Upper Proterozoic and Cambrian Rocks in the Caborca Region, Sonora, Mexico—Physical Stratigraphy, Biostratigraphy, Paleocurrent Studies, and Regional Relations

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By JOHN H. STEWART, MARK A. S. MCMENAMIN,[1] and JUAN MANUEL MORALES-RAMIREZ[2]

ABSTRACT

Exposed upper Proterozoic and Cambrian rocks in the Caborca region, Sonora, Mexico, consists of a shallow-water miogeoclinal sequence of quartzite, siltstone, dolomite, limestone, and minor amounts of conglomerate and greenstone. A revised stratigraphic sequence is divided into 14 formations, 11 of which have been previously named and 3 of which are named here. The sequence is as much as 3,300 m thick and rests unconformably on a basement terrane of 1,600- to 1,750-m.y.-old metamorphic and igneous rocks, intruded by 1,400-m.y.-old porphyritic granite and 1,100-m.y.-old granite. The sequence contains a wide assortment of fossils that include algallike filaments, possible trace fossils, and conical stromatolites (*Conophyton* and related forms) in the upper Proterozoic rocks; a primitive shelly fauna in the lowermost Cambrian rocks; and archaeocyathids, trilobites, *Salterella*, *Hyolithes*, *Girvanella*, gastropods, and brachiopods in the overlying Cambrian rocks. Paleocurrent measurements in six different formations reveal no dominant trend, although individual studies characteristically show a single dominant direction or oppositely directed paleocurrents suggestive of the ebb and flow of tides.

The revised stratigraphic sequence in the Caborca region is correlated, much of it unit for unit, with stratigraphic sequences in the southern Great Basin region of eastern California and southern Nevada, in the San Bernardino Mountains of southern California, and in the Sierra Agua Verde of central Sonora, Mexico.

The upper Proterozoic and Cambrian rocks of the Caborca region have long been recognized as a southward extension of the Cordilleran miogeocline, but interpretations have varied as to whether or not many of these rocks have been tectonically displaced. The position of the Caborca rocks to the southeast of correlative rocks in the Southwestern United States may be due to an eastward curvature of the Cordilleran miogeocline into northern Mexico, to major left-lateral offset along the Mojave-Sonora megashear, or to a combination of both these factors. A complex pattern of tectonic disruption involving left-lateral and subsequent right-lateral offset is also possible.

INTRODUCTION

Upper Proterozoic and Cambrian rocks in the Caborca region (figs. 1, 2) have long been recognized as important in understanding the tectonic framework of North America. These rocks are generally considered to be a southward extension of shallow-water shelf deposits of the Cordilleran miogeocline (Eardley, 1951, pl. 2; Stewart, 1970, fig. 36; Poole and Hayes, 1971; Stewart and Poole, 1975; Cameron, 1981; Dickinson, 1981; Stewart, 1982), but interpretations have varied as to how much they have been tectonically displaced. Silver and Anderson (1974) and Anderson and Silver (1979) suggested that the Precambrian and Paleozoic rocks of the Caborca region have been offset 700 to 800 km along a left-lateral fault, the Mojave-

FIGURE 1.—Index map showing location of Caborca region, Mexico, and localities mentioned in text.

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Sonora megashear, from the Western United States. Part of the evidence for this possible offset is the similarity of the Cambrian rocks in the Caborca region and those in the Western United States. Other geologists (Stewart and Poole, 1975; Peiffer-Rangin, 1979; Stewart, 1982) have speculated that the Cordilleran miogeocline may curve eastward in northern Mexico, to account for the position of the rocks in the Caborca area. A clear understanding of the stratigraphy of the rocks in the Caborca area is needed before these concepts can be evaluated. The present report describes new information from the Caborca region that corrects errors in the previously described stratigraphic section and allows precise correlations with rocks in the Western United States.

PREVIOUS WORK

The presence of Cambrian and Precambrian rocks in the Caborca region was first reported by

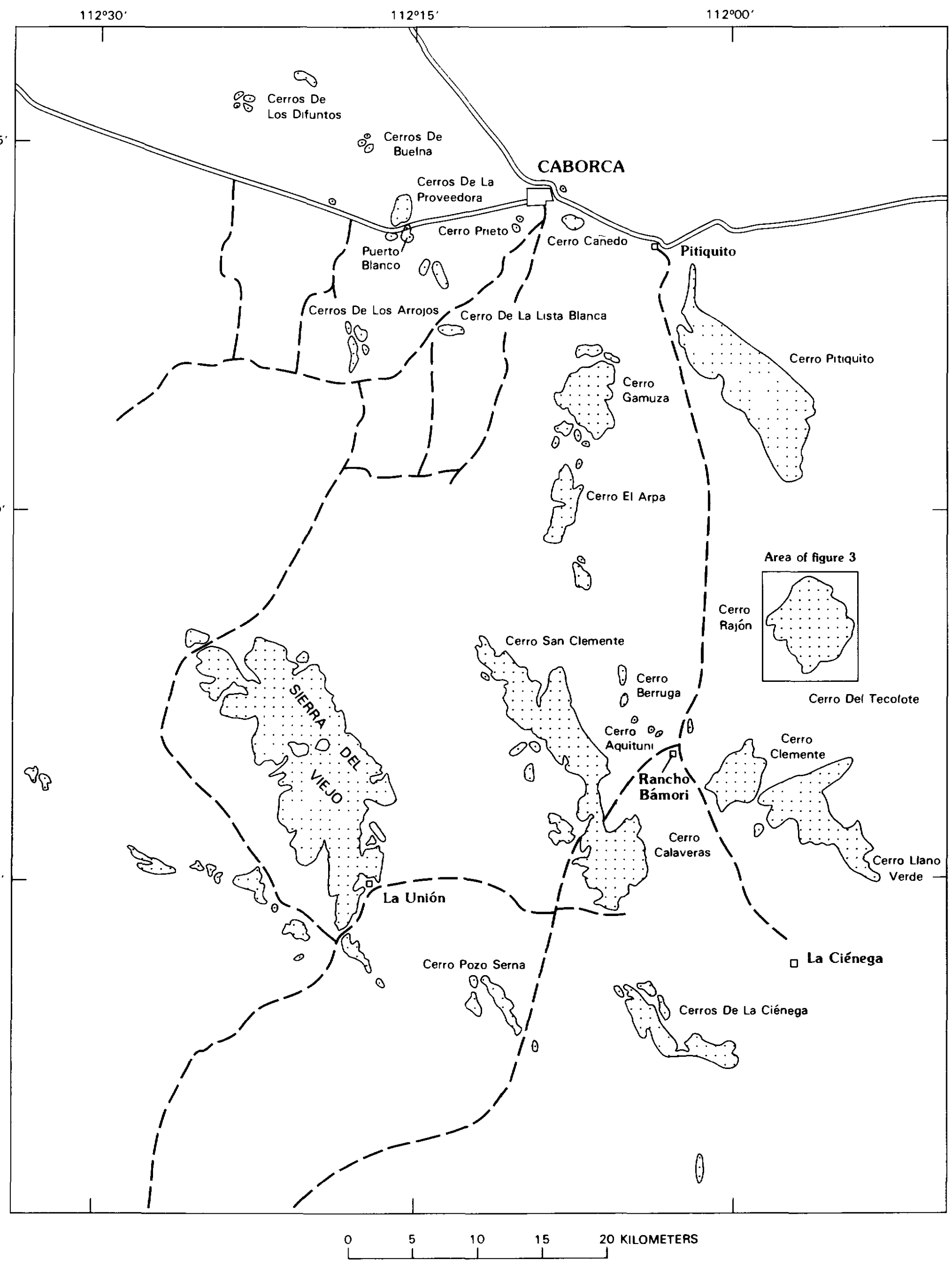

FIGURE 2.—Map of Caborca region, Mexico, showing outcrops of upper Proterozoic and Cambrian rocks. In part after Merriam and Eells (1979) and Longoria and others (1978). Stippled areas, outcrops; double line, major road; dashed line, secondary road. See figure 1 for location.

Stoyanow (1942) on the basis of fossils collected by Isauro G. Gomez and L. Torres. This discovery led to a joint investigation of the Precambrian and Paleozoic stratigraphy of the region by A. R. V. Arellano of the Instituto de Geologia, Universidad Nacional Autonoma de Mexico, and G. A. Cooper of the U.S. National Museum, sponsored in part by the Smithsonian Institution. Arellano and Cooper and their colleagues described and named the Cambrian formations of the Caborca region and studied the fauna (Arellano, 1946, 1956; Cooper and Arellano, 1946, 1952; Lochman, 1948, 1952, 1953, 1956; Cooper, 1952; Cooper and others, 1952, 1954, 1956; Johnson, 1952; Okulitch, 1952; Stoyanow, 1952). Arellano (1946) and Cooper and Arellano (1946) also briefly described the stromatolite-bearing Precambrian rocks in the Caborca region.

Damon and others (1962) and Livingston and Damon (1968) dated the crystalline basement rocks of the Caborca region and briefly described the overlying Precambrian sedimentary rocks. Fries (1962) described the general occurrence of Precambrian and Paleozoic rocks in the region.

In the 1970's, studies of crystalline basement rocks in the Caborca region were made by Anderson and Silver (1970, 1971), Cserna (1970), and Anderson and others (1978, 1979). These geologists also described the relations of these rocks to the overlying upper Proterozoic sequence.

In 1972, J. L. Eells made the first detailed study of the upper Proterozoic rocks of the Caborca region. He mapped parts of the Cerros de la Ciénega, Cerro Calaveras, Cerro Aquituni, and Cerro San Clemente areas and divided the upper Proterozoic rocks into 12 units. Eells' results were summarized by Anderson and others (1978, 1979).

Stratigraphic studies and regional mapping in several areas of the Caborca region were undertaken in the late 1970's by J. F. Longoria and coworkers (Longoria and others, 1978; Longoria and Perez, 1979; Longoria, 1980, 1981; Gonzalez, 1981; Longoria and Gonzalez, 1981; Mendoza, 1981; and Perez, 1981). Longoria and his colleagues named five formations and one group in the Precambrian succession.

Precambrian stromatolites in the Caborca region were studied by Benmore (1978), Gamper and Longoria (1979), Weber and others (1979), Cevallos-Ferriz and Weber (1980), Weber and Cevallos-Ferriz (1980), Cevallos-Ferriz (1981), and Cevallos-Ferriz and others (1982).

Correlations of the Caborca rocks with similar rocks in the Western United States were made by Lochman (1956), Eells (1972), Fritz (1975), Palmer and Halley (1979), Cameron (1981), and Stewart (1982). The Cambrian strata at Caborca were compared with the Cambrian strata in Argentina by Baldis and Bordonaro (1981).

Part of the Caborca region was mapped in reconnaissance by Merriam and Eells (1979).

PRESENT STUDIES

The senior author first studied the upper Proterozoic rocks in the Caborca area during a 3-day trip in 1977. He returned in 1978 on a field trip organized as a part of the "Primer Simposio sobre la Geologia y Potencial Minero en el Estado de Sonora" (Roldán and Salas, 1978), and again in 1981 in connection with the Geological Society of America's Cordilleran Section Annual Meeting (Longoria, 1981). After the 1981 meeting, the senior author and J. M. Morales-Ramirez spent 5 days in the region, measuring paleocurrent directions and studying the stratigraphy of the upper Proterozoic and Lower Cambrian rocks. In March 1982, all three authors of this report were in the field together for 16 days. During this time, the Cerro Rajón stratigraphic section was measured and compared with sections measured by Eells (1972) and Longoria and coworkers (Longoria, 1981). Additional paleontologic collecting was done in December 1982 by M. A. S. McMenamin, and a field trip to check correlations was made in February 1983 by the senior author, Jaime Roldán-Quintana, Sergio Cevallos-Ferriz, and Alfonso Salcido-Reyna.

ACKNOWLEDGMENTS

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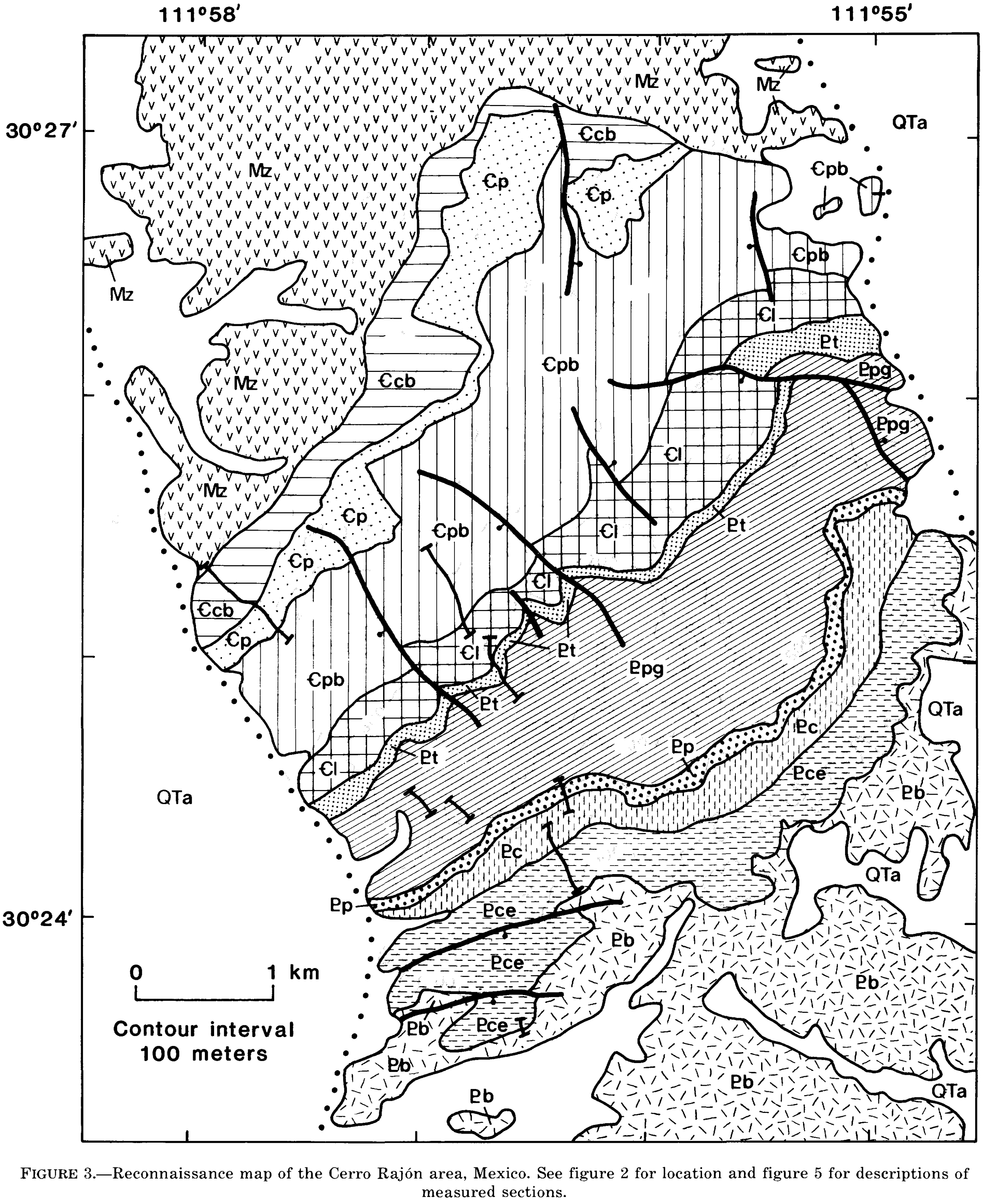


FIGURE 3.—Reconnaissance map of the Cerro Rajón area, Mexico. See figure 2 for location and figure 5 for descriptions of measured sections.

ing the age of the stromatolites. D. L. Kidder and W. K. Gross provided valuable field assistance in December 1982. C. S. Cameron helped by freely sharing his knowledge of the stratigraphic section in the San Bernardino Mountains, Calif., and by discussions of correlations of the rocks in the San Bernardino Mountains with those in the Caborca region. R. E. Powell and J. C. Matti provided logistic support in the San Bernardino Mountains and pointed out important problems with the stratigraphic relations there.

PHYSICAL STRATIGRAPHY OF UPPER PROTEROZOIC AND CAMBRIAN ROCKS

The stratigraphy we describe in this report is based primarily on exposures of rocks in the Cerro Rajón area (fig. 3), which contains the most complete upper Proterozoic and Lower Cambrian stratigraphic section in the Caborca region. The section is well exposed and relatively little faulted and is a standard with which less complete, less well exposed, and more highly faulted sections in the Caborca region can be compared (fig. 4). Figure 5 shows a stratigraphic column of the Cerro Rajón section, details on which have been reported by Stewart (1984).

The Cerro Rajón area was first mapped by Longoria and others (1978) and Longoria and Perez (1979), who described a lower Precambrian sequence of granodiorite and pegmatite and an upper Precambrian sequence that they divided into two formations, the Pitiquito Formation and the over-

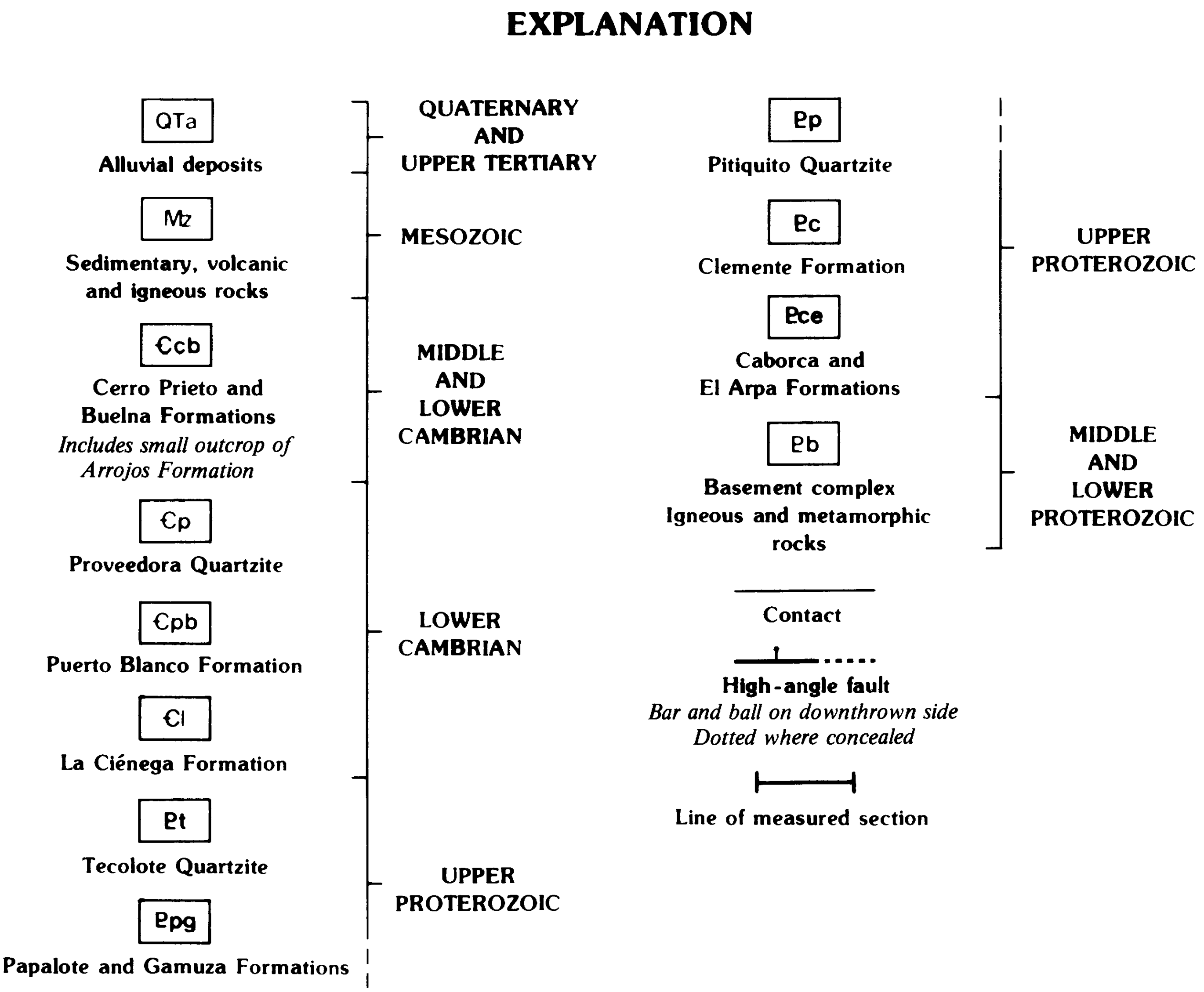


FIGURE 3.—Continued.

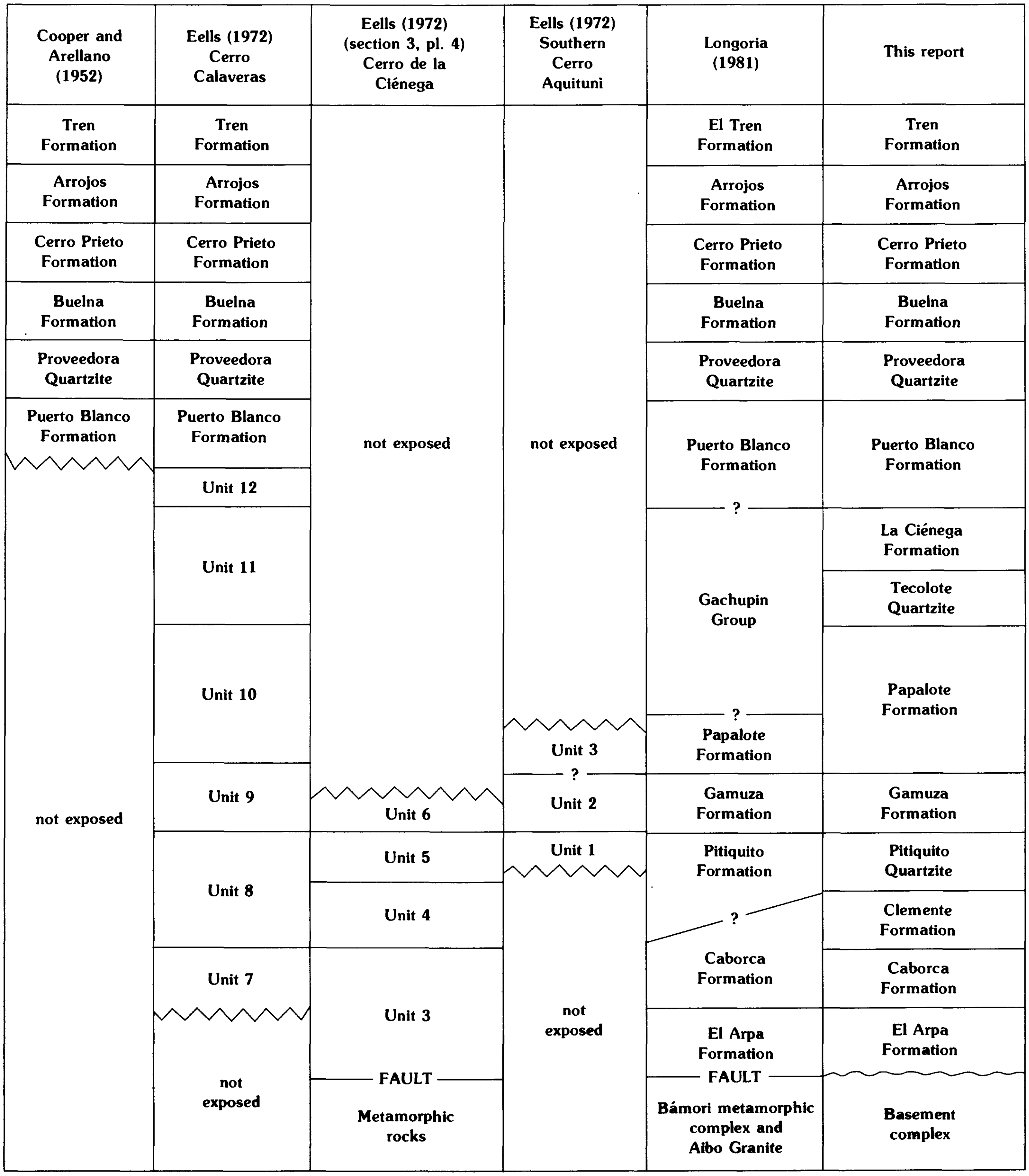


FIGURE 4.—Correlation of nomenclature used in the Caborca region, Mexico.

lying Gamuza Formation. They mapped the contact of the Pitiquito and Gamuza with the lower Precambrian igneous rocks as a thrust fault and, in addition, showed the Pitiquito and Gamuza Formations to be repeated three times by major thrust faults. However, we found no evidence for any of these thrust faults. The contact between the lower Precambrian and upper Precambrian rocks is, in our view, a sedimentary contact. Our work further indicates that the Pitiquito and Gamuza Formations are not duplicated three times; instead, the rocks in each of the three "thrust plates" mapped by Longoria and others (1978) and Longoria and Perez (1979) are different and in stratigraphic continuity with rocks in the adjacent "thrust plates." Longoria and coworkers also showed the Gamuza Formation in the Cerro Rajón area as structurally overlain along the Rajón fault by the Rajón Group of Jurassic age. However, we found no evidence of the Rajón fault. The lower units of the Rajón Group as mapped by Longoria and others (1978) and Longoria and Perez (1979) are clearly upper Proterozoic to Middle Cambrian rocks (Puerto Blanco, Proveedora, Buelna, Cerro Prieto, and Arrojos Formations) in continuity with older upper Proterozoic strata.

Our work also indicates errors in the sequence of units described by Eells (1972), who recognized a succession of 12 numbered units and several named formations in the Cerros de la Ciénega, Cerro Calaveras, Cerro Aquituni, and Cerro San Clemente areas. As indicated in figure 4, some of Eells' units are repeated three times.

In this report, we recognize 14 upper Proterozoic and Cambrian formations, 11 of which have been previously named and 3 of which we name here (fig. 4). The formational names used here appear to be applicable to the upper Proterozoic and Cambrian rocks throughout the Caborca region. In the Sierra del Viejo, which is presently being studied by Sergio Cevallos-Ferriz, Alfonso Salcido-Reyna, and Andres Pelayo-Ledesma, all the formations we describe here are recognized, although some are much thicker than elsewhere in the Caborca region and one is present only in the southern part of the sierra.

EL ARPA FORMATION

The El Arpa Formation was named by Longoria (1980, 1981) for outcrops on the east flank of the northernmost part of the Cerro El Arpa area (fig. 2). In the type area, the El Arpa is 190 m thick and consists of a basal sequence about 20 m thick of cross-stratified sandstone, quartzite, conglomerate, and sandy dolomite, with an overlying 170 m thick sequence of medium-gray and light-brown dolomite which is locally silty or sandy. In the Cerro El Arpa area, the El Arpa Formation overlies the Aibo Granite, dated at 1,110 ± 10 m.y. (Anderson and others, 1978, 1979). The contact between the Aibo and the El Arpa was considered a fault by Earl Ingerson (in Arellano, 1956) and Longoria (1981), and as a sedimentary contact by Damon and others (1962), Cserna (1970), and Anderson and others (1978, 1979). We agree with the latter group that the contact is sedimentary because of the presence of granitic clasts in conglomerate of the basal unit (Damon and others, 1962;

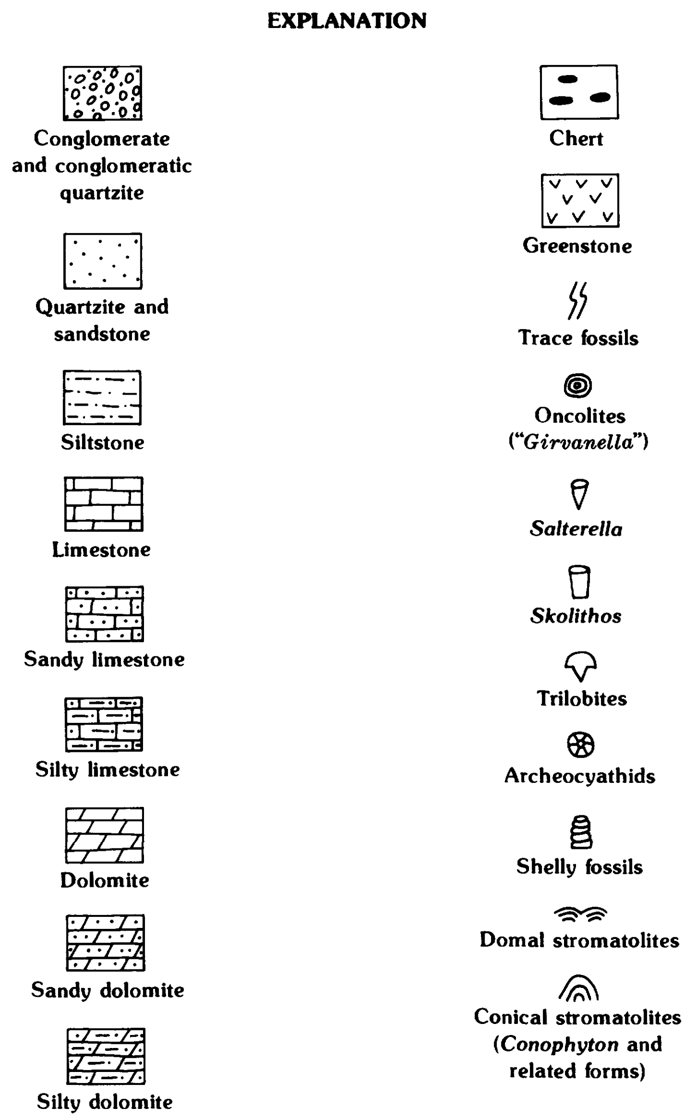
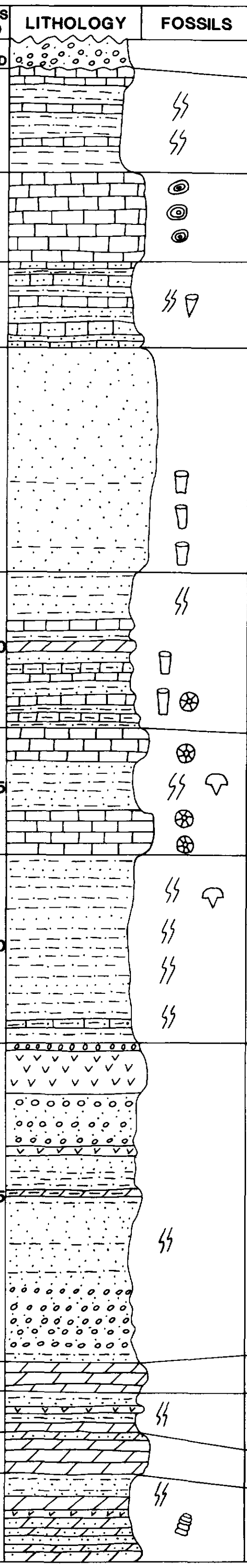


FIGURE 5.—Stratigraphic column in the Cerro Rajón area, Mexico. See figure 3 for locations of sections.



FORMATION (AGE)	THICKNESS (METERS)		DESCRIPTION
RAJÓN GROUP (JURASSIC)	NOT MEASURED		Boulder conglomerate, pale red, composed of pebbles to boulders as large as 1 m of quartzite. Only basal part examined.
ARROJOS FORMATION (MIDDLE CAMBRIAN)	93.0 INCOMPLETE		Siltstone, pale red, fine to medium silt. Minor amounts of pale-yellowish-brown, very pale orange, and light-gray very thin to thin beds of limestone.
CERRO PRIETO FORMATION (LOWER CAMBRIAN)	82.0		Limestone, light gray to medium gray, thin bedded. Abundant oncolites (<u>Girvanella</u>) in lower half, sparse in upper half.
BUELNA FORMATION (LOWER CAMBRIAN)	77.5		Mixed rock types. Siltstone, greenish gray to yellowish gray, coarse silt. Quartzite, yellowish brown, fine to medium grained, laminated and cross stratified. Limestone and dolomite, sandy in part, light gray, commonly weathering moderate brown, laminated and cross stratified.
PROVEEDORA QUARTZITE (LOWER CAMBRIAN)	201.0		Quartzite, pinkish gray, fine to medium grained, scattered coarse grains, laminated to very thin bedded; common very thin tabular planar sets of low-angle cross strata. Abundant <u>Skolithos</u> in lower 90 m. Sparse siltstone layers in lower 83 m.
PUERTO BLANCO FORMATION (LOWER CAMBRIAN)	717.0	141.0	Unit 4. Siltstone, greenish gray and grayish orange, common tracks, trails, and burrows in upper 44 m. Limestone to silty limestone, medium gray, laminated to very thin bedded, common cross strata. Quartzite, very pale orange to yellowish gray, very fine to fine grained, laminated to thin bedded, common <u>Skolithos</u>. Dolomite, medium gray, weathering light brown, laminated to thin bedded, common cross strata. Archeocyathids, possibly reworked clasts, occur in lower one-fourth of unit. Shelly trash beds occur in limestone locally.
		117.5	Unit 3. Archeocyathid-bearing yellow-gray to light-gray indistinctly thin bedded limestone at base and at top of unit. Middle part of unit is yellowish-gray and greenish-gray siltstone, yellowish-gray very fine to fine grained quartzite, and minor sandy limestone, limestone, and siltstone.
		173.0	Unit 2. Siltstone, yellow gray, dusky yellow, and grayish red, micaceous, abundant borrows, tracks, and trails. Quartzite, very fine grained, evenly laminated. Sparse limy siltstone to silty limestone beds.
		285.5	Unit 1. Volcaniclastic sandstone to boulder conglomerate, brownish gray, composed of greenstone, dolomite, sandy dolomite, and siltstone clasts set in a silty fine to very coarse grained sand matrix. Greenstone, greenish gray, altered mafic minerals in chloritic matrix. Quartzite, pale red and olive gray, mostly very fine to fine grained, sparse fine- to medium-grained parts, evenly laminated. Siltstone, in parts intergradational with very fine grained quartzite, olive gray. Sparse silty dolomite.
LA CIÉNEGA FORMATION (LOWER CAMBRIAN) (TYPE SECTION)	178.0	27.0	Unit 4. Dolomite, light gray, indistinctly laminated to very thin bedded, sparse intraclast conglomerate.
		37.5	Unit 3. Siltstone, pale olive, laminated. Quartzite, yellowish gray, very fine to medium grained, laminated and cross stratified. Common dolomite and sandy dolomite. Greenstone (1.5 m thick) in middle.
		37.5	Unit 2. Dolomite, medium gray, indistinctly laminated to thin bedded. Common cross-stratified sandy dolomite in top 7.5 m.
		76.0	Unit 1. Dolomite and sandy dolomite, light brown, fine to medium quartz grains, laminated and cross stratified. Quartzite, pinkish gray, fine to medium grained, laminated to thin bedded and cross stratified. Minor siltstone, silty dolomite, and greenstone.

FIGURE 5.—Continued.

FORMATION (AGE)	THICKNESS (METERS)		LITHOLOGY	FOSSILS	DESCRIPTION
CONTINUED FROM BOTTOM OF PREVIOUS PAGE					
TECOLOTE QUARTZITE (UPPER PROTEROZOIC) (TYPE SECTION)	168.5				Quartzite, pinkish gray, medium to coarse grained, evenly laminated, sparse cross-stratified parts. Sandy dolomite and dolomite, medium gray, weathering light brown, fine to coarse quartz grains. Sandy dolomite occurs mostly in thin trough and tabular planar sets of cross strata; dolomite is mostly laminated to thin bedded.
PAPALOTE FORMATION (UPPER PROTEROZOIC)	404.5	157.0			Unit 6. Dolomite, medium light gray, weathering light olive gray, indistinctly laminated to thin bedded. Sparse small-scale cross strata, intraclast conglomerate, and intraclast microconglomerate. Contains minor amounts of moderate red siltstone from 12 to 22 m above base.
		31.5			Unit 5. Quartzite, pinkish gray, fine grained, laminated, sparse cross strata. Sandy dolomite to dolomite, grayish red, weathering light brown, fine to coarse quartz grains, laminated, sparse cross strata.
		157.0			Unit 4. Dolomite, medium light gray, evenly laminated to thin bedded. Common sandy dolomite from 42 to 45 m above base. Domal stromatolites from 15.0 to 15.5 m above base.
		7.5			Unit 3. Silty dolomite to dolomitic siltstone, pale red to pale reddish brown, evenly laminated.
		20.0			Unit 2. Dolomite, medium light gray, laminated.
		31.5			Unit 1. Poorly exposed, pale-red quartzite and siltstone and medium-gray dolomite.
GAMUZA FORMATION (UPPER PROTEROZOIC)	135.0	60.0			Upper unit. Stromatolitic dolomite, medium gray, weathers medium gray with irregular grayish orange mottling, composed of conical stromatolites (<u>Conophyton</u> and related forms) mostly 5 to 20 cm in diameter.
		4.5			Middle unit. Dolomite, siltstone, and chert, grayish red.
		70.5			Lower unit. Dolomite, medium gray, laminated to thin bedded, common wavy laminae suggestive of algal mats. Basal 13.5 m contains common dolomitic siltstone and 1-m-thick bed of quartz granule conglomerate.
PITIQUITO QUARTZITE (UPPER PROTEROZOIC)	77.0				Quartzite, pale red, fine to medium grained, sparse medium- to coarse-grained parts, laminated to thin bedded, common thin trough and tabular planar sets of small-scale cross strata. Sparse dolomitic sandstone.
CLEMENTE FORMATION (UPPER PROTEROZOIC) (TYPE SECTION)	210.3	81.0			Unit 6. Siltstone to very fine grained sandstone, pale red and greenish gray, common drag marks, flute casts, and ripple marks. Basal 30 m contains two beds of intraclast conglomerate containing siltstone clasts as large as 15 cm.
		2.6			Unit 5. Oolitic dolomite, aphanitic dolomite, and intraclast conglomerate composed of oolitic dolomite clasts, very pale orange.
		12.7			Unit 4. Siltstone, greenish gray, fine silt.
		33.0			Unit 3. Siltstone to very fine grained quartzite, pale red, laminated to very thin bedded. Sandy limestone to dolomite in middle.
		18.0			Unit 2. Quartzite to granule conglomerate composed mostly of quartz clasts, pale red, laminated, and cross stratified.
		63.0			Unit 1. Siltstone to very fine grained quartzite, pale red to grayish red, laminated to very thin bedded. Minor amounts of light-brown dolomite in basal 5 m.
CABORCA FORMATION (UPPER PROTEROZOIC)	126.6	45.0			Upper unit. Dolomitic limestone and dolomite, dark gray, laminated to thin bedded, common low-angle cross strata. Common microchip conglomerate composed of 2- to 6-mm-wide plates of dolomite in a lime mud matrix. Sparse intraclast conglomerate.
		81.6			Lower unit. Dolomite to dolomitic limestone, medium gray, laminated to very thin bedded. Minor amounts of silty to sandy dolomite, siltstone, and sandstone.
EL ARPA FORMATION (UPPER PROTEROZOIC)	89.7	37.5			Unit 3. Dolomite and minor dolomitic limestone, medium light gray, laminated to thin bedded.
		43.2			Unit 2. Dolomite, sandy dolomite, quartzite, sandstone, and siltstone. A 1.7-m-thick greenstone occurs in upper part.
		9.0			Unit 1. Arkosic sandstone, yellow gray, medium to coarse grained, laminated to thin bedded and cross stratified. Basal 10 cm contains clasts of megacrysts from underlying porphyritic granite.
BASEMENT COMPLEX	NOT MEASURED				Porphyritic granite, greenish gray with pinkish-gray orthoclase phenocrysts as long as 4 cm in very coarse grained matrix of quartz and chloritized mafic minerals, 1,400±20 m.y. old (L. T. Silver, oral commun., 1982). Common irregular masses of greenstone.

FIGURE 5.—Continued.

Anderson and others, 1978, 1979) and because of the lateral continuity of this basal unit along the outcrop.

In the Cerro Rajón area (fig. 5), the El Arpa Formation is 89.7 m thick and consists of a lower unit of arkosic sandstone and conglomerate about 9 m thick; a 43.2-m-thick slope-forming middle unit of dolomite, sandy dolomite, quartzite, sandstone, siltstone, and thin greenstone (possibly a sill); and a 37.5-m-thick cliff-forming upper unit of medium-light-gray dolomite. The basal sandstone and conglomerate unit rests depositionally on middle Proterozoic porphyritic granite containing megacrysts as much as 4 cm long. The occurrence of clasts of these large megacrysts in conglomerate of the basal unit of the El Arpa Formation clearly demonstrates that the base of the El Arpa in the Cerro Rajón area is a sedimentary contact. The age of the pre-El Arpa porphyritic granite is 1,400±20 m.y. (L. T. Silver and T. H. Anderson, oral commun., 1982). Pre-El Arpa granitic and metamorphic rocks elsewhere in the Caborca region, except for the 1,110-m.y.-old Aibo Granite, range in age from about 1,600 to 1,750 m.y. (Anderson and Silver, 1970, 1971; Anderson and others, 1978, 1979; recalculated using new decay constants by L. T. Silver and T. H. Anderson, oral commun., 1982).

The El Arpa Formation also occurs in the Cerros de la Ciénega (fig. 2), where it forms the lower part of unit 3 of Eells (1972). There, the distinction between the El Arpa and the overlying Caborca Formation is less clear than in the Cerro El Arpa and Cerro Rajón areas. In section 3 of Eells (1972, pl. 4), in the Cerros de los Ciénega, the El Arpa and Caborca Formations were described as a single unit by Eells. We were able to distinguish the two formations in Eells' section 3, although the two formations are, indeed, similar. In the Cerros de la Ciénega, Eells (1972) showed his map unit 3 in fault contact with underlying metamorphic rocks of the crystalline basement. Although our work was not complete enough to demonstrate the nature of this contact, the lowest unit in the El Arpa Formation along Eells' section 3 is a quartzite similar to the basal unit of the El Arpa Formation in the Cerro El Arpa and Cerro Rajón areas. The presence of this probable basal unit in Eells' section 3 suggests that the basal contact of the El Arpa Formation in the Cerros de la Ciénega may, at least locally, be a sedimentary contact.

CABORCA FORMATION

The Caborca Formation was named by Longoria (1980, 1981) for outcrops on the east flank of the northernmost part of the Cerro El Arpa area, where it is 105 m thick. In the type area, it consists of two major units—a slope-forming lower unit about 85 m thick of greenish-gray and pale-red siltstone and minor amounts of gray and brown dolomite, and a cliff-forming upper unit about 20 m thick of dark-gray dolomite. The upper unit is distinguishable from a distance by well-defined thin to thick bedding.

In the Cerro Rajón area, the Caborca Formation is 126.6 m thick and contains the same two units as in the Cerro El Arpa area. The lower unit, which is 81.6 m thick in the Cerro Rajón area, is composed primarily of medium-gray to light-brown dolomite and dolomitic limestone and relatively minor amounts of sandy to silty dolomite, siltstone, and sandstone, in contrast to the dominant siltstone within the unit in the Cerro El Arpa area. The upper unit, which is 45 m thick in the Cerro Rajón area, is lithologically similar to the upper unit in the Cerro El Arpa area. In Cerro Rajón and, less abundantly, in Cerro El Arpa, the upper unit contains microchip conglomerate composed of 2- to 6-mm-wide plates of dolomite in a lime-mud matrix.

The Caborca Formation also occurs in Eells' section 3 in the Cerros de la Ciénega, where it forms the upper part of his unit 3 and is composed largely of dolomite. Minor units of siltstone and very fine grained sandstone in the upper part of Eells' unit 3 appear to be correlative with the lower unit of the Caborca Formation. The cliff-forming upper unit of the Caborca Formation is well defined at the top of Eells' unit 3.

The lowest unit exposed on the east side of Cerro Calaveras (fig. 2)—unit 7 of Eells (1972)—also is correlative with the Caborca Formation. This unit is 150 m thick and consists of a lower 90-m-thick subunit of thin-bedded limestone and an upper 60-m-thick subunit of thin-bedded to laminated dolomite. These two subunits apparently correspond to the lower and upper units of the Caborca recognized elsewhere. The Caborca Formation is the lowest unit exposed on Cerro Calaveras, but its base is not exposed there.

CLEMENTE FORMATION

The name "Clemente Formation" is proposed here for a 210.3 m-thick unit of siltstone, sandstone, quartzite, conglomerate, and minor dolomite exposed in the Cerro Rajón area. The type section (composite) is 2.3 km south-southeast of Cerro Rajón (El Prieto quad., H12A77, 1:50,000-scale map) at lat 30°24.4′ N., long 111°56.4′ W. The name is derived from Cerro Clemente, 11 km south-southwest of the type section (El Prieto quadrangle map) (fig. 2).

The Clemente Formation in the type section can be divided into six distinctive units. Unit 1 is 63 m thick and consists of pale-red to grayish-red siltstone to very fine grained quartzite and minor amounts of light-brown dolomite in the basal 5 m. Unit 2 is 18 m thick and consists of pale-red to grayish-orange-pink cross-stratified quartzite to granular conglomerate composed mostly of quartz clasts. Unit 3 is 33 m thick and consists of pale-red to light-brownish-gray siltstone to very fine grained quartzite with a medial sandy-limestone to dolomite layer. Unit 4 is 12.7 m thick and consists of greenish-gray siltstone. Unit 5 is a distinctive 2.6 m thick very pale orange to pale-red oolitic dolomite (fig. 6), aphanitic dolomite, and conglomerate composed of rounded clasts of the oolitic dolomite. Unit 6 is 81 m thick and is composed of pale-red and greenish-gray siltstone to very fine grained sandstone and, in the lower half of the unit, two distinctive intraclast conglomerate beds composed of tabular clasts of siltstone as large as 15 cm across. Drag marks, flute casts, and ripple marks (fig. 7) are common on bedding-plane surfaces of the siltstone and sandstone of unit 6.

The Clemente Formation is missing owing to faulting in the Cerro El Arpa area except for a small outcrop in the northernmost part of the range, where about 110 m of strata correlative with unit 6 of the Clemente Formation is recognized. The Clemente is also recognized on the east side of Cerro Calaveras, where it forms all but the top 30 m of unit 8 of Eells (1972), and in the Cerros de la Ciénega, where it forms unit 4 of Eells (1972, sec. 3, pl. 4). All six units of the Clemente Formation are recognized on Cerro Calaveras and in the Cerro de la Ciénega, although the thicknesses and dominant lithology of the units vary somewhat from locality to locality. The Clemente Formation also crops out in the Cerro Clemente and Cerro Llano Verde areas, as was pointed out to us by Sergio Cevallos-Ferriz and Alfonso Salcido-Reyna.

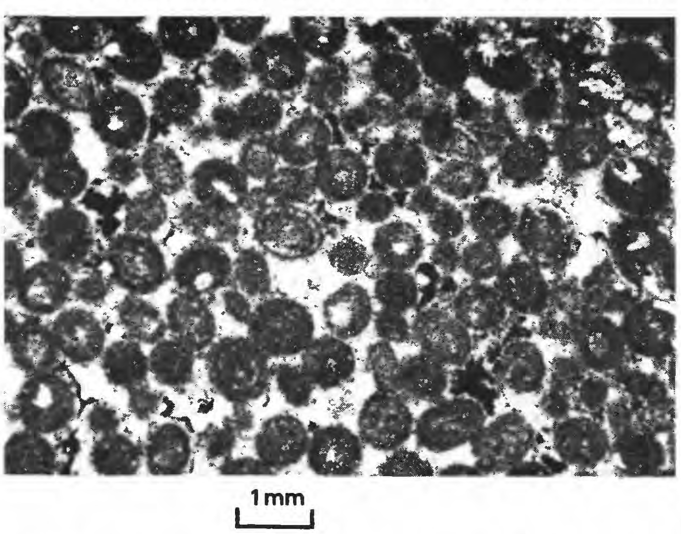


FIGURE 6.—Photomicrograph of oolitic dolomite from unit 5 of the Clemente Formation, east side of Cerro Calaveras. Specimen number MM-82-63. Photograph by S. M. Awramik.

PITIQUITO QUARTZITE

The name "Pitiquito Formation" was introduced by Longoria and others (1978, fig. 1) and Longoria and Perez (1979, p. 125 126). The holostratigraphic type (type section) is on the east flank of the extreme northern part of the Cerro Gamuza area (fig. 2), and the parastratigraphic type (reference section) is in the eastern and northern parts of the Cerro El Arpa area (Longoria, 1980, 1981). The holostratigraphic type of the Pitiquito Formation consists of 89 m of white to reddish-brown fine- to medium-grained thick-bedded cross-stratified

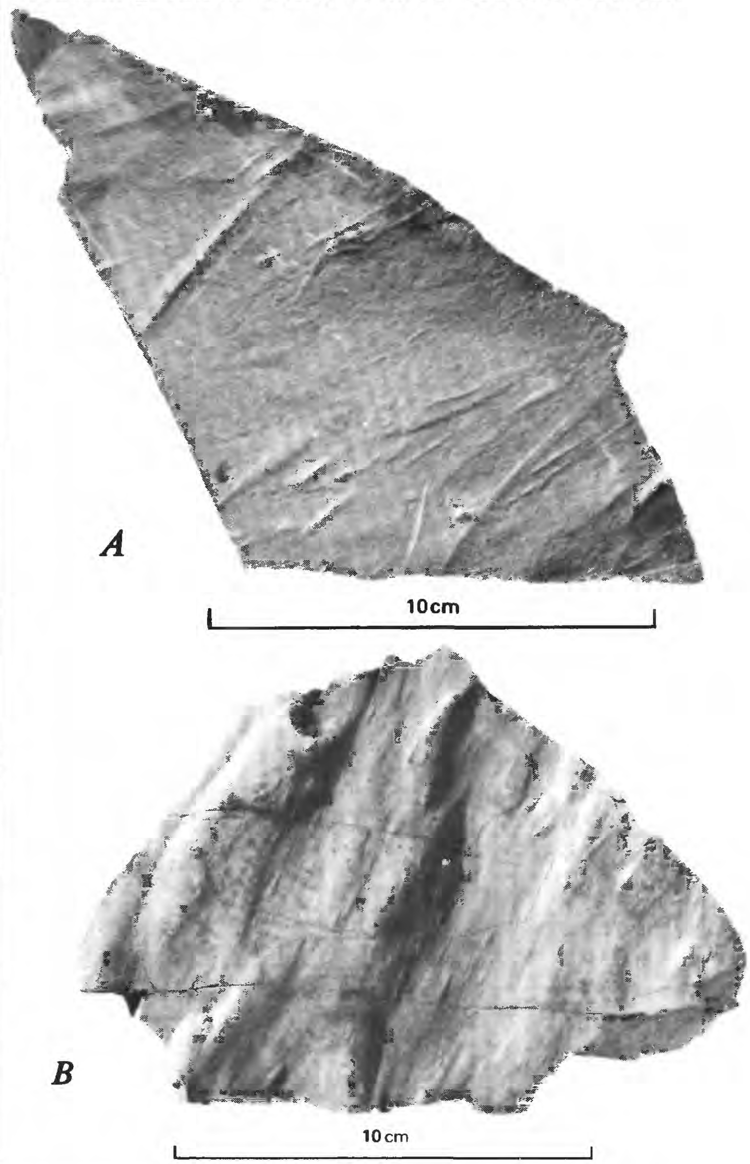


FIGURE 7.—Drag marks (*A*) and possible flute casts (*B*) in unit 6 of the Clemente Formation in the Cerro Rajón area.

quartzite. The lower contact as mapped by Longoria (1980, 1981) and Gonzalez (1981) is in fault contact with the structurally underlying Chino Group of Jurassic age. At the parastratigraphic type section, the Pitiquito Formation is more completely exposed than at the holostratigraphic type and consists of a lower 110-m-thick unit of interbedded phyllite, orthoquartzite, and sandy dolomite, and an upper 175 m-thick unit of homogeneous cliff-forming quartzite. The contact of the Pitiquito Formation and the underlying Caborca Formation in the Cerro El Arpa area is a low-angle fault according to Longoria (1980, 1981) and Gonzales (1981), although Anderson and others (1978, 1979) showed it as a high-angle fault. Our observations agree with the latter interpretation.

We here modify Longoria's definition of the Pitiquito Formation by restricting it entirely to a quartzite sequence and by referring to it as the Pitiquito Quartzite rather than the Pitiquito Formation. In the Caborca region, the quartzite that we here define as the Pitiquito Quartzite is a distinctive unit, easily distinguishable from the siltstone and very fine grained quartzite of the underlying upper part of the Clemente Formation and the dolomite of the overlying Gamuza Formation. The Pitiquito Quartzite, as defined here, is an easily mappable unit that we believe should stand alone as a formation. Our definition of the Pitiquito is in harmony with the holostratigraphic type, where the formation is almost entirely quartzite (Longoria, 1980, 1981). In the parastratigraphic type in the Cerro El Arpa area, however, Longoria (1980, 1981) included a 110-m unit of phyllite, orthoquartzite, and sandy dolomite in the lower part of his Pitiquito. We here include this 110-m unit in the Clemente Formation. In the Cerro Rajón area, our definition of the Pitiquito contrasts with that of Longoria and Perez (1979, p. 125-126, figs. 4, 5), who included in the Pitiquito a sequence of phyllite and quartzite below the main cliff-forming quartzite. We include this phyllite and quartzite in our Clemente Formation and restrict the name "Pitiquito" to the cliff-forming quartzite.

In the Cerro Rajón area, the Pitiquito Quartzite of our definition is 77 m thick and consists of pale-red fine- to medium-grained quartzite. It is laminated to thin bedded and contains common thin tabular planar and trough sets of small-scale cross strata. The lower part contains a few light-brown-weathering dolomitic sandstone layers.

In addition to the exposures in the Cerro El Arpa, Cerro Gamuza, and Cerro Rajón areas described above, the Pitiquito Quartzite also occurs in the Cerro San Clemente and Cerro Aquituni areas (fig. 2), where, as noted by Longoria and others (1978, fig. 1), Longoria and Perez (1979, fig. 2), and Longoria (1980, 1981), it forms map unit 1 of Eells (1972). In the Cerros de la Ciénega, it forms map unit 5 of Eells (1972). On the east side of Cerro Calaveras, it forms the top 30 m of map unit 8 of Eells (1972). The Pitiquito also crops out low on the west side of the Cerro Pitiquito area, but the quartzite high in the Cerro Pitiquito area is probably the Tecolote Quartzite, not the Pitiquito as mapped by Mendoza (1981). The Pitiquito also crops out in the Cerro Llano Verde and Cerro Clemente areas and in the southern part of the Sierra del Viejo. Alfonso Salcido-Reyna (written commun., 1983) has indicated that the Pitiquito Quartzite is missing in the northern part of the Sierra del Viejo in sequences that otherwise contain all the formations from the El Arpa to the Papalote.

GAMUZA FORMATION

The name "Gamuza Formation" was introduced by Longoria and others (1978) and Longoria and Perez (1979). The holostratigraphic type (type section) of the formation is on the east flank of the northernmost part of the Cerro Gamuza area (fig. 2; Longoria, 1980, 1981). The parastratigraphic type (reference section) is on the east flank of the northernmost part of the Cerro El Arpa area (Longoria, 1980, 1981).

The name "Gamuza beds," according to Arellano (1956), was originally used in the Caborca area by W. T. Keller and F. E. Wellings in 1922. This name was then, and in several subsequent papers (Arellano, 1956; Anderson and others, 1978, 1979; Weber and others, 1979), used as a general term to describe the stratigraphic section that Longoria (1980, 1981) included in the El Arpa through Papalote Formations. Because the name "Gamuza" is now used to describe a formation, we believe that the broader usage in the term "Gamuza beds" should be abandoned.

In the type area, the Gamuza Formation consists of dark-gray dolomite containing abundant conical stromatolites in the upper half. The formation forms a distinctive dark-gray resistant unit that contrasts with the underlying reddish-brown relatively nonresistant Pitiquito Quartzite and the overlying light-gray relatively nonresistant Papalote Formation. Longoria (1981) reported that the holostratigraphic type of the Gamuza Formation consists of a lower 390 m of dark-gray thick-bedded sandy dolomite and an upper 114 m of medium- to thick-bedded black stromatolitic dolomite. He reported that the parastratigraphic type is only 80 m thick and consists dominantly of gray dolomite containing stromatolites in the upper part. Our work on the Gamuza Formation suggests that it is fairly uniform in thickness and lithology throughout the Caborca region and that it probably is generally 100 to 150 m thick. Thus, we think that the thickness of 514 m reported by Longoria (1981) for the Gamuza Formation in Cerro Gamuza is in error and that the 80 m reported by him for the formation in the Cerro El Arpa area is closer to its true thickness.

In the Cerro Rajón area, the Gamuza Formation is 135 m thick and consists of three distinctive units. The lower unit is 70.5 m thick and consists of medium-gray laminated to thin-bedded cliff-forming dolomite containing intraclast conglomerate and irregular laminae suggestive of algal mats. The middle unit is 4.5 m thick and consists of gray-red dolomite, siltstone, and minor chert, and forms a nonresistant unit between the cliff-forming lower and upper units. The upper unit is 60 m thick and consists of medium-gray stromatolitic dolomite with irregular grayish-orange mottling. The stromatolites (Gamper and Longoria, 1979; Weber and others, 1979) consist of vertical conical structures (*Conophyton* and related forms) that generally range in diameter from 5 to 20 cm (fig. 8).

The three units recognized in the Gamuza Formation in the Cerro Rajón area are widespread in the Caborca region. We have noted them on the east side of Cerro Calaveras and in the Cerros de la Ciénega (sec. 3 of Eells, 1972). In the Cerro El Arpa and Cerro Pitiquito areas and near La Union in the Sierra del Viejo, we recognized the lower and upper units but not the middle unit.

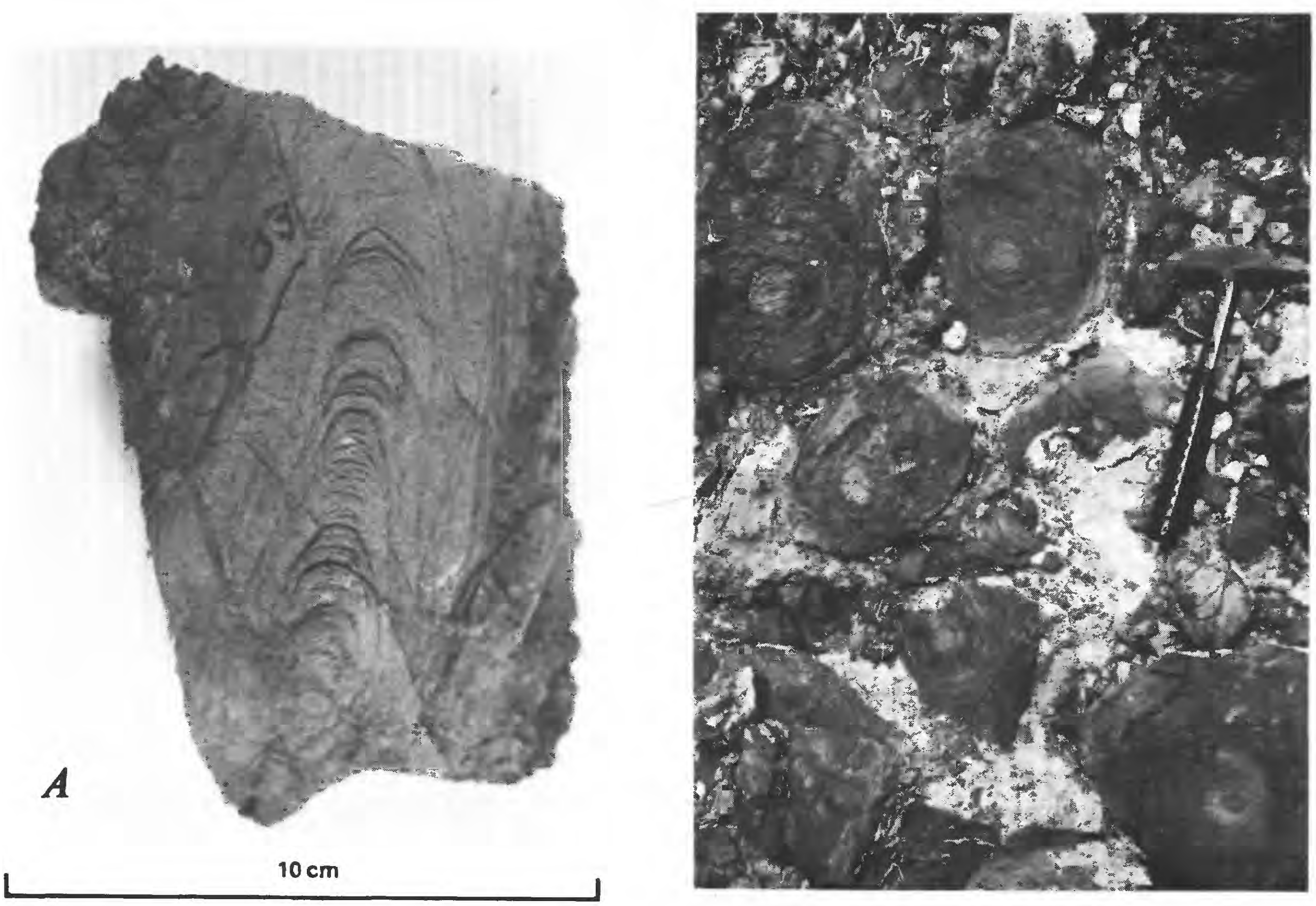


FIGURE 8.—Conical stromatolites in upper unit of the Gamuza Formation in the Cerro Rajón area. *A*, *Conophyton*, section parallel to axis of vertical stromatolite column. Specimen MM-62-33. *B*, *Conophyton* and *Jacutophyton*, section viewed from top perpendicular to vertical axis of stromatolite column. Hammer is 35 cm long.

The Gamuza Formation is widely exposed in the Cerros de la Ciénega, Cerro Calaveras, Cerro Aquituni, and Cerro San Clemente areas mapped by Eells (1972), although Eells did not recognize the equivalence of units now known to be the Gamuza. The Gamuza Formation is correlated with the lower 110 m of unit 9 of Eells (1972) in Cerro Calaveras, with unit 6 of Eells (1972, pl. 4, sec. 3) in the Cerros de la Ciénega, and with unit 2 of Eells (1972) in the Cerro Aquitini area. Longoria and others (1978, fig. 1), Longoria and Perez (1979, p. 126, fig. 2), and Longoria (1980, 1981) previously noted that Eells' unit 2 is the Gamuza. The Gamuza Formation also crops out in Cerro Llano Verde, Cerro Clemente, Cerro Pitiquito, and the Sierra del Viejo.

PAPALOTE FORMATION

The name "Papalote Formation" was introduced by Longoria and others (1978) and Longoria and Perez (1979). The holostratigraphic type (type section) is in the northernmost part of the east flank of the Cerro El Arpa area, and the parastratigraphic type (reference section) is in the Cerro Gamuza area (Longoria, 1980, 1981).

In the holostratigraphic type in the Cerro El Arpa area (Longoria, 1980, 1981), the Papalote Formation is 188 m thick and consists of light-gray laminated to thick-bedded dolomite, commonly containing algal-mat structures. In the Cerro El Arpa area, the Papalote Formation conformably overlies the Gamuza Formation, but the top is not exposed. In the parastratigraphic type in the Cerro Gamuza, the Papalote Formation is overlain by the Gachupin Group of Longoria (1980, 1981), although Longoria did not clearly indicate where he placed the contact of the Papalote Formation and Gachupin Group.

We here define the Papalote Formation as lying conformably above the Gamuza Formation, as did Longoria (1980, 1981), and below the Tecolote Quartzite as defined in this report. Such a definition is a departure from the usage of Longoria (1980, 1981) who apparently included what we here include in the upper part of the Papalote Formation within his Gachupin Group. We believe that this modified definition of the Papalote is justified because most of what we now call the Papalote is lithologically similar dolomite. The Papolote as we define it is an easily mappable unit lying between the distinctive stromatolite-bearing upper unit of the Gamuza Formation and equally distinctive light-colored quartzite and sandy dolomite of the Tecolote Quartzite. We also believe that the name "Gachupin Group" is not needed, and so we do not use it in this report. As defined by Longoria (1981, 1982), the Gachupin Group contains several distinctive units that should, in our opinion, be defined as separate formations. The Gachupin Group of Longoria (1980, 1982) includes what we here define as the upper part of the Papalote Formation, the Tecolote Formation, and part of the La Ciénega Formation.

As defined here, the Papalote Formation in the Cerro Rajón area is 404.5 m thick, consists mostly of dolomite, and is divided into six units. Unit 1 is about 31.5 m thick and consists of slope-forming poorly exposed pale- to moderate-red siltstone and quartzite and medium-gray dolomite. Unit 2 is about 20 m thick and consists of cliff-forming light-gray laminated dolomite. Unit 3 is 7.5 m thick and consists of slope-forming pale-red to pale-reddish-brown silty dolomite to dolomitic siltstone. Unit 4 is 157 m thick and consists of ledge-forming light-gray evenly laminated to thin-bedded dolomite. Domal stromatolites occur in the lower part of unit 4, but no conical *Conophyton*-like stromatolites were noted. Unit 5 is 31.5 m thick and consists of pinkish-gray fine- to medium-grained laminated cross-stratified quartzite and sandy dolomite to dolomite. Unit 6 is 157 m thick and consists of medium light-gray to light olive gray indistinctly laminated to thin bedded dolomite, with sparse moderate red siltstone in the lower part.

In addition to its occurrence in the Cerros El Arpa, Gamuza, and Rajón areas described above, the Papalote Formation has also been identified in the Cerro Pitiquito area (Longoria and others, 1978; Longoria and Perez, 1979; Mendoza, 1981; our observations in 1982); in the Cerro Aquituni and Cerro San Clemente areas (Longoria and others, 1978; Longoria and Perez, 1979; Longoria, 1980, 1981), where it forms unit 3 of Eells (1972); and on the east side of Cerro Calaveras, where it forms the upper 30 m of unit 9 and all of unit 10 of Eells (1972). On Cerro Calaveras, the Papalote Formation contains six units, the same as those in the Cerro Rajón area, although the thickness and lithology of these units on Cerro Calaveras differ somewhat from those in the Cerro Rajón area. In particular, unit 1 on Cerro Calaveras contains more quartzite, and unit 5 is thicker and contains more quartzite than in the Cerro Rajón area. Granule conglomerate also occurs in unit 1 on Cerro Calaveras, whereas it is absent in the Cerro Rajón area. The Papalote Formation is also extensively exposed in the Sierra del Viejo, where it appears to be at least twice as thick as in the

Cerro Rajón area and forms much of the high crest of the range (Alfonso Salcido-Reyna, oral commun., 1983).

TECOLOTE QUARTZITE

The Tecolote Quartzite is here named for outcrops in the Cerro Rajón area. The type section is 1.3 km southeast of Cerro Rajón at lat 30°24.9′ N., long 111°56.7′ W. The unit is named for Cerro El Tecolote (fig. 2), 8.2 km south-southeast of the type section (El Prieto quad., H12A77, 1:50,000-scale map).

In the type section, the Tecolote Quartzite is 168.5 m thick and composed of pinkish-gray and yellowish-gray medium- to coarse-grained quartzite and sandy dolomite, and minor amounts of very finely crystalline dolomite. The quartzite and sandy dolomite are evenly laminated to thin bedded and contain common thin trough and tabular planar sets of cross strata.

The Tecolote Quartzite is also recognized on the east side of Cerro Calaveras, where it forms the lower 70 m of Eells' unit 11. It also occurs 3 km southeast of Cerro Clemente at lat 30°18′ N., long 111°58.5′ W. The quartzite in the upper part of the Gachupin Group of Longoria (1980, 1981) in Cerro Gamuza may also be the Tecolote Quartzite, but we have not examined the rocks in this area with enough detail to be sure. We have also noted the Tecolote Quartzite near the crest of the Cerro Pitiquito area; these rocks were mapped—erroneously, we believe—as the Pitiquito Formation by Mendoza (1981). The Tecolote Quartzite also crops out on Cerro Llano Verde and in the Sierra del Viejo (Alfonso Salcido-Reyna, oral commun., 1983).

LA CIÉNEGA FORMATION

The La Ciénega Formation is here named for outcrops in the Cerro Rajón area. The type section (composite) is 1 km southeast of Cerro Rajón at lat 30°25′ N., long 111°56.8′ W. (El Prieto quad., H12A77, 1:50,000-scale topographic map). The formation is named for the village of La Ciénega, located 24.6 km south of the type section (La Ciénega quad., H12A87, 1:50,000-scale topographic map).

In the type section, the La Ciénega Formation is 178 m thick and is divided into four major units. Unit 1 is 76 m thick and consists of a mixture of rock types, including dolomite, sandy dolomite, silty dolomite, quartzite, siltstone, and greenstone, and forms a slope with minor ledges. Unit 2 is a 37.5 m thick ledge-forming medium-gray dolomite, with common sandy dolomite in the top 7.5 m. Unit 3 is 37.5 m thick and consists of a slope-forming sequence of dolomite, sandy dolomite, siltstone, quartzite, and greenstone. Unit 4 is 27 m thick and consists of ledge-forming medium-light-gray dolomite.

The La Ciénega Formation is also recognized near and along the crest of Cerro Calaveras, where it forms the upper 180 m of unit 11 of Eells' (1972). It also occurs near the crest of Cerro Pitiquito, where it was mapped erroneously by Mendoza (1981) as either the Gamuza or Papalote Formation. The La Ciénega also crops out 2.1 km southwest of Cerro Clemente at lat 30°18.5′ N., long 112°0.6′ W., and probably also 3 km southeast of Cerro Clemente at lat 30°18′ N., long 111°58.5′ W.

PUERTO BLANCO FORMATION

The Puerto Blanco Formation was named by Cooper and Arellano (1952, p. 4) for outcrops on the west side of Cerro de la Proveedora, 11 km west of Caborca (fig. 2), where it consists of about 293 m of green shale, sandstone, and limestone, containing diagnostic Lower Cambrian fossils. The base of the Puerto Blanco Formation is not exposed on Cerro de la Proveedora. In the Cerro Calaveras and Cerro Aquituni areas, Eells (1972) studied a more complete succession of upper Proterozoic and Lower Cambrian rocks than that exposed on Cerro de la Proveedora. He defined the Puerto Blanco Formation as a siltstone, quartzite, and limestone unit lying between his volcaniclastic unit 12 below and the Proveedora Quartzite above. His unit 12 is 90 m thick and composed of volcaniclastic boulder conglomerate, litharenite, and, in places, porphyritic olivine basalt.

Longoria (1981), although he did not discuss Eells' (1972) definition of the Puerto Blanco Formation, included basalt flows, volcanic agglomerate, and volcanic breccia in his Puerto Blanco. These volcanic and volcaniclastic units mentioned by Longoria (1981) are, in part, equivalent to unit 12 of Eells (1972). Thus, Longoria (1981) broadened the original definition of the Puerto Blanco. In the present report, we follow Longoria's usage and include the volcanic and volcaniclastic units, including unit 12 of Eells, in the Puerto Blanco Formation. Such a usage seems useful because, in the Cerro Rajón area, basalt (greenstone) and volcaniclastic rocks are interstratified with siltstone and quartzite similar to those included by Eells (1972) in his Puerto Blanco Formation. A similar relation was observed about 3.5 km southeast of Cerro Clemente at lat 30°18′ N., long 111°58′ W., where a black vesicular basalt occurs within a sequence of siltstone and very fine grained sandstone similar to rocks included in the Puerto Blanco Formation by Eells (1972). Finally, the volcaniclastic rocks here included in the Puerto Blanco Formation are generally nonresistant and topographically weather to form valleys along with the remainder of the Puerto Blanco Formation.

In the Cerro Rajón area, the Puerto Blanco Formation is 717 m thick and is divided into four major units. Unit 1 is 285.5 m thick and characterized mainly by the presence of volcaniclastic rocks and greenstone. The volcaniclastic rocks include sandstone to boulder conglomerate composed of greenstone, dolomite, sandy dolomite, and siltstone clasts set in a silty fine to very coarse grained sand matrix. The greenstone contains altered mafic minerals set in a chloritic matrix. Unit 1 also contains nonvolcanigenic siltstone and quartzite, including, in the middle, 80 m of pale-red fine-grained quartzite and minor siltstone. Unit 2 is 173 m thick and consists of greenish-gray to yellow-gray siltstone and minor very fine grained quartzite. Unit 3 is 117.5 m thick and is divided into three parts. Archaeocyathid-bearing limestone occurs in the upper and lower parts, and siltstone, quartzite, and minor limestone in the middle part. Unit 4 is 141 m thick and consists of well-bedded limestone, silty limestone, siltstone, quartzite, and minor amounts of dolomite. *Skolithos* (=*Scolithus*, a vertical burrow) is common in the quartzite of unit 4.

The Puerto Blanco Formation changes facies markedly from one locality to another in the Caborca region. At one locality 3.5 km southeast of Cerro Clemente, the Puerto Blanco Formation consists of fine- to coarse-grained cross-stratified sandstone in the lower part, of siltstone and very fine grained sandstone in the middle part, and of limestone in the upper part. No volcaniclastic rocks occur in the lower part in contrast to the Cerro Rajón section, and the only volcanic rock is a vesicular basalt less than 20 m thick that occurs in the middle siltstone and very fine grained sandstone of the formation.

In the Cerro Calaveras and Cerro Aquituni areas, Eells (1972) divided the Puerto Blanco Formation into three members. As mentioned above, we also include unit 12 of Eells (1972) in the Puerto Blanco Formation, and so the Puerto Blanco Formation, as we define it in Eells' study area, is divided into four units. These four units are comparable to, but differ considerably in detail from, the four units in the Cerro Rajón area. Unit 1 (unit 12 of Eeels, 1972) in the Cerro Calaveras and Cerro Aquituni areas is 90 m thick and consists of volcaniclastic boulder conglomerate, litharenite, and, locally, porphyritic olivine basalt (Eells, 1972). Unit 2, Eells' lower member of the Puerto Blanco Formation, is 194 to 288 m thick and consists of siltstone and very fine grained to fine-grained sandstone and quartzite. Unit 3, Eells' middle member of the Puerto Blanco Formation, is 68 to 126 m thick and consists entirely of limestone on Cerro Calaveras and of archaeocyathid-bearing limestone, quartzite, and dolomite in the Cerro Aquituni area. Unit 4, Eells' upper member of the Puerto Blanco Formation, is 90 to 100 m thick and consists of very fine grained to fine-grained quartzite in the lower part and of siltstone in the upper part. *Skolithos* (a vertical burrow) is common in the quartzite of unit 4. The largely siliciclastic unit 4 of the Cerro Calaveras and Cerro Aquituni areas contrasts with the largely carbonate unit 4 of the Cerro Rajón area.

More study is needed to document and interpret the facies changes in the Puerto Blanco Formation. Our work clearly indicates that significant facies changes occur but is insufficient to understand their regional distribution and origin.

PROVEEDORA QUARTZITE

The Proveedora Quartzite was named by Cooper and Arellano (1952, p. 4) for outcrops on Cerro de la Proveedora, 11 km west of Caborca. The Proveedora consists of pinkish-gray fine- to medium-grained vitreous quartzite that in most areas forms a conspicuous ridge or ledge. The quartzite is laminated to very thin bedded, although in most places stratification is difficult to see, and contains minor amounts of very thin tabular planar sets of low-angle cross strata. Micaceous coarse-grained siltstone occurs in thin to thick sets in the lower part of the formation. *Skolithos* (a vertical burrow) is common in quartzite in the lower half of the formation. The Proveedora Quartzite is 223 m thick in the type area, 201 m thick in the Cerro Rajón area, and 224 m thick in the Cerros Calaveras area (Eells, 1972). It also occurs in the Cerro Clemente area, in the Cerros de la Ciénega (Eells, 1972), and in the southernmost part of the Sierra del Viejo (A. R. Palmer, written commun., 1981).

BUELNA FORMATION

The Buelna Formation was named by Cooper and Arellano (1952, p. 4, 7, 12) for Cerro de Buelna, about 14 km northwest of Caborca. The Buelna consists of limestone, dolomite, sandy limestone and dolomite, and minor quartzite and siltstone. The formation is 101 to 121 m thick in the type area, 77.5 m thick in the Cerro Rajón area, 68 m thick in the Cerro Calaveras area (Eells, 1972), and 104 m thick in the Cerro de la Ciénega area (Eells, 1972). It also occurs in the Cerro Clemente and Cerro Pozo Serna areas.

CERRO PRIETO FORMATION

The Cerro Prieto Formation was named by Cooper and Arellano (1952, p. 7) for Cerro Prieto, about 2 km southwest of Caborca. The Cerro Prieto Formation is characterized by massive cliff-forming medium-gray limestone containing abundant spherical oncoliths (*Girvanella*), about 1 to 2 cm in diameter. Its dark color and resistant weathering contrast with the lighter colored and relatively nonresistant overlying and underlying Buelna and Arrojos Formations. The Cerro Prieto Formation is 100 m thick in the type area, 82 m thick in the Cerro Rajón area, and 88 m thick in the Cerros de la Ciénega. The Cerro Prieto Formation also occurs in the Cerro Clemente area and in the southernmost part of the Sierra del Viejo.

ARROJOS FORMATION

The Arrojos Formation was named by Stoyanow (1942, p. 1264) but was more completely described by Cooper and Arellano (1952, p. 9). It is named for the Cerros de los Arrojos, about 19 km west-southwest of Caborca. The Arrojos Formation consists of nonresistant thin-bedded limestone, limy siltstone, and siltstone. It is 310 m thick on Cerro de la Proveedora (Cooper and others, 1952, fig. 6) and 201 m thick in the southern Cerros de la Ciénega (Eells, 1972). Only the lower 93 m is exposed in the Cerro Rajón area.

TREN FORMATION

The Tren Formation was named by Cooper and Arellano (1952, p. 9) for outcrops in the Cerros de los Arrojos, 19 km west-southwest of Caborca. It consists of massive medium-gray dolomite and limestone, and forms a conspicuous resistant unit on Cerro de la Proveedora and in the Cerro de los Arrojos. A complete section is not known in the Caborca region. The exposed part is 490 m thick in the type area. Eells (1972) reported that the lower 100 m is exposed in the Cerro Calaveras area.

BIOSTRATIGRAPHY

The upper Proterozoic and Cambrian rocks in the Caborca region contain a wide assortment of fossils (fig. 9) that include algal filaments in the El Arpa Formation, possible trace fossils from the Clemente Formation, *Conophyton* and related stromatolites from the Gamuza Formation, a primitive shelly fauna from the La Ciénega Formation, archaeocyathids, trilobites, and brachiopods from the Puerto Blanco Formation, and various trilobites and brachiopods from the Buelna through Tren Formations. A detailed description of some of these fossils has been given by McMenamin (1984).

A silicified microbiota of blue-green algallike filaments occurs in the El Arpa Formation in black silicified wackestone chert collected from the Cerro El Arpa area (McMenamin and others, 1983). Two filament morphologies are present: narrow dark-walled tubes and thicker translucent tubes. The first filament is a tubular nonseptate form, 2 to 3 μm in diameter, as large as 120 μm long, with thin (less than 0.2 μm) dark walls. These filaments are found between and within peloids in the wackestone. Aside from the absence of septae, they most closely resemble the Late Proterozoic genus *Eomycetopsis* (Schopf, 1968). The other filament is larger (avg diameter, 5 μm) and is unlike that of any previously described Proterozoic morphology.

At the base of unit 6 of the Clemente Formation, traces suggestive of metazoan activity (fig. 10; McMenamin and others, 1983, fig. 3e) and dimpled mound structures (fig. 11) which are probably pit-and-mound fluid-escape structures occur in a red sandy siltstone in the Cerros de la Ciénega. These traces (fig. 10) are too complex to be easily discounted as sedimentary structures, and a metazoan origin seems most likely. Nevertheless, we note that the Clemente Formation contains various unusual sedimentary structures (flute casts, tool markings, dewatering structures, and traillike scratches) and so caution must be exercised when interpreting fossillike markings (Cloud, 1973).

Conical stromatolites that occur in unit 3 of the Gamuza Formation have received a good deal of study (Gamper and Longoria, 1979; Weber and others, 1979; Cevallos-Ferriz and Weber, 1980; Weber and Cevallos-Ferriz, 1980; Cevallos-Ferriz, 1981; Cevallos-Ferriz and others, 1982). The assemblage is dominated by *Jacutophyton* and *Conophyton* (fig. 8) and by *Platella*. Many of the conical stromatolites are large (as much as 1 m wide and as much as 2 m high).

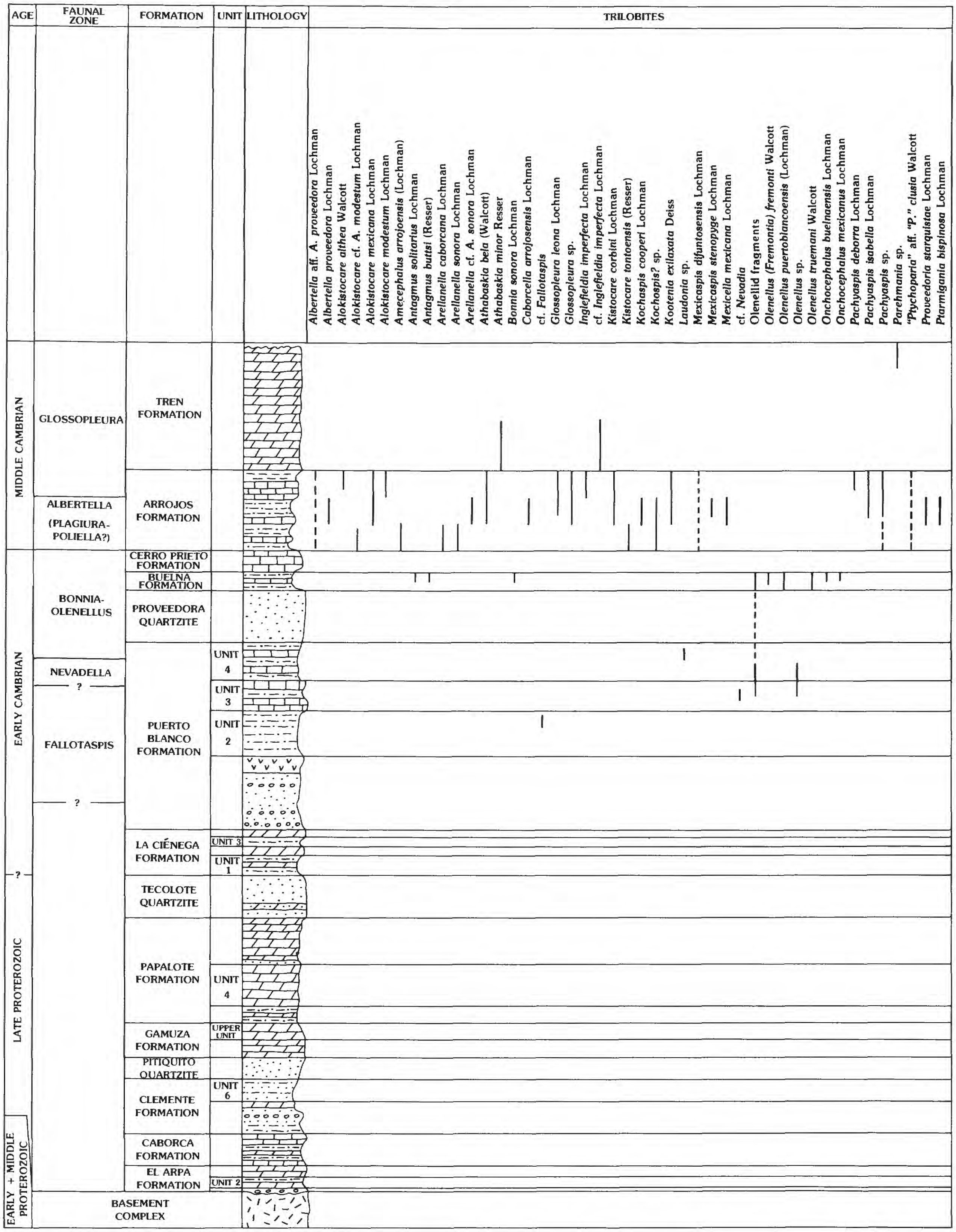


FIGURE 9.—Distribution of fauna and flora in upper Proterozoic and Cambrian strata of the Caborca region, Mexico. Based in part on Cooper and others (1952), Lochman (1953), Rowell (1962), Fritz (1975), Weber and others (1979), Yochelson (1981), A. R. Palmer (written communs., 1981-82), S. M. Awramik (oral commun., 1982), and McMenamin and others (1983). See figure 5 for explanation of lithologic symbols.

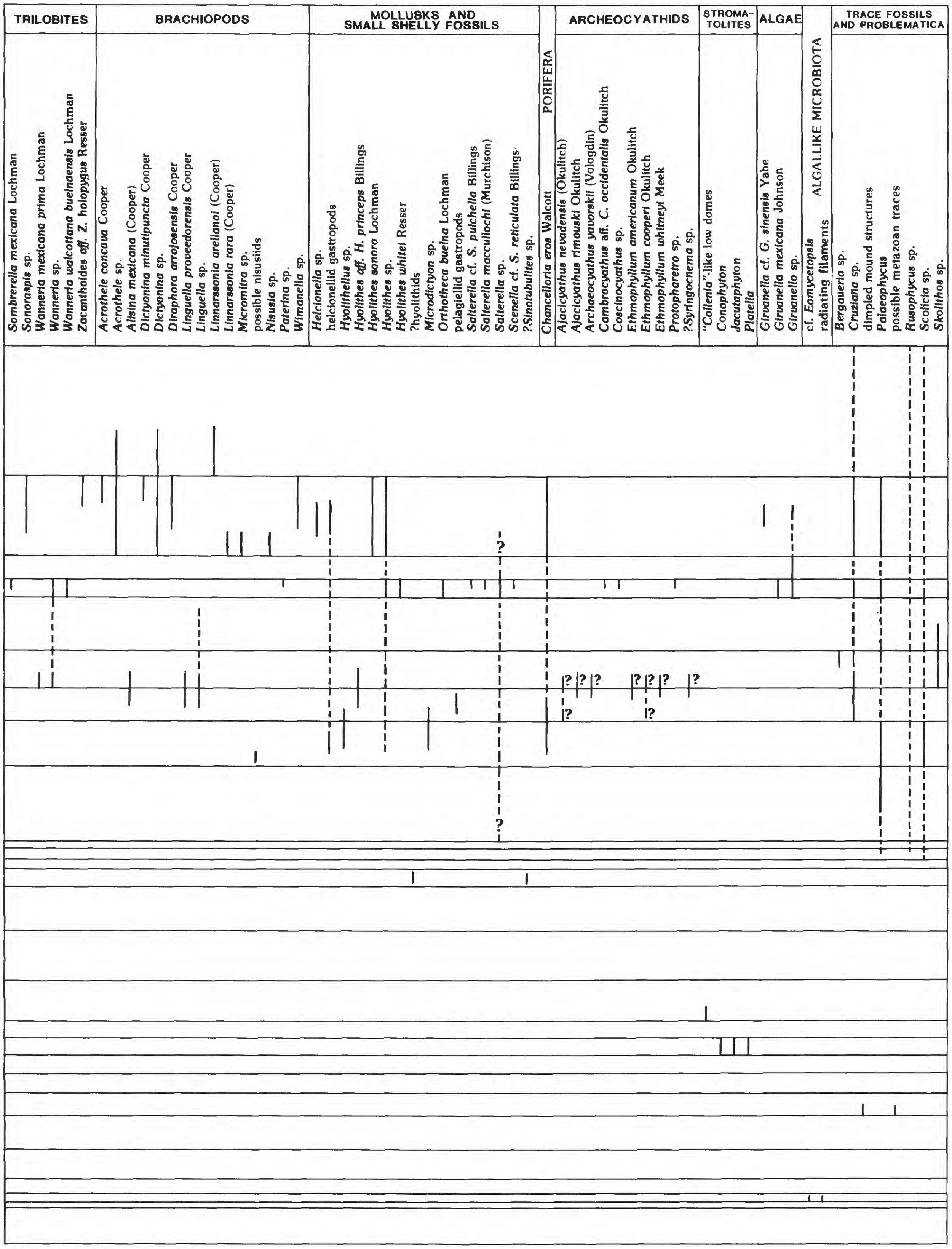


FIGURE 9.—Continued.

Weber and others (1979) suggested a middle Riphean (Middle or early Late Proterozoic) age for these stromatolites, equivalent to the Riphean R_2 (or possibly R_3) stromatolite biostratigraphic zone of Keller and Semikhatov (1976, table 1). I. N. Krylov (written commun. to S. M. Awramik, 1982) believed this to be a plausible age assignment, but he cautioned that both *Jacutophyton* and *Conophyton* are known from the Vendian and Early Cambrian, and the microstructure of these Caborca stromatolites is unlike that of Riphean conical stromatolites of the Siberian platform. Keller and Semikhatov (1976) showed both *Jacutophyton* and *Conophyton* ranging into the lower Vendian, and a recent report from China (Gao and others, 1982) described *Conophyton* from the Chigebrak Formation, which is probably Vendian in age.

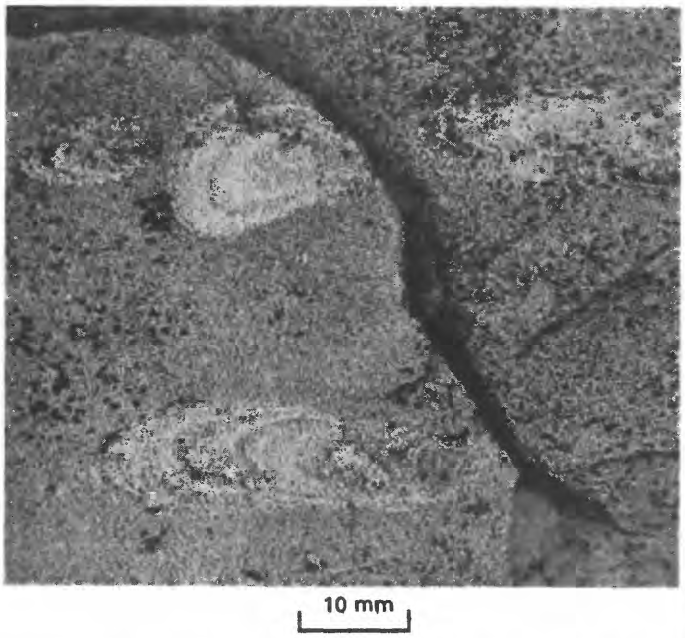


FIGURE 10.—Possible metazoan trace fossils from unit 6 of the Clemente Formation, Cerros de la Ciénega. Specimen MM-82-79.

FIGURE 11.—Dimpled mound structure (probably pit-and-mound fluid-escape structures) in unit 6 of the Clemente Formation, Cerros de la Ciénega. Specimen MM-82-79b.

Considering the possible occurrence of trace fossils well below the stromatolites, a post-middle Riphean age (possibly Vendian) seems most likely for the Mexican stromatolites. We emphasize, however, that a Vendian age for this distinctive *Jacutophyton-Conophyton* stromatolite assemblage would be quite anomalous and would necessitate an important revision of stromatolite biostratigraphy. If these stromatolites are middle Riphean, they seriously challenge our interpretation of the traces in the Clemente Formation as trace fossils (pre-middle Riphean trace fossils have never been unambiguously documented) and our correlation (discussed below) of the Clemente Formation with the Johnnie Formation (of Vendian age) of California and Nevada. Before our discovery of possible trace fossils and units resembling the Rainstorm member of the Johnnie Formation below the Caborca stromatolites, the Gamuza Formation was thought (Benmore, 1978) to correlate with the *Conophyton*-bearing Crystal Springs Formation (Roberts, 1974) and with the ?*Conophyton*-bearing Beck Spring Formation (D. Pierce, written commun., 1983) of the Pahrump Group in the Death Valley region.

Stromatolites were also noted in the Papalote Formation, but these are sparse and consist of low domal "*Collenia*"-like forms.

A pre-trilobitic small shelly fauna occurs in unit 1 of the La Ciénega Formation. The fauna consists of millimeter-size tubular and conical shells preserved as discontinuous channel-lag horizons (as much as 20 cm thick) and coquina in a sandy dolomitic limestone approximately 50 m above the base of unit 1 of the La Ciénega Formation. Associated 10-cm-thick crossbeds and very coarse sand grains attest to conditions of high-energy deposition. The tubular fossils are generally broken to less than 10 mm in length, but at least five different morphologies are still recognizable (McMenamin and others, 1983). Unornamented tubes weathering out of the carbonate matrix (fig. 12) may belong to the genus *Sinotubulites* (Chen and others, 1981), known from sedimentary rock near the Sinian-Lower Cambrian boundary in the Yangtse Gorge, China. Other fossils from the La Ciénega Formation include regularly annulated tubes (tube diameter, commonly 1.2 1.8 mm); smooth-walled forms with multiple wall layers, possibly nested hyolithids (diameter, commonly 2.0-3.0 mm); and robust tubes with irregular annulations, also possibly *Sinotubulites* (avg diameter, 2.4 mm). The affinities of these shells are uncertain at present.

A similar fauna of probable earliest Cambrian age has been recently reported from the uppermost part of the Reed Dolomite and the lowermost part of the Deep Spring Formation at Mount Dunfee, Esmeralda County, Nev. (Gevirtzman and others, 1982). This fauna includes small calcareous shelly fossils, tentatively identified as *Coleoloides* Walcott, *Coleolella* Missarzhevskii, and *Salanytheca* Missarzhevskii, as well as other, undescribed forms (Signor and others, 1983). The irregularly annulated robust tube and smooth single-walled tubes of the Caborca shelly fauna may also be present in the Nevada fauna. The stratigraphic positions of the Mexican and Nevadan shelly-fossil occurrences are virtually identical. The shelly fossil *Wyattia reedensis*, described from the Reed Dolomite in the White-Inyo Mountains, Calif. (Taylor, 1966), may be correlative with both the Nevada and Sonora pre-trilobitic faunas. In fact, both faunas contain *Wyattia*-like fossils. Cribricyathid-like tubular shelly fossils (if these poorly preserved specimens are, indeed, fossils), reported from the D member of the Stirling Quartzite (Langille, 1974), are smaller (mean diameter, 0.52 mm) than tubes from Caborca and Mount Dunfee, and their stratigraphic position suggests that they represent a somewhat older fauna.

FIGURE 12.—Unornamented tabular shelly fossils from unit 1 of the La Ciénega Formation, Cerro Rajón area. Possibly genus *Sinotubulites* Chen, Chen, and Qian, 1981. Specimen MM-82-84.

A possible specimen of the trace fossil ?*Rusophycus* was recovered from pale-olive shale of unit 3 of the La Ciénega Formation. *Rusophycus* is thought to be a trilobite resting trace, and trace fossils ascribed to the activities of trilobitelike organisms are known to occur below the oldest trilobite body fossils in the White-Inyo Mountains and Death Valley regions (Alpert, 1977).

The shelly faunas from the La Ciénega, Reed, and Deep Spring Formations appear to belong to the pre-trilobitic-shelly-fossil biostratigraphic interval known from many parts of the world. These faunas are commonly referred to as "Tommotian" in age by correlation with pre-trilobitic faunas from the Tommotian Stage of the Siberian platform, but their age equivalence is far from being definitively established. Albert (1977) suggested that Tommotian-equivalent sediment can be recognized in western North America by the occurrence of trilobite ichnofossils (such as *Rusophycus*) below the lowest trilobite body fossils. Thus, the La Ciénega Formation may correlate, in part, with Siberian strata of Tommotian age and should be considered the pre-*Fallotaspis* Zone of Fritz (1972).

The Puerto Blanco Formation contains trilobites (Lochman, 1948, 1952, 1953, 1956; A. R. Palmer, written commun., 1982, 1983) assigned to the *Bonnia-Olenellus*, *Nevadella*, and *Fallotaspis* Zones of Fritz (1972, 1975), as well as archaecyathids (Okulitch, 1952), *Salterella* (Lochman, 1952), hyolithids (Lochman, 1952), the trace fossils *Planolites*, *Scolicia*, *Bergaueria*, *Cruziana*, and *Rusophycus*, linguloid and obolelloid brachiopods (Cooper, 1952), possible nisusiid brachiopods, *Hyolithellus* (McMenamin and others, 1983), tommotiids, helcionellid and pelagiellid gastropods, and *Microdictyon* sp. (*M*. gen. and sp. indet. of Mathews and Missarzhevskii, 1975).

In the Cerro Rajón area, siltstone in unit 1 of the Puerto Blanco Formation contains *Planolites* and ?*Scolicia*, but no body fossils are known. Brachiopods (possibly nisusiids) occur 30 m above the base of unit 2. Similar brachiopods are known from the *Fallotaspis* Zone of the White-Inyo Mountains (Rowell, 1977). *Microdictyon* sp. (*M*. gen. and sp. indet. of Mathews and Missarzhevskii, 1975) occurs 65 m above the base of unit 2; this fossil is known from sedimentary rocks of Atdabanian and younger age (S. Bergtson, oral commun., 1983). The Atdabanian Stage of the Siberian platform was correlated by Gangloff (1975) with the *Fallotaspis* zone of Fritz (1972). A partial trilobite cephalon with long genal spines (comparable to *Fallotaspis* but possibly not belonging to this genus) was found by S. M. Awramik in an olive shale approximately 120 m above the base of unit 2. Considering these biostratigraphic data in the Cerro Rajón area, an Atdabanian age (*Fallotaspis* zone) for unit 2 seems reasonable.

Archaeocyathids occur in limestone at the top and bottom of unit 3 of the Puerto Blanco Formation in the Cerro Rajón area. Nevadiid trilobites from the shale beds between the archaeocyathid-bearing limestone beds have the long eyes of the genus *Nevadia* but possess a much narrower cephalon—the pleural regions are not so wide as the forms illustrated by Nelson (1976), from the White-Inyo Mountains of eastern California (A. R. Palmer, written commun., 1983). These trilobites are tentatively considered to be part of the *Fallotaspis* zone because they appear to be generally similar to the trilobites within the *Fallotaspis* zone in the Montenegro Member of the Campito Formation of the White-Inyo Mountains (A. R. Palmer, written commun., 1983).

Olenellid trilobite fragments, ?*Wanneria*, and *Linguella* have been reported from the Proveedora Quartzite (Cooper and others, 1952). Except for the abundant trace fossil *Skolithos* in the lower half of the Proveedora, however, fossils are generally rare.

The Buelna, Cerro Prieto, Arrojos, and Tren Formations contain an extensive trilobite fauna (Lochman, 1948, 1952, 1953, 1956; Stoyanow, 1952; Fritz, 1975), as well as: *Girvanella* oncolites (Johnson, 1952) in the Buelna, Cerro Prieto, and Arrojos Formations; hyolithids, *Salterella*, and archaeocyathids in the Buelna Formation (Lochman, 1952; Okulitch, 1952); and brachiopods in the Buelna, Arrojos, and Tren Formations (Cooper, 1952). The Cerro Prieto and Buelna Formations are assigned to the *Bonnia-Olenellus* Zone of Fritz (1972, 1975). The transition to the Middle Cambrian (*Pagiura-Poliella*? and *Albertella* Zones) occurs near the base of the Arrojos Formation (Fritz, 1975). Fritz indicated that the boundary between the *Albertella* and *Glossopleura* Zones is about 200 m above the base of the Arrojos Formation on Cerro Proveedora.

Johnson's (1952) description of calcareous *Girvanella* filaments from oncolites in the Buelna Formation (*G. mexicana*, filament diameter, 20-28 μm) and the Arrojos Formation (*G.* of. *sinensis*, filament diameter, 9-12 μm) indicates that these Lower Cambrian oncolites can be properly referred to as *Girvanella* oncolites. Stratigraphers should be wary of identifying all nonmicrofossiliferous oncolites as *Girvanella*, because other blue-green allike micro-organisms besides *Girvanella* can participate in the construction of oncolites (Rezak, 1957; Brown, 1981).

PALEOCURRENT STUDIES

We made a total of 321 individual measurements of the dip directions of cross strata in upper Proterozoic and Lower Cambrian rocks in the Caborca region (fig. 13). These readings were at 14 localities and included data from six different stratigraphic units: the El Arpa Formation, the Pitiquito Quartzite, the Tecolote Quartzite, the Puerto Blanco Formation, the Proveedora Quartzite, and the Buelna Formation. The measurements were corrected for tilt imposed by the structural dip of units, but no attempt was made to correct for rotation caused by plunging folds. Most measurements were made in strata with a structural dip of less than 60°, which would result in an angular error of 10° or less, regardless of the plunge of folds (Ramsey, 1961). The units in which measurements were made are generally fine to coarse grained quartzite or dolomitic sandstone that contain tabular planar sets, and a lesser number of trough sets, of small-scale cross strata.

A considerable variation of paleocurrent direction as determined from cross strata is evident in the Caborca region (fig. 13). Overall, no dominant direction is evident ("all readings" insert, fig. 13). Studies at individual localities, however, characteristically show a dominant paleocurrent direction or oppositely directed paleocurrent directions suggestive of currents generated by the ebb and flow of tides.

The absence of a dominant paleocurrent direction in the Caborca region was a disappointment because we had expected that paleocurrent directions might be fairly consistent, judging from such a consistency in many regions of the United States. The overall pattern in the United States (fig. 14) shows flow directions generally westward in Idaho and Nevada, southwestward in Arizona, southwestward to southward in New Mexico and western Texas, and southward to southeastward in central Texas. Stewart (1982) suggested that these paleocurrent directions are generally at right angles to the continental margin; if so, then the southwesterly, southerly, and southeasterly transport directions in the Southern United States would indicate a generally easterly trend of the continental margin across the Southern United States and northern Mexico. We had hoped that paleocurrent data in the Caborca region would

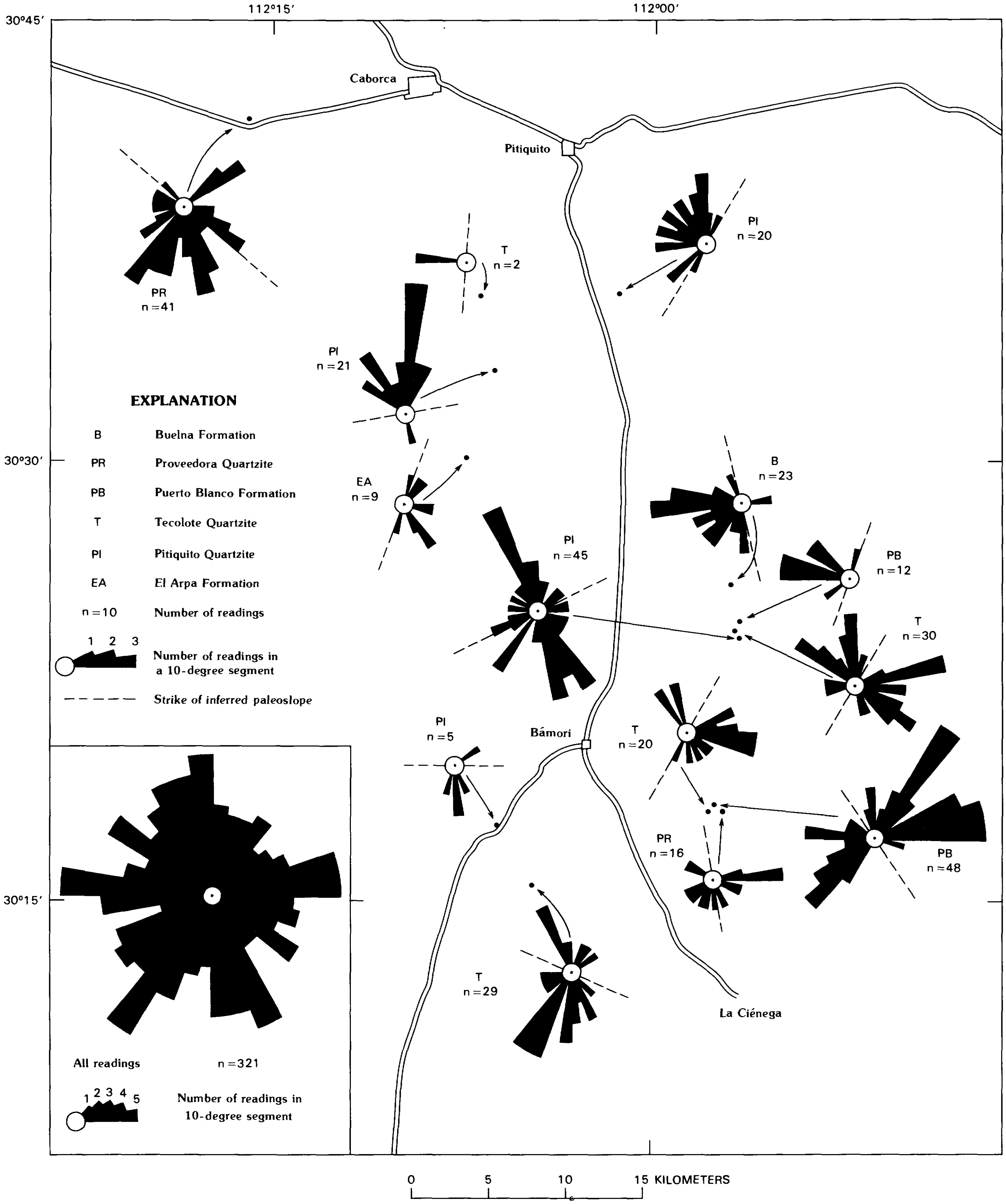


FIGURE 13.—Paleocurrent directions in upper Proterozoic and Lower Cambrian rocks of the Caborca region, Mexico.

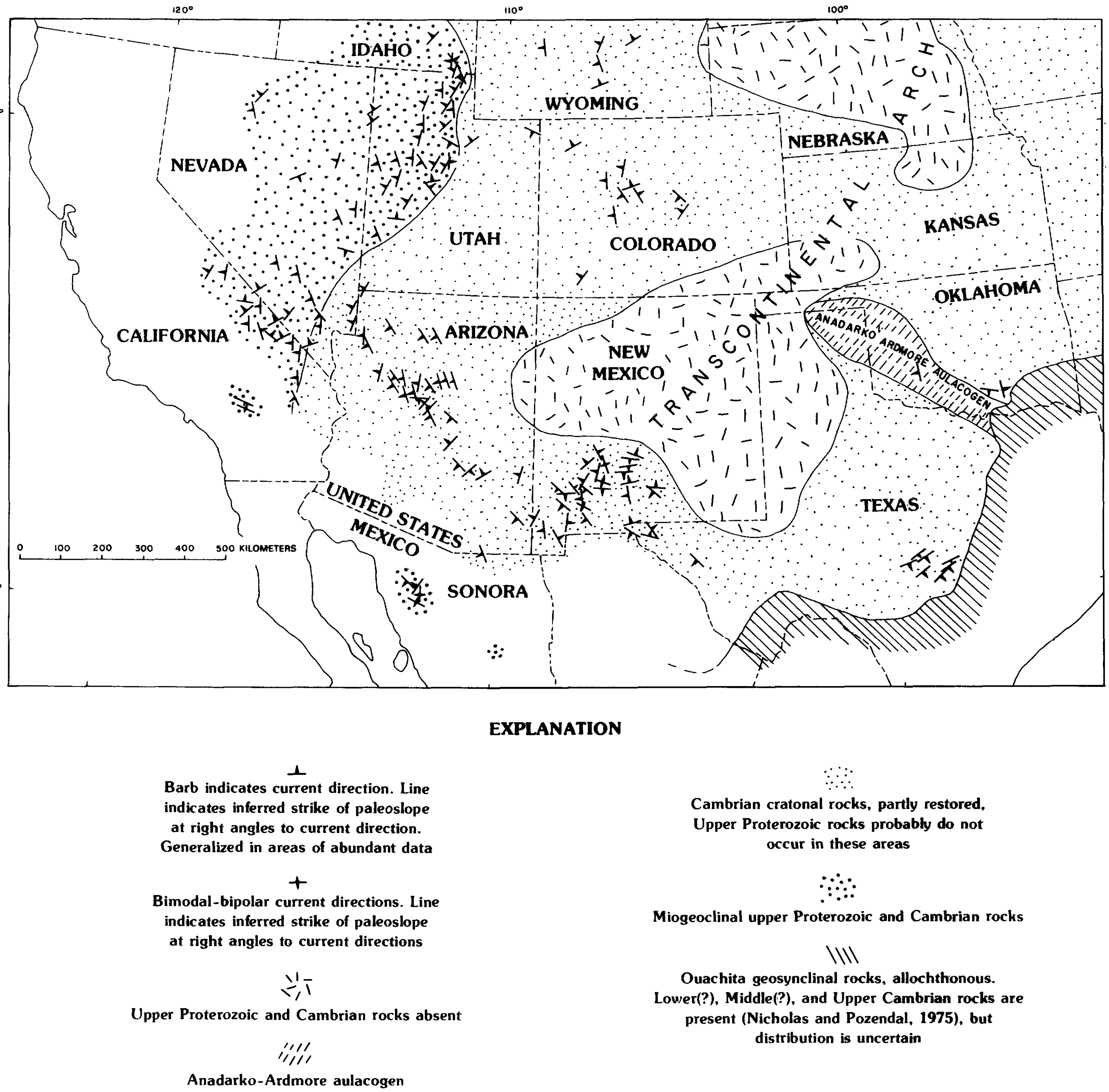


FIGURE 14.—Paleocurrent directions and paleogeography from Late Proterozoic to Late Cambrian time in the Western United States and Sonora, Mexico. Paleocurrent studies in miogeoclinal belt are from upper Proterozoic and Lower Cambrian strata. Studies in cratonal areas are in clastic units at the base of the Cambrian sequence in each area. These basal rocks young progressively toward the interior of the continent and range in age from Early Cambrian adjacent to the miogeocline to Late Cambrian in interior cratonal areas. Data from McKee (1940), Wilson (1962), Seeland (1968, 1969), Stewart (1970), Hereford (1977), and Thompson and Potter (1981); figure 13 of this report; and fieldwork by J. H. Stewart in the San Bernardino Mountains, Calif. Additional current-direction data, though not used here, were reported by Diehl (1974, 1979), Williams and others (1974), Moore (1976), Benmore (1978), and Wertz (1982).

help evaluate this concept, but the results are inconclusive.

REGIONAL CORRELATIONS

Upper Proterozoic to Middle Cambrian strata in the Caborca region can be correlated in detail with strata of the southern Great Basin in eastern California and southern Nevada, of the San Bernardino Mountains in southern California, and of the Sierra Agua Verde in central Sonora (fig. 1).

SOUTHERN GREAT BASIN

Upper Proterozoic to Middle Cambrian strata in the southern Great Basin consist, in ascending order, of: the Noonday Dolomite, the Johnnie Formation, the Stirling Quartzite, the Wood Canyon Formation, the Zabriskie Quartzite, the Carrara Formation, and the lower part of the Bonanza King Formation (fig. 15). Eells (1972) indicated that the Puerto Blanco Formation of the Caborca region correlates with part of the Wood Canyon Formation; the Proveedora Quartzite, with the Zabriskie Quartzite; the Buelna, Cerro Prieto, and Arrojos Formations, collectively, with the Carrara Formation; and the Tren Formation, with the lower part of the Bonanza King Formation (fig. 15). We propose here that units 4 to 6 of the Clemente Formation correlate with the Rainstorm Member of the Johnnie Formation; the Pitiquito Quartzite, the Gamuza Formation, the Papalote Formation, and the Tecolote Quartzite, with the Stirling Quartzite; and the La Ciénega Formation, with the lower member of the Wood Canyon Formation (fig. 15). Precise correlations of the El Arpa and Caborca Formations and of units 1 to 3 of the Clemente Formation are not possible, although these rocks are lithologically similar to some parts of the Noonday Dolomite and the Johnnie Formation, to which they may be related.

In previous discussions by Cameron (1981, 1982) and Stewart (1982), the sequence of rocks below the Puerto Blanco, and, in part, the Puerto Blanco itself were considered to significantly differ lithologically from strata presumably within the same stratigraphic interval in the southern Great Basin. These supposed dissimilarities were based on comparisons with a stratigraphic section in the Caborca region that is now known to be partly in error. The new information presented in this report reveals a close similarity of the pre-Puerto Blanco strata in the Caborca and southern Great Basin regions.

The correlation of units 4 to 6 of the Clemente Formation of the Caborca region with the Rainstorm Member of the Johnnie Formation of the southern Great Basin is based on strong lithologic similarities as well as on a similar sequence of units (fig. 16). Unit 4 of the Clemente Formation is a greenish-gray siltstone that strongly resembles the lower part of the siltstone unit of the Rainstorm Member. This part of the Rainstorm Member is extensively exposed in the Death Valley region, where it has been considered to be possibly an altered tuff (Wright and Troxel, 1966). Unit 5 of the Clemente Formation consists of a distinctive oolite or oolitic intraclast conglomerate that is correlated with a lithologically identical oolite ("Johnnie oolite") in the siltstone unit of the Rainstorm Member in the southern Great Basin area (fig. 6). The "Johnnie oolite" is extensively exposed in the southern Great Basin region (Stewart, 1970), where it is everywhere less than 4 m thick and is so distinctive that it can be recognized out of context of the surrounding rocks. The oolite unit of the Clemente Formation is somewhat unusual in that it everywhere contains and, in most places, is composed entirely of intraclast conglomerate composed of clasts of the oolite. Such intraclast conglomerate, however, also occurs in the "Johnnie oolite" in the southern Great Basin (Benmore, 1978, p. 81-84), although it is not so common as in the Caborca region. Unit 6 of the Clemente Formation consists predominantly of pale-red and greenish-gray siltstone to very fine grained sandstone and minor silty limestone, containing abundant drag marks, flute casts, and ripple marks (fig. 7). The siltstone and sandstone and their characteristic drag and flute marks are similar to siltstone, limy siltstone, and limestone of the carbonate unit of the Rainstorm Member of the Johnnie Formation of the southern Great Basin (Stewart, 1970, 1974) and correlative units which have been recognized throughout a large area of eastern California, southern and eastern Nevada, and western Utah (Stewart, 1974; Christie-Blick, 1982).

The Pitiquito Quartzite, the Gamuza Formation, the Papalote Formation, and the Tecolote Quartzite are correlated with the Stirling Quartzite of the southern Great Basin on the basis of the presence of quartzite (Pitiquito and Tecolote Quartzites) similar to that in the Stirling. This correlation is supported by the position of the Pitiquito-Gamuza-Papalote-Tecolote sequence between the Clemente Formation below (correlated with the upper part of the Johnnie Formation) and the La Ciénega Formation above (correlated with the lower member of the Wood Canyon Formation) (fig. 15). The predominant carbonate sequence of the Gamuza and Papalote Formations differs from the predominant quartzitic sequence of the Stirling Quartzite. The Stirling, however, does contain some carbonate—the D member of the Stirling Quartzite in the northern Death Valley region contains 78 m of largely carbonate rock. In addition, the D member thickens northwestward (Stewart, 1970) to form the 520 m thick Reed Dolomite of the White-Inyo Mountains of eastern California.

The correlations presented here are based on physical stratigraphy and disagree with correlations based on stromatolite zonation. *Conophyton*

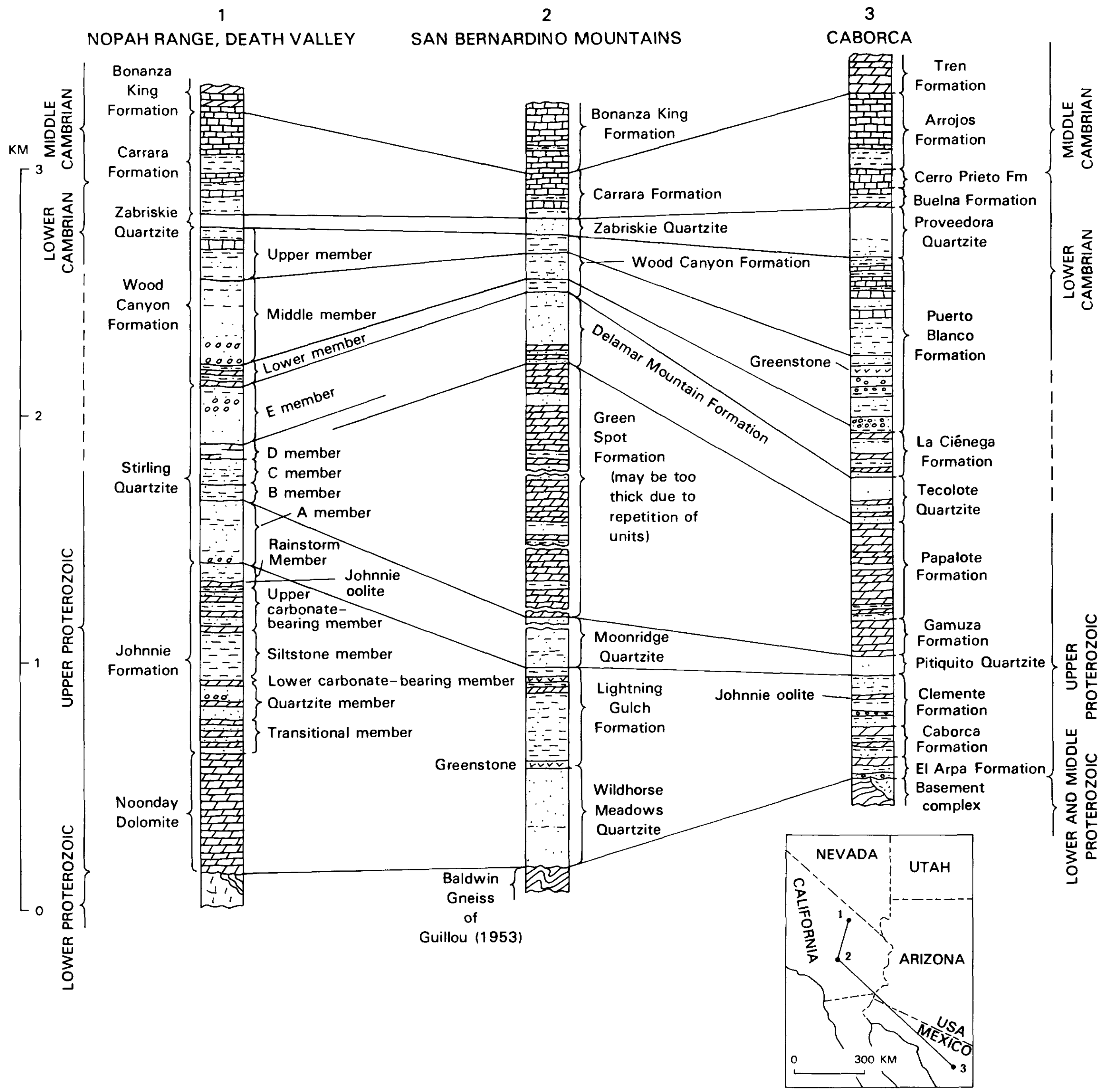


FIGURE 15.—Correlation of Middle Proterozoic to Cambrian rocks from California to Mexico. Nopah Range section after Stewart (1970), San Bernardino Mountains section after Cameron (1981,1982), and Caborca section after figure 5 of this report and Cooper and others (1952). Lithologic symbols same as in figure 5.

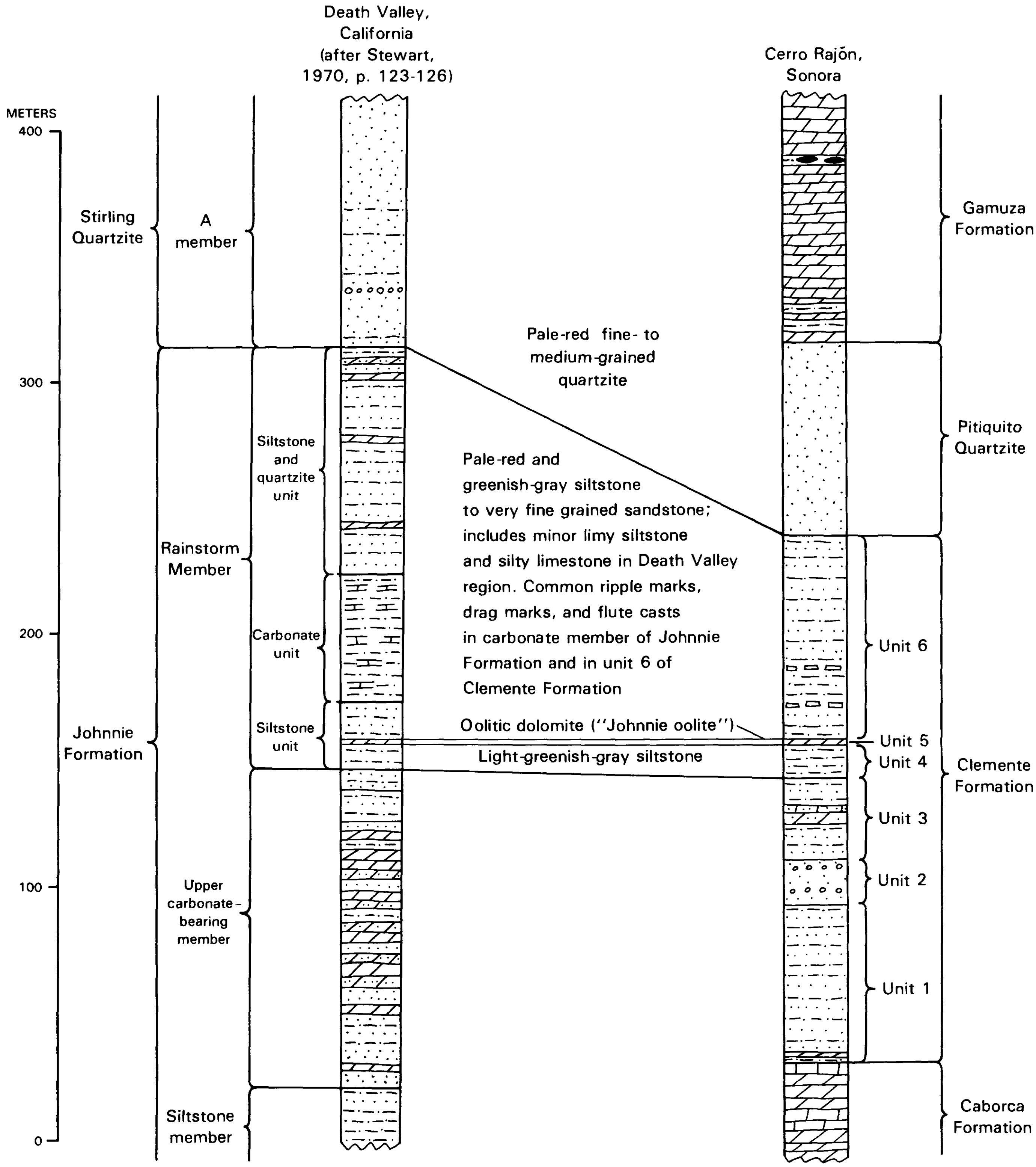


FIGURE 16.—Correlation of part of the Clemente Formation and the Pitiquito Quartzite in the Caborca region with part of the Johnnie Formation and the Stirling Quartzite in the Death Valley region. Lithologic symbols same as in figure 5.

and associated stromatolites in the Gamuza Formation of the Caborca region are commonly considered to be Middle Proterozoic (middle Riphean) (Weber and others, 1979), whereas stromatolites (Cloud and Semikhatov, 1969) in the Johnnie Formation of the southern Great Basin, a unit considered to be older than the Gamuza in our correlations (fig. 15), are considered to be Late Proterozoic (Vendian). However, as discussed in the section above entitled "Biostratigraphy," *Conophyton* may range into the Vendian; and the occurrence of possible metazoan trace fossils below *Conophyton* supports a post-middle Riphean age for these stromatolites.

The correlation of the La Ciénega Formation with the lower member of the Wood Canyon Formation is based on the similar lithology of these two units, which consist largely of greenish-gray siltstone, very fine grained to medium-grained quartzite, and dolomite. The two cliff-forming dolomite units (units 2, 4) of the La Ciénega Formation are considered to be the same as the upper two conspicuous dolomite units in the lower member of the Wood Canyon Formation.

Unit 1 of the Puerto Blanco Formation locally contains grayish-red cross-stratified fine- to medium-grained sandstone and quartzite similar to that in the middle member of the Wood Canyon Formation, with which unit 1 is correlative in part. Much of unit 1, however, is composed of volcanogenic conglomerate and greenstone unlike any rocks in the middle member of the Wood Canyon Formation. The volcanogenic rocks in unit 1 are mostly coarse conglomeratic strata that are locally derived and probably of little use in establishing regional correlations.

Units 2, 3, and 4 of the Puerto Blanco Formation are correlated with the upper member of the Wood Canyon Formation. This correlation is supported by the dominance of siltstone and very fine grained quartzite in units 2 through 4 and in the upper member of the Wood Canyon Formation, as well as by the occurrence of archaeocyathid-bearing limestone in both sequences. The threefold division of unit 3 is similar to the threefold division of the Poleta Formation, a unit equivalent to part of the upper member of the Wood Canyon Formation (Stewart, 1970), in the White-Inyo Mountains region and adjacent areas of the southern Great Basin. Unless these units are time transgressive, however, correlation of unit 3 with the Poleta does not seem to be valid because the trilobites (see section above entitled "Biostratigraphy") in unit 3 most closely resemble those in the Montenegro Member of the Campito Formation that underlies the Poleta Formation.

The lithologies of the Proveedora Quartzite and the correlative Zabriskie Quartzite are remarkably similar. Both formations are composed of pinkish-gray fine- to medium-grained quartzite containing generally small scale low-angle cross strata. *Skolithos* (=*Scolithus*) tubes are characteristic of the lower parts of these correlative quartzite units.

The Buelna, Cerro Prieto, and Arrojos Formations consist of interstratified siltstone and limestone, with minor amounts of sandy dolomite, sandy limestone, and quartzite lithologically similar to the correlative Carrara Formation of the southern Great Basin. These correlative rocks contain faunas of the *Bonnia-Olenellus*, *Plagiura-Poliella*, *Albertella*, and *Glossopleura* Zones (Fritz, 1972, 1975; Palmer and Halley, 1979). In detail, the Cerro Prieto Formation can be correlated (A. R. Palmer, written commun., 1981), on the basis of stratigraphic relations and fossils, with the Gold Ace Limestone Member of the Carrara Formation of the southern Great Basin and with the laterally equivalent Mule Spring Limestone of the White-Inyo Mountains of California.

The Tren Formation and the correlative Bonanza King Formation consist of thick sequences of carbonate of comparable age (Eells, 1972).

SAN BERNARDINO MOUNTAINS

Upper Proterozoic and Cambrian rocks crop out in the San Bernardino Mountains and in the Victorville area of southern California (Stewart and Poole, 1975; Tyler, 1975, 1979; Cameron, 1981, 1982; Miller, 1981). The most complete sequence occurs in the San Bernardino Mountains, where the sequence was divided by Cameron (1982) into the following units, in ascending order: the Wildhorse Meadows Quartzite, the Lightning Gulch Formation, the Moonridge Quartzite, the Green Spot Formation, the Delamar Mountain Formation, the Wood Canyon Formation, the Zabriskie Quartzite, the Carrara Formation, the Bonanza King Formation, and the Nopah(?) Formation. The Wildhorse Meadows Quartzite was considered by Cameron (1981, 1982) to rest unconformably on the Baldwin Gneiss of Guillou (1953), a unit of gneiss and schist at least 1,750 ± 15 m.y. old (Silver, 1971). The sequence of units in the San Bernardino Mountains is difficult to determine because of metamorphism, complex structure, and poor outcrops, and some uncertainty exists about the exact sequence of units in that area. We accept the section described by Cameron (1981, 1982), although further work might require revisions to it.

We here propose that the Pitiquito Quartzite of the Caborca region correlates with the Moonridge Quartzite of the San Bernardino Mountains, the Gamuza and Papalote Formations with the Green Spot Formation, and the Tecolote Quartzite with the Delamar Mountain Formation (fig. 15). Correlations of higher units, the La Ciénega through Tren Formations with the Wood Canyon Formation through Bonanza King Formations, which also occur in the southern Great Basin, were discussed above in connection with correlations with the southern Great Basin region.

The correlation of the Pitiquito, Gamuza, Papalote, and Tecolote with units in the San Bernardino Mountains is based primarily on similar lithology and sequence of units. This correlation is also strongly supported by the occurrence in both sequences of conical stromatolites in comparable parts of the stratigraphic section (fig. 15). In Caborca, these stromatolites consist of *Conophyton* and related forms in the Gamuza Formation. In the San Bernardino Mountains, the stromatolites (Cameron, 1981, 1982) occur in the lower part of the Green Spot Formation and consist of conical and columnar forms, possibly including *Conophyton*. On the west slope of the nearby Ord Mountains, a conical and columnar stromatolite was collected by C. Meisling from a carbonate unit which may be the Green Spot Formation.

Correlation of the units below the Moonridge Quartzite (fig. 15) is uncertain. The Lightning Gulch Formation is lithologically similar to some parts of the Clemente Formation of the Caborca region and to the partly correlative Rainstorm Member of the Johnnie Formation of the southern Great Basin region. Drag marks and flute casts, typical of unit 5 of the Clemente Formation and of the Rainstorm Member, were not seen in the Lightning Gulch Formation in the San Bernardino Mountains, although metamorphism may have obliterated such features. No oolitic unit similar to the "Johnnie oolite" of the southern Great Basin or the correlative oolite in the Clemente Formation was noted in the San Bernardino Mountains. The Wildhorse Meadows Quartzite has no lithic equivalents at the base of the upper Proterozoic stratified sequence in the Caborca or southern Great Basin regions.

SIERRA AGUA VERDE

A section of Cambrian rocks in the Sierra Agua Verde about 100 km east of Hermosillo in central Sonora was discovered in February 1982 by J. H. Stewart, A. K. Armstrong, and F. G. Poole. This Sierra Agua Verde section is important because it contains Lower to Upper Cambrian rocks in a region where none had previously been recognized. These rocks are, in part, a continuation of the formations recognized in the Caborca region.

The Cambrian sequence in the Sierra Agua Verde consists, in ascending order, of: an equivalent of the Puerto Blanco Formation, the Proveedora Quartzite, equivalents of the Bonanza King Formation and the Dunderberg Shale, and, possibly, a thin overlying carbonate unit (fig. 17). The equivalent of the Puerto Blanco Formation consists of yellow-gray, medium-gray, and pale-red siltstone to phyllitic siltstone, with minor amounts of yellow-gray very fine grained to fine-grained quartzite, yellow-brown fine- to coarse-grained quartzite to pebble conglomerate, and medium-gray limestone. These rocks are poorly exposed and locally structurally contorted, and the thickness of the sequence of units was not determined. The top 80 m of the equivalent of the Puerto Blanco Formation is exposed in apparent stratigraphic continuity with the overlying Proveedora Quartzite and contains the brachiopod *Obolella* and the Lower Cambrian trilobite *Nevadella* (A. R. Palmer, written commun., 1982). The presence of *Nevadella* assures a time equivalent of these rocks in the Sierra Agua Verde with the Puerto Blanco Formation of the Caborca region, although the lithology is not exactly the same. The Proveedora Quartzite of the Sierra Agua Verde closely resembles the Proveedora Quartzite of the Caborca region and contains *Skolithos* (=*Scolithus*) in its lower part, as does the Proveedora in the Caborca region. Siltstone interstratified with quartzite of the Proveedora in the Sierra Agua Verde contains the Lower Cambrian trilobite *Olenellus gilberti* (A. R. Palmer, written commun., 1982), a fossil that occurs in the upper part of the Zabriskie Quartzite (the correlative of the Proveedora in the southern Great Basin) or in the overlying lower part of the Carrara Formation in the southern Great Basin. Middle and Upper Cambrian rocks in the Sierra Agua Verde consists of rocks considered to be equivalents of the Bonanza King Formation and the Dunderberg Shale, as well as, possibly, a thin sequence of carbonate rock overlying the Dunderberg Shale (fig. 17). The Bonanza King Formation equivalent may, in part, be correlative with the Tren Formation of Caborca, but this correlation is uncertain because only the lower part of the Tren is exposed in the Caborca region and only the upper part of the Bonanza King equivalent is exposed in the Sierra Agua Verde. The only fossils in the Middle and Upper Cambrian sequence in the Sierra Agua Verde are found in the Dunderberg Shale equivalent, within which linguloid and acretretid brachiopods (*Angulotreta*) and hexactinellid sponge spicules occur (A. R. Palmer, written commun., 1982). *Angulotreta* is Late Cambrian in age and characteristic of the lower part of the Dunderberg Shale in the southern Great Basin (A. R. Palmer, written commun., 1982). Early Ordovician conodonts, identified (John Repetski, written commun., 1983) from carbonate rocks 69 m above the Dunderberg equivalent, indicate that, at most, only a thin sequence of Cambrian rock occurs above the Dunderberg Shale equivalent in the Sierra Agua Verde.

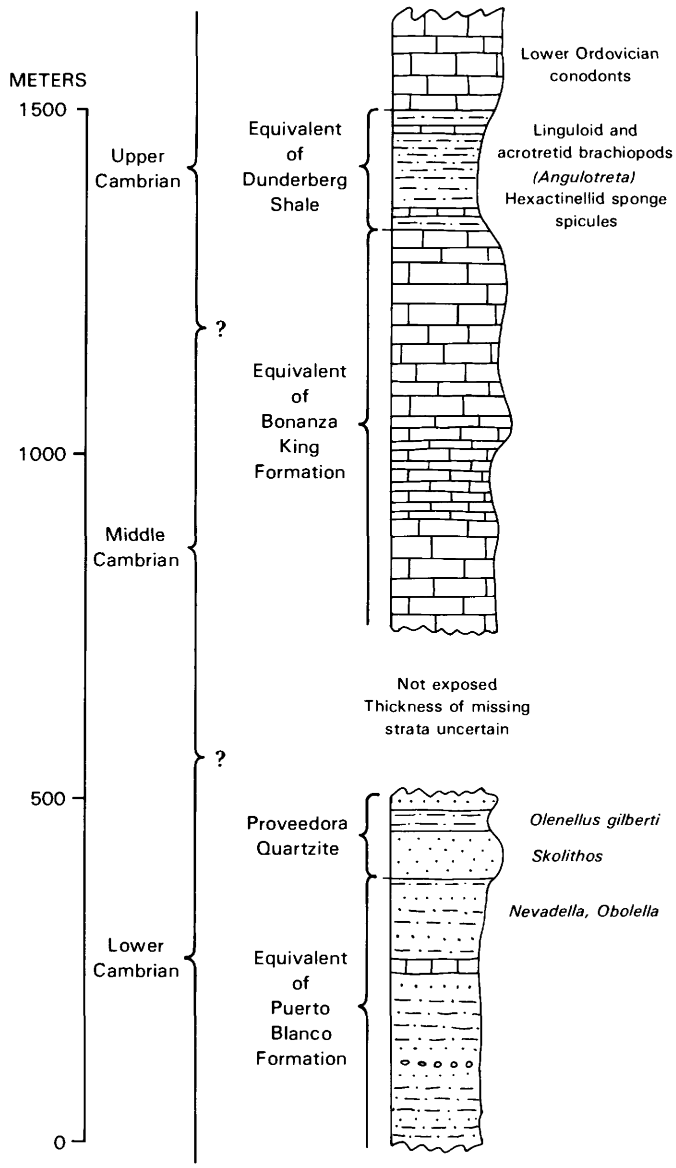


FIGURE 17.—Stratigraphic column in the Sierra Agua Verde, Sonora, Mexico.

TECTONIC AND PALEOGEOGRAPHIC SETTING

The thick terrigenous detrital and carbonate rocks of Upper Proterozoic and Cambrian age in the Caborca region are part of a widespread miogeoclinal sequence interpreted as a continental-terrace deposit along the margin of the North American Continent (Stewart and Poole, 1974). The miogeoclinal deposits and the trend of the inferred continental margin are well defined in most of the Western United States (fig. 14), but uncertainties exist about the trend of the margin and the extent of its tectonic disruption in the Southwesternmost United States and northern Mexico.

Three tectonic and paleogeographic models are considered here.

MODEL A

Model A (fig. 18*A*) shows the changing trend of upper Proterozoic and Paleozoic rocks and curving of the continental margin eastward in northern Mexico (Eardley, 1951; Stewart and Poole, 1975; Stewart, 1976; Peiffer-Rangin, 1979). The margin may extend eastward across northern Mexico and join with the Ouachita margin in the South-Central United States (Stewart, 1970, 1982; Peiffer-Rangin, 1979). This model, though appealing in its simplicity, fails to account for the remarkable similarity of the stratigraphic sequence in the Caborca region to those in the San Bernardino Mountains and the southern Great Basin—similarities which suggest that these regions were once closer together and subsequently disrupted tectonically. The model also fails to explain independent evidence of left-lateral disruption of crystalline basement rocks (Silver and Anderson, 1974; Anderson and Silver, 1979) in the Southwestern United States and northern Mexico.

MODEL B

Silver and Anderson (1974) and Anderson and Silver (1979) proposed that a major Mesozoic left-lateral megashear (the Mojave-Sonora megashear) extends southeastward from the southern Inyo Mountains, across the eastern Mojave Desert region, into Sonora, Mexico, and beyond. They noted that Precambrian orogenic and magmatic rocks ranging in age from 1,600 to 1,800 m.y. are disrupted by this shear zone. From the similarities between the stratigraphic columns in the Inyo Mountains/Death Valley region and the Caborca, Mexico, region on opposite sides of the megashear, they suggested that these areas originally were closer together and have subsequently been displaced left laterally about 700 to 800 km to their present positions.

However, the concept of the megashear as presented by Silver and Anderson (1974) and Anderson and Silver (1979) does not account for the presence of Cordilleran miogeoclinal rocks in the San Bernardino Mountains-Victorville area (Stewart and Poole, 1975; Cameron, 1981, 1982; Miller, 1981). The presence of these rocks suggests that the Cordilleran miogeoclinal belt once extended southwestward across the Mojave Desert region to the San Andreas fault (Stewart and Poole, 1975; Davis and others, 1978; Burchfiel and Davis, 1981; Cameron, 1981, 1982; Miller, 1981). If so, major left-lateral offset on the Mojave-Sonora megashear is impossible, unless the San Bernardino Mountains-

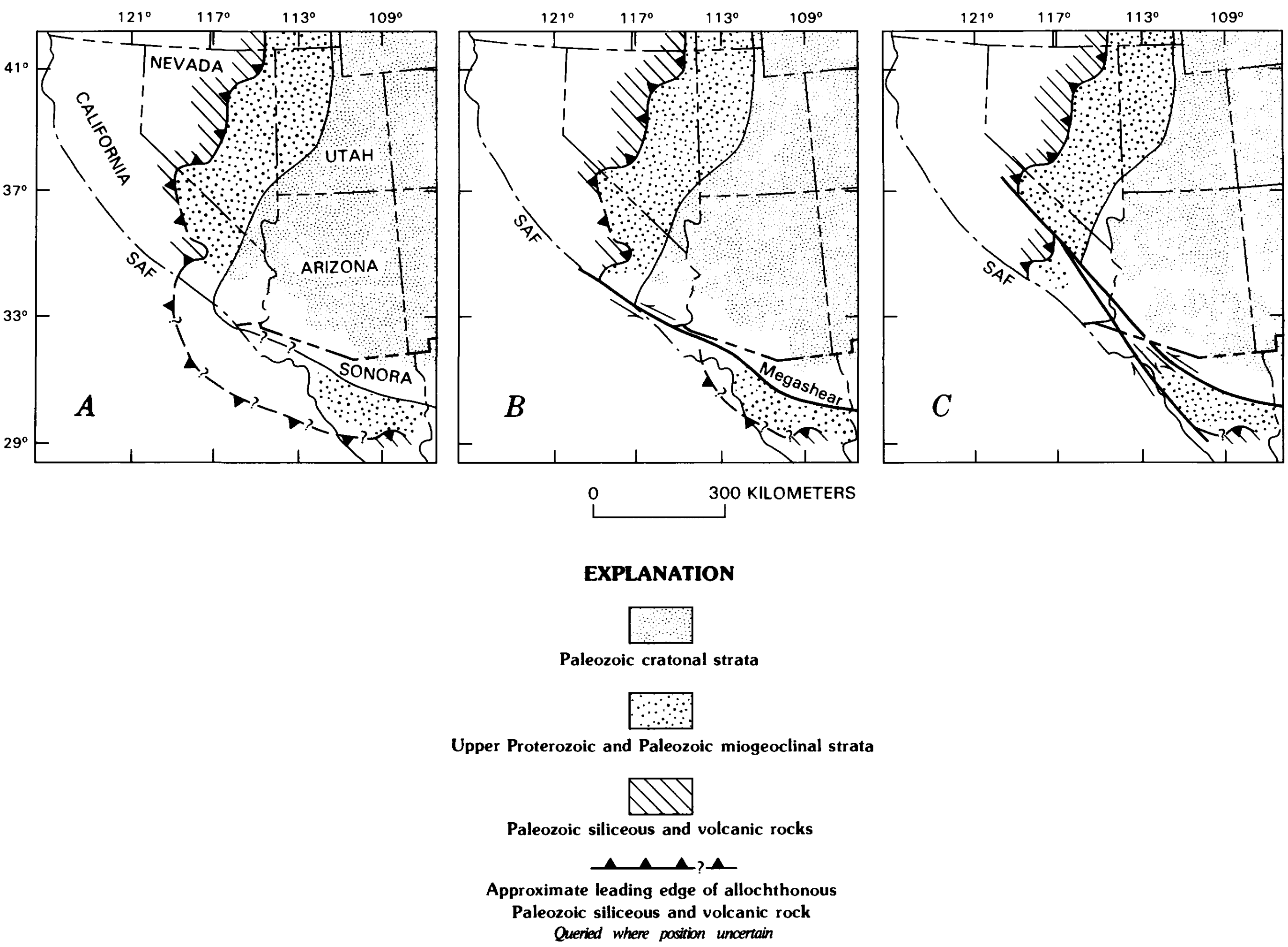


FIGURE 18.—Tectonic and paleogeographic models of the Southwestern United States and northern Mexico. *A*, Major facies and tectonic belts curve around the Southwestern United States and northern Mexico, unbroken by major left-lateral faults. *B*, Facies and tectonic belts are offset to southeast into northern Mexico along a major left-lateral fault. Fault as shown corresponds in Mexico to the Sonora-Mojave megashear of Silver and Anderson (1974) and Anderson and Silver (1979), but lies west of their proposed megashear in southern California. *C*, Facies and tectonic belts are offset to southeast into northern Mexico along a major left-lateral fault corresponding to the Mojave-Sonora megashear as originally defined. Later movement along a major right-lateral fault offsets western part of the Caborca block northwestward into southern California. SAF, San Andreas fault. Terrane west of San Andreas fault in western California and Baja California is not shown because of uncertainties in palinspastic reconstruction (Gastil and Miller, 1981).

Victorville rocks reached their present position by complex postmegashear displacements, such as tectonic transport along low-angle faults (L. T. Silver, oral commun., 1982), from a position east of the megashear, or as transport as a block northward from a position originally west of the megashear.

A possible interpretation (fig. 18*B*; Cameron, 1981, 1982; Stewart, 1982) is that the megashear, if it exists, lies south of the San Bernardino Mountains, a position compatible with the distribution of the Zabriskie Quartzite and the correlative Proveedora Quartzite (fig. 19). Although the Zabriskie Quartzite in the San Bernardino Mountains-Victorville area is on line with outcrops of the Zabriskie in the southern Great Basin region, the correlative Proveedora occurs to the southeast in a position that could indicate southeastward offset relative to the Southwestern United States. Such an offset also accounts for the similarity of the Caborca rocks to those in the Southwestern United States.

The concept of the Mojave-Sonora megashear or a related left-lateral fault does not rule out the possibility that the upper Proterozoic and Paleozoic continental margin of North America extended across northern Mexico. The distribution of upper Proterozoic and Paleozoic rocks in northern Mexico (fig. 18) suggests that an eastward trend of this margin would exist, even if the Mexican rocks were palinspastically restored to their presumed original positions before left-lateral movement. This eastward trend is also inferrable from paleocurrent studies (Stewart, 1982) that show a progressive change in trend from westerly in Idaho and Utah, through southerly in New Mexico, to southeasterly in Texas (fig. 14).

MODEL C

Comparison of the upper Proterozoic and Cambrian rocks of the Caborca, San Bernardino, and southern Great Basin regions suggests a third model (fig. 18*C*) in which the Caborca rocks were displaced southeastward along the left lateral Mojave-Sonora megashear, situated where Silver and Anderson (1974) originally placed it across the eastern Mojave Desert and Sonora. After this offset, a tectonic block that includes the San Bernardino Mountains-Victorville area was detached from the southwest side of the Caborca block and moved right laterally northwestward to its present position. This concept is appealing because some parts of the the Caborca sequence appear to be more closely tied lithologically to the sequence in the southern Great Basin than to that in the San Bernardino Mountains. In the Caborca region, rocks correlative with the Rainstorm Member of the Johnnie Formation of the southern Great Basin, including a distinctive 2.6 m thick oolite (the "Johnnie oolite"), indicate a close tie to the southern Great Basin. In the San Bernardino Mountains, however, this oolite is absent, and the Rainstorm Member, even if it is present, is not clearly defined. These correlations suggest that some parts of the Caborca sequence are more closely allied to the southern Great Basin than to the San Bernardino Mountains. Such comparisons are, nonetheless, risky because part of the Caborca and San Bernardino sequences are very similar. The Pitiquito-Gamuza-Papalote-Tecolote sequence of the Caborca region and the Moonridge-Green Spot-Delamar Mountain sequence of the San Bernardino Mountains are similar lithologically and have a similar order. The occurrence of conical stromatolites in the Gamuza Formation and of similar stromatolites in the lower part of the Green Spot Formation also indicates a similarity. However, these relations are all compatible with the idea

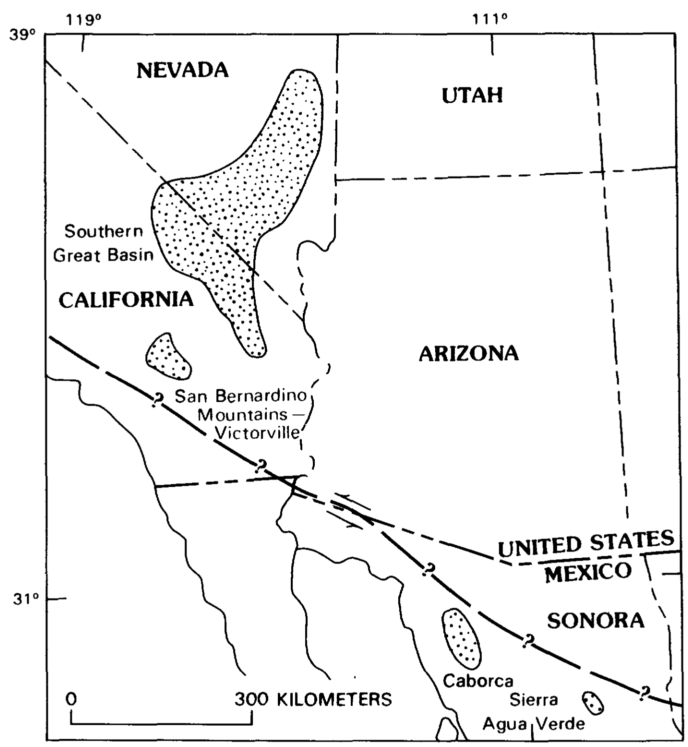


FIGURE 19.—Generalized distribution of the Zabriskie Quartzite in Nevada and California and of the correlative Proveedora Quartzite in northern Mexico (stippled areas), showing possible left-lateral offset.

that the strata of the Caborca region are intermediate in facies between strata of the southern Great Basin and San Bernardino Mountains. If so, a complex pattern of disruption, such as that in model C (fig. 18*C*), is possible.

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