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GEOLOGY OF THE SIERRA DE CRUILLAS TAMAULIPAS, MEXICO.

by

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of the requirements for the degree of Master of Arts.

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INTRODUCTION

In the summer of 1930 an expedition from the University of Michigan under the leadership of Prof. Lewis B. Kellum made a study of the geologic and biologic features of the San Carlos Mountains of Tamaulipas, Mexico.

During the latter part of the summer the writer had the privilege of making a detailed study of the easternmost range of these mountains known as the Sierra de Cruillas. The following paper is primarily a discussion of the geology of this range. A brief description of the geography is followed by a more detailed discussion of the sedimentary and igneous rocks and of the structural relationships. The few fossils found are, also, described.

This range was chosen for detailed work because it is a complete mountain unit separated from the mountains on the west by a north-south erosional and structural depression and surrounded on the north, south, and east sides by the coastal plain from which it rises quite abruptly. Due to its position it is the key to the structure of the eastern half of the San Carlos Mountains. The surrounding plains are pierced by many volcanic plugs, and within the mountain area are numerous intrusive igneous masses with hypabyssal characters. Lastly, the area was sufficiently small to permit detailed study during the four weeks available.

The writer's field studies were carried on from temporary camps established at two places on opposite sides of

the range. One was at El Milagro on the western edge of the Sierra de Cruillas, the other near the sacred shrine of the Virgen de Manserrata near the eastern border. A Mexican boy was employed to cook and look after camp; another native, familiar with the range, acted as guide and field assistant.

Rough country roads, difficultly passable for an automobile, skirt the margin of the Sierra in most parts. From Cruillas a car can enter the valley on the western side of the range as far as El Milagro, or may approach the north side of the range south of Rinconada. East of the mountains a north-south road from Cruillas to Jimenez passes within a mile of the Sierra. An automobile can get to La Laguna ranch from this main road.

Within the Sierra there are no roads and few trails are even passable for pack animals. Only five real trails enter or cross the mountains, though numerous cow paths and stream channels and areas of thin underbrush make it possible to reach all parts of the Sierra on foot. On the eastern side of the mountains three trails radiate from the Virgen de Manserrata; one to Cruillas, one to Rinconada, and the third southeast to Arroyo Mimbres, connecting with the main road east of the mountains. All of these are passable for saddle animals. On the western side, two trails extend from El Milagro across the mountains. One of these leads northeast to Rancho Rinconada, passing southeast of Loma Palmar and

descending the canyon of Arroyo Palmar to the east; the other extends southeast across Savania del Lervaniz, then south to a tributary of Arroyo Agua Grande and east to La Noria and La Laguna ranches outside the mountains.

All mapping was by pace and compass traverse. As a rule the canyons were followed because there the walking was less difficult, the rock exposures fresher, and the trails less obstructed by underbrush. Canyon Mimbres in its lower two miles is excellent for travel but the tributaries of this stream can be traversed only with great difficulty owing to the accumulation of large limestone blocks in the bed and the dense tangle of brush.

Due to the fact that only a few of the canyons had been named by the natives it was found convenient to refer to them by the letters of the alphabet. The southeastern hills in this report are named Lomas del Sur. Names applied to the largest topographic highs refer to groups of hills of nearly the same height. These are related structurally and physiographically.

The topographic map of the Sierra de Cruillas as prepared by the Mexican survey is so inaccurate as to be worthless in the field. The outlines of the area were approximately determined by Prof. Kellum in 1926. At this time he made several traverses into the interior and determined the general relationship of this uplift to the folded region to the west.

The writer's study of this range was supervised by Prof.

Kellum who spent considerable time with him in the field and made all arrangements for the native help employed during the field work. Prof. E. H. Watson spent a day studying the igneous body on Loma Palmar. Other members of the expedition were helpful in collecting fossils, in taking pictures, or in giving suggestions. The writer is also indebted to Prof. Hunt for his assistance in the determination of the igneous rocks.

GEOGRAPHY

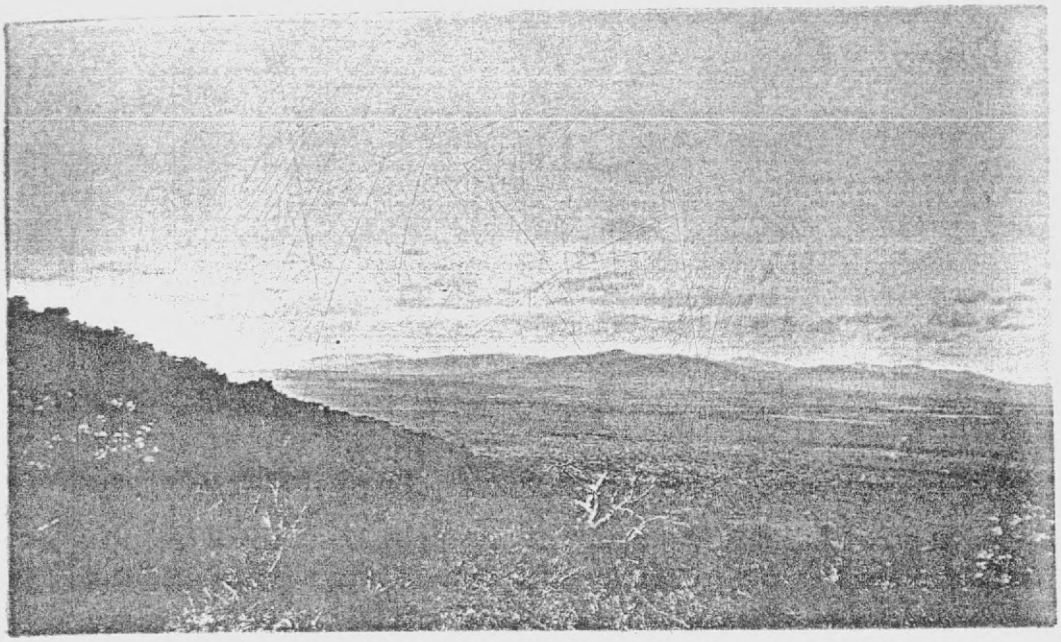
Location

The San Carlos Mountains are situated in northeastern Mexico slightly north of the center of the state of Tamaulipas and about a hundred miles southwest of Brownsville, Texas. They extend roughly east-west about forty miles. The Gulf of Mexico is about forty miles to the east and the Sierra Madre Oriental about twenty-five miles to the west. The mountains consist of several distinct topographic units, of which the easternmost is named the Sierra de Cruillas from the town of Cruillas lying about three miles north of the northeast edge of this range.

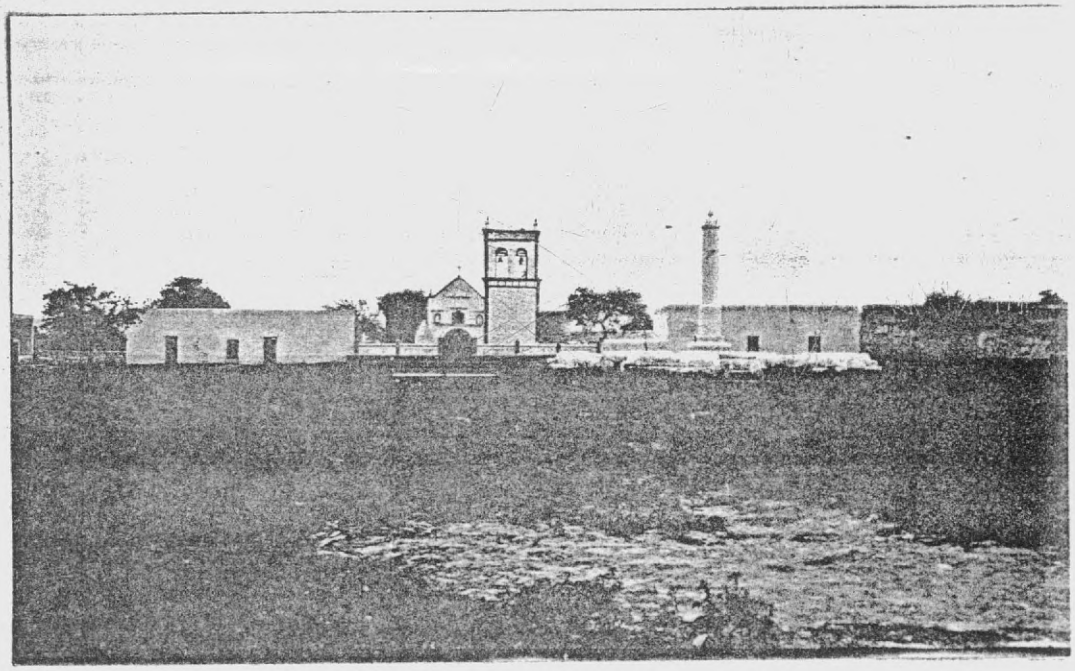
Culture

Cruillas is a typical, quiet, Mexican country town with a population estimated to be about 1500. Scattered around Cruillas for several miles are numerous cornfields which belong to the people in town. About a quarter of a mile to the west is a grove of oak trees which shelters several wells. Half a mile to the south of town a large earthen dam has been built across an arroyo to catch the run-off after heavy rains.

El Milagro is a village of about 100 people, situated on the west-central side of the Sierra de Cruillas in the valley which separates this range from the Sierra de Patado. The people of Milagro make a livelihood by raising livestock and by cultivating the few patches of soil in the valleys.



A. Sierra de Cruillas from 10 miles northeast of Cruillas.



B. Plaza in Cruillas.

There are no people living in the Sierra de Cruillas proper, but several ranches are located in the plain or valleys along its margin. In the valley of Milagro, one-half mile south of the village, is Rancho Los Pinos. Three miles north of the village is Rancho Los Torres. In the plain about one mile south of the southeast corner of the range is Rancho La Laguna. West of the ranch buildings about half a mile is a pond, which covers several acres. To the north of the buildings a few hundred yards several wells have been dug along a large arroyo. In the month of September, which was exceedingly dry, water was running in the arroyo a few yards down stream from these wells. A mile north of the northeast corner of the Sierra de Cruillas is the stock ranch of Rinconada. Here a large dam holds sufficient water for many cattle during the summer months.

One very interesting work of man, located in the eastern part of the range itself, is the sacred shrine of the Virgen de Manserrata. Here are the remains of a stone house and of a wall surrounding it. Nearby grow a number of large oak trees. Beneath one of these trees is a cave formed by solution along a joint plane. The steps leading down to the floor of the cave consist of limestone debris upheld by the roots of the oak. The cavity is not over ten feet in length or height, or over four feet in width. Its walls are dark from candle smoke. From them and from the ceiling hang strips of white crepe paper. At the back on a shelf in the wall about three feet from the floor is a brown doll not over two

feet high and clothed with long white dresses. The Mexican guide interpreted this figure by one word "Dios".

During the summer hundreds of people visit this shrine coming from places as distant as Matamoras. Usually sickness is the incentive for the pilgrimage. On they come, old and young, on foot and on horseback, leave an offering both financial and symbolic, and then return home.

Climate

The San Carlos Mountain region is quite arid. The climate is hot and tropical. The rainy season comes during the winter months with maximum precipitation in September. Occasionally cold winds from the north bring snow to the mountains. Fortunately for the expedition, this year was exceptional in that most of the rain fell in June and only a few showers occurred during the remainder of the summer. The run-off is unhindered in the uplands where the soil and grass are scant, but on reaching the plain the torrential waters are soon absorbed by the dry, limy soil and then evaporated by the hot, dry air, thereby producing a haze which was present at nearly all times during the summer.

Nature of the Fauna and Flora

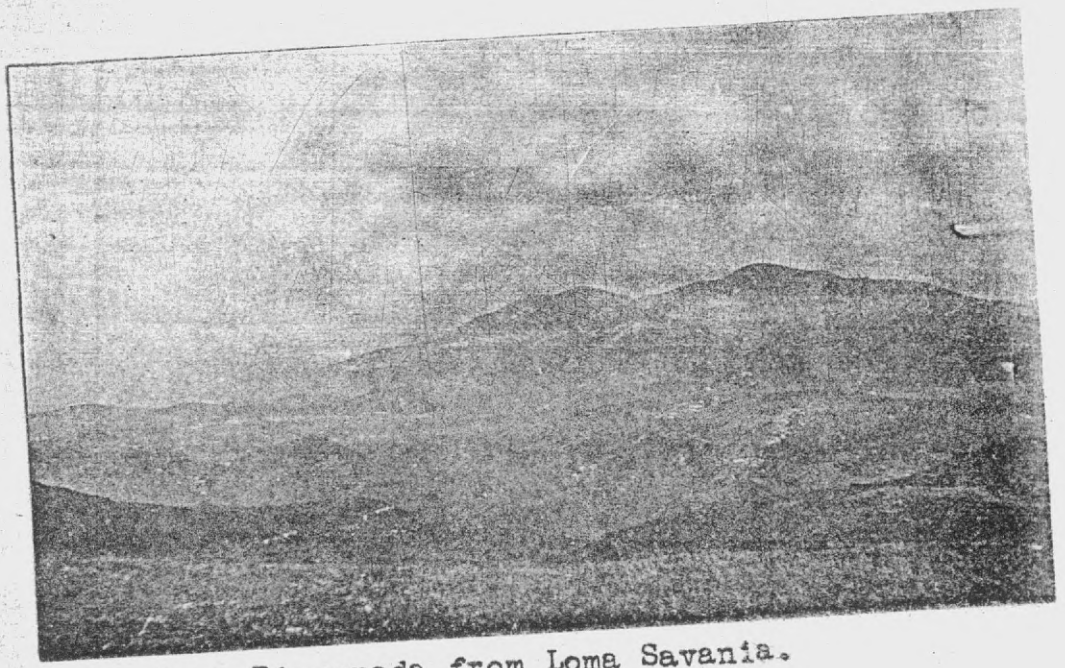
The type of vegetation in the Sierra de Cruillas is typical of a dry, subtropical region. The distribution of the varied flora is influenced by the nature of the soil, which in turn is determined largely by the character of the

underlying rock. Throughout most of the area the country rock is limestone, but locally the surface is underlain by igneous rock. The latter weathers easily to form a yellow to brown soil on which grass and flowers flourish, patches of scrub oak occur locally and palm trees are common. Some of the palms grow to large size and seem always to indicate the presence of underlying igneous rock. Underbrush is conspicuously absent or grows very sparsely on soil derived from the igneous rock.

The limestone decomposes slowly due to the dryness of the region and very little soil is formed. However, brush grows exceedingly prolific on it and in places is practically impassible, due to the tangle of branches and the numerous sharp thorns covering them. Much of the vegetation is higher than a man's head but affords practically no shade due to the small amount of leaf surface. Many cactaceous plants thrive here but are more abundant on the plains.

Most of the animals are well adapted to the hot, dry climate and the brushy vegetation. Burros and goats thrive on the leaves of the mesquite and similar trees. Among the wild animals, mapaches and turkeys are very numerous. There are, also, a few deer, a few peccaries, and some cat-like animals such as the tigre. Rodents are numerous in the valleys and plains. Snakes are scarce in the mountains but lizards and turtles are found nearly everywhere in great abundance. Ants and ticks are constant pests.

A. Cruillas from Loma Rinconada.



B. Loma Rinconada from Loma Savania.

TOPOGRAPHY

The Sierra de Cruillas is roughly trapezoidal in marginal outline with the maximum length of seven miles along the north side in an east-west direction and a width of four miles in a north-south direction.

The maximum relief is about 1250 feet above the plain. The topography is very rugged due to almost complete predominance of physical over chemical weathering, thereby producing steep cliffs and crags along the canyon walls and huge piles of large, angular blocks at their bases, or at the heads of the canyons and gorges. The effect of the dissolving action of rain water is very evident on the surfaces of the limestone layers exposed on the ridges. They are ploughed with small, rounded, irregularly arranged furrows about half an inch in depth, and resemble the impressions made by drawing the fingers over the surface of modeling clay. In addition, the weathered outcrops are traversed by numerous fractures which have been widened by solution. But the main work of rain water is done at the time of the storm itself, when torrents of water carry the weathered debris down the canyons to the edge of the mountains and deposit them in long, thick piles. The canyons in their middle courses are thus swept quite clean, whereas their upper courses remain choked with accumulated debris where the transporting power of the water is less effective.

There are four conspicuous topographic highs. Savania

del Llervaniz situated a little southwest of the center of the region represents a group of hills of which the highest is about 2560 feet (780 meters)[1] above sea level. About two miles to the northwest is another group of hills called the Palmar which are about 70 meters lower. Loma Rinconada in the northeast corner of the area is about the same height. The southeastern group of hills, now named Lomas del Sur are topped by a ridge about half a mile long at an elevation of probably 670 meters. These topographic highs are roughly dome shaped with canyons draining them in nearly all possible directions.

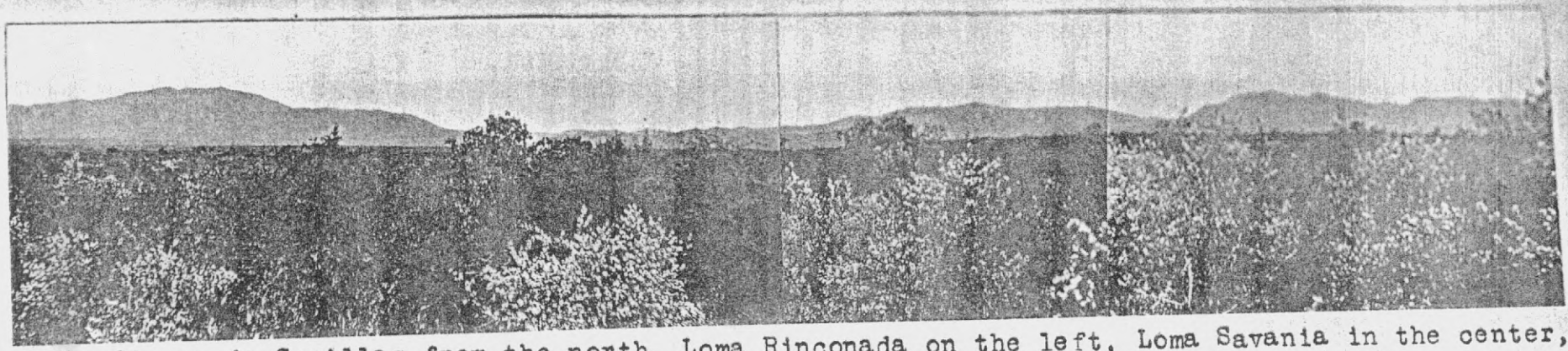
Canyon Mimbres and its branches drain the entire central portion of the mountains. It begins on the Savania in Canyon C, flows east to the junction of Canyon F, then southeast to Canyon E, and then east. In the middle of its course it is deeply entrenched and bounded by limestone cliffs several hundred feet high over which some of its minor tributaries enter as slightly hanging valleys. Here, also, the gradient of the canyon bed is less than the dip of the strata and behind the upturned edges of the latter large holes have been scoured in times of flood. This canyon is the largest in the range and separates the three topographic highs of Savania, Rinconada, and Lomas del Sur.

The second largest drainage system is that of Canyon Palmar which begins in a deeply eroded igneous mass in Loma

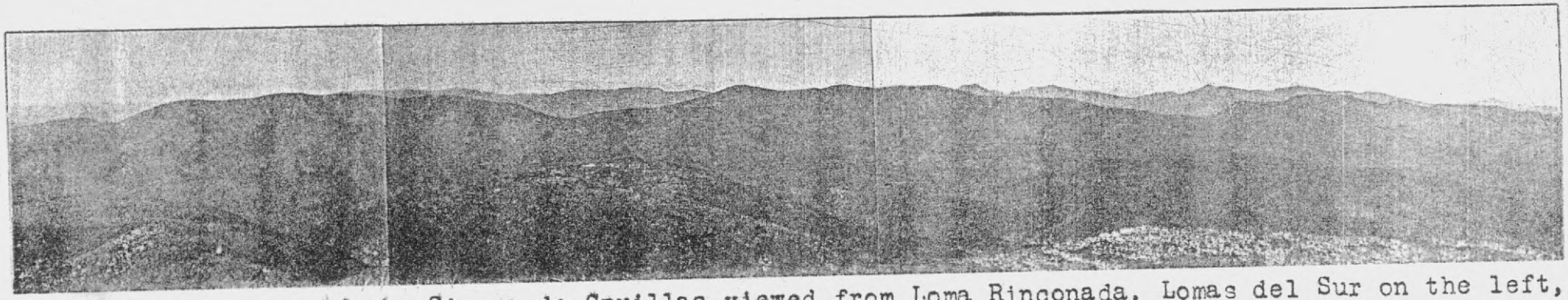
[1] Elevations in this range were determined by the aneroid and handlevel and are therefore of limited accuracy.

Palmar, flows south for a quarter of a mile and then northeast, thus separating Loma Savania from Loma Palmar. Three other deep canyons of major importance are Trinchera, Guijano, and Grande. Of lesser importance are Canyons Mesquite, de la Gueva, Mapache, Virgen, Yeso, de Leon, and about a dozen other unnamed canyons.

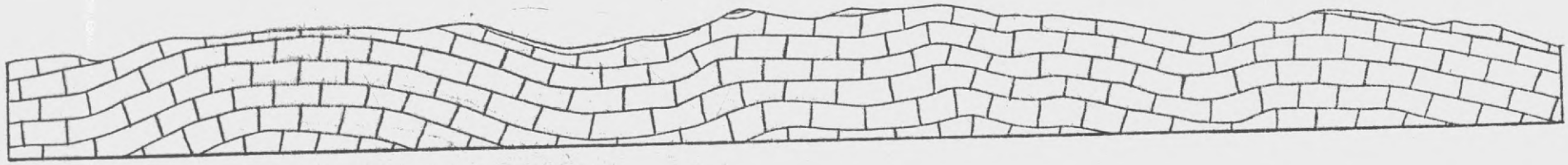
The drainage is consequent. Throughout the entire area it follows in a general way the dip of the beds. Thus the topographic highs are anticlinal highs. From their crests deep canyons radiate approximately at right angles to the strike and drain into the major synclinal valleys which they frequently enter at a sharp angle. Canyon Mimbres flows southeast across the Savania-Rinconada saddle and then east along the syncline separating the anticlines Lomas del Sur and Rinconada. Similarly Canyon Palmar occupies a synclinal depression. Not only does every important syncline contain a canyon but the largest canyons occur in the synclines.



A. Sierra de Cruillas from the north. Loma Rinconada on the left, Loma Savania in the center, Loma Palmar on the right.



B. The center of the Sierra de Cruillas viewed from Loma Rinconada. Lomas del Sur on the left, Loma Savania in the center, Loma Palmar at the right.



C. Structure Section of B.

PHYSIOGRAPHIC HISTORY

Erosion began in this region at the end of the Cretaceous when the strata were folded and elevated above the sea. Subsequent diastrophic movements and igneous intrusion have probably greatly accentuated this initial uplift and speeded up the erosive processes. Since the Mendez shale is now exposed in the San Carlos Mountains in the syncline immediately east of the Kemp Range and below the igneous masses on top of Cerro Jatero and Cerro El Chino, it probably covered the entire mountain area at the beginning of the uplift. This shale has been entirely removed from the Sierra de Cruillas and only a few remnants of the underlying San Felipe are preserved in the synclines. This shows that at least 3600 feet of shales and limestones have been completely removed, but does not necessarily mean that the Sierra de Cruillas was ever much higher than now. It seems certain that in the early Tertiary the rate of weathering in the soft, calcareous shales of the Mendez and the shaly limestones of the San Felipe must have been much faster than at present in the massive, resistant Tamaulipas limestone even if, as now, disintegration dominated over decomposition.

Due to slumping, which is characteristic of the Mendez and the San Felipe beds when unsupported, the deep canyons now carved in the Tamaulipas probably did not come into being until the overlying shales were removed in greater part and

are therefore especially characteristic of the late Tertiary and the present.

STRATIGRAPHY

General Features

The rocks exposed in this area are sedimentary, igneous, and metamorphic. The sedimentary rocks are of Lower and Upper Cretaceous age. To these may be added the limestone conglomerates forming today along the lower parts of the canyons. The igneous rocks of several kinds, principally in the form of sills, are younger than the Upper Cretaceous formations but are considered to have been formed in the same period. The metamorphic rocks were formed near the igneous-limestone contacts.

The accompanying table shows the age, Texas equivalents, relationship of formations, thickness, and general lithology of the sedimentary formations. Their areal extent is shown on the geologic map of the region.

The total thickness of Lower and Upper Cretaceous strata in the San Carlos region is estimated to be about 7127 feet (2173 meters). The thickness in the Sierra de Cruillas from the lowest exposure of the Tamaulipas limestone to the highest exposure of the San Felipe is about 1000 feet (305 meters). Limestone is the principal rock, although some shale is present in the San Felipe. In addition there is at least 200 feet of interbedded sill rock in some sections.

FORMATIONS IN THE SIERRA DE CRUILLAS REGION WITH PROBABLE FOREIGN EQUIVALENTS

PERIOD	EUROPE	TEXAS	SIERRA DE CRUILLAS Formation	Mem.	Thick.	LITHOLOGY
Recent					5 to 30'	Coarse gravels at edge of Mts.
Upper Cretaceous or Eocene	?			shale	1800'	Shales calcareous and nodular. Much like the Mendez
Upper Cretaceous	Santonian	Taylor		sandstone	4-16'	Fine-grained, gray, hard, fissile.
	Coniacian	Austin Chalk	Mendez shale	shale	2853'	Calcareous, nodular layers with occasional finer seams. Medium to dark gray. Weathers light gray, with some yellow in the more calcareous layers. The latter when metamorphosed resembles limestone.
	Turonian	Eagle Ford shales	San Felipe limestone and shales	Transition	50'	Thin-bedded lm. & sh., gray.
Comanchean	Cenomanian	Washita division			820'	Thin bedded limestones with interbedded calcareous shales. The former usually not more than 4" thick Slumping common. Chert rare. Light yellowish-gray to dark gray. Weathers darker. Bedding planes smooth
	Upper Albian			Trans.	100'	Thin-bedded limestones 6"-12" th., wavy bedding; gray; abundant bl. chert
	Middle Albian	Fredericksburg division	Tamaulipas lm.	Massive limeston.	800'	Massive beds 2'-6' thick. White to dark gray, but usually light gray. Weathers medium gray. Bedding planes seldom wavy. Stylolitic structures locally characteristic. Chert nodules (gray, brown, or black) present in rows parallel to bedding. Pyrite conc. rare.

Upper Cenomanian

SEDIMENTARY ROCKS

Lower Cretaceous Rocks

Tamaulipas Limestone

The Tamaulipas limestone is the oldest formation exposed in this area. The estimated exposed thickness is 800 feet but the total thickness is probably much greater. It consists of two persistent members,---an upper transition series about 100 feet thick and a lower, more massive series about 700 feet thick.

The massive limestone of the basal member varies from white to dark gray but is generally light gray. The weathered surface varies from light to dark gray and usually is slightly darker than the fresh surface. In some places the weathered surfaces are tinged with yellow. The rock is hard, uniform in character, and heavy bedded. The thickness of the beds varies from two to six feet and becomes thinnest near the top of the member. The bedding planes are seldom wavy. They are manifested by sharp breaks, or sometimes by very small partings of a softer limestone, often by well developed stylolitic structure, and frequently by chert nodules arranged in rows parallel to the bedding. Although chert is not as abundant as in the overlying transition beds it is fairly common in certain sections. It occurs only as nodules which are usually light gray, or in some places grayish-yellow, or yellowish-brown. Along any one row, however, the nodules are always the same color. These nodules may be rounded or

irregular and are seldom over six inches in diameter, although sometimes adjacent nodules merge to form an intricate mat along a bedding plane. In addition to the chert, small iron concretions are present but rare. Solution cavities along joint planes are characteristically exposed on the canyon walls.

The transition beds at the top of the Tamaulipas are made up of thinner ledges of limestone, six inches to a foot in thickness, with wavy bedding planes and partings of shaly limestone and shale. Black chert is very abundant along the bedding planes either as nodules or in lenticular bands one to six inches in thickness and varying from a few inches to five feet in length. The nodules are of irregular shape and rarely exceed four inches in diameter. The limestone on a fresh surface has a variable gray color, usually darker than the limestone of the underlying massive member of the Tamaulipas. On a weathered surface it is lighter gray or locally yellow.

The parallelism of the chert layers and nodules to the bedding planes, the definite color of the chert of any particular horizon, the frequent mat-like extent, all point to a syngenetic origin. At least it must have been formed in great part before the end of the Cretaceous because in certain places in the San José region on the western side of the San Carlos Mountains, the chert layers have been broken and sheered as a result of folding.

The transition beds were probably deposited in shallow

waters as indicated by their shale partings and wavy bedding. The presence of a neretic fauna near the top of the massive member of the Tamaulipas shows that the seas had become quite shallow before the transition beds were deposited. About twenty feet below the latter at station eight was found a fairly well preserved fauna, consisting of pelecypods and ammonites with traces of gastropods and belemnites. The bed in which this fauna occurs is about eight inches thick and the surface is not wavy. In the overlying bed which is non-fossiliferous there is a small band of black chert. Evidently the conditions of sedimentation changed gradually from those in which massive bedded limestones were formed to those in which thin-bedded limestones were formed, and these changes were probably produced by a gradual shallowing of the sea.

The fauna found near the top of the massive member of the Tamaulipas strongly indicates that the associated beds are of Middle Albian age or Gault. The fossils have been identified as follows: Inoceramus (Actinoceramus) subsulcatiformis Böse, Puzosia San Carlosi Imlay n.sp., Phylloceras sp., Parahoplites sp., Oxytropidoceras sp.. I. subsulcatiformis is very similar to I. subsulcatus Wiltshire of the English Gault and P. San Carlosi is closely related to Puzosia mayoriana (d'Orbigny), also of the Gault.

An unconformity exists between the Middle and Upper Cretaceous in adjacent regions in Mexico and Texas, but none was recognized in the San Carlos Mountains. Although this does not prove the absence of an unconformity, it seems probable that, in an area as removed from the rising lands as this was in Middle Cretaceous times, sedimentation may have continued uninterrupted from one period into the next.

Upper Cretaceous

San Felipe

The San Felipe formation in the Sierra de Cruillas has an estimated thickness of 870 feet and is composed of two members. The lower 820 feet consists of thin-bedded limestones, shaly limestones, and shales. The upper 50 feet is a transitional series into the Mendez shales.

The color of the limestone is usually light yellowish gray but may vary to dark grayish yellow. On a weathered surface it has a similar color but is generally darker and in some places dark brown. The thin-bedded limestones are seldom over four inches in thickness but occasionally thicker layers occur, some of which resemble the Tamaulipas limestone. Intercalated with these are shaly limestones and shales which frequently form the greater portion of the outcrop. Elsewhere the thin-bedded limestones predominate. The washing out of shale layers commonly causes the limestone ledges to slump so that it is difficult to obtain a reliable strike and dip reading on these beds.

The characteristic features of the San Felipe are the thin-bedded limestones with intercalated ledges of shaly limestones, the yellow color, the slumped and broken beds, and the scarcity of chert.

Mendez Shale and Overlying Shales

Although not occurring within the Sierra de Cruillas these Upper Cretaceous shales outcrop within a half mile of the eastern side and should be considered, especially as they very probably covered the entire region when folding began. The following description is based on the study of the well exposed shale section near El Mulato, which is located on the plain near the northcentral part of the San Carlos Mountains.

Here the total thickness of the shales between the San Felipe and the undoubted Eocene deposits is 4660 feet (1421 meters). At present the Mendez shale is thought to constitute 2853 feet (870 meters) of the total thickness and its upper limit is drawn at the base of a sandstone lens which varies from 4 to 16 feet in thickness. The shales above and below this lens are quite similar. They are medium to dark gray on a fresh exposure, and weather to light gray with locally a tinge of yellow in the more calcareous layers. These calcareous layers generally break into chunky or nodular bodies with curved surfaces. Intercalated with them at frequent intervals are small seams of fine shale. An abundance of foraminifera is found in the entire section.

IGNEOUS ROCKS

Microgranite

Distribution and Structural Relations

Microgranite is the most common igneous rock in the Sierra de Cruillas. It occurs principally in the form of sills or more rarely in dikes. Two main sills have been intruded in the Tamaulipas limestone. The lower one is exposed only on Loma Rinconada where it is overlain by 650 feet of Tamaulipas limestone. Exposures of microgranite about 200 feet thick occur where canyons have cut headward into the northeast-southwest anticlinal ridge. The limestone capping the ridge slopes over the microgranite along the canyon walls. Although the base of the igneous mass is not exposed it is considered to be a sill because of its close resemblance in structural features and in composition to other microgranites in the same area that are definitely sills. The second large sill has its greatest exposure on the Savania and on the Lomas del Sur where it may be traced continuously for three miles. Certain outliers, regarded as erosion remnants of this sill, increase the areal extent to six miles. It is further believed that all the bodies on the Savania and on the Lomas del Sur are parts of one sill, since they have approximately the same stratigraphic position and are separated only where crossed by canyons. This sill before erosion would have covered most of the Savania anticline and the anticline of Lomas

del Sur. There is no trace of it on the north side of the latter, or on Loma Rinconada at the same stratigraphic position.

The sill varies in thickness from 50 feet to 185 feet and is thinnest on the flanks of the anticlines. At some places it cuts across the bedding planes and follows a higher or lower horizon so that its position varies from about 30 feet below the base of the transition beds to within these beds themselves. At some places ledges of limestone a foot or two in thickness and up to a hundred feet in length project from the igneous mass. At other places small off-shoots from the main sill have wedged themselves between limestone layers. In a few cases the limestones have been broken into small fragments and surrounded by igneous material. Well developed jointing was observed only at one place. That was in Canyon C about 1000 feet upstream from station 293.

On the map it may be noted that the sill does not outcrop in the westernmost anticlinal flexure of the Lomas del Sur. Its absence here implies either that it pinches out before reaching this anticline, or that it cuts across the bedding to form a dike. The steeply inclined beds along the southeastern flank of the Savania suggest that some fracturing may have taken place and thereby formed conduits by which the magma reached higher horizons. The presence of this sill on the Savania and the southern side of the

Lomas del Sur and its absence from the other anticlines of the Sierra de Cruillas suggests that the immediate sources of the magma were within the anticlines bearing the sills and not from the larger Patado body.

There are several other smaller bodies of microgranite which are not definitely related to the two largest sills. A three-foot dike striking N 85° E occurs in Canyon Guijana near station four. The limestone is slightly darkened near the contact. In the same canyon near station one hundred and thirty-three is a 15 foot dike striking N 87° W. The exposed length is 50 feet. Considerable alteration of the limestone has taken place for 3 feet and slight alteration occurs as far as 6 feet from the contact. About 250 feet upstream from here is a sill 12 feet thick. The limestone is somewhat darkened near the contact.

The thickness of cover over the intrusive microgranite sheet must have been at least 1000 feet for the lower large sill of Loma Rinconada, by safely including only the transition beds of the Tamaulipas and the San Felipe. But since it seems most probable that the Upper Cretaceous shales also covered the region at the time of folding which seemingly preceded intrusion, the total thickness of the overlying sediments must have been about 5600 feet for the upper large sill of Savania and 6250 feet for the lower sill of Loma Rinconada..

Petrology of the Microgranite

Plate , figure

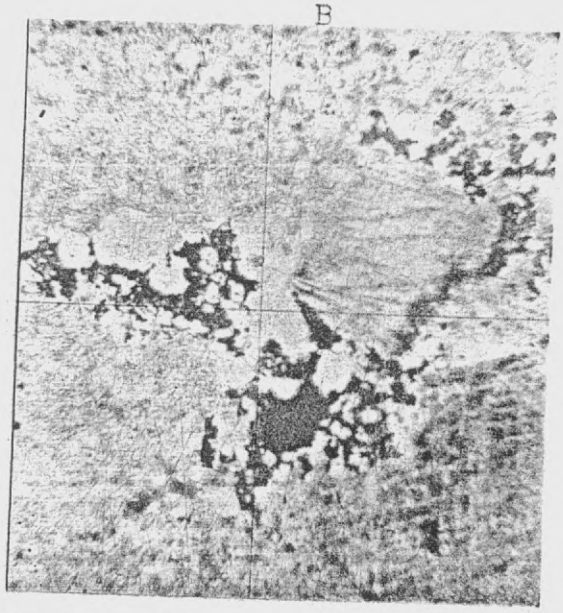
The color of the freshest microgranite is light gray. Shades of pink are produced by slight alteration so that the common color is somewhat darker. Megascopically the groundmass is aphanitic with a few porphyritic crystals of quartz and orthoclase. The quartz is gray, or colorless, the orthoclase is mottled white and pink. Both occur as automorphic crystals averaging half a millimeter in length and attaining a maximum of two millimeters. Specks of magnetite sometimes occur in groups of sufficient size and number to speckle the rock.

Microscopically the groundmass is holocrystalline and consists of a mixture of very fine-grained quartz and feldspar abundantly sprinkled with magnetite. Brown biotite occurs sparsely only in the freshest specimens. Riebeckite is present in most sections as scattered, sponge-like crystals with a distinctive deep-blue color. Hematite specks are usually present. Epidote is uncommon. Fine rutile needles may sometimes be observed under high magnification. In one section small crystals of purple fluorite were found lining cavities.

The quartz phenocrysts sometimes show hexagonal outlines but are commonly rounded due to corrosion. The orthoclase phenocrysts are idiomorphic and usually clouded by alteration to kaolinite.

A

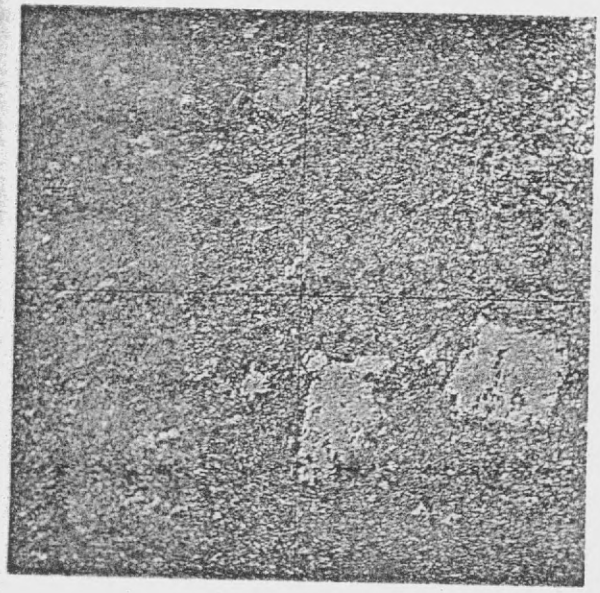
B



A. Microgranite from the sill on Loma Rinconada; x 100, crossed nicols. Phenocrysts of orthoclase and quartz in a groundmass of the same material which is abundantly sprinkled with magnetite.

B. Same section as A but with nicols open showing the blue, sponge-like riebeckite.

C



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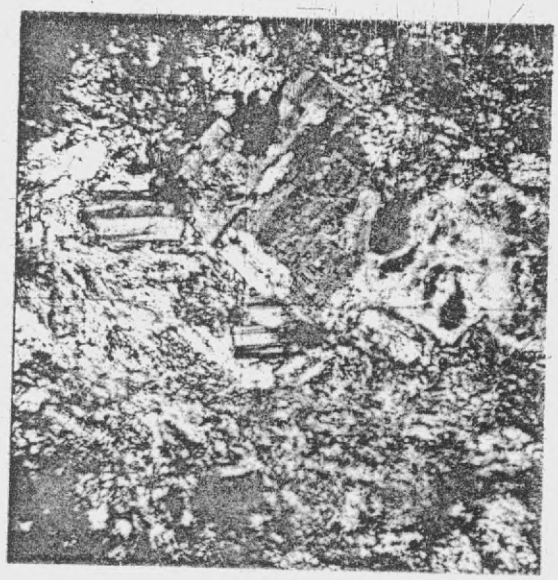


C. Fine grained microgranite from the sill near the highest point of Lomas del Sur; x 100.

D. Granophyre from the sill on Loma Savania near station 107; x 100, crossed nicols.

The most common decomposition products are kaolinite and limonite. The latter may have come from biotite or pyrite. Pyrite was not seen in any fresh rock section but the frequent cubic outlines of the limonite grains suggests its former presence.

A Granophyric Variation of the Microgranite

A specimen taken from the sill capping the highest hill of the Savania near station one hundred and seven shows structures characteristic of granophyres. A specimen from the same sill near station one hundred and eleven about 200 yards south of the former is a typical microgranite as already described. Therefore the granophyre must be considered as a minor variation of the microgranitic type.

The fresh rock is nearly white with many phenocrysts of colorless to gray quartz measuring up to two millimeters in diameter. Small phenocrysts of feldspar are not readily discernible. The main ground mass is aphanitic.

In thin section phenocrysts are fairly common and consist of quartz, orthoclase, oligoclase, and sanidine. The feldspars are quite abundant and idiomorphic. The sanidine contains inclusions. The composition of the oligoclase was found to be $Ab_{78}An_{22}$.

The groundmass consists of a micrographic intergrowth of quartz and feldspars. Fine needles of rutile are present. The decomposition products are kaolinite and limonite.

Vogesite

Distribution and Structural Relations

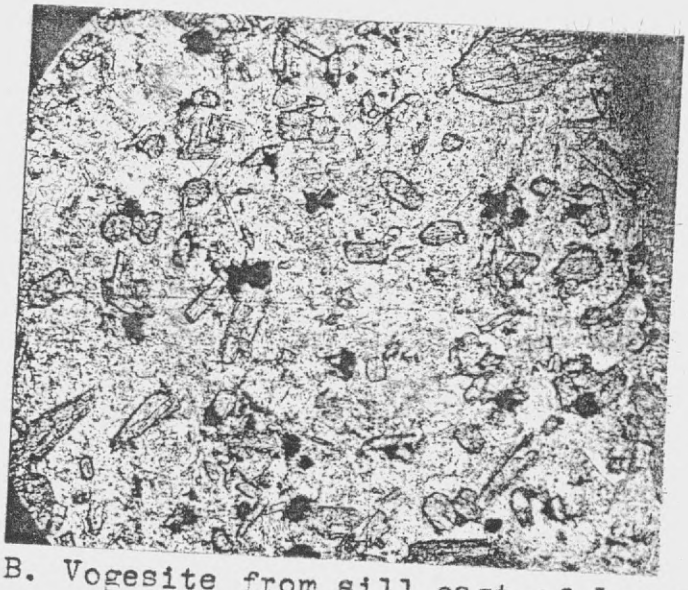
The lamprophyre, vogesite, occurs as a sill about 90 feet thick and at least two and a half miles long. It outcrops on the plains a quarter of a mile east of the Lomas del Sur. Its surface expression is a low ridge which sometimes rises to a height of 50 feet above the plain. At the north end of the sill the dip is 36° E but farther south decreases to 25° E. It is probably only one of a group of sills, because a mile to the east are ridges with similar relief. These were not examined. The enclosing Mendez shale is slightly metamorphosed for about six feet from the contact as evidenced by its more resistant character and a color change from light gray to light yellow.

Lithology

The color of the fresh rock is dark gray. It weathers slowly to a deep brown or reddish brown. Megascopically the groundmass is fine-grained, with a decided porphyritic tendency due to the presence of phenocrysts of hornblende, augite, and orthoclase. Hornblende occurs as numerous fine needles as long as six millimeters. Augite is not as abundant and does not exceed two millimeters in length. Orthoclase occurs as irregular masses up to seven millimeters in diameter.

In thin section the phenocrysts are found to consist of barkevicitic hornblende, both aegirine and titanium augite, and orthoclase. In some instances an aegirine

A. Trachyte; x 100, crossed nicols. The lath-shaped crystals of orthoclase and oligoclase(?) show a more or less parallel arrangement.



B. Vogesite from sill east of Lomas del Sur; x 100. Phenocrysts of barkevicitic hornblende, both aegerine and titanium augite, and orthoclase. Groundmass of orthoclase, analcite, and abundant magnetite.

augite core is surrounded by colorless augite. The phenocrysts occur as well developed crystals with sharp outlines. Magnetite is abundant and together with hematite and apatite occurs either as inclusions in the hornblende, or disseminated in the groundmass. Titanite is also present. The groundmass consists essentially of orthoclase with some analcite occurring as isotropic interstitial material. Numerous fine needles of apatite were also observed. The secondary minerals include calcite, sericite, and kaolinite, but the rock is comparatively unaltered.

Trachyte

Occurrence

A four foot sill of trachyte was found lying between the Tamaulipas and the San Felipe limestone near station one hundred and thirty-one in a small canyon half a mile east of El Milagro.

Lithology

The fresh rock is light pink. The outcrops weather to a yellowish-pink or yellowish-gray. At first glance it resembles a fine-grained sandstone.

In thin section the specimen shows typical trachytic structure without phenocrysts. The feldspars, orthoclase and a plagioclase (probably oligoclase), occur as lath-shaped crystals with more or less parallel arrangement. Apatite needles are abundant. Among the subordinate constituents are magnetite, quartz, hematite, calcite, and rutile. Kaolinite and abundant limonite were also observed.

Basalt

Distribution and Structural Relationships

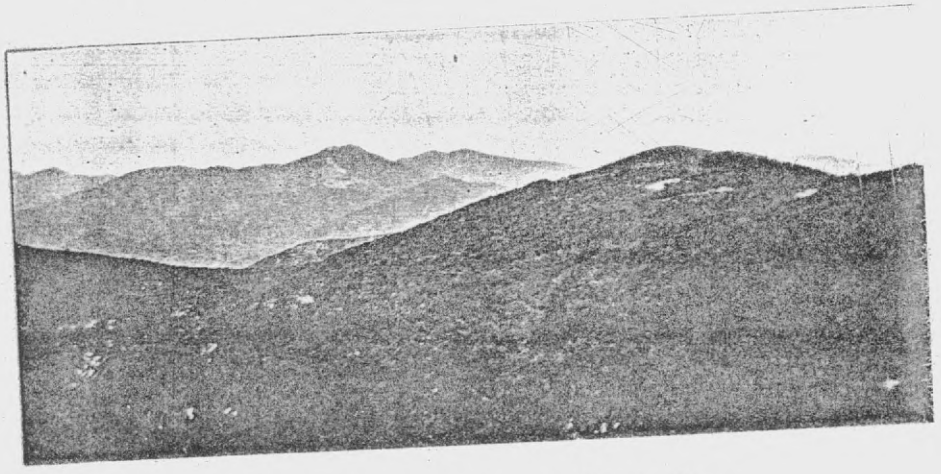
Basalt occurs as a laccolith at Loma Trinchera, as a probable plug near the highest part of Loma Palmar, and as sills in other places in the region.

Loma Trinchera is a small hill on the northern slope of the Palmar anticline at the very edge of the plain above which it rises several hundred feet. Its crest, which trends N 60° E, coincides with the thickest portion of the laccolith. The latter is elongated from east to west parallel to the strike of the beds. It is about 650 yards long and at least 100 yards thick. The greatest width of outcrop is 350 yards. The thickness decreases rapidly both to the east and the west of Loma Trinchera so that the mass becomes a thin sheet throughout at least half of its length. At its north end the laccolith is overlain by about 8 feet of the transition beds of the Tamaulipas limestone, which in turn is overlain by a 12 foot sill. Columnar structure is fairly well developed. The top of the hill consists of vertical columns about a foot in diameter. Many similar blocks have fallen down the steep slopes and have accumulated in large stream-like piles.

Another basaltic body occupying about 12 acres occurs near the crest of the Palmar anticline. Canyon Palmar has cut headward into it exposing about 150 feet. This basalt, unlike all the other basaltic masses in the region, is much

A. Loma Trinchera in the middle foreground.

B. The Palmar Plug.



C. Basaltic sill on Loma Savania.
Patado Range to the west.

weathered and decayed. Due to this fact the exact relationship of the basalt to the limestone could not be observed. E. H. Watson, who examined this igneous body, considered that it was most probably a plug.

A remnant of a basalt sill occurs on the top of a high hill near the crest of the Savania anticline. This basalt is about 100 feet thick and apparently does not weather easily. It is underlain by massive Tamaulipas limestone but is not far below the transition beds.

Two small sills outcrop on the plain north of Loma Rinconada. They are both about 50 feet thick and occur in the lower part of the San Felipe formation.

Another very small sill of basalt was found on the eastern slope of Loma Rinconada about 200 feet below the base of the transition beds of the Tamaulipas.

Petrology of the Basalts

The basalts of the Sierra de Cruillas belong to several varieties which are described below. The fresh rock is nearly black and contains small phenocrysts of olivine. It weathers to a dark brownish-black.

Olivine Basalts

Olivine basalt was found in the plug on Loma Palmar and in the sill on Loma Savania.

A specimen from Loma Palmar contains phenocrysts of augite and olivine, the latter showing red iron stained

borders. The groundmass consists of augite, olivine, labradorite, and magnetite.

A slide of a sample from the sill on Loma Savania shows essentially the same constituents, but the feldspar is much less abundant, apatite is present, and the augite of the groundmass is granulitic.

Hauyne-basanite

Hauyne-basanite occurs in the laccolith of Loma Trinchera. The principal phenocrysts are olivine and augite. The groundmass consists of olivine, augite, magnetite, plagioclase, and some glass containing trichites. Blue hauyne crystals are quite abundant. Serpentine has been formed along fractures in the olivine. Small amounts of iron oxide are, also, present.

Nepheline-hauyne Basalt

This type occurs in the sills near station one hundred and forty-four north of Loma Rinconada. The phenocrysts are olivine, augite, and hauyne. The augite sometimes has an aegirine-augite core. The olivine has altered to serpentine along fractures. The groundmass consists of olivine and augite. Plagioclase is very scarce. Biotite is present. Nephelite, which may be detected with difficulty, occurs in the groundmass.

Age of the Basalts

The stratigraphic range of the basalts and the micrographite overlaps at least 150 feet. The former shows some glass in its groundmass, whereas the latter is holocrystalline.

These relationships suggest that the basalts were deposited nearer the surface than were the microgranites and therefore at a later period after erosion had removed some of the overlying strata.

A

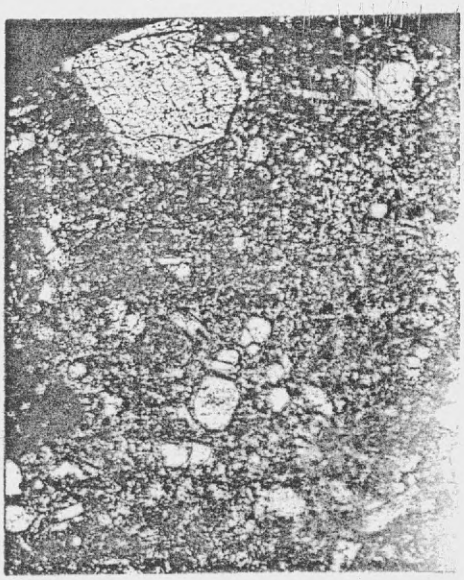
B

A. Olivine basalt from the Palmar plug; x 100. (see p.31) Phenocrysts of augite and olivine; The latter shows iron stained borders. Groundmass of augite, olivine, labradorite, and magnetite.

B. Haüyne-basanite from Loma Trinchera; x 100. (see p.32) Phenocrysts of olivine and augite. Blue haüyne crystals are abundant.

C

D



C. Haüyne-basanite from Loma Trinchera; x 100. Another picture from the same slide as B which shows glass containing trichites of magnetite.

D. Nepheline-haüyne basalt from sill near station 144; x 100. Phenocrysts of olivine, augite, and haüyne. (see p.32)

METAMORPHIC ROCKS

The intrusion of the microgranitic and basaltic masses into the Tamaulipas limestone produced contact metamorphism. The limestone adjacent to the basaltic masses of Palmar and Trinchera is scarcely altered, but that adjacent to the microgranitic sills and dikes, wherever they occur, is usually conspicuously altered.

The altered limestone may be readily distinguished from the unaltered gray Tamaulipas limestone by its darker color. Locally near the contact with the microgranite the limestone has been recrystallized to marble and is white. The usual color of the altered limestone is deep yellow or brown. The outcrops are crossed by numerous veinlets of quartz which stand out as little ridges due to the faster weathering of the limestone.

Black limestone was observed at several places on Loma Rinconada about 230 feet above the microgranite. It was, also, found at station 15 in Canyon Palmar. When examined in the field it was thought that the black color might have been produced in some way by the nearby igneous intrusions. However, examination of thin sections showed the black color to be due to the presence of carbonaceous material. It is therefore not an indication of metamorphism.

The greatest amount of metamorphism has occurred in the limestone overlying the large microgranite sills of Loma

Rinconada and Lomas del Sur. The zone of alteration varies considerably in thickness superadjacent to the large sill on Lomas del Sur and Loma Savania. This zone attains a maximum thickness of 50 feet near the highest point of the Lomas del Sur and a minimum thickness on Loma Savania where in a few places practically unaltered limestone occurs in actual contact with the microgranite sill.

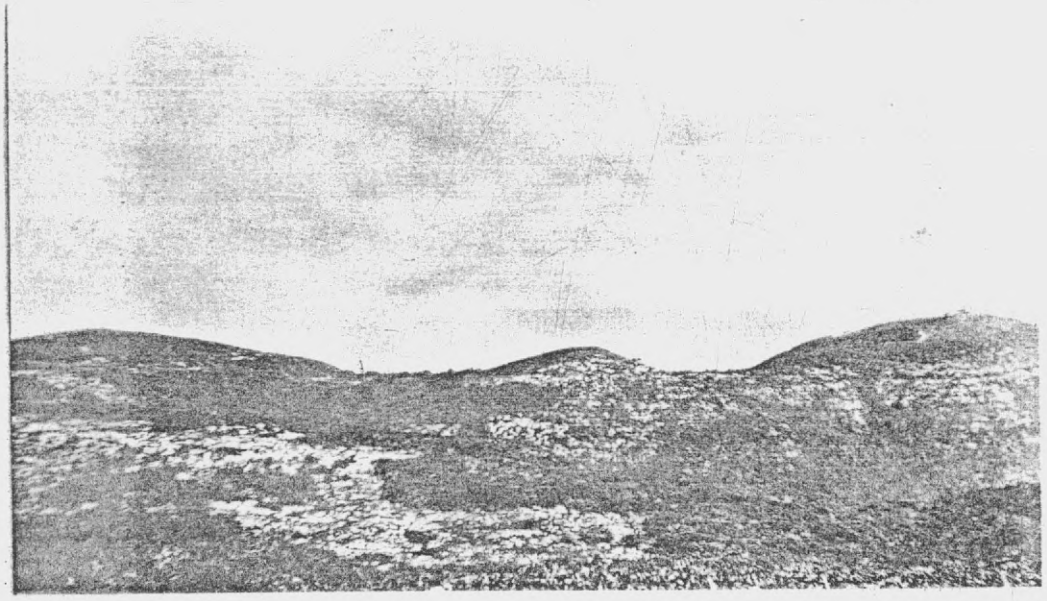
Above the microgranite sill on Loma Rinconada there is another conspicuous zone of metamorphosed limestone which has an average thickness of 225 feet. The total thickness of the underlying sill is not known because its base is not exposed. It is probably much thicker than the sill on Lomas del Sur and Savania because the zone of alteration is present around all the outcrops of the sill and is nearly four times as great as the zone of altered limestone above the sill on Lomas del Sur. The degree of metamorphism is also much greater.

For both zones, metamorphism of the limestone is usually greatest at the contact with the microgranite and becomes progressively less away from it. However, several exceptions to this generalization were noted. The most conspicuous exception was found on the southwestern slope of Loma Rinconada. The section here, which was measured from the bottom of the canyon near station 249 to the top of Loma Rinconada at station 167, is as follows:

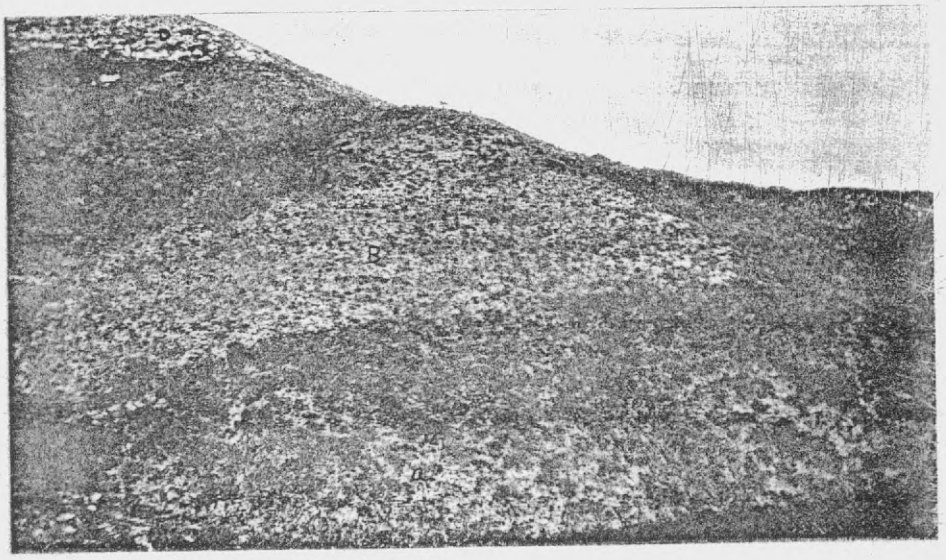
Feet	
370	Dark gray, massive Tamaulipas limestone. Weathers light to dark gray.
125	Much altered Tamaulipas limestone traversed by numerous quartz veins. Weathers dark gray to dark brown.
105	Slightly altered Tamaulipas limestone. Somewhat bleached near the contact with the underlying microgranite.
200	Microgranite.
800	

This section shows that the most altered limestones are separated from the igneous rocks by 105 feet of only slightly altered limestones. This suggests that metamorphism was due to quartz bearing solutions given off by the magma rather than by actual contact with the molten magma.

Considering the metamorphism of the limestone in more detail, it was found by microscopic examination that the altered limestone exhibited different degrees of metamorphism. In some cases only finely crystalline calcite has been produced but in other cases the calcite grains are larger and show twinning. Quartz may occur quite abundantly either as small veinlets, or disseminated throughout the calcite groundmass. Magnetite always accompanies the quartz. Associated limonite was probably derived in part from the magnetite but the cubic shape of some of the limonite masses indicate that they were formed by decomposition of pyrite. In the most altered specimens examined, grossularite garnet was found occurring as numerous small six sided crystals in



A. The top of Loma Savania. The three hills are capped with microgranite.



B. Section of the sill and altered limestone measured on Loma Rinconada. a-Microgranite, b-Slightly altered limestone, c-Much altered limestone, d-Unaltered limestone. Top of hill not in picture.

both calcite and quartz. Associated with the garnets are small pyroxene granules which are probably diopside. In one section a crystal of plagioclase was also found.

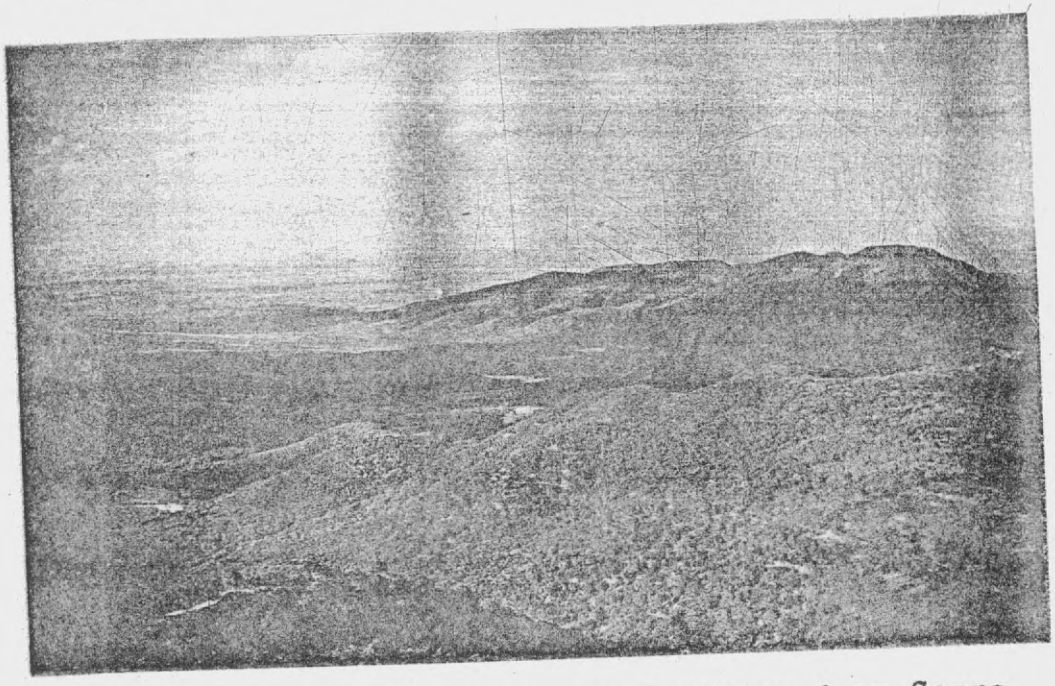
The mineral composition of the altered limestone explains the variation in its physical appearance. Where the metamorphosed zone has not been affected by the injection of quartz material the normal gray color of the Tamaulipas limestone is merely bleached. Most of the metamorphosed zone, however, has been penetrated by small veins of quartz which stand out noticeably on weathered surfaces. Here the limonite, derived from the oxidation of magnetite and pyrite, commonly forms a residual yellow or brown coating on the limestone so that the outcrop may resemble weathered San Felipe limestone. The fresh surface varies from dark gray to brown, and frequently has a vitreous luster due to re-crystallization of the limestone.

STRUCTURE

The mountainous area comprising the Sierra de Cruillas coincides in a general way with the area of structural uplift. In two places, however, erosion has planed off the steeply inclined beds causing a portion of the anticlinal area to be included in the marginal plain. At the southeast end of Loma Rinconada, steep beds of Tamaulipas and San Felipe limestone underlie the plain for a quarter of a mile east of the mountains. Along Arroyo Palmar, southwest of Rinconada ranch, the northeast end of the Palmar anticline projects into the plain a quarter mile beyond the foothills of the Sierra.

The major structure of Sierra de Cruillas is an irregular dome-like uplift trending in a general northeast-southwest direction. On the north, south, and east it is bordered by the coastal area of little structural disturbance. On the west is the great Milagro syncline or saddle which extends in a northwest-southeast direction and separates it from the uplift of Sierra de Patado. Superimposed upon the major uplift are four minor folds or elongated domes whose position and form produce the anomalous shape and trend of the range. The crests of these secondary structures correspond in a general way to the highest areas in the topography of the mountains. Loma Palmar, in the northwestern part of the range, is on the axis of the Palmar anticline; southeast of this a group of higher hills, called the Savania del

A. The Sierra de Cruillas from Cerro Hespiche. This view of the western side of the range shows the Palmar anticline on the left, the Savania anticline in the center, the Rinconada anticline in the distant center, and Lomas del Sur in the distant right.

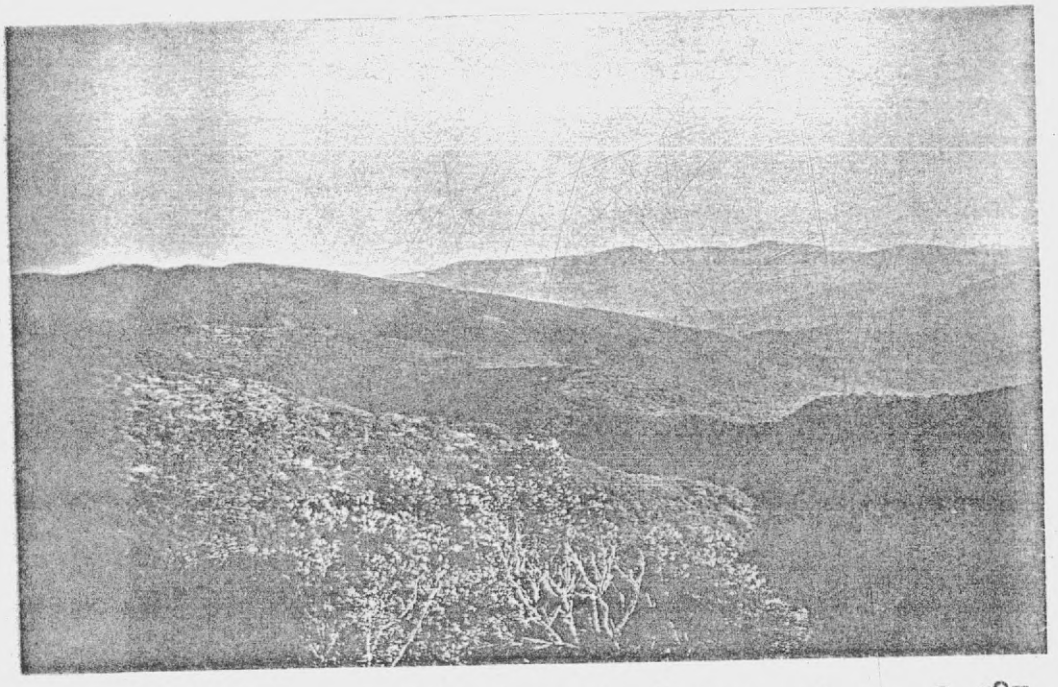


B. North end of the Sierra de Cruillas from Cerro Samora showing the Palmar anticline and the numerous canyons draining it.

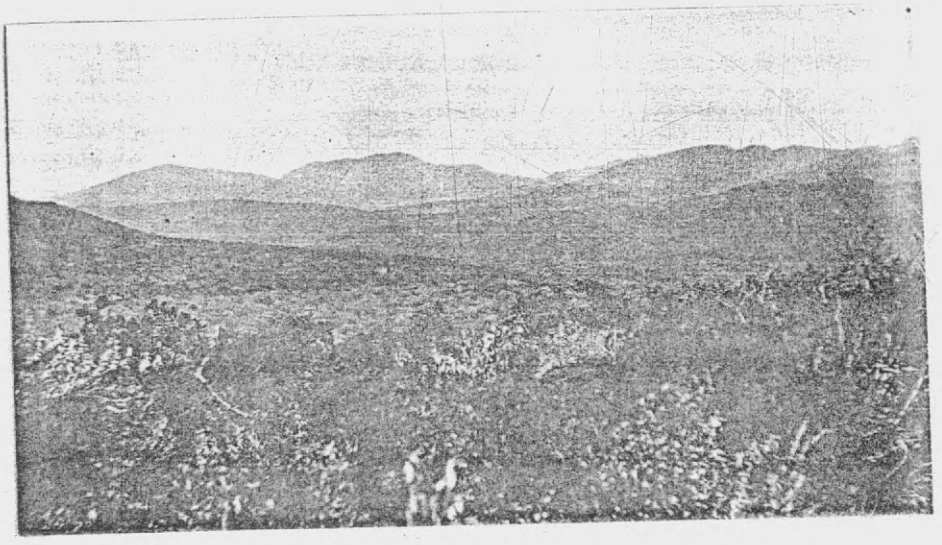
Llervaniz, is near the crest of the Savania anticline; to the east, the Lomas del Sur represent the topographic expression of a third line of folding; and at the northeast end of the Sierra, the highest part of Loma Rinconada is along the crest of the Rinconada anticline. The Rinconada anticline is a continuation of the Savania anticline to the southwest and is separated from it by a shallow structural saddle. The line of folding which passes through these two "highs" is the principal axis of the Sierra de Cruillas uplift. It extends about N 55° E. The Palmar anticline, lying to the northwest and the Lomas del Sur anticline to the southeast extend nearly parallel to this central axis. Projected southwestward across the Milagro syncline these three lines of folding seem to be a continuation of similar minor axes in the Sierra de Patado.

The Rinconada-Savania trend is in line with an anticline passing through Cerro Samora, the Palmar anticline seems to be related to the anticline of Cerro Lechugillosa, and the trend of the Lomas del Sur anticline may be continued in a broad anticline to the south of Cerro Samora.

Considering in more detail the structural highs of the Sierra de Cruillas, the Savania anticline is seen to be the largest of the four. The amount of structural uplift is greater and the surface elevations along it are higher than in any other part of the range. To the west the beds dip into the Milagro saddle at about 20°; to the east they pass



A. The Milagro saddle from the Palmar plug. S 8°E.



B. Looking south along Arroyo Carizzo from Loma Chata.

more gently into the saddle separating the Savania from the Rinconada anticline; on the northwest flank, where a shallow syncline separates the Savania from the Palmar anticline, the dips vary between 6° and 30°; on the southeast, where the flank of the anticline coincides with the margin of the range, the dips vary from 30° to 60°. The Savania anticline is therefore asymmetrical with the steeper flank on the southeast. The syncline which parallels the anticline on the northwest is also asymmetrical due to the more pronounced folding along the Savania anticline to the southeast than along the Palmar anticline to the northwest. There is a pronounced reëntrant of San Felipe limestone along this syncline just northeast of El Milagro ranch where the syncline crosses the northwest-southeast trend of the Milagro saddle. West of El Milagro there is a similar reentrant of San Felipe on the east flank of the Patado Range, where the syncline extends westward between the folds observed on Cerro Samora and Cerro Lechugillosa.

The Rinconada anticline is nearly symmetrical but is somewhat steeper on the southeast side. To the south and southwest the beds dip rather gradually at about 15° to 20° into a syncline and a saddle separating the Rinconada anticline from the anticlines of Lomas del Sur and Savania del Llervaniz respectively. On the north and east flanks, the anticline is bounded by the coastal plain and the beds dip irregularly at about 20°. Along the margin of the mountains

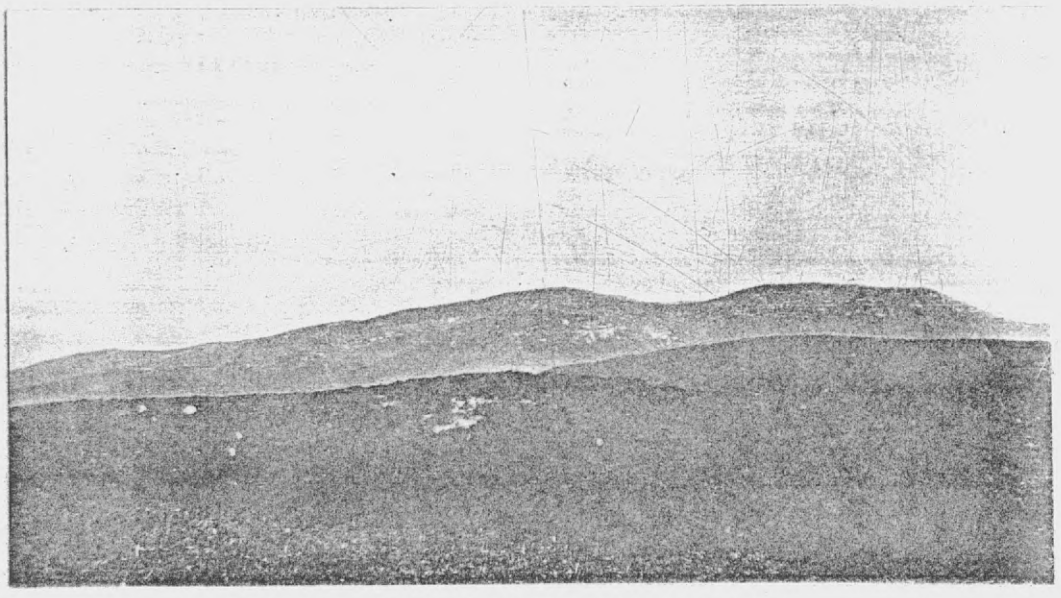
the dip increases to 25° and 30°. A decided plunge occurs at the extreme northeastern end on an anticlinal nose and along the southeast side where steeply tilted beds continue out into the plain about a quarter of a mile.

The Palmar anticline is broad and asymmetrical. From the crest near the southern side the beds dip northwest at about 10° to the edge of the mountains where they increase to about 20° for a short distance. The eastern end of the anticline extends out on the plain half a mile and steepens near the contact of the Tamaulipas and San Felipe limestones.

The asymmetrical anticline of the Lomas del Sur is dome-shaped due to the existence of several subsidiary folds on its flanks. But the main axis is quite distinct and makes an acute angle with the east-west topographic ridge. One of the minor folds extends southwest into the plain. On the Lomas del Sur anticline the steepest dips are found on the south and east sides.

The maximum structural uplift of the Sierra de Cruillas is estimated to be 5620 feet (1714 meters). To obtain this figure it was first postulated that Cruillas is situated approximately at the top of the Mendez shale. Below Cruillas there should be about 870 meters of Mendez shale and 264 meters of San Felipe to the top of the Tamaulipas. The sum of these (1134 meters) minus the altitude of Cruillas (234 meters) places the top of the Tamaulipas 900 meters below sea level. The highest point in the range at 780 meters is

A. Crest of the Palmar anticline viewed from the east.



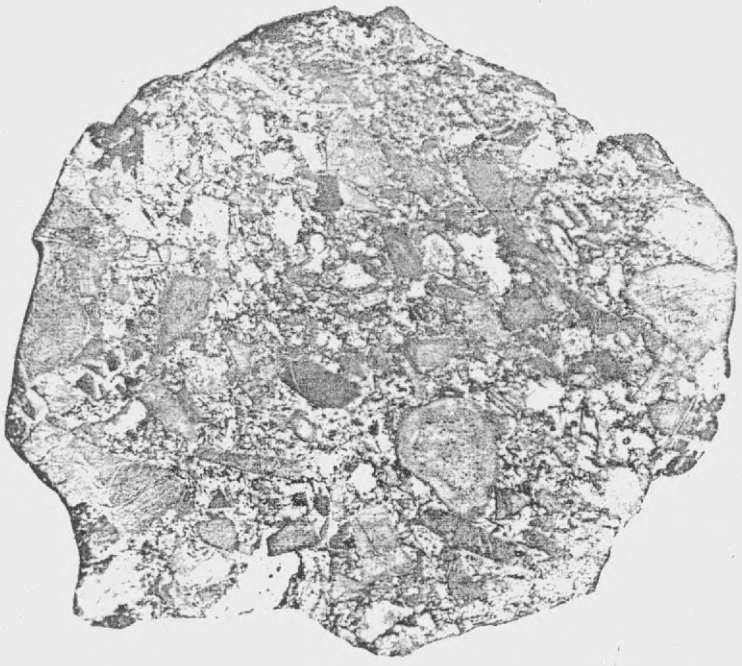
B. Loma Palmar viewed from the south.

near the base of the transition beds of the Tamaulipas. Adding the thickness of the latter (34 meters) to 780 meters places the greatest height of this formation at 814 meters above sea level. Then the structural elevation must be 814 meters plus 900 meters equals 1714 meters (5622 feet).

Many minor flexures on the flanks of the main anticlines account for their broad dome-like shape. These flexures tend to obscure the main structure.

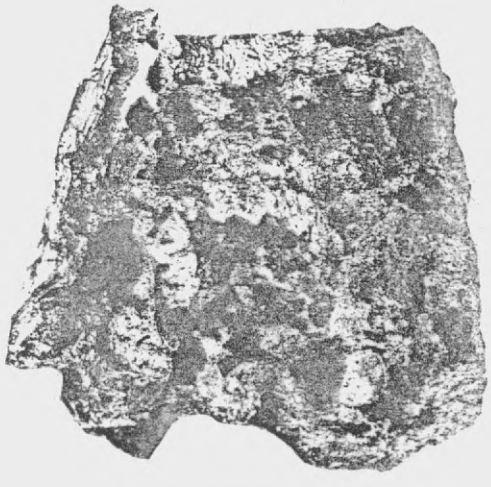
The great thickness of the Tamaulipas limestone, its massive bedding, and the steep dips observed in the Sierra de Cruillas indicate that there must have been a great weight of overlying sediments in order to induce folding without faulting. But the fact that many of the sills and laccoliths occur near or at the base of the transition beds of the Tamaulipas suggests that some fracturing and weakening may have occurred in these less competent limestones thereby forming a plane of weakness along which magma might easily be intruded. This view is supported by the finding of two peculiar types of breccias closely associated with the same sill at two localities. On Loma Savania near station one hundred and twelve, there is a four-foot ledge of rock consisting of numerous small, sharply angular fragments of slightly metamorphosed limestone enclosed by an igneous matrix. The ledge is underlain by massive non-fractured Tamaulipas limestone and is overlain by a two foot layer

A



A. Fresh surface of a breccia from Loma Savania near station 112. Shows angular limestone fragments enclosed by an igneous matrix which is principally quartz.

B

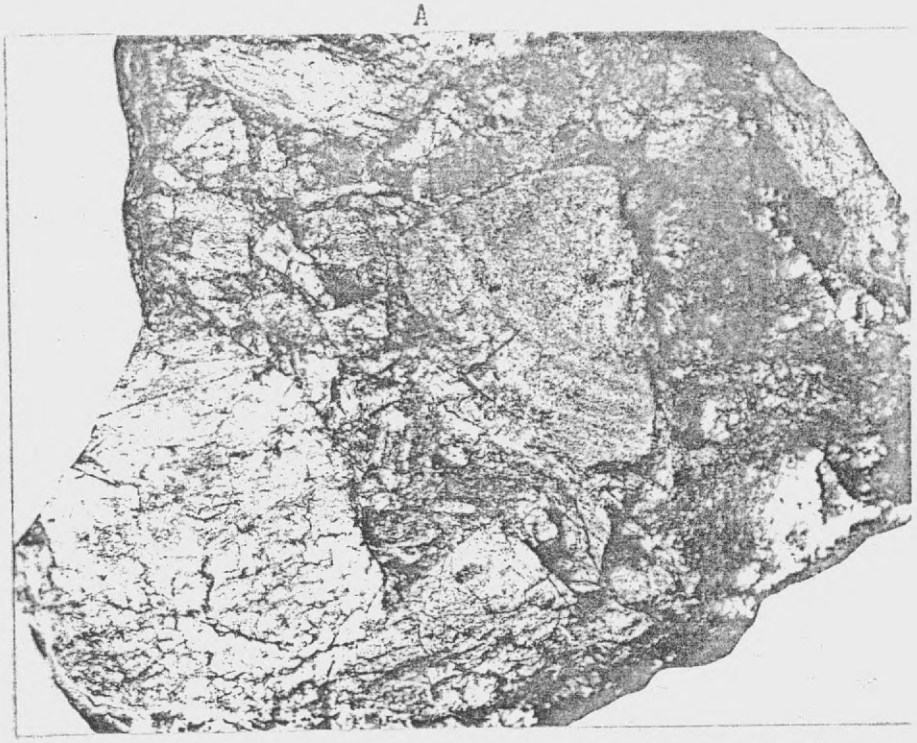


B. Weathered surface of a breccia from same outcrop as A. The quartz stands out due to leaching of the limestone.

of similar gray massive limestone, which in turn is overlain by about 40 feet of igneous rock. From these relationships it seems that the igneous material must have been intruded into a shattered zone where the limestone was more brittle than in the beds above and below. A second locality where a breccia occurs is near the highest point of the Lomas del Sur on the hillside above station two hundred and thirty-four. Here only the upper portion of the sill is exposed. It grades into a coarse breccia about 12 feet thick consisting of much altered limestone and igneous fragments surrounded by a matrix of igneous material. The breccia grades into a much fractured limestone devoid of igneous material. Both of these breccias occur a few feet below the base of the typical, thin transition beds of the Tamaulipas. Another explanation of the origin of these breccias is that the force of the igneous intrusion along some plane of weakness may have been sufficient to fracture the limestone and thus form a breccia.

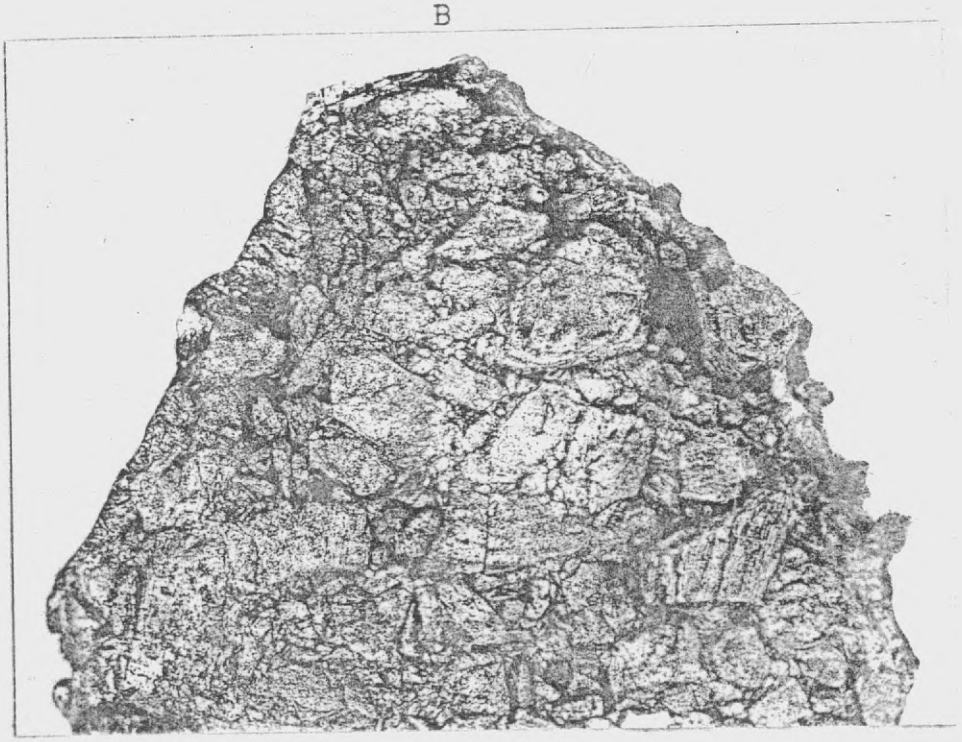
It may be noted from the structure sections along lines A-B and C-D that the sills are thinnest on the flanks of the anticlines. Thus the sill which caps the highest part of Loma Savania is 56 meters thick near station one hundred and seven but thins to 19 meters near station one hundred and thirteen only a quarter of a mile to the south of the former. The same sill is about 30 meters thick near station two hundred and seventy-seven in the Lomas del Sur but thins

A



A. Fresh surface of a breccia from the Lomas del Sur above station 234. The fragments consist of much altered limestone and microgranite.

B



B. Weathered surface of A.

to 15 meters near station two hundred and seventy-four. This thinning on the flanks of the anticlines indicates that the intrusion did not precede the formation of the anticlines.

SUMMARY OF STRUCTURE

1. There are four dome-like uplifts (Savania, Rinconada, Palmar, and Lomas del Sur) coinciding with topographic highs.

2. The axial trend of the folds is N 55° E.

3. The major Rinconada-Savania trend seems to be a continuation of the anticline passing through Cerro Samora, the Palmar trend is related to an anticline passing through Cerro Lechugillosa, and the Lomas del Sur trend may be continued in a broad anticline south of the Samora anticline.

4. The Savania anticline is asymmetrical. The beds dip west at 10° and pass into the Milagro saddle at 20°; to the east the dip is about 10° into the saddle separating the Savania from the Rinconada anticline; to the north the dip is about 15° into an asymmetrical syncline (whose steepest flank is on the south) which separates the Savania from the Palmar anticline; on the southeast the Savania anticline plunges with dips of 30° to 60°.

5. The Rinconada anticline is nearly symmetrical with an average dip of 15°, which increases near the edge of the mountains to 25° and becomes as great as 40° along the southeast side.

6. The anticlines of Palmar and Lomas del Sur are asymmetrical with their crests nearest the side of the Savania-Rinconada trend. From their crests the beds dip

into the intervening synclines at about 8°. In the anticline of Lomas del Sur the steepest dips are on the southeast side.

7. The dips of all these anticlines increase suddenly at the edge of the mountains.

8. The thinning of the sills on the flanks of the anticlines shows that intrusion did not precede folding.

9. The maximum structural uplift is about 5622 feet (1714 meters).

GEOLOGIC HISTORY

The Tamaulipas limestone deposited during the Middle Cretaceous is the oldest formation exposed in the San Carlos Mountains where it is probably 2000 feet thick. Most of it was formed at considerable depths in a slowly subsiding basin as evidenced by the purity of the limestone, thick-bedding, fine texture, and paucity of fossils. The scattered remnants of such free swimming forms as ammonites and belemnites and the absence of bottom-living forms in the massive limestone, except near its top, suggests fairly deep waters. Toward the end of the period the basin became shallow. This is first heralded by a fauna typical of the neretic zone, such as pelecypods and gastropods in addition to cephalopods, found about 130 feet below the top of the formation. The upper hundred feet, consisting of thin-bedded, wavy limestones and interbedded cherts were certainly deposited in shallow water.

The overlying San Felipe limestones and shales of the Upper Cretaceous were apparently deposited conformably on the Tamaulipas limestone in the San Carlos region. The shales probably indicate that a land area to the northwest was rising so that the rivers with increased velocity commenced to bring greater quantities of silt to the sea. After about 1000 feet of alternating limestones and shales had accumulated the uplift of the land areas became more pro-

nounced and increasingly greater amounts of silt were deposited in the sea. The Mendez shales, which were thus formed, grade gradually from the San Felipe with perfect conformity. These shales are about 2850 feet thick and are separated from 1800 feet of similar overlying shales by a thin sandstone member. In summing up the history of sedimentation in this region it may be noted that in the Middle Cretaceous deposition occurred in a fairly deep basin, that throughout both the Middle and Upper Cretaceous depression of the basin continued but at a decreasing rate and sedimentation at an increasing rate. Finally at the end of the Mesozoic the entire area was uplifted, folded, and subjected to erosion.

Since the youngest formation found in the synclinal basins of the Sierra San Carlos is the Mendez shale, the uplift apparently occurred after the deposition of the latter, and presumably near the end of the Upper Cretaceous. At least the Eocene seas deposited their sandstones and shales on the now rapidly rising arc of the Sierra San Carlos.

After the initial period of folding, intrusions of igneous rock domed certain areas within the uplift or extended as sills of varying thickness over large areas. The molten rock probably reached the surface in some places forming volcanoes and lava flows which subsequent erosion has entirely removed. Not only do the igneous masses represent several period of intrusion but volcanic activity has continued

to recent times. On the flanks of the Kemp Range on the west side of the San Carlos Mountains, lava flows were observed resting on the debris which has accumulated in the valleys of the present erosion cycle.

During the Tertiary period erosion carved the uplift into rugged mountains. In the Pliocene and Pleistocene the debris from the disintegration of the limestones and volcanic rocks was carried and heaped together in the valleys and plains where it was cemented into hard rock by the deposition of lime.

PALEONTOLOGY

Albian Fossils from the Tamaulipas Limestone of the Sierra de Cruillas

Inoceramus (Actinoceramus) subsulcatiformis Böse.

Plate 14, figures 1-15

Inoceramus (Actinoceramus) subsulcatiformis Böse, Univ. Texas Bull. No. 2748. pp. 189-193, pl. 18, figs.1-5, 1927.

Böse originally described this species from a single specimen found in the Edwards limestone as follows:

"Shell small of oblong contour, higher than wide, asymmetrical, inequivalve, the left valve being larger and more convex than the right one. Hinge line straight and very short. Both valves are smooth in the upper portion and show strong radial folds in the lower one. The seam is straight only in the upper third and strongly plicated on the rest, the ribs of one valve corresponding to the interstices of the other.

Left valve.--High oblong, oval in the lower portion, beak well pointed, strongly bent over the hinge line and twisted forward. In the front part below the beak appears a smooth and concave semilunar area limited by a slight curved fold; the back portion of the beak is evenly curved toward the hinge line and the seam. The surface of the valve is smooth in and below the umbonal region; this smooth portion has an oblique form, beginning in front near the beak and reaching diagonally down toward the posterior side. This smooth portion shows only fine concentric lines of growth which in their shape do not follow parallel to the outline of the smooth portion but are more or less parallel to the general outline of the valve. In the lower portion the valve shows nine radial folds or ribs, the posterior ones of which are very inconspicuous. The anterior rib begins near the beak and ends at the seam, enclosing the semilunar area mentioned above. The next rib begins a little lower but is very strong and much longer than the first one. In the same manner follow two more ribs, each of them beginning a little lower than the other and ending at the border of the valve. Then almost in the middle portion we see two much shorter and rather low ribs which may represent an individual irregularity. On the posterior part we find four more ribs, all shorter than on the anterior portion and mostly less strong; the last two are very short and low.

Right valve.--High oval, beak lying far toward the anterior portion, slightly twisted forward, not very prominent, situated below and a little forward of the beak of the left valve. Hinge line short and straight and lying behind the beak. Valve not quite as evenly convex as the left one but showing a much greater convexity in the anterior portion while the posterior side is flattened. The area corresponding to that of the left valve is not very clearly defined, but in this region the shell bends strongly toward the seam and a very faint swelling curves from the beak to the place where the corresponding fold of the left valve reaches the seam. The upper portion of the valve is smooth and shows only concentric lines of growth which follow parallel to the outline of the smooth portion. On the lower third of the valve we find eight short but partly strong ribs or folds which correspond to the interstices between the ribs of the left valve."

Böse recognized the great similarity of this species to Inoceramus concentricus var subsulcata Wiltshire but distinguished it from the latter by several minor differences.

"First, the outline of the shell is not quite as asymmetrical as in I. subsulcatus and especially the very characteristic wing on the posterior side which we find in I. concentricus as well as in I. subsulcatus, is practically missing in our specimen. In both I. concentricus as in I. subsulcatus the line from the point of the beak to the posterior portion of the left valve shows always a decided inflection which in some specimens may be very slight but always seems to be present. This inflection is missing in our specimen and the corresponding line is entirely straight. This makes our left valve appear much more symmetrical. On the other hand our specimen is much more slender than I. subsulcatus, while this later species is always rather broad."

The forms from the Sierra de Cruillas likewise differ from I. subsulcatus in being more symmetrical and in the weak development of a wing on the posterior side. However, there is an inflection of "the line from the point of the beak to the posterior portion" on some left valves. Its presence on some valves and absence on others suggests that it is only an individual variation and therefore of no specific importance.

The close relationships of I. subsulcatiformis to the European I. subsulcatus is clearly shown by the specimens collected in the Sierra de Cruillas. In the European species all stages can be found between the non-plicated I. concentricus to forms nearly as highly plicated as I. subsulcatus.[1] A similar series was found in the Sierra de Cruillas. Among the fifty specimens examined there are a few small forms which show no plications, but the majority of the forms bear a plication on the anterior part of the left valve. This plication may be very shallow or very pronounced. A few individuals have more than one plication. Several specimens show two, another has three, and two have five plications each. Here is evidently a species in which the individuals show the same variability in sculpture as I. subsulcatus and differ from the latter only in the minor characteristics already mentioned.

The general description and figures of the specimen from the Edwards limestone, as given by Böse, accord nicely with the specimens collected in the Sierra de Cruillas and probably belong to the same species. The fact that Böse's specimen bears 9 plications does not place it outside this species because one of the characteristics of the species is variability in the number of plications.

[1] Spath, The Cretaceous Lamellibranchia, Vol. 2, Pt. 7, p. 268. Paleontographical Society. Vol. LXIV, 1910.

The specimens from the Sierra de Cruillas show considerable range in size. The smallest is 15 mm. in height and the largest 65 mm. Several average specimens have the following dimensions:

Valve	Height	Width	Thickness
Left --------	55 mm.	38 mm.	23 mm.
Left --------	42 mm.	30 mm.	17 mm.
Left --------	39 mm.	29 mm.	13 mm.
Right --------	44 mm.	31 mm.	9 mm.
Right --------	43 mm.	30 mm.	13 mm.

Number of specimens: Fifty single valves.

Age: Middle Albian, Massive member of the Tamaulipas limestone about twenty feet below the top.

Locality: Sierra de Cruillas, one-half mile east of El Milagro at station eight. The same species has been found in the Tamaulipas limestone two miles southeast of San Carlos near the southern end of the Kemp Range.

U. T. M. Nos. 15321-15329

Puzosia San Carlosi Imlay, n.sp.

Plate 15, figures 1-4

Shell of medium size, involute; coiling serpental, subangustumbilicate; whorls slightly compressed, nearly as wide as tall, sides slightly convex, venter evenly rounded, umbilical edge rounded with wall nearly vertical. Seven sigmoid constrictions on the outer whorl, inclined forward on the venter as an evenly rounded sinus; faint costae between constrictions most conspicuous on venter. Suture line complicated with much frilling, bifid saddles and a nearly symmetrical trifid, deep lateral lobe.

Dimensions:--Holotype. No. 15247

Diameter	53 mm.	(1)
Height of last whorl	32 mm.	0.60
Width of last whorl	30 mm.	1.57
Diameter of umbilicus	15 mm.	0.28

Discussion:--Our single specimen was found in a brittle limestone matrix. The outer whorl, which is composed of similar brittle limestone, shows sutures, but the inner whorls, which are calcified, show no sutures. The sutures are not exceptionally well preserved and the tracing of their complications is only approximately accurate.

The above description and the accompanying figures show that our form is closely related to P. mayoriana (d'Orbigny).[1] It differs, however, in several respects.

[1] Spath, Ammonoidea of the Gault, Pt. 1, p. 44. Paleontographical Society, Vol. LXXV (1921).

The shell is more inflated than P. mayoriana, the umbilical ratio is less, there are seven constrictions instead of four or five, and the sinus formed by a forward bending of the constrictions on the venter is not nearly as acute. P. communis Spath[1] has as many constrictions as our form but is much more compressed. P. provincialis (Parona and Bonarelli)[2] and P. quenstedi (Parona and Bonarelli) have a smaller number of constrictions and the suture line is not as frilled. In the last named species the sinus on the venter is apparently not as pronounced.

Although the form from the San Carlos Mountains is an entirely distinct species from P. mayoriana, it apparently occurs in a similar stratigraphic horizon, that is, in beds of Middle Albian age which are the equivalents of the Gault.

Number of specimens: One.

Age: Middle Albian, Massive member of the Tamaulipas limestone about twenty feet below the top.

Locality: Sierra de Cruillas, one-half mile east of El Milagro at station eight.

[1] Loc. cit. (1921) Pal. Soc. Vol. LXXV, p. 47.

[2] Parona and Bonarelli, "Fossili Alb. Escragnolles," Pal. Ital., vol. ii, p. 81 (29), pl. II, figs. 4a,b,c. (1896).

Phylloceras sp.

Plate 15, figure 6

This genus is represented by a single crushed specimen. The shell is involute and compressed. The whorl-section was evidently elliptical. The umbilicus is almost closed. The test is covered with small straight striae which extend from the umbilicus to the venter where they are most pronounced. Near the periphery there are 22 striations in a space of 11 mm. The diameter of this incomplete specimen is 29 mm.

Number of specimens: One.

Age: Middle Albian, Massive member of the Tamaulipas lime-stone very near the top.

Locality: Sierra de Cruillas, one mile northeast of El Milagro at station thirty-seven.

Oxytropidoceras sp.

Plate 15, figure 5

The form found in the Sierra de Cruillas is not readily referable to any species of Oxytropidoceras which has been examined. It is preserved as a cast of a portion of the outer whorl. The whorl is compressed, sublatumbilicate, fastigate. Ribs numerous, narrow with slightly wider interspaces, round-topped, sigmoid, of two lengths not regularly alternating, of which the longer two-thirds reach the umbilical

margin; some ribs branched; some ribs more pronounced than others. Diameter (incomplete) 72 mm.

Number of specimens: One.

Age: Middle Albian, Massive member of the Tamaulipas limestone very near the top.

Locality: Sierra de Cruillas, one mile northeast of El Milagro at station thirty-seven.

Parahoplites sp.

Plate 15, figure 7

There is a small cast of an outer whorl which has been referred to this genus. The whorl is convex with a diameter of 9 mm. There are 14 ribs in a length of 24 mm. These are of two sizes which alternate regularly. The longer ribs are slightly curved and reach the umbilicus. The shorter ribs are straight and extend two-thirds of the distance from the periphery to the umbilicus.

Number of specimens: One.

Age: Middle Albian, Massive member of the Tamaulipas limestone very near the top.

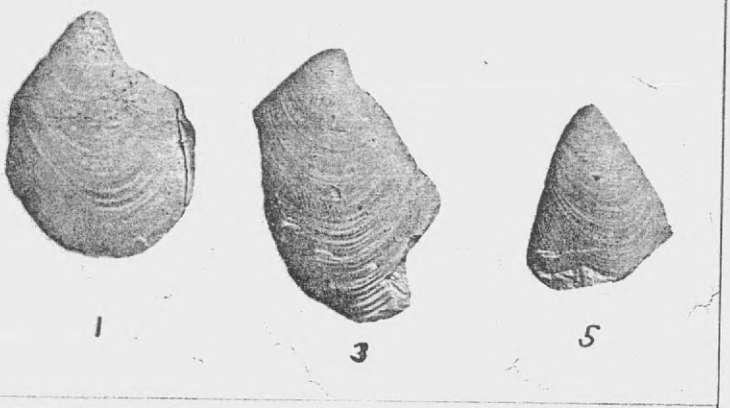
Locality: Sierra de Cruillas, one mile northeast of El Milagro at station thirty-seven.

PLATE 14

Inoceramus (Actinoceramus) subsulcatiformis Böse. (p.50)
(All natural size)

Figure 1.--Left valve with one very shallow plication. 15331
2.--Side view of preceding specimen. 15331 ?
3.--Left valve with one very shallow plication. 15332
4.--Side view of preceding specimen.
5.--Left valve showing one pronounced and one shallow plication. 15339
6.--Anterior view of preceding specimen showing the curvature of the beak.
7.--Largest left valve in collection. Shows one plication. 15334
8.--Left valve with no plication. 15337
9.--Left valve with one pronounced plication. 15336
10.--Left valve showing four plications, three strong and one faint. 15338
11.--Left valve with one strong plication. 15330
12.--Right valve showing only concentric growth lines. 15329
13.--Another right valve. 15329
14.--Left valve with one plication. 15333
15.--Portion of a left valve showing four plications. 15335

Specimens 3 (4) and 15 are from the Tamaulipas limestone two miles southeast of San Carlos near the southern end of the Kemp Range. The remainder of the specimens are from the top of the massive member of the Tamaulipas limestone taken one-half mile east of El Milagro at station eight.



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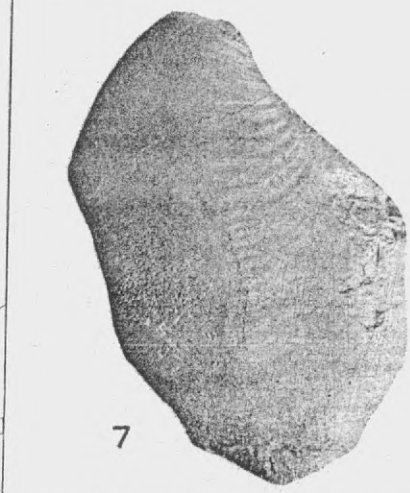

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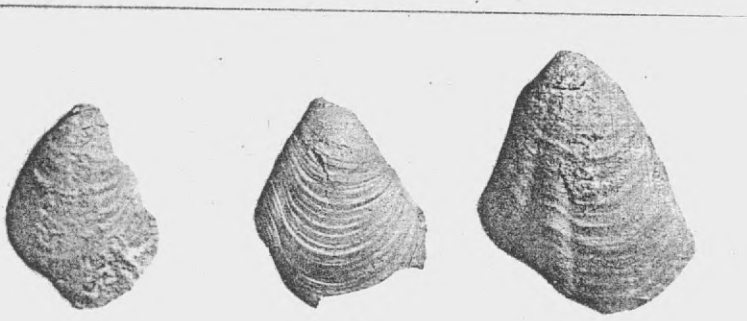

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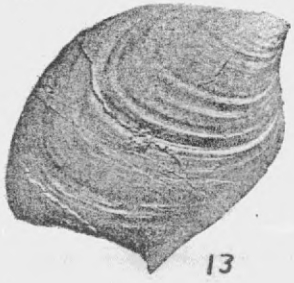

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PLATE 15

Puzosia San Carlosi Imlay n.sp. (p. 54).

Figure 1.--Side view of holotype. Top of the massive member of the Tamaulipas limestone taken one-half mile east of El Milagro at station eight. (Natural size)
2.--Peripheral view of preceding specimen.
3.--Partial suture line of type specimen.
4.--Another sketch of suture lines of the type.

Oxytropidoceras sp. (p. 56)

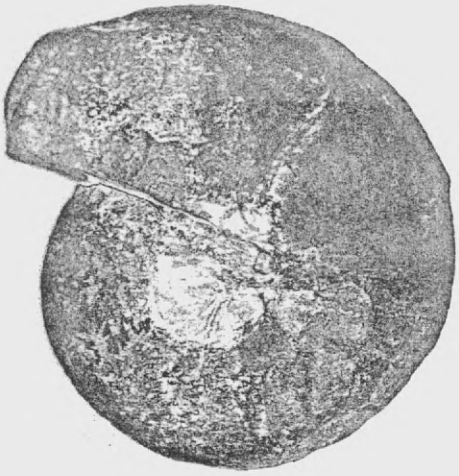
5.--Side view of specimen from the top of the massive member of the Tamaulipas limestone at station thirty-seven one mile northeast of El Milagro.

Phylloceras sp. (p. 56)

6.--Side view of specimen from the top of the massive member of the Tamaulipas limestone at station thirty-seven one mile northeast of El Milagro.

Parahoplites sp. (p. 57)

7.--Side view of specimen from the top of the massive member of the Tamaulipas limestone at station thirty-seven one mile northeast of El Milagro.



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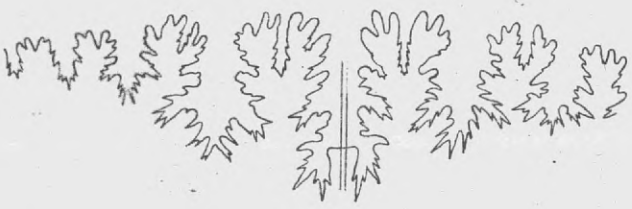

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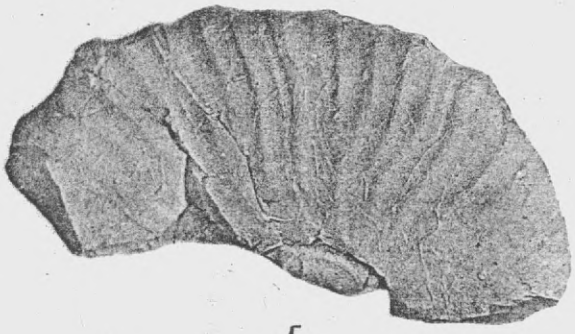

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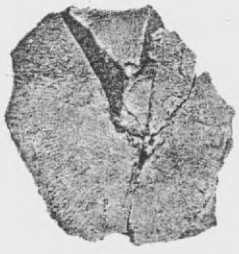

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