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The Pb-Zn ore deposits of San Felipe, Sonora, Mexico: "Detached" mineralization in the Basin and Range Province

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RESUMEN

La minas de plomo-zinc-plata de San Felipe (Sonora, México) se encuentran en las cercanías de una estructura que presenta las características de un complejo metamórfico ("metamorphic core complex") por lo menos en su parte noreste. Esta estructura está caracterizada por una denudación asociada a la extensión terciaria, la cúal afectó el norte de México y el oeste de los Estados Unidos durante el Mioceno. Las unidades del bloque superior, entre las cuales se encuentra el pórfido eocénico superior que contiene en parte los yacimientos de San Felipe, se deslizaron varios kilómetros desde su posición original a lo largo de una falla de despegue: la falla El Amol. Esta falla corta la zona mineralizada dejando las partes más profundas (skarns) en el bloque inferior, en la parte más alta de la Sierra. Este ejemplo muestra que la distensión debe ser tomada en cuenta en el marco de una exploración minera moderna o en el caso de nuevas búsquedas de reservas en yacimientos conocidos. Se conocen por lo menos dos otros yacimientos en Sonora afectados por procesos similares, un depósito de tungsteno en el flanco oeste de la Sierra de Mazatán, y una parte de la zona oxidada de La Caridad (falla La Caridad). En Arizona, el depósito de San Manuel-Kalamazoo es un ejemplo clásico de un pórfido cuprífero afectado por la extensión terciaria.

PALABRAS CLAVE: "Basin and Range", falla de despegue, complejo metamórfico, yacimientos de San Felipe, Sonora.

ABSTRACT

The lead-zinc-silver deposits of San Felipe, Sonora, Mexico are located in the vicinity of a metamorphic core complex, in its northeastern part. This structure is characterized by a denudation associated with Tertiary extension which affected northern Mexico and the western United States during Miocene. The units of the upper plate, including the Eocene porphyritic rhyolite which contain parts of the San Felipe deposits slided to the NE some kilometers from its original position along the El Amol detachment fault. This fault is exposed for about 40 km, with a general trend N 60º W and dips of 20 to 45º NE. The El Amol fault cuts the mineralized zone leaving the deeper parts (skarns) of the system in the lower plate, in the highest part of the Sierra de Aconchi. At least two other ore deposits in Sonora have been affected by extension, including a tungsten deposit in the west flank of the Sierra Mazatán and part of the La Caridad mine (La Caridad fault). In Arizona, the San Manuel-Kalamazoo copper deposit was also affected by Tertiary extension. Effects of extension should be taken into account when exploring for new reserves in old districts.

KEY WORDS: Basin and Range, detachment fault, metamorphic core complex, San Felipe ore deposits, Sonora.

INTRODUCTION

One of the main structures related to the extensional Basin and Range province is the metamorphic core complex. Several models have been proposed to explain the formation of this structure (Wernicke, 1985, Malavieille, 1987, or Lister and Davis, 1989). The extension rate is important enough to uplift the middle crust locally to the surface. Uplift is accompanied by sliding of the upper units along a major low-angle detachment fault. The main features of the metamorphic core complexes are as follow (Crittenden *et al.*, 1980, and references therein):

(1) A lower plate largely composed of Proterozoic rocks: This is the metamorphic core which was intruded several times during Tertiary.

(2) An upper plate with lower-grade or not metamorphic supracrustal rocks of Paleozoic to Tertiary age.

(3) Both plates are separated by a major low-angle detachment fault with structural features changing with depth. The deeper ductile fabric is mylonitic and the shallower structures are brittle (cataclastic). During the uplift of the deeper levels, the brittle deformation overprints the ductile one.

The Basin and Range province of which the Great Basin, Nevada, is the most evident expression in its northern part is not restricted to the western United States. It passes round the Transition Zone in southwestern of Colorado Plateau and extends to Mexico, mainly Sonora, but also more to the south (Henry and Aranda-Goméz, 1992). The states of Sonora and Baja California Sur (Carrillo-Chávez, 1992) are the only two states where metamorphic core complexes have been described in Mexico. Coney (1980) mentioned three in Sonora: The ranges called Magdalena (Nourse, 1990), Madera and Mazatán, to which we may add the Pozo Verde Sierra astride on the boundary between Arizona and Sonora (Figure 1). We propose to add the Sierra de Aconchi, that exhibits in its norteastern area the same structural features described above (Calmus *et al.*, 1992). We propose a new tectonic interpretation of geologic units of the Aconchi area, and we discuss the effects of the Tertiary extension on the break-up of the San Felipe Pb-Ag-Zn ore deposits.

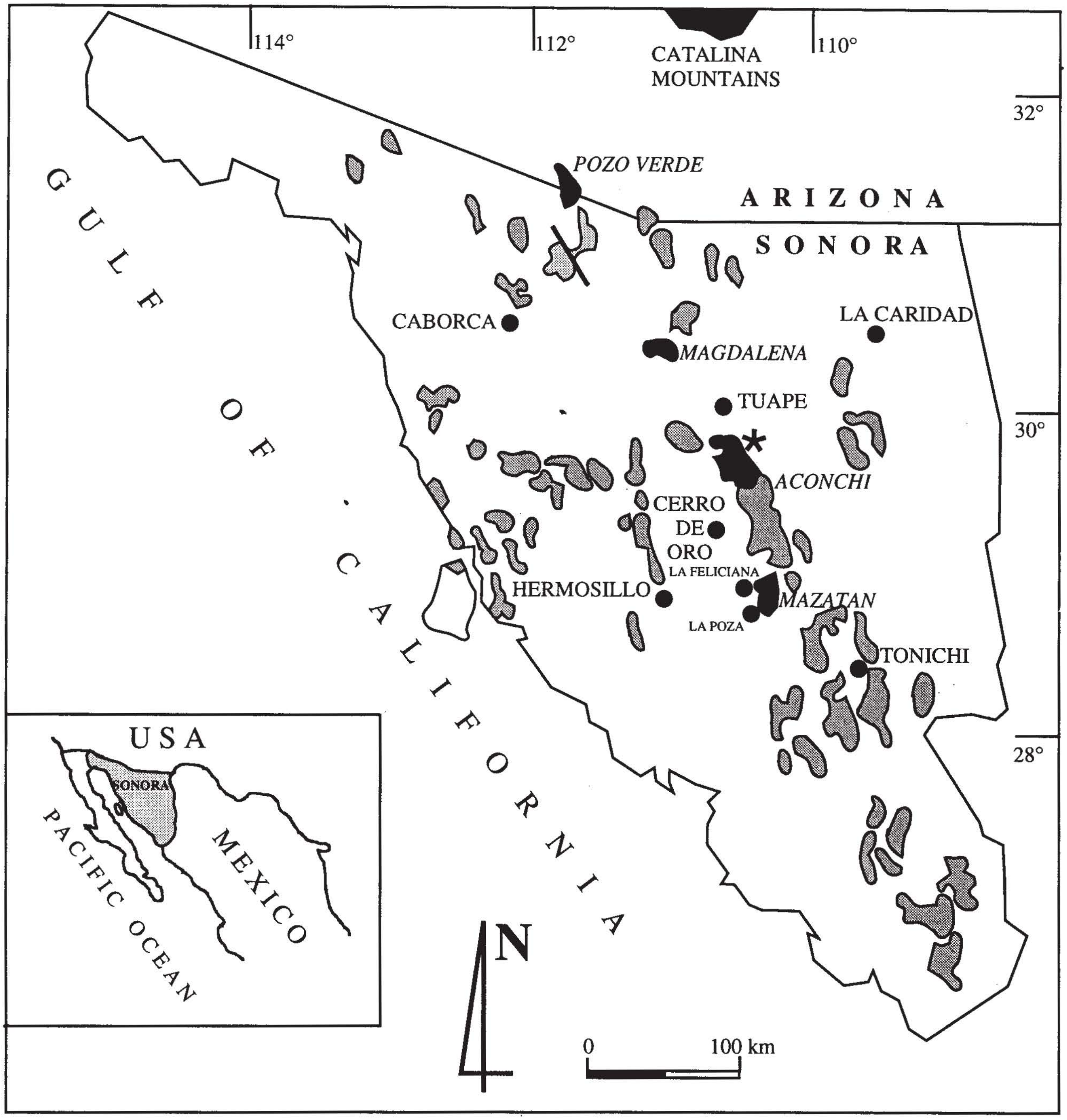

Fig. 1. Simplified distribution map of Tertiary granitoids in Sonora, Mexico (striped areas) and location of the metamorphic core complexes (black areas). Star: Location of the rhyolitic porphyry of San Felipe.

GEOLOGIC SETTING

The Sierra of Aconchi (950 Km^2), is located in north-central Sonora (Figure 1). It is part of the Sonoran batholith which extends on roughly 19 000 Km^2. The Basin and Range morphology cuts it and conceals a large part of the batholith under Miocene detritic continental and lacustrine sequences as the Baucarit Formation, and under more recent alluvial fans.

Except for some roof-pendants, of mainly Paleozoic or Cretaceous rocks scattered over the batholith mass, the pre-batholithic units are found essentially in the northern area of the Sierra. They may be divided in two units :

(1) *A Proterozoic assemblage* consists of two tectonic units separated by a thrust fault attributed to the Upper Jurassic nevadian tectonic phase (Figueroa-Valenzuela and Grijalva-Haro, 1989). The lower unit consists of amphibolitic gneiss, amphibolites and orthogneiss that present sometimes a myrmekitic structure. A 1675 Ma U-Pb age on zircon has been obtained by Anderson (oral communication, cited in Rodríguez-Castañeda, 1984). The upper unit consists of a hornblende granodiorite, a metamorphic unit

with quartzite and paragneiss intruded by U-Pb 1100 Ma granite, similar to the Aibo granite of the Caborca area, northwestern Sonora, (Anderson and Silver, 1971). This upper unit is covered by an Upper Proterozoic sedimentary sequence (carbonates and sandstones).

(2) *A Jurassic volcanic unit* (not shown on Figure 3) overlies the Proterozoic rocks north of the Sierra de Aconchi. It consists mainly of andesites and volcanic breccia. It is correlated with the andesitic formations of the same age that are common in the Tuape region, Central Sonora (Rodríguez-Castañeda, 1984).

(3) *Lower Cretaceous rocks* are found only as a roof pendant in the "Los Locos" mine at the top of the Sierra de Aconchi; it consists of limestone, fine sandstone and intercalations of conglomerates with quartzite pebbles. The contact metamorphism has destroyed all fossils, but the rocks are lithologically similar to the Lower Cretaceous Cerro de Oro Group, which is found 30 km southwestwards (Castro-Rodríguez and Morfín-Velarde, 1988). Lower Cretaceous rocks are at the same topographic level than the Paleozoic rocks or the Proterozoic basement, in contact with the Jaralito Granite. This disposition is due to thrusting during the mid-Cretaceous and Late Cretaceous-Early Tertiary Laramide orogenesis. This is the case for example of the Cerro de Oro area where the Upper Proterozoic and Lower Cambrian thrust the Lower Cretaceous rocks.

(4) *The youngest unit* affected by intrusions of the Sierra de Aconchi is a volcanic unit considered by Chávez-Aguirre (1978) as Lower Cretaceous. In the northeast part of the Sierra, in the contact with the San Felipe Porphyry, it is mainly composed by andesites (Figure 3). This unit is probably of Upper Cretaceous age and may be correlated with the Tarahumara Formation (Wilson and Rocha, 1949), widespread in Central Sonora (McDowell *et al.*, 1994).

The post-batholitic rocks are composed of three main units:

(1) *An Oligocene volcano and sedimentary unit*, chiefly of felsic pyroclastics deposits and some andesitic flows. Polygenic conglomerates are intercalated in this unit. The Oligocene age is inferred from stratigraphic relations: the unit is underlain by the San Felipe Porphyry of Early Eocene and is overlain by the Miocene Baucarit Formation. This unit is not hydrothermally altered unlike rocks intruded by the Late Eocene two-mica granite.

(2) *The Baucarit Formation*, composed of continental clastic rocks was first described by Dumble (1900). The Baucarit Formation is widespread in valleys of Central Sonora, and consists mainly of andesitic basalts at the base and alternating polygenic conglomerates and sandstones in its upper part. The origin of the Baucarit Formation is related to the filling of grabens of the Basin and Range Province; its composition depends on the surrounding lithologies. It contains local basaltic flows of Early Miocene age (Damon, in Cochemé, 1985). In Central Sonora, it is overlain by the tuffaceous Lista Blanca Formation with an age of 10.4 ± 0.2 Ma (Morales-Montaño *et al.*, 1990). In the northwest part of the Sierra de Aconchi we have found no volcanic flows within the Baucarit Formation; however, Roldán (1976) reported them to the south. To the south of Torreón Ranch, the clasts in the Baucarit Formation are mainly of granitic (>90%) and subordinate volcanic origin.

(3) *Basaltic flows* (Figure 3) are horizontal and overlie unconformably the Baucarit Formation.

The batholith contains three intrusions:

(1) *The El Jaralito granitoid* consists of granite, monzogranite in the core and granites near the roof of the intrusion (Richard, 1991). K-Ar ages of mineral and whole rock reported by Anderson *et al.* (1980), Mead (1982) and Gastil (1986, written communication cited in Roldán-Quintana, 1991) range between 51.8 Ma and 69.6 ± 2 Ma. Petrographic and geochemical studies by Roldán-Quintana (1991) show that these granitoïdes are calc-alkaline and belong to a series associated with subduction (Damon *et al.*, 1983; Richard *et al.*, 1989).

(2) *The porphyritic rhyolite (San Felipe porphyry)* is a stock and contains brecciated intrusive rocks (Roldán-Quintana, 1976) of the subvolcanic facies of the calc-alkaline magma of the El Jaralito granitoid. The porphyry contains characteristic ameboid quartz-eyes as phenocrysts. The intrusion yields a K/Ar age of 50.47±1. 66 Ma on K-feldspar (Roldán-Quintana, 1976). This porphyry is silicified and has been altered to quartz-sericite; it yields a K/Ar age of 49.5 ± 2 Ma on sericite in the Santa Rosa mine (Roldán-Quintana, 1976). Most of the ore deposits of San Felipe are associated with this porphyry; however some of the exploited mineralized veins are cut by the porphyry and must be consequently older, e. g. the NE-SW or E-W veins of the Artemisa Mine which cut cross Cretaceous andesite (Figure 2).

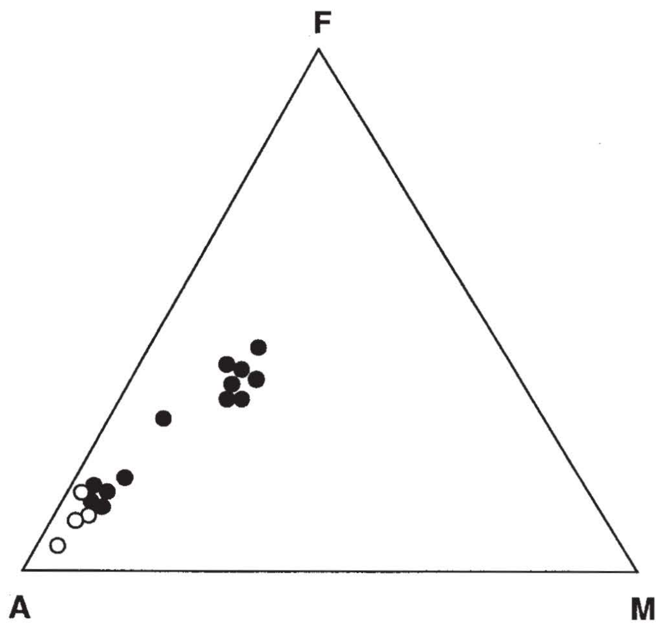

Fig. 2. AFM diagram for samples of the El Jaralito and Aconchi granites. stars: El Jaralito granite, circles: Aconchi granite, from Roldán-Quintana, 1991.

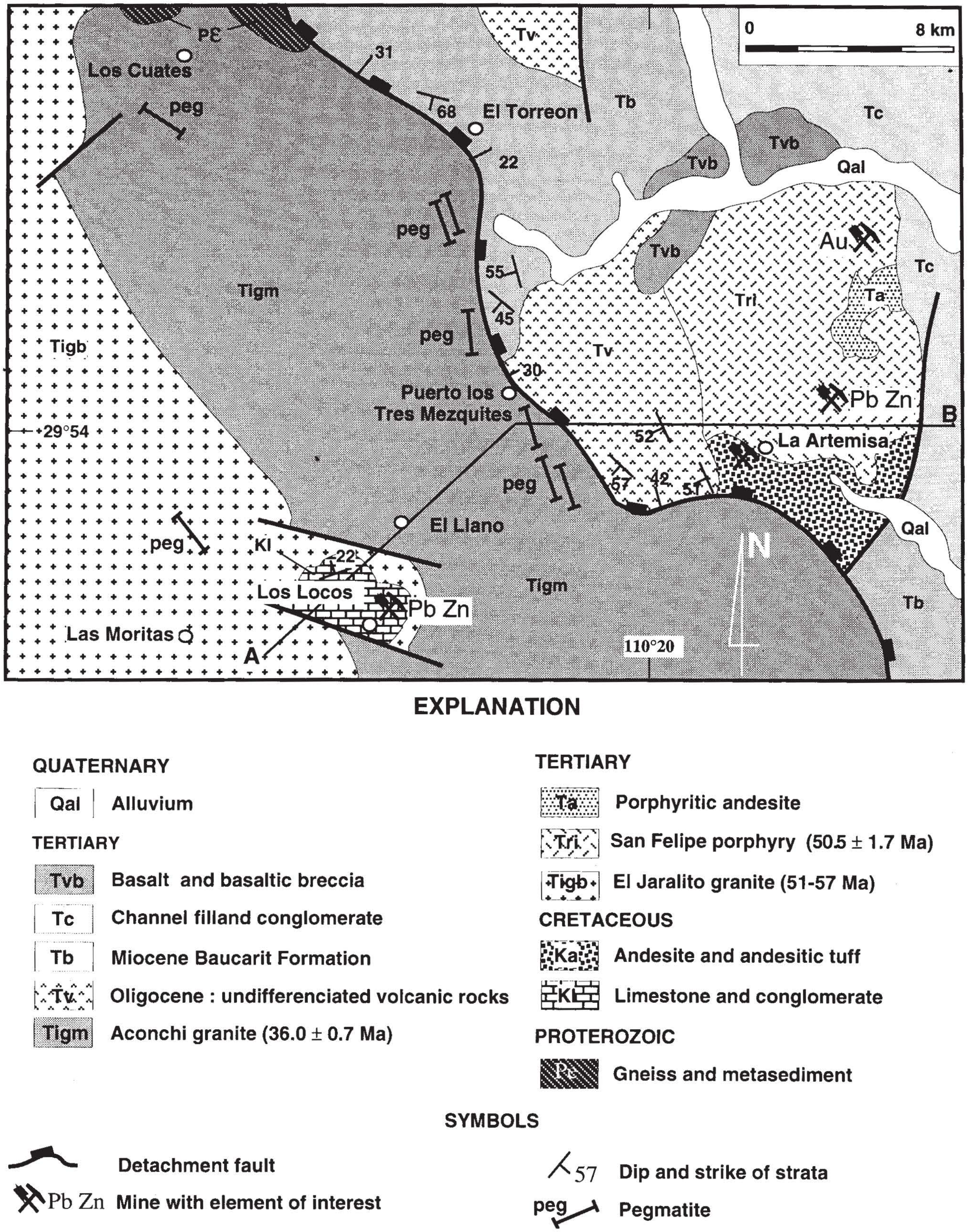

Fig. 3. Structural sketch map of the northeastern part of the Sierra de Aconchi .

(3) *The Aconchi granite* is characterized by the association of two micas, biotite and muscovite (Roldán-Quintana, 1991). Muscovite yields a K/Ar age of 36.0 ± 0.7 Ma (Damon in Roldán-Quintana, 1979) and plagioclase and bi-

otite yield respectively 36.5 ± 0.8 and 32.0 ± 0.7 Ma (Damon *et al.*, 1983a). This was followed by the intrusion of two pegmatitic veins, which lack internal deformation: (1) the first pegmatite strikes generally N-S and contains columbite-tantalite crystals but lacks garnet. Because of the lack of garnet, we associate the beryl-bearing pegmatites located at south of the Aconchi granite, near the contact with the El Jaralito granite to these columbite-tantalite-bearing pegmatites. (2) the second generation of pegmatite contains garnets belonging to the pyralspite series. Some pegmatitic veins are 4 m wide. South of Los Cuates Ranch, we may find two types of garnet-bearing pegmatites: the first one has no preferred direction and contains small rare garnets (< 1 mm). The second one has a NW-SE general direction and contains larger and more abundant garnets (1-4 mm) as well as biotite clusters up to several centimers across. Garnets are generally located near the edge of the pegmatitic veins. Some crystals are also present in Proterozoic gneiss and Aconchi granite.

Both granitic and pegmatitic units are together crosscut by many andesitic dykes, more abundant by the edge of the Sierra de Aconchi. Two K-Ar whole rock ages yield 28.3 ± 0.7 Ma and 26.7 ± 0.6 Ma (Damon *et al.*, 1983b). Dykes strike between N60W and N20W, and dip steeply to the NE or to the SW. This is consistent with the N50E to N70E orientation of extension, and also agrees with the direction of sliding of the San Felipe porphyry.

Major element concentrations, modes and garnet paragenesis of the Aconchi granite (Richard, 1991) suggest that it belongs to crustal leucogranites. According to Cochemé and Demant (1991), the fusion of the crust may be related with a cinematic reorganization after the collision between the East-Pacific Rise with the North American continent (Atwater, 1970; Engebreston *et al.*, 1985). This would not have originated a crustal thickening but rather the beginning of the pre-Basin and Range extension, associated with rise of the mantle.

Most of the core of the Sierra de Aconchi consists of Tertiary granite. The Proterozoic units are exposed at the northernmost and northeasternmost of the Sierra in both upper and lower plates. The lack of Proterozoic rocks in the core of the metamorphic core complexes is also typical of other similar structures in Sonora. The oldest rocks in the lower plate of Magdalena-Madera, Pozo Verde and Jarillas-Potrero-Tortugas metamorphic core complexes are Jurassic in age (Nourse, 1989; Nourse *et al.*, 1994), but a quartz monzonitic granite in the core of the Sierra de Mazatán yields a Rb-Sr age of 1475 ± 29 Ma (Damon, in Radelli, 1986). The differences in the lower plates of the metamorphic cores complexes in Sonora may be attributed to denudation and to the pre-Tertiary structure related to Mesozoic tectonics.

STRUCTURAL SETTING

The three magmatic units described above (El Jaralito granite, San Felipe porphyry, Aconchi granite) together form the Aconchi and El Jaralito batholiths. Yet they do not represent a structural unit. Actually, if we observe the structural position of these magmatic units into the "Metamorphic Core Complex", the San Felipe porphyry and the El Jaralito granite though genetically associated, are separated by a low-angle normal fault dipping between 20º and 45º: The El Amol detachment fault. This fault was previously mapped by Roldán-Quintana (1991) and can be followed about 40 km along a sinuous path. A spectacular view can be had south of the Tres Mezquites Pass (Figure 3), where the fault is exposed in an area of 5 to 6 km^2 (Figure 4). Here the western foot wall is Aconchi granite and the eastern hanging wall is tilted Oligocene volcanoclastics which unconformably overlie the San Felipe porphyry. The contact is underlined by the Arroyo Los Lavaderos (Figure 4).

North of Tres Mezquites Pass, the Oligocene volcanoclastic unit is overlain by the Baucarit Formation which presents high dip angles, until 80º, against the dip of the El Amol fault. The dip of the Baucarit Formation is due to tilting from detachment fault activity. Many secondary faults are associated with the El Amol fault both in the hanging wall and the foot wall. Near the Ranch El Torreón, in the foot wall, the andesitic dykes discordant in the Aconchi granite are systematically faulted by low-angle or horizontal normal faults with offset of a few meters to the north or the northeast.

The El Amol fault, where observed, always is characterized by cold cataclastic deformation. No clear mineral lineation is associated. In thin sections, the minerals (mainly quartz and plagioclases) show normal parallel or conjugate fractures which agree with the main displacement along the El Amol fault (Figure 5). Ductile structures are found only in sharp shear zones, 1 mm to 1 cm wide; they often feature strechted and/or folded primary muscovites.

Some detachment faults are old reactivated compressive structures (Malavieille, 1987; Sosson, 1990), but the El Amol fault does not show superimposed older compressive and younger extensive structures. Except for the sharp shear zones along the El Amol fault, the Aconchi granite have no foliation or mineral lineation. Some others granites in the Sonoran batholith do show foliation and mineral lineation associated with extension processes. For example the Precambrian calc-alkaline granite of the Sierra Mazatán has a mylonitic zone at the base of the detached cover and a N60°E to N 80°E mineral lineation, which corresponds to the main regional stretching direction during the Basin and Range extension.

Thus the El Amol fault, at its present outcrop, may have been formed under shallow conditions and relatively low pressures and temperatures. These P-T conditions did not permit a ductile-style of deformation and plastic straining of felspar and quartz crystals. We suggest that the El Amol fault, as far as it can be observed, corresponds to the upper part of a detachment fault which is higher than the mylonitic front (see, for example, the model of metamorphic core complex development by Lister and Davis, 1989). The El Amol fault might correspond to the superfi–

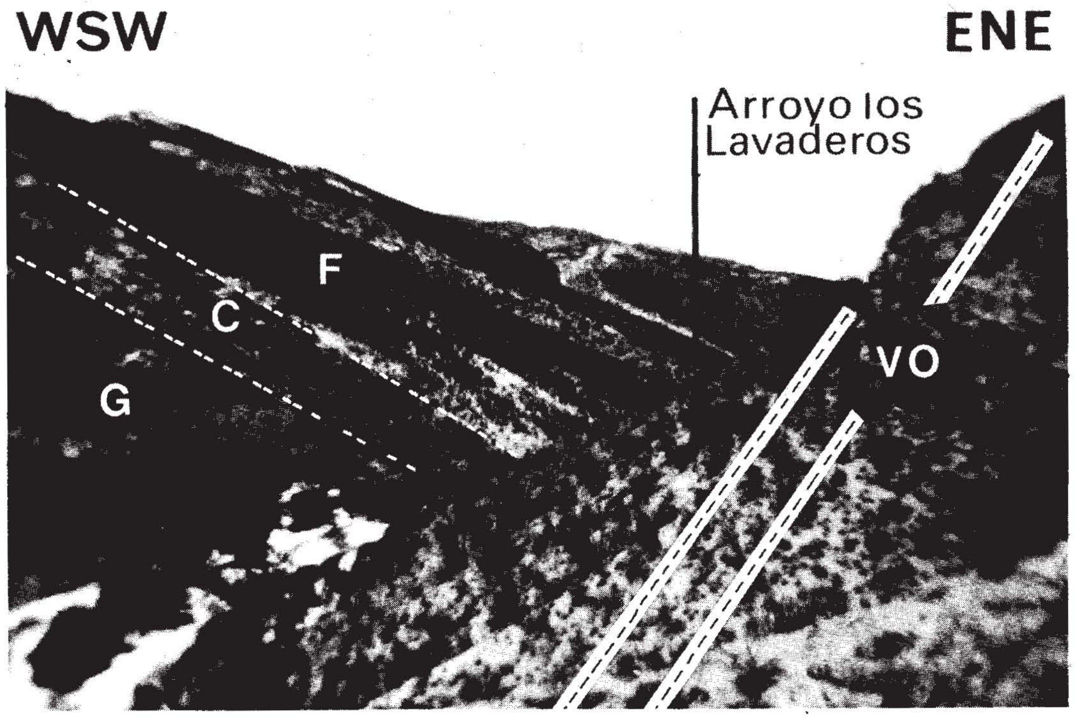

Fig. 4. View toward the north of the El Amol Fault. Note the structural plane in the background. This surface corresponds to the more resistant cataclastic carapace. F: Structural plane of the El Amol Fault; G: Aconchi granite; C: cataclasite; VO: Oligocene volcanics. Strata of the Oligocene volcanic rocks are underlined by two white lines with dashed lines.

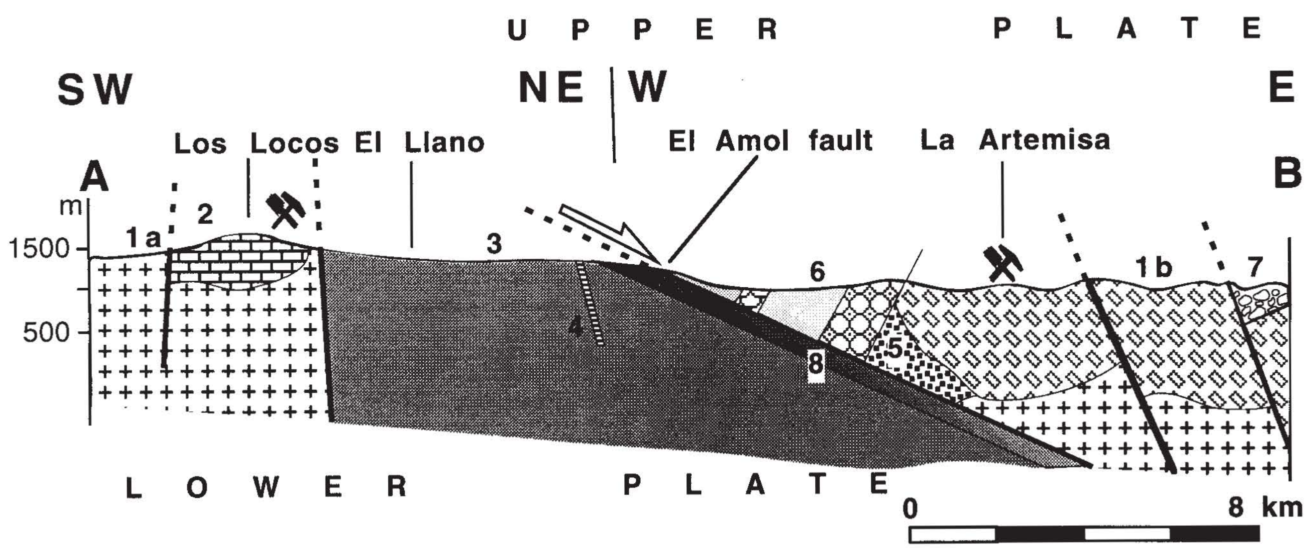

Fig. 5. Cross section AB of the northeastern area of the Sierra de Aconchi. See location on the map of the Figure 2. 1a: El Jaralito granite; 1b: San Felipe rhyolitic porphyry; 2: Early Cretaceous marine sediments; 3: Aconchi granite; 4: pegmatite dyke; 5: Late Cretaceous andesites; 6 Oligocene felsic volcanic rocks and conglomerate; 7: Tertiary channel fills and conglomerate; 8: El Amol detachment fault.

cial part of the former delamination zone, or to a brittle detachment fault of a later stage. If it is a detachment fault, we estimate a maximum displacement along the fault as long as 8 to 10 km. This evaluation following the model of Lister and Davis (1989) agrees with the distance measured between Los Locos mine and the San Felipe porphyry.

ORE DEPOSITS

The ore deposits of the San Felipe mining district consist of veins and skarns. The more common minerals are galena, arsenopyrite, pyrite, sphalerite, chalcopyrite, magnetite in a gangue including quartz, calcite, garnet and epidote. In terms of the structural setting of the area, we may class the mines of the San Felipe district in two groups: (1) the most important mines located in the upper plate of the detachment fault, including San Felipe, Santa Rosa, Las Lamas, and Artemisa mines; (2) the Los Locos mine which is located in the lower plate, but near the top of the range. Chávez-Aguirre (1978) attributed the Pb-Zn-Cu deposits to circulation of hydrothermal solutions from the rhyolitic porphyry. He added that, in the case of the Los Locos mine, the rhyolitic porphyry intrusion probably mobilized metals in the Jurassic volcano-sedimentary sequence. However, the porphyry is missing in the mine. Note that the sequence which has been interpreted as Jurassic by Chávez-Aguirre (1978) is actually younger, as it contains Albian fossils discovered in interbedded calcareous strata of a correlative unit located a few kilometers south of the Los Locos mine (Roldán-Quintana, 1991). Furthermore, in Sonora, metallogenic concentrations are unknown in the Jurassic volcano-sedimentary formations. We conclude that the Los Locos mineralization must be related to the El Jaralito granite. The absence of porphyry is explained by tectonic truncation by the El Amol fault.

Concerning the hanging wall mines, our work around the Artemisa mine suggests that the porphyry clearly cut the mineralized veins. The ore deposit of Artemisa mine is located mainly in a vertical, east-west, 3 m thick vein plus two secondary parallel veins. They cut across an altered andesitic sequence and sandstone and hornfelds. The intrusive contact of the porphyry trends NE-SW. Mineralization occured before emplacement of the porphyry and may associate to the El Jaralito granite intrusion, as in the Los Locos mine. The intrusion of El Jaralito granite is the only earlier magmatic event likely to have induced these hydrothermal phenomena. This agrees with Chávez-Aguirre (1978), who suggests that (1) the mineralized deposits of the San Felipe group resulted partly from a source other than the porphyry, e.g. the Mesozoic volcanic rocks; (2) the younger Aconchi granite (muscovite granite of Chávez-Aguirre) does not show mineralization except for some beryllium geochemical anomalies. Reynoso [personal communication to Roldán-Quintana] thinks that the Los Locos deposits located in the foot wall are similar to the San Felipe mineralization in the hanging wall .

El Jaralito granite and San Felipe rhyolitic porphyry must be contemporaneous and cogenetic. Chávez-Aguirre, (1978) suggests that the porphyry might correspond to an apophysis of El Jaralito granite. The geographic extension of the San Felipe porphyry and its tilted position lead us to estimate the top of the granite at 1 km depth in the upper plate after the Miocene extension occurred.

DISCUSSION

The timing of extensional Tertiary deformation may be constrained with only a few radiometric ages in Sonora. In the Sierra de Aconchi, the younger intrusion is the Aconchi two-mica granite at 36.5 ± 0.8 Ma (Damon *et al.*, 1983a). The beginning of extension is probably related to the intrusion of NW striking andesitic dykes at 26.7 ± 0.6 Ma (Damon *et al.*, 1983b), and with the emplacement of NW to NNW striking undated pegmatitic veins. These data are the same for the Magdalena metamorphic core complex, where a two-mica granite of the lower plate was dated at 33.2 ± 0.7 Ma (Gilmont, 1978), and mafic volcanic rocks of the upper plate at 27.3 ± 0.6 Ma to 21.6 ± 1.0 Ma (Miranda-Gasca and DeJong, 1992). In the Sierra de Mazatán, the K-Ar muscovite age of 33.9 ± 0.8 Ma for a two mica pegmatite (Damon, in Radelli, 1986) is very similar; but a hornblende andesitic dyke yielded a younger K-Ar age of 21.1 ± 0.5 Ma (Damon, in Radelli, 1986). Still, these few ages may allow us to conclude that magmatic events during the latest Eocene and Oligocene occurred at similar ages in three metamorphic core complexes of Sonora. More radiometric ages and studies should be necessary in order to know if the ages of the two-mica granites correspond to deep rapid cooling before extension, or to tectonic denudation (see the discussion in Lister and Baldwin, 1993). In the second case, the beginning of extension would be 9 Ma to 10 Ma earlier than the first pulse of mafic magmatism, i. e. in Late Eocene time.

The preceding analysis allows to propose the following model for the Tertiary evolution of the northeastern part of the Sierra de Aconchi:

(a) At the beginning of Late Oligocene age, all geologic units except the Baucarit Formation were in their original place before the beginning of extension: The batholith (considered here as the entire El Jaralito batholith + the San Felipe porphyry + the Aconchi batholith) and host-rocks were covered by early Tertiary volcanics rocks. It is difficult to estimate the thickness of the pre-Tertiary hostrocks. We previously estimated the thickness of the San Felipe porphyry as 2 to 3 km during emplacement, but deposition of early Tertiary volcanics rocks was probably preceded by a period of erosion. The presence of Lower Cretaceous rocks at the same topographic level as Paleozoic and Proterozoic rocks is explained by thrusting during middle and Upper Cretaceous tectonics. This would be the case for the Cerro de Oro structures, 40 km southwestwards of the San Felipe district.

(b) The El Amol fault activity began probably at the end of Oligocene time. The Baucarit Formation is very widespread in Sonora and has been dated indirectly by the volcanic rocks which underlie or overlie it. In the area of Tonichi, about 100 km south-southeastward of the San Felipe porphyry, the Baucarit Formation overlies 31 Ma old andesite and underlies a 14 Ma old basalt (Damon *et al.*, 1981). Elsewhere in Sonora these authors have obtained ages of Early and Middle Miocene for the same formation. South of Tonichi, MacDowell and Roldán-Quintana (1992) obtained an age of 27.7 Ma for rhyolitic tuff and ignimbrites that underlie the Baucarit Formation, and an age of 14.1 Ma for a rhyolitic ignimbrite at the top of the lower member of the Baucarit Formation. Based on these ages we conclude that the Baucarit Formation began to be deposited during the first stage of extension. The erosion of the upper plate of the Sierra de Aconchi and the coarse sedimentation were contemporaneous. The San Felipe porphyry was displaced eastward from the El Jaralito granite, and slided eastwards along the El Amol fault. The increase of extension rate may (1) induce a correlative decrease in dip of the El Amol fault associated with the activity of an antithetic deeper fault, or (2) induce the tilting of the upper plate as a domino-style block above the non-rotated El Amol fault.

(c) During Late Miocene and Early Pliocene, the whole system was truncated by normal faults which accentuated the horst and graben morphology.

In Sonora, there are at least two others examples of mines like San Felipe deposit, which have been detached during the Neogene extension.

(1) The tungsten skarn deposits located around the metamorphic core complex of Mazatán at 500 to 700 m high. The geometry is similar than in San Felipe, for example on the western flank of the Sierra. The skarns were developed in Paleozoic limestone and are found in the upper plate of the detachment fault (e. g. Cerro La Poza, Cerro La Feliciana, see location on Figure 1) where the mylonitic granite near the fault is part of the lower plate up to 1500 m high. Tungsten mineralization was formed before extension at a higher level of the granite but was displaced downward during extension and doming.

(2) At La Caridad Cu-Mo deposit, near Nacozari (Figure 1), the La Caridad fault cut the hydrothermal system Caridad-Caridad Vieja. This N50ºW fault dips 20º to NE and belongs to a N40º-50ºW fault system together with La Florida and Pilares faults. Berchenbriter (1976) suggests that the Caridad Antigua epithermal deposit belongs to the hanging wall of the Caridad Porphyry Copper and was displaced to its present location along the La Caridad fault.

In Arizona, the porphyry copper of San Manuel-Kalamazoo, located in Proterozoic hostrocks, is closely similar. The orebody has been tilted and cut by the San Manuel fault which separated the orebody in two blocks (Lowell, 1968). This ore deposit is 10 km north of the Santa Catalina metamorphic core complex and its peculiar structure is the result of Tertiary extension. Implications for exploration are similar.

Examples of metamorphic core complexes have multiplied in recent years. This interpretation is associated with extensional tectonics even in areas where observed structures have previously been interpreted as having resulted entirely from compression. This is the case for the late Variscan metamorphic core complex of the Montagne Noire, France (Echtler and Malavieille, 1990), or the metamorphic core complex of Naxos and Paros Islands, Greece (Gautier *et al.*, 1990).

Structural analysis is essential to mineral exploration in regions that have undergone extension. The Aconchi ore deposits crop out and are therefore easier to locate in their structural context. But, in the same region, it is likely that many ore deposits associated with Late Cretaceous or Tertiary intrusions before the Neogene extension, are buried below continental deposits. The case of Aconchi is clear enough to use as an example. Oligo-Mio-Pliocene extension in northwestern Mexico and the southwestern United-States had an effect upon the localization of ore deposits related to Mesozoic and Early Tertiary intrusions. Using the metamorphic core complex model, the metallogenic implications may be extended to other old or recent Cordilleras. The precise knowledge of the offsets along horizontal or low-angle normal faults is a fundamental criterion for mining exploration in regions with crustal extension .

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