METALLOGENETIC MAP OF SONORA, MEXICO

by

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Abstract

In the recently complete metallogenetic map of Sonora, information about geologic environment and type of deposit of many Sonoran localities is given. Nonmetallic deposits are graphite, anthracite, fluorite, and beryl. The first two, of Triassic age, are of sedimentary origin, commonly forming lenses. Sonora is the leading graphite-producing state. Fluorite is produced from veins in Tertiary volcanic rocks. Beryl in minor quantities is associated with granitic pegmatites. Precious and base metals, including tungsten, are mined from igneous metamorphic zones, epithermal and mesothermal veins, breccia pipes, and low-grade porphyry-type bodies. Gold has been produced from placers.

In the last ten years, porphyry-type deposits have been of most interest. Copper of this kind is found as an extension of the well-known porphyry copper province of the southwestern United States, but it also continues in a belt along the Pacific margin of the Republic of Mexico. In Sonora most copper deposits are found in stocks that intrude calc-alkaline volcanic as well as sedimentary, metamorphic, or even other plutonic rocks. However, in some localities cupolas of great batholiths are mineralized. In these, the shape of the orebodies is disclike and the typical vertical zonation is absent. Intrusive and collapse breccias are relatively common.

Alteration and mineralization patterns are not unlike those of the Arizona deposits. In some areas the potassic, phyllic, and propylitic zones are well exposed, whereas in others only the sericitic-propylitic or the propylitic zones can be observed. The mineralogy is that of the most accepted models. One deposit, however, contains mainly molybdenite. In some breccias scheelite and wolframite have been noted. The age of mineralization is Late Creceous-early Tertiary, during which time the Laramide Revolution produced intense magmatic activity. Recent radiometric studies indicate that the mineralization is progressively younger toward the eastern portion of Sonora. Regional associations between structures and igneous rocks suggest that the deposits formed as a result of subduction of an oceanic plate, probably active until late Oligocene time.

Introduction

The Department of Geology of the University of Sonora, Hermosillo, recently concluded the first step in the elaboration of the metallogenetic map of the state of Sonora. This step consisted of the compilation and partial classification of available information from private and government sources and the careful plotting of hundreds of mines and prospects on the map. In a second step, certain deposits will be selected for the purpose of genetic interpretation. Finally, it is hoped that a reasonable explanation of the processes that produced many commercial and noncommercial deposits can be put in a hypothesis that explains, at least partially, the metallogeny of this part of Mexico.

Physiographically Sonora can be divided into three provinces. The Province of the Barrancas occupies a transitional zone between the Sierra Madre Occidental and the Basin and Range region. Its main characteristic is abrupt topography with very narrow canyons. The Basin and Range province is typical of that of southwestern United States. As is well known, its origin is tectonic. The Desert province in the western part of the state consists of wide valleys interrupted here and there by small hills.

Geologic Environment

The rocks of Sonora range in age from Pre-

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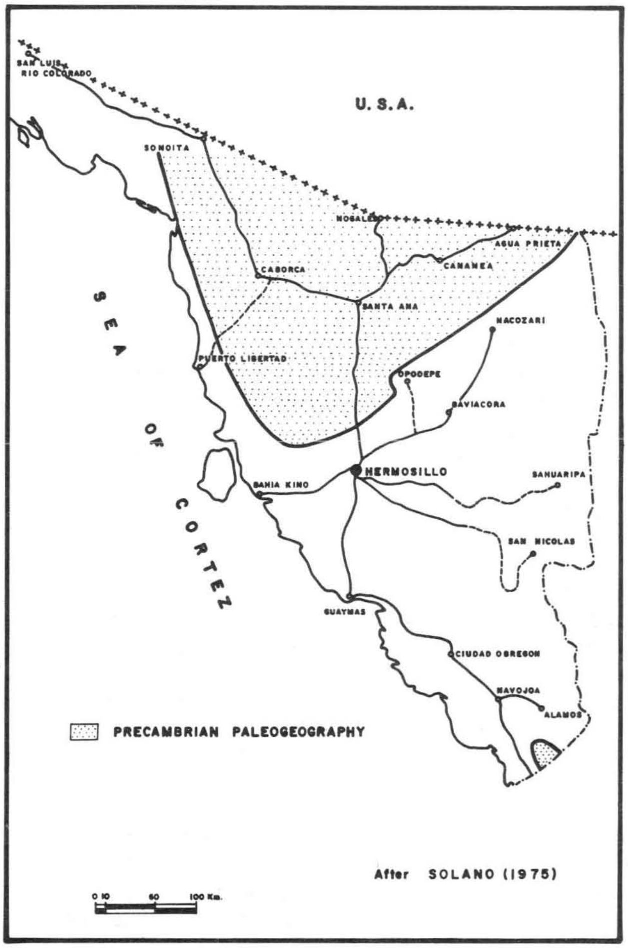

Fig. 1. Precambrian paleogeography, Sonora

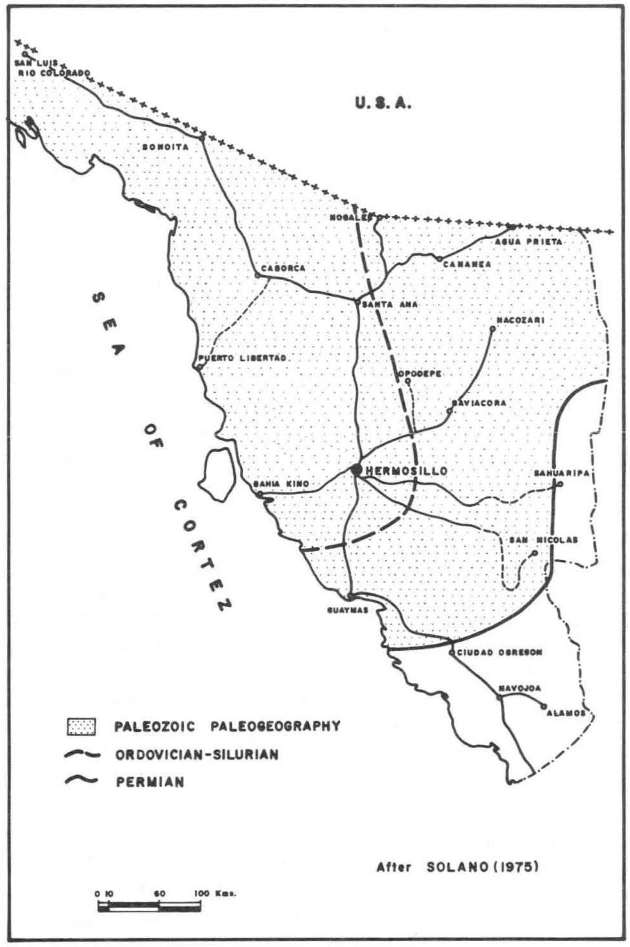

Fig. 2. Paleozoic paleogeography, Sonora

cambrian to Holocene (Fig. 1). The Precambrian rocks (1800-1125 m.y., Anderson and Silver, 1975) traditionally have been divided into "older" and "younger." The former (1800-1600 m.y.) are mainly igneous and metamorphic rocks, which include diorite, quartz monzonite, granodiorite, pegmatite, latite, granulite, amphibolite, metarhyolite, mica-schist, and greenschist.

The latter, which rest unconformably on the older Precambrian, consist primarily of quartzite, phyllite, dolomite, and such anorogenic rocks as the Cananea Granite (1440 m.y.), plutonic bodies of quartz monzonite porphyry (1450 m.y.), and granophyric granites (1125 m.y.) (Anderson and Silver, 1975). It is known that the older rocks were perturbed by orogenic movements. However, many authors (Rangin, 1976; Anderson and Silver, 1975) agree that later tectonic movements have erased much of the structural grain of the lower Precambrian rocks.

During Paleozoic time (Fig. 2) the Precambrian craton and most of Sonora were covered by huge thicknesses of calcareous, arenaceous and lutitic sediments. All periods are represented; however, their structure has not been adequately analyzed.

The Mesozoic events are the better known for obvious reasons. Terrigenous and mixed rocks, which include sandstone, shale, and carbonaceous and graphitic shales, were deposited during Late Triassic—Early Jurassic time east of meridian 110°; to the west this sequence grades into sandstone with intercalations of marine shale and limestone (Fig. 3). Minor plutonism and volcanism took place in northwest Sonora (Anderson and Silver, 1975). From Middle Jurassic to Early Cretaceous time the volcanism increased. The erosional products were deposited in two parallel basins separated by a noticeable insular arc. These basins received volcaniclastic sediments, being controlled by a barrier to the east. Beyond the barrier, in the northeast portion of Sonora and in Chihuahua, limestone was deposited (Figs. 4 and 5). Later abundant epicontinental clastic and calcareous sediments were deposited above the volcanic sequence, and Middle

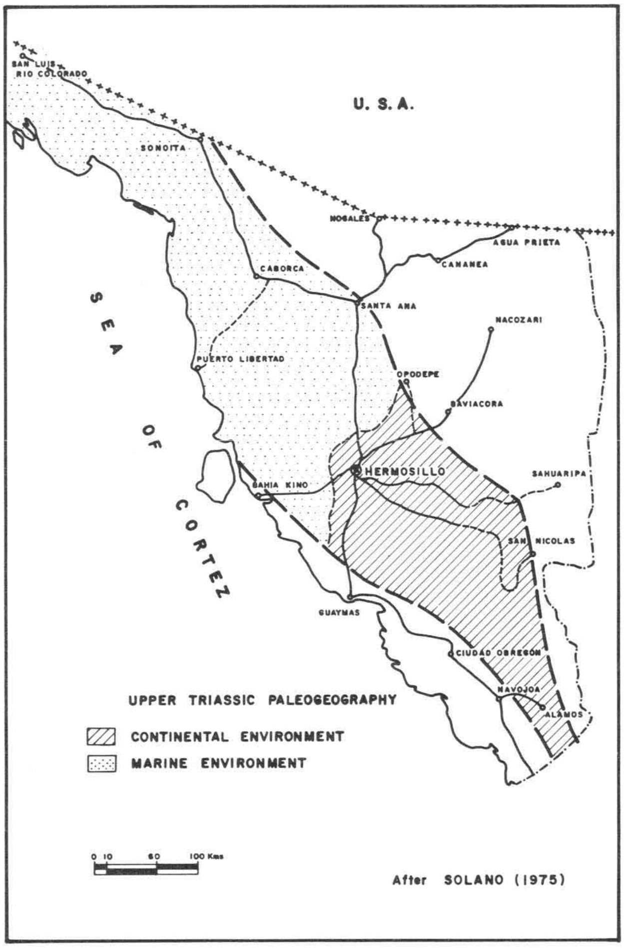

Fig. 3. Upper Triassic paleogeography, Sonora

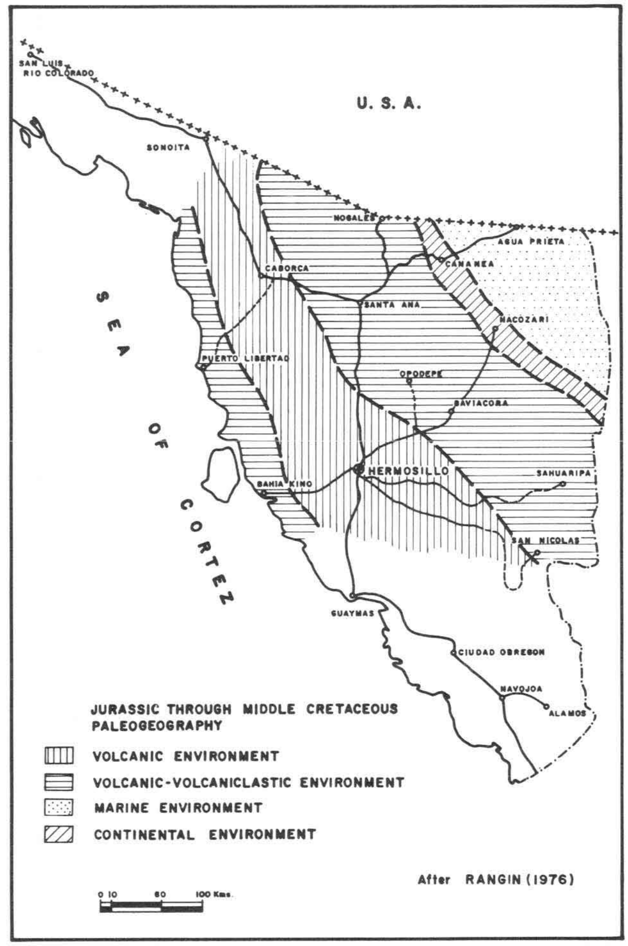

Fig. 4. Jurassic—mid-Cretaceous paleogeography

Cretaceous tectonism affected them, originating folds in northwest-southeast and west-northwest-east-southeast directions (Rangin, 1976). Late Cretaceous time (90 m.y. ago) saw marked intrusion of granodioritic bodies and related volcanism (Anderson and Silver, 1975), minor episodes of sedimentation of lacustrine material associated with gypsum in the western part of the state and sedimentation of detrital material (in which dinosaur bones have found), and extrusion of some volcanic rocks in the eastern portion. The igneous rocks are progressively younger toward the east.

Laramide tectonics resulted in normal and thrust faults. The latter moved Lower Cretaceous rocks above Upper Cretaceous ones with the principal structural directions being northwest and east-southeast (Rangin, 1976). Plutonism and volcanism were especially active processes in the central and eastern part of the state up to the Paleocene (Gastil, 1974). The youngest plutonic rocks of Sonora belong to the Eocene (50 m.y., Solano, 1975). Miocene and Oligocene andesitic, rhyodacitic, and rhyolitic tuffs are widespread. The Pliocene epoch was a time of great block faulting and some extrusion of basalts. These were rapidly covered by alluvial sediments. Pleistocene basaltic volcanism covered small, isolated areas (Fig. 6).

Nonmetallic Minerals

Fluorite, coal, and graphite are the most important nonmetallic minerals of Sonora (Fig. 7). Coal and graphite are found in lutitic horizons of the Upper Triassic Barranca Formation. Sonora is an important world producer of graphite, which occurs in beds approximately one meter thick. The coal is of anthracitic type. Both coal and graphite originated by dynamic and thermal metamorphism. There are many fluorite manifestations in Sonora, but only two are of economic importance: Esqueda in the northern part of the state and Santa Rosalía in the eastern portion. Both deposits are in veins located in premineral faults that put in contact differing volcanic country rocks such as andesite and rhyolite. Vein thicknesses reach some meters in both deposits,

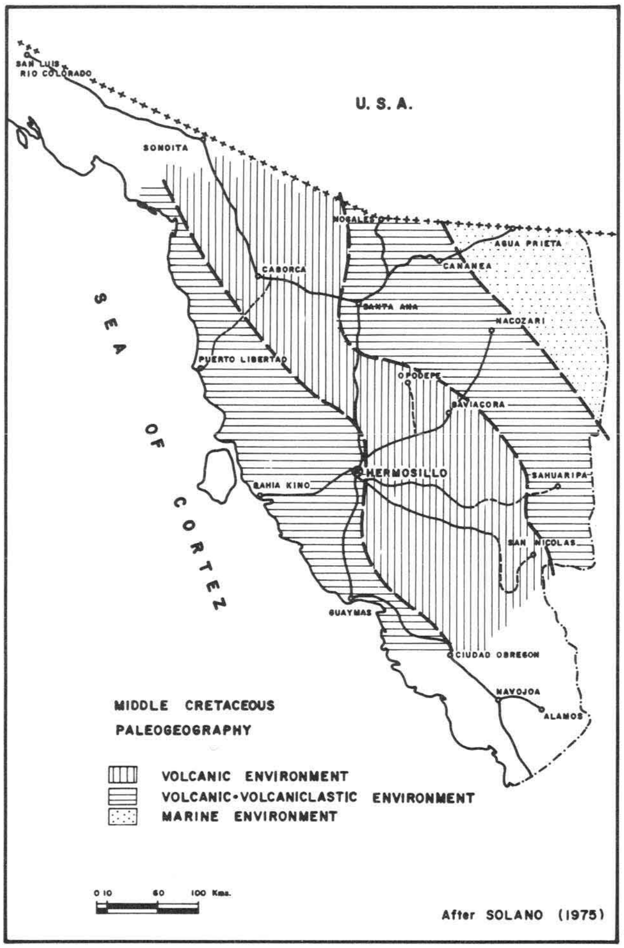

Fig. 5. Mid-Cretaceous paleogeography

but grade is better at Esqueda. Gangue minerals are barite, quartz, and calcite. Minor fluorite associated with granitic rocks is found elsewhere in the state. Beryllium is found in pegmatites in the Aconchi batholith, but no economic significance is attached to this occurrence.

Metallic Minerals

The metallic minerals of Sonora are numerous and important. They have been so in the past, and their future is bright.

Tungsten, Iron, and Radioactive Minerals

Tungsten has been an important element in the economy of Sonora. It can be found in granitic pegmatites or in plutonic bodies where it is of minor interest. Of major importance are the igneous metamorphic deposits, such as Baviacora. Other interesting occurrences are as a by-product of igneous metamorphic zinc-copper deposits and more rarely associated with the collapse breccias of the porphyry coppers. The common mineral is scheelite, but wolframite has been noted in some breccias. A common assemblage in the breccias is scheelite-chalcopyrite-pyrite-molybdenite. The last three minerals are also found in small quantities in the metasomatic bodies. The mineralization is of Laramide age.

Only one contact-metamorphic iron deposit has been exploited at El Volcán (Fig. 9). The known deposits of radioactive minerals are of several origins. In some, the ores are located in oxidized zones (San Antonio de la Huerta, El Picacho, Arizpe), whereas others are concentrated with hypogene sulfides (Noche Buena, El Rosario). Mineralization can also be in veins, in skarns, sedimentary beds, breccias, and fracture zones in granitic rocks. The principal minerals are pitchblende, kasolite, uranophane, uranopilite, bassetite, johannite, autunite, iriginite, torbernite, and metatorbernite. The age of ore deposition apparently is Cambrian in the sediments, Laramide in the plutonic and contact metamorphic bodies, and middle Cenozoic in the vein deposits (García y Barragan, 1976).

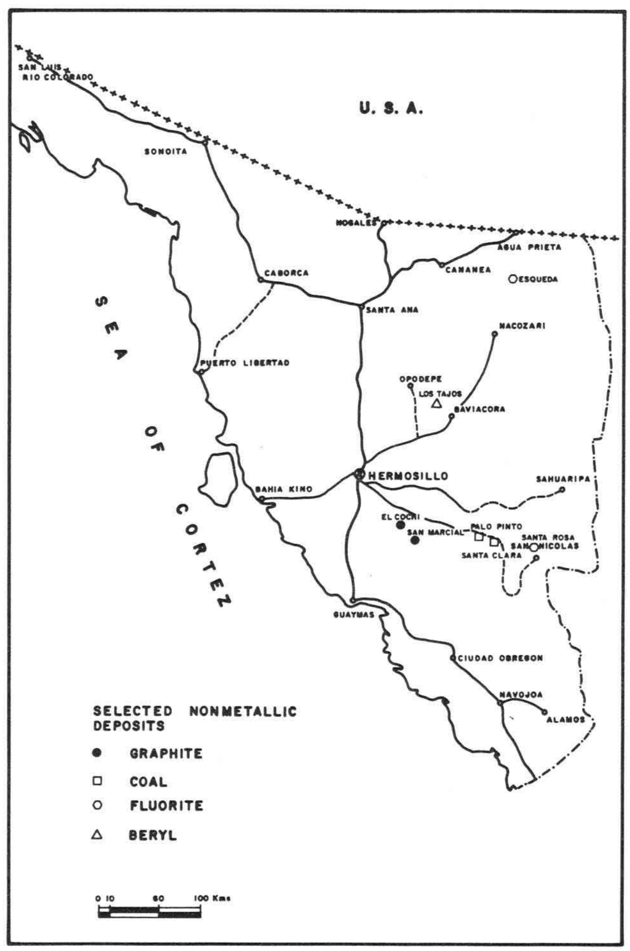

Fig. 7. Selected nonmetallic deposits, Sonora

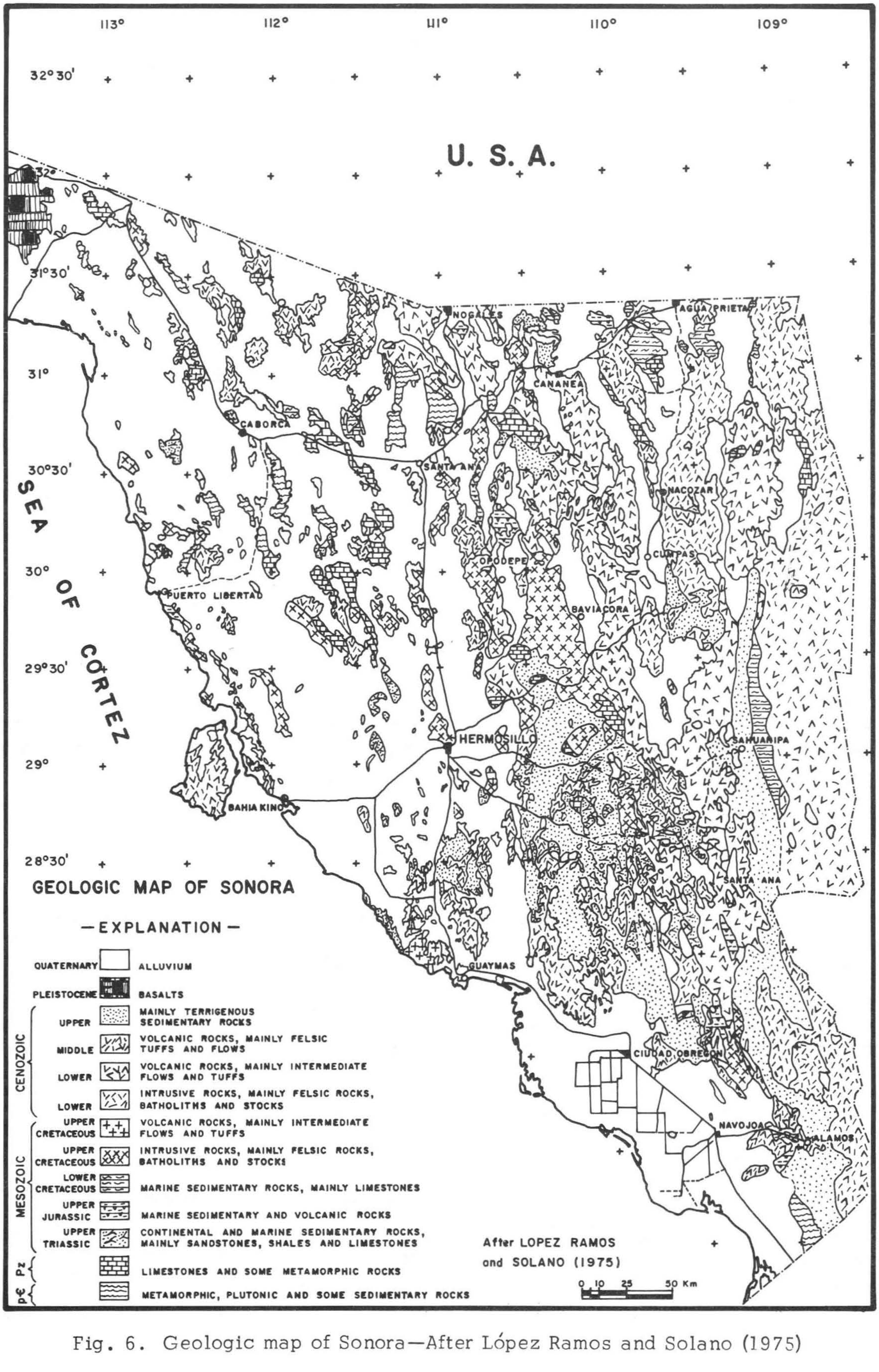

Fig. 6. Geologic map of Sonora—After López Ramos and Solano (1975)

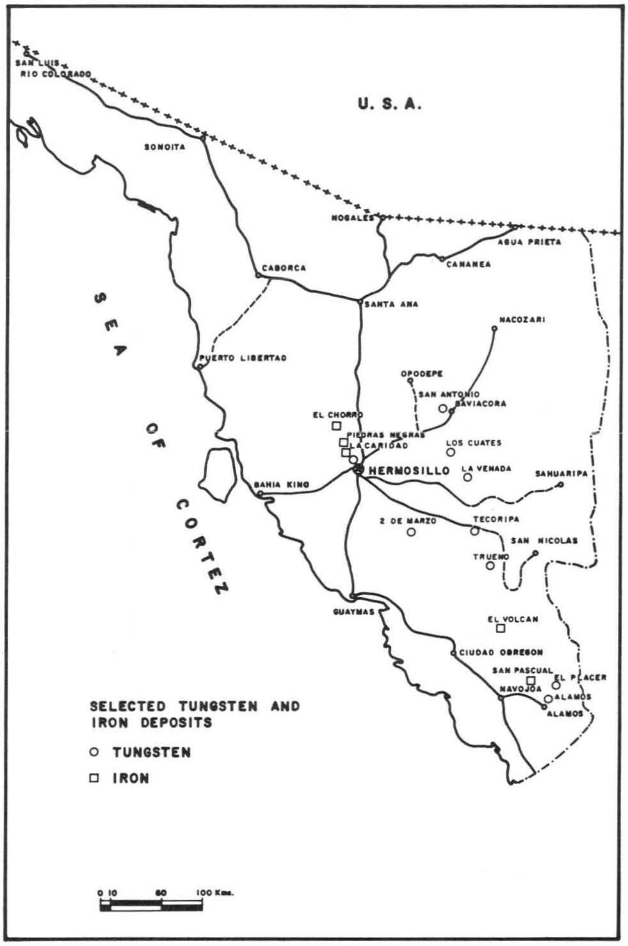

Fig. 8. Selected tungsten and iron deposits

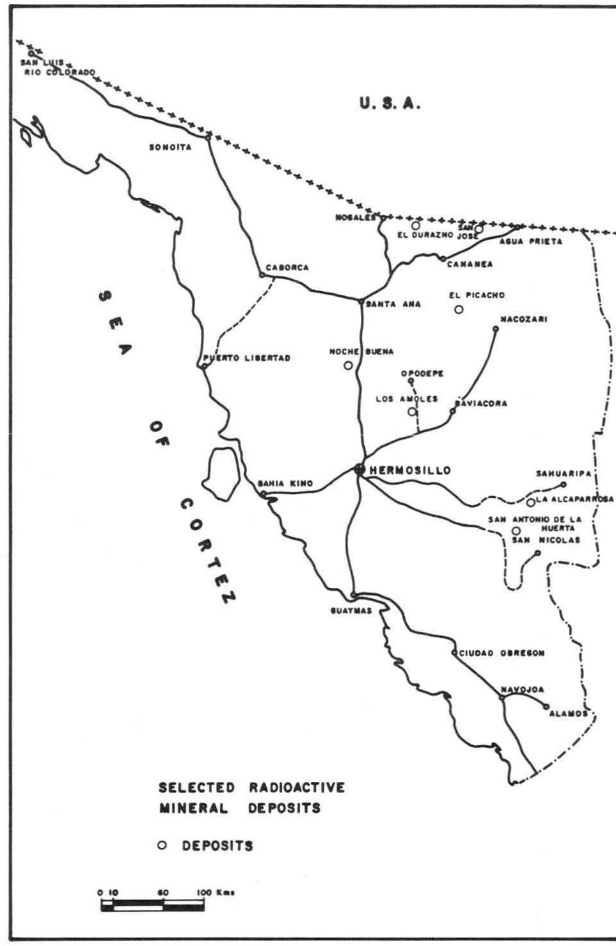

Fig. 9. Selected radioactive mineral deposits

Zinc and Lead (Fig. 10)

These elements are found in igneous metamorphic deposits or in veins. With the latter, silver can be of important value. There appear to be two ages of mineralization. The metasomatic ores are commonly associated with hypabyssal granitic rocks which contain little copper and pyrite and are of Laramide age. Here marmatite, chalcopyrite, pyrite, occasional pyrrhotite and magnetite, and little galena with little silver are common and represent the greatest reserves in the state. Examples of these deposits are Cananea, San Felipe, El Tecolote, and Cabullona. The host rocks are skarns with garnet, pyroxene, and scapolite derived from limestones of various ages.

The vein deposits are enclosed by sedimentary rocks of various ages or by volcanic rocks of middle Cenozoic age. Sphalerite and galena with silver values and minor chalcopyrite are dominant in the lower parts of the veins but gradually disappear upward into quartz-rich rocks with an increase in gold and silver grades. Examples are Lampazos and San Javier.

Silver and Gold (Fig. 11)

Silver and gold are commonly associated with the base metals. The common minerals are argentite, polybasite, and pyrargyrite-proustite. Very little information is available on gold mineralogy. Principal silver vein deposits are El Tigre, Las Chispas, La Colorada, Lampazos, and San Javier (Wisser, 1966). Gold also occurs as small deposits in quartz-rich Precambrian and Paleozoic metamorphic rocks on the western portion of the state. Placer deposits derived from the above are minor.

Copper and Molybdenum (Fig. 12)

Two types of copper and molybdenum deposits occur in Sonora: those in veins, which are small and of little importance, and the large disseminated porphyry type. The latter are an extension of the well-known porphyry copper province of the southwestern United States.

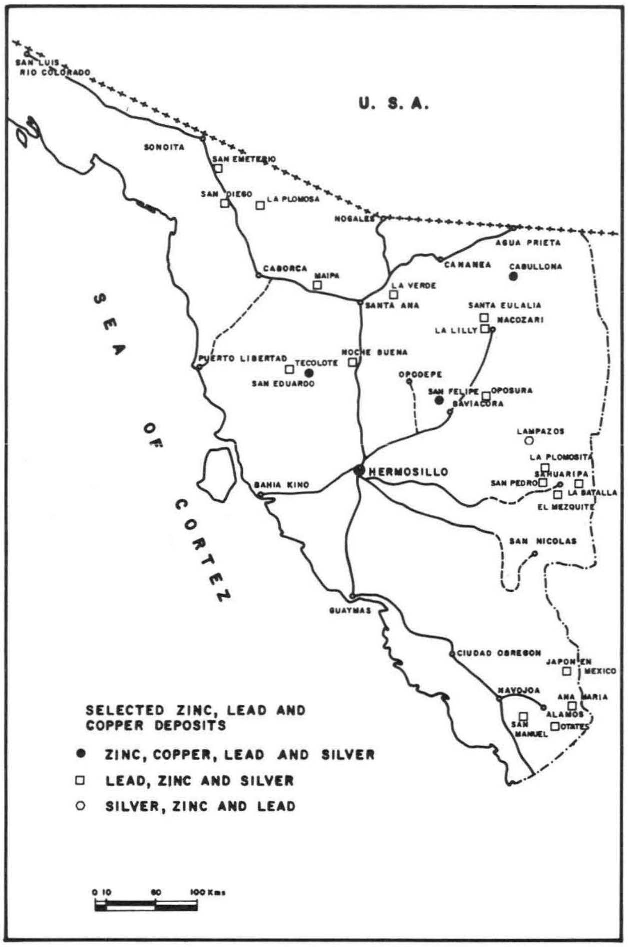

Fig. 10. Selected Zn-Pb-Cu deposits

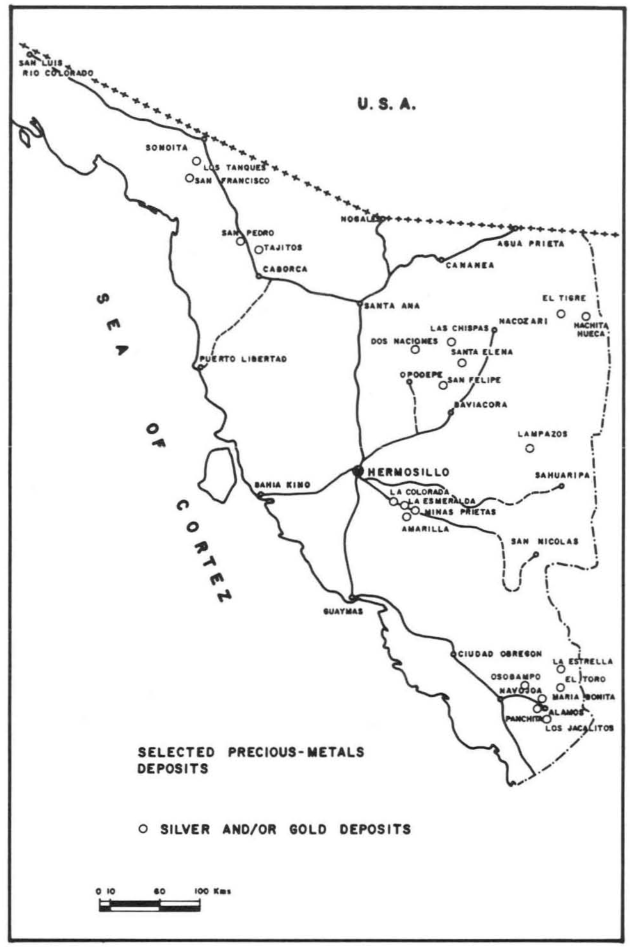

Fig. 11. Selected precious metals deposits

Three classifications are recognized (Sillitoe, 1975):

1. Stockwork deposits with a columnar shape and alteration-mineralization in the form of envelopes. They are associated with stocks and can have breccia pipes related to them.

2. Plutonic roof rock deposits. These are large masses in which the alteration and mineralization are semiplanar or discoid. They are restricted mainly to the roof rocks but many penetrate to the cupola of the batholiths.

3. Breccia pipe deposits, isolated or in groups, intrusive or collapse in origin. Most mineralization is copper-molybdenum; however, Meztli is almost exclusively a molybdenum deposit whereas San Antonio de la Huerta is copper only.

Associated intrusive rocks of most deposits range from granodiorite to quartz monzonite. Only La Florida and San Antonio de la Huerta are in dioritic to andesitic rocks. The La Caridad and Cananea deposits were formed as a result of hydrothermal processes related to multiple porphyry intrusions. Textures, degree of alteration, and mineralization reveal repeated periods of magmatism. San Antonio de la Huerta and Piedras Verdes are good examples of deposits in which sedimentary rocks were either totally or partially the hosts. Most of the deposits, however, were emplaced within volcanic calc-alkaline rocks of andesitic composition (Solano, 1975). A few, including La Caridad, Fortuna de Cobre, and Meztli (El Creston), are hosted by altered plutonic rocks. Aurora and Batamote formed at the roofs of intrusive rocks, which show little or no alteration. The collapse breccia pipes are hosted by batholithic rocks (Los Verdes) or by volcanic rocks (Cobre Rico, Washington, and Pilares). There is no apparent intrusive body in the vicinity of the latter three; Los Verdes could represent the root of a collapse breccia pipe.

Two types of breccias are recognized: those formed by collapse with or without as-

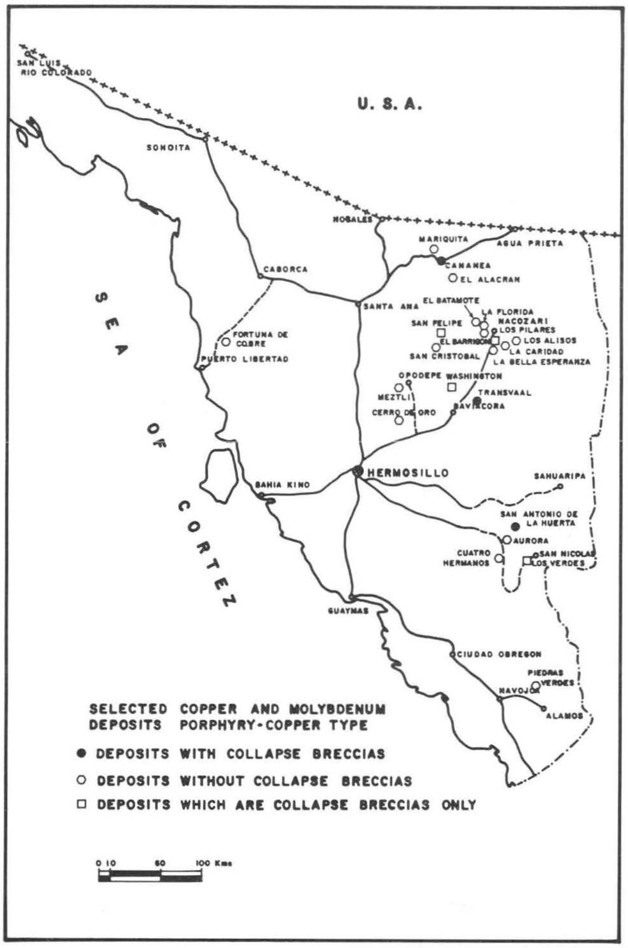

Fig. 12. Selected Cu-Mo porphyry type deposits

sociated stockwork mineralization and those of hydrothermal intrusive origin that are found within the mineralized bodies. Collapse breccias generally have an elliptic form with a rather prominent long axis, thus presenting a columnar shape. Their contacts with the non-brecciated zones are sharp. The fragments are commonly angular and form small, planar flakes in agglomerations near the walls or around rounded fragments. Their size is extremely variable, ranging from a few centimeters to some meters in maximum diameter. After brecciation, the resulting pore spaces were filled with either quartz and sulfides or quartz and tourmaline.

The intrusive breccias, dike, pipe, or sill-like in shape, are intimately associated with stockwork bodies. Generally they are smaller than the collapse breccias and more numerous. Transvaal, La Caridad, Cuatro Hermanos, and Cananea are typical localities. Commonly, the fragments are rounded and fragments of several rock types can be found. Characteristically, the cementing material is rock flour and sericitic alteration is dominant. At La Caridad, and perhaps in Cananea, intrusive breccias are important ore controls. In many places, the breccias are the deposits themselves (Los Verdes, Pilares, Washington, San Antonio de la Huerta, and elsewhere in Mexico). In some areas the two types of breccias can be found (Transvaal, Cananea, and even La Caridad).

Even though the Mexican porphyry belt has notable variants, the Sonora localities validly conform to the alteration-mineralization model of Lowell and Guilbert (1970). Fortuna de Cobre, Meztli, El Alacran, and Transvaal exhibit a central potassic zone that grades outward into a sericitic zone and further into a propylitic zone. Meztli (El Creston) has good molybdenum values in the potassic-sericitic interface. At La Bella Esperanza and Cananea (where superimposed alteration zones can be observed inside a vast and early potassic zone; Sillitoe, 1975), sericitic and propylitic alteration are of note. In both Cananea and La Caridad there exists a potassic zone, thus confirming the validity of the Lowell and Guilbert model. Piedras Verdes, Lucia, Aurora, Batamote, Mariquita, and Cuatro Hermanos, which are in roof pendants, have a discoid shape with sericitic-propylitic alteration. At Cuatro Hermanos the alteration is shallow, thus offering the possibility of a potassic zone at depth.

All intrusive breccias are located within either the sericitic or propylitic zones with the exception of the Transvaal breccia, which is in the potassic zone. The collapse breccias, on the other hand, can be in the potassic zone (San Judas, La Verde, Transvaal, and partially Los Verdes) or in the potassic zone that grades into sericitic and further into propylitic zones (Los Verdes and Washington) or in the sericitic-propylitic zone further enveloped by a propylitic zone (Pilares and Cobre Rico). San Antonio de la Huerta breccia is silicified. Tourmaline and alunite are common in some breccias. In collapse breccias the common mineral assemblage is pyrite-chalcopyrite-molybdenite-scheelite-wolframite.

Supergene enrichment is not noticeable in most deposits; major exceptions are Cananea, San Antonio de la Huerta, Washington, Cobre Rico, and Los Verdes. At San Antonio, copper silicates and carbonates are exposed at the surface.

Most porphyry copper deposits of Sonora are of Laramide age (Livingston, 1974) and are related to batholithic rocks whose ages range from 90 m.y. in western Sonora to 53 m.y. at Aurora (Fig. 13). As far as the genesis is concerned, a plate tectonic environ-

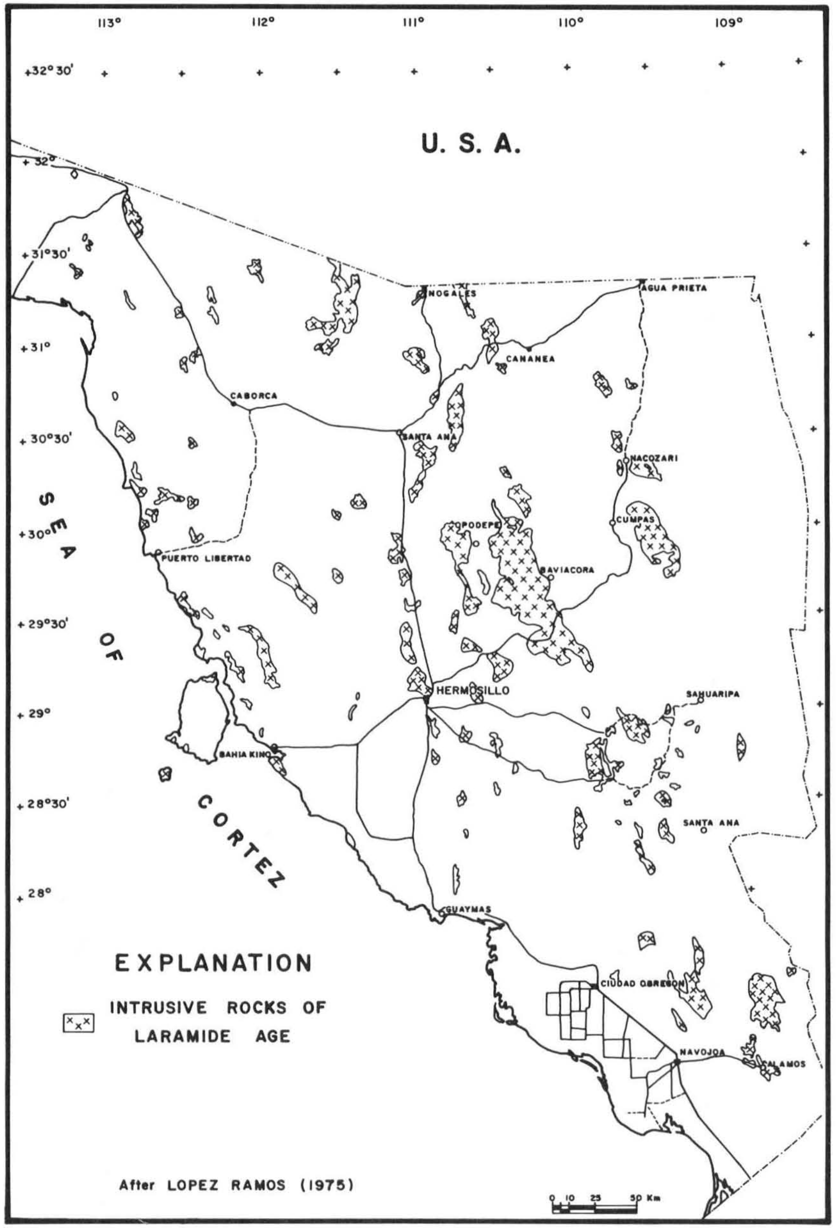

Fig. 13. Intrusive rocks of Laramide age

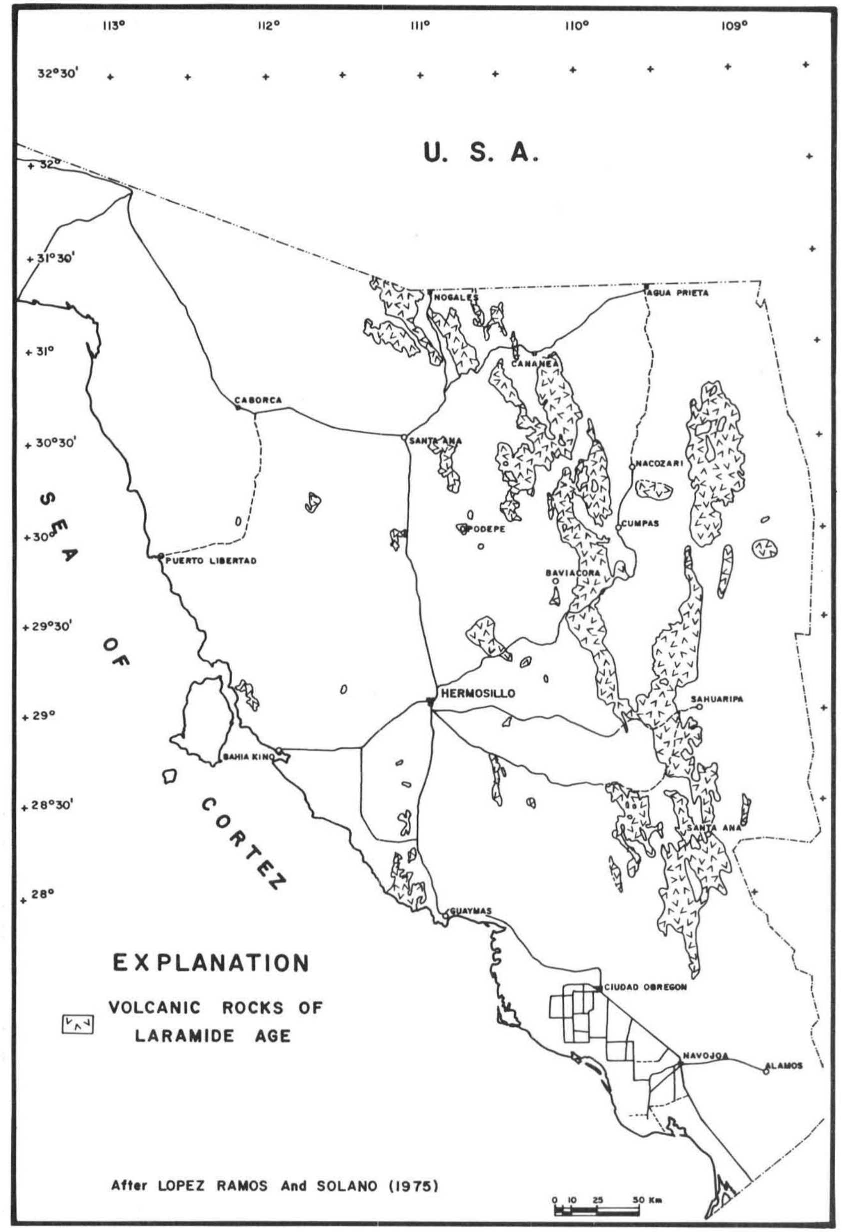

Fig. 14. Volcanic rocks of Laramide age

ment similar to that proposed for Canada and the rest of the Pacific Coast seems to have been present when the Sonora ores formed (Solano, 1975; Sillitoe, 1975; Farías and Peña L., 1975). Gastil (1975) also explained the formation of the batholithic belt of Baja California and Sonora as a result of the partial fusion of a subduction plate during the Mesozoic—early Cenozoic interval (Fig. 14). The intimate relation between batholiths and orebodies and the fact that their ages diminish progressively toward the east seem to support the plate tectonic view; so does the calc-alkaline composition of the associated and widespread volcanic rocks.

Antimony and Manganese

Antimony and manganese mineralization has been reported, but the extent of the deposits is not known.

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