Geofís. Int., Vol. 28-5, 1989, pp. 1007-1028
Spec. Vol.: Dynamics and Evolution of the Lithosphere, Part 2.

STRUCTURAL ANALYSIS OF TWO JUXTAPOSED JURASSIC LITHOSTRATIGRAPHIC ASSEMBLAGES IN THE SIERRA MADRE ORIENTAL FOLD AND THRUST BELT OF CENTRAL MEXICO

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(Received: January 27, 1988)
(Accepted: March 20, 1989)

RESUMEN

Una comparación general de tres áreas vecinas en la Sierra Madre Oriental en el centro de México sugiere la existencia de una corteza continental mesozoica bordeada por una zona de subducción.

Al oriente de la Cabalgadura de Higuerillas afloran 2 400 - 3 500 m de espesor de depósitos marinos compuestos de (1) calizas arcillosas y lutitas depositadas durante el Jurásico Superior - Neocomiano; (2) calizas de la parte superior del Cretácico Inferior y (3) rocas pelíticas del Cretácico Superior.

Al oeste de la Cabalgadura de Higuerillas, dos conjuntos litotectónicos se encuentran yuxtapuestos: el más occidental contiene en su parte inferior intercalaciones de grauvaca micácea de grano fino con lutita filitizada, rocas volcano-sedimentarias y pedernales con radiolarios, relacionadas con un arco magmático. La edad de estas litologías puede pertenecer al Jurásico Medio o al Jurásico Superior. Sobre estas rocas descansan, separadas por una discordancia angular, conglomerado, caliza marina de batimetría moderada, arenisca, lutita y capas rojas de edad neocomiana. El conjunto oriental consiste en brecha, conglomerado, piroclastos de composición ácida y otras rocas siliciclásticas depositadas durante el Kimeridgiano Superior hasta el Titoniano Inferior. Las rocas siliciclásticas de grano grueso se depositaron probablemente cuando la anterior plataforma continental Norteamericana se deformó por fallamiento normal de alto ángulo, que estuvo activo aún en el Neocomiano - Barremiano y que pudo ser responsable del profundizamiento de la plataforma donde se depositaron las series litológicas de ese período.

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Los afloramientos jurásicos situados más al oeste de la Cabalgadura de Higuerillas incluyen grauvaca, toba y pedernales con radiolarios, fracturados y desgarrados *in situ* en una matriz arcillosa y que exhiben con frecuencia un crucero penetrativo que se inclina de 0 a 40° hacia el SW.

Este tipo de deformación está casi ausente en las rocas siliciclásticas de grano grueso situadas al oriente. El límite entre estos dos conjuntos litotectónicos está definido por el lineamiento que aquí se denomina El Frontón, como una zona de lentes de cizallamientos por fallamiento inverso imbricado.

ABSTRACT

A general comparison of three neighboring areas in the Sierra Madre Oriental of central Mexico, in the east of the Querétaro State, suggests the existence of a Mesozoic continental crust bordering a subduction zone.

East of the Higuerillas Thrust there is a 2 400 - 3 500 m thick outcrop of marine deposits composed of (1) Upper Jurassic - Neocomian shaly limestone and shale; (2) Middle Cretaceous limestone, and (3) Upper Cretaceous pelitic rocks.

West of the Higuerillas Thrust, two lithotectonic assemblages are juxtaposed: the westerly one contains in its lower part intercalations of fine grained micaceous greywacke within phyllitic shale, volcano-sedimentary rocks, and radiolarian-ribbon chert, related to a magmatic arc. The age of these lithologies could be Middle to Late Jurassic. Following up-section and separated by an angular unconformity, there are shallow marine limestone, conglomerate, sandstone, shale and red beds of Neocomian age. The eastern assemblage consists of coarser siliciclastic and alkaline volcanoclastic rocks of late Kimmeridgian to Tithonian age.

The sequence east of the Higuerillas Thrust extends over a larger area and is more representative of the lithology of the Sierra Madre Oriental fold-and-thrust belt. The siliciclastic rocks were probably deposited when the former North American shelf was being cut by high-angle normal faults, which may still have been active from the Neocomian to the Barremian time.

The Jurassic assemblage outcropping more westerly of the Higuerillas thrust include *in situ* disrupted and fragmented greywacke, tuff and radiolarian ribbon chert in a muddy matrix and display frequently penetrative cleavage dipping 0 - 40° to the southwest.

This deformation style is nearly absent in the coeval coarser rocks placed to the east. The limit between the two assemblages is defined by the El Frontón Fault Zone, which consists of a series of imbricate thrust slices.

INTRODUCTION

The Sierra Madre Oriental Fold-and-Thrust Belt (Suter, 1987) extends from the American border until 19° lat. N in eastern Mexico, where it becomes overprinted by the Trans-Mexican Volcanic Belt (Figure 1). It is stratigraphically characterized by Upper Jurassic to Upper Cretaceous marine shelf deposits. The evolution of this region during Late Jurassic to Neocomian time was influenced by the opening of the Gulf of Mexico (Buffler *et al.*, 1980; Salvador, 1987). It corresponds to a continental margin whose tectonic regime was extensional. During Paleocene to Eocene time,

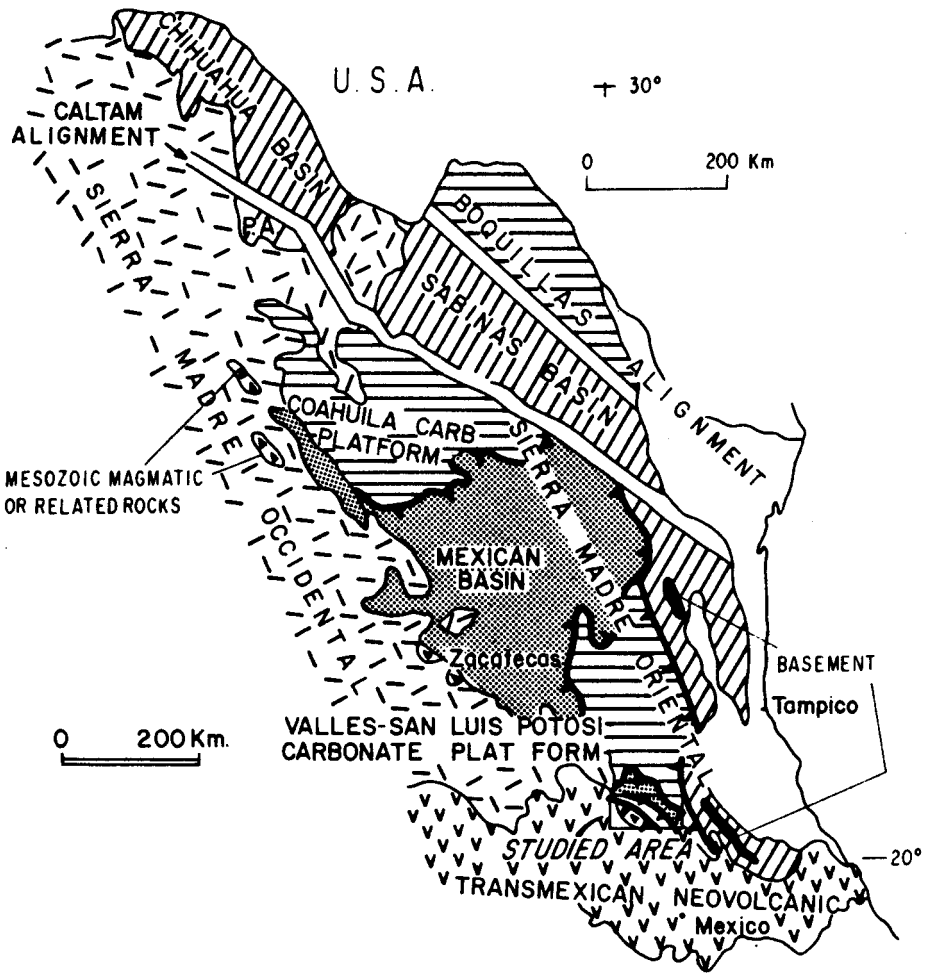

Fig. 1. Tectonic outline map of central and northeastern Mexico (after Tardy, 1986). Modified in the south.

the tectonic regime was compressional or of the strike-slip type (Heim, 1936; De Cserna, 1956); the resulting bulk shortening in east central Mexico is 40%, in the form of a classical fold-and-thrust belt (Suter, 1987).

Reconnaissance mapping in the well-exposed mountain ranges of eastern Querétaro State (Figure 2 and 3) reveals two regional stratigraphic assemblages (Figure 2) (Chauve *et al.*; 1985).

(1) In the west, the Jurassic San Juan de la Rosa Formation is overlain by an angular unconformity, followed up-section by the Neocomian La Peña Azul Formation and the Tamabra and Tamaulipas Formations.

(2) In the east, there are 2 400 - 3 500 m thick shelf deposits of the Upper Jurassic - Neocomian Las Trancas Formation, the Middle Cretaceous El Abra, Tamabra and Tamaulipas, and the Upper Cretaceous Soyatal-Méndez flysch Formations. There is no obvious unconformity between these formations. The carbonate formations define the southwestern limit of the Valles - San Luis Potosí Platform, the Zimapán shelf basin and the El Doctor carbonate bank (Figures 1, 3).

The San Juan de la Rosa Formation (Figure 2), formerly mapped as the westernmost outcrops of the Las Trancas Formation, represents back-arc deposits (Carrillo and Suter, 1982) derived from a Jurassic arc in the west (Bonneau, 1972; Clark *et al.*, 1982; Coney, 1978, Servais *et al.*, 1982, 1986).

El Chilar Anticline at San Antonio and a good exposure of two different lithotectonic assemblages at Higueras (Figure 3) that have previously been considered part of the San Juan de la Rosa Formation, help to understand the tectonic history of this area. Based on independent lines of evidence, I propose that the eastern and northeastern outcrops of the San Juan de la Rosa Formation are Jurassic parautochthonous shelf deposits, whereas the western outcrops of this formation are Jurassic allochthonous rocks. For this reason, I subdivide the San Juan de la Rosa Formation into two members as outlined below. The core of El Chilar Anticline represents the limit between the two assemblages in form of a stack of thrust slices, and could also represent the frontier of the Sierra Madre Oriental fold-thrust belt.

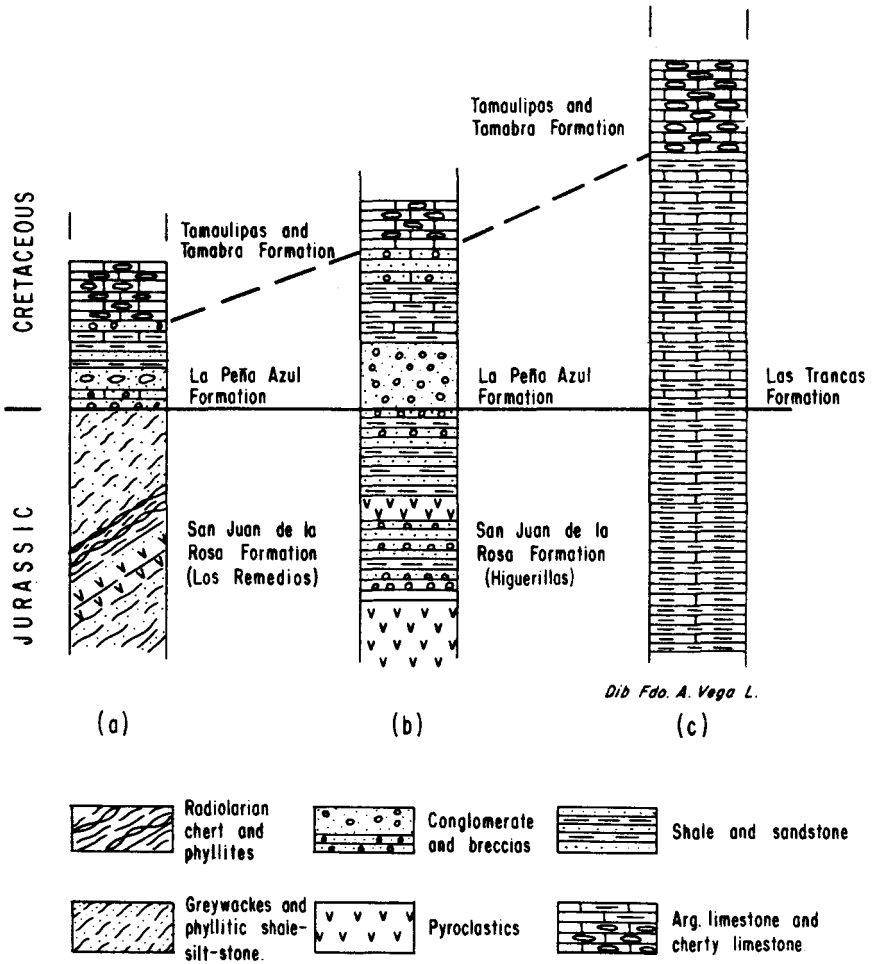

Fig. 2. Schematic stratigraphic sections of the Upper Jurassic-Lower Cretaceous rocks: a) West of El Chilar anticline, b) east of El Chilar anticline, and c) Zimapán Basin.

LITHOSTRATIGRAPHY

Los Remedios member

In San Antonio and in most of the core of El Chilar Anticline (Figures 2 and 3) thick schistous and phyllitic shales outcrop together with siltstones intercalated with thinnly bedded chert, tuffs and silicified fine-grained rocks with radiolarians. Their age could be Middle to Late Jurassic (Chauve *et al.*, 1985). The volcano-sedimentary and phyllitic rocks show alignments of sericite minerals and also cleavage of a micro to mesoscopic scale. The greywackes are laminated and contain quartz, detritical muscovite, pyrite and hematite, which gives the rocks a pink and rusty coloration. This rock sequence of fine texture is informaly named here Los Remedios member. These rocks were tested by applying a petrological tectonic model (Crook, 1974), suggesting an active margin.

In the eastern and northeastern outcrops, the San Juan de la Rosa Formation forms a hectometric package of detrital and pyroclastic rocks presenting notable coarser grainsize (Figures 2 and 3). Common rocks in this member are polymictic conglomerate, breccia, arkose, lithic and feldspathic greywacke sandstone, slaty shale, pyroclastic rocks and lavas of rhyolitic to rhyodacitic compositions containing quartz, potassium feldspar, plagioclase and micas (altered biotite). Their age is Upper Jurassic (Martínez-Hernández, 1979). Two radiometric K/Ar age determinations of the lavas resulted in 77 ± 4 Ma, and 84.9 ± 4 Ma (Chauve *et al.*, 1985). The top of this series is of remarkably constant lithology. It is composed of lenses of black shale in sandstone and pyroclastic rocks.

In the Bonanza Anticline, beyond the map of Figure 3, the base of Las Trancas Formation contains conglomeratic sandstone and lenses of pyroclastic rocks lithologically identical with that of the sandstone and pyroclastic rocks of the Higuerillas member.

Peña Azul Formation

La Peña Azul Formation in Los Remedios area rests with angular unconformity upon Los Remedios member (Chauve *et al.*, 1985) (Figures 3 and 4). It is composed of conglomerates with pebbles of Los Remedios member in a sandy, or carbonate matrix. Here, along more than 4 km, we found this basal conglomerate with a thick-

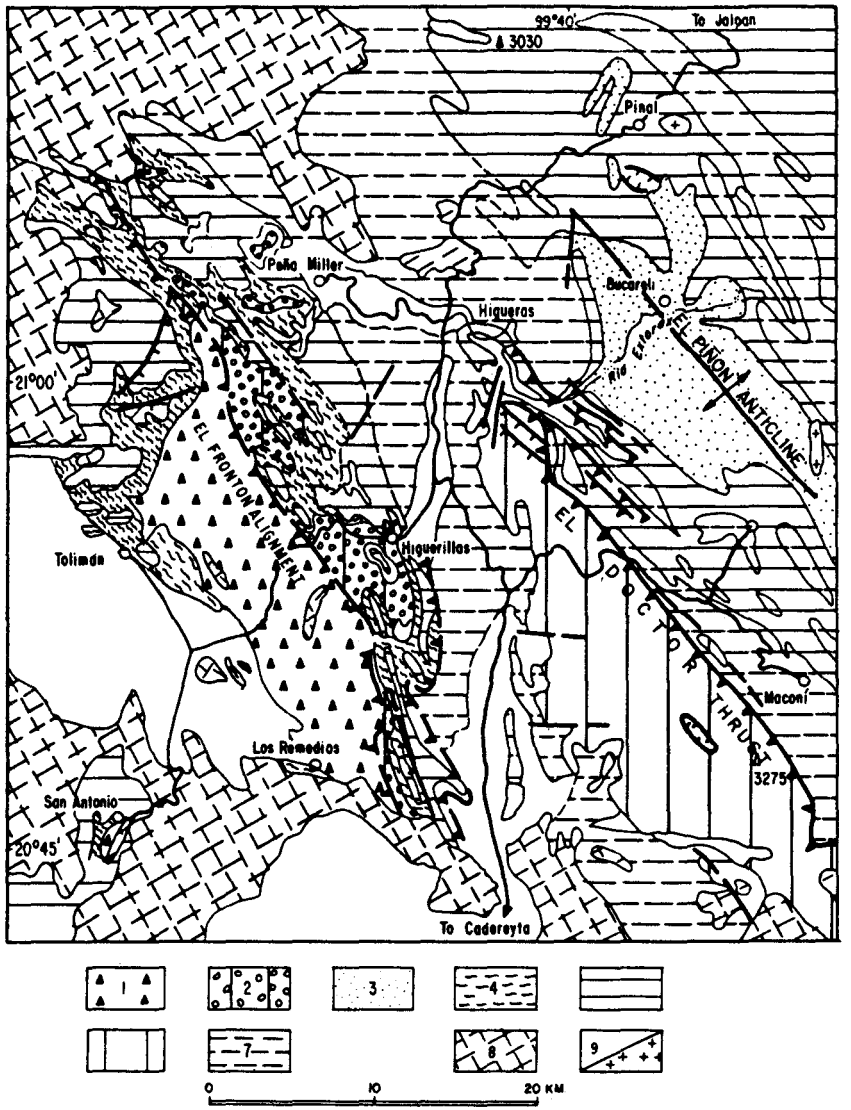

Fig. 3. Structural map of the Sierra Madre Oriental in eastern Querétaro State (after Carrillo and Suter, 1982; M. Carrillo M., in press) with the possible tectonic contact zone in El Chilar anticline core.
1. Los Remedios member; 2. Higuerillas member; 3. Las Trancas Formation; 4. La Peña Azul Formation; 5. Tamabra and Tamaulipas Formations; 6. El Doctor Formation (El Abra); 7. Soyatal-Méndez Formations; 8. Cenozoic Formations. 9. Intrusive rocks.

ness ranging from a few centimeters to 40 m, truncating different beds of the underlying Los Remedios member. Up-section, the series changes gradually to sandstone, shale, marl and limestone banks of the Tamabra Formation. Their fossil fauna is of Neocomian age (Chauve *et al.*, 1985; González-Arreola and Carrillo, 1986).

In the San Antonio area (Figure 3), the contact of La Peña Azul Formation with the underlying Los Remedios member is tectonic or buy angular unconformity. The lower part of the Peña Azul Formation is composed of 100 m thick red shales and some lenses of coarse-grained bentonites. The red beds are overlain by metric size lenticular conglomerates and breccias with pebbles of the same formation. In general, the Tamaulipas and Tamabra Formations overlay the former Las Trancas Formation in disconformity or low angle unconformity (Segerstrom, 1961).

In the eastern flank of El Chilar Anticline, the contact between the Higuerillas member and La Peña Azul Formation is by disconformity. On top of the black shale and breccia, there are conglomerates, sandstone and shale. At the top, the series consists of thin to medium bedded shale, marl and shaly limestone, with thin gypsum local intercalations. The presence of the conglomerate is fairly constant but its thickness ranges from a few centimeters to 100 m, as for example in La Peña Azul mountains. Thickness of the gray-black shale and shaly limestone also varies from near zero as for example west of Higuerillas, to 150 - 200 m in La Peña Azul mountains. The fauna is of Neocomian - Barremian age (Chauve *et al.*, 1985; González-Arreola and Carrillo, 1986). The shaly limestone and shale contain small open-coiled ammonites. Identical lithological-faunistic associations can regularly be found in the upper part of Las Trancas Formation, which outcrops in the Zimapán Basin.

COMPARISON OF DEFORMATIONAL FEATURES IN LOS REMEDIOS AND HIGUERILLAS MEMBERS

In the middle part of Los Remedios member, the most distinctive deformational feature is stratal disruption, with a series ranging from well bedded outcrops to layers displaying pinch-and-swell structures and boudinage to the most intensely deformed rocks consisting of isolated lenses of varying size derived from dismembered greywackes, chert or silicified rocks surrounded by a mudstone matrix. In some places, chert and silicified blocks evidence a previous deformation.

Besides the latter, there are long bands of decametric size exhibiting spaced cleavage dipping in general 0 - 40° to the southwest. Frequently the outcrops are cut by

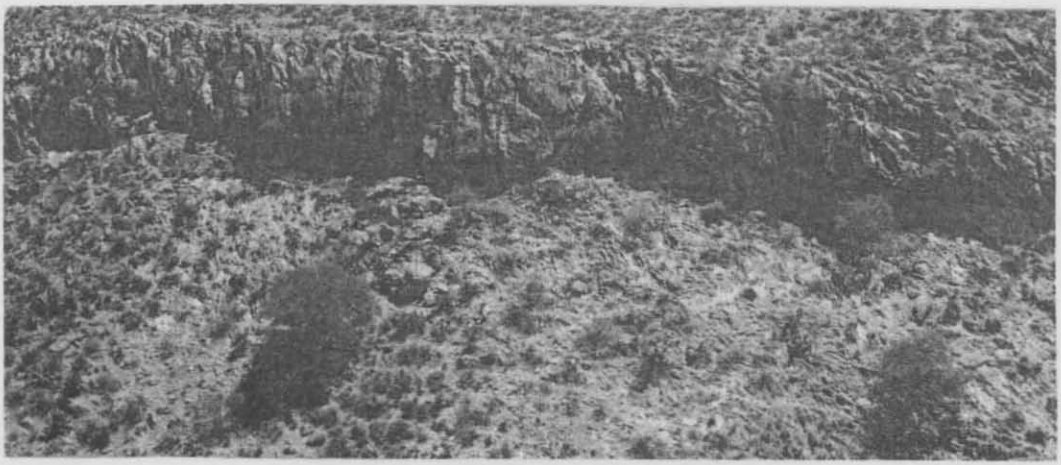

Fig. 4. a) Panoramic of the angular unconformity between Los Remedios member and La Peña Azul Formation at Los Remedios Ranch.

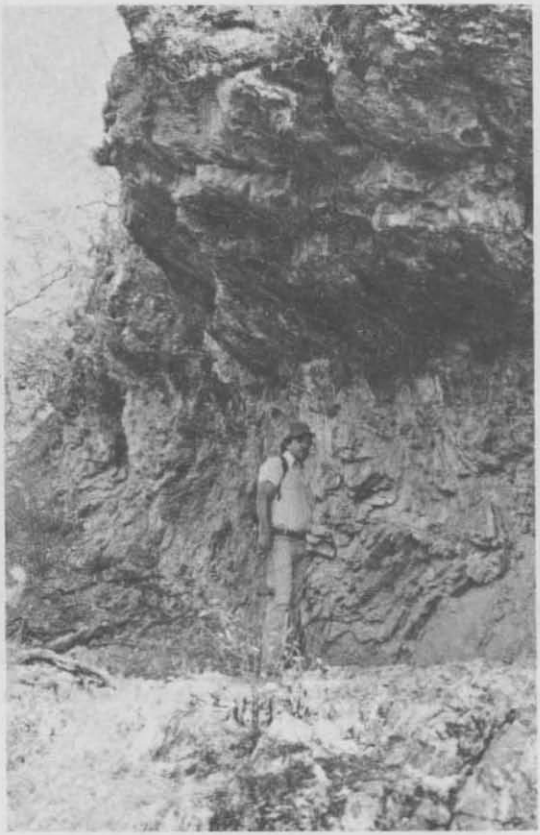

Fig. 4. b) Close-up view of the angular unconformity between Los Remedios member and La Peña Azul Formation at Los Remedios Ranch.

shear surfaces striking and dipping parallel or at low angle with that of the general fragmentation. The preferred orientation of the elongate and lenticular rhomb-shaped sandstone fragments define a foliation that is subparallel to the sedimentary layering (Figure 5; Cowan, 1987).

Other typical deformational features are veins filled with fibrous quartz cement, which are subperpendicular to the sandstone surfaces.

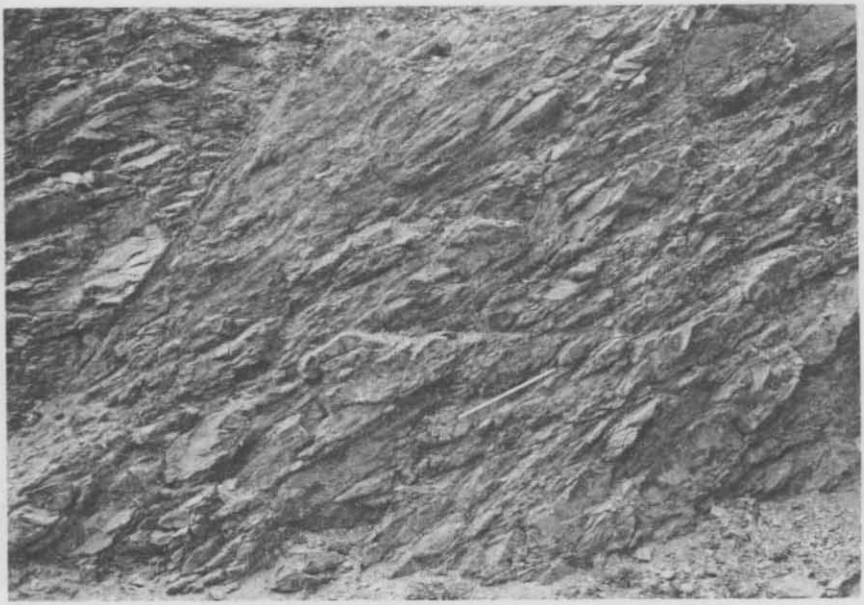

Fig. 5. Lenticular rhomb-shaped frágments of sandstone surrounded by sheared phyllitic shales. Outcrop at El Ronco Hill.

Metre-wide isolated folds with tight and open closures can be observed. They have variably dipping hinge lines and are some times screwed. Centimeters-size isoclinal folds in thinner bedded greywackes can sometimes be observed, immersed in the cleaved incompetent phyllitic shales (Figure 6). Following the syntax of Ramsay and Hubert (1985), they are intrafolial folds.

The problem of the angular unconformity between this member and La Peña Azul Formation is taken up again here, because there is another substantial difference between Los Remedios and Higuerillas members.

In La Peña Azul Formation there are thin-bedded intercalations of fine-grained sandstone, marl, limestones and shale. Some mesoscopic folds are present. They are recumbent with subhorizontal fold axial lines of variable strike. A weak spaced axial-plane cleavage is present; the separation between the cleavage planes is centimetric near the axial surface and more widely spaced in the limbs.

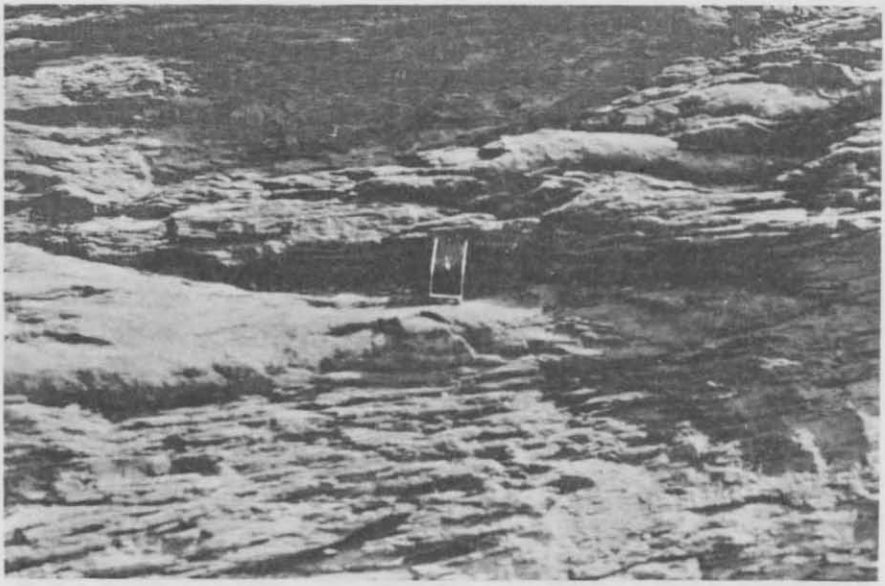

Fig. 6. Thin beds of greywacke forming intrafolial folds in the cleaved incompetents phyllitic shales. Outcrop at Km. 70 of the Tolimán-Higuerillas road.

While the cleavage in Los Remedios member is most frequently anastomosed and more closely spaced, in some places there are two cleavage generations. Over decametric traverse distances, no folds can be found while the penetrative cleavage is constant and most intense, where tectonics slivers are most frequent and stratal disruption is more marked.

Beneath the unconformity surface, many deca to centimeter size closed and open folds of high-angle downward facing hinge lines are present (Figure 7). These fold axes have a northeast direction and dip between 50° and 90° to the SW or NE. Their limbs have approximately EW and N-NW directions. This additional contrast is further evidence for the existence of the angular unconformity relationship between Los Remedios member and La Peña Azul Formation. Nevertheless, the basal competent banks of the overlying formation show low angle faulting of Laramide reac-

Fig. 7. Downfacing folds of the greywackes and phyllitic shales, Los Remedios Ranch.

tivation. The strike of the subhorizontal strias is approximately the same as the one of the axial planes of the down facing folds.

CRUSTAL EXTENSION IN THE HIGUERILLAS MEMBER

Suter and Carrillo (1982) signaled the widespread, lithological heterogenity of the Higuerillas assemblage, where particularly breccia blocks thicker than 1 m, alkaline pyroclastic rocks, polimictic conglomerates with boulders and pebbles, arkose and shale reflect erosion of a high standing source area. Furthermore, the outcrop band is abruptly limited by the tectonic contact with Los Remedios member to the west of El Doctor range, and to the east, because below the northern environs of this sierra there are breccia blocks, coarser sandstone and pyroclastic rocks. Such contin-

uous renewal of a sediment source during the interval that ranges from Late Jurassic to Barremian along a well defined zone most probably was accomplished by normal faulting. In the core and eastern flank of El Piñón Anticline, on the other hand, there are no sandstone nor pyroclastic rocks of importance. The coarse clastic rocks in the core of the Bonanza fold nappe could be derived from a source located in the area of the later Valles - San Luis Potosí carbonate platform.

Altered rocks in form of hydrothermal sulfides are frequently observed in the Higuerillas member, whereas the immediately overlying shales of La Peña Azul Formation or even the Tamabra Formation are not altered, as for example NW of the Higuerillas village. Furthermore, La Peña Azul Formation changes markedly its thickness. Particularly, the upper levels with shale and shaly limestone with small and open-coiled ammonites indicate active high-angle faulting also in Neocomian-Barremian age. In the upper part of this formation and at the base of the Tamabra Formation, there are varied intercalations of conglomeratic and siliciclastic rocks with brecciated limestone. These facies types were interpreted by Epstein and Friedman (1985) as due to active faulting during sedimentation east of the Valles - San Luis Potosí Platform.

In both the Higuerillas member and La Peña Azul Formation there is mesoscopic evidence of erosion and in a few places of synsedimentary faulting. The thin intercalations of gypsum with marine shale and marly shale is further evidence for the subsidence of this basin.

SUPERIMPOSED STRUCTURES

Besides the folds described near the unconformity there are other mesoscopic structures. The most typical in both members is intensely overprinted faulting. The distance between the faults is decametric or even metric. There are two principal groups: (1) subhorizontal faults and (2) faults striking NW and dipping 40 - 70° to the SW and NE. Both groups frequently contain very well striated surface. The second group reveals oblique-slip faulting with a major dip-slip component. The steps on various planes indicate normal faulting, but there are no general rules about the kinematic significance of the steps (Hobbs *et al.*, 1976). The subhorizontal or low-angle dipping faults of the first group are reverse faults. This interpretation is based on drag folds in the hanging-wall in some outcrops. In the Higuerillas and Higueras locations, imbricate faulting is also present.

DISCUSSION

Correlation based on deformational styles holds to pitfalls, because of the generally different rocktypes. However, the Higuerillas member contains slaty-shales and sandstone intercalations, which are of ressembling mechanics competent to deformation as that of greywackes and phillites of the Los Remedios member, and the fragmented foliation is not present. On the contrary, in the Higuerillas member most pebbles and blocks of conglomerate and breccia are not micro-sheared in their surrounding envelope by the shale and siltstone, while in Los Remedios Member, at least a half of their mesoscopic outcrops are micro-sheared disrupted strata.

The micro-structural characters presented in the stereonets are only a trial for a semi-quantification with respect to hypothetic evidence of angular unconformity between the Peña Azul Formation and Los Remedios member. This relationship has been sustained by qualitative criteria previously described by Chauve and others (1985). This trial was equally carried out for braided schistosity of Los Remedios member and overprinted faulting localized in partial sectors.

The data presented in figure 8 were obtained in Los Remedios area within the limits of the unconformity relationship shown in figure 3. In this area the bedding of La Peña Azul Formation strikes and dips most generally NW-0-30° to SW. The cleavage planar plains are spaced 1 cm and are linked to some folds of metric amplitude, approximately parallel to the axial plane in the hinge area. The few folds with schistosity plains observed show more or less the same orientation. This deformation is interpreted as of Laramide age.

At Los Remedios member the schistosity is clearly more closely spaced, in places 2 mm. This braided schistosity shows a variable orientation. As the orientation of down faced hinge lines are approximately perpendicular to that of the Laramide regional trend, it suggests that this orogeny folded the schistosity. Additionally, the unconformity surface exhibits fault strias of the same orientation as that of the down faced fold hinges, which supports this hypothesis.

Figures 8 and 9 represent the schistosity and overprinted faulting in El Jaboncillo area and in partial outcrops across the route between Tolimán and Higuerillas. If the prevailing faulting was essentially extensional we interpret the data as a conjugate set.

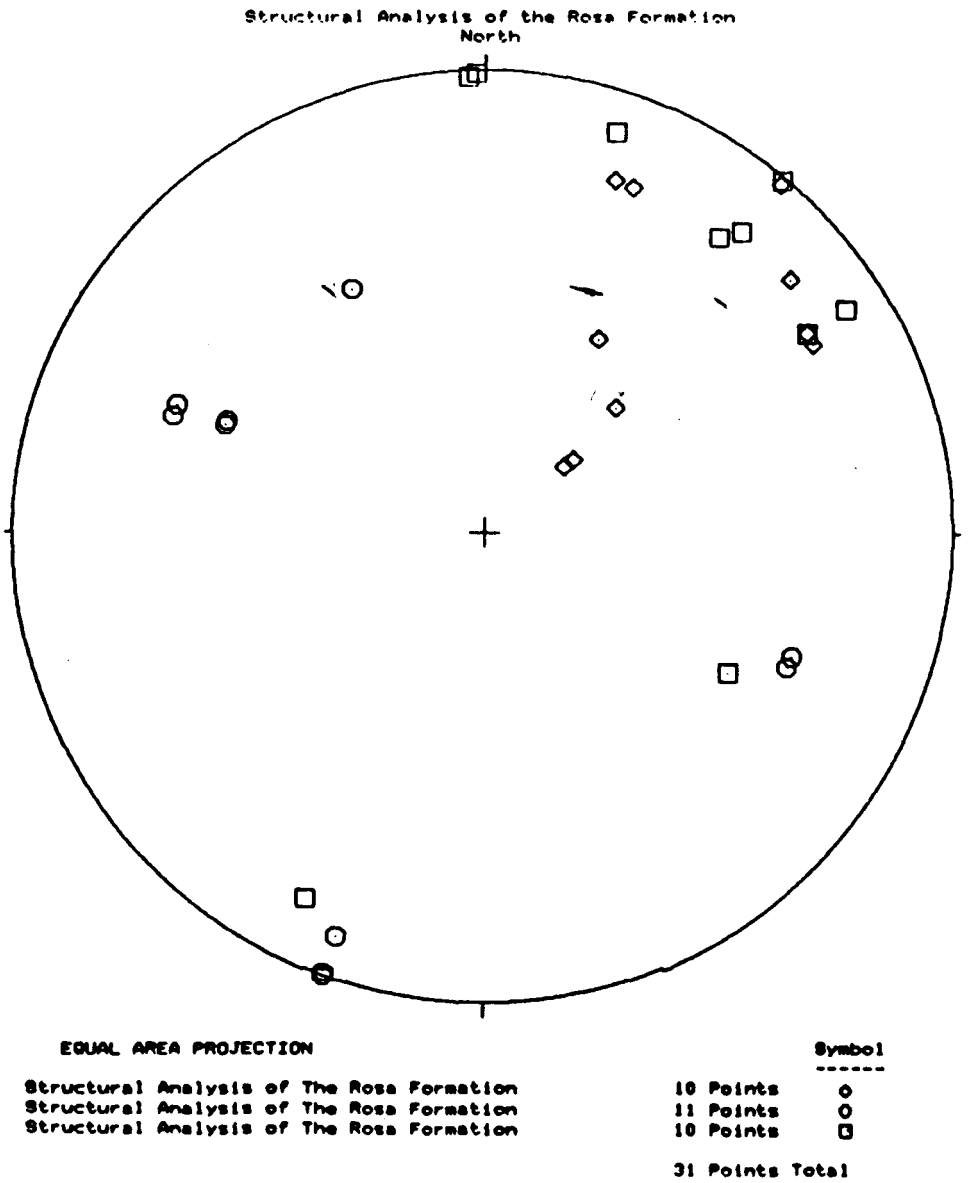

Fig. 8. a) Some measures of the schistosity ◇, bedding □, and down faced hinge lines○ at Los Remedios member, just below the angular unconformity plane.

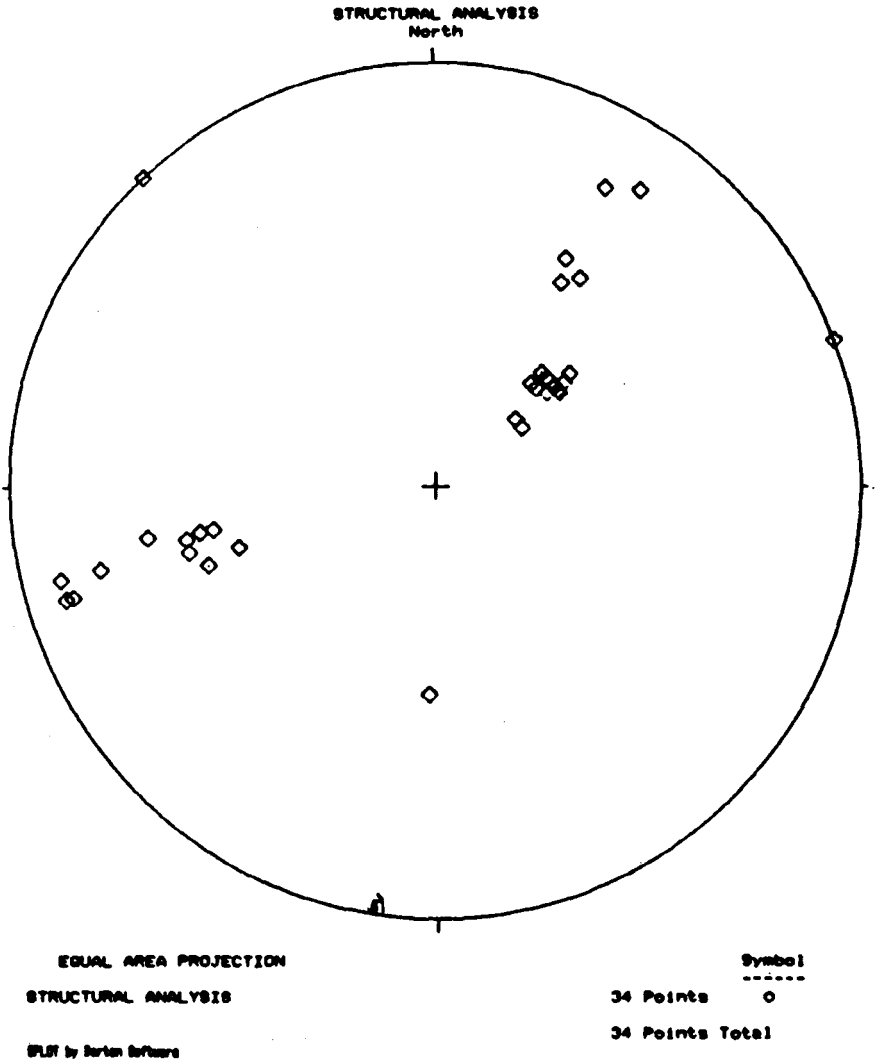

Fig. 8. b) Some measures of the schistosity at Los Remedios member, in the Jaboncillo area. Note that the average of strike and dip is between N120° - N160°; 0° - 50°SW.

CONCLUSIONS

The San Juan de la Rosa Formation is composed of two lithological and structural assemblages: (1) the Middle or Upper Jurassic Los Remedios member, characterized by fine grain deposits derived from an active magmatic arc located to the west and (2) the Upper Jurassic Higuerillas member, composed of coarser grain clastic and alkalin volcano-clastic rocks. The first assemblage was affected by *in situ* stratal disruption and also, in places, by penetrative cleavage, dipping generally 0-40° to the SW. The second assemblage is probably affected by Upper Jurassic-Neocomian rifting. La Peña Azul Formation rests with angular unconformity on Los Remedios member and with disconformity on the Higuerillas member.

The documented intrafolial folds indicate that the formation of the folds was followed by a period of strong extension, which lead to a rupture of the fold wavetrain (Ramsay and Huber, 1985). Cowan (1987) explains this kind of stratal disruption as possibly being generated by parallel-layer extension.

In central Mexico, extensive continental Cenozoic deposits cover the mesozoic rocks, but in Zacatecas State (Fig. 1) 370 km northwest of the area here discussed, Servais *et al.* (1986) report abundant Upper Jurassic basalt pillow lavas and the same epimetamorphic lithological association found in Los Remedios member of the studied area, which is affected by Nevada deformation (Mullan, 1978). To the east, Tardy (1978) reports embryonic rifting tectonics responsible for the deepening of the miogeoclinal basins where - following Salvador (1987) - Tethyan or Pacific early transgression occurred. The Jurassic deposits, underlain or not by oceanic crust, and located behind an active magmatic arc proposed by Servais *et al.* (1982, 1986), would have a great extension. It was reported by Bilodeau (1982) in Arizona, in this report in central Mexico and by Carfantan (1986) in the south.

Both members were affected by the Laramide orogeny which is documented by El Frontón Fault zone, a major tectonic contact, by an imbricate system of reverse faults striking NNW with predominant vergence to the NE. The major Laramide feature is El Frontón fault zone. The abnormal radiometric age obtained in San Juan de la Rosa Formation could be caused by this orogeny.

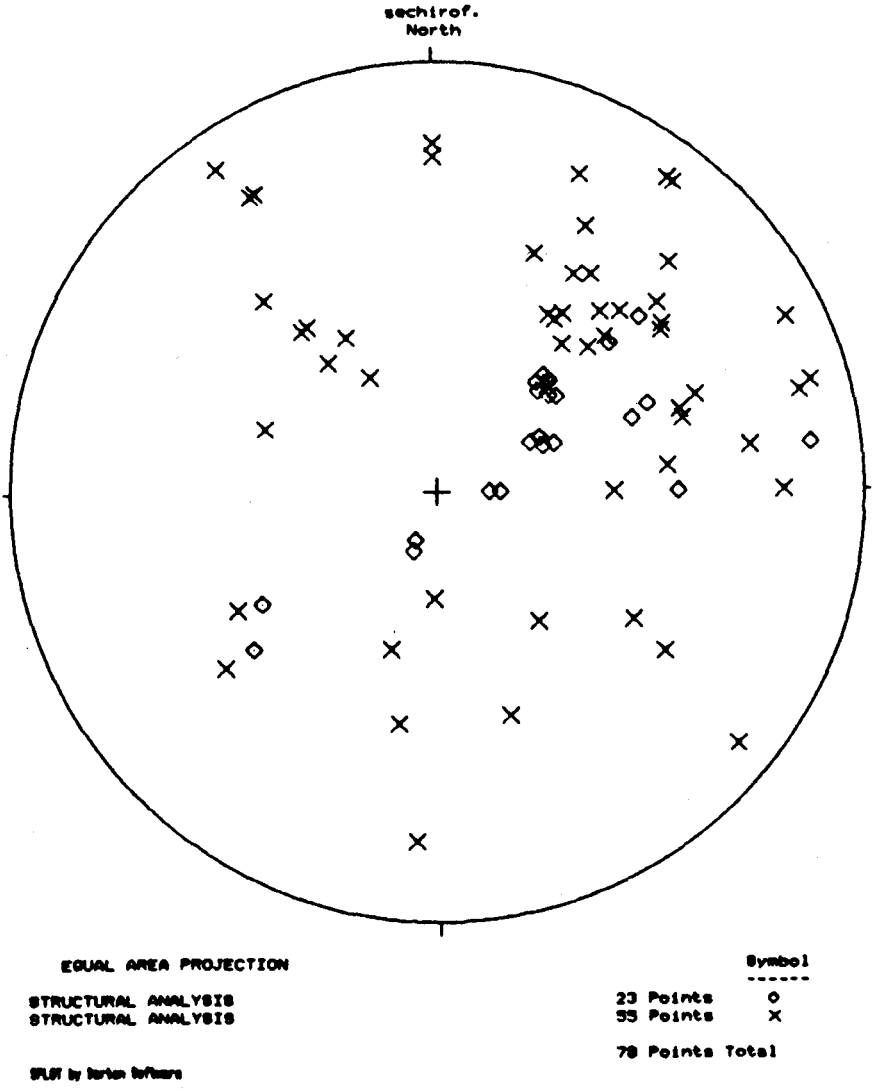

Fig. 9. Partial measures across the route between El Ronco Hill - Higuerillas of faults most of major normal component and schistosity. Note that the schistosity in Los Remedios member is NW 0 - 50°SW.

ACKNOWLEDGEMENTS

The author most gratefully acknowledges the enlighting discussions with M. Suter as well as his critical review and I would also like to thank Z. de Cserna for his criticism of the manuscript in 1987, and to V. Garduño, M. Ferrari and O. Quintero for their help in the tectonic analysis.

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