Univ. Nal. Autón. México, Inst. Geología,
Revista, vol. 4, núm. 1 (1980), p. 19-31

TECTONICS OF THE EXTERNAL PART OF THE SIERRA MADRE ORIENTAL FORELAND THRUST-AND-FOLD BELT BETWEEN XILITLA AND THE MOCTEZUMA RIVER (HIDALGO AND SAN LUIS POTOSI STATES)

*Max Suter**

RESUMEN

En la región entre Xilitla y el Río Moctezuma, Estados de Hidalgo y San Luis Potosí, se pueden observar dos estilos diferentes de deformación, los cuales se deben principalmente a diferencias en la litología y espesor de las rocas involucradas.

El área entre el frente de la Sierra Madre Oriental y el borde de la plataforma cretácica de Valles-San Luis Potosí (Anticlinorios de Huayacocotla y Pisaflores) se caracteriza por pliegues paralelos de plano axial subvertical y, en menor grado, por cabalgaduras. Los pliegues de primer orden se desarrollaron en la Formación Tamán, la cual se plegó como una capa aislada y competente a causa de su posición entre las formaciones Santiago y Pimienta, que son altamente incompetentes. Las rocas encima de la Formación Pimienta se deformaron como una sola unidad porque forman un paquete de rocas competentes de espesor considerable. Estas rocas adoptaron en parte la forma de los pliegues de primer orden, y en parte desarrollaron pliegues disarmónicos de segundo orden, tanto abiertos como cerrados. Esto propició el adelgazamiento de los estratos de la Formación Pimienta en los sinclinales y flancos de los pliegues, de donde la roca fluyó hacia los núcleos. La componente horizontal de desplazamiento en el Anticlinorio de Huayacocotla, con respecto a la cima de la Formación Pimienta, es de 3,550 m, o 23 por ciento. Este valor debe considerarse como mínimo, ya que las rocas muestran un acortamiento adicional producido por los pequeños pliegues concéntricos de tipo *chevron*. Se puede mostrar en un caso (cabalgadura frontal al oeste de Tamazunchale) y es posible en otros dos casos también que una cabalgadura haya sido rotada pasivamente por la formación de un pliegue situado al este del accidente referido, lo que sugiere que la deformación procedió desde el oeste hacia el este.

El borde de la Plataforma de Valles-San Luis Potosí fue activado tanto como una cabalgadura con acortamiento de unos 5 km, donde su orientación fue aproximadamente normal a las trayectorias del esfuerzo principal máximo y como una falla de desplazamiento lateral, donde formó un ángulo agudo con la dirección del esfuerzo principal máximo. Esto permitió que el desplazamiento de la Cabalgadura de Xilitla contribuyera parcialmente al desplazamiento de la cabalgadura frontal al poniente de Huichihuayán.

La interpretación de Tardy y colegas (1975) de la Cabalgadura de Xilitla como el frente de un manto de corrimiento con un acortamiento lineal de más de 150 km es incorrecta.

La disolución por presión y el fracturamiento parecen haber sido los mecanismos principales de la deformación. Las rocas no sufrieron alguna deformación medible dúctil y penetrativa; los ooides en la base de la Cabalgadura de Xilitla no son aplastados, pero son afectados por un crucero estilolítico perpendicular a la estratificación.

ABSTRACT

Two different styles of deformation can be observed in the study area, between Xilitla and the Moctezuma River, States of Hidalgo and San Luis Potosí, that are mainly controlled by the lithology and thickness of the involved rocks.

The area between the belt margin and the edge of the Cretaceous Valles-San Luis Potosí carbonate platform (Huayacocotla and Pisaflores anticlinoria) is characterized by mostly upright parallel folds and to a lesser extent by overthrusts. Open first-order folds developed in the Tamán Formation, which buckled as an isolated competent layer due to its position between the highly incompetent Santiago and Pimienta Formations. The rocks above the Pimienta beds buckled as a whole since they form a stack of well-bedded competent layers, which lacks thicker internal incompetent layers. They adopted partly the shape of the first-order folds and formed partly open to close disharmonic second-order folds. The Pimienta beds were in the latter case thinned in the synclines and fold limbs from where the material flowed into the fold cores. The horizontal displacement component of the Huayacocotla Anticlinorium is (with reference to the upper limit of the Pimienta beds) 3,550 m or 23 percent. This is a minimum value since the rocks show an additional shortening caused by *chevron*-type small-scale concentric folds. It can be shown in one case (border thrust to the west of Tamazunchale) and is possible in two other cases that an overthrust was passively rotated by the formation of a fold to its east, which suggests that the deformation proceeded from west to east.

The platform edge was activated as an overthrust (shortening ± 5 km) where it was oriented approximately normal to the trajectories of the maximum principal stress and as a transcurrent fault

---

**Instituto de Geología, Universidad Nacional Autónoma de México, Ciudad Universitaria, Delegación Coyoacán, 04510 México, D.F.*

**Present address: c/o Schlumberger Offshore Services, Computation Centre, Apartado Postal 53-937, Delegación Miguel Hidalgo, 11300 México, D.F.*

where its direction formed an acute angle with the same stress trajectories, transforming thereby partly the displacement of the Xilitla Thrust onto the border thrust to the west of Huichihuayán.

The interpretation by Tardy and coworkers (1975) of the Xilitla Thrust, as the front of a major overthrust-nappe with a linear shortening of more than 150 km, is refused.

Pressure solution and brittle fracture seem to have been the dominant deformation mechanisms. The rocks did not suffer any measurable penetrative ductile deformation; ooids at the base of the Xilitla Thrust are unflattened, but are marked by a closely spaced stylolitic cleavage perpendicular to bedding.

INTRODUCTION

This paper describes structurally the very external part of the Sierra Madre Oriental in southernmost San Luis Potosí and northern Hidalgo States (Huasteca, approximately 21°20' latitude north) and is based on structural mapping on 1:50,000 black and white vertical aerial photographs (DETENAL, 1978).

The study area (Figure 1) is covered by DETENAL 1:50,000 topographical sheets F14C39, F14D31, F14D41 (provisional editions of 1979) and by the Tamazunchale sheet (14Q-e5, 1:100,000, 1954) of the Mexican Defense Department. It is located between the Moctezuma River in the south and the region comprising Huichihuayán-Tlamaya-La Silleta in the north. Laterally it extends from the western end of the Chicontepec Foreland to the second outermost major structure of the Sierra Madre fold-thrust belt (Pisaflores Anticlinorium in the south, Cerro Grande Anticline in the north).

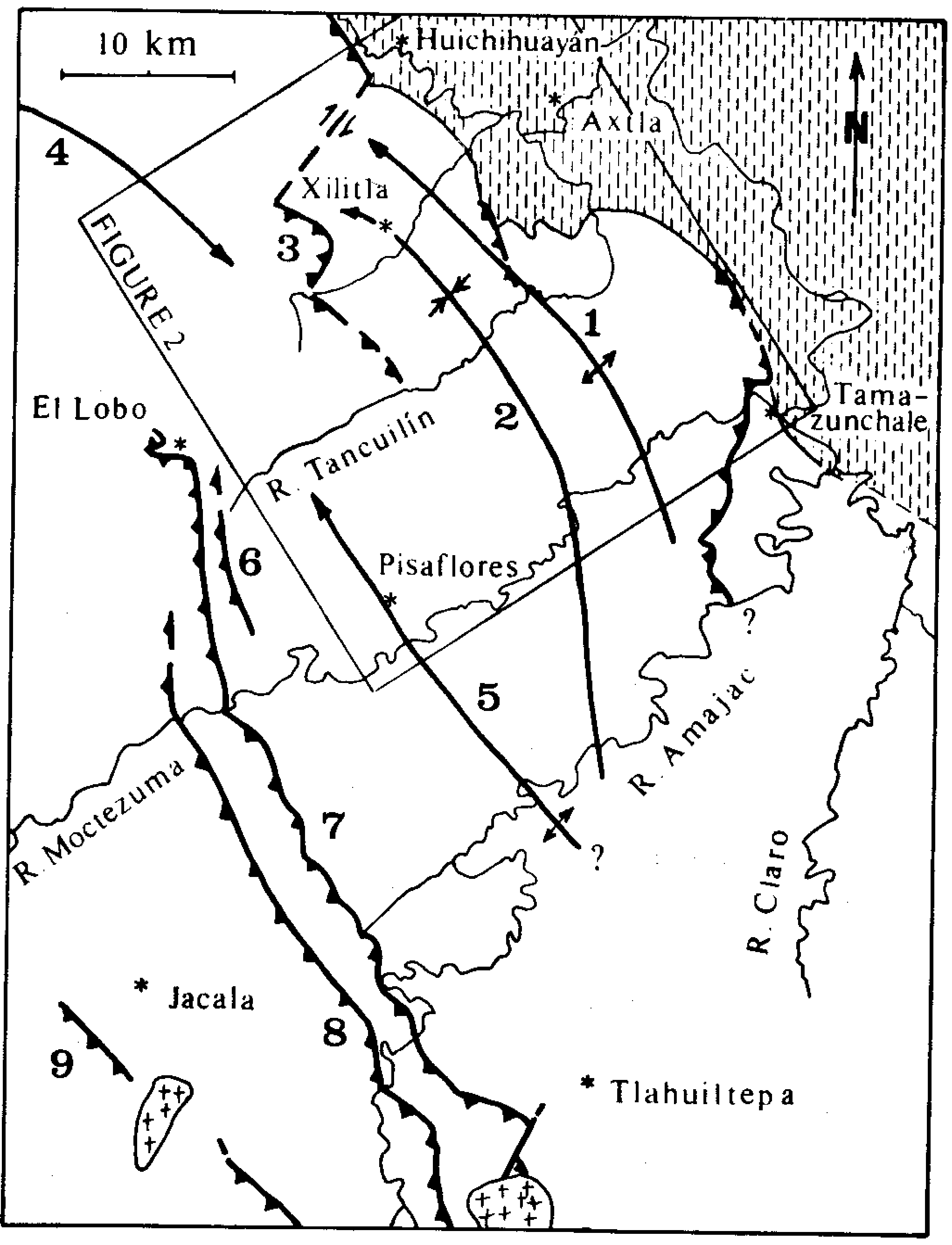


Figure 1.- Tectonic map, showing the main structures of the study area and of its surroundings. Dashed: foreland. 1 = Huayacocotla Anticlinorium. 2 = Xilitla-Chapulhuacán Syncline. 3 = Xilitla Thrust. 4 = Cerro Grande Anticline. 5 = Pisaflores Anticlinorium. 6 = Agua Zarca Thrust. 7 = Lobo-Ciénega Thrust. 8 = Misión Thrust. 9 = Agua Fría Thrust. Sawteeth on upper plates. Crosses = Intrusions. Framed area = Figure 2.

Topography ascends from about 100 m (Huichihuayán and Moctezuma valleys) in the east to nearly 3,000 m in the west (Sierra de Xilitla). Morphology is partly characterized by karst denudation (karst features of the area are described by Bonet, 1953), partly by the drainage network of the Arroyo Seco and the Moctezuma and Tancuilín rivers, whose transcurrent valleys provide excellent three-dimensional exposures.

Previous regional studies of the area include a reconnaissance map (1:300,000), sections and description by Heim (1940), and a guide-book itinerary with a map (1:200,000) by Bonet (1956a). A compilation map of the eastern part of the study area (1:333,334) is given by Carrillo (1965). The uplands between the Moctezuma and the Tancuilín rivers had not been mapped previously.

LITHOSTRATIGRAPHY

Santiago Formation (Reyes, 1964; Cantú, 1971).- Before the definition of this formation, its strata were regarded as a part of the Tamán Formation; it is of middle Callovian to late Oxfordian age (Cantú, 1971), constitutes the lowermost outcropping formation and is conformably underlain by the Tepéxic Formation (Erben, 1956) to the south of the investigated area (Huayacocotla Anticlinorium in the Amajac valley), and conformably overlain by the Tamán Formation. It is characterized by black-brown-grayish shales, argillaceous limestones and thin-bedded black limestones, of mudstone-wackestone depositional texture with pelagic fauna (Pedrazzini and Basáñez, 1978), corresponding to the standard facies belt 1 and standard microfacies (SMF) type 3, following Wilson's nomenclature (1975). Outcrops are restricted to the cores of the Huayacocotla and Pisaflores Anticlinoria in the Moctezuma valley (Figure 2). Thickness is about 150 m in the western part of the Huayacocotla Anticlinorium in the Amajac canyon, and diminishes to about 100 m in the eastern part of that structure; it exceeds 200 m in the Moctezuma valley. Blue-gray, pyrite-bearing shales are dominant in the outcrops of the Amajac canyon and in the surroundings of Pisaflores, whereas the formation is more calcareous in the outcrops to the east of Tamán, and thus not well distinguishable from the Tamán Formation.

Tamán Formation (Heim, 1926a).- Concordantly overlain by the Pimienta Formation, of early Kimmeridgian to early Tithonian age (Cantú, 1971). It includes black, well-bedded lime mudstone and intercalated thin, black shale layers and represents the same facies belt and SMF type as the carbonates of the Santiago Formation. Outcrops are limited to the cores of the Huayacocotla (Moctezuma valley) and Pisaflores (Moctezuma and Tancuilín valleys) Anticlinoria. Its thickness is 150-200 m in the Huayacocotla Anticlinorium and in the Pisaflores Anticlinorium near Pisaflores, but exceeds 500 m in the Tancuilín valley. Following Hermoso and Martínez (1972), the Tamán beds are substituted to the southeast of the study area by the synchronous

"Chipoco" formation, that represents a slope environment. Aguayo (1977) described an outcrop at the base of the hanging wall of the Xilitla Thrust at the Xilitla-San Juan del Río highway (San Antonio section), which had been mapped by Velázquez and Palazuelos (1976) as Tamán Formation, and interpreted the section as "Chipoco" formation, correlating it with other "Chipoco" sections beyond the region of this study. As it will be shown later (p.26), no Tamán ("Chipoco", respectively) beds crop out at the before mentioned locality; the oldest exposed strata of the Xilitla thrust-plate are Pimienta beds, and the section studied by Aguayo includes, in reality, the uppermost part of the Pimienta Formation and a sliver of Tamaulipas Inferior, and it is stratigraphically at least 300 m higher than supposed by that author.

Pimienta Formation (Heim, 1926a).- Concordantly overlain by the Tamaulipas Inferior Formation, of Tithonian age (Cantú, 1971).* Consists of red-brown and greenish shales (partly bentonites), argillaceous limestone (partly with spherical limestone nodules) and black, thin-bedded lime mudstone with chert layers and nodules. Standard facies belt 1 and SMF 3. In the upper part of the formation graded bioclastic-oolitic-lithoclastic packstones can be observed (slope environment, SMF 4 and 5), *e.g.* along the La Gloria-Neblinas trail (Tancuilín valley) or at the Xilitla-San Juan del Río highway to the northwest of Xilitlilla, where they are intercalated with laminated pelagic lime mudstone (Aguayo, 1977). A platform, that extended to the south of the PEMEX Agua Nueva 1 well (Carrillo, 1971, p. 85) during the deposition of the Pimienta beds, but did not reach the study area, is very likely to have been the source area for the lithoclasts and ooids that can be found in the Pimienta and in the lower part of the Tamaulipas Inferior Formation. Thickness of the formation is about 300 m, but often deviates from this amount due to tectonic thinning or thickening. The lower part of the formation is excellently exposed in the cuts of the new Pisaflores- Chalahuite dirt road.

Tamaulipas Inferior Formation.- Synonyms: Tenestipa Limestone (Heim, 1926a), Chapulhuacán Formation (Bodenlos, 1956). It is of Berriasian to Valanginian age (Carrillo, 1971) and is concordantly overlain by the Otates shales. Well-bedded light-gray lime mudstone-wackestone and micro-bioclastic calcisiltite with chert layers and nodule and outstanding vertical stylolites. Standard facies belt 1, SMF types 2 and 3. Thickness is about 250 m in the Arroyo Seco and Tancuilín valleys and about 350 m in the Moctezuma valley. There are good outcrops along the Xilitla-San Juan del Río highway, where the lowermost beds partly contain ooids as do the uppermost Pimienta beds.

The rocks above the before-mentioned formations can paleogeographically be divided into two sequences; one that was deposited on the Valles-San Luis Potosí carbonate platform (Carrillo, 1971) in the west, and the other accumulated in a basin in the east. An excellent review is given by Wilson (1975, chapter XI).

El Abra Formation.- Synonym: El Doctor (Bonet, 1956a). On the map a platform-interior and a platform-edge facies are distinguished (for subfacies and SMF types, see Griffith *et al.,* 1969; Carrillo, 1971; Coogan *et al.,* 1972, and Wilson, 1975).

Platform-interior member.- Synonym: El Abra facies (Heim, 1940). Light colored, well-banked limestones, partly with chert nodules. Its thickness is at least 700 m in the Cerro Grande area, its top is already eroded in the study area. The lowest part of the platform-interior facies is of Barremian age, if the "calizas de plataforma sin nomenclatura formal" are included, that crop out to the west of the study area (core of the Valle de Guadalupe Anticlinorium; Carrillo, 1971) and cannot be distinguished lithologically from the overlying El Abra Formation.

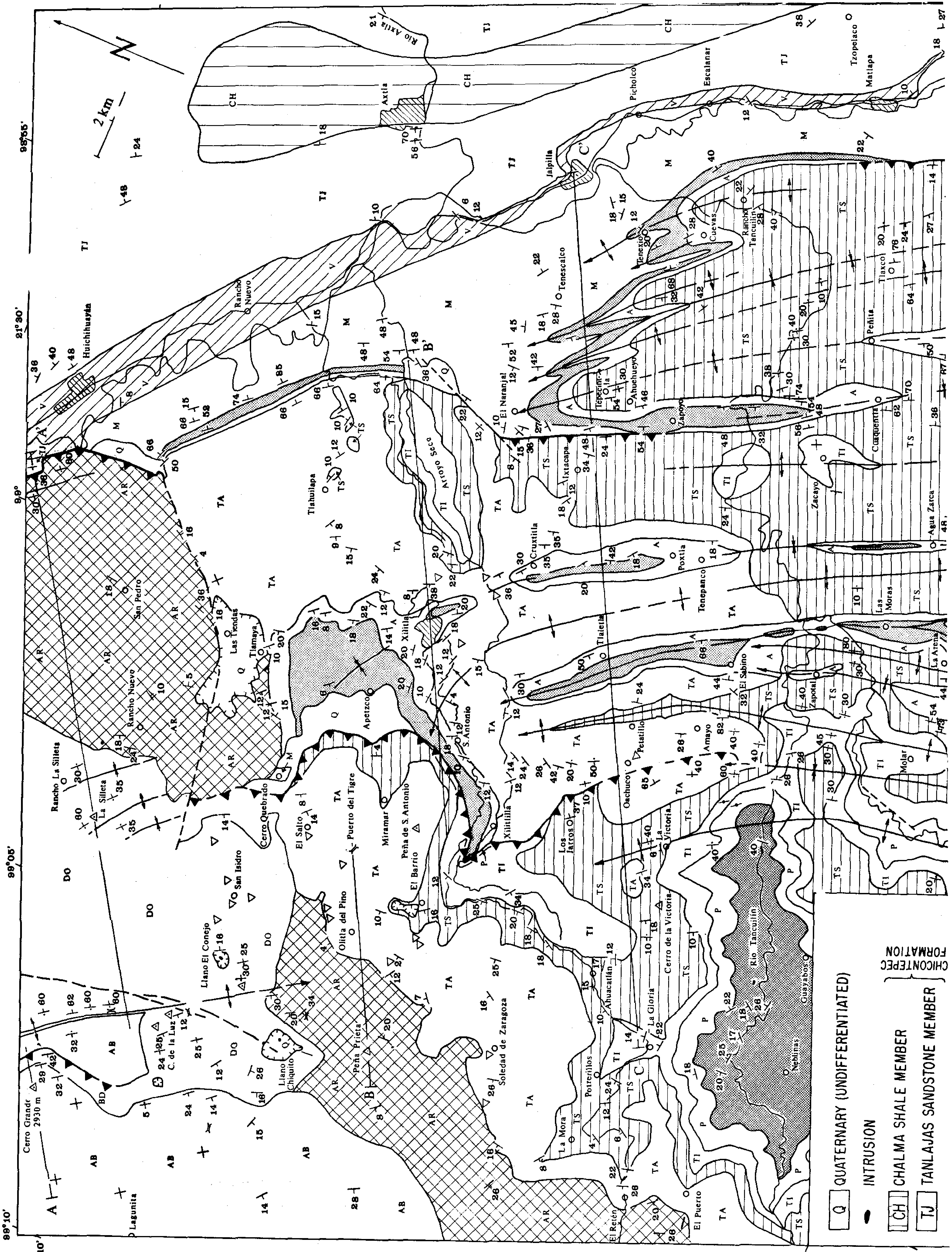
Platform-edge member.- Synonym: Taninul facies (Heim, 1940). Albian-Cenomanian (Bonet, 1956b). Lateral change into the platform-interior member can be observed (to the west of the study area) at the Xilitla-San Juan del Río highway (5 km to the west of El Lobo) and along the dirt road that leads from that highway to Tres Lagunas. The bank-interior facies is underlain in the Cerro Grande area (Figure 2), at the base of the hanging wall of an overthrust, by more than 200 m of dark brown-grayish dolostone, called basal dolomite by Carrillo (1971). Thickness of the member is at least 900 m to the southeast of Llano Chiquito (Peña Prieta).

Tamabra Formation (Heim, 1940).- Overlying conformably the Tamaulipas Superior Formation, underlying conformably the Agua Nueva Formation and merging laterally into the platform-edge member of El Abra Formation in the west, and into the upper part of the Tamaulipas Superior Formation in the east. It is made up of well-bedded light-gray pelagic lime mudstone-wackestone with chert nodules and with extraclasts derived from the Valles-San Luis Potosí platform. In the Xilitla area the upper part of the formation consists of thick-bedded bioclastic grainstone. Breccias can be observed in La Soledad de Zaragoza, between Puerto del Tigre and El Salto (dolomite components), or in Arroyo Seco below the Xilitla-Cruxtitla trail (for locations see Figure 2). Its thickness is about 600 m at the platform edge near Olitla del Pino and about 200 m in the Xilitla area. For sedimentological descriptions of the Tamabra Formation of the area, see Enos (1974) and Carrasco (1977).

Tamaulipas Superior Formation.- Synonym: Ahuacatlán Formation (Bodenlos, 1956). Conformably overlain by the Tamabra Formation in the west and by the Agua Nueva Formation in the east. Separated from the underlying Tamaulipas Inferior Formation by a 0 to 20 m-thick bentonite sequence (Otates shales). Well-banked light-gray lime mudstone-wackestone with chert layers and nodules. Morphologically well distinguishable from the over- and underlying formations by its low relief. Beds are generally thinner than those of the Tamaulipas Inferior Formation. Interbedded green bentonite layers are frequent but nearly absent in the Tamaulipas Inferior Formation. Thickness is about 200 m in the west and exceeds 400 m in the southeast (where Tamabra does not exist). The part of the Tamaulipas Superior Formation which is overlain by the Tamabra Formation

---

*There is a contradiction, however: Bonet (1956b) reports repeatedly *Calpionella elliptica* Cadisch and *Tintinnopsella carpathica* (Murgeanu and Filipescu) from the area between Tamazunchale and Tamán (samples 152-156) and to the southwest of Tamán (samples 160-166) out of Pimienta beds, the latter ones are situated very near to Heim's (1926a) type locality of the Pimienta Formation. Following the Standard Calpionellid Zonation these two species belong to the Berriasian (Flügel, 1978; Trejo, 1980, fig. 4).


QUATERNARY (UNDIFFERENTIATED)
INTRUSION
CHALMA SHALE MEMBER
TANLAJAS SANDSTONE MEMBER
CHICONTEPEC FORMATION
Q
CH
TJ
2 km
N
99°10'
99°05'
99°
98°55'
21°30'
21°15'
Rio Axtla
Axtla
Huichihuayán
Rancho Nuevo
Jalpilla
Picholco
Escalanar
Tzopelaco
Matlapa
El Naranjal
Tenescalco
Tenexio
Cuevas
Rancho Tancuilín
Tlaxcol
Peñita
Tepecinco
Ahuehueyo
Zapoyo
Cuaquentla
Ixtacapa
Tlahuilapa
Arroyo Seco
Cruxtitla
Poxtla
Tenepanco
Zacayo
Agua Zarca
Las Moras
La Arena
Tlaletla
El Sabino
Zapotal
Molar
Amayo
Petatillo
Oachuco
La Victoria
Los Jarros
Xilitlilla
S. Antonio
Apetzco
Xilitla
San Pedro
Las Tiendas
Tlamaya
Rancho Nuevo
Rancho La Silleta
La Silleta
Cerro Quebrado
El Salto
Puerto del Tigre
Miramar
Peña de S. Antonio
El Barrio
Olitla del Pino
San Isidro
Llano El Conejo
C. de la Luz
Llano Chiquito
Peña Frieta
Soledad de Zaragoza
Cerro de la Victoria
Ahuacatlán
La Gloria
Potrerillos
La Mora
El Reten
El Puerto
Rio Tancuilín
Guayabos
Neblinas
Cerro Grande 2930 m
Lagunita
A
A'
B
B'
C
C'
AB
AR
BD
DO
TA
TI
TS
M
V
P

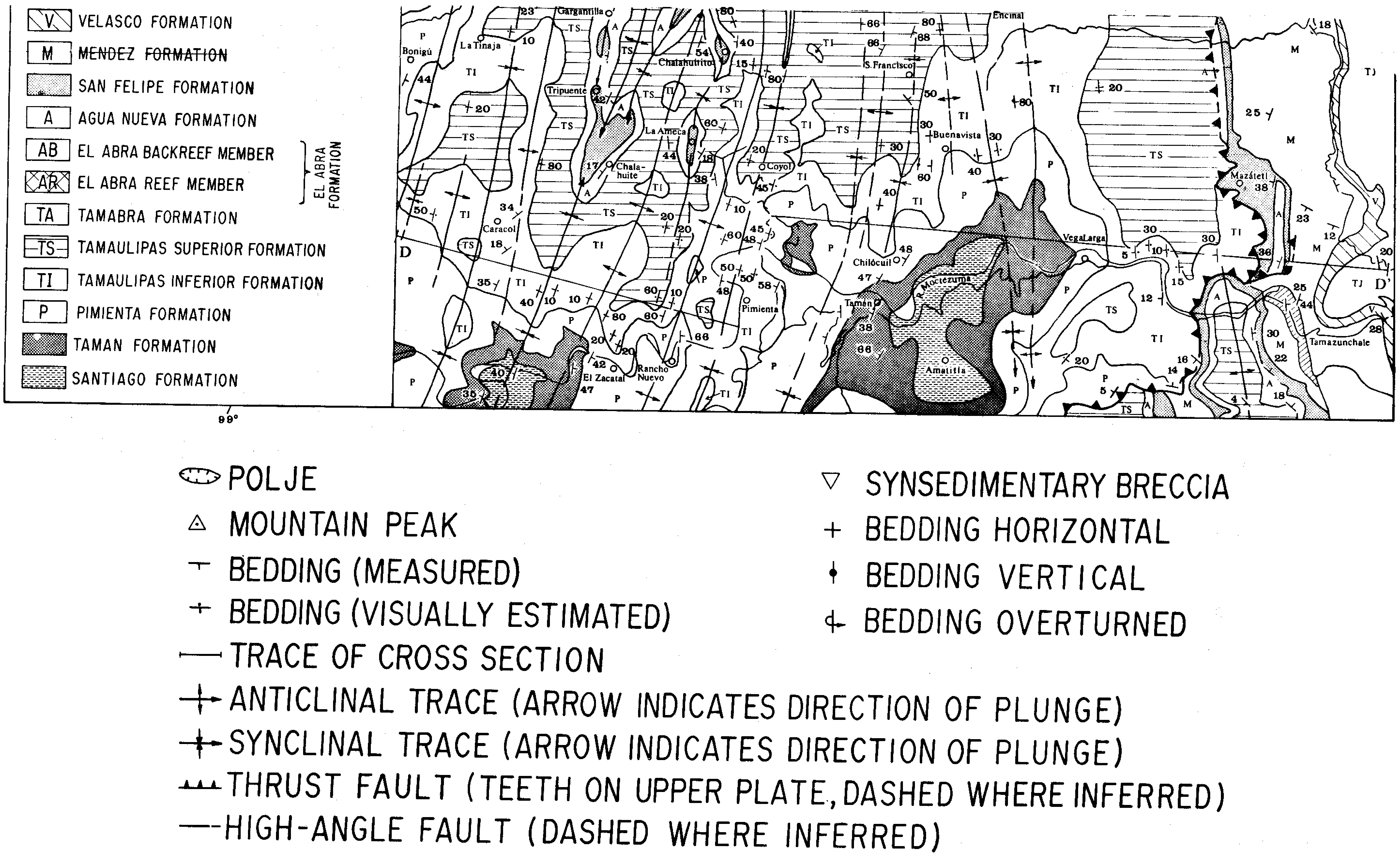


Figure 2.- Tectonic map of the study area, based on the topographical sheets F14C39, F14D31, and F14D41 (provisional editions of 1979) by DETENAL. For location of the study area see Figure 1. The marked traces belong to the sections on Figure 3. DO = Dolostone and BD = Basal dolomite of El Abra Formation.

cannot be distinguished in the field from that part which replaces the Tamabra Formation laterally to the east, and which is sometimes referred to as "Cuesta del Cura" formation.

Agua Nueva Formation (see Muir, 1936).- Synonym: Xilitla Formation (Heim, 1940). Cenomanian-Turonian at its type locality (Soto, 1980). Conformably overlain by the San Felipe Formation. Consists of black, thin-bedded basinal lime mudstone-wackestone with chert nodules and interbedded green bentonites and chert layers; it is reddish-yellow-brown when weathered. The limestone beds show partly pinch-and-swell structures and synsedimentary (?) extension joints. Its thickness is about 100 m and fairly constant.

San Felipe Formation (see Muir, 1936).- Coniacian -middle Campanian (Soto, 1980). Conformably overlain by the Méndez Formation. Greenish-gray thin-bedded lime wackestone-packstone with intraclasts and abundant pelagic microfauna, partly with chert nodules; intercalated with green shales and sandstone layers which show sometimes graded bedding (*e.g.* at the Xilitla-Apetzco dirt road) and (outside the study area, at the El Lobo-Agua Zarca dirt road) partial Bouma sequences with graded and convolute bedding. Thickness was measured as 146 m at the El Lobo-Agua Zarca road and is about 80 m in the Tamazunchale area.

Méndez Formation (see Muir, 1936).- This unit is of Campanian to Maastrichtian age (Bonet, 1956b), and reaches the Danian according to Gamper (1977). Conformably overlain by the Velasco Formation. Contains yellow-brown argillaceous limestone, intercalated with thin shale and sandstone layers. Outcrops are restricted to the east of the Huayacocotla Anticlinorium and (to the west of the study area) to the syncline between the Lobo-Ciénega and the Xilitla Thrust.

Velasco Formation (*in* Maldonado, 1956).- Paleocene. Conformably overlain by the Chicontepec Formation (contact exposed along the Federal Highway 85, between La Y Griega de Xilitla and the Axtla bridge). Made-up of blue-brown shales of 50 to 100 m thickness, partly interbedded with thin sandstone layers (flysch-bedding).

Chicontepec Formation (*in* Maldonado, 1956).- Paleocene to early Eocene. Like the Velasco Formation, it is formed by flysch-type sediments, consisting of rhythmical, graded sequences with a sandstone and a shaly part that indicate deposition by turbidity currents. Two members can be distinguished close to the Huayacocotla Anticlinorium, which are:

1.- Tanlajás sandstone member (Heim, 1940).- Conformably overlain by the Chalma shale member. Blue-yellow-brown. The sand-siltstone inverval of the flysch-sequences is thicker than the shale interval which gives the member a morphological competency. As a contrast, the shale intervals are dominant in the morphologically weak Velasco and Chalma units, that bracket the Tanlajás sandstone. Thickness is close to 1,000 m in the Maguey 2A well, about 12 km to the east of Axtla (Mendiola, 1965).

2.- Chalma shale member (Heim, 1940).- Same lithology as the Velasco Formation. Its top is already eroded in the study area. At the Tamazunchale-Chapulhuacanito dirt-road, bottom-marks and trace fossils are found in these beds in a quarry near Tezontla.

INTRUSIVE ROCKS

Several small intrusions were mapped in the region, which are all of gabbroid composition.

1.- A N 80°E striking dike can be followed for 250 m along the trail that leads from El Puerto to the Lobo-Agua Zarca dirt road. In its eastern prolongation other intrusions crop out at the La Gloria-Guayabos trail (Figure 2) and in the bed of Tancuilín River.

2.- Two intrusions crop out in the center of Llano Chiquito and at its northern end and seem to be related to a north-trending fault system.

3.- Small intrusions, without obvious structural control, were found in Llano El Conejo and at the Rancho Nuevo-Rancho La Silleta trail.

In agreement with evidence from farther southwest, where major overthrusts are overprinted by granodiorite intrusions in the area of the Jacala and Tlahuiltepa municipalities (Figure 1), it is assumed that the intrusions are younger than the formation of the early Tertiary Sierra Madre Oriental foreland thrust-and-fold belt.

GEOMETRY AND LITHOLOGY OF THE EDGE OF THE VALLES-SAN LUIS POTOSI CARBONATE PLATFORM

For the overall geometry of the platform, the reader is referred to the paper of Carrillo (1971, fig. 10). The contact between the El Abra platform-edge deposits and the Tamabra foreslope facies passes in the northeastern part of the study area below the surface and reaches the Sierra Madre Oriental to the southwest of Huichihuayán (Figure 2). It then crosses the Huayacocotla Anticlinorium in a N 45°E-trending lineament, which is visible on LANDSAT images. The plate to the northwest of the lineament (bank-edge facies) shows an (synsedimentary) inclination of about 15° against the lineament and its relief is 300 to 400 m higher than that of the flat-lying counterpart to the southeast (foreslope facies). The lineament was very probably activated as a strike-slip fault during the formation of the Xilitla and the border thrust (see p. 28).

Synsedimentary breccias are frequent in the Llano San Ysidro region (Figure 2). They contain 20 percent dolostone, 20 percent rudist boundstone and 60 percent components of the platform-interior (mainly miliolid-limestone). Due to the dolomitization present in that area, it is not clear whether these breccias are part of the bank-interior realm or whether a channel existed across the bank-edge, which could explain the great extension and thickness of the Tamabra Formation in the surroundings of Xilitla.

The orientation of the bank edge changes gradually from N 45°E in the Tlamaya area, into a north-south direction to the south of the Xilitla-San Juan del Río highway, from where several major overthrust faults developed along the bank edge over a distance of more than 50 km. The area between El Salto and El Retén seems, therefore, to be the only part of the platform edge which was not activated as a fault during the formation of the Sierra Madre fold-thrust belt, and thus it would be a good place for a detailed study of the platform-foreslope-basin transition. The platform-edge facies shows a basinward inclination of 20° in the southern wall of the Peña Prieta and is slightly outbuilding. No synsedimentary faulting could be observed along the escarpment.

CERRO GRANDE ANTICLINE

The Cerro Grande Anticline is the morphologically most dominant feature of the study area. Cerro Grande, situated in its western limb, is the highest point of the Sierra de Xilitla (approximately 2,930 m) and several mountains of this structure are higher than 2,500 m, but they are seldom visible from the nearby foreland due to haze.

The fold trends south-southeast. Its shape is fairly symmetric between Llano El Conejo and Llano Chiquito with 0-30°-dipping limbs, but is asymmetric in the Cerro Grande area with a 0-42°-dipping western and a 60°-dipping eastern limb. Its width there is approximately 4 km and the structural relief is 1,000-1,200 m (Figure 3A).

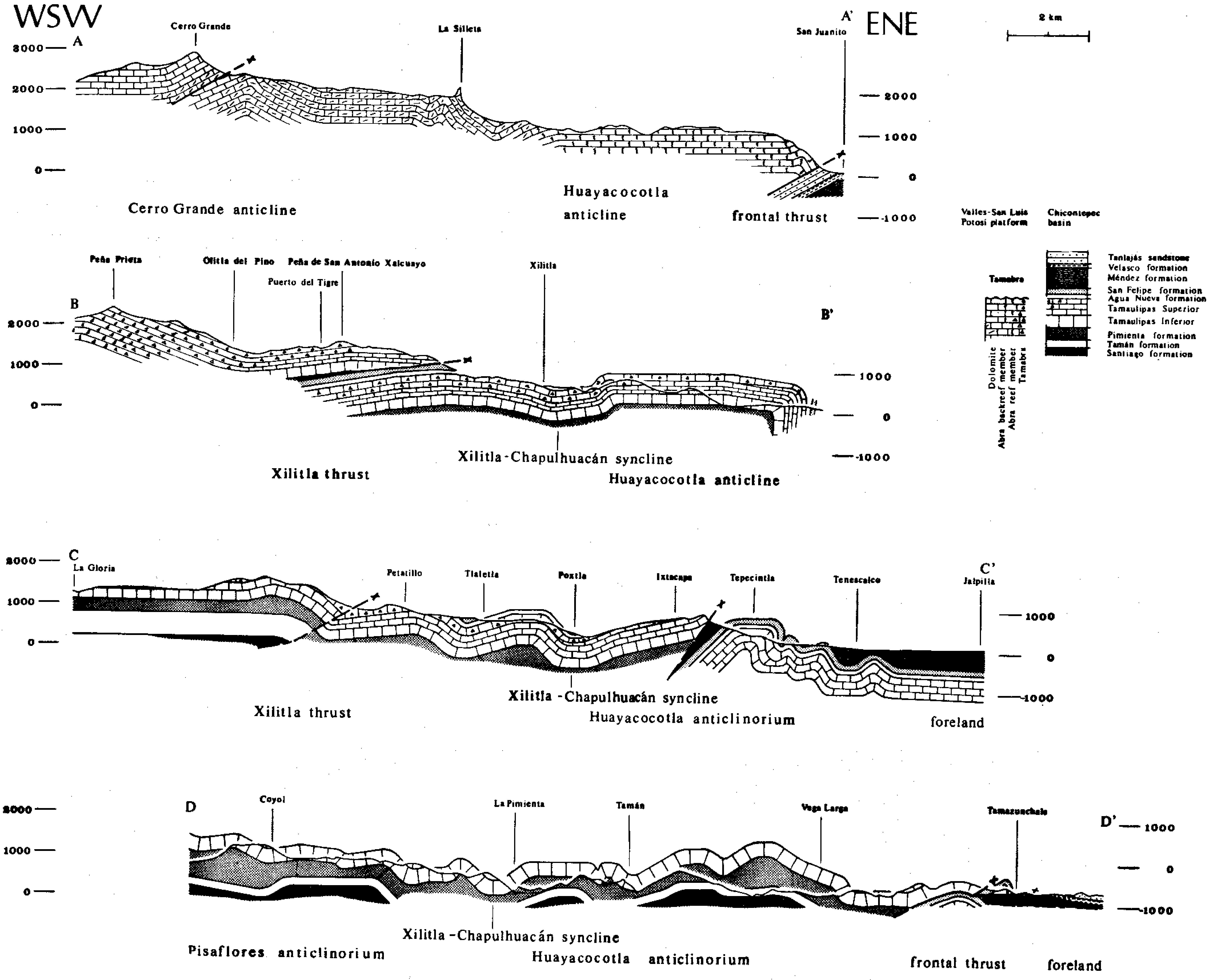


Figure 3.- Sections across the study area. The traces are marked on Figure 2.

The anticline trends oblique to the edge of the Valles-San Luis Potosí carbonate platform and terminates in the south where it reaches the bank-edge facies. This relation suggests that the fold originated on evaporites (Guaxcamá Formation) which are partly present in the protected platform interior and which acted as a lubricant layer (*cf.* Carrillo, 1971).

The fold is situated approximately in the northern prolongation of the Pisaflores Anticlinorium (Figure 1), but the *décollement* horizon and the geometry of the two structures are different.

An overthrust fault is exposed on the southern wall of the Cerro Grande (Figures 2, 3A), where basal dolomite is thrusted over El Abra limestone of the platform-interior. The fault dips approximately parallel to the bedding of its plates, and has an inclination of 30° W and a minimal horizontal displacement component of 700 m. The overthrust might be the northern continuation of the Agua Zarca or of the Lobo-Ciénega thrusts (Figure 1). The possible connection could be checked by means of a more detailed mapping with a subdivision of the El Abra bank-interior facies.

XILITLA THRUST

The Xilitla Thrust was first described by Heim (1926b, 1940), who mapped the outcrop of the subhorizontally inclined thrust between Xilitla and the Arroyo Seco correctly, but assumed the unrotated hanging wall to consist of the Tamasopo Limestone, a platform facies-type of the Upper Cretaceous. Bonet (1956a, fig. 10) determined the hanging wall to contain a sequence that ranges from Pimienta beds to the El Abra Formation, but erroneously mapped the tectonic contact to pass in direction of Ahuacatlán, mistaking thereby the Tamaulipas Superior Formation (because of its high bentonite content) for Pimienta beds. Velázquez and Palazuelos (1976) finally drew the thrust with a dip of about 60° and with drag folds forming a limb in both, the hanging and the footwall, which gives the impression of an eastward overturned fold with a minor forelimb-thrust. According to the same authors, the hanging wall contains, at the Xilitla-San Juan del Río highway, the uppermost part of the Pimienta beds which are in tectonic contact (normal fault) with Tamán beds, that have overridden the Agua Nueva of the footwall. In reality, a normal fault of this size, which should also displace the younger formations of the upper plate, cannot be observed. The lithology of the lower part of the hanging wall consists (from top to bottom) rather of the Tamaulipas Inferior Formation and about 50 m of Pimienta beds that are in tectonic contact with a sliver of Tamaulipas Inferior and thrusted over San Felipe beds.

The geometry of the thrust is excellently exposed normal to its trend in the Arroyo Seco valley (Figures 4, 5). The mean inclination of the thrust is 7.5° (6.5° in the upper, 9° in the lower part). Neither the upper nor the lower plate are frontally rotated due to frictional drag. The San Felipe beds of the footwall are not transected by the shear plane, but keep their thickness all along the distance between the most interior and the most exterior outcrop. The mean angle, on the other hand, contained by the exposed beds of the upper plate and the fault is 8° (α) for the interval Tamaulipas Inferior to Tamabra Formations and $< 2.5°$ for the Pimienta Formation. This suggests that the corresponding rocks of the lower plate are also truncated under that angle. The Xilitla Thrust, therefore, very probably includes a ramp segment with an inclination α that connects the outcropping layer-parallel fault-segment with a lower *décollement* running in the Pimienta beds. Another evidence for a ramp geometry of the lower plate is the fold, being exposed in the upper plate (Figure 5), with an angle of 85.5° between its axial plane and bedding. The fold is likely to have been caused by the migration of the thrust sheet through the unexposed upper hinge of the lower plate that connects the tectonic ramp with the upper layer-parallel thrust-segment. A value for the ramp height h is given by the greatest measurable structural relief of the fault which is 1,050 m. A lower limit is put on the length of the upper layer-parallel fault-segment (Δx_1) by the horizontal component, normal to the structural trend, of the distance between its erosional front to the east of Miramar and the most internal outcrop of the footwall near Xilitlilla; it measures 3,600 m. The overall linear shortening Δx of the Xilitla Thrust in the Arroyo Seco section includes the translational component Δx_1 and the rotational component $\Delta x_2 = h(1/\sin\alpha - 1/\tan\alpha)$ which is caused by the transport of the hanging wall through the ramp segment. Δx measures somewhat less than 3,700 m. This value has to be taken as a minimum amount since it is not known for what distance the thrust originally passed horizontally in the San Felipe beds, and since shortening above the San Felipe and below the Pimienta Formations has not been considered.

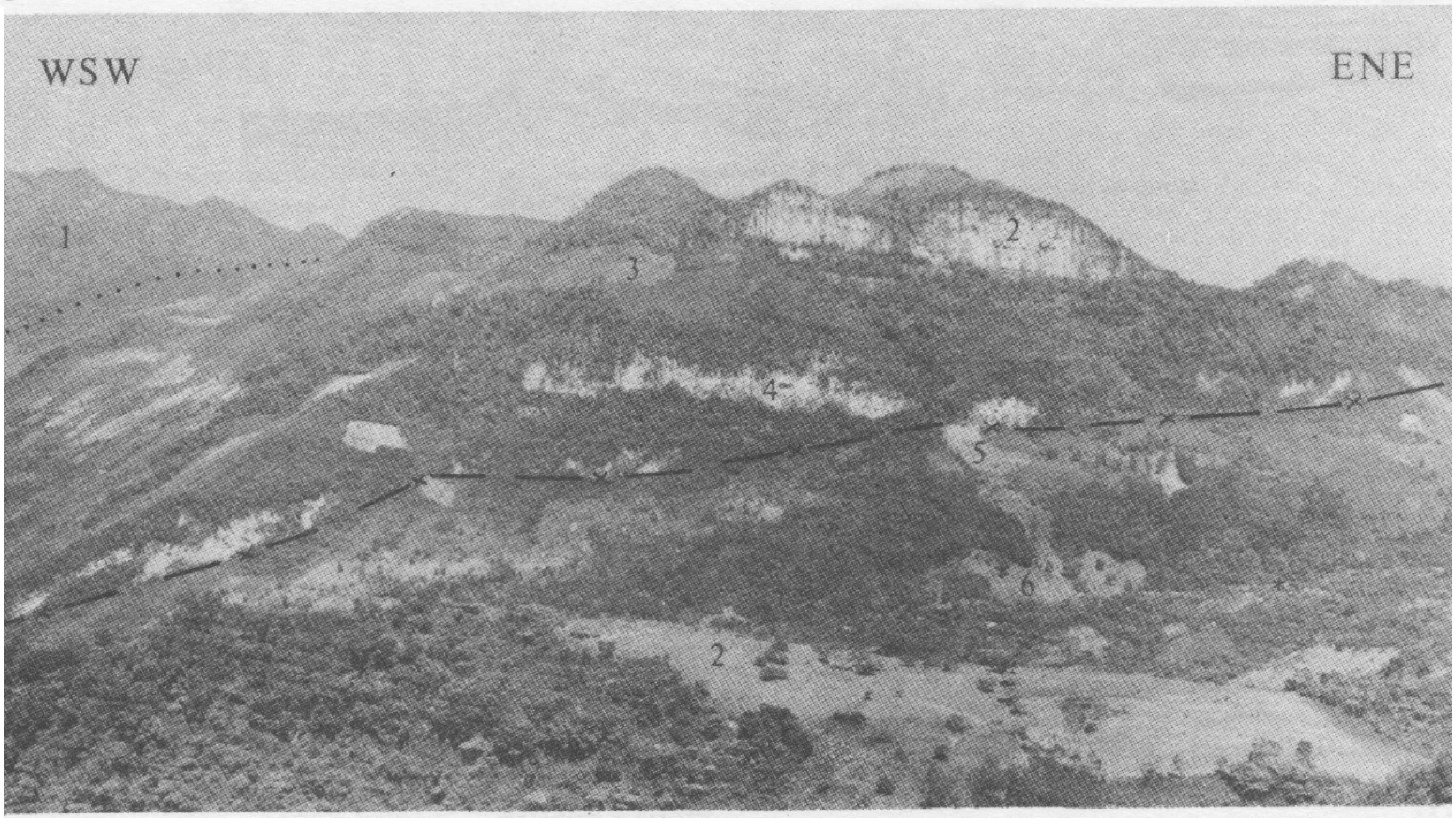


Figure 4.- Xilitla Thrust in the Arroyo Seco valley. 1 = El Abra reef member. 2 = Tamabra Formation. 3 = Tamaulipas Superior Formation. 4 = Tamaulipas Inferior Formation. 5 = San Felipe Formation. 6 = Agua Nueva Formation. * = Xilitla-San Juan del Río highway.

A certain control of this quantitative shortening estimation is given by the fact that the thrust tapers towards the south and terminates in the Tancuilín valley with a high angle of inclination. The shortening increase between the Tancuilín river and the Arroyo Seco section must be gradual; no strike-slip fault could be recognized across which a discontinuous shortening change would have been possible. A linear shortening increase implies kinematically a clockwise rigid-body rotation of the upper plate or an anticlockwise rotation of the lower plate around its southern tip with an angle β. Given the distance r between the center of rotation and the Arroyo Seco section of 8,500 m and the before-mentioned shortening amount Δx, we get a rotation of approximately 25° (Figure 6).

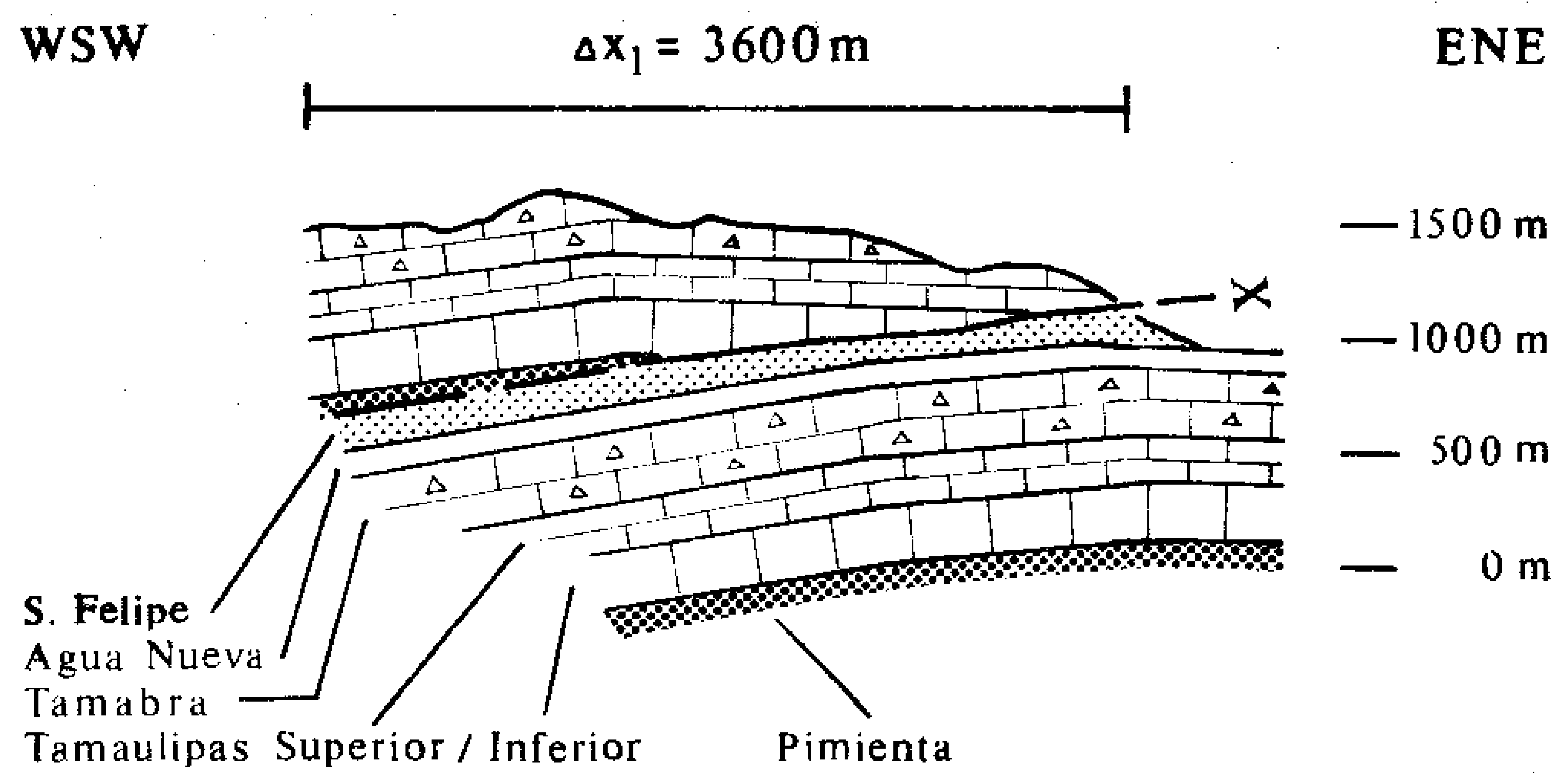


Figure 5.- Section across the Xilitla Thrust. Same trace as section 3B.

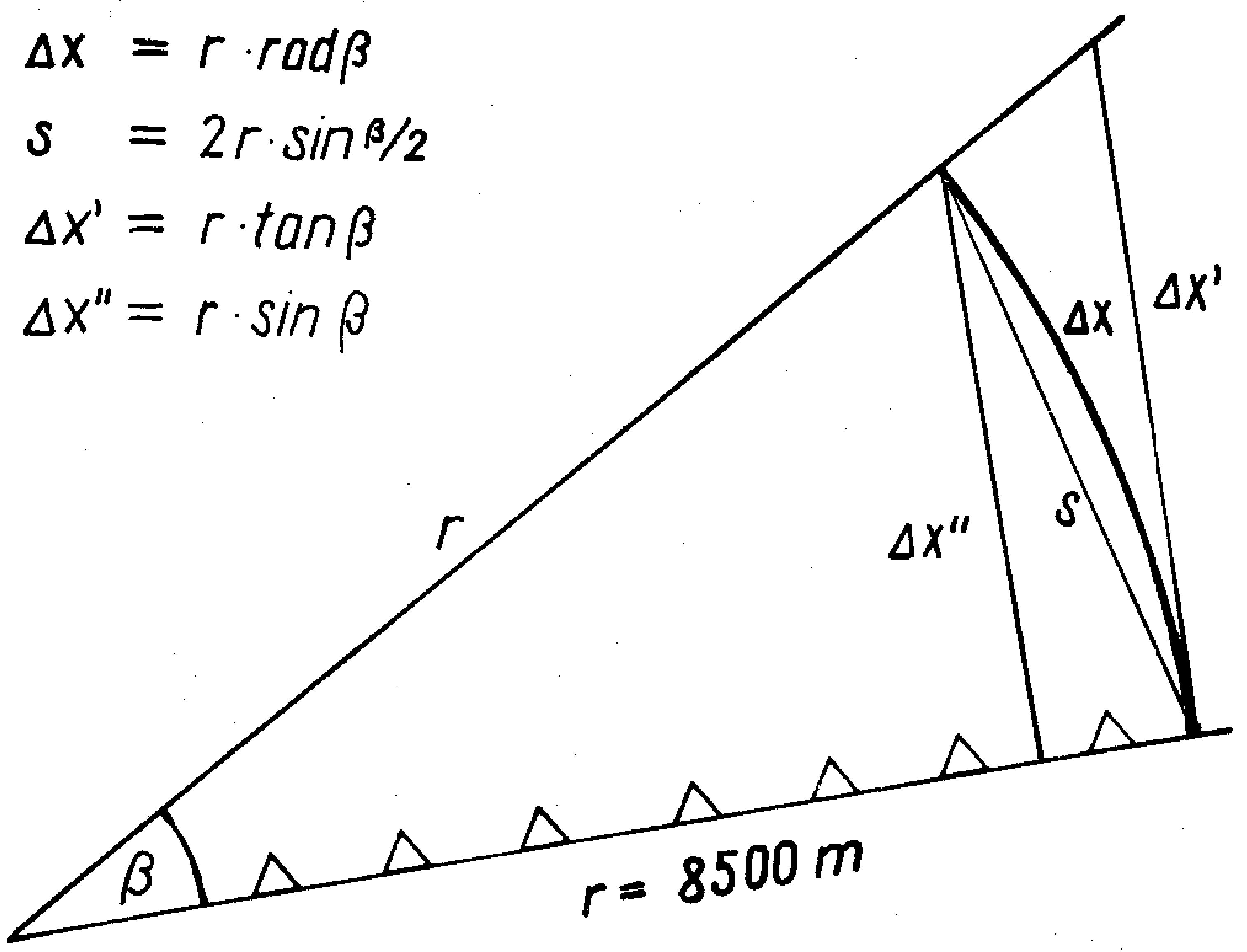


Figure 6.- Modeling of the gradual shortening increase of the Xilitla Thrust between the Tancuilín River and the Arroyo Seco section (distance r) as a rigid-body rotation (with the angle β) around the southern tip of the thrust. Δx= displacement-path curve for point A. Note that measuring the shortening normal to the structural trend, either too great ($\Delta x'$) or too small ($\Delta x''$) values are obtained.

The front of the overthrust is well defined to the north of the Arroyo Seco by the Upper Cretaceous of the footwall and an escarpment up to the village of Cerro Quebrado (Figure 2), where Méndez shales directly overly the El Abra Formation. From there on no Upper Cretaceous crops out and the upper plate shows a fold in the dolomitized El Abra Formation, whose eastern limb is formed by the La Silleta needle peak (Figure 3A).

It should be mentioned that Tardy and coworkers (1975) suggest a connection of the Xilitla Thrust with a thrust they observed more internally, to the east of San Luis Potosí, and which lies about 190 km farther west-northwest in the Sierra Madre fold-thrust belt. Given the north-northwestern trend of the intermediate compressive structures, about which no information is given in that paper, there results a linear shortening of at least 150 km for this nappe, which is about twice the shortening of the Helvetic Alps (Hsü, 1979). The thrust has to be nearly horizontal if the two localities are points of one and the same north-northwest striking plane and it needs a strong southern plunge to cross all the structures of the belt over such a great distance as shown in their figure 1 (unless the more internally situated outcrop is part of a window). The suggestion by Tardy and coworkers is not sufficiently documented, and it seems that the observed overthrusts are rather two different features, whose shortening does not exceed 10 km each.

Deformation mechanism.- Small-scale features can be studied in the lowermost part of the upper plate, where the fault is crossed by the San Juan del Río-Xilitla highway. The well-bedded limestones were deformed under about 1,500 m of cover. They show normal to and, less frequent, concordant with bedding mm-large joints, that are filled with euhedral, equigranular to bladed calcite crystals. The veins often begin on bedding planes and become gradually thinner towards the middle of the layers. Tensile stresses must have developed locally during the movement of the thrust plate causing these extensional cracks, though the regional stress-field was compressive. Riedel shears, on the other hand, are absent, which can be explained by the well-known little tensile strength of brittle rocks. (The uniaxial tensile strengths in experimental rock deformations tend to be 10-20 times lower than the compressive strengths, Paterson, 1978).

The recrystallized calcite, which fills the tension cracks, does not exceed 5 volume-percent of the whole rock, but this gives only a lower limit for the amount of dissolved material, since the rock body forms an open system. It is probable, but could not be proved, that the solution occurred at places in the tectonic pore space, which is formed by the before-mentioned tension cracks or by shear faults, when the rock body was under compression.

Ooids, present close to the thrust fault, that would make excellent strain markers, are partly deformed at grain-grain boundaries (diagenetic deformation due to stress concentration at grain-grain contacts) but are unflattened (see photographs *in* Aguayo, 1977). They are affected, however, by a closely spaced stylolitic cleavage that is oriented approximately perpendicular to bedding.

PISAFLORES ANTICLINORIUM

The Pisaflores Anticlinorium is bounded on the west by the Agua Zarca and the Lobo-Ciénega thrusts (Figure 1) and on the east by the Xilitla-Chapulhuacán Syncline. The structure consists of various anticlines and synclines that plunge towards the north (Figure 2). The folds developed by *décollement*, partly on the Pimienta beds, and partly on lower incompetent formations (Figure 3D). The deformational style is discussed together with that of the Huayacocotla Anticlinorium.

HUAYACOCOTLA ANTICLINORIUM

The Huayacocotla Anticlinorium is a mayor structure of the Sierra Madre Oriental, and extends from the study area to the south for more than 150 km*. An overall description of the northern part of the Huayacocotla Anticlinorium is given by Carrillo (1965).

The northernmost studied part of the anticlinorium is bounded on the east by an overthrust and to the west by a syncline whose axial trace passes between La Silleta and

---

*Compare Carta Geológica de la República Mexicana, 1976. Note, however, that Xilitla is erroneously situated in the Chicontepec foreland on that map, about 10 km to the east of its real location; and that the synclines in the surroundings of Xilitla, which are filled with Upper Cretaceous, appear on the map as Quaternary.

Rancho La Silleta (Figure 3A). The border thrust was described by Bonet (1956a, p. 103): El Abra limestone is thrusted over Tanlajás flysch near San Juanito, which gives a Paleocene to early Eocene maximum age for this deformation (Hidalgoan orogeny, de Cserna, 1960). More to the south, El Abra beds are thrusted over the Méndez Formation at the Huichihuayán-San Pedro trail, and the frontal thrust is very likely to reach laterally the before mentioned (p. 24) N 45°E-trending lineament which is formed by the edge of the Valles-San Luis Potosí carbonate platform.

The geometry of the anticlinorium changes discontinuously across that lineament. There is no frontal thrust and its eastern limb is situated about 1,200 m more to the west than on the northern side of the lineament (Figure 2). It can be concluded, therefore, that the lineament was activated as a Hidalgoan dextral tear fault, resulting partly from the compression of the Xilitla Thrust (which is well defined only up to the hypothetical western prolongation of this lineament) and partly from that of the border thrust (Figure 6). Such strike-slip faults are known, for example, from the Southern Alps (Trevisan, 1938) or from the Jura Mountains (Suter, 1978, 1979). The existence of a transcurrent fault implies a dextral relative movement along the lineament, which measures approximately the unknown magnitude of the shortening of the border thrust to the west of Huichihuayán. Though the Hidalgoan activation of the lineament is compatible with the structural evidence on a kilometer-scale, it could not be substantiated by a survey of small-scale features. At the Las Tiendas-San Pedro trail no fractures could be found along the escarpment, and joints measured near the lineament, at the road that leads from Tlamaya to a phosphorite mine, strike N 80°W.

A second section (Figure 3B) crosses the Huayacocotla Anticlinorium in the Arroyo Seco area, where the latter consists of a nearly symmetric box fold. The structural relief is 450-500 m with reference to the Xilitla-Chapulhuacán Syncline and the linear shortening of the western limb is about 130 m. Less documented is the eastern limb. At the dirt road from Y Griega de Xilitla to El Jobo and at the road connecting Federal Highway 85 with Xilitla, the eastern limb is vertical to slightly overturned and its sequence is normal. However, neither the shortening of the eastern limb nor the depth of the *décollement* horizon of the fold can be calculated, since the depth of the syncline to the east which is filled with an unknown quantity of Méndez beds and flysch, is not known.

To the south of Arroyo Seco the Tamaulipas Superior is thrusted over Méndez beds between El Naranjal and Ahuehueyo with a throw of at least 700 m, and without frontal drag of neither the hanging nor the footwall. The segment to the north of the Naranjal-Ixtacapa dirt road is possibly a nearly vertical younger (basin-and-range type) dip-slip fault that cuts the overthrust with an acute angle, since the intersection of the fault with the topography forms there a fairly distinctive, N 22°E-trending lineament. This likelihood is supported by the mean orientation of the abundant joints (N 12°E) near the supposed interference of the two faults (Figure 7). Provided that the fault-segment to the north of the Naranjal-Ixtacapa dirt road is part of the overthrust, then the eastward-directed fault must have a negative gradient and is thus likely to have been passively rotated by the formation of the eastern limb of the Huayacocotla Anticlinorium. The overthrust then must vanish away in the Méndez beds, or run in the Méndez beds up to the evident frontal thrust to the west of Huichihuayán. The southern termination of the overthrust must be situated somewhere between Ahuehueyo and Río Tancuilín. While Tamaulipas Superior is thrusted over Méndez beds at the Ahuehueyo-Ixtacapa trail, a normal, 60° E-dipping sequence is found in the Tancuilín valley.

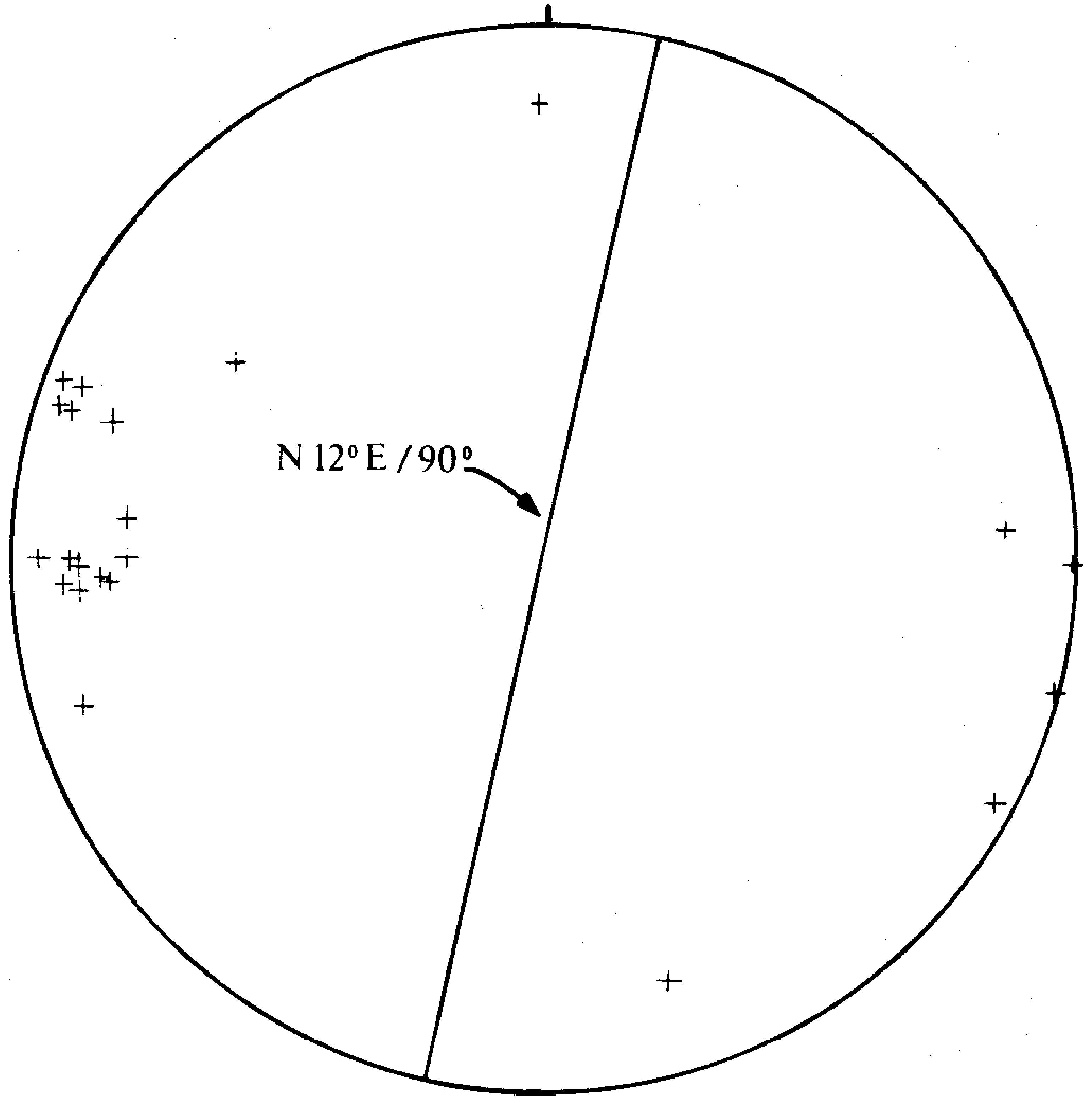


Figure 7.- Lower-hemisphere Wulff-net plot of joints measured at the conspicuous curve 1 km to the west-southwest of the El Naranjal schoolhouse. For explanations see text.

The southern end of the overthrust coincides with the appearance of four conical folds in the foreland (Figures 2, 3C). The inclination of the overthrust is unknown. The thrust might cut the western limb of the adjacent foreland fold (and thus be younger), or its inclination might be greater than that of the 45° W-dipping footwall (as is assumed on the section), implying a rotation of the predating thrust by the subsequent formation of the foreland fold.

Due to these new folds the anticlinorium reaches, despite of its large width, only the Tamaulipas Superior Formation in the transcurrent outcrops of the Tancuilín valley. This is in disagreement with the maps of Carrillo (1965), where the core reaches Tamán beds, or of Bonet (1956a, fig. 10) where, instead of the new foreland folds, a frontal thrust with Pimienta beds at its base is presented.

More to the south, the anticlinorium's structure shall be discussed by means of the outcrops in the Moctezuma valley (Figure 3D), the trace corresponds approximately with that of Heim's section (1926a, fig. 2) and of Bodenlos' section JJ' (1956, fig. 15): The Tamán Formation, which crops out to the west of Tamán and between Tamán and La Vega, buckled as an isolated competent layer, due to its position between the highly incompetent Santiago and Pimienta formations. It forms thereby upright, open, parallel first-order folds (for fold nomenclature see Ramsay, 1967). The rocks above the Pimienta beds buckled as a whole, since they form a stack of well-bedded competent layers which lacks thicker internal incompetent layers. They adapted partly the geometry of the first-order folds, but also formed upright, open to close, parallel second-order folds, due to the discrete surfaces of low cohesion between the Tamaulipas Inferior and the Pimienta, and between the Pimienta and the Tamán Formation, and due to the thickness of the Pimienta beds. The Pimienta beds were thereby thinned in the synclines and fold limbs from where the material flowed into the fold cores (Figure 3D), which resulted in a wide range of thickness from 150 to 750 m. The situation is similar to the disharmonic behaviour of some Jura folds, where the Dogger and the Malm limestones show a different geometry, due to the incompetency of the intermediate shales of the lower Oxfordian (Suter, 1976, fig. 8).

The linear shortening Δx of the anticlinorium is, with reference to the Pimienta-Tamaulipas Inferior contact, 3,550 m; $\Delta x/(x + \Delta x) = 23°/_0$ (1,600 m rotational component and 1,950 m translational component due to the frontal thrust). This is a minimum value, since the rocks show an additional shortening by means of small-scale chevron-type third-order concentric folds. The shortening of the border thrust was estimated by adding the measurable horizontal displacement component of the Tamaulipas Inferior Formation (1,600 m) to the shortening which is caused by an assumed 30° shearing of the not outcropping part of the lower plate, down to the top of the same formation (350 m). The shortening of the Huayacocotla Anticlinorium has a magnitude which is typical for foreland fold-thrust belts. In a structural cross-section through the outermost 15 km of the Jura Mountains, for example, an overall linear shortening of 28 percent was obtained (Suter, 1981).

The border thrust (first mentioned by Heim, 1926a; 1926b) is well traceable on the northern slope of the Moctezuma valley to the west of Tamazunchale. The thrust is crossed by Federal Highway 85, 2.5 km to the west of the Moctezuma bridge (tectonic contact of Lower Tamaulipas with San Felipe beds), from where it ascends with 15-25° dip (but parallel to bedding) to 350 m and shows more to the east for a short distance a negative gradient (Figure 3D). The overthrust must have been folded by the formation of the underlying small fold, in whose core Tamaulipas Superior crops out in the Moctezuma valley.

To the north of Tamazunchale, the border thrust is well defined to the west of Mazátetl (tectonic contact of Tamaulipas Superior with San Felipe beds, no frontal rotation of the thrust slab) and to the southwest of Matlapa (Matlapa-Tlaxco trail, Tamaulipas Superior thrusted over Méndez beds, no frontal rotation of the thrust slab), but cannot be observed in the intermediate area, where the anticlinorium terminates in a limb. The thrust passes there very probably in the Méndez beds or in the Tamaulipas Superior Formation.

To the south of Tamazunchale, the displacement of the frontal thrust increases gradually. The fault reaches the Amajac canyon to the north of Cahuasas, where the Liassic Huayacocotla Formation is thrusted over the Tamaulipas Limestone, and where it is evident that it is not the Santiago Formation that acted as the basal *décollement*. It is the purpose of current field work to decipher the deformational history of the polyphase deformed rocks below the Tepéxic Formation in the Amajac, Claro and Jalpa valleys, and to determine whether or not the crystalline basement was involved in the Hidalgoan deformation phase.

EXTENSIONAL FAULTING

North to north-northeast striking, subvertically dipping extensional faults, that very probably postdate the compressive deformations, were found to the north of Llano Chiquito (Figure 2) and to the north of El Naranjal p. 28, Figure 7).

RELATIONSHIP BETWEEN THE DEFORMATIONAL STYLE AND THE FACIES CONFIGURATION OF THE MIDDLE CRETACEOUS

The zone between the 1,500-2,000 m-thick El Abra reef and backreef facies and the 650-800 m thick Tamaulipas basin facies was of potential shear instability during the Hidalgoan deformation phase; the magnitude of the horizontal tectonic components of the governing stress-field must have changed by a factor 2 to 5 across the eastern edge of the Valles-San Luis Potosí carbonate platform. It is not surprising, therefore, that main overthrusts developed, where the bank edge was orientated approximately normal to the trajectories of the maximum principal stress (as deduced from fold axes; Agua Zarca Thrust, Lobo-Ciénega Thrust, Misión Thrust; Figure 8). On the other hand, the platform edge was activated as a transcurrent fault, where its direction formed an acute angle with the same stress trajectories (kinematic connection of overthrusts, partial transformation of the displacement of the Xilitla Thrust onto the frontal thrust to the west of Huichihuayán). More complicated is the situation at the southern end of the Xilitla Thrust, where mappable strike-slip faults are absent. Its shortening partly becomes gradually consumed by the formation of folds in the basin facies (Figure 2), partly it seems to be replaced by the shortening of the overthrusts to the southeast (Figure 8).

CONCLUSIONS

The availability of recent vertical aerial photographs and reliable topographic maps allowed to quantify partly the geometry and the style of deformation of an area that previously had been known at best from reconnaissance work, and to make some simple kinematic suggestions. Nevertheless, questions remained which refer to the tectonics of the rocks below the Santiago Formation (depth of the basal *décollement*?, subsurface geometry of the Xilitla and the border thrust?), and which could be solved by means of well data or reflection seismic sections, but might partly also be enlightened by the extrapolation of surface data from the Amajac, Claro and Jalpa valleys, where the rocks below the Santiago Formation crop out, due to the axial plunge of the Huayacocotla Anticlinorium towards the north (Fries and Rincón-Orta, 1965, pl. 1).

The deformational style differs in some points from previous descriptions in that a) the axial surfaces of most folds are approximately vertical and not overturned to the east, as it is generally assumed (*e.g.* Carrillo, 1971, p. 71, 73), and b) the thrusts are no limb thrusts, as it is often stated (*e.g.* de Cserna, 1971), and are not related to the rupturing of folds. Limb thrusts develop in experiments principally in late stages, when the shortening exceeds 50 percent (Dubey, 1980), while the rotational displacement component of the Huayacocotla Anticlinorium (Figure 3D, reference horizon: upper Pimienta limit) is only 16 percent ($x = 8{,}750$ m, $\Delta x = 1{,}600$ m, $\Delta x/(x + \Delta x) = 0.16$). The overthrusts are rather low-angle Mohr-type shear-faults and must join somewhere a basal detachment fault.

The style of deformation has a certain affinity to the Jura Mountains (Laubscher, 1977), as was already recognized by Heim (1940).

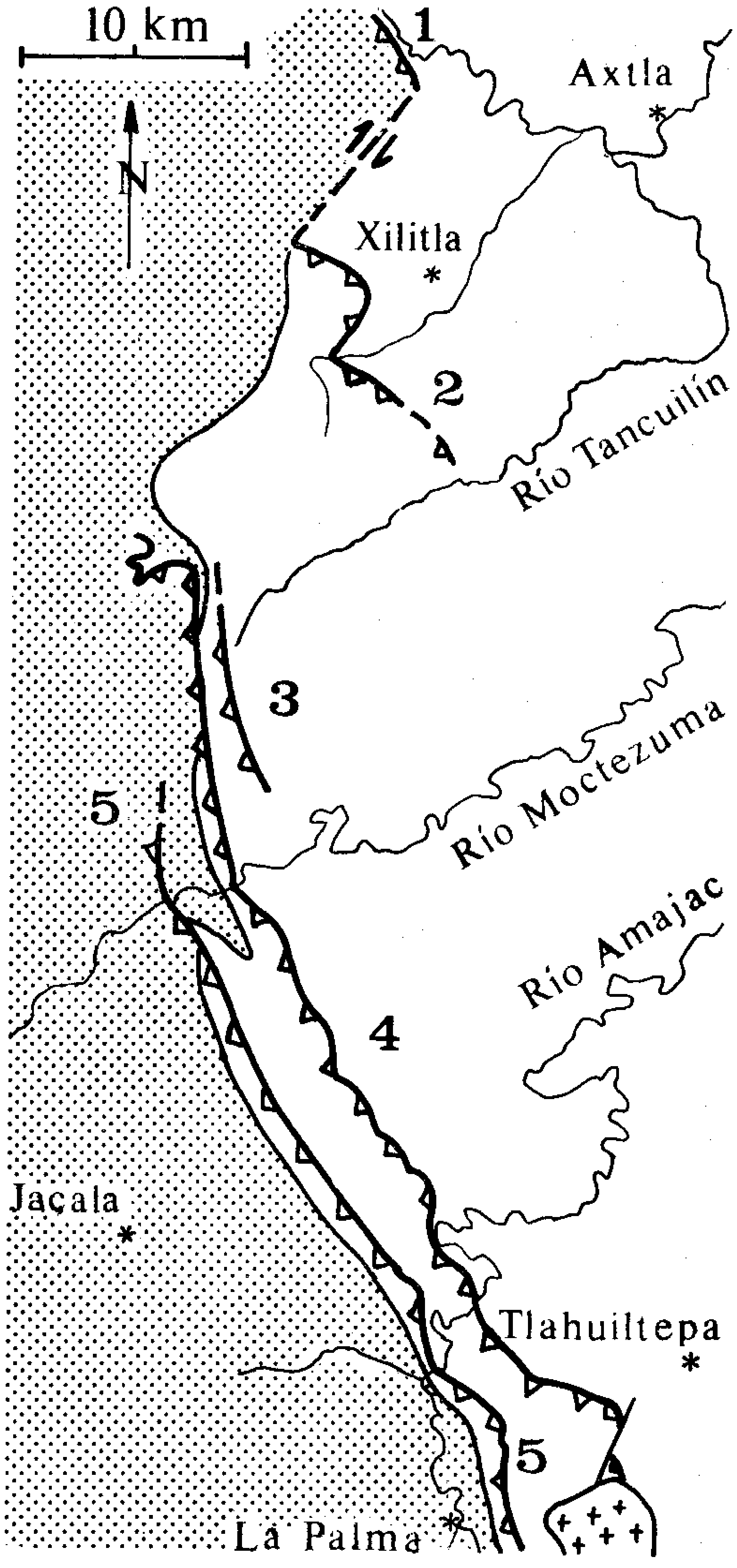


Figure 8.- Hidalgoan deformations at the eastern edge of the Valles-San Luis Potosí carbonate platform. Imbricate thrust sheets (shortening 3-5 km each) formed where the bank edge was approximately normal to the early Tertiary trajectories of the maximum principal stress (as deduced from fold axes), whereas a transcurrent fault developed, where the bank edge formed an acute angle with the same stress trajectories. Dotted: Valles-San Luis Potosí Platform.

ACKNOWLEDGEMENTS

This report is part of a joint-project of the Geological Institute of the University of Basel (Switzerland) and the Geological Institute of the Mexican National Autonomous University (UNAM). I would like to thank Dr. Z. de Cserna (UNAM) for introducing me to the study area, Drs. Z. de Cserna and F. Ortega (UNAM) for carefully reviewing the manuscript, Ing. J. Meneses de Gyves (Petróleos Mexicanos, México) for providing me with unpublished PEMEX reports, Ing. J. Carrillo-Bravo (Petróleos Mexicanos, México) for discussion and Ing. E. Velázquez (Petróleos Mexicanos, Tampico) for assistance in the field. Financial support was provided by the Technical Cooperation Department of the Swiss Ministry of Foreign Affairs (contract t.541), logistic and financial support by the UNAM Geological Institute. Discussion in the field with María Fernanda Campa, Miguel Carrillo, Zoltan de Cserna, Stanislaw Kwiatkowski, Jay Namson, Hans Laubscher and Fernando Ortega was helpful.

REFERENCES CITED

Aguayo, J.E., 1977, Sedimentación y diagénesis de la Formación "Chipoco" (Jurásico Superior) en afloramientos, Estados de Hidalgo y San Luis Potosí: Rev. Inst. Mex. Petróleo, v. 9, p. 11-37.

Bodenlos, A.J., 1956, Notas sobre la geología de la Sierra Madre en la sección Zimapán-Tamazunchale: México, D.F., Cong. Geol. Internal., 20, Excursiones A-14 y C-6, p. 293-309.

Bonet, Federico, 1953, Cuevas de la Sierra Madre Oriental en la región de Xilitla: Univ. Nal. Autón. México, Inst. Geología, Bol. 57, 96 p.

——1956a, Itinerario Taninul-Tamazunchale: México, D.F., Cong. Geol. Internal., 20, Excursiones A-14 y C-6, p. 93-118.

—— 1956b, Zonificación microfaunística de las calizas cretácicas del este de México: México, D.F. Cong. Geol. Internal., 20, monogr., 102 p.

Cantú, Abelardo, 1971, La serie Huasteca (Jurásico Medio-Superior) del centro este de México: Rev. Inst. Mex. Petróleo, v. 3, p. 17-40.

Carrasco, V.B., 1977, Albian sedimentation of submarine autochthonous and allochthonous carbonates, east edge of the Valles-San Luis Potosí platform, Mexico: Soc. Econ. Paleont. Mineral., Spec. Publ. 25, p. 263-272.

Carrillo-Bravo, José, 1965, Estudio geológico de una parte del Anticlinorio de Huayacocotla: Bol. Asoc. Mex. Geólogos Petroleros, v. 17, p. 73-96.

—— 1971, La plataforma Valles-San Luis Potosí: Bol. Asoc. Mex. Geólogos Petroleros, v. 23, p. 1-102.

Coogan, A.H., Debout, D.G., Maggio, Carlos, 1972, Depositional environments and geologic history of Golden Lane and Poza Rica trend, Mexico, an alternative view: Am. Assoc. Petroleum Geologists Bull., v. 56, p. 1419-1447.

Cserna, Zoltan de, 1960, Orogenesis in time and space in Mexico: Geol. Rundschau, v. 50, p. 595-605.

—— 1971, Development and structure of the Sierra Madre Oriental of Mexico: Geol. Soc. America, Abstr. with Prog., v. 3, p. 377-378,(abstract).

Dubey, A.K., 1980, Late stages in the development of folds as deduced from model experiments: Tectonophysics, v. 65, p. 311-322.

Enos, Paul, 1974, Reefs, platforms and basins of middle Cretaceous in northeast Mexico: Am. Assoc. Petroleum Geologists Bull., v. 58, p. 800-809.

Erben, H.K., 1956, El Jurásico Medio y el Calloviano de México: México, D.F., Cong. Geol. Internal., 20, monogr., 140 p.

Flügel, Erik, 1978, Mikrofazielle Untersuchungsmethoden von Kalken: Berlin, Springer, 454 p.

Fries, Carl, Jr., and Rincón-Orta, César, 1965, Nuevas aportaciones geocronológicas y técnicas empleadas en el Laboratorio de Geocronometría: Univ. Nal. Autón. México, Inst. Geología, Bol. 73, p. 57-133.

Gamper, M.A., 1977, Acerca del límite Cretácico-Terciario en México: Univ. Nal. Autón. México, Inst. Geología, Revista, v. 1, p. 23-27.

Griffith, L.S., Pitcher, M.G., and Rice, G.W., 1969, Quantitative environmental analysis of a Lower Cretaceous reef complex: Soc. econ. Paleont. Mineral., Spec. Publ. 14, p. 120-137.

Heim, Arnold, 1926a, Notes on the Jurassic of Tamazunchale (Sierra Madre Oriental, Mexico): Eclogae geol. Helvetiae, v. 20, p. 84-87.

——— 1926b, The front ranges of Sierra Madre Oriental from Victoria to Tamazunchale: México, D.F., Petróleos Mexicanos, unpublished report.

——— 1940, The front ranges of Sierra Madre Oriental, Mexico, from Ciudad Victoria to Tamazunchale: Eclogae geol. Helvetiae, v. 33, p. 314-352.

Hermoso de la Torre, C., and Martínez, J., 1972, Medición detallada de formaciones del Jurásico Superior en el frente de la Sierra Madre Oriental: Bol. Asoc. Mex. Geólogos Petroleros, v. 24, p. 45-64.

Hsü, K.J., 1979, Thin-skinned plate tectonics during neo-Alpine orogenesis: Am. Jour. Sci., v. 279, p. 353-366.

Laubscher, H.P., 1977, Fold development in the Jura: Tectonophysics, v. 37, p. 337-362.

Maldonado, Manuel, ed., 1956, Visita a las localides-tipo de las formaciones del Eoceno, Oligoceno y Mioceno de la cuenca sedimentaria de Tampico-Misantla, en la llanura costera del Golfo de México: México, D.F., Cong. Geol. Internal., 20, Excursión C-16, 94 p.

Mendiola, José, 1965, Estudios geológicos de la porción norte de la cuenca de Chicontepec, Estado de San Luis Potosí: San Luis Potosí, Univ. Autón. San Luis Potosí, professional thesis, 51 p., (unpublished).

Muir, J.M., 1936, Geology of the Tampico region: Tulsa, Am. Assoc. Petroleum Geologists, 280 p.

Paterson, M.S., 1978, Experimental rock deformation-the brittle field: Berlin, Springer, 254 p.

Pedrazzini, Carmen, and Basáñez, M.A., 1978, Sedimentación del Jurásico Medio-Superior en el Anticlinorio de Huayacocotla-Cuenca de Chicontepec, Estados de Hidalgo y Veracruz, México: Rev. Inst. Mex. Petróleo, v. 10, p. 6-25.

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

Reyes, D.E., 1964, El Jurásico Superior del área de Tamán, S.L.P.: México, D.F., Petróleos Mexicanos, IG 508, unpublished report.

Soto, Fidel, 1980, Zonificación microfaunística de parte de los estratos cretácicos del cañón de la Borrega, Tamps.: México, D.F., Soc. Geol. Mexicana, V Conv. Geol. Nal., p. 42-43, (abstract).

Suter, Max, 1976, Tektonik des Doubstals und der Freiberge in der Umgebung von Saignelégier: Eclogae geol. Helvetiae, v. 69, p. 641-670.

——— 1978, Geologische Interpretation eines reflexionsseismischen W-E-Profils durch das Delsberger Becken: Eclogae geol. Helvetiae, v. 71, p. 267-275.

——— 1979, Strukturelle Geometrie des Faltenjuras im nördlichen Bereich der Ferrière-Linie: Eclogae geol. Helvetiae, v. 72, p. 375-400.

——— 1981, Strukturelles Querprofil durch den nordwestl. Faltenjura, Mt-Terri-Randüberschiebung-Freiberge: Eclogae geol. Helvetiae, v. 74, p. 255-275.

Tardy, Marc, Longoria, J.E., Martínez, J., Mitre, L.M., Patiño-Avila, Manuel, Padilla, Ricardo, and Ramírez, Calixto, 1975, Observaciones generales sobre la estructura de la Sierra Madre Oriental; la aloctonía del conjunto Cadena Alta-Altiplano Central, entre Torreón, Coah. y San Luis Potosí, S.L.P. México: Univ. Nal. Autón. México, Inst. Geología, Revista, núm. 1, p. 1-11.

Trejo, Mario, 1980, Distribución estratigráfica de los tintínidos mesozoicos mexicanos: Rev. Inst. Mex. Petróleo, v. 12, p. 4-13.

Trevisan, L., 1938, Il fascio di fratture tra l'Adige e la "Linea delle Giudicarie" e i suoi rapporti col massiccio intrusivo dell' Adamello: Stud. trent. Sci. nat., v. 17, p. 3-13.

Velázquez, E.C., and Palazuelos, R.C., 1976, Etapa No. 2, Ahuacatlán, Qro.- Cd. Valles, S.L.P.: *in* Análisis de los principales estilos de deformación estructural y su probable origen entre Tequisquiapan, Qro.- Cd. Valles, S.L.P. México, D.F., Petróleos Mexicanos, p. 33-83, unpublished guide-book.

Wilson, J.L., 1975, Carbonate facies in geologic history: Berlin, Springer, 471 p.