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GEOLOGY OF SIERRA DE SAMALAYUCA, CHIHUAHUA, MEXICO

by

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ABSTRACT

Sierra de Samalyuca is a linear range about 410 meters high and 19 kilometers long, just west of the Juarez-Chihuahua highway, 55 kilometers south of Juarez. The three rock types in the sierra are mildly metamorphosed shale, conglomerate, and quartzarenite. They were probably derived from a northern source which yielded chiefly metaquartz, metachert, and igneous quartz. These rocks were deposited at some time after Precambrian and probably before Late Jurassic time. They now stand in an asymmetrical anticline whose axis strikes N 50° W.

These rocks appear to underlie outcrops of Late Jurassic rocks which crop out 2 kilometers northeast of the sierra. Although the Jurassic rocks are not metamorphosed and appear to have been deposited on undeformed rocks that now form the sierra, the sierra rocks now contain metamorphic minerals including muscovite, chlorite and sericite. The micas formed as a result of large shear stresses developed during the folding of the rigid, thick quartzarenite and conglomerate beds. The more plastic Jurassic siltstone and limestone beds yielded before developing large stresses, and consequently, micas did not form.

Cleavage is well developed in all three rock types in the sierra. In the shale beds, the cleavage approximates axial-plane cleavage; in the quartzarenite and conglomerate beds, it is fracture cleavage. Three cross faults that cut the sierra appear to have strike-slip displacement and to be penecontemporaneous with folding.

The rocks in Sierra Samalayuca are the oldest rocks in the region. There are three explanations for this structural high. The sierra may be an upthrown basement block, an allochthonous thrust sheet, or an abnormally high fold. The attitudes of the sierra rock and the Jurassic outcrops are subparallel. At places in this region, magnetic gradients seem to indicate high-angle faults in the basement, however, such steep gradients are absent near the sierra, hence I favor the fold interpretation. A well being drilled by Pemex near the axis of the anticline may indicate which interpretation is correct.

RESUMEN

La Sierra de Samalayuca, de 410 m de altura y 19 km de largo, está situada al oeste de la carretera Juarez-Chihuahua, 55 km al sur de Ciudad Juarez. Los tres tipos de roca que afloran en la sierra son: lutita poco metamorfizada, conglomerado, y cuarzoarenita. Estas rocas son probablemente derivadas de una fuente de origen situada al norte, la cual dió principalmente metacuarzo, metapedernal y cuarzo igneo; fueron depositadas poco despues del Precámbrico y probablemente antes del Jurásico, ahora afloran en un anticlinal asimétrico orientado N50°W.

Las rocas aparentemente subyacen a las rocas del Jurásico Tardio que afloran a 2 km al noreste, las cuales no están metamorfizadas y parecen haber silo depositadas sobre las rocas no deformadas de la sierra; las rocas de la sierra contienen ahora mineralcs metamórficos incluyendo muscovita, clorita y sericita. Las micas se formaron como resultado de grandes esfuerzos cortantes desarrollados durante el plegamiento de las capas rigidas y gruesas de cuarzoarenita y conglomerado. Las capas de limolita y caliza jurásicas más clásticas, cedieron antes de desarrollar esfuerzos grandes y consecuentemente no se formaron micas.

El clivaje está bien desarrollado en los tres tipos de rocas de la sierra. En la lutita, el clivaje se aproxima al clivaje de piano axial; en la cuarzo-arenita y las capas conglomeráticas hay clivaje de fractura. Tres fallas transversalcs que cortan la sierra parecen tener desplazamiento a rumbo y a la vez ser penecontemporáneas al plegamiento.

Las rocas de la Sierra de Samalayuca son las rocas más antiguas de la región. Existen tres explicaciones para este alto estructural: la sierra puede ser un bloque del basamento levantado, puede ser una cobijadura alóctona o un pliegue anormalmente elevado. Las rocas de la sierra y los afloramientos jurásicos son subparalelos; en algunas localidades de la region, los gradientes magnéticos parecen indicar fallas de alto ángulo en el basamento, Pero estas gradientes inclinados están ausentes cerca de la sierra; de ahi que favorezca yo la interpretación de pliegue.

El pozo ahora perforado por Pemex cerca del eje del anticlinal obviamente puede indicar cual interpretación es la correcta.

INTRODUCTION

The Sierra de Samalayuca is a linear range bearing northwest from the Juarez-Chihuahua highway, 55 kilometers south of Ciudad Juarez. The beds exposed in the sierra stand in an anticline, completely surrounded by bolson fill. On the northeast and southwest sides of the sierra are small hills in some of which are beds of Neocomian age; in others the rocks contain no fossils, but are somewhat similar in texture and lithology to either the Neocomian rocks or the rocks of the sierra.

The rocks in the sierra have yielded no guide fossils, but Ramirez (Navarro, 1968) found shell fragments in the limestone cobbles of a conglomerate bed. Therefore the possible ages of the sierra rocks range from Cambrian to Early Cretaceous.

The Neocomian rocks are unmetamorphosed, but the sierra rocks appear considerably metamorphosed, a discrepancy which has led to problems concerning the nature of the boundary between the sierra and the Neocomian rocks. The boundary is nowhere exposed, and it has come to be assumed that it is an angular unconformity with a large lacuna.

In 1964 and 1966, studies of the geology of the sierra were made by Compania Fresnillo, at the time operating copper mines in the sierra (Wilson, 1964, and Duarte, 1966) . These studies were primarily structural, showing attitudes of ore bodies, with little information about the petrography and mode of ore emplacement. By the time of my investigation, more was supposed about the geology of the Sierra de Samalayuca than was known.

ACKNOWLEDGMENTS

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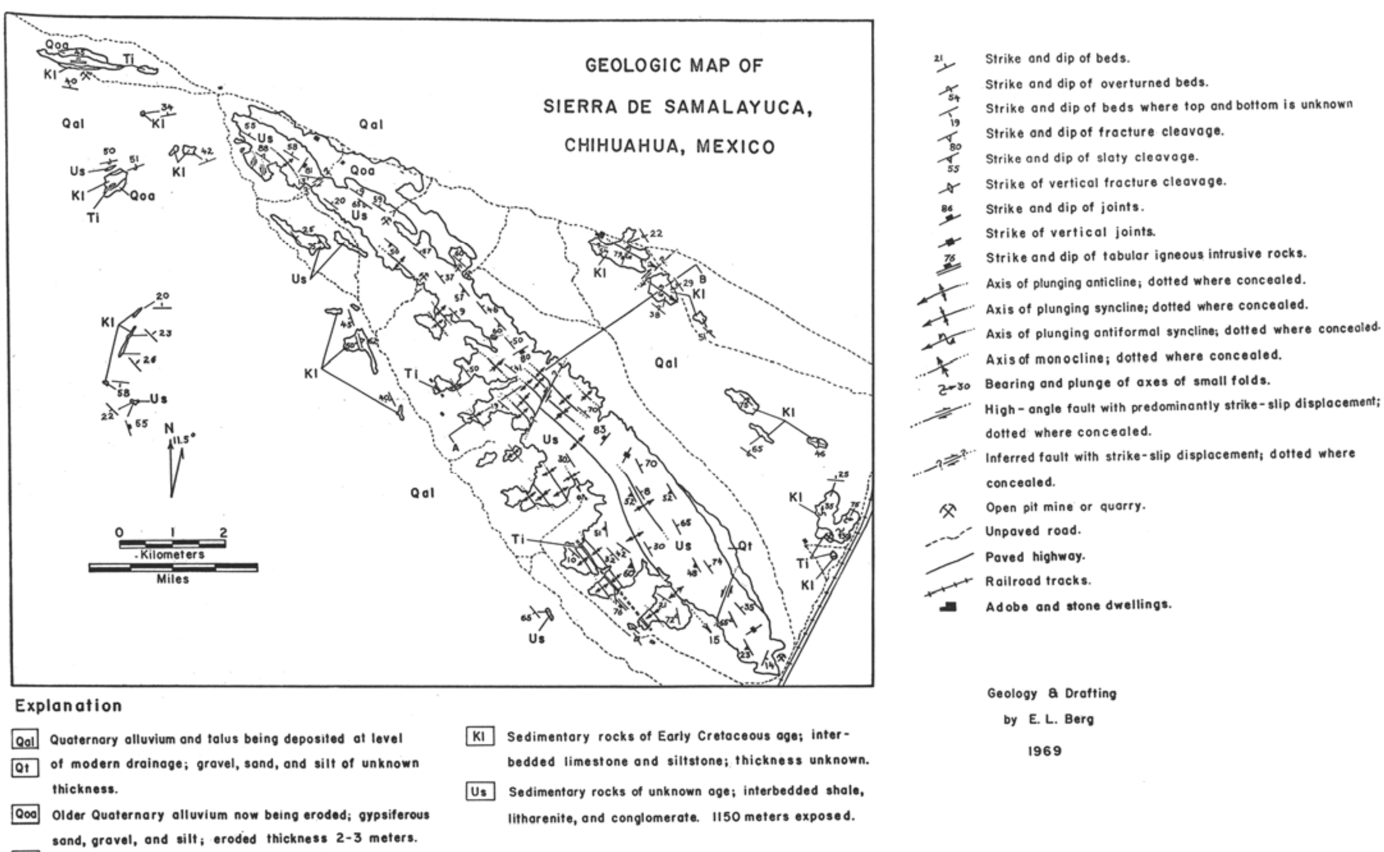
Dr. William R. Muehlberger, Prof. Ronald K. DeFord, and Dr. Keith Young all contributed to this report by giving freely of their valuable time and widespread knowledge of northern Mexico.

REGIONAL GEOLOGY

Before 1968, little was known of the age of the rocks exposed in the sierra and rocks near the sierra appeared to have few fossils. They appeared to be metamorphosed, in some places having every appearance of greenschist, hence most investigators considered the rocks of the sierra to be much older than the fossiliferous rocks. The fossil beds have been considered Jurassic by most authors, including King (1947) and Humphrey (Diaz, 1956). Recent maps show the sierra as Jurassic, but many geologists considered the sierra rocks to be as old as Precambrian because of the metamorphism.



A recent restudy shows that the age of the ammonites from "Jurassic" rocks is Neocomian. Petrographic and structural investigations described in this paper indicate that the sierra and Neocomian rocks were deformed at the same time, and that the grade of metamorphism of the sierra rocks is much lower than previously supposed.

It appears that the sierra rocks were deposited between Late Paleozoic and Early Cretaceous time. The sediment-type distribution in the sierra indicates that the elastic material came from the north or northeast, possibly a nearby mountainous terrain composed of a metamorphic basement complex.

In the Franklin Mountains at El Paso, there is an angular unconformity between Precambrian and Cambrian rocks. Periods of non-deposition and erosion occur throughout the Paleozoic section, and an unconformity is present on the Permian rocks. Most of these unconformities do not appear to represent periods of mountain-building. The history of the southeast New Mexico-West Texas region suggests that the most probable time of exposure of a basement complex in a mountainous terrain was between Late Carboniferous and Early Permian time.

In the Hueco Mountains east of El Paso, rocks of Early to Late Paleozoic age are unconformably overlain by lower Cretaceous rocks, but do not appear likely to have supplied the siliciclastic material at Samalayuca.

Near Van Horn, farther east, metavolcanic and metasedimentary rocks of Precambrian age are unconformably overlain by the Precambrian (?) Van Horn Sandstone, which bears obvious lithologic and textural similarity to the Samalayuca rocks. This in turn is overlain by the Powwow Conglomerate Member of the Permian Hueco Limestone. In places the Powwow Conglomerate rests directly on the older Precambrian metamorphic rocks. The Samalayuca rocks may be correlative with, or reworked from, the Van Horn Sandstone.

On a field trip to the Samalayuca area in 1968, W. T. Haenggi stated that the rocks in the sierra were texturally similar to the Las Vigas Formation; the Las Vigas Formation is primarily of Aptian age however, and the sierra rocks are no younger than Neocomian. It is possible that the Neocomian rocks in the area correlate with the Navarrete Formation, which has also yielded Neocomian fossils, and underlies the Las Vigas Formation. (Haenggi, 1966). However, the sierra rocks may correlate with the older Las Casitas or La Caja Formations.

STRUCTURAL GEOLOGY

The rocks exposed in the sierra have been folded into an asymmetrical, non-plunging anticline bearing N 50° W. The southeasternmost 2 kilometers are sharply hinged to plunge 15° southeast. The northwest end stops abruptly without plunge along a linear feature distinctly visible on aerial photographs. Recent seismic work done by Seismic Services for Pemex indicates that linear features in this orientation are high-angle faults with predominantly vertical displacement (Fuller, 1969). The southwest limb of the anticline dips about 20°, but is interrupted by several minor folds.

At the time of folding, movement occurred along many strike-slip faults oriented perpendicularly to the fold axis. At least three of these faults cut the whole anticline (Fig. 1). Minor folds on opposite sides are dissimilar and cannot be matched across the faults. In many places, cross-faults have little lateral continuity, and do not cut the whole anticline, but appear to die out by deflecting across beds until displacement is absorbed between bedding planes. In places, shear stress in the orientation of the cross-faults was relieved by formation of en-echelon gash fractures where faults did not break completely through.

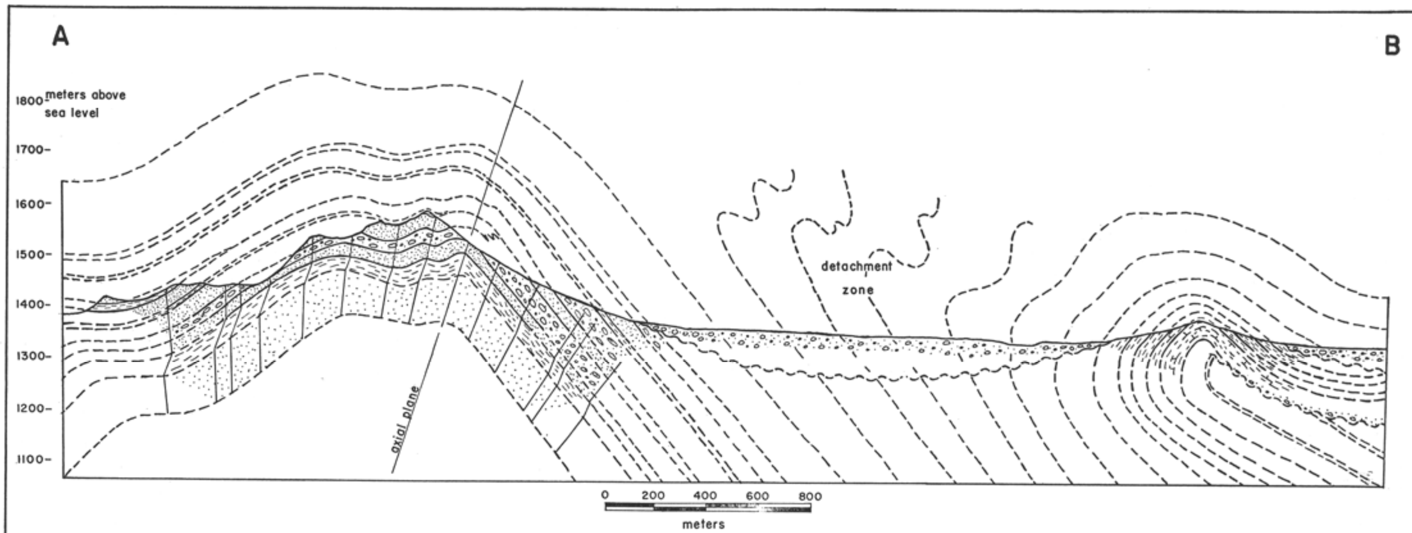
The 3 chief rock types exposed in the sierra—shale, litharenite, and conglomerate—all show well-developed foliation. In the shale beds, axial-plane cleavage is predominant, but is refracted where the shale beds contact conglomerate and litharenite beds. In these more competent rocks, cleavage approximates fracture cleavage orientation (Fig. 2).

In addition to cleavage, the rocks of the sierra have been fractured by regular, planar joints. Most of the joints strike within 30° of normal to the axis of the anticline, and dip more than 60°. Most joints show plumose markings and slickensides, cataclastic veneers, and sheared grains are rare, therefore, these joints are probably tensional features.

The sequence in which folds, cross-faults, cleavage, and joints formed is not clearly definable. Joints can form as soon as the deforming stress pattern is established (Badgely, 1965, and Price, 1966), since they need not be a product of finite strain in the rocks, as is cleavage. If the joints formed before the cross-faults, which have nearly the same orientation, they were preserved as tensional markings. Considerable elongation parallel to the axis of the anticline is evidenced by thick (1/2-4 cm) coatings of milky quartz on joints oriented perpendicularly to the axis. Actual elongation of detrital grains in oriented thin sections were not observed.

As only minor features are discontinuous across the cross-faults, the faults probably formed after the major anticline had been folded, but before the actual end of deformation. The cleavage in the rocks probably formed throughout the period of deformation. Thin sections of litharenite show that sericite growth was not oriented, except along previously existing fracture cleavage. Slaty cleavage in the shale beds is oriented approximately parallel to axial-plane cleavage, and may be due to both rotation and oriented growth of sericite. The very low-grade metamorphism exhibited in the rocks of the sierra as a whole indicates that the rotational origin was the most important. Therefore, the cleavage appears to be a somewhat later feature than the jointing, although their periods of formation overlapped, as evidenced by inconsistent cross-cutting relationships observed in the field.

The nature of the boundary between the sierra rocks and Neocomian rocks near the sierra is unknown. At an outcrop near the northwest end of the sierra, nonfossiliferous foliated litharenite and non-foliated limestone containing ammonite imprints crop out within 80 meters of each other,



Vertical section AB, showing structural relationship of antiformal syncline to sierra, and relationship of fracture and slaty cleavage. Bedding is not to scale. Thickness of alluvial fill is not known. Note that cleavage in shale beds has same orientation as axial plane, but cleavage in sandstone and conglomerate beds fans out across the anticline.

FIGURE 2

in parallel overturned orientation. On both the northeast and southwest flanks of the sierra, non-foliated siltstone and limestone beds crop out one to two kilometers from the sierra, and strike parallel to the axis of the anticline. Although the sierra and the fossiliferous rocks may not be conformable, it appears that they were parallel at the time of deformation.

Both the sierra and fossiliferous rocks are intruded by diabase dikes, which cut across bedding and folds. The intrusion was probably associated with volcanic activity in the area during Tertiary time.

The antiformal syncline off the northeast side of the sierra (Fig. 1) is probably a flap structure formed after the main period of deformation, possibly after intrusion, by collapse following erosion of supporting beds (Fig. 2).

The linear feature that cuts the northwest end of the sierra is probably much younger than the folding. Other faults in the same orientation, farther west in Chihuahua, appear to cut bolson fill, so this "fault" may be the youngest structure in the mapped area.

METAMORPHIC FEATURES

Previous investigators have considered the rocks of the sierra to be metamorphic, but none studied them petrographically. Some confusion in the past concerning the grade of metamorphism was due to evident metamorphism of the detrital constituents of the sandstone and conglomerate beds. In some places, the shale beds have a phyllitic texture, and to the naked eye appear similar to talc. In thin sections, however, the "talc" reveals itself as sericite, and the detrital grains in the rock appear not to have been metamorphosed in place. There is a distinct gap in size of optically continuous particles in the chert and metachert grains. Chert grains have optically continuous particles less than 5 microns in diameter (Folk, 1969); all metachert grains have particles greater than 15 microns in diameter. The difference suggests the metachert is detritus from the source area. Little if any optical reorientation of quartz grains occurred in place, for isolated strained quartz grains occur in shale beds where stresses could not have been great enough to deform the quartz.

The metamorphic constituents of the rocks are chlorite, muscovite, phengite, and sericite. The muscovite appears to have grown by assimilation of sericite grains and clay minerals, and is found in small amounts in the shale, conglomerate, and litharenite beds. The chlorite and phengite appear to have grown in hydrous solution in the litharenite and conglomerate beds. Its formation was retarded in the shale beds by their low permeability. Phengite in the rocks indicates the presence of a silica-rich groundwater at the time of its formation (Deer, Howie, & Zussman, 1966). Dolomite rhombs are present in all detrital grains, but are most common in metachert grains, which may have had greater permeability and solubility than the quartz and common chert had at the time of replacement.

If the replacement dolomite was present before the mica formed, the upper limits of metamorphic conditions would be between 440° C at 200 kilobars and 500° C at 1600 kilobars (Bowen, 1940) . Above these limits, the dolomite would have reacted with silica and water to produce talc. The reaction could have been retarded if the silica grains scaled the dolomite from water, or if the rock were dry at the time of metamorphism. The presence of the hydrous micas, chlorite and phengite, indicates that the rocks were not dry. Because the rocks were wet, and because great shear stress developed in the thick, rigid, quartzite and conglomerate beds during folding, the mica minerals could have formed under temperatures and pressures much lower than those given by Bowen.

The absence of metamorphic minerals in the nearby Cretaceous rocks is probably due to the relatively lesser rigidity of these rocks. If both the Cretaceous rocks and the sierra rocks were deformed at the same time, much greater shear stress would have developed in the sandstone and conglomerate beds of the sierra than in the Cretaceous limestone and siltstone beds.

Although the Cretaceous rocks were severely deformed, they developed no cleavage, not even in siltstone beds where sericite growth might be expected. Oriented samples from the axis of the antiformal syncline north of the sierra showed 17.6 percent elongation parallel to the axis of the fold, using the Cloos method of constant-volume strain measurement (Cloos, 1947) . Thin sections of these siltstone samples disclosed no sericitization.

DEPOSITIONAL FEATURES

The shale and sandstone exposed in the sierra are distributed evenly throughout the area, but the conglomerate is much more common on the northeastern flank of the southeastern half of the sierra than elsewhere. All three rock types occur in tabular beds having nearly planar boundaries with no evidence of channeling and scouring. The conglomerate and sandstone beds are from a few centimeters to 3 meters thick and the shale beds are from 2 to 20 centimeters thick. There is no consistent order to the sequence in which the three types of rock were deposited. The sandstone, shale, and conglomerate occur in discrete units, with no gradational boundaries or graded bedding. Where sandstone or conglomerate beds rest on shale, the bottoms of the beds in many places show load casts.

The detrital constituents of the sandstone and conglomerate, in order of abundance, are common quartz, vein quartz, metamorphic rock fragments such as slate and marble, as well as metachert, chert, and metallic oxides. Because the quartz and metachert compose about 70 percent of the rock, it may be called a litharenite, following Folk's 1968 classification of sandstones. The litharenite is poorly to moderately sorted; quartz and chert of sand size are angular, and metamorphic rocks fragments are subround. Quartz and chert of pebble and cobble size are well-rounded, subspherical, and generally elongated in one direction. The elongation is a transportational feature, for oriented sections disclosed no relation between the long axes of cobbles and strain ellipsoids for the sierra.

The scarcity of channeling and crossbeds indicates that the sandstone and conglomerate were deposited in an open body of water. The similarity of the sandstone and conglomerate beds may indicate that they were both deposited in the same manner, the difference in size of the material being due to different sorting and transportational mechanisms that operated before deposition. Different source areas might also produce the size difference, but the similarity of the detritus indicates that they both were derived from the same source rock. The thin shale beds were probably deposited as muds between influxes of coarse detrital material. They appear to have greater lateral continuity than the sandstone and conglomerate beds, and undoubtedly had much more time to be moved by offshore currents than the coarse material.

The rocks in the sierra may have been deposited on a near-shore submarine fan. The sand probably accumulated on a beach during normal conditions and was transported seaward during more turbulent periods. The conglomerate may have been brought in by rivers that emptied onto the fan during floods. The predominance of conglomerate on the eastern northeast flank of the sierra indicates that the source area was to the north or northeast possibly in southeast New Mexico or west Texas.

RECENT HISTORY

At present, material eroded from Sierra de Samalayuca is being deposited in surrounding closed basins. Remnants of an older and higher level of basin-fill lap onto the northeastern side of the sierra (Fig. 1) . These higher deposits are now being eroded by streams with a lower base level than that of the streams that deposited the major part of the bolson-fill. The lowering of base level may be explained by the fact that fine-grained material is now being blown out of the basins. In an earlier more humid climate, the basins may have been damp enough and covered with enough vegetation to prevent blowout and at times they may have been occupied by lakes that raised the base level of the older streams.

The basin fill on the northeast side is now being eroded by small, subsequent streams working back from the Rio Grande; however, these widely spaced streams do not yet affect drainage near Sierra de Samalayuca.

Groundwater in the basin fill may be perched near the sierra in some places where large plates and blocks of selenite are forming within 20 to 30 centimeters of the surface of the basin deposits. At the top of perched water tables water circulation would be continuously upward on account of evaporative drawoff. Thus a continuous supply of Ca^{++} ions would be available. Eardley and Stringham (1952) suggested that bacteria are responsible for the oxidation of sulfur and formation of large selenite plates along the shorelines of Great Salt Lake. The same processes may have been operative at Samalayuca.

To the east and south of Samalayuca is a large field of moving sand dunes. The quartz grains in the sand are not of the type exposed at Sierra de Samalayuca, nor of any type from strata I have seen in the area. It has been suggested that the ancestral Rio Grande transported the sand to a large lake occupying the area south and west of Samalayuca. After the dessication of the lake, the sand was blown eastward out of the lake bed across considerably higher terrain to its present site. The dunes may become immobile as they approach the mountain ranges for no moving dunes exist closer than two kilometers from the windward flanks of Sierra de Samalayuca and Sierra del Presidio. Instead of lapping up against the windward flanks of the ranges, the sand seems to accumulate in large dunes parallel to the axes of the ranges. These large dunes may mark the point where storm winds are deflected upward by the ranges.

ECONOMIC GEOLOGY

The rocks of the sierra and the younger beds near the sierra have been intruded by diabase dikes and sills. Although these were dry intrusions that altered country rock only slightly, there are a few places where the rock has been mineralized. The intrusive rock itself bears considerable limonite as fracture coatings. A deposit of this type is mined on the northwest end of the sierra, where a large sill lies on, and is intercalated with, a bed of calcareous sandstone.

The most common ore minerals, malachite and azurite, occur on fracture surfaces and as finely disseminated grains in shale. As intrusions are lacking near most of the deposits of this type, it is not certain what concentrated the ore minerals there. Perhaps the heat of the intrusions mobilized water in the rock, causing the minerals to precipitate on fracture surfaces. This water may have been partly responsible for the formation of thick quartz coatings on joint surfaces throughout the sierra.

The largest mining operations were undertaken by Compania Fresnillo until 1966, when activity ceased. In April of 1969, one of the malachite deposits was being worked, but I was unable to determine the name of the operator. The ore was being hand sorted and loaded into trucks which carried the concentrate into Juarez, or, when railroad cars were available, dumped it at the station in Samalayuca. One barite deposit along the contact between a diabase plug and Neocomian silty gypsiferous rock on the eastern edge of the map area (Fig. 1) has been mined, but by whom and for what purpose I was unable to learn.

There are 3 fresh-water springs with ponds on the northeast flank of the sierra, but only the middle one may be used by strangers without fear of sickness. Water for the houses in Samalayuca is taken from hand-dug wells at the homesites and almost all of these wells are less than 15 meters deep. The houses are built of adobe and of stone from the sierra.

Juniper trees on the sierra were once used for building and for firewood, but only a handful of living trees remain today.

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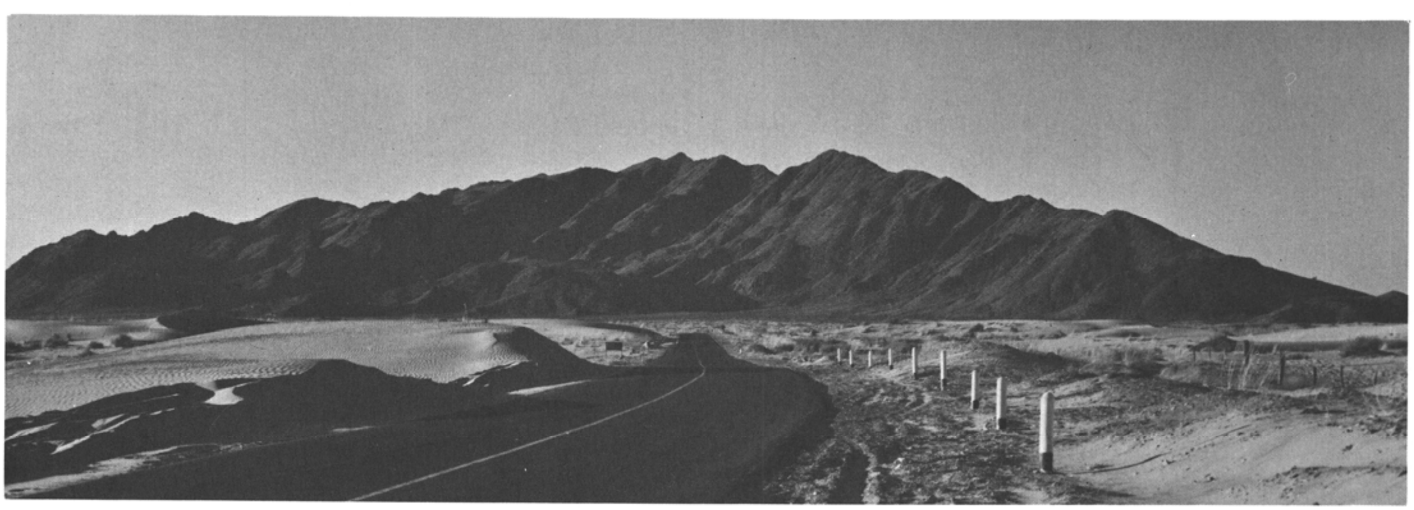

Southeastern end of Sierra de Samalayuca from a point within Los Médanos—one of the larger dune fields in North America.