Revista Mexicana de Ciencias Geológicas, volumen 17, número 2, 2000, p. 97-111
Universidad Nacional Autónoma de México, Instituto de Geología, México, D.F

CONTRASTING STYLES OF LARAMIDE FOLDING ACROSS THE WEST-CENTRAL MARGIN OF THE CRETACEOUS VALLES-SAN LUIS POTOSÍ CARBONATE PLATFORM, MEXICO

José Jorge Aranda-Gómez [1]*,
Ramón Torres-Hernández [2],
Gerardo Carrasco-Nuñez [1], y
Alfredo Aguillón-Robles [2]

ABSTRACT

Along the west-central limit between the Central Mexico Mesozoic Basin and the Valles-San Luis Potosí carbonate platform exist marked variations in style and intensity of Laramide folding (Late Cretaceous-Early Tertiary). These variations are attributed to: 1) prominent inter- and intra-formational changes in lithology and bedding thickness, and 2) overall thickness contrast between the Cretaceous sedimentary sequences accumulated in the basin and the carbonate platform. Tight, NE-verging folds with fold widths in the order of meters to tens of meters formed in those sites where only thinly bedded, slightly argillaceous, basin calcareous turbidites were deposited. Folding is disharmonic in other localities where thicker beds of slide breccias, made of clasts derived from the nearby carbonate platform, are interlayered with the basin turbidites. Breccia sheets controlled the formation of mesostructures, with fold widths in the order of hundreds of meters, while second order folds, with fold widths in the order of meters, were formed in the thinner bedded argillaceous limestones.

Thick strata of shallow water carbonates, deposited in and around isolated patch reefs in the platform interior, formed open (fold widths in the order of several kilometers), almost symmetrical folds with near vertical axial planes. Despite significant facies changes in the limestone, associated with the presence of patch reefs, no variations in the folding style are related with them.

The occurrence of anhydrite strata (Guaxcamá Formation) under isolated portions of the carbonate platform interior also played an important role in the folding style, causing the tectonically induced accumulation of evaporite near the cores of some folds and/or formation of diapirs. This phenomenon modified the structures and caused intense fracturing in the central portion of the Sierra de Guadalcázar. In few places, anhydrite was injected along fractures in the limestone. Meteoric water infiltration and dissolution of the anhydrite developed intense karsticity and caused the formation of an extensive collapse breccia. Division of the Sierra de Guadalcázar into several domains suggests that the structural anomalies in respect to its immediate surroundings are concentrated in an area where anhydrites are exposed. Furthermore, the emplacement of the mid-Tertiary Cerro de San Cristóbal intrusive, a tin-bearing subvolcanic granite, did not caused doming by forceful injection at the core of the Sierra de Guadalcázar.

Keywords: Laramide folding, Cretaceous, Valles, San Luis Potosí, Carbonate platform, Mexico

RESUMEN

A lo largo del límite centro-occidental entre la Cuenca Mesozoica del Centro de México y la plataforma carbonatada Valles-San Luis Potosí existen variaciones notables en la intensidad y estilo de plegamiento laramídico (Cretácico tardío-Terciario temprano). Estas variaciones se atribuyen a: 1) cambios marcados, inter- e intra-formacionales, en litología y espesor de los estratos y 2) al contraste entre el espesor total de las secuencias sedimentarias cretácicas, acumuladas en la cuenca y la plataforma carbonatada. En los sitios donde sólo existen turbiditas calcáreas de cuenca, con estratificación delgada y ligeramente arcillosas, se formaron estructuras cerradas, con ancho de pliegue del orden de metros a decámetros y ligeramente recostadas hacia el NE. En otros lugares, en donde hay bancos de brechas sedimentarias de deslizamiento

[1] UNICIT, Instituto de Geología, Universidad Nacional Autónoma de México, Apartado Postal 1-742, Querétaro, Qro, México, 76001.
*jjag@servidor.unam.mx; gerardoc@servidor.unam.mx
[2] Instituto de Geología, Universidad Autónoma de San Luis Potosí, Manuel Nava # 5, Zona Universitaria, San Luis Potosí, S.L.P., México, 78290.
jrtorres@deimos.tc.uaslp.mx; aaguil@sdt.univ-brest.fr

formadas por clastos provenientes del borde de la plataforma, intercalados con las turbiditas de cuenca, el plegamiento es disharmónico. Los bancos calcáreos controlaron la formación de las mesoestructuras, con ancho de pliegue del orden de cientos de metros. Los pliegues de segundo orden, con anchos de pliegue del orden de metros, se formaron preferentemente en las calizas arcillosas con estratificación delgada.

Los bancos calcáreos en el interior de la plataforma, en donde existieron arrecifes aislados, formaron pliegues abiertos (ancho de pliegue del orden de kilómetros), casi simétricos, con planos axiales subverticales. A pesar de que existen cambios significativos en la facies de estas calizas, causados por la presencia local de parches arrecifales, estos no influyeron en el estilo del plegamiento.

La presencia de anhidritas de la Formación Guaxcamá, bajo regiones aisladas del interior de la plataforma carbonatada, también jugó un papel importante en el plegamiento, creando diapiros y/o acumulaciones de anhidrita en los núcleos de algunos pliegues. En la parte central de la Sierra de Guadalcázar este fenómeno causó modificaciones notables en las estructuras y un fracturamiento intenso, llegando las anhidritas en algunos lugares a romper e inyectarse a través de la caliza. Infiltración de agua meteórica y disolución de la anhidrita permitió el desarrollo de karsticidad extraordinaria y la formación de una brecha de colapso extensa. La división de la sierra en varios dominios indica que sus anomalías estructurales, con respecto a la región circundante, se asocian directamente a un área en donde están expuestas las anhidritas y que el emplazamiento del intrusivo terciario subvolcánico del Cerro de San Cristóbal, formado por granito con estaño, no fue el causante, por inyección forzada, de la forma dómica anómala del núcleo de la Sierra de Guadalcázar.

Palabras clave: Plegamiento laramídico, Cretácico, Valles, San Luis Potosí, Plataforma carbonatada, México

INTRODUCTION

In the area now located between the cities of San Luis Potosí and Matehuala (Figures 1, 2), marine sedimentation was controlled during the Cretaceous by two large paleogeographic features: the Valles-San Luis Potosí Platform (VSLPP; Carrillo-Bravo, 1971; Basáñez-Loyola *et al*., 1993) and the Central Mexico Mesozoic Basin (CMM; Morán-Zenteno, 1994). This phenomenon produced a marked contrast in the lithology and thickness and, consequently, in the mechanical properties of the sedimentary units (Suter, 1984; Contreras-Pérez, 1993). The basin sequence is composed of thinly bedded (up to 20 cm thick) calcareous turbidite with abundant chert (Cuesta del Cura and Peña Formations), pelagic mudstone (Indidura Formation), and sandstone interlayered with shale (Caracol Formation). It differs markedly from the roughly time-equivalent units deposited on the carbonate platform, which display a variety of facies and lithologies (*e.g*., Enos, 1974; Wilson, 1975; Basáñez-Loyola *et al*., 1993). In the studied area, the exposed platform sequence is, by far, volumetrically dominated by medium (30-50 cm) to thick beds (up to 1 m) of shallow water carbonates of El Abra Formation. Patch reefs occur in the platform interior. These structures display ill-defined bedding and are surrounded by massive- to poorly bedded calcareous breccia. Irregular patterns of dolomitization overprint the patch reef deposits. Marl and shale (Soyatal Formation) and a sequence of sandstone interbedded with shale (Cárdenas Formation) overlie El Abra Formation along the western edge of the VSLPP. Locally, shallow water carbonates of the upper portion of El Abra Formation (Albian-Turonian) are underlain by a pre-Aptian evaporitic sequence known as the Guaxcamá Formation, which is formed mainly by anhydrite, gypsum and minor carbonates and native sulphur (Valencia-Islas and Villaseñor-Rojas, 1997) and represents sabkha facies of the platform interior.

The nature of the boundary between the basin and the western part of the VSLPP is poorly documented in the area between San Luis Potosí and Matehuala. Torres-Hernández (1994) suggested that this boundary of the VSLPP was attenuated, and the transition basin-carbonate platform was a gently dipping slope. This interpretation was based on: 1. The absence of large continuous outcrops of thick calcareous breccias, equivalent to the Tamabra Formation, exposed on the eastern flank of the carbonate platform, and 2. Isolated reports of infrequent olistoliths (Zárate-Muñoz, 1977; Torres-Hernández *et al*., 1998), slide structures (de Cserna and Bello-Barradas, 1963), and very thick strata of calcareous breccia interlayered with thinly bedded calcareous mudstones (Aranda-Gómez and Luhr, 1996). Alternatively, as documented by Suter (1987) for the area west of El Doctor reef (Figure 1) and southwestern portion of the VSLPP in the state of Querétaro, the foreslope of the platform may be covered by basin sediments thrusted over the western margin of the carbonate platforms. Moreover, recent work by Torres-Hernández and co-workers (1998) has shown that in the area between San Luis Potosí and Matehuala is exposed a set of major thrust faults along the western margin of the VSLPP (Figure 2). This phenomenon was produced during the Laramide Orogeny. Regardless of the true nature of the boundary, between San Luis Potosí and Matehuala (Figure 2a, b), there is a belt where thinly-bedded, deep water, calcareous carbonate mudstone (Cuesta del Cura and Peña Formations) is in places interlayered with medium-to-thick bedded breccia sheets made of clasts derived from the nearby carbonate platform.

It has been pointed out by several workers that in the region around the city of San Luis Potosí (Figure 2a) the style of folding of the Laramide structures in the CMMB rocks contrasts with that observed in the rocks of the VSLPP (Figures 2b, 3). Rocks corresponding to the transitional zone between the basin and the carbonate platform were deformed

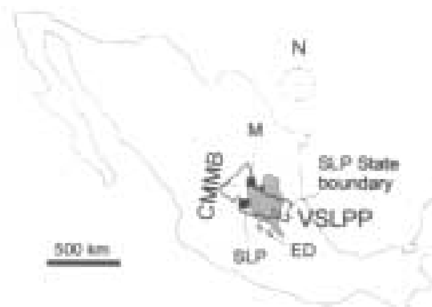

Figure 1. Location map of the Valles-San Luis Potosí Platform (VSLPP) and the Central Mexico Mesozoic Basin (CMMB). El Doctor reef (ED) lies S of the carbonate platform. Also shown for reference are the outline of the State of San Luis Potosí and the cities of San Luis Potosí (SLP) and Matehuala (M).

as overturned folds associated to large thrust faults (Figure 3) with vergence to the northeast (Tardy, 1980; Torres-Hernández, 1994; Suter et al., 1997). The CMMB sequence, exposed in El Coro and San Pedro sierras (Figures 3, 4), usually display tight folds, slightly overturned to the NE (Aranda-Gómez and Labarthe-Hernández, 1977; Labarthe and Tristán, 1978). Platform carbonates (El Abra Formation) in the Álvarez and Santa Catarina sierras (Figures 2a, 3) mostly exhibit open symmetric folds with upright axial planes (de Cserna and Bello-Barradas, 1963; Garza-Blanc, 1978). However, until now, these observations have not been documented quantitatively. Similar structural relations have been carefully studied farther south, at ~ 21º N latitude, in a section across the Sierra Madre Oriental by Suter (1987), along the eastern edge of the VSLPP (Suter, 1984) and in the Sierra Gorda of Querétaro by Carrillo-Martínez (1990, 1996).

The Sierra de Guadalcázar (SG), where platform interior sediments are exposed, is anomalous compared to the surrounding Laramide folds (e.g., Carrillo-Bravo, 1971; Torres-Hernández, 1994). North of Sierra de Guadalcázar, the NW-trending axes of the Laramide structures gradually turn to the N and NE (Figure 2a). In the region, where this change in the trend of the structures occurs, there are several Quaternary volcanoes (K-Ar > 0.5 Ma), made of mantle xenolith-bearing alkalic basalts (Luhr et al., 1989; Pier et al., 1989; Aranda-Gómez et al., 1993; Aranda-Gómez and Luhr, 1996). At the SG itself some of the traces of the axial planes of the regional folds appear to be abruptly truncated or bent around its core. The SG is crowned by a broad, flat area known as the Realejo altiplano, and in that area there are large karstic basins (poljes) filled in part by collapse breccia (Wenzens, 1973; Torres-Hernández, 1994). These structural and morphological features have been ascribed to the presence in the area of an anhydrite diapir of the Guaxcamá Formation (Carrillo-Bravo, 1971; Torres-Hernández, 1994) and/or to the influence of a mid-Tertiary, forcefully intruded, subvolcanic granite in El Realejo altiplano (Wittich and Ragotzy, 1920; Urías, 1963; Alonso-Lomelí, 1981). Alternatively, as pointed out by Suter (written communication, 1998), karst formation may be related to dissolution and removal of the underlying evaporitic sequence. Likewise, anhydrite in an anomalous position has been observed in other parts of the VSLPP, at the contact between the sedimentary sequence and granitic stock (Suter, 1990, p. 22). These last two options not necessarily require of the formation of a diapir to explain the karsticity and/or the presence of anhydrite near the intrusive contact.

Field observations show a concentration of the strain at the boundary between the VSLPP and the surrounding epicontinental basins (e.g., Suter, 1987) with less shortening both in the platform and basin interiors. Numerical modeling of the stress distribution has also shown that the dominant structural element at these boundaries is thrusting (Contreras-Pérez, 1993). A smaller portion of the strain is accomplished as folding.

PURPOSE AND SCOPE

To document and quantify the contrasting styles of folding in the area and its relation to the local stratigraphy, we compiled structural information (bedding plane attitudes) in the limestone outcrops near the border and at the near-vertical walls of two Quaternary maars (Aranda-Gómez et al., 1993). The Joya Honda maar (Figures 2-4) is in the CMMB, a short distance from the forereef area of the VSLPP. This is indicated by breccia sheets, derived from the reefs that fringed the western margin of the carbonate platform, interlayered with thin beds of calcareous mudstone and shale with abundant bands and nodules of black chert of the Cuesta del Cura Formation (Aranda-Gómez et al., 1993). Structural data were also compiled near the southern margin of the Joya Prieta maar (Labarthe-Hernández, 1978; Aranda-Gómez et al., 1993), which is located well into the VSLPP (Figure 2), in an area where lagoonal facies carbonates are exposed. These accumulated in the platform interior.

In this paper we compare the detailed structural information collected at the maars with bedding plane attitude data sets compiled from published regional maps (Aranda-Gómez and Labarthe-Hernández, 1977; Torres-Hernández, 1994) and new information gathered in reconnaissance traverses across Sierra Los Librillos, and in Sierra La Cuchilla Gorda (Figure 2a). Analysis of the information, using p diagrams (stereographs where poles to the bedding planes in a cylindrical fold plot near a great circle. The pole of the great circle, the p pole, corresponds to the trend and plunge of the fold axis) shows that there is a direct relation between the dominant lithology and layer thickness (and inferred sedimentary environment) and the style of Laramide folding along the west-central margin of the VSLPP. These conclusions appear to be valid regardless of the scale of the

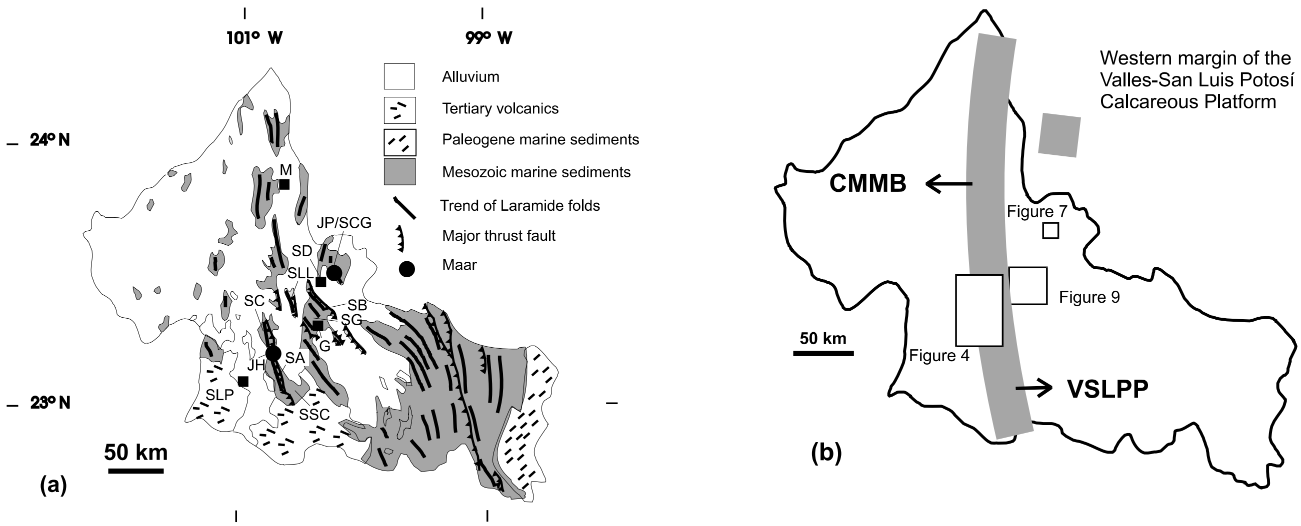

Figure 2. (a) Geologic sketch map of the State of San Luis Potosí. It shows the regional trend of Laramide structures, major known thrust faults (after de Cserna, 1992, and Torres-Hernández and Tristán-González, 1994), and the location of sierras de Álvarez (SA), El Coro (SC), Santa Catarina (SSC), Los Librillos (SLL), Guadalcázar (SG), La Cuchilla Gorda (SCG), and Buenavista. Quaternary maars are Joya Honda (JH) and Joya Prieta (JP), and towns mentioned in the text are Santo Domingo (SD), Guadalcázar (G), San Luis Potosí city (SLP), Matehuala city (M). (b) Approximate location of the transitional zone between the CMMB and VSLPP.

observations (meters to hundreds of meters around the maars or kilometers to tens of kilometers across the sierras).

LARAMIDE FOLDS IN THE EASTERN PART OF THE CMMB

JOYA HONDA

A major NNW-trending set of Laramide structures is exposed northeast of the city of San Luis Potosí (Figures 2a, 4). Its southern part has been described as the Sierra de Álvarez-San Pedro anticlinorium (de Cserna and Bello-Barradas, 1963; Aranda-Gómez and Labarthe-Hernández, 1977; Labarthe-Hernández and Tristán, 1978) and in its northwestern portion as the Sierra El Coro-Arista anticlinorium (Zárate-Muñoz, 1977; Aranda-Gómez and Labarthe-Hernández, 1977). Near its center this set of structures is cut by a transverse ENE-trending fault, which offsets the axes of the folds with a right-lateral displacement (Figure 4). In the area where this transverse fault zone occurs, there are several Quaternary volcanoes (K-Ar = 1.1-1.4 Ma; Aranda-Gómez and Luhr, 1996). These extruded basanites with mantle and crustal xenoliths (Greene, 1975; Greene and Butler, 1979; Aranda-Gómez, 1982; Ruiz et al., 1983; Gómez-Morán, 1986; Aranda-Gómez and Ortega-Gutiérrez, 1987; Luhr et al., 1989; Pier et al., 1989; Heinrich and Besch, 1992; Aranda-Gómez and Luhr, 1993). The most spectacular volcano in the area is the Joya Honda maar, a large elliptical crater (800 x 1,200 m), excavated more than 200 m below the pre-volcanic surface (Aranda-Gómez and Luhr, 1996). North of the maar, the limestones are covered by a heterolithologic tuff-breccia. This is composed mainly of accidental fragments, locally derived from the underlying Mesozoic sediments, juvenile tephra made of basanite, and a small proportion of mantle and lower crustal xenoliths.

In the near-vertical walls of Joya Honda, Laramide folds are well exposed (Figure 5). They developed in the Mesozoic marine limestone of the Cuesta del Cura and Peña Formations. At this locality, these folds have steep-dipping SW limbs (50°-70°) and nearly vertical (80°-90°) overturned NE limbs. The attitude of the axial planes, inferred from the geologic maps (Aranda-Gómez and Labarthe-Hernández, 1977; Aranda-Gómez et al., 1993) and from the vertical section exposed in the crater walls, is ~247/70 (pole to the axial plane ~337/20). The SW dipping limbs of the major folds usually display complex second-order parallel folds. Chevron-, box-, and cuspate-types of folds are present among these secondary structures, and they commonly change into one another (Figure 5). This secondary folding is more pronounced where the thinly bedded calcareous mudstones dominate, whereas those parts of the sequence where thicker, more competent beds of slide-breccia occur, folding tend to be simpler. A mirror image of these structures can be seen on the southern wall of the maar, where limestone is exposed all the way to the rim of the crater.

A data set composed of 130 readings of bedding plane attitudes was compiled along a ~1,000 m long traverse adjacent to the southern rim of the Joya Honda crater.

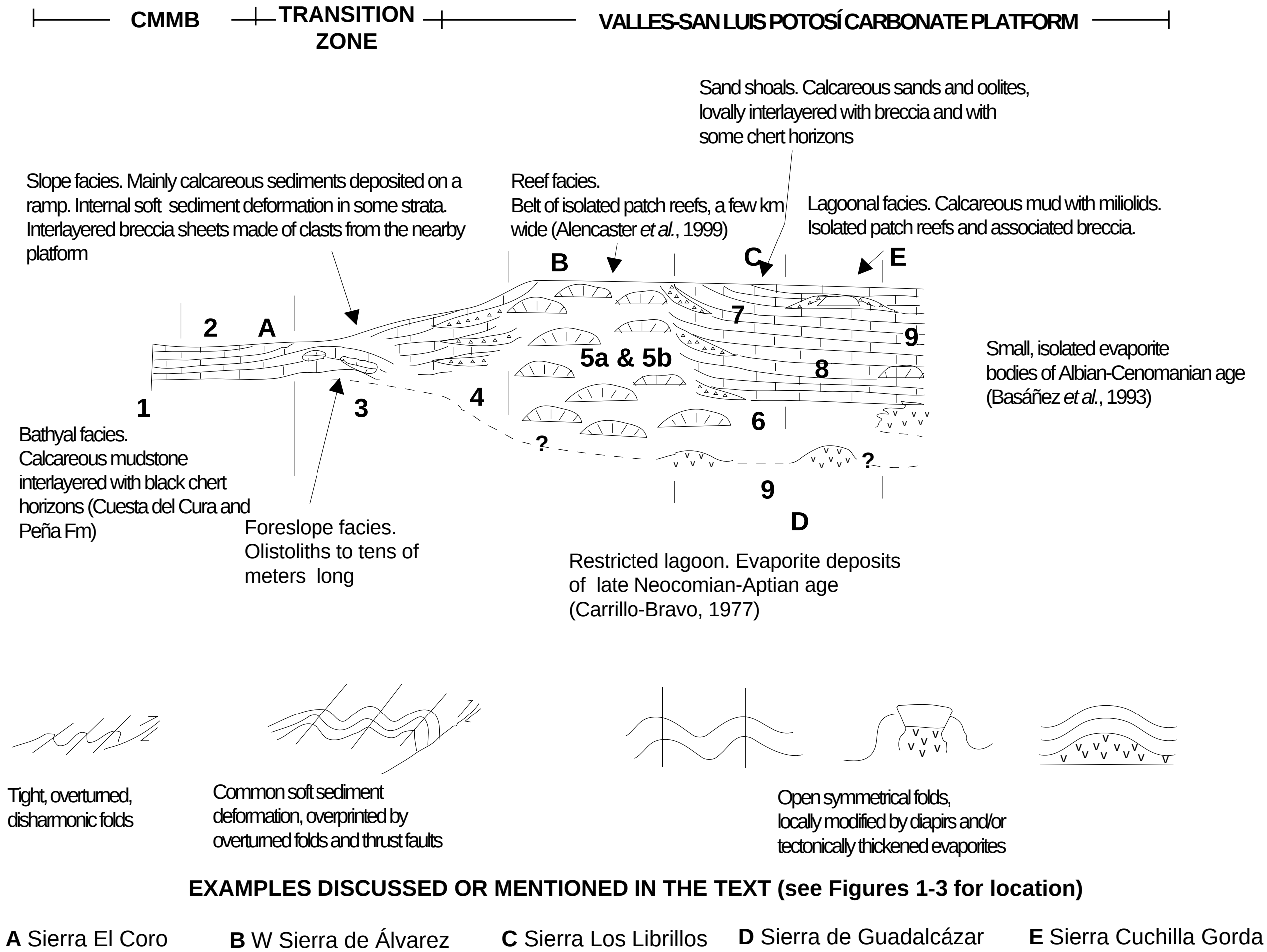

Figure 3. Facies change across the western edge of the VSLPP and structural styles associated. Note that there is a pronounced change in the average bed thickness and overall thickness of the sequence between the basin and the carbonate platform. On the average, the basin sequence is more argillaceous than that accumulated on the platform. Locally, thin-bedded limestone and marls with shale partings and black chert horizons form the basin sequence. Digits in the drawing refer to the facies belts described by Wilson (1975).

Measurements were made approximately every 10 m, except where small, second order folds were clearly exposed. In those places, our attitude readings were more closely spaced, in order to characterize the overall shape of the secondary structures. Contoured equal area lower hemisphere plots of the poles to bedding are shown in Figure 6a-d. The whole data set (Figure 6a) defines a girdle with the p pole (trend and plunge of the fold axis) located at ~339/01. The presence of several concentrations of poles along the girdle, and the clear association in the field of the secondary folds with the thinly bedded strata is interpreted as evidence of disharmonic folding in the area (Figure 5). To evaluate the significance of the pole clusters along the girdle in Figure 6a, the data set was divided into three subsets on the basis of field observations. Figures 6b and 6c represent bedding plane attitudes measured at second order folds with fold widths in the order of 1 to 3 m. Figure 6d depicts the whole data set after filtering out the readings corresponding to second order folds. Inspection of figures 6a-d suggests that data points which define the pole clusters around 206/53 and 093/60 (Figure 6b), and 255/18 and 270/60 (Figure 6c) correspond to the limbs of the second order folds. The pole clusters around 070/45 and 070/07 (Figures 6a and 6d) coincide with the limbs of major folds exposed in the walls of the crater.

SIERRA DEL CORO

To compare Joya Honda data, which represent mesostructures (fold width in the order of several 100's of m) and secondary folds (on meters scale), with the regional structure, we compiled the available information for the northern part of the Sierra El Coro-Arista anticlinorium (Aranda-Gómez and Labarthe-Hernández, 1977). These data were plotted in Figure 6e, which shows concentrations of poles to bedding around 079/53 and 077/33. This is roughly equivalent to the orientation of mesostructures exposed in Joya Honda. Other clusters in Figure 6e probably correspond to readings made in secondary folds. Note that the structural data compiled by Aranda-Gómez and Labarthe-Hernández (1977) are biased, because these authors avoided the obvious second

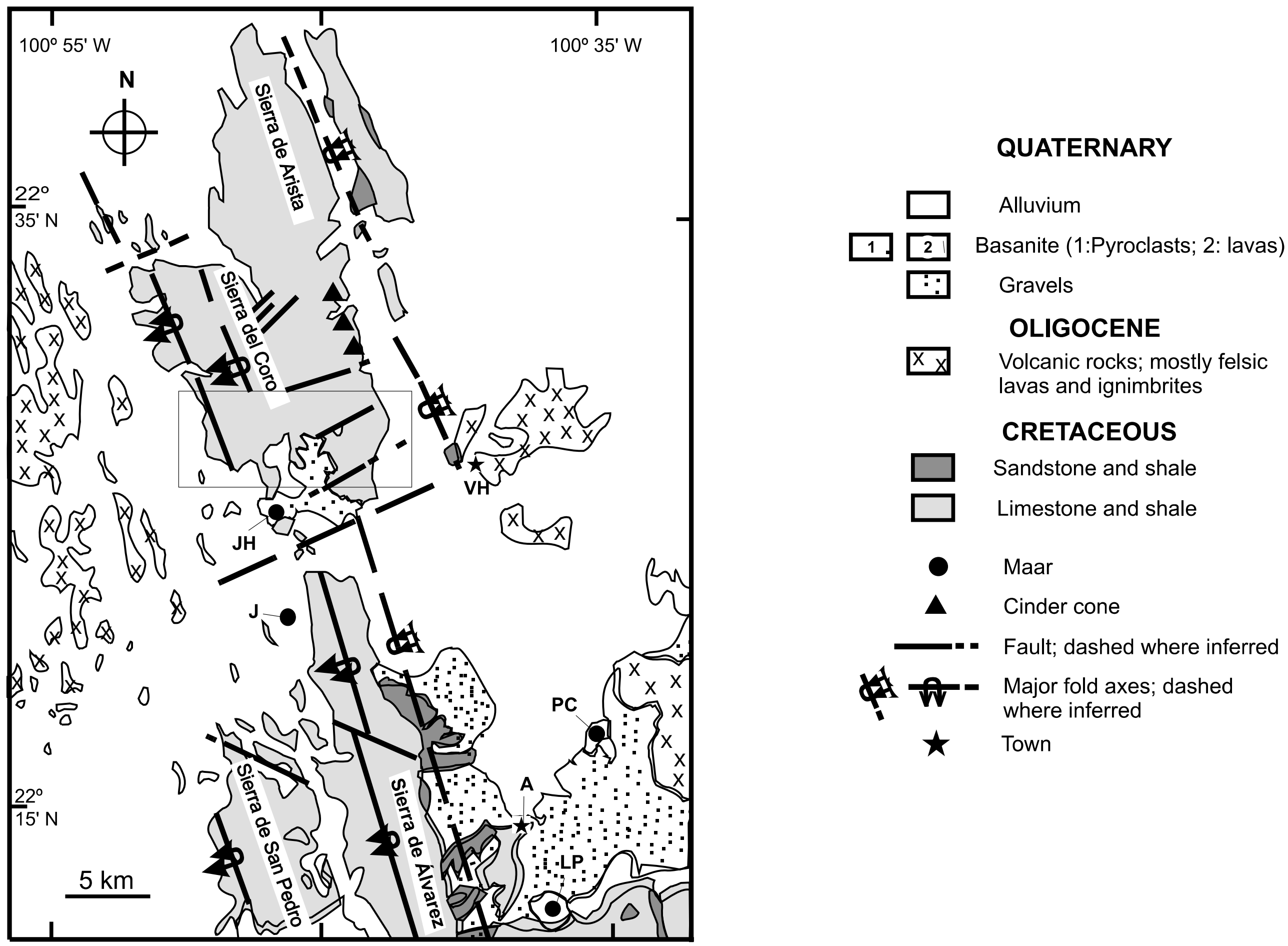

Figure 4. Generalized geologic map of the Sierra de Álvarez-El Coro anticlinorium. Box north of JH enclose the area where data was compiled for the structural analysis of Sierra del Coro. Towns: VH = Villa Hidalgo; A = Armadillo. Other maar volcanoes: J = Joyuela; LP = Laguna de los Palau; PC = Pozo del Carmen. Modified from Aranda-Gómez and Luhr (1996). The location of Figure 4 is marked on Figure 2b.

order folds during the regional mapping. A plot of all the available bedding plane attitudes in the area (Figure 6f: Joya Honda and N Sierra El Coro together) is remarkably similar to the diagram obtained for the well-exposed folds in the walls of Joya Honda (Figure 6a). Mesostructures in the area tend to have near horizontal axes trending ~340º-350º (given by the p poles in Figures 6a, d, e and f), whereas the secondary folds follow the same trend but have slightly plunging (7°-19º) axes, either to the SE or the NW (Figure 6, b and c).

LARAMIDE FOLDS IN THE WEST-CENTRAL PART OF THE CARBONATE PLATFORM

LOCAL STRUCTURE AT JOYA PRIETA

One hundred kilometers northeast of Joya Honda, near the town of Santo Domingo (Figure 2a) there is a distinct change in the orientation of the Laramide folds. In the region of this fold-trend change there is another group of xenolith-bearing Quaternary maars. South of Santo Domingo the axes of the folds have azimuths of ~325°, whereas close to the area where the volcanoes are located, there is a gradual change to more northerly trends. North of the volcanic field, the fold axes are oriented ~10° (Aranda-Gómez et al., 1993). By far, medium to thick beds of platform carbonates of El Abra Formation dominate the outcrops in the area of Santo Domingo. Small outcrops of sandstone and shale of the Cárdenas Formation are exposed in the cores of large synclines. Quaternary alkalic basalts occur around the isolated maars as tephra deposits or as rare cinder cones and/or small lava fields.

The Joya Prieta maar is a large (750 x 500 m) elliptical crater with its long axis oriented N75°E, approximately perpendicular to the Laramide folds in the pre-volcanic basement. In the northern wall of the maar, very thick beds of El Abra limestone are exposed. They are partially covered by a near-vent alkali basalt agglutinate and lava flow (Figure 7). Resting atop these pre-maar volcanics is a pyroclastic sequence comprising a base surge deposit overlain by a well indurated and distincly bedded, heterolithologic tuff-breccia composed

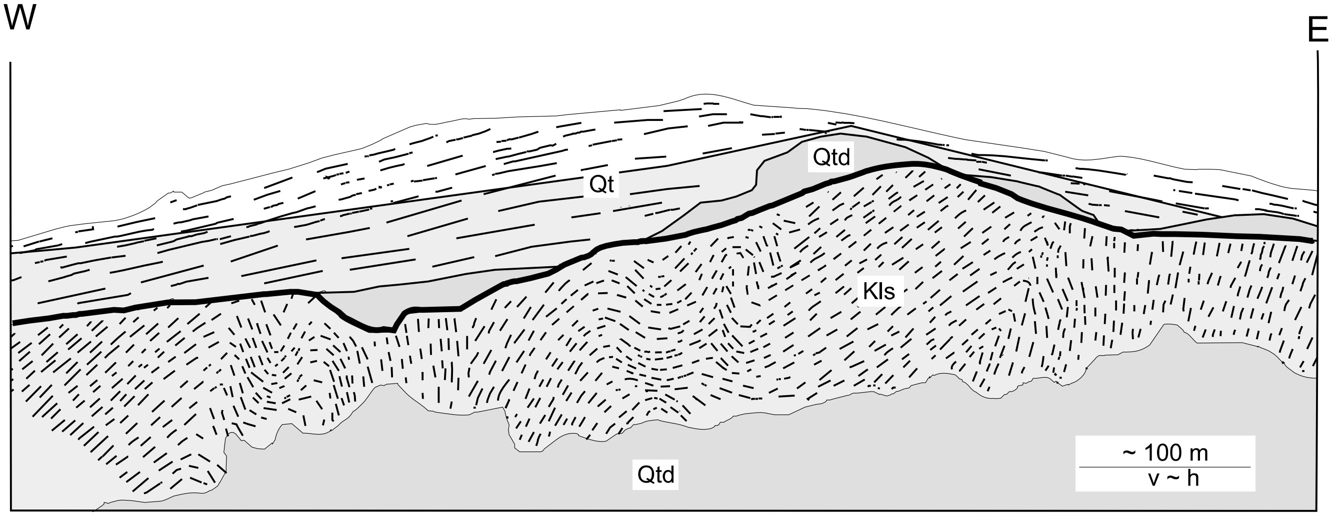

Figure 5. Geologic sketch of the northern wall of Joya Honda. The diagram was prepared tracing the contacts between the different lithologic units and the bedding in the marine sediments and pyroclastic sequence on a series of panoramic photos. The maximum height of the crater's wall is ~300 m. Note that the overall shape of the structure in the limestones (Kls) is that of a slightly overturned anticline. However, in the southwestern limb of the structure there are several second-order folds. Common types of second-order folds observed on the walls of the crater and around the maar are chevron-, box- and cuspate-type folds. The Quaternary tephra (Qt) forms a broad open pseudofold for the reason of the presence of drape bedding due to the irregular surface (heavy line) in which was accumulated. Qtd = Talus deposit (simplified from Aranda-Gómez et al., 1993).

of accidental fragments of country rock, juvenile clasts of alkali basalts, and a small proportion of crustal feldespathic granulites and mantle-derived ultramafic xenoliths and megacrysts. This pyroclastic sequence is related to phreatomagmatic explosions associated with the maar formation. The attitude of the tephra beds roughly mimics the pre-maar surface, forming a pseudo-fold caused by the presence of mantle bedding in the surge beds. In the southern rim of the crater, due to the volcanic sequence is absent, probably caused by northerly-directed phreatomagmatic blasts. A portion of a Laramide structure, with a fold width in the order of several kilometers, is exposed on the southern wall of the maar. The hinge zone of the structure occurs in the crater area.

A data set (n = 58) of bedding-plane attitudes was compiled on a traverse along the southern part of Sierra La Cuchilla Gorda (Figures 7 and 8a). Thirty-six of the readings are from the immediate surroundings of the crater and the hinge zone of the fold (Figure 8b). In general, the measurement of attitudes was difficult by the nature of the limestone. The very thick beds of carbonate, solution features on the surface of the layers, and conspicuous fracture sets obscure the bedding. The attitude of the strata was determined on the basis of the primary sedimentary lamination in the limestone, inferred from subtle changes in the textures of carbonates, contrasting degrees of dolomitization, occurrence of horizons of bioclasts and synsedimentary breccias associated with small patch reefs. The hinge zone and part of the northeastern limb of the fold is well exposed in the crater wall. Only a small portion of the southwestern limb is exposed, as the limestone is covered by alluvium in the valley located between the sierras Cuchilla Atravesada and Cuchilla Gorda. Interpretation of aerial photographs suggests that Sierra Cuchilla Atravesada is still part of the SW limb of the fold. These facts are reflected in the uneven concentration of poles in the p diagrams of Figure 8 (the apparent asymmetry in the pole concentration is a product of sampling bias). The data in the immediate surroundings of the maar (Figure 8b) define a girdle of a symmetric open fold with p axis located at 161/04, and a near-vertical axial plane.

REGIONAL STRUCTURE IN THE JOYA PRIETA AREA

The diagram corresponding to the Cuchilla Gorda data set (Figure 8a) shows three concentrations of poles. Visual inspection and comparison with the well-exposed portion of the structure in the crater walls indicates that the pole concentrations at 262/72 and 071/41 correspond to the limbs of the fold. The weak cluster around 283/27 coincides with bedding plane readings made in a zone where several bodies of fault breccia were identified in the field, and in the area located immediately east of the fault zone. Therefore, this cluster is interpreted as a disrupted and rotated part of the northeastern limb of the fold.

In the traverse across Sierra La Cuchilla Gorda, we observed pronounced changes in the lithology of the carbonates were observed that suggest the presence of an isolated patch reef within the dominant lagoonal facies (Figure 3). Despite these local variations in texture, fossil content, and degree of dolomitization and grain size, all the

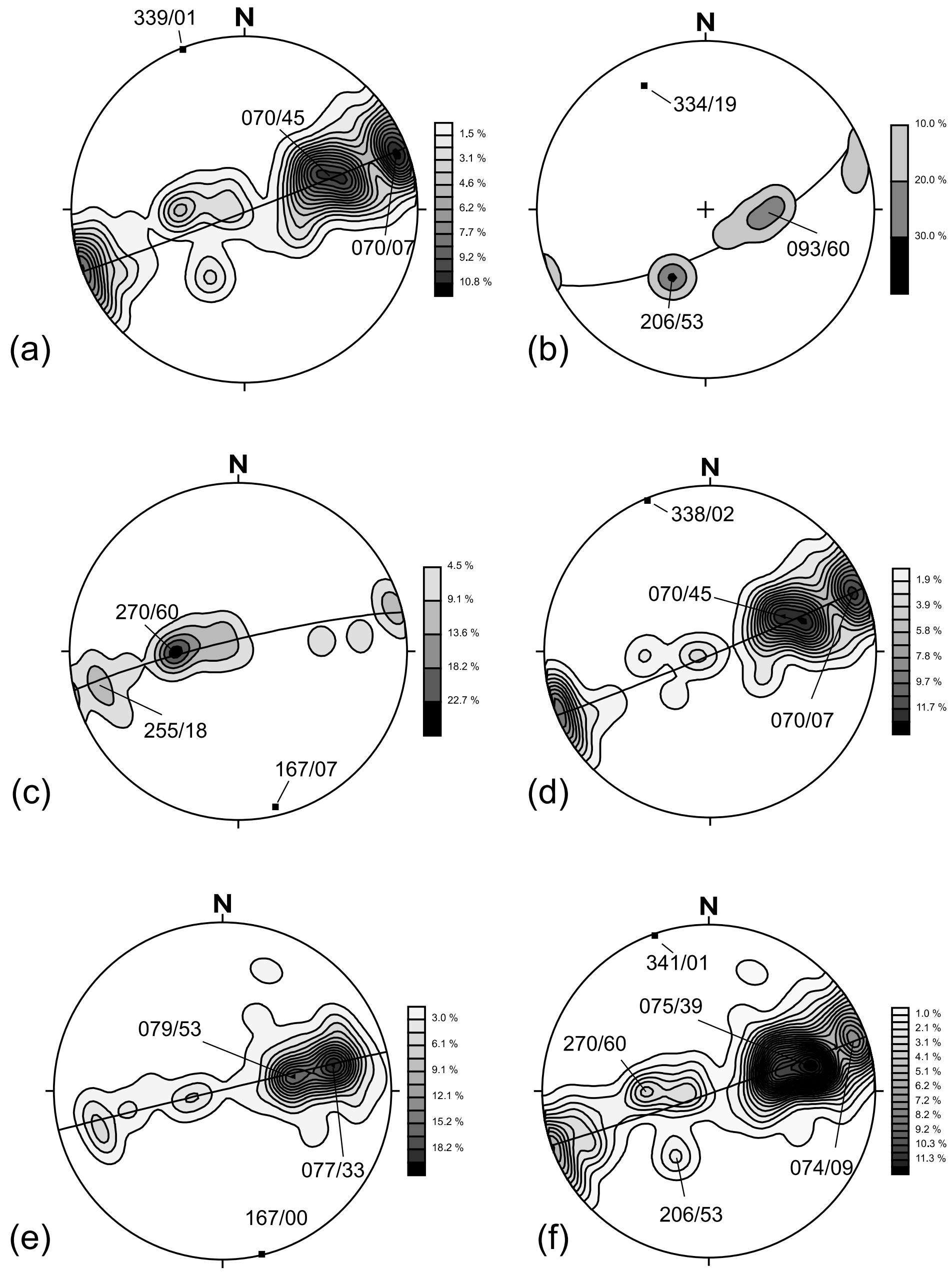

Figure 6. Contoured plots of poles to bedding projected into the lower hemisphere of an equal area net. (a) Data collected along the southern rim of the Joya Honda maar (n=130), (b) and (c) detailed measurements in second order folds exposed in the southern rim of the maar (n=10 and n=22, respectively), (d) Same as plot (a) after filtering out the data corresponding to obvious second order folds [i.e., (b) and (c)], (e) compiled structural data (n=66) shown in the regional map (see box in Figure 1c for location) of the southern part of Sierra El Coro (Aranda-Gómez and Labarthe-Hernández, 1977), and (f) combined data set (n=196) using the information of both the southern part of Sierra El Coro and Joya Honda. All the diagrams show the great circle fitting best to the girdle and its pole (p axis).

medium to thick strata of dense carbonate display the same style of deformation.

INFLUENCE OF THE GUAXCAMÁ EVAPORITES ON THE DEFORMATION OF EL ABRA FORMATION

REGIONAL STRUCTURE OF SIERRA DE GUADALCÁZAR

The Sierra de Guadalcázar is located between Joya Honda and Joya Prieta (Figure 2a), and the sedimentary rocks exposed there correspond to the platform interior facies of the VSLPP. The sequence consists of evaporite and dolostone of the Guaxcamá Formation (pre-Aptian; see discussion in Basáñez-Loyola et al., 1993; Valencia-Islas and Villaseñor-Rojas, 1997), limestone of El Abra Formation (Late Aptian-Santonian), marls and shales of the Soyatal Formation (Early Campanian), and sandstone and shale of the Cárdenas Formation (Late Campanian-Maastrichtian). In the central part of the sierra, there is a large (~12 x 9 km), roughly elliptical area occupied by calcareous breccia. This breccia was intruded

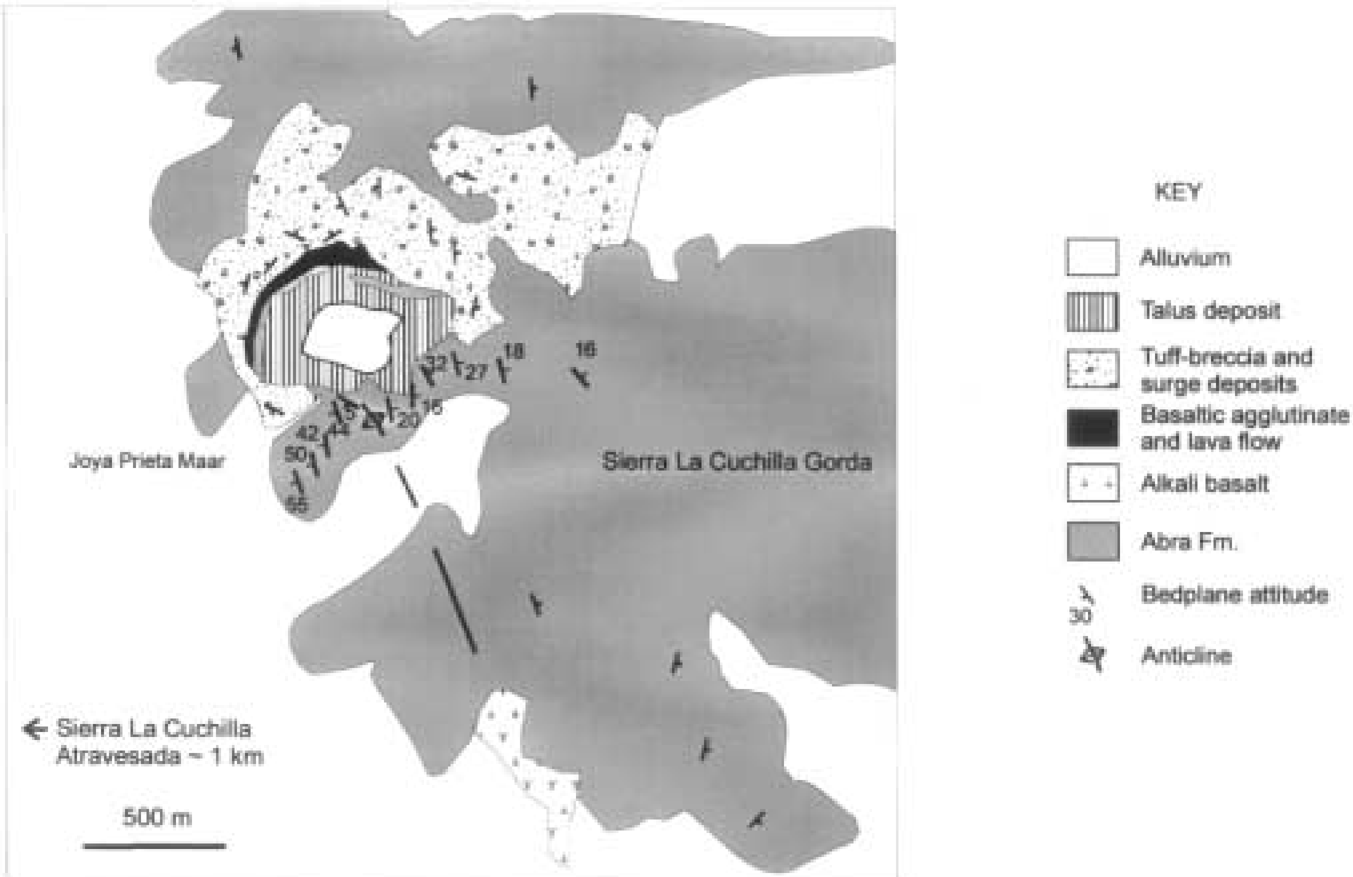

Figure 7. Simplified geologic map of the Joya Prieta maar and its surroundings. The location of this map is marked in Figure 2b.

by the Cerro San Cristóbal stock, a subvolcanic, mid-Tertiary (K-Ar ~ 32 Ma; Mújica and Jacobo-Albarrán,1983), tin-bearing granite (Figures 9, 10).

Sierra de Guadalcázar is markedly different from the surrounding structures. Northeast of Guadalcázar, the fold axes follow the regional trend (~ 320°) and their traces are relatively straight. With decreasing distance to the core of the sierra (Cerro San Cristóbal), the axes of the folds become concave toward the mid-Tertiary stock and collapse breccia (Figure 9). Immediately north and west of the breccia outcrop (in the area locally known as Sierra La Trinidad, Figure 10), the strata are disrupted and their trends tend to be subparallel to the contact between the breccia and the marine sequence. Northwest of the sierra, across the Núñez Valley, in the sierras Las Playas and Las Mulas, the fold axes and traces of thrust faults are NNW, N-S and NNE trending (Figures 9-10).

Small outcrops of the Guaxcamá evaporites are completely surrounded by limestones of El Abra Formation in the Sierra La Trinidad area (Figure 10). Based on field observations (Torres-Hernández, 1994), it is believed that these evaporites were injected through fractures in El Abra limestones and come from an underlying diapir (Torres-Hernández, 1994; Valencia-Islas and Villaseñor-Rojas, 1997). Keys to the understanding of the extent of this structure are: 1. the calcareous breccia at the Realejo altiplano, and 2. the distribution of large karstic basins (poljes) studied by Wenzens (1973). The breccia is a remarkable, unbedded deposit mostly composed of a chaotic, closely packed, clast-supported, mixture of fragments of El Abra limestone, which range in size from few centimeters to tens of meters, and a small proportion of travertine fragments and rare clasts of gypsum. Eroded in the breccia are a large number of sinkholes and wide karstic basins; the most outstanding by their sizes are the Guadalcázar, El Realejo and La Trinidad poljes (Figure 10).

The breccia around the San Cristóbal stock is interpreted either as the product of roof collapse of a diapir (Torres-Hernández, 1994) or, alternatively, as evaporites tectonically accumulated in the core of a regional fold (Suter, written comunication, 1998). According to Torres-Hernández (op. cit.), emplacement of the Guaxcamá evaporites produced sets of radial and concentric fractures in the thick-bedded platform carbonates. These discontinuities largely enhanced the secondary permeability of the platform carbonates and probably allowed the flow of groundwater into the evaporites,

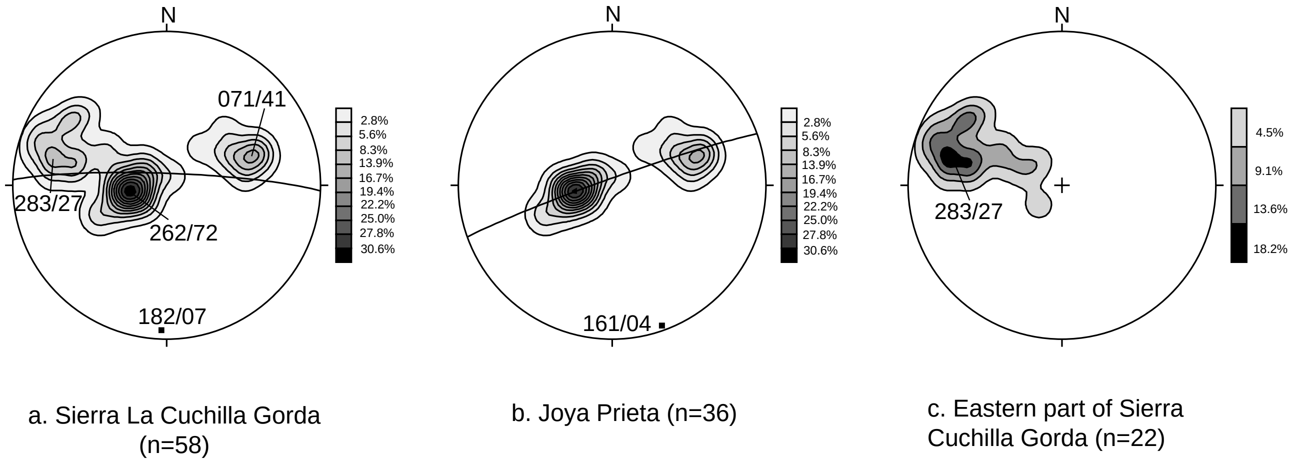

Figure 8. Contoured plots of poles to bedding projected into the lower hemisphere of an equal area net. (a) data collected in Sierra La Cuchilla Gorda traverse (n=58). (b) data collected in the southern rim of the Joya Prieta maar (n=36). (c) Cuchilla Gorda set (n=22) after filtering out the data corresponding to the anticline exposed in the southern wall of Joya Prieta. Beds in the eastern portion of the fold were disrupted and rotated by a cataclastic fault zone oriented N5°E/60°SE.

causing the formation of large interconnected caves that ultimately caused the roof collapse of the structure, producing the breccia (Torres-Hernández, 1994). Collapse occurred during the Early Tertiary, prior to the emplacement of the Cerro de San Cristóbal stock and La Enramada intrusive, is indicated by the contact relations and intense hydrothermal alteration and mineralization in the breccia near the intrusive contact. The breccia has remained as a rock mass with much higher secondary permeability (compared to the surrounding folded carbonates). Large-scale karstification occurred producing the huge dissolution basins known as the Trinidad, Realejo and, specially, Guadalcázar poljes, and a large number of smaller sinkholes at the Realejo altiplano.

A comparison between the p diagrams collected at the maars, Sierra Los Librillos and the one corresponding to the SG data set shows that the orientation of the fold axial planes is roughly similar in the sierras El Coro, Guadalcázar and Cuchilla Gorda (Figure 2a). However, the dispersion in the SG diagram (Figure 11a) is much larger than that observed around the craters and in the sierras El Coro (Figure 6e) and Cuchilla Gorda (Figure 8a). To evaluate the origin of this phenomenon, the SG data set was split into several subsets on the basis of visual inspection of Figure 10. First, we considered that if the stock was emplaced in a collapse breccia, the bedding-plane attitudes measured in large (tens to hundreds of meters) blocks that still preserve stratification must show a large degree of disruption due to rotation at the time of breccia formation. Second, with increasing distance to the core of the SG, the effect on the Laramide structures of either the tectonically thickened evaporite and/or the mid-Tertiary stock must decrease. Thus, we considered the sierras Las Mulas and Las Playas (Figure 9) as a different structural domain. The area immediately around the collapse breccia was considered as a third domain. The p diagrams for these domains are shown in Figures 11b, c, d. The diagrams corresponding to the collapse area (Figure 11c) and to the sierras Las Mulas and Las Playas (Figure 11b), show relatively well defined girdles with low dispersion, and the orientation of the fold axes are not unlike others in the western part of the carbonate platform. The diagram corresponding to the area around the collapse breccia is also consistent with the regional tectonic fabric, but shows much larger dispersion (Figure 11d). Visual inspection of Figure 10, indicates that stratification is more disrupted in the areas north and west of the collapse breccia, especially in the region where the Guaxcamá anhydrites were injected through the overlying El Abra formation (Torres-Hernández, 1994). Therefore, the structural domain around the breccia was in turn split into two subdomains: one that is located south of the core of the SG and includes Sierra El Aguaje and the Mesozoic sediments south of the Guadalcázar-El Ábrego polje. The other one formed by the data compiled at Sierra La Trinidad, near the Guaxcamá and granite outcrops. Figures 11e and 11f show that most of the dispersion comes from Sierra La Trinidad.

On the basis of the analysis of the p diagrams, we concur with Torres-Hernández (1994) that the structural anomalies at SG are related to the modification of a Laramide fold by the emplacement in its core of a tectonically thickened evaporite body. Furthermore, well data indicate that the Guaxcamá Formation have a thickness up to 2,700 m in the Guaxcamá-1 well (Basáñez-Loyola et al., 1993), located ~35 km SSE of El Realejo altiplano. This disruption occurred before the emplacement of the mid-Tertiary stock, as shown by contact relations between the intrusive and the breccia. However, the girdle obtained in the domain defined by the

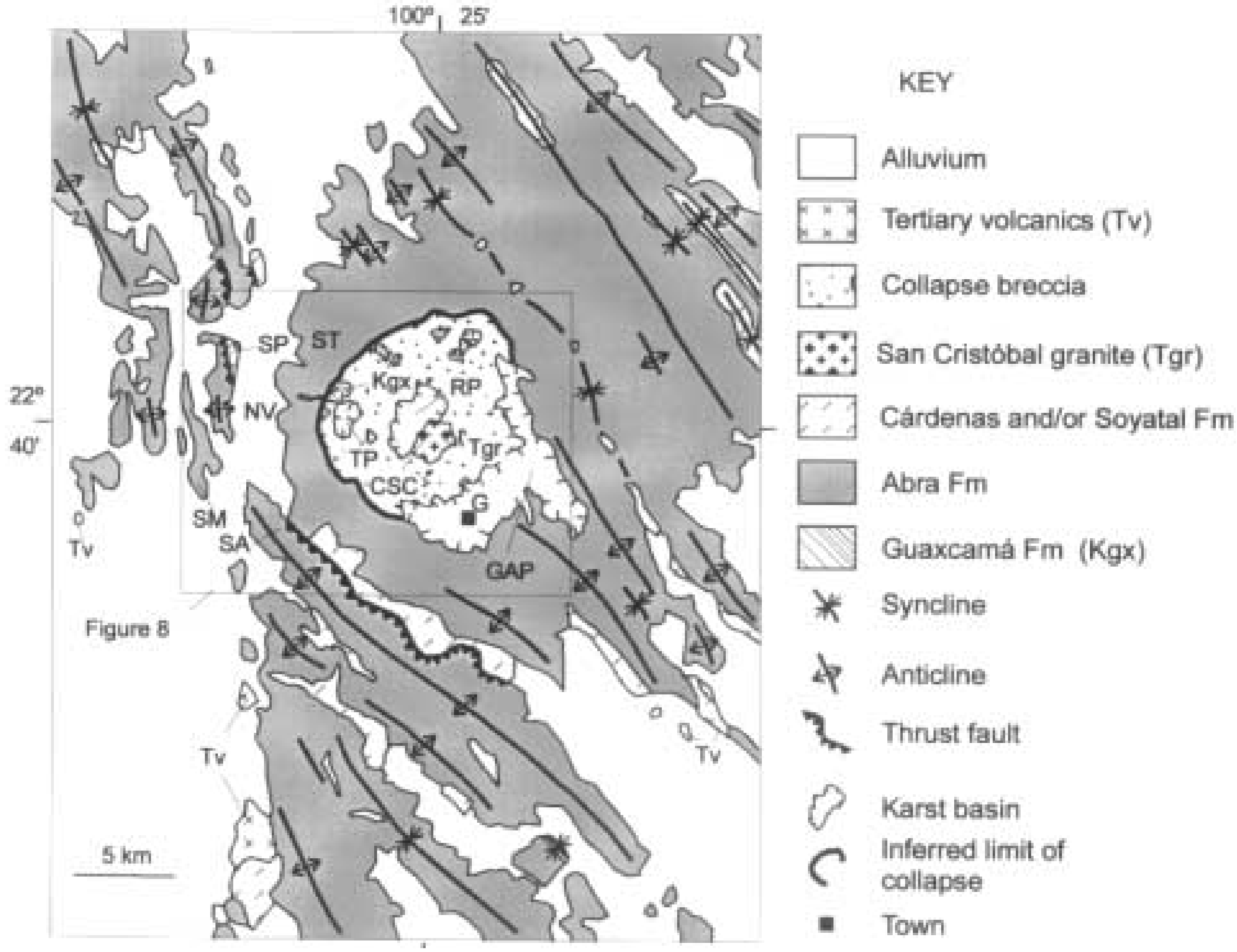

Figure 9. Regional geological map of the area around Sierra de Guadalcázar (SG), the rectangle gives the location of Figure 10. Note that some of the fold axes northeast of SG appear to be truncated and other axes are bent around the core of the sierra. Key: SA= Sierra El Aguaje; SP= Sierra Las Playas; SM= Sierra Las Mulas; ST= Sierra La Trinidad; CSC= Cerro San Cristóbal Stock; TP= Trinidad Polje; RP= Realejo Polje; GAP= Guadalcázar Polje; NV= Núñez Valley; G= town of Guadalcázar. Modified from Torres-Hernández (1994).

breccia (Figure 11c), which is similar in orientation to the regional folds observed in the area, argues against the interpretation of the large limestone outcrops at the Realejo altiplano as gigantic clasts in the breccia. We believe that the structural data around Cerro San Cristóbal were collected at limestone pillars that separated a tight network of caves. After a series of collapses, only the pillars surrounded by the breccia remained as relics of the original structure. Likewise, the structural data in the breccia collapse area do not support the hypothesis of a forcefull emplacement of the granitic stock (cf. Wittich and Ragotzy, 1920; Urías, 1963; Alonso-Lomelí, 1981).

SUMMARY AND CONCLUSIONS

There is a ~N-S trending transitional zone between two major paleogeographic units of Cretaceous age in the area located between San Luis Potosí and Matehuala. To the east of this zone a carbonate platform complex was located where locally very thick beds of shallow water carbonates (El Abra Formation) accumulated to a total thickness estimated in the order of 1,500-2,000 m (Suter, 1987), and in places may reach 2,720 m (Basáñez-Loyola et al., 1993). Late Cretaceous sequences (~30-200 m) of limestone-shale and sandstone-shale were deposited atop the platform carbonates (de Cserna and Bello-Barradas, 1963; Torres-Hernández, 1994). To the west a marine basin was located where a roughly coeval, much thinner (~425 m, Labarthe-Hernández et al., 1982) sequence of well-bedded cherty limestone was accumulated, which is overlain by limestone-shale and sandstone-shale sequences. In the basin-carbonate platform transition, the thin-bedded calcareous turbidite sometimes contain olistoliths and thicker beds of slide breccias made of shallow water carbonate clasts. El Abra Formation is in places underlain and /or changes laterally to the evaporites of the Guaxcamá Formation of the platform interior (Figure 3).

Both sedimentary sequences were deformed during the Latest Cretaceous-Early Tertiary Laramide Orogeny (Suter, 1984). Shortening was accomplished mostly by thrusting at the

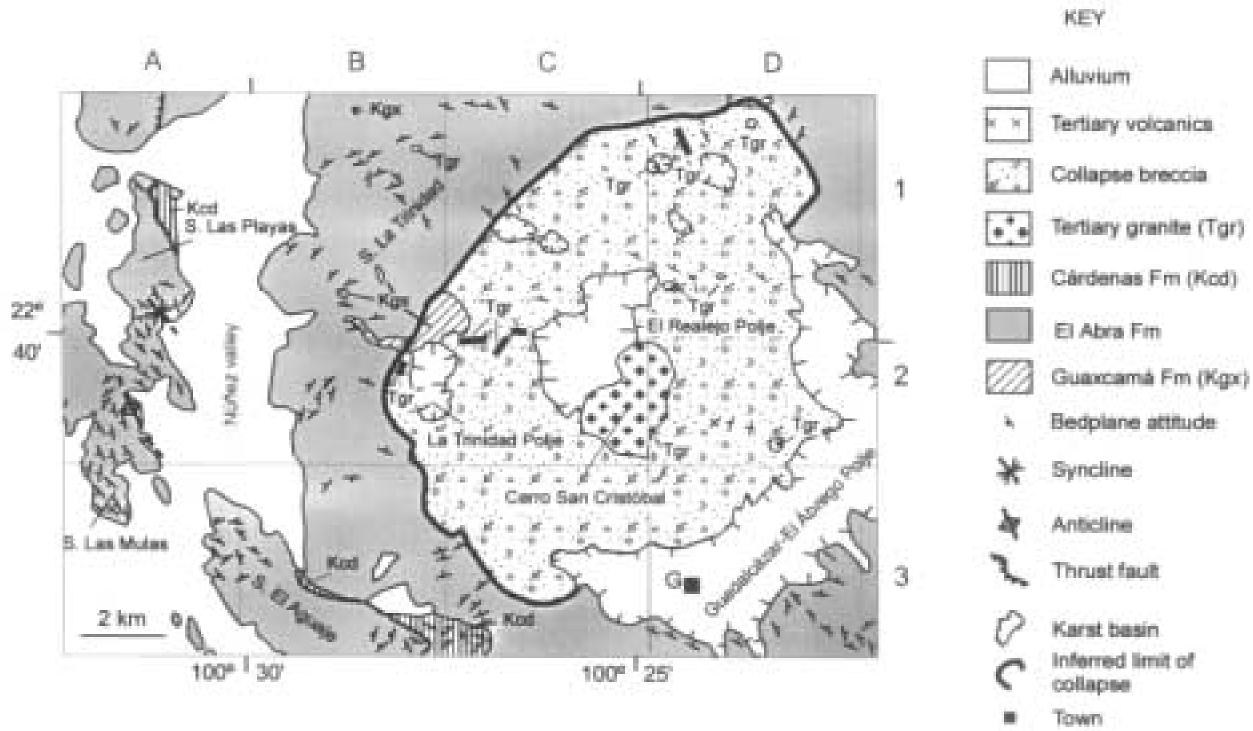

Figure 10. Generalized geologic map of Sierra de Guadalcázar (SG). Note the presence of large karstic basins at the collapse area. It is likely that the Guadalcázar-El Ábrego Polje, together with the northern and northwestern limit of the collapse breccia, roughly delineates the area disturbed by the tectonically thickened anhydrite; the most perturbed area is around the outcrops of the Guaxcamá Formation. Modified from Torres-Hernández (1994). G-Guadalcázar.

margins of the carbonate platform, whereas folding dominated in the surrounding basin and in the platform interior. Location of major thrust faults and the change in the folding style roughly coincides with the gross lithological and overall thickness changes between the basin and platform sequences (Figure 3). Folding style and intensity in the comparatively more incompetent basin rocks contrast with that observed in El Abra Formation. Basin rocks in the surroundings of Joya Honda/Sierra El Coro developed tight overturned folds. Major folds in the area (fold width in the order of several hundred meters) can better be described as anticlinoria and synclinoria, as the structures display numerous second order folds. The overall shape of the major structures appears to be controlled by the thicker and more competent beds of slide breccia made of clasts derived from the carbonate platform. Second order folds (fold width in the order of 1-3 m) originated from the thinner, argillaceous, deep-water calcareous turbidite, as seen on the wall of Joya Honda (Figure 5).

Transitional zone rocks, corresponding to the reef talus and western slope of the carbonate platform complex (Figure 3), display slide structures and penecontemporaneous folds. Laramide deformation partially overprinted these primary features producing overturned folds and thrust faults with small to moderate displacements (hundreds of meters to few kilometers) masking the nature of the western border of the carbonate platform (Suter, 1987; Torres-Hernández, 1994; Torres-Hernández and Tristán-González, 1994).

The intensity and style of deformation in rocks of the backreef contrast markedly with the basin and forereef areas. In Joya Prieta/Sierra Cuchilla Gorda the structure is an open, symmetric anticline with a near vertical axial plane and estimated fold width in the order of several kilometers. Despite significant changes in the lithology of the carbonates in the zone, related to the presence of patch reefs in the carbonate platform interior, these are not reflected by the local structure as in Joya Honda. A change in the attitude of NE limb of the anticline is related to rotation caused by a N5°E, 60°SE fault.

Locally, inside of the carbonate platform complex, the occurrence of Guaxcamá anhydrites played an important role in the style of deformation. The near-cylindrical folds observed elsewhere in the region were disrupted by the formation of diapirs or by the tectonic accumulation of anhydrite at the core of some folds. This fact is seen in the p diagrams of Sierra de Guadalcázar as an increase in the dispersion of the structural data and, to a minor degree, in the Sierra Los Librillos, which has small outcrops of anhydrite. Division of Sierra de Guadalcázar into several structural domains shows that the anomalous bedding plane attitudes are located in the area where anhydrite is exposed (Sierra La Trinidad). Outside of this disrupted area the orientation of the structures is similar to that observed in other areas of the region. The p diagram of the collapse area around El Realejo altiplano indicates that the large outcrops of limestone were not rotated. Therefore, they are interpreted as pillars that separated a tight network of caves

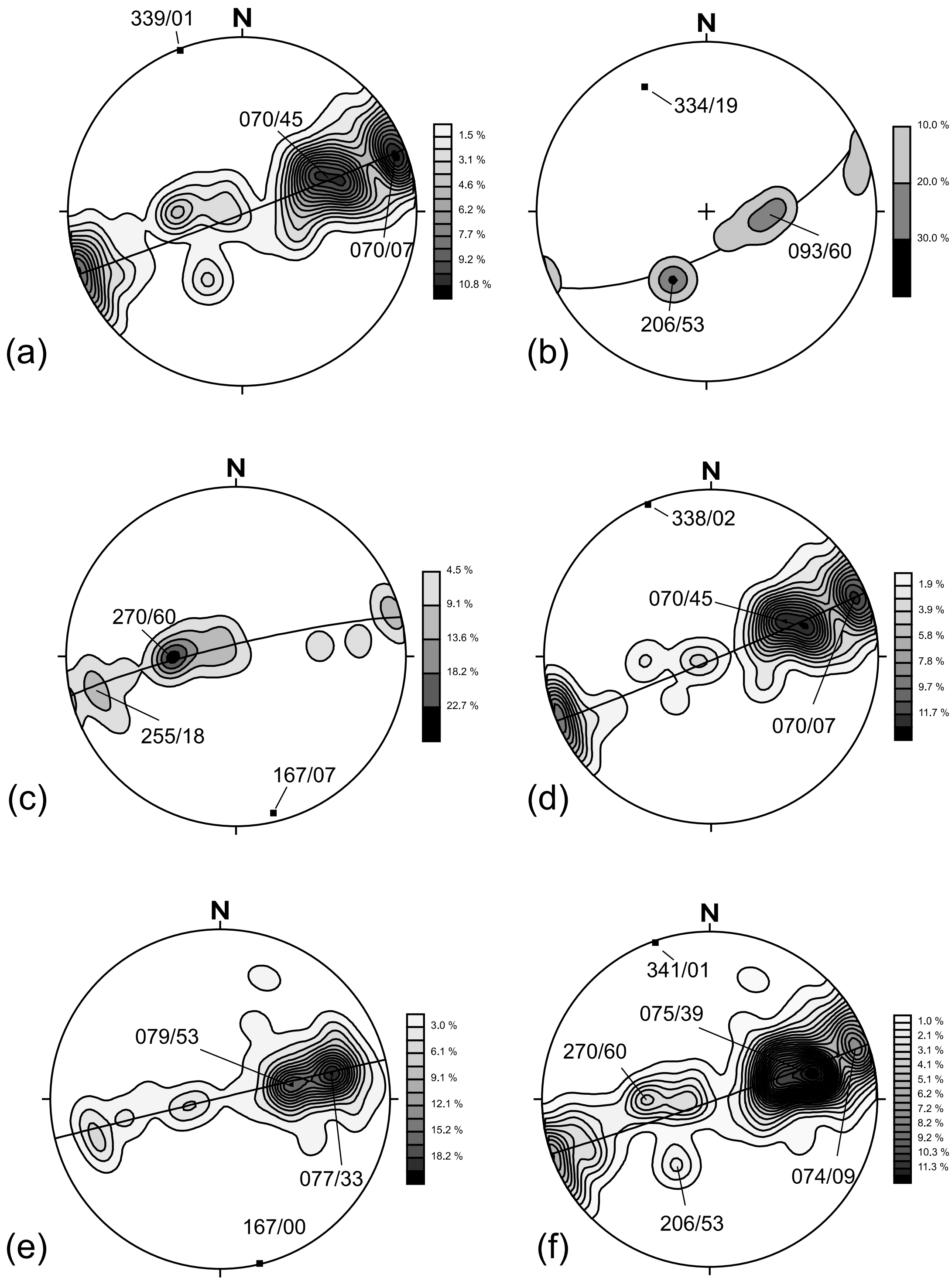

Figure 11. Contoured plots of poles to bedding projected into the lower hemisphere of an equal area net. (a) All the measurements shown in Torres-Hernández (1994) map of Sierra de Guadalcázar (n = 183). (b) Data collected at Sierra Las Mulas and Las Playas (n = 35). (c) Structural data collected in pillars surrounded by collapse breccia (n=26). (d) Data collected around the collapse breccia (n = 118), except Sierra Las Mulas and Las Playas. (e) Data collected in the Sierra La Trinidad area (n = 66), W, NW and N of the collapse breccia. (f) Data collected at Sierra Las Mulas and Las Playas and in the area south of the collapse breccia (n=91). Insets nearby each plot show the coverage area for the data employed.

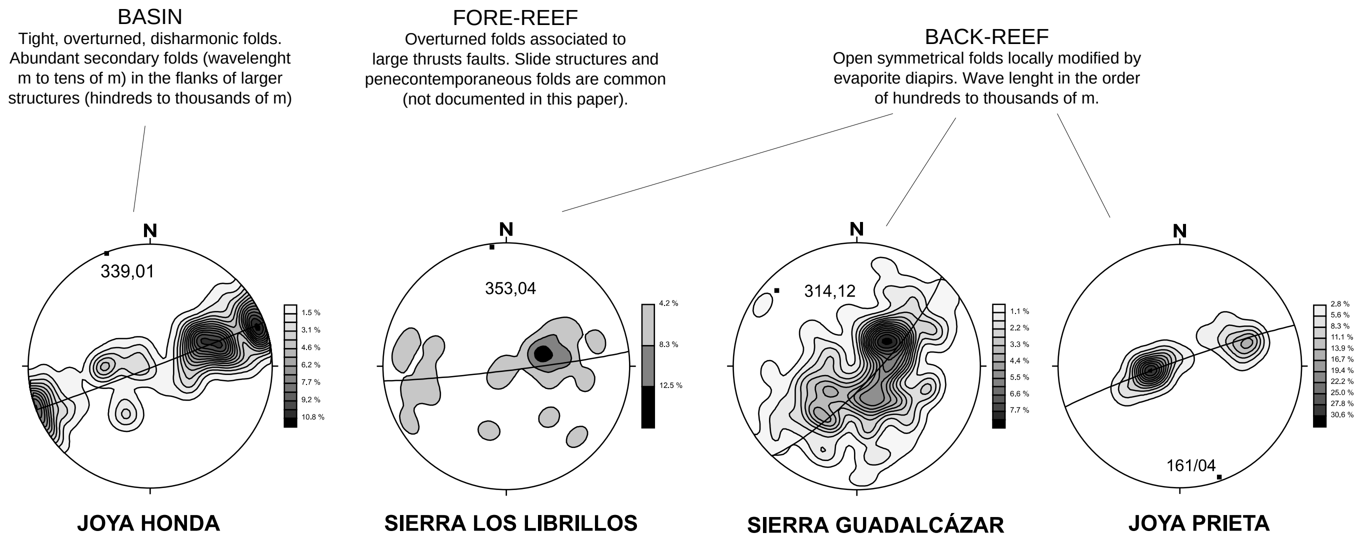

Figure 12. Summary of the results obtained in the structural analysis of data collected along the west-central margin of the VSLPP.

rather than as gigantic clasts in the collapse breccia. No evidence of forcefull emplacement or doming around the Cerro de San Cristóbal stock was found.

ACKNOWLEDGMENTS

Max Suter, Gustavo Tolson, and J. L. Wilson critically reviewed an earlier version of the manuscript. Their comments helped to improve the paper. Jorge and Andrés Aranda López assisted in the field and helped to prepare some of the figures. Conacyt (project 3657PT) provided financial support for this research to J. Aranda.

BIBLIOGRAPHICAL REFERENCES

Alencaster, G., Torres-Hernández, R., Tristán-González, M., Barbosa-Gudiño, R., López-Doncel, R., Pons, J.M. and Omaña, L., 1999, El Abra Formation in the western part of the Valles-San Luis Potosí Platform (Mexico): Erlanger geol. Abh., Sonderband 3, p. 7-8.

Alonso-Lomelí, L.F., 1981, Estudio geológico minero del área del Realejo y parte norte de la hoja Guadalcázar en el Estado de San Luis Potosí: Universidad Autónoma de San Luis Potosí, Facultad de Ingeniería, B.Sc. thesis, 49 p. (Unpublished).

Aranda-Gómez, J.J., 1982, Ultramafic and high grade metamorphic xenoliths from Central Mexico: University of Oregon, Eugene, Oregon, PhD thesis, 228 p. (Unpublished).

Aranda-Gómez, J.J., and Labarthe-Hernández, G., 1977, Estudio geológico de la Hoja Villa Hidalgo, S.L.P: Universidad Autónoma de San Luis Potosí, Instituto de Geología y Metalurgia, Folleto técnico 53, p. 33-58.

Aranda-Gómez, J.J. and Luhr, J.F., 1993, Geology of the Joya Honda and Santo Domingo maars, San Luis Potosí, Mexico—a visit to the mantle and crustal xenolith localities in the Sierra Madre Terrane, in Ortega Gutiérrez, F., Centeno-García, E., Morán-Zenteno, D.J. y Gómez-Caballero, A., eds., Pre-Mesozoic basement of NE Mexico, lower crust and mantle xenoliths of central Mexico and northern Guerrero terrane: Universidad Nacional Autónoma de Mexico, Instituto de Geología, First Circum-Pacific and Circum-Atlantic terrane conference, Guanajuato, Mexico, Guidebook of field trip A, p. 10-35.

Aranda-Gómez, J.J. and Luhr, J.F., 1996, Origin of the Joya Honda maar, San Luis Potosí , Mexico: Journal of Volcanology and Geothermal Research, v. 74, p. 1-18.

Aranda-Gómez, J.J., Luhr , J.F. and Pier, J., 1993, Geología de los volcanes cuaternarios portadores de xenolitos provenientes del manto y de la base de la corteza del Estado de San Luis Potosí: Universidad Nacional Autónoma de Mexico, Instituto de Geología, Boletín 106, p. 1-22.

Aranda-Gómez, J.J., and Ortega-Gutiérrez, F., 1987, Mantle xenoliths in Mexico, in Nixon, P.H., ed, Mantle xenoliths, Wiley, p. 75-84.

Basáñez-Loyola, M.A., Fernández-Turner, R., and Rosales-Domínguez, C., 1993, Cretaceous platform of Valles-San Luis Potosí, northeastern central Mexico: American Association of Petroleum Geologists Memoir 56, p. 51-59.

Carrillo-Bravo, J., 1971, La Plataforma Valles-San Luis Potosí: Asociación Mexicana de Geólogos Petroleros, Boletín, v. 23, núms. 1-6, p. 1-102.

Carrillo-Martínez, M., 1990, Geometría estructural de la Sierra Madre Oriental, entre Peñamiller y Jalpan, Estado de Querétaro: Universidad Nacional Autónoma de Mexico, Instituto de Geología, Revista, v. 9, núm. 1, p. 62-70.

Carrillo-Martínez, M., 1996, Structural geometry of the Sierra Gorda between Jalpan and Tequisquiapan: Instituto de Investigaciones en Ciencias de la Tierra, UAH, e Instituto de Geologia, UNAM, II Convención sobre la Evolución Geológica de Mexico y Recursos Asociados, Libreto guía de las excursiones geológicas. Excursión 2, p. 67-73.

Contreras-Pérez, J., 1993, Distribución de esfuerzos y estabilidad mecánica de márgenes de plataformas carbonatadas: Universidad Nacional Autónoma de Mexico, Instituto de Geofísica, Unidad Académica de los ciclos Profesional y de posgrado, Colegio de Ciencias y Humanidades, MSc thesis, 56p. (Unpublished).

De Cserna, Z., 1992, IV.2.1 Tectónica, in Atlas Nacional de México: México, D.F., Universidad Nacional Autónoma de México, Instituto de Geografía

De Cserna, Z., y Bello-Barradas, A., 1963, Geología de la parte central de la Sierra de Álvarez, Municipio de Zaragoza, Edo. de San Luis Potosí: Universidad Nacional Autónoma de Mexico, Instituto de Geología, Boletín 71, p. 23-63

Enos, P., 1974, Reefs, platforms and basins of middle Cretaceous in northeast Mexico: American Association of Petroleum Geologists Bulletin, v. 58, p. 800-809

Garza-Blanc, S.A., 1978, Cartografía geológica de la hoja Santa Catarina, SLP: Universidad Autónoma de San Luis Potosí, Instituto de Geología y Metalurgia, Folleto técnico 61, 40 p.

Gómez-Morán, C., 1986, Geochemistry and petrology of crustal xenoliths from Xalapasco de la Joya, state of San Luis Potosí, Mexico: Houston, Texas, University of Houston, Ms. thesis, 306 p. (Unpublished).

Greene, G. M., 1975, The geochemistry of spinel lherzolites from Xalapasco de la Joya in San Luis Potosí, Mexico: Houston, Texas, University of Houston, M.Sc. thesis, 43 p. (Unpublished).

Greene, G.M., and Butler, J.C., 1979, Spinel lherzolites from Xalapasco de la Joya, San Luis Potosí, S.L.P., Mexico: Mineralogical Magazine, v. 43, p. 483-486.

Heinrich, W., and Besch, T., 1992, Thermal history of the upper mantle beneath a young back-arc extensional zone—ultramafic xenoliths from San Luis Potosí, central Mexico: Contributions to Mineralogy and Petrology, v. 111, p. 126-142.

Labarthe-Hernández, G., 1978, Algunos xalapascos en el Estado de San Luis Potosí: Universidad Autónoma de San Luis Potosí, Instituto de Geología y Metalurgia, Folleto técnico 58, 17 p.

Labarthe-Hernández, G., Tristán-González, M., y Aranda-Gómez, J.J., 1982, Revisión estratigráfica del Cenozoico de la parte central del Estado de San Luis Potosí: Universidad Autónoma de San Luis Potosí, Instituto de Geología y Metalurgia, Folleto técnico, v. 85, 208 p.

Labarthe, G., and Tristán, M., 1978, Cartografía geológica de la hoja San Luis Potosí: Universidad Autónoma de San Luis Potosí, Instituto de Geología y Metalurgia, Folleto técnico 59, 41 p.

Luhr, J.F., Aranda-Gómez, J.J., and Pier, J.G., 1989, Spinel- lherzolite-bearing, quaternary volcanic centers in San Luis Potosí, Mexico. I. Geology, Mineralogy, and Petrology: Journal of Geophysical Research, v. 94, no. B6, p. 7,916- 7,940.

Morán-Zenteno, D., 1994, The Geology of the Mexican Republic: American Association of Petroleoum Geologists, Studies in Geology # 39, p. 46-54.

Mújica, M.R., and Jacobo-Albarrán, J., 1983, Estudio petrogenético de las rocas ígneas y metamórficas del Altiplano Mexicano: Instituto Mexicano del Petróleo, Reporte interno (unpublished).

Pier, J.G., Podosek, F., Luhr, J.F., Brannon, J., y Aranda-Gómez, J.J., 1989, Spinel-lherzolite-bearing, quaternary volcanic centers in San Luis Potosí, Mexico. II. Sr and Nd isotopic systematics: Journal of Geophysical Research, v. 94, no. B6, p. 7,941-7,951.

Ruiz, J., Ortega-Gutiérrez, F., and Essene, E.J., 1993, Geochemical and petrographic characteristics of inclusions in Cenozoic alkalic basalts from central Mexico: EOS, Transactions AGU, v. 64, p. 343.

Suter, M., 1984, Cordilleran deformation along the eastern edge of the Valles-San Luis Potosí carbonate platform, Sierra Madre Oriental fold-thrust belt, east-central Mexico: Geological Society of America Bulletin Bulletin, v. 95, p. 1,387-1,397.

Suter, M., 1987, Structural traverse across the Sierra Madre Oriental fold-thrust belt in east-central Mexico: Geological Society of America Bulletin, v. 98, p. 249-264.

Suter, M., 1990, Hoja Tamazunchale 14Q-e(5) con geología de la hoja Tamazunchale, Estados de Hidalgo, Querétaro y San Luis Potosí, Universidad Nacional Autónoma de Mexico, Instituto de Geología, Carta Geológica de Mexico, Serie 1:100,000, núm. 22

Suter, M., Contreras-Pérez, J., and Ochoa-Camarillo, H., 1997, Structure of the Sierra Madre Oriental fold-thrust belt in east-central Mexico: Instituto en Investigaciones en Ciencias de la Tierra, U. A. H., e Instituto de Geologia, UNAM, II Convención sobre la Evolución Geológica de Mexico y Recursos Asociados, Libreto guía de las excursiones geológicas. Excursión 2, p. 45-63.

Tardy, M., 1980, Contribution a l'étude géologique de la Sierra Madre Orientale du Mexique: Université Pierre et Marie Curie de Paris, France, Thèse de Doctorat d'Etat, 459 p. (Unpublished).

Torres-Hernández, J. R., 1994, Análisis de la evolución estructural de la Sierra de Guadalcázar, S.L.P: Universidad Nacional Autónoma de Mexico, Facultad de Ciencias, MSc thesis, 77 p. (Unpublished).

Torres-Hernández, J.R., Barboza-Gudino, R., Tristán-González, M., Pons, J.M., y Alencaster, G., 1998, La cabalgadura San Luis-Matehuala, la parte trasera de la Faja de Pliegues y Cabalgaduras de la Sierra Madre Oriental en la parte centro oriental de Mexico, Primera Reunión Nacional de Ciencias de la Tierra, Mexico D.F., Sociedad Geológica Mexicana, p. 117 (abstract).

Torres-Hernández, J.R., and Tristán-González, M., 1994, La cabalgadura El Huizache-Buenavista, la más importante de la parte noroccidental de la Plataforma de Valles-San Luis Potosí: GEOS, v. 14, núm. 5, p. 81.

Urías, R.A., 1963, Estudio geológico de la Sierra de Guadalcázar: Universidad Autónoma de San Luis Potosí, Instituto de Geología y Metalurgia, Folleto técnico 8, 35 p.

Valencia-Islas, J.J., and Villaseñor-Rojas, P.E., 1997, Implicaciones geodinámicas de los resultados de la geoquímica de rocas e isótopos de azufre de la Formación Guaxcamá: Actas INAGEQ, v. 3, núm. 1, p. 1-11.

Wenzens, G., 1973, Investigaciones geomorfológicas en la región cárstica del norte de San Luis Potosí y sur de Nuevo León: Sociedad Geológica Mexicana, Boletín, v. 34, núm. 1-2, p. 71-79.

Wilson, J.L., 1975, Carbonate facies in geological history: Berlin, Springer-Verlag, 471p

Wittich, E., and Ragotzy, F., 1920, Apuntes preliminares acerca de la zona de Guadalcázar, SLP: Petróleo, v. 13, núm. 196, p. 5.

Zárate-Muñoz, J.C. ,1977, Cartografía geológica de la Hoja Villa Arista, S.L.P.: Universidad Autónoma de San Luis Potosí, Instituto de Geología y Metalurgia, Folleto técnico 52, 47 p.

Manuscript received: March 15, 1998
Revised manuscript received: March 12, 2000
Manuscript accepted: March 21, 2000