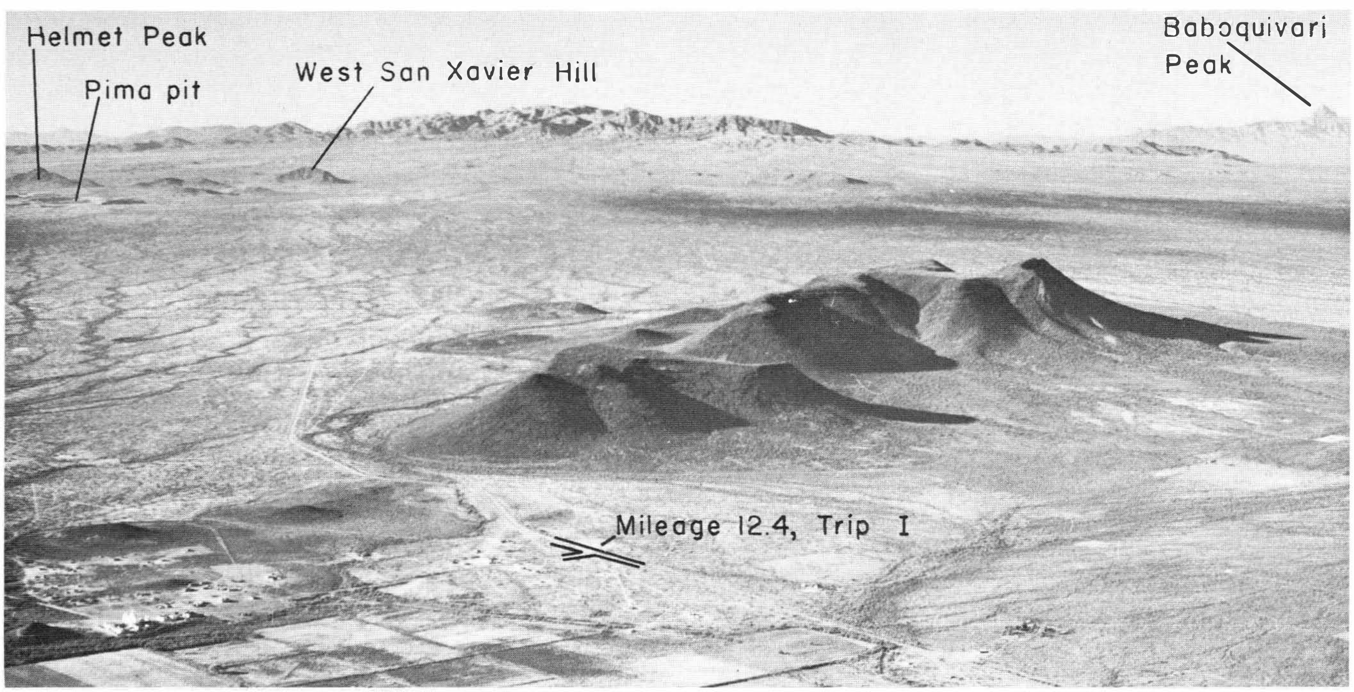
A. Unconformity between upper and lower tuff breccias on north side of main collapse depression, Cerro Colorado (figs. 38 and 39). Both sections dip outward (away from observer) beyond rim of the depression, but the upper section reverses dip where it is continuous over the rim, appearing within the depression as a moderately to steeply inclined cover plastered across the truncated beds of the lower section. Photo by William C. Miller.



B. Aerial view southwest across the Del Bac Hills to the Sierrita Mountains, showing Black Mountain (fig. 29) in right foreground and, in the middle distance, the north end of the East Sierrita area (fig. 44). Mission San Xavier del Bac in left foreground. Photo by Tad Nichols.

FIGURE 40. North wall of Cerro Colorado, Sonora, Mexico, and aerial view of Del Bac Hills, Pima County, Arizona.

STRUCTURE AND ORE DEPOSITS OF THE EAST SIERRITA AREA

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INTRODUCTION

The lower slopes of the east side of the Sierrita Mountains, here referred to as the East Sierrita area (fig. 44), are located about 25 miles south of Tucson, Arizona. The East Sierrita area includes the Pima mining district at its north end and the Esperanza mine at its south end. The general geology of the Sierrita Mountains and some detailed observations on mining properties in the area were described briefly by Ransome (1922). Detailed geological mapping of many isolated units has been carried out in the area (Mayuga, 1942; Houser, 1949; Whitcomb, 1948; Lutton, 1958; Burroughs, written communication, 1959; Studebaker, written communication, 1959; Thacpaw, written communication, 1959) and this information has been utilized, or modified, to conform with the writer's observations.

The Sierrita Mountains rise to more than 6,000 feet above sea level and from the toe of the range, at an altitude of about 4,500 feet, the bajada drops gradually to the floor of the Santa Cruz Valley, at an altitude of about 2,700 feet. Isolated peaks, such as Mineral Hill, Helmet Peak, the San Xavier Hills, and Twin Buttes, stand about 500 feet above the level of the bajada. These hills consist of Paleozoic limestone and quartzite, but the pediment surface below the poorly consolidated alluvium underlying the bajada is carved on Precambrian granite, and Cretaceous-Tertiary sedimentary, volcanic and intrusive rocks, and Tertiary alluvial conglomerate and breccia.

Rocks of the area have been complexly folded and faulted. Geological mapping is complicated by not enough outcroppings to permit accurate detailing of the structure, yet too many apparently insignificant outcroppings to permit confident generalization. This presentation gives only a general outline of the geology of the area.

STRATIGRAPHY

The Paleozoic stratigraphy of the East Sierrita area closely approximates that of the Tucson Mountains (Stoyanow, 1936; Brown, 1939; Bryant, 1952). However, the units appear to have been locally thinned or thickened by bedding faults, and both sequence and continuity are interrupted by faulting. Most of the Paleozoic units are represented in the Mineral Hill and Twin Buttes sections, which are compared in table 8 with the section at Picacho de Calera in the Tucson Mountains. In all three areas, the Bolsa quartzite overlies Precambrian granite or Pinal schist.

Insufficient work has been done to permit correlation of the Cretaceous-Tertiary rocks in the East Sierrita area with the Tucson Mountain section, although some of them are lithologically similar. The Cretaceous-Tertiary rocks include arkosic sandstone and volcanic rocks, and red shale, siltstone and sandstone which may be equivalents, respectively, to the Amole arkose and the Recreation red beds (Brown, 1939). Agglomerate and tuff containing fragments of the intrusives which cut arkose and red beds are found cropping out in the area south of Helmet Peak. Poorly cemented, faulted and tilted conglomerate, fanglomerate and breccia are well exposed in washes between Helmet Peak and Twin Buttes. J. R. Cooper (oral communication, 1958) refers to these as the "Helmet fanglomerate." Similar conglomerate on the San Xavier Reservation to the north is called the "San Xavier conglomerate beds" and is tentatively assigned to middle Tertiary (Heindl, 25).

Table 8. Comparison of thicknesses of Paleozoic sections at Picacho de Calera, Mineral Hill and Twin Buttes

Age	Unit	Thickness in feet		
		Picacho de Calera Hills (Bryant, 1952)	Mineral Hill (Mayuga, 1942)	Twin Buttes
Pennsylvanian-Permian	Naco group	1,000+	750+	600+
Lower Mississippian	Escabrosa limestone	600	350	550
Upper Devonian	Martin limestone	275	225	440
Cambrian	Rincon limestone	40	-	-
	Abrigo formation	300	350	200
	Cochise formation	300	-	-
	Bolsa quartzite	700	600	500

IGNEOUS INTRUSIONS

Two general periods of intrusive activity have been recognized in the East Sierrita area: (1) Precambrian Sierrita granite, and (2) Late Cretaceous to Quaternary(?) plutons of varied composition and character.

Sierrita Granite

Coarse-grained oligoclase granite, commonly referred to as the "Sierrita granite", forms the basement rock and much of the core of the Sierrita Mountains. It is exposed in a long strip in the western part of the area shown in figure 44. The granite has been encountered beneath the sediments in drill holes as far east as the Mission prospect.

The Sierrita granite may be assigned a minimum age by its unconformable position below the Cambrian Bolsa quartzite, although the unconformity forms a zone of weakness which is generally disguised by faulting and alteration.

Relics or xenoliths of diorite, schist and gneiss are distributed throughout the granite and have both sharp and gradational contacts with it. Pegmatite dikes, quartz masses and veins, and aplite dikes of uncertain ages cut the granite.

Late Cretaceous-Quaternary(?) Intrusives

Dikes and plugs ranging in composition from basalt to rhyolite cut the Cretaceous-Tertiary sediments. Fragments of these intrusives appear in younger agglomerate and as pebbles in the "Helmet fanglomerate". These units are in turn cut by other intrusives.

In the Twin Buttes area a biotite granite stock with a north-south elongation cuts the Paleozoic formations. A series of intrusives ranging from diorite to granite appears to intrude the Cretaceous-Tertiary beds and to heal a fault between the Sierrita granite and the Cretaceous-Tertiary sedimentary and volcanic rocks just north of the Esperanza mine. Tongues of these intrusives are involved in the Esperanza mineralization.

A small syenite pluton invaded along the east-trending part of the San Xavier thrust north of West San Xavier Hill and a similar intrusive is reported from the Pima mine workings. Syenite and nepheline syenite were identified in drill hole cores at the Esperanza mine and a monzonite plug was delimited by drilling in the Mission prospect.

A multitude of fine-grained porphyritic intrusives follow east- to east-northeast-trending zones of structural weakness in the Cretaceous-Tertiary beds. These include andesite, dacite, rhyolite and latite porphyry dikes, sills and small elongated plugs. In general, the later intrusives appear to be more acidic than the earlier ones, although detailed structural and petrographic data are lacking. An exception to this compositional trend is a late basalt-andesite porphyry dike which cuts the "Helmet fanglomerate" and breccia.

STRUCTURE

The East Sierrita area has been tectonically active since the end of Paleozoic time. Following the deposition of the Paleozoic sediments the rocks record a history of continued folding and faulting which was culminated in a great overthrust during the post-middle(?) Tertiary. The overthrust apparently was offset by north-south normal breaks and west-northwest left-lateral movements. The left-lateral movements represent the latest structural deformation for which there is evidence within the East Sierrita area.

Left-Lateral Faulting

The entire structural history of the East Sierrita area appears to have been dominated by movement along steep left-lateral faults that trend west-northwest to west. The fold pattern is consistent with such a fault system and may be related to it. At the Morgan mine the major break that separates the Sierrita granite and Paleozoic rocks from the Cretaceous-Tertiary rocks appears to be a left-lateral fault. Andesite plugs in the area between Helmet Peak and the Paymaster mine are located along generally east-west faults. Left-lateral movement may have offset the klippe from the Helmet Peak anticline, and may be responsible for the abrupt termination of the San Xavier thrust sheet to the south. Basalt-andesite dikes similar to those which cut the "Helmet fanglomerate" have been offset by left-lateral movement in the Foy Ridge area. Renewed movement along these faults appears to have formed the fractures carrying lead-silver mineralization in the Paymaster, Helmet Peak and Olivette groups of mines.

Folding

Paleozoic beds have been crumpled into asymmetrical, broken folds with axial planes trending north-northwest and generally overturned to the northeast. Many minor folds follow similar trends. The brittle limestone beds are generally shattered and the folding may have occurred under shallow cover. The Cretaceous-Tertiary rocks apparently are folded more gently, but due to the massive character of these rocks and the lack of good marker horizons, attitudes are difficult to determine and complexities of structure may pass unnoticed.

The three principal folds mapped are (1) the Helmet Peak anticline, (2) the San Xavier syncline, and (3) the McGee Road anticline (fig. 44).

Helmet Peak Anticline

The Paleozoic limestone of the Helmet Peak anticline forms the peak proper. The anticline is tightly folded, overturned to the east and plunges steeply (60^{o}) to the south. The anticline appears to have been thrust southeastward over the Cretaceous-Tertiary beds and the axis was swung to the south. The trends of folding in the Paleozoic and Cretaceous-Tertiary rocks are discordant. Klippen of Paleozoic limestone lie on Cretaceous-Tertiary beds south and east of Helmet Peak.

San Xavier Syncline

The San Xavier syncline is correlative to and lies northeast of the Helmet Peak anticline. Cretaceous-Tertiary red beds are preserved in its trough. The syncline may be related to the broad synclinal structure formed in the Cretaceous-Tertiary sediments that appear to have been pierced or overridden by the Helmet Peak anticline.

McGee Road Anticline

The McGee Road anticline lies west and southwest of Twin Buttes. It is a broad northwest-trending structure overturned to the northeast exposing the Sierrita granite along its axis. The Paleozoic sediments along its flanks have been badly shattered but generally retain their relative stratigraphic positions.

Faulting Related to Folding

Bedding plane faults probably related to the folding are abundant and have served to channel alteration and mineralization. They are difficult to identify although they are reflected in the thinning of the stratigraphic section.

East-west normal faults, which generally dip steeply to the south, seem to have developed shortly after the period of folding. These fractures have influenced the localization of intrusions and areas of silication in the limestone, and the distribution of sulphide mineralization. The mineralized fault structures at Mineral Hill and the San Xavier mines are typical of these structures (MacKenzie, 29; Irvin, 30). Movement along the normal faults is estimated to be several hundred feet, although late reverse movement has obscured the magnitude of the original movement.

Thrusting and Reverse Faulting

At least two periods of thrusting occurred in the East Sierrita area. The earlier thrusting is pre-ore and the faults are generally steeper than those of the later period of faulting. The younger faulting is generally post-ore.

The earlier thrusts, such as the Foy Ridge (fig. 41A) and the north part of the San Xavier (fig. 41B) thrusts, generally trend east-west and dip to the south. Movement along the Foy Ridge thrust is estimated to be on the order of a few thousand feet. Tertiary diorite, granite and syenite have invaded and healed these thrusts and copper mineralization may be localized along them. Normal faults related to the initial folding were given reverse movement during this period of thrusting. The reverse movement along the normal faults developed north- to northeast-trending tear fault offsets and the flat thrust offsets at the San Xavier mine (Irvin, 30). The eastward-trending portion of the San Xavier thrust north of West San Xavier Hill may represent this early period of thrusting as indicated by the syenite intrusion along the fault (fig. 44).

The second period of thrusting occurred possibly in post-middle Tertiary time and may have involved the "Helmet fanglomerate"---although this is not firmly established. The thrust is later than the granite and the andesite intrusives which cut the Cretaceous-Tertiary series. It is generally unmineralized, although some late hydrothermal activity may have accompanied or followed the faulting. Lead-silver mineralization extending down the thrust-fault zone at the Paymaster mine has been reported (Mayuga, 1942), but Mayuga was unable to observe this part of the mine workings. The strongly silicified character of the fault zone in the Paymaster mine area also suggests late hydrothermal activity. No ore has been found in the "Helmet fanglomerate," but this may be due to a lack of localizing structures.

It is suggested that the Helmet Peak anticline was modified during the second period of thrusting. The core of Paleozoic limestones in the San Xavier and Mineral Hill areas may have resisted the thrusting, resulting in its realinement and a backward thrusting of the anticlinal structure to the southeast. This thrusting is suggested by the Paleozoic limestone klippen lying on the Cretaceous-Tertiary sediments south and east of the peak, and by the discordant relations of the Helmet Peak anticline with the structure of the Cretaceous-Tertiary rocks.

Coincident with the thrusting there was renewed movement along earlier structures, particularly the northward-trending tear faults.

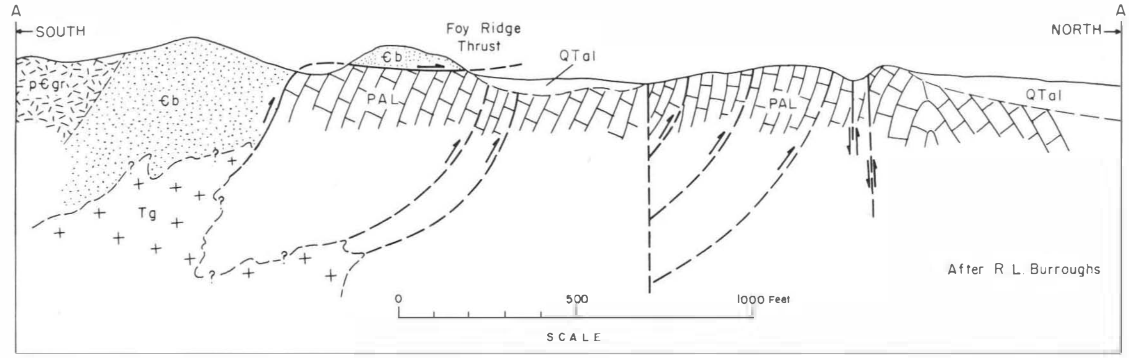
Late Normal Faulting

Normal faulting marks one of the last phases of tectonic activity. East of the Paymaster mine, the "Helmet fanglomerate" and breccia are in fault contact with Sierrita granite along a north-trending normal fault (J. R. Cooper, oral communication, 1958). This fault cuts the San Xavier thrust sheet. The basalt-andesite dikes which cut the conglomerate parallel this fault structure and may follow breaks related to the same tensional forces.

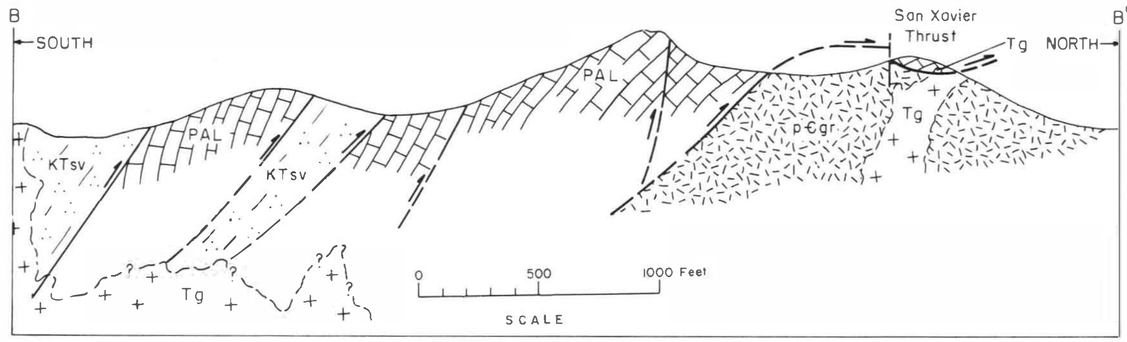
ORE DEPOSITS

Ore deposits of the East Sierrita area may be divided into three general categories, which may overlap in part:

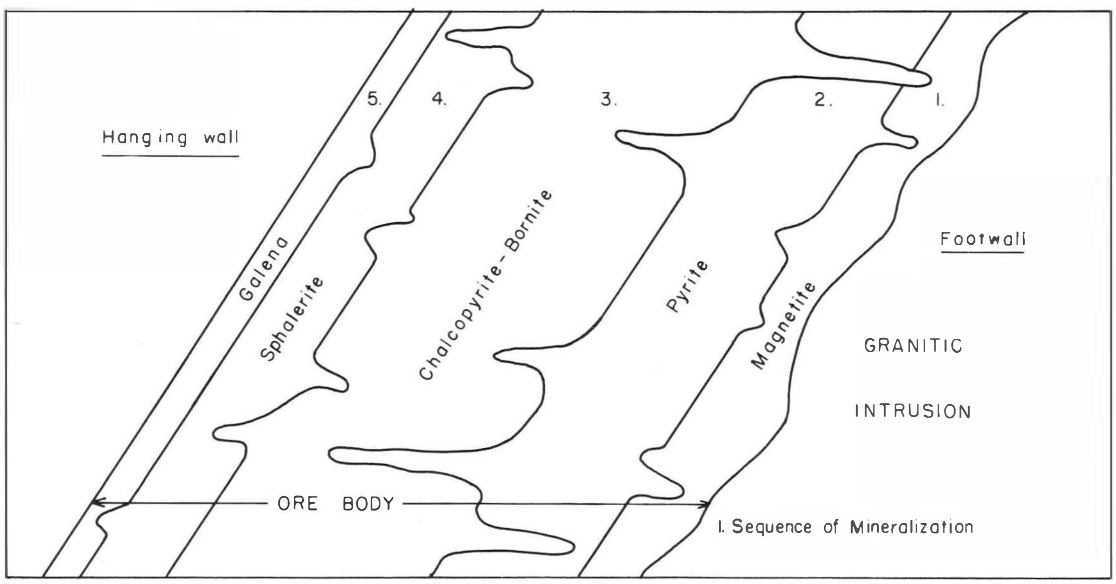
1. Small, shallow-seated, low-temperature fissure veins which carry appreciable gold and silver values and a spotty distribution of lead, zinc and copper. Examples are the veins exploited in the Paymaster and Olivette groups. The fissure



A. Generalized north-south geologic cross section through the Foy Ridge thrust fault (fig. 44). Precambrian (?) "Sierrite" granite (p€gr); Cambrian "Bolsa" quartzite (€b); Paleozoic limestone, undifferentiated (PAL); Tertiary (?) granite, quartz monzonite and syenite (Tg); Tertiary-Quaternary alluvium (QTal).



B. Generalized north-south geologic cross section through the San Xavier thrust fault (fig. 44). Precambrian (?) "Sierrita" granite (p€gr); Paleozoic limestone, undifferentiated (PAL); Cretaceous (?)-Tertiary (?) sedimentary and volcanic rocks, undifferentiated (KTsv); Tertiary-Quaternary alluvium (QTal).



C. Schematic sketch showing zonal arrangement and sequence of mineralization of ore in the Mineral Hill and Daisy mines area.

FIGURE 41. Generalized cross sections in the East Sierrita area and schematic sketch showing zonal arrangement of ore at Mineral Hill and Daisy mines, East Sierrita area (fig. 44), Arizona.

vein deposits in the East Sierrita area are concentrated west and southwest of Helmet Peak within the San Xavier thrust sheet. These have been described in detail by Ransome (1922) and Mayuga (1942) and little can be added to their accounts. With minor exceptions, they have not been mined since Ransome's examination. Mineralization appears to occupy east-trending, left-lateral faults and related north to northeast tension fractures that occur within the Cretaceous-Tertiary sediments and andesite intrusives. The vein deposits are not recognized south of the San Xavier thrust sheet. East of the Paymaster mine they are cut off by a late, normal fault. Mineralization may have occurred during the development of the San Xavier thrust sheet. More detailed data on these deposits are difficult to obtain because the mine workings are now inaccessible.

2. Pyrometasomatic deposits carrying copper and/or lead-zinc mineralization occur in silicified limestone, with or without observable contacts with intrusive rocks. At the Mineral Hill and Daisy mines, MacKenzie (29) recognizes a zonal distribution for the iron, copper, zinc and lead minerals outward, in that order, from the intrusive contact or heat channelway (fig. 41C). Elsewhere, one or two of these zones may dominate the pattern. At the San Xavier mine, the lead-zinc phase predominates with some iron-copper mineralization in the western part of the mine workings. The Pima mine, the Mission prospect and the Twin Buttes group of mines represent the iron-copper zone.

3. Disseminated copper ores in sedimentary, volcanic and intrusive rocks occur in areas of intense fracturing of rocks other than limestone. The copper deposit at the Esperanza mine and the low-grade ores at the Pima mine are examples of this type. Syenite, quartz monzonite and monzonite intrusives appear to be closely related to this mineralization in space and time at the Pima mine, the Mission prospect and at the Esperanza mine. Richard and Courtright (32) emphasize the close genetic relationship between certain types of pyrometasomatic mineralization and the normal porphyry copper deposit. Alteration and capping characteristics of the disseminated deposits are similar to those found in normal porphyry copper deposits of the southwest.

The pyrometasomatic and disseminated deposits are further discussed by MacKenzie (29), Irvin (30), Journeay (31), Richard and Courtright (32) and Schmitt, and others (33).

SUMMARY

The structural features in the East Sierrita area are believed to be capable of being explained as the results of recurrent displacement since Cretaceous, and possibly since Paleozoic time, along a left-lateral break in the basement rocks. The following sequence of post-Cretaceous events is suggested.

1. Folding of Paleozoic and Mesozoic rocks along west-northwest axes with overturning to the north and the development of bedding plane faults. The folding was followed closely be east-trending normal faulting.

2. Development of east-trending southward-dipping low-angle thrust faults; development of reverse movement along the earlier normal faults; and development of steep north- to northeast-trending tear faults.

3. Intrusion of diorite, andesite, biotite granite (rhyolite), syenite, quartz monzonite and monzonite plutons along the fault structures; closely associated metamor-

phism, alteration and copper, lead, zinc and molybdenum mineralization.

4. Development of steep east-trending left-lateral shears with correlative northeast tension fractures; intrusion of dikes, sills and plugs along these breaks. Followed by reopening of these structures and possible lead-silver mineralization.

5. Deposition of the Tertiary volcanic agglomerate and the "Helmet fanglomerate" and breccias with possible volcanic flows.

6. Thrusting of the San Xavier thrust sheet with realinement and possible backward thrusting of the Helmet Peak anticline, accompanied by some hydrothermal activity effecting silicification of the fault zone and possible continuation of the lead-silver mineralization or redistribution of earlier metal values.

7. Renewed left-lateral movement offsetting the San Xavier thrust on the south and displacing Helmet Peak klippe.

8. Development of north-trending east-dipping normal faults and tension fractures with accompanying intrusions of basalt-andesite porphyry dikes.

9. Renewed left-lateral movement offsetting the basalt-andesite porphyry dikes.