normal faults define the sixth deformation (D6) with subvertical s1-axis and N-S trending s3-axes.

Key words: Structural geology, tectonics, deformation analysis, Acatlán Complex, southern Mexico.

1. GEOLOGICAL FRAME

Crustal complexes in southern Mexico vary in their geological evolution. They are bordered by steep dipping mylonite zones (Salinas-Prieto, 1984; Ortega-Gutiérrez et al., 1990; Ratschbacher et al., 1991) and have been classified as "suspect terranes" (Campa and Coney, 1983) in terms of crustal units with regional extension and unknown paleogeographic and paleotectonic origin (Coney et al., 1980; Ben-Avraham et al., 1981; Howell et al., 1985; Coney, 1989). The origin of these terranes was discussed in detail by Herrmann et al. (1994) and Meschede (1994). Figure 1 illustrates the outline of the Oaxaca, Guerrero and Xolapa terranes which surround the Mixteca terrane. The Transmexican Volcanic Belt covers the Mixteca terrane towards the North. The basement of the Xolapa terrane mainly consists of migmatite, gneiss, amphibolite and locally marble (De Cserna, 1965; Ortega-Gutiérrez, 1981). Plutonites intruded into these units reveal intrusion ages of 128-138 Ma (Morán-Zenteno et al., 1990). The Xolapa terrane was interpreted as a deep part of a magmatic arc (Ortega-Gutiérrez, 1981; Caballero-Miranda et al., 1990; Herrmann et al., 1991).

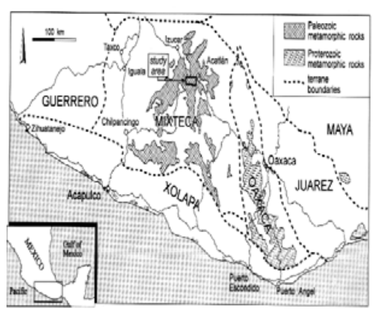

Fig. 1. "Suspect terranes" (modified after Coney and Campa, 1983) and metamorphic basement rocks (after Ortega-Gutiérrez et al., 1992) in southern Mexico showing the location of the study area.

The Guerrero terrane is mainly formed by volcanic and sedimentary sequences of Jurassic to Middle Cretaceous age. Campa and Coney (1983) divide this "composite terrane" into three subunits. Calcalkaline intrusive rocks (Köhler et al., 1988) indicate a magmatic arc in the Guerrero terrane. The metamorphic basement complex of the Oaxaca terrane, called the Oaxacan Complex, is mainly composed of Precambrian rocks consisting of gneiss and anorthosite, metamorphosed up to granulitic facies. Radiometric ages from 940 to 1080 Ma suggests a relation of the Oaxacan Complex to the Grenville orogeny (Fries et al., 1962; 1966; Anderson and Silver, 1971; Ruiz et al., 1988). The crystalline basement is covered by Cambrian-Ordovician sedimentary rocks. Trilobites encountered in these rocks are similar to Gondwana trilobites (Olenid-Ceratopygid province; Pantoja-Alor and Robinson, 1967). Permo-Carboniferous sedimentary rocks overlie both units discordantly (Ortega-

Gutiérrez, 1981).

The basement of the Mixteca terrane is the Acatl‡n Complex, which is composed of metamorphic Paleozoic rocks. It is discordantly overlain by terrigeneous, fluvial, and marine sedimentary rocks of late Paleozoic to Mesozoic age (Ortega-Gutiérrez, 1981). The base of these sedimentary rocks is formed by conglomerates derived from the Acatl‡n Complex. Late Carboniferous to Permian continental sedimentary units of the Matzitzi Formation also overlay the Precambrian Oaxacan Complex (Yañez et al., 1991). Our own investigations confirmed that the Acatlán Complex is separated from the Oaxacan Complex by an approximately 300 m wide zone of mélange type rocks, mylonites and cataclasites (Ortega-Gutiérrez, 1975; 1978b; Meschede, 1994).

In this paper we describe the deformation history of the Acatlán Complex in an area W of Acatlán de Osorio in the State of Puebla (Figure 2). We define the Esperanza Group consisting of a series of metamorphosed igneous rocks (Esperanza granitoids) and sedimentary rocks (see Figure 2). High metamorphic gneisses and micaschists as well as metagranitoids from the Esperanza Group, phyllites and quartz-phyllites from the Cosoltepec Formation, and greenstones from the Xayacatlán Formation (see Table 1) are exposed in the study area. The abundance of eclogites in Mexico, first described in the Xayacatlán Formation (Ortega-Gutiérrez, 1974), points to a high-pressure metamorphic event (M0) with approximately 8-12 kb and 500-550°C. The high grade metamorphic units are overlain by very low grade metamorphic rocks of the Tecomate Formation, which contain fossil fragments as well as deformed conglomerates derived from the Esperanza Group. A total thickness of 15 km is given by Ortega-Gutiérrez (1978a) for the rock units, which are considered to be part of the Acatlán Complex.

The *E* nd-values of -8.5 to -12 and crustal residence ages (TDM) of 1.4 to 1.7 Ga for most of the meta-sedimentary units and also for the Esperanza granitoids of the Acatlán Complex agree with the Nd-isotopic distribution within the Oaxacan Complex (Patchett and Ruíz, 1987). This implies that the meta-sediments of the Acatlán Complex are mainly derived from Grenvillian crust probably represented by the neighbouring Oaxacan Complex.

We distinguish six deformation phases with different magnitude and geodynamic significance. The relict eclogites of the Xayacatl‡n Formation define the pre-existing rocks which were overprinted by the first deformation phase (D1; Table 2). The ductile deformation events were distinguished by variations in metamorphic facies. Events of brittle deformations were separated by statistical analyses of fault planes with slickensides.

Table 1

Age and lithological units of the Acatlán Complex (after Yañez et. al., 1991 (1); Ortega Gutiérres, 1978a (2) and own data (3)).

Table 1

Age and lithological units of the Acatlán Complex (after Yañez *et al.*, 1991([1]); Ortega-Gutiérrez, 1978a ([2]) and own data ([3])).

Late Paleozoic	Method	Radiometric age	Lithology [1]	oldest deformation
Totoltepec pluton	U-Pb	287 ± 2 Ma[1]	Very low grade metamorphosed and deformed trondhjemitic intrusion	D_3
Tecomate Formation	K-Ar T_{DM}	288 ± 14 Ma[3] 1,4-1,7 Ga[1]	Metapelites, metaarcoses and metagreywackes including a conglomerate unit containing deformed granitic components and pelloised lime layers with fragments of invertebrates.	D_3
high metamorphic basement				
Cosoltepec Formation	T_{DM}	1,0-1,65 Ga[1]	On the base amphibolites, overlain by quartzites, chiris, metapelites and calcareous schists, followed of phyllites, quartz phyllites with intercalated greenstones.	D_1
Esperanza Group	Rb-Sr (Mu-WR) U-Pb Sm-Nd (Gt-WR) T_{DM}	330 ± 5 Ma[1] 371 ± 34 Ma[1] 411 ±123 Ma[1] 1,4-1,7 Ga[1]	Granite, aplite and pegmatite including metasediment units and greenstones. Some zones are deformed from protomylonite to ultramylonite.	D_1
Xayacatlán Formation	Rb-Sr (Mu-WR) Sm-Nd (Gt-WR) T_{DM}	332 ± 4 Ma[1] 318 ± 4 Ma[1] 388 ± 44 Ma[1] 416 ± 12 Ma[1] 0,7-1,1 Ga[1]	Mylonitic greenstones and amphibolites, serpentinites, eclogites, as well as metapelites and metaquartzites with ophiolitic affinity.	D_0

[3]) K-Ar dating of serizites of a pelloised lime layer of the Tecomate Formation.

Sample	mineral	size [µm]	$^{40}Ar_{rad}$ scc/gm • 10^{-5}	$\%^{40}Ar_{rad}$	isotopic age
ML6	muscovite	<63	0.292	54.9	288 ± 14 Ma

2. STRUCTURAL ANALYSIS

The first deformation (D1; Table 2) is characterized by mica-schists partly containing garnet and paragneisses of the Esperanza Group injected by folded aplite dikes. The abundance of the dikes increases towards the intrusion body of the Esperanza granitoid, indicating intrusive contacts. The S1-foliation, formed during the high-temperature deformation of D1, is preserved in relict form. Large muscovites and biotites are conserved on intrafolial folded S1-foliation planes in mica-schists and are fractured during the second deformation. S1/S2 intersection lineations are visible, where S1 remained in a mostly acute angle to S2. The intersection lineations are parallel to the stretching lineation L2. The S1-foliation was not observed in the phyllites and quartz-phyllites of the Cosoltepec Formation (Figure 2).

Potassium feldspar blasts of different size in mica-schists from the Esperanza Group containing large D1-muscovites are interpreted as a metasomatic input of potassium from the Esperanza granitoids (Mehnert, 1968; Best, 1982). Ortega-Gutiérrez (1975) interpreted potassium feldspar megablasts of more than 10 cm as most probably of igneous origin. In the geological map (Figure 2), the limit between micaschist and augenschist is indicated where potassium feldspar blasts exceed a size of 5 cm. The matrix of the augenschist, however, is made of micaschist. Thus, we interpret the growth of the megablasts as a reaction due to anatexis and intrusion of the Esperanza granitoid. Recrystallized feldspar (Or) was partly observed within the pressure shadows of the feldspar-porphyric clasts.

Table 2

Deformation events in the Acatlán Complex correlated with plate tectonic events

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Deformation events in the Acatlán Complex correlated with plate tectonic events

	age	metamorphism	direction	geodynamic process	Plate tectonic relation
D_6	? to recent	none	N-S extension	Uplift and postorogenic collapse	
D_5	Late Cretaceous to Tertiary	none	WNW-ESE compression	Brittle deformation	Sinistral transtensive extension caused of the formation of the Caribbean sea and the eastward movement of the Chortis block.
D_4	? to Late Cretaceous	none	NE-SW compression	Brittle to ductile deformation	NE directed subduction of the Farallon plate
D_3	Late Carboniferous to Perm	very low grade	E-W compression	Intrusion of the Totoltepec Pluton Folding	Collision of North America and Gondwana
				Sedimentation of the Tecomate-Formation	
D_2	Early Carboniferous	Low grade diaphtoresis	Top to S N-S extension	Extension (ductile deformation)	Separation of North America from Gondwana
D_1	Early Devonian	High temperature	?	Heating to anatexis	Stacking within an orogenic wedge Acadian orogenic event
D_0	?	High pressure	?	Subduction	?
				Sedimentation (origin of the sediments from a Proterozoic crust)	

The second deformation (D2; Table 2) is characterized by a greenschist facial diaphtoresis. The Esperanza granitoids and micaschists were partly chloritized and the micas grown during D1 were transformed into sericite. Sericite grew on the S2-foliation planes, which are encountered as the dominant foliation in the entire working area. The foliation is steeply inclined towards the W or E and includes a stretching lineation L2, represented by dynamically recrystallized quartz, which dips gently towards N to NW (Figure 3a, b). B2-fold axes from isoclinal intrafolial folds as well as from ptygmatically folded competent layers, are nearly parallel to the L2 direction.

Dynamic recrystallization of quartz during D2 documents a deformation temperature of more than 270¡C. Brittly deformed feldspar indicates a temperature below 500°C (Voll, 1980). Clasts of potassium feldspar, drifted along shear bands (Figure 4a), S-C structures and rotated potassium-feldspar porphyroclasts with asymmetric pressure shadows can be observed in oriented thin sections perpendicular to the foliation S2 throughout the entire working area. Quartz microfabrics indicate some non-coaxially accumulated strain (Figure 3c). Samples from upright oriented units yield a tectonic transport of the hanging wall towards S to SSE. Mesoscale mylonites and ultramylonites with severed fold cores, rotated clasts, shear bands (Figure 4b) and boudinaged, antithetically rotated aplitic dikes crop out in local, meter to ten meters thick shear zones. The shear zones are developed in less competent layers of the Esperanza Group and indicate the same kinematic criteria as found in samples outside of the shear zones.

Strain analyses on deformed potassium feldspars in augen-gneisses of the Esperanza Group (Figure 3a,d; outcrops 134, 135) were performed with the Rf/f method (Ramsay and Huber, 1983). Strain ellipsoids were calculated with the program TRISEC (Milton, 1980). In samples from granitoids of the Esperanza Group strain analyses were performed in three orthogonal planes (XY, XZ and YZ) using the scanner method (Weger, 1993; Figure 3a,d; samples sr1-4). Most of the calculated strain ellipsoids for the Esperanza Group cluster around the line of plane strain in the Flinn diagram (Figure 3d). Two samples (sr3, sr4; Figure 3d) yield intensive constrictional strain indicating local extensive deformation. The inhomogeneity may be a result of size, differences in density and reciprocal influence of the large potassium feldspar crystals, which cause the matrix to suffer various amounts of deformation. The Tecomate Formation, which is exposed east of the map section, does not show the older deformations of D1 and D2. Strain ellipsoids, calculated on the basis of deformed conglomerate componentes, group within the field of flattening strain (Figure 3d, see also Ortega-Gutiérrez, 1979). They are different from the Esperanza Group and support the conclusion that the Tecomate Formation was not affected by D2.

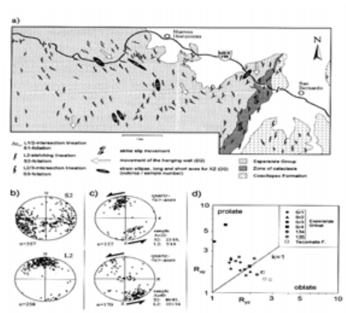

Fig. 3. (a) Structural map (geological boundaries see Fig. 2); (b) S2-foliation planes and L2-stretching lineation in the working area; (c) orientation of quartz-<c>-axes (X = direction of L2): Ac22 = quartz phyllite of the Cosoltepec Formation; Ac40 = paragneiss of the Esperanza Group; (d) Flinn diagram showing the results of strain analyses: Sr1-4 = samples from granitoids, 134, 135 = outcrops of augenschists of the Esperanza Group; open squares = conglomerates of the Tecomate Formation.

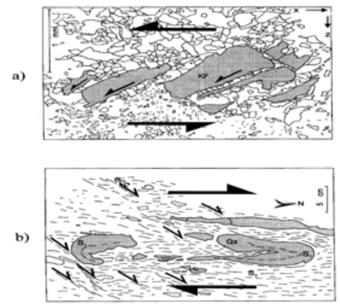

Fig. 4. (a) Sketch of a thin section from the Esperanza granitoid (showing the X-Z plane): Orthoclase is broken and moved along shear bands; sense of movement (D2) of the hanging wall is towards the South (S2: 312/31; L2: 349/23). (b) Sketch of a horizontal surface in an outcrop of mylonites within the Esperanza Group: D1/2 folded quartz layers are seperated, shear bands (arrows) indicate dextral sense of movement during D2 (S2 is subvertical).

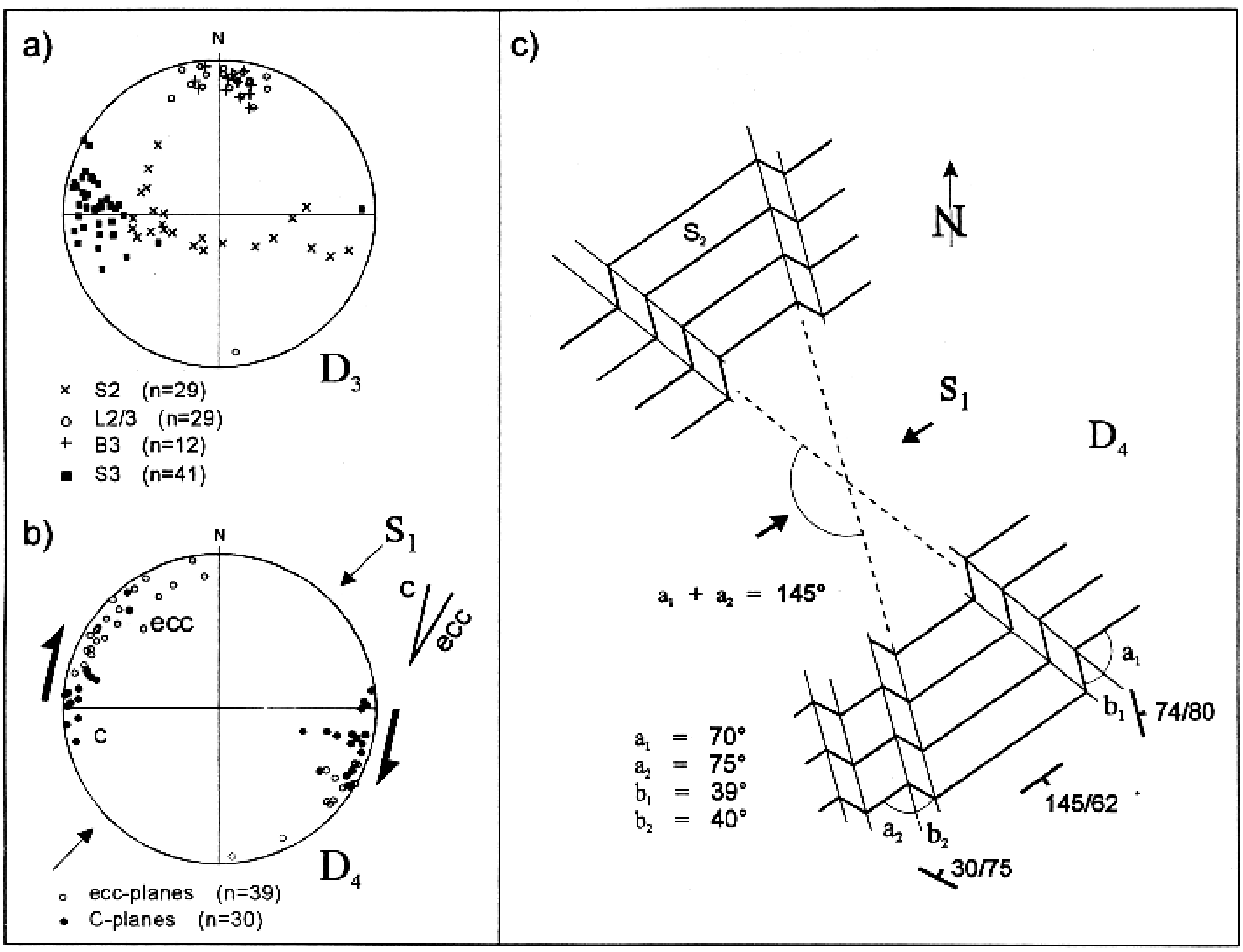

Fig. 5. (a) Structural features of quartz phyllite of the Cosoltepec Formation. Steeply eastward dipping S3-foliation indicates west-vergence of D3-folds. (b) C- and ecc-planes within the zone of cataclasites (D4) west of San Bernardo (see Fig. 2). (c) Conjugated kink bands in mica schist of the Esperanza Group. Angle relations prove compressive kink bands with a compression axes approximatly NE-SW directed.

The third deformation (D3; Table 2) folded the Acatlán Complex in narrow to isoclinal, west vergent folds with fold axes subparallel to L2/3. The dimension of those D3-folds ranges from decimeter to meter size. Isoclinal D1- and D2-folds of the Esperanza Group are again folded by the third deformation. An S3-cleavage occurs subordinated. However, a distinct S3-cleavage is developed in quartz-phyllites of the Cosoltepec Formation. The intersection lineation L2/3 is subparallel to the stretching lineation L2 (Figure 5a). The well developed cleavage of the Tecomate Formation is parallel to the S3-cleavage of the Cosoltepec Formation, mostly dipping towards the E (Figure 5a). Therefore it will be ascribed to the third deformation (D3). A very low grade metamorphism (M3) affecting the rocks of the Tecomate Formation did not significantly overprint the high metamorphic rocks in the study area. A slightly developed cleavage in the Totoltepec intrusion is also inclined towards the E, and is attributed to the S3-cleavage.

Axes of small-dimensioned kink folds, box folds and conjugated kink bands in phyllites and micaschists are mostly in subvertical position. The orientation of the fold limbs and the relation of the fold angles of conjugated kink bands indicate a subhorizontal NE-SW directed compression (Figure 5c). Calcite-enriched greenstones, which are probably part of the Xayacatlán Formation (Ortega-Gutiérrez, 1974; 1978a), are included as competent layers within an approximately 200 m wide, steep dipping shear zone between the Cosoltepec Formation and the Esperanza Group (Figure 2; 5b). The rocks of the shear zone are mainly cataclastically deformed. Riedel-shear fractures and ecc-structures (extensional crenulation cleavage; Platt and Vissers, 1980) indicate a dextral sense of movement, which can be interpreted as the result of a NE-SW directed compression (Figure 5b). This represents the fourth deformation (D4, Table 2).

Brittly deformed structures were documented by statistical analysis of fault planes with slickensides. Inhomogeneous data sets were separated from homogeneous ones prior to the calculation of the paleostress axes. The separation was carried out with the help of graphical and mathematical methods. The applicability of such separation is justified by comparison with other data sets from southern Mexico, where overprinting criterias are observed (Meschede et al., 1996). Well-developed slickensides were encountered in calcite-enriched greenstone layers, where calcite fibers indicate the sense of motion. Kinematic data on fault planes in gneisses and mica-schists consists mostly of Riedel-shears, crack edges and fine chlorite fibres.

Various graphical and mathematical methods were applied for the calculation of the paleostress tensors: (1) The P/T-method modified after Turner (1953) calculates theoretical compression (P) and extension (T) axes for each single plane. The position of s1 and s3 is given by the maximum density of the calculated axes. (2) The dihedra method after Angelier and Mechler (1977) calculates a compressive and an extensive quadrant for each fault plane. The superposition of all quadrants of a data set yields areas of maximum compression and maximum extension (according to s1 and s3). (3) The calculation method of Hardcastle and Hills (1991) tests thousands of tensors against the data set by stepwise rotating the calculation tensor. For each tensor the fullfillment of the fracture condition of Coulomb ($t = C + \mu sn$) is tested for each fault plane of a data set.

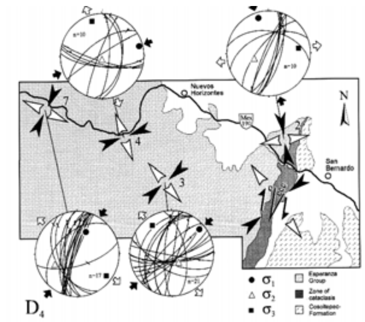

Fig. 6. D4 fault populations and the principal directions of the calculated paleostress tensors (õ1<õ2<õ3).

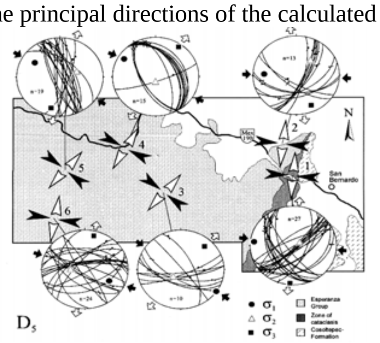

Fig. 7. D5 fault populations and the principal directions of the calculated paleostress tensors (<õ1<õ2<õ3).

The calculations resulted essentially in two groups of paleostress tensors with subhorizontal s1-axes and s3-axes (strike-slip faulting) and one group with subvertical s1-axes and subhorizontal s3-axes (extension) (Figures 6, 7, 8). Paleostress tensors with NE-SW oriented s1-axes and NW-SE oriented s3-axes were obtained from data sets in orthogneisses of the Esperanza Group (Figure 6). This direction correlates with the direction of compression interpreted from ecc-structures and conjugated kink bands (D4). The deformation regime of D4 is transitional from brittle to ductile. Fault planes which belong to this deformation are considered to represent the oldest brittle deformation event in the study area. Fault populations revealing paleostress tensors with a ESE-WNW directed subhorizontal s1-axes, defining the fifth deformation, could be separated from almost all data sets (D5; Figure 7, Table 2). Normal faults representing paleostress tensors with s3-axes indicating extension in about N-S direction, are considered to be the result of the youngest deformation (D6; Figure 8, Table 2).

3. EVOLUTION OF THE ACATLAN COMPLEX

The oldest deformation event documented by distinct structures (D1; Table 2) in the Acatlán Complex happened in the Silurian to Early Devonian period (388-416 Ma, Table 1) as indicated by syntectonic metamorphism and intrusion ages, which were obtained by Sm-Nd age dating of meta-sediments from the Xayacatlán Formation and by U-Pb age dating of zircons from the Esperanza granitoid. Rb-Sr ages of muscovites from the same rocks are 318±4, 330±5 and 332±4 Ma (Table 1; Yañez et al., 1991). This may be the result of (1) the lower closing temperature of muscovite compared to garnet, or (2) a second metamorphic event of lower temperature, which opened only the Fig. 8. D6 fault populations and the principal directions of the calculated paleostress tensors (s1<s2<s3). Rb-Sr system. Yañez et al. (1991) favour the second interpretation because the garnets are fractured and do not show any indication of continuing synkinematic growth during the second deformation phase.

87Sr/86Sr isotopic ratios from 0.727 to 0.743 for the Esperanza granitoid (Ya-ez et al., 1991) indicate melting of crustal material, which may represent the stacking of an orogenic wedge. During this orogeny the material was deeply buried which caused high-temperature metamorphism (M1) with anatexis during its culmination and the intrusion of the Esperanza granitoid. A preceding subduction event with formation of eclogites (D0; Table 2) is assumed.

The second deformation (D2; Table 2), represented in the Acatlán Complex by diaphtoresis and subhorizontal extension, could be the consequence of uplifting and cooling being a retrograde formation of M2, or a separate tectonic event. We interpret the long time period of at least 40 Ma between both events (D1 and D2) as suggesting an independent event D2, responsible for the Early Carboniferous metamorphic ages.

From late Carboniferous to Permian the third deformation (D3; Table 2) folded the Acatlán Complex again. We interpret the low-grade metamorphosed Tecomate Formation as a molasse-type sediment, which was deposited between the second and third deformation and metamorphosed during D3. Sericite, formed during D3 gave a K-Ar age of 288 ± 14 Ma (Table 1) dating the D3 deformation event. A similar U-Pb age of zircons of the Totoltepec pluton (Yañez et al., 1991; Table 1) correlates with isotopic ages of intrusive bodies within the Oaxacan Complex (Ruiz-Castellanos, 1979), the Mixtequita- and the Chiapasbatholithes (Weber et al., 1996; Damon et al., 1981). This dates the intrusion of the Totoltepec pluton to a later stage of the third deformation.

Paleostress tensors, calculated from various data sets of fault planes, document the younger deformation phases which can be traced over large areas of southern Mexico (Meschede, 1994; Meschede et al., 1996). Fault populations with NE-SW directed subhorizontal s1-axes should be related with the fourth deformation (D4; Table 2), due to matching kinematic directions. Vertical kink fold axes and cataclastically deformed rocks in steeply inclined shear zones characterize D4.

Subhorizontal s1-axes of the second group of paleostress tensors are ESE-WNW oriented and define the fifth deformation (D5; Table 2). Consistent orientations of the paleostress tensors were found over large distances in southern Mexico and this deformation is correlated to sinistral-transtensive movements along a fault system which extends into the Motagua-Polochic fault system in Guatemala. This fault system is the consequence of the early formation of the Caribbean Sea and eastward motion of the Chortis block as a response to the change in plate motion of the Farallon plate from NE to eastward in the Paleocene (Herrmann, 1994; Herrmann et al., 1994). The extensional directions (s3) of the youngest deformation (D6; Table 2) are approximately perpendicular to the general strike of mountain ranges and subparallel to the topographic gradient. We interpret those extensional movements as a result of the uplift of the crustal blocks in southern Mexico (Meschede et al., 1996).

4. DISCUSSION

Ruiz et al. (1988) proposed two models for a kinematic correlation between southern Mexico and North to South America. The "Cordillera model" considers the crustal complexes as terranes in the sense of Coney et al. (1980). A correlation between metamorphic rocks of the Proterozoic and the Paleozoic of southern Mexico and orogenic belts with similar ages of North America (Grenville province or Appalachians) can be excluded. The "Appalachian-Caledonian model" assigns a common Paleozoic orogeny to the Acatl‡n Complex, the Oaxacan Complex, the Appalachian-Caledonian and the Grenville belt of North America. However, a direct connection between those orogenic belts is difficult due to their spatial arrangement. Paleomagnetic studies of the Acatlán Complex indicate a displacement of the Mixteca terrane relative to North America in post-Acadian time (e.g.

Fang et al., 1989). In southern Mexico, the Precambrian Oaxacan Complex is located east of the Paleozoic Acatlán Complex, whereas in North America Precambrian rocks of the Grenville province are located west of the Paleozoic rocks of the Appalachian belt (e.g. Ruiz et al., 1988). The "Appalachian-Caledonian model" favours a position of the Oaxacan Complex to the Gondwana side of the Paleozoic ocean, whereas the Acatlán Complex is considered to be part of the suture zone between Gondwana and Laurentia.

Our interpretation favours the Appalachian-Caledonian model by Ruiz et al. (1988). Observed structural features of the Acatlán Complex, radiometric age datings (Yañez et al., 1991) and paleogeographic reconstructions based on paleomagnetic data (e.g. Kent and van der Voo, 1990) are used to construct a model of the kinematic development of the Acatlán Complex. The different tectonothermal events may be interpreted as consequences of the orogenic cycle with repeated collisions of the Gondwana and North American continents (see also Yañez et al., 1991).

The ages of metamorphism in the Acatlán Complex, which we attribute to the first deformation event, are considered to be related to the Acadian orogeny as a result of stacking within an orogenic wedge. These ages correspond to a Rb-Sr, Bi-WR age of an augengneiss of the Garzon massif in Colombia (390 ± 12 Ma, Priem et al., 1989). No similar emplacement or metamorphism ages are known from other parts of Mexico. Therefore, a connection of the Acatlán Complex to the North American continent during this orogeny is not conclusive. We suggest that the Paleozoic basement of the Mixteca terrane is related to the Gondwana continent (see also Rowley and Pindell, 1988).

Subhorizontal extension at a deep crustal level during Carboniferous times caused the second deformation event which is probably related to the separation of Gondwana from the North American plate. The third deformation is considered as the result of a renewed collision event in the late Carboniferous to Permian. The fourth deformation phase may be related to the subduction of the Farallon plate in a NE-direction during Late Cretaceous (Engebretson et al., 1985). Sinistral-transtensive motion parallel to large lateral displacement systems in southern Mexico caused the fifth deformation due to the Late Cretaceous-Tertiary eastward movement of the Caribbean Sea (Meschede et al., 1996). The most recent deformation is interpreted as a consequence of post-orogenic extension due to uplift of the Mixteca terrane.

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