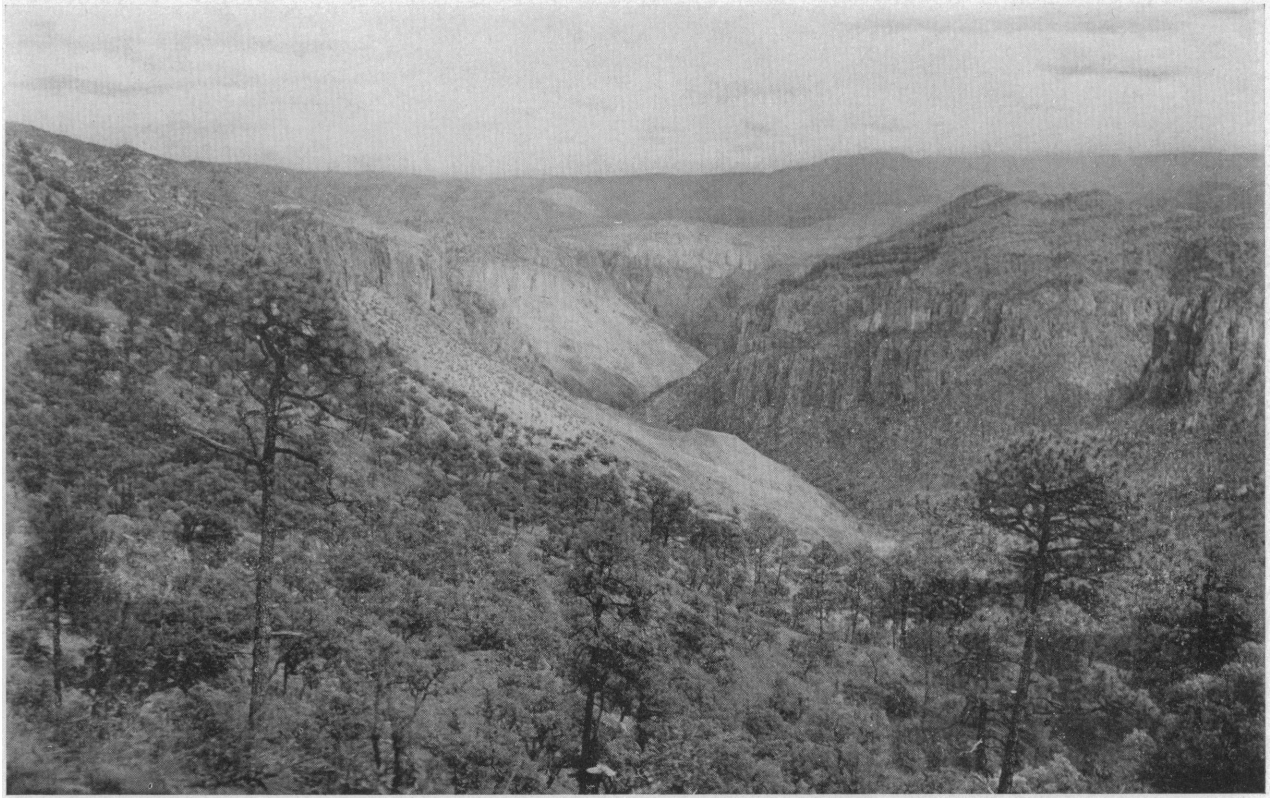

AROS CAÑON NEAR GUAYNOPITA.

The river here is about 1600 meters below the distant rim. The inner gorge, 600 meters deep, shows the angular form characteristic of youthful drainage.

55.(72.1)

Article XVIII.— A GEOLOGICAL RECONNAISSANCE IN THE WESTERN SIERRA MADRE OF THE STATE OF CHIHUAHUA, MEXICO.

By Edmund Otis Hovey.

Plates XVIII–XXXV.

Text Figures 1–13 and a Map.

The elevated plateau or series of plateaux forming the principal portion of Old Mexico rises irregularly toward the south from about 1220 m. above the sea near Ciudad Juarez, opposite El Paso, Texas, to about 2250 m. near the city of Mexico along the line of the Mexican Central railway. West of this line the rise is more rapid along a series of bolsons separated by mountain ranges from the bolsons traversed by the Mexican Central road, and the 2200 m. level for portions of the plateau is attained about 160 km. northwest of Chihuahua. The general plateau ends toward the east in the series of mountain ranges known as the Sierra Madre del Oriente and towards the west in the Sierra Madre del Occidente. Toward the south the plateau feature is lost in the maze of mountain peaks south and west of the City of Mexico. Felix and Lenk[1] consider the plateau to be cut off at the south by a nearly east and west fault along the valley of the Balsas River, but Aguilera has refuted this idea in his brochure entitled "Sobre las condiciones Tectónicas de la República Mexicana."[2] Toward the north the plateau merges into the high plains of Arizona and New Mexico.

The general geology of the Mexican plateau has been discussed by several writers, but the detailed structure is comparatively little known. Its quadrilateral form and the arrangement of the mountains along great continental structure lines have been made clear by R. T. Hill. The volcanoes have been studied by Ordoñez, Waitz, Farrington and others, the mining geology by Ordoñez, Böse, Hill, Weed and Kemp among recent writers. The real character of the Western Sierra Madre, however, seems to have been unknown or overlooked and large areas of the region have been left uncolored on the geological maps of the country or colored generally for rhyolite, as was done by Ordoñez in the map accompanying Bol. Inst. Geológico de Mexico, No. 14, 1900.

[1] Zeits. d. deutsch. geol. Gesell., Vol. XLIV, pp. 303–323, 1892.
[2] Mexico. Tip. de la Sec. de Fomento. 1901.

The development of the vast natural resources of the Western Sierra Madre has been retarded by the great landed proprietors of the country, who have merely desired extensive ranges for their cattle and have discouraged exploration, in spite of the wonderful riches which have been taken from the mines at sundry points. The demand for timber for the mines of Arizona, New Mexico and northern Sonora, the known or suspected existence of valuable ores of gold, silver and copper, and favorable changes in the Mexican laws have, however, attracted the attention of American capitalists, as a result of which the country is gradually opening up.

One of the parties exploring a portion of the region was under the leadership of Robert T. Hill, formerly of the United States Geological Survey,

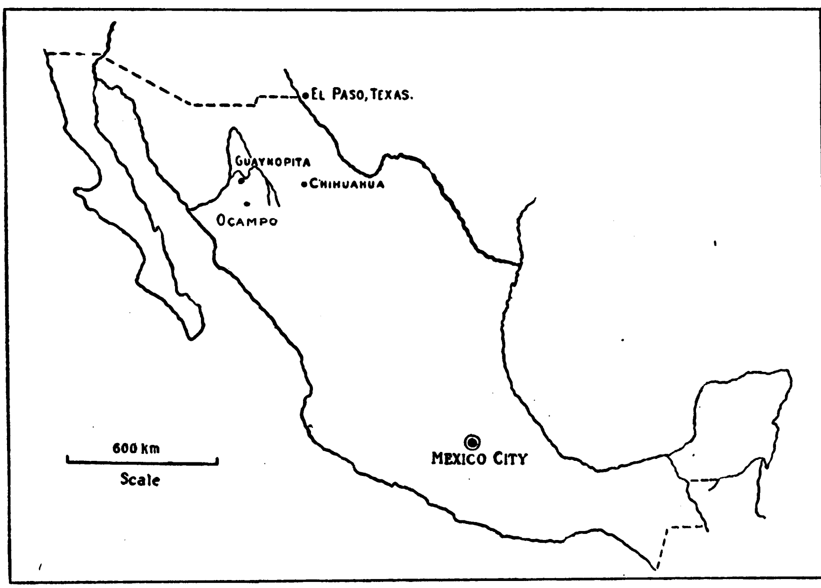

Fig. 1. Outline map of Mexico showing location of the district discussed.

and was formed for the purpose of studying the conditions of mineralization in the mountains. The American Museum of Natural History was invited to send the writer with the party for the purpose of studying the physiography and general geology of the region traversed and to make collections of photographs and rocks for the Museum.[1] The expedition left El Paso 14 February, 1905, and spent about seven weeks in the Western Sierra Madre. The present article is based upon the joint observations of the

[1] The other members of the party were John Seward, mining engineer, and Frank H. Fayant, journalist.

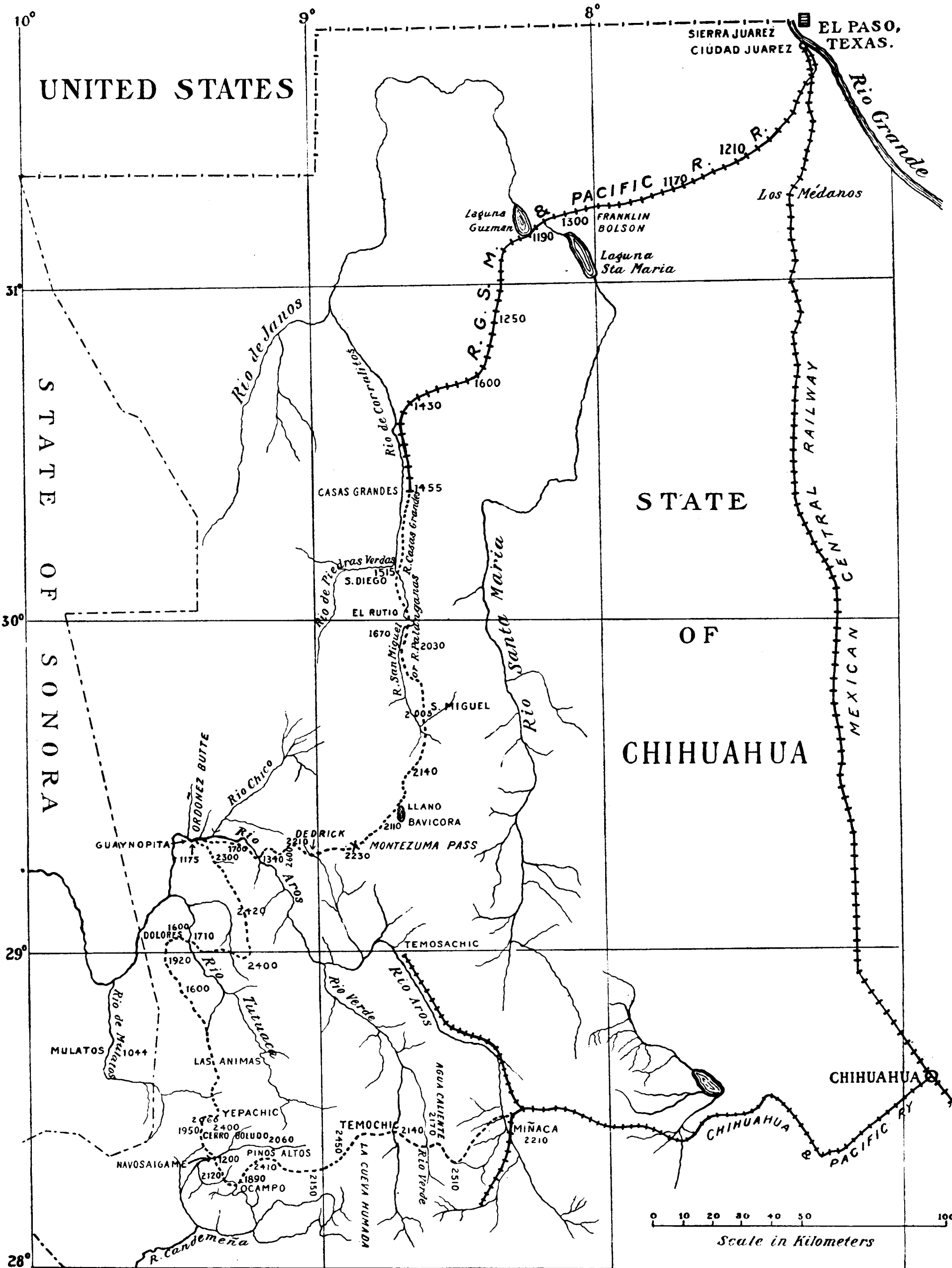

Fig. 2. Sketch map of the northwestern portion of the State of Chihuahua, Mex., showing by means of the railroads and the dotted line the route traversed by the writer in February–April, 1905. The numbers give elevations (mostly aneroid determinations) in meters.

two geologists of the party, who had the privilege of traversing together a heretofore practically unknown region, geologically speaking.

The route followed was from Ciudad Juarez southwestward 150 miles over the Rio Grande, Sierra Madre and Pacific railroad to the then terminus for trains at Nuevas Casas Grandes; thence southward 125 miles by wagon and pack train through Hacienda San Diego, Hacienda El Rutio, Cañon of the San Miguel, Hacienda San Miguel, Llano Bavicora and Montezuma Pass to the lumber camp of Dedrick; thence westward 32 miles across and along the Aros (Yaqui) river and cañon to the mining camp of Guaynopita; thence southward 125 miles by way of the divide between the Aros and Tutuaca rivers, Dolores, Las Animas, Yepachic, Cerro Boludo (or Voludo) and Navosaigame to Ocampo (Jesus Maria); thence northward and northeastward 100 miles by way of Pinos Altos, La Cueva Humada, Temochic and Agua Caliente to Miñaca, which was then the terminus of the Chihuahua and Pacific railway; thence by rail 120 miles east to Chihuahua and from there 225 miles north to Ciudad Juarez, completing the circuit. The journey from Dedrick to Miñaca was accomplished altogether on mules and with pack train.

The region has not been visited frequently by tourists or investigators, and but three recent publications regarding it have come to the writer's notice. John R. Bartlett, United States Commissioner on the Mexican Boundary commission, 1850–1853, traversed the northern part of the State of Chihuahua from the west in 1852, visiting Janos, Corralitos and Casas Grandes[1] and going out across the mesa to Ciudad Juarez, then known as El Paso del Norte. Bartlett's narrative gives a good idea of the difficulties encountered by travelers only a half-century ago and some notion of the surface features of the route followed, but the most important part of the account is that describing the ruins at Casas Grandes. In 1884 A. F. Bandelier, then carrying on explorations for the Archæological Institute of America, crossed the Western Sierra Madre from the west forty miles south of the international boundary and, turning southward, studied the prehistoric ruins as far as a point thirty-five miles southwest of Casas Grandes. Bandelier penetrated nearly to the high plateau of the Sierra Madre before he was obliged to turn back, and he writes regarding the region:[2] "If the interior of the Sierra Madre is ever opened to travel and civilization, it will be found prolific in resources of divers kinds, and as interesting to the naturalist as to the student of archæology." Carl Lumholtz also visited Casas Grandes in 1891, and in 1892 he traversed much of the country described in the present article. In his book "Unknown Mexico"[3] Lumholtz

[1] Personal narrative, Vol. II, pp. 339–379. 1854.
[2] "Investigations in the Southwest," Part II, p. 563.
[3] Scribners. New York. 1902.

has treated of the archæology and ethnology and has written somewhat of the wonderful scenery of the region, including the Aros cañon at Guaynopa, a few miles west of Guaynopita.

The region falls naturally into three subdivisions: the desert and semi-arid country from Ciudad Juarez to El Rusio, 16 km. south of Hacienda San Diego; the high plateau country which is covered with oak or pine according to altitude and dotted with grassy prairies, including the Llano Cristo (Hacienda San Miguel), Llano Bavicora and similar "enclosed basins," and the cañon district through which in its ramifications the rivers descend from the high plateau to the deserts or to the lowlands and the ocean, and containing numerous mesas, or tablelands, which are the remnants of ancient inclosed basins.

Leaving the banks of the Rio Grande at Ciudad Juarez, alt. 1125 m.[1] the Rio Grande, Sierra Madre and Pacific railway skirts the eastern and southern base of Sierra de Juarez, or Cerro Muleros, slowly rising till at km. 22 the level of the great Mesa, or table-land, is attained, 135 m. above the Rio Grande. This plateau corresponds in position with the highest terrace along the El Paso and Southwestern, Southern Pacific and Santa Fé railroads a few miles west and northwest of El Paso and is similar to that in appearance and constitution. Wastes of sand and arid soil, held in place to some extent by bunch grass, greasewood and mesquite, stretch away in every direction, and the monotony of the plain is relieved only by the summits of the half-buried mountains, mostly volcanic in origin, which are to be seen here and there. These mountains have played a rôle in the formation of the mesa to which reference will be made later.

The mesa presents a rather abrupt terrace-like face to the immediate valley of the Rio Grande, but the upper surface of the table-land slopes gently away therefrom. This disposition of the surface together with the dryness of the climate, has prevented the weak drainage of the mesa from forcing its way to the Rio Grande, while the paucity of the rainfall renders extremely slow the robbing of the mesa drainage by the drainage of the Rio Grande. The surface of the mesa rises almost without a break into the bordering and included mountains and ridges.

Near km. 38 the railroad passes through the almost completely buried outliers of the Sapello Mountains. These seem to be of well-bedded Cretaceous (?) limestone standing almost on edge and apparently are the southern extension of the beds exposed in Juarez Mountain. At km. 45 the road enters the region of Los Médanos which it crosses transversely for thirty kilometers. The "médanos" are moving dunes of barren sand, some of

[1] The altitudes and distances along the railway are taken from the official map and profile of the road.

them low, but others 20 to 60 m. or more in height, and the region which they characterize extends for more than one hundred miles from near the international boundary southeastward beyond the Mexican Central railway. The strip is comparatively narrow, the section of the Sierra Madre and Pacific railway being made at nearly the widest part. The plain here is about 1210 m. above the sea. Destruction of the sparse vegetation in any part of the mesa is liable to cause drifting of the sand under the influence of the strong winds which prevail during a large part of the year. Sometimes the drifts cause serious interference with railroad operation. Where the dunes cross the Sierra Madre road they are only 5 to 6 m. high.

The effect of the mesquite is not only preservative but also constructive. The plant is normally a tree fifteen to twenty feet high, but on the desert the portion usually above ground is only the ultimate branches, the trunk and heavier branches being below the surface. Sand and soil drift into oval mounds with north-south axis around the mesquite trees and bunch-grass takes root on the surface. Kangaroo rats burrow deeply into the mounds, and other creatures find refuge or food there. The arid districts teem with life in surprising manner. The mesquite and the greasewood (*Covellia*) are practically the sole source of fuel in the arid region and the mountains furnish water by irrigation canals or flumes, hence the inhabitants are said to "dig for food and climb for water." Furthermore they "cut hay with a hoe," since the bunch grass, green or dry, furnishes fodder for cattle and horses and is gathered by pulling it up by the roots.

From km. 70 to km. 75 the railroad descends rather rapidly 35 m. through well-developed "bad-land" topography on a small scale to the floor of an extensive basin 1170 m. above the sea, or 90 m. below the rim of the mesa where it overlooks the Rio Grande. The basin is almost perfectly flat and is 15 km. across by the railroad. This is the Franklin bolson, or pocket desert, and a small portion is occupied by a shallow laguna or lake during part of the rainy season. Between km. 95 and km. 120 the railroad cuts through the tops of a range of "buried mountains" known as the Sierra San Blas, consisting of limestone ridges associated with basaltic cones and flows. The cones seem to be destructional forms.

Here again the surface of the mesa rises in suggestive fashion into the gulches and around the buried tops of the associated mountains, showing abundantly the "conoplains" recently described by Miss Ogilvie.[1] This feature, the nature of the recent deposits and the condition of the rock-fragments lying upon the mountain sides everywhere throughout the arid regions indicate the arid, or desert, cycle of subaërial denudation as dis-

[1] Amer. Geol., vol. XXXVI, pp. 27–34, 1905.

tinguished from the "normal" cycle obtaining in well-watered districts.[1] The original recent land surface was formed of folded limestone ridges and lava flows and fragmentary ejecta; it comprised many constructional valleys and basins. The great diurnal variations in temperature, often amounting to 100° F. (Libby) in these regions, subject the rock ledges and fragments to severe strains, causing continual flaking or spalling and continual reduction in the size of the rock masses, even without the aid of frost. The resulting masses, both large and small, descend the slopes by gravity and are in turn attacked by the disintegrating and decomposing forces. Occasional showers, even in the semi-arid regions, cause sheet-flood transportation and erosion and transfer much material to the depressions in the surface. The winds transport vast quantities of sand and even small pebbles, though the rate of transportation is probably slower and more uneven than it is with water. Whirlwinds too are important agents of transportation in the desert. When deposited in the temporary or permanent lagunas, or lakes, the transported material is laid down in well-stratified beds, some of which are the adobe clay of the arid-regions.

An important feature of wind erosion and deposition is that they are not determined by any base level, as is the case with water. Wind scoops out hollows below the general level of the land and carries its load of sand to higher as well as to lower positions. The distance to which the material is carried depends upon its coarseness of grain and the violence of the wind. The fine sand and dust are transported far and wide. The exposed surfaces of pebbles, boulders and cliffs show the wearing and polishing effects of the wind-driven sand. The tops of many buried mountains are to be seen on the journey across the dry mesa. As has been noted by Davis, when the internal drainage does not escape from the forming basins, the tendency of the wash, slide-rock and small fragments is to fill the basins with deposits whose limiting position is one of horizontality. Measurements were not made to determine the distance to which fragments of a given size have traveled into the basin from the surrounding parent ledges, but in general it may be said that the finer material is in the central portion of the basins. This, however, is not due to simple transportation, as the process of disintegration is continuous and progressive.

At km. 125 from Juarez the railroad reaches Laguna de Guzman, a body of water about 40 km. long from southeast to northwest and 15 to 25 km. wide. The lake is shallow, however, and its dimensions, area and shape vary greatly with the seasons. The evaporation is said to exceed 2 m. a year, and it is not a rare occurrence for the lake to become entirely

[1] See the writings of W. M. Davis, R. T. Hill, C. R. Keyes de Lapparent, McGee, Penck, Walther and others.

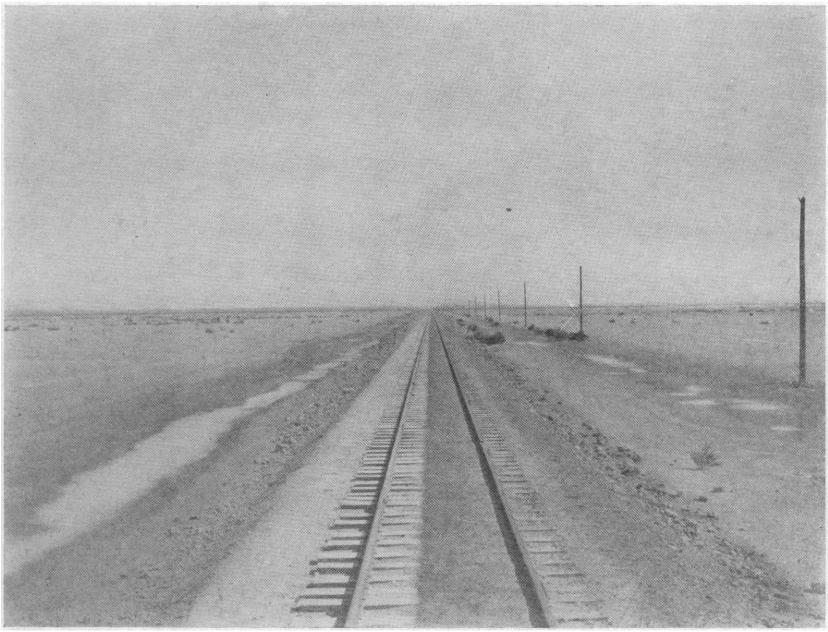

FIG. 1. FRANKLIN BOLSON ON THE R. G., S. M. AND P. R. R.

A typical arid "bolson," or pocket desert, 86 km. from El Paso. Slight depressions in the surface collect water during showers and form "settling tanks" for the deposition in stratified beds of wind-driven sand and dust.

FIG. 2. CORRALITOS BASIN AND SIERRA DE CORRALITOS FROM THE R. G., S. M. AND P. R. R.

A typical semi-arid basin 200 km. from El Paso, receiving sufficient moisture during the winter to support an extremely scanty vegetation.

dry. Laguna de Guzman receives the drainage of the Casas Grandes river, but the discharge into the lake is diminishing year by year on account of the extended irrigation projects along the middle course of the stream. Within a few kilometers on the other (south) side of the railroad track is the similar body of water known as the Laguna de Santa Maria, which is the receiving basin of the Santa Maria river, a stream running nearly parallel (N. N. W.) with the Casas Grandes much of its course. The water of the Guzman laguna is too alkaline to be fit for drinking, but copious springs of sweet fresh water are found in the vicinity. West of the laguna rises the mountain mass known as the Sierra de Guzman, consisting principally of volcanics. Warm springs are known at the east base of these mountains.

Turning to the south from Guzman station the railroad passes into an inclosed basin in which is a large laguna. The Urrutia mountains, known also as the Corral de Pedro, bound the basin on the west with a series of small cones and lava flows. These, like the opposite mountains, the Sierra Santa Maria, east of the railroad, are of volcanic origin. From the passing train one readily determines the nature of many slopes to be dry wash consisting of coarse and fine, subangular and rounded fragments, pebbles and boulders. The process of sorting and transporting is evident. South of the Urrutias are the Sabinal mountains, 156 km. from El Paso. The Sabinal range is reported to have a core of granite, upon which rest at high angles beds of Cretaceous limestone. The granite is an intrusive mass, to judge from the reports of mine owners of the region. Carbonate ores of lead and silver characterize the contact zone and are worked by the Sabinal and Adventurera groups of mines. This area of granite and limestone is charted upon Castillo's geological map of Mexico. The station of Sabinal is in an inclosed basin at 1250 m. above tide, or 80 m. above the Urrutia basin.

Near km. 170 the railroad turns to the southwest and begins to climb rapidly to surmount the pass of San Pedro between the high Sierra Capulin on the north and northern outliers of the lower Sierra Escondida on the south. These outliers from near km. 175 to near km. 190 (the station of San Pedro is at km. 188) present a series of comparatively low, flat-topped buttes or table mountains, the upper portion of which consists of columnar lava, probably basaltic in character. They have been carved from an extensive sheet of lava overlying the beds of tuff or breccia.

At km. 193 the railroad crosses the pass at an elevation of 1600 m. and enters the Corralitos basin, the scanty drainage of which has been captured by the Casas Grandes river, if one can speak of "drainage" in such an arid basin. The San Pedro group of silver-lead mines is in the contact zone between Cretaceous limestone and underlying intrusive granite in the old pass of the same name about 8 km. north of the railroad. The railroad descends 190 m. in 25 km. to km. 218 (the station of Corralitos is at km. 215). Near km. 222 the road enters the Casas Grandes basin, altitude 1455 m., which extends a distance of about 30 km. to the new town of Terrazas.

The Casas Grandes basin is typical of the semi-arid inclosed basins, now traversed by rivers, which are to be found scattered throughout the Sierra Madre region. Its surface is almost perfectly level, the railroad rising from north to south across it at a grade averaging .2 of 1 per cent, and the river, the Casas Grandes, is nearly at base level, doing scarcely any erosion except in times of flood. The plain at the north end of the Casas Grandes basin is dotted with small conical hills of columnar basalt covered with loose angular blocks of rock, and a great area of this character stretches away to the southeast. These low cones are destructional forms and show almost the last stage in the burying of a mountain. The eastern portion of the basin shows symmetrical destructional cones of volcanic material apparently basaltic in character. The mountains on the west of the basin are the foothills of the main cordon of the Western Sierra Madre. They rise to greater elevations than do those to the east. The basin is about 35 km. wide from west to east and is very fertile along the river where irrigation is practicable. The Mormon colony "Colonia Dublan" is a thriving recent settlement in the midst of the basin. In exceptionally rainy years even the "dry" ranches are productive of much grass.

That the pre-Columbian inhabitants of the region valued this basin as a place of residence is shown by the extensive ruins to be found upon a terrace of the river at the place known by reason of these remains as "Casas Grandes," *par excellence*. The ruins cover a surface several acres in extent, and are supposed by Bandelier[1] to have housed a population of between 3,000 and 4,000 souls. The adobe of the ancient walls consists of the red clay of the district mingled with gravel and laid in troughs, one tier being allowed to set before the next tier was laid atop of it, just as concrete buildings are put up today in our own and other countries. This ancient adobe, which is certainly more than 400 years old, gives some notion of the extreme slowness with which erosion goes forward in a semi-arid climate. In this part of the region the ground is largely covered with scanty grass and other vegetation, which undoubtedly prolongs the period of erosion through preventing the winds from taking up a heavy load of sand to hurl against obstacles.

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[1] Investigations in the Southwest, part 2, p. 544. 1892.

Modern adobe differs from the ancient in being made of clay mixed with straw and formed into large bricks. The resulting material is not nearly as durable as the ancient, and the difference between the two is strikingly brought out in several structures at Casas Grandes in which the modern inhabitants have built the ancient ruins directly into the walls of the new houses. Some of the ruins contain rooms, the walls of which have been finished by a plaster made of sifted adobe clay and laid on smoothly. Much excellent pottery of good design and workmanship has been found in the ruins, and the indications are that the unknown inhabitants were of a comparatively high degree of civilization. They probably were driven out of their homes or exterminated by the attack of some hostile tribe of Indians. The modern Mexican town of Casas Grandes straggles over the river terrace, and its inhabitants depend for their meager subsistence upon the grazing and the frequent crops raised by rather primitive methods of irrigation along the river.

Blue limestone (of Cretaceous age?) is reported to exist in the mountains west and south of the Casas Grandes basin.

About 10 km. south of the railway station of Casas Grandes the inclosed basin of the same name ceases against rhyolitic hills. Four km. further south the rock is a much-indurated rhyolitic tuff presenting fine-columnar structure. The rhyolite is overlain by beds of scoriaceous basaltic lava in the cavities of which there is much secondary chalcedonic silica. This is at the junction of the San Miguel and Piedras Verdes rivers, which unite to form the Casas Grandes. These rivers well illustrate the confusion of names as applied to streams in Mexico. The river, here called the Casas Grandes, extends from the junction of the forks just mentioned to the Laguna de Guzman, flowing a distance of 240 km. Its upper half is known by the name of Casas Grandes, while the lower half is called the Corralitos river on some maps. Above the junction point the San Miguel, which is also known as the Palanganas, is the real continuation of the Casas Grandes, and should not receive an independent name. The Casas Grandes river decreases in size as it proceeds on its course below the town of Casas Grandes. Evaporation and irrigation remove more water than the arid region replaces.

The two forks of the Casas Grandes river come together in the northern part of the San Diego basin, which is the eighth of the bolsons and basins through which we passed after attaining the mesa south of Sierra de Juarez. It is a small basin, about 24 km. long from N. N. W. to S. S. E. by 16 km. wide; elevation about 1500 m.[1] above the sea. Since its drainage was

[1] All the following altitudes are given from readings of an aneroid barometer, unless otherwise stated.

captured by the Casas Grandes river alluvial fans have become rather prominent along the rim. There still exist transverse "trincheras" or low dikes of stones and earth which were built in pre-Columbian time for the purpose of preventing the displacement by rains and simple sliding of the soil needed for cultivation. The San Diego basin is bounded by steep mountain walls which increase in altitude toward the south until at El Rutio they rise 600 to 700 m. above the plain and rapidly close in upon the river, the San Miguel, which debouches near this point from a picturesque cañon.

In the northern part of the San Diego basin there is a melon-shaped hill consisting of basalt. This flow is older than a portion at least of the basin deposits, inasmuch as it has been partly buried by them. In several districts in Chihuahua and in southern New Mexico and Arizona the dissected basins and bolsons show a similar intercalation of comparatively recent flows of basaltic lava, and basalt also occurs in some of the lower beds of the Aros cañon. The melon shape of the hill is a peculiar feature which perhaps may be explained by assuming that the bed lies over a vent through which the lava welled up with comparative gentleness. Near the junction of the Piedras Verdes river with the San Miguel a flow of scoriaceous basalt lies directly upon a thick flow of rhyolite.

The San Diego basin forms the major portion of the hacienda, or estate, of the same name belonging to General Luis Terrazas, a hero of the Mexican contest against the French in the 60's and for many years governor of the state of Chihuahua. General Terrazas is probably the largest individual landed proprietor in the world. His haciendas comprise millions of acres of the best land of Chihuahua and are said to extend in a practically unbroken series for 500 km. across the State. An administrador is in control of each hacienda, and under him there is a little army of servants, farm hands and cattlemen. Existence on these estates is still usually one of almost feudal simplicity, each hacienda being practically self-supporting. The energies of the haciendas are directed toward the production of cattle, horses and mules, with only agriculture enough to raise sufficient corn (maize) for local consumption and the carrying of stock over exceptional seasons. The agricultural work of the country is carried on in most primitive fashion. Single-handled wooden plows are in use which are made from the natural knees of tough trees like the live-oak. Sometimes the point of the share is protected by a bit of iron, but the implement is, at best, a very crude affair which entails an enormous waste of labor in its use. Specialized and efficient farm implements are making very slow headway in the Republic of Mexico, on account of the poverty and conservatism of the farming population.

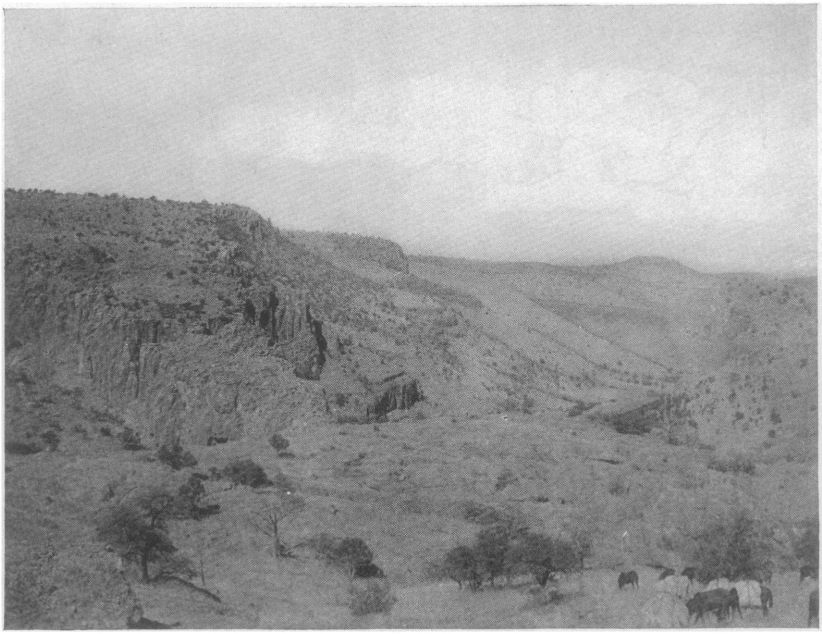


FIG. 1. SAN MIGUEL CAÑON.

Upper reaches looking N. W. from near Arroyo Metate. Total depth of cañon about 800 m. Rocks are rhyolite and andesite flows and tuffs and basalt flows.

FIG. 2. SAN MIGUEL CAÑON NEAR ARROYO METATE.

The lower gorge, some 150 m. deep, has been cut in a heavy composite bed of rhyolite. Many caves in the cañon were once occupied by human inhabitants.

At the southern end of the San Diego basin at an altitude of about 1,600 m. above the sea, we plunged directly into the cañon of the San Miguel river. This gorge has been carved to a depth of about 800 meters through a succession of flows of andesite, rhyolite and basalt, alternating with beds of corresponding tuffs. At the mouth of the cañon augite-andesite is the basal rock and is partly covered by a flow of basalt. The basalt is perfectly fresh and may be the youngest rock of the section in spite of its low relative position. Flow structure is strongly in evidence in the lava beds and some of the tuff beds have been considerably indurated. The region occupied by the great gorge is estimated to be 7 or 8 km. wide. The region is one of moderate vegetation, and the mountain slopes are covered with grass and a scanty growth of small live oaks and jack pines. The whole section exposed, from Hacienda San Diego to the top of the Cordon del Metale, is about 900 m. thick.

After following up the cañon for a distance of 10 or 12 km. we turned abruptly to the east and climbed out of the gorge by way of the Arroyo Metate and a neighboring arroyo to the south and crossed over the Cordon del Metate at an altitude of about 2200 m. The view across the cañon to the westward shows that it consists of a well-dissected plain between the bounding walls and that the main river flows through a comparatively youthful gorge which it has cut in the lowest exposed bed of solid rhyolite. This bed is about 150 meters thick, and is at least double in make-up, for 12 m. above the river we observed a thin bed of tuff in it separating an earlier from a later flow. The upper surface of the lower bed is scoriaceous and contains rounded masses of relatively dense rock which may be the remains of ancient bombs. The flows are columnar in structure with platey parting near their upper and lower surfaces. Above this bed of rhyolite there are apparently several of andesite and an upper flow of rhyolite in the composition of the walls of the cañon. Roughly speaking, we have the following section on the San Miguel (Palanganas) river from the junction with the Piedras Verdes river to the summit of the Cordon del Metate, which forms the eastern wall of the main San Miguel cañon; rhyolite flows and tuffs associated with basalt, 100 m.; augite andesite overlain by basalt, 160 m.; rhyolite flows and tuffs, 150 m.; augite andesite flows and tuffs 350 m.; rhyolite flows and tuffs, 240 m. There was a considerable interval of erosion between the uppermost andesite flow and the overlying rhyolite.

The intercalated tuff beds have given opportunity for the formation of the vertical walls of the arroyos and the cañon, since they have been eroded at a more rapid rate than the beds of solid rock, thus undermining the latter. Furthermore, the planes of separation between the lava beds and the contact zones between the lava and the underlying tuff are the locus of many shallow caves, some of which in time past have been used as human habitations.

Crossing the Cordon del Metate we came out upon the Llano Cristo, another inclosed basin about 30 km. long from north to south, at an elevation of about 2150 to 2180 m. above the sea, or more than 700 m. above the Casas Grandes basin. Llano Cristo, however, is not a simple flat plain, but is rather a series of basins at practically the same elevation. The surrounding mountains rise from 200 to 250 m. above it. The surface of Llano Cristo seems in part at least to be the original surface of a great flow of andesite, the hollows of which have been filled more or less completely with wash. Here and there rhyolite is in evidence at a higher level, as is shown in the section given above.

Most of the drainage is entirely internal, but toward the south the head waters of the San Miguel river and some of its branches have cut back into the plain, and the San Miguel cañon heads near the manor house of the Hacienda San Miguel. The soil of the Llano Cristo is fertile and produces fine grass and crops of maize without irrigation. The hacienda of San Miguel, which includes the Llano Cristo, is one of the best of those belonging to General Tarrazas, comprising more than 1,000,000 acres of land and supporting even with the primitive methods employed 40,000 head of cattle. Eight thousand steers are branded yearly. Two hundred persons live at the manor house, which is a regular fortification, built to withstand the attacks of roaming bands of Apaches and other hostile tribes of Indians.

South of the house the plain is marked by two series of prominent terraces along a tributary of the San Miguel. The upper of the two terraces rises gradually into the wash from the mountains and contains gravel which is partly consolidated. The San Miguel (Palanganas) river has its source in the so-called "continental divide" about 30 km. south of the manor house. The term continental divide is misleading in a region like the Western Sierra Madre, where the relationships of the chief cordons are confused by the great eroded cañons and valleys; where there is so much internal drainage in high basins, and where the division at best is between oceanic (Pacific) and interior drainage, since none of the rivers originating on the eastern slopes of these mountains, with the exception of the Conchos, reaches oceanic (Atlantic) drainage.

After leaving the Llano Cristo basin our route southward led us across low ridges and small basins at elevations of 2100 to 2170 m. above the sea in which are several "cienegas," or marshes. The ridges are rocky and are sparsely timbered with an open forest of large long-leafed pine trees, but the basins are, as usual, covered only with grass. It is a fine grazing country. The ravines show much scoriaceous lava, probably andesitic in character, but the higher portions of the ridges and the plateau are evi-

FIG. 1. LLANO BAVICORA.

A typical inclosed basin with an almost perfectly level floor of "wash" from the disintegration of the neighboring and included mountains. In the distance is the top of a flow of basalt.

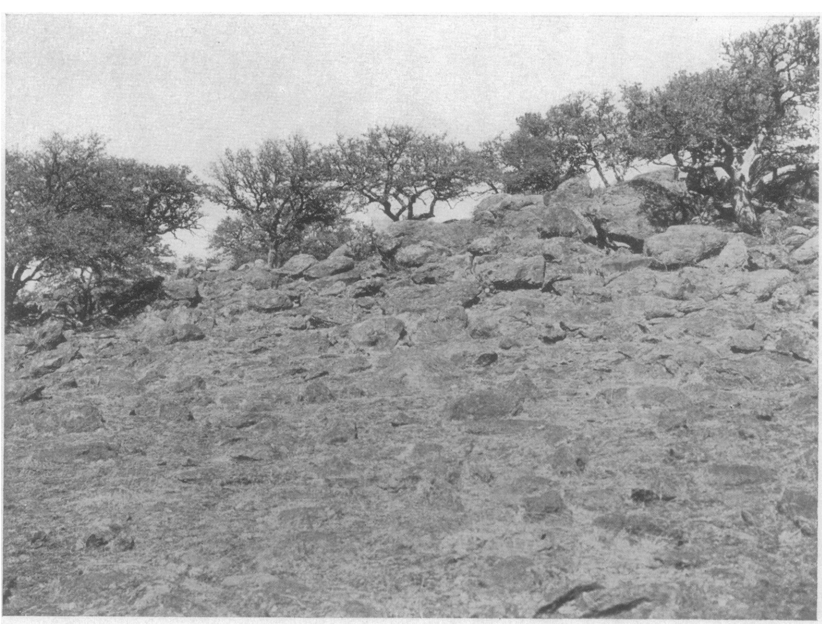


FIG. 2. LLANO BAVICORA.

Detail of a promontory of basalt, showing the rock in the process of disintegration, degradation and transportation.

dently part of a great flow of rhyolite. About 40 km. from the hacienda house of San Miguel we entered the Llano Bavicora, a vast level expanse which forms the heart of the rich million-acre tract belonging to the Hearst estate.

The Llano Bavicora is a typical inclosed basin about 50 km. in length from northeast to southwest by about 32 km. in width. Its drainage seems to be entirely internal, and a laguna occupies a shallow depression in the middle, receiving the discharge of four or five considerable but variable streams. The basin occupied by the laguna is so shallow that the area covered by the waters and the outline of the shores vary greatly with the seasons. The general elevation of the plain is about 2110 m. above the sea. Low flat tongues of rhyolitic wash come far out into the basin from the low surrounding mountains. Opal and chalcedony pebbles are abundant in the wash. These are so numerous indeed that silica in this form must play an important part in the total of material. Many ledges of rhyolite and some of basalt border or jut out into the Llano Bavicora like the bluffs and headlands along the shores of the ocean. The bold capes, peninsulas and islands of lava are covered with residual boulders showing the gradation from ledge to soil. The degradation of the basalt progresses more rapidly than that of the rhyolite beds.

Our route across the Bavicora plain had been from northeast to southwest, but at the border we turned westward and plunged into the forest, slowly rising from the time we left the plain until Montezuma Pass was reached at altitude 2230 m. on the divide between the Bavicora drainage and that of the Aros river. The pass receives its name from an assemblage of about two hundred mounds marking the location of a large village of supposed pre-Columbian origin. At the time of our visit the mounds had never been investigated or studied, but such a state of affairs can not be expected to obtain long, with the increase of American travel through the region. Fifteen kilometers west of Montezuma Pass we reached the new lumber camp of Dedrick in the midst of the heavy pine forest at an elevation of about 2210 m. above tide, upon the little creek known as the Chuchupati, which flows southward as a consequent stream until it breaks across the cordon and empties into the northward flowing Aros river, a member of the Pacific drainage system.

The region immediately about Dedrick is composed of rhyolite flows and tuffs. The flows are both lithoidal and vitreous. The obsidian is brown, black and pearl gray in color, and is both heavily massive and platey in structure. Some of the platey rock is a very glassy rhyolite which has suffered much from devitrification. The obsidian shows beautiful lines of flow, either all black or alternating brown and black, and much of it is perlitic in texture. The brown is often the matrix for rounded masses of the black. Fragments of obsidian are abundant in the tuff. The most striking feature of the petrography of the surface of this portion of the plateau is the predominance of andesite, in contrast with the prevalence of rhyolite to the east and south of this region, as described by Ordoñez. The great mountain ridges rising above the high plateau seem generally to be of rhyolite, and they contain much obsidian as well as lithoidal lava.

About five kilometers west of Dedrick we reached the rim of the vast cañon of the Aros river, the trail passing over the divide at 2565 m. (average of two readings) above tide. At this altitude there occurs a rather fine-grained soft conglomerate 20 m. thick containing rounded and subangular fragments of obsidian and other igneous material too much decomposed for identification. This deposit seems to be consolidated stream wash from the neighboring ridge. On the south side of the pass over which the trail has been made the ridge of rhyolite rises to an elevation of probably 2775 or 2800 m., which seems to be about the maximum elevation of the highest portions of the cordons in this part of Chihuahua.

The view across the cañon of the Aros is superb. The cañon is estimated to be 12 to 16 km. wide and the river is from 1450 to 1600 m. below the highest portions of the rim. Innumerable beds of lava, indurated tuff and basin conglomerate or sandstone expose vertical faces of more or less brightly colored rock, contrasting in pleasing fashion with the grass-covered talus slopes and the forests of pine or live-oak, according to altitude, while the crimson trunk of an occasional madroña tree and the pale greens of the cacti and the magueys add charming variety to the foreground of the scene.

The west-facing slopes of the eastern wall of the cañon are steeper than the east-facing slopes of the cañon and of the region east of the cañon. This is an indication that the degradation of the plateau is proceeding eastward and shows how the Pacific drainage has robbed the internal drainage of the basins of the central part of the Western Sierra Madre and is carrying the process farther eastward. The diurnal variation of temperature is greater on a west-facing slope than on an east-facing slope, on account of the higher heating power of the afternoon sun as compared with the morning sun, while the nocturnal temperature is presumably the same on both slopes. The greater the variation in temperature the greater the strains produced in the rocks and the more rapid the disintegration. The prevailing winds come from the west bringing moisture from the Gulf of California. This moisture is almost all precipitated in the high mountains, and the rains are driven against the western slopes by the prevailing winds and are thus an aid in removing the rock débris.

The trail to the river leads down through a maze of side gorges, along sharp divides between deep ravines and across a level plain which is the remains of an inclosed basin. Nearly 450 meters below the summit of the pass we came upon an extensive flow of augite-andesite 45 or 50 meters in thickness. The rock thus identified is black when fresh, with prominent phenocrysts of plagioclase (labradorite?). The altered zones of the mass show the feldspar phenocrysts changed to dark red in color. Under the microscope the rock is seen to have an extremely fine-grained hyalopilitic groundmass with porphyritic augite crystals subordinate in prominence to the plagioclase. The augite phenocrysts show resorption phenomena and sometimes their presence is to be inferred only from aggregates of minute magnetite crystals. The plagioclase phenocrysts, which contain many microlitic inclusions, are not excessively twinned, the basal cleavage is well marked and the angle of extinction on (001) of 30° is taken as indicating a feldspar at least as basic as labradorite. The ground-mass contains but little glass and what there is is light brown in color. Pyrite is a rare constituent in very small crystals.

About 500 meters below the pass we traversed for several kilometers the level top of a mesa formed by the local conglomerate and sandstone of an ancient inclosed basin which has been deeply incised by tributaries of the Aros river since its drainage was captured by the master stream. We estimated the maximum thickness of these basin deposits to be not less than 150 m. but they are variable in development, their base being the uneven surface of the original lava flows. We have spoken of "buried" mountains in the bolsons of northern Chihuahua, but here in this cañon we might as appropriately speak of "resurrected" mountains, since old peaks once covered by the accumulation of débris in the inclosed basin have been uncovered again by the dissection of the basin since the capture of its drainage by the Aros. A resurrected mountain of andesite is shown in the illustration, pl. XXII.

The number of lava flows in the region has been great. In one unimporant side arroyo were counted 19 well-marked beds of lava, aside from several beds of tuff, and this must be only a fraction of the total number. Volcanic activity must have been tremendous throughout the Sierra Madre Occidental in Tertiary or, at least, post-Cretaceous times, and there was flow after flow of andesite, dacite (?), rhyolite and basalt, together with deposits of corresponding tuffs. About 800 m. below the rim we encountered red rhyolitic tuff, strongly bedded, with strike N. 10° E. (true) and dip 27° E., conformably below which was similar white tuff. The tuff beds were, together with intercalated rhyolite, perhaps 300 m. in thickness. On the farther (northern) side of an arroyo north of these tuff beds and in a line with their strike there is a massive flow of rhyolite, estimated at 75 m. in thickness, and andesite (?) comes against the rhyolite on the east.

About 850 m. below the pass over the rim of the cañon there is a small mesa almost entirely cut off from the surrounding ridges. This seems to be the remains of an inclosed basin about 350 m. below the level of the large inclosed basin just described. Its upper surface appeared to be composed of basin conglomerate and sandstone. We did not visit it.

Our trail descended the bed of a little stream carved in a bed of andesitic lava at its contact with an underlying bed of decomposed red porphyritic lava. We reached the Aros river about 1225 m. below the pass over the cañon rim. At this point therefore the Arós river is approximately 1340 m. above sea level. At the trail crossing, which is a ford except when the river is in freshet, there is a bed of vesicular basalt (?) the upper surface of which preserves the ropy appearance of a surface flow. The convexity of the "ropes" is toward the south, showing that the direction of the flow was from the north. The bed is now in a horizontal position and there are indications of its being a double flow or even more complex. It is conformably overlain by a reddish yellow, rather soft sandstone about 1.25 m. thick, the thickness changing with the inequalities of the surface on which the deposit was made. It seems reasonable to suppose that the sandstone is a consolidated basin deposit, though it may indeed mark the course of an ancient stream. There is said to be considerable horizontally bedded sandstone in the various cañons and arroyos, but exact data regarding other occurrences are lacking. Above the sandstone at our crossing of the Aros there is a heavy bed of extremely altered vesicular basaltic lava. This bed and that below the sandstone have their vesicles filled in part with altered zeolitic material.

Recapitulating the section exposed in the east wall of the Aros cañon on the Dedrick-Guaynopita trail we have, beginning below: basalt (?) of undetermined thickness, with its surface about 1345 m. above the level of the sea; reddish yellow, soft sandstone, 1.25 m.; massive augite andesite flows, 100 m.; red and white rhyolitic tuffs with intercalated beds of rhyolite, 300 m.; augite andesite with rather coarse-grained groundmass, 180 m.; basin sandstones and conglomerates, 120–140 m.; strongly porphyritic augite andesite with very fine-grained groundmass 50 m.; concealed by wash of gravel and sand, 450 m.; rhyolite (to summit of cordon west of Dedrick) 250 m. This gives a total thickness of about 1,475 meters, but it must be remembered that the determinations were made with an aneroid barometer while passing once over a crooked trail.

We found the Aros river to be in flood, though still 4.5 m. below the highest level for recent years, as recorded on the banks. We roughly

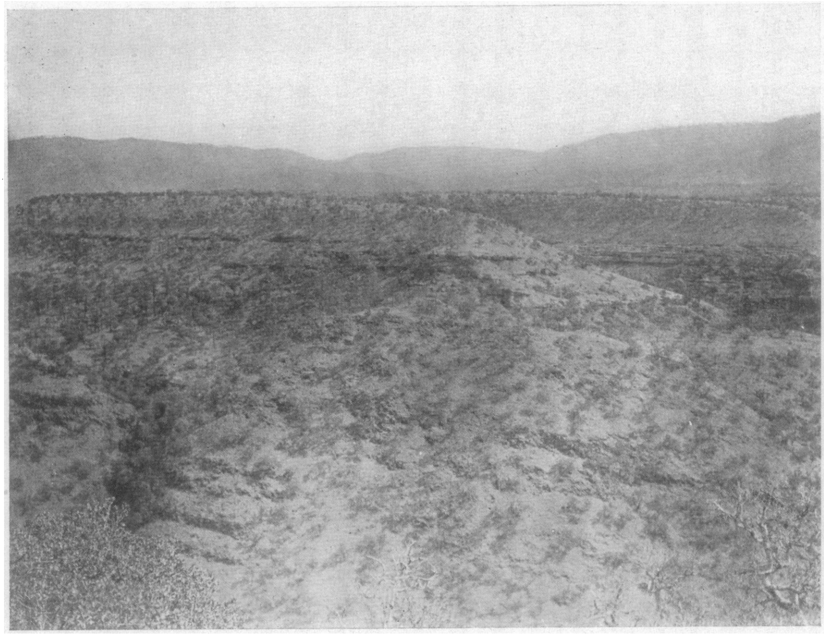


FIG. 1. AROS CAÑON.

Dissected inclosed basin near Dedrick. The beds are basin conglomerates and sandstones resting discordantly on andesite flows and tuff beds.

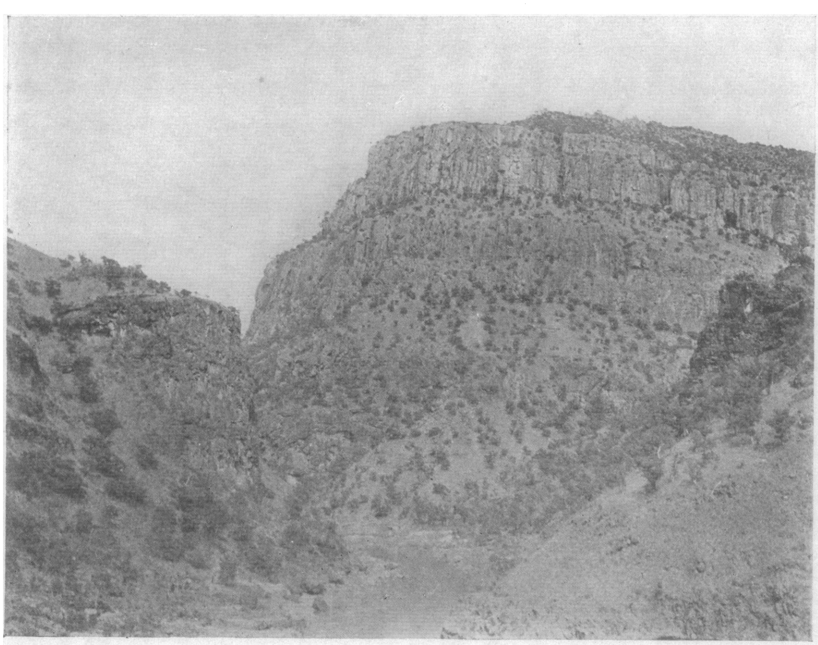


FIG. 2. AROS CAÑON.

Near junction with Rio Chico. The great bluff, 220 m. high, shows beds of rhyolite alternating with beds of tuff.

calculated the width of the river at 40–45 m. and the rate of the current at about 100 m. per minute, but about 200 m. below our ferry the banks of the stream contracted considerably and there were dangerous rapids. The stream was much too high for fording, hence we constructed a rude raft with split cedar logs and ropes and transferred ourselves and our baggage safely to the farther side. Before the floods came, a stout rope had been stretched across the river and tied to convenient trees. This rope and a long rope which we had with us gave us the means of pulling our raft from one side of the river to the other with the aid of the swift current. Horses, mules and burros swam the stream without much difficulty.

The Aros cañon is described as beginning about 8 km. N. W. of the little town of Temosachic on the Chihuahua and Pacific railway. The first section of its extremely tortuous course is toward the south for about 40 km. until it receives the important tributary from the southeast known as the Rio Verde, then it turns abruptly through more than 90° and pursues a northwesterly course for about 100 km. to the junction with the Rio Chico, where it bends westward in a grand curve for about 20 km. past Guaynopita and then follows a southerly course again for 50–60 km., receiving on the way the important Tutuaca river from the south-southeast. Near Guadalupe the Aros turns through an angle of 180° and then flows northwest and west to its junction with the Yaqui river, of which it is the chief affluent.

This river system is a most interesting example of a series of consequent streams whose drainage has been captured by a master stream cutting its way backward transversely to the original slopes of the lavas and tuffs making up the main mass of the plateau region. A striking feature of this system is the entrance of most of the tributaries into the Aros in an inverted, *i. e.*, an upstream, sense, or direction. The Aros itself flows southward for several kilometers before its junction with the northflowing Rio Verde, which is the major stream at this point; the Chico flows southward into the northflowing Aros; the northflowing Tutuaca empties into the southflowing Aros; even the minor branches show the same feature and flow in an "upstream" direction into the major branches and the great river.

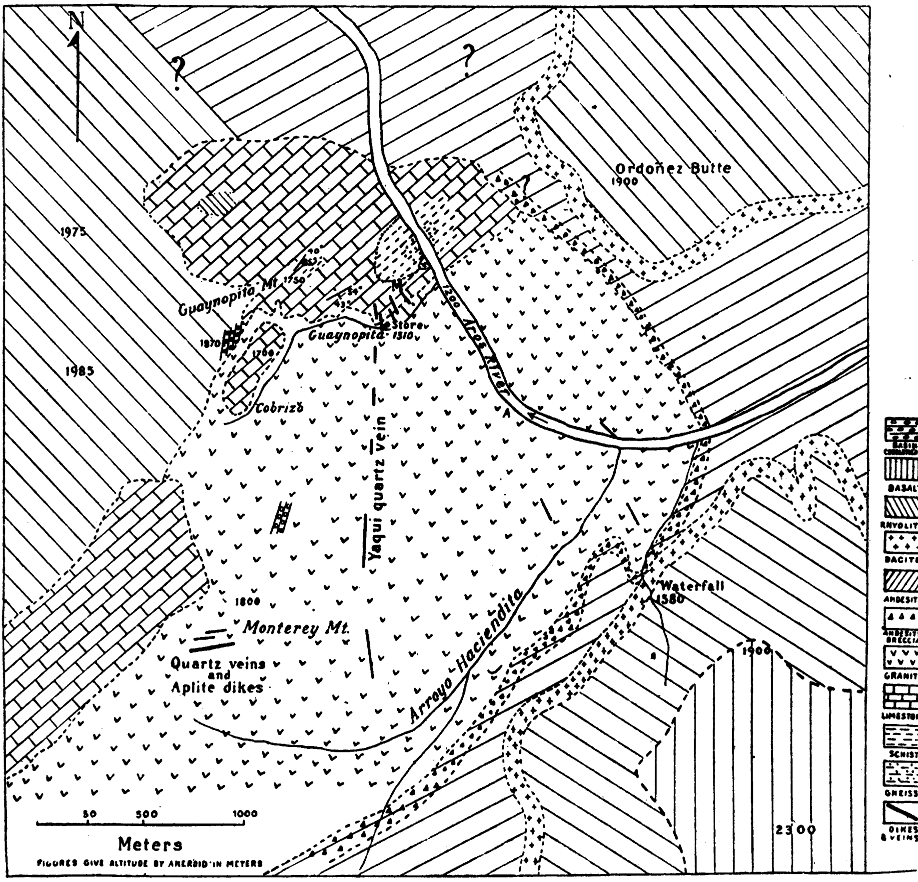
From the ferry we advanced northwestward down the cañon about 3 km. to a widening of the gorge where we camped upon the surface of the basaltic flow which we encountered at the ferry. The large, perfect and numerous potholes, now 8–10 m. above low water level, testify to long-continued presence of rapids at this point, and there are many such groups along the swift stream. The construction of the trail exposed fresh surfaces of the vesicular basalt and the author observed apophyllite, natrolite, calcite and quartz among the minerals filling the vesicles of the old lava. Above this flow there is a heavy bed of well-consolidated basaltic agglomerate or breccia. The hard agglomerate fills the shrinkage fissures in the upper part of the basalt flow. Above the agglomerate there is a heavy bed of andesite.

Above the andesite there occur several beds of rhyolitic lava and tuff. An almost vertical cliff 220 m. high near our camp beside the river showed at least eight beds of rhyolite in its composition. Opposite this great cliff we turned abruptly to the south and climbed rapidly out of the lower portion of the cañon. About 90 m. above the river the trail crosses a dike of rhyolite porphyry cutting through the dark-red, devitrified obsidian or glassy rhyolite forming the country rock. The dike is from 2 to 7.5 m. wide and can be traced readily for about 200 m. in a direction N. 55°–60° W. The dike bifurcates toward the northwest and is lost. Slicken-sided surfaces associated with this dike prove differential movement to have taken place in the country rock. Above the red beds there is a heavy bed of very light-colored, pinkish white rhyolite forming a striking feature of the landscape. The rock is so much like the dike rock just described that it seems probable that they are parts of the same magma, though there seems to be no immediate genetic connection with the dark-red rhyolitic rock.

Pursuing our way up the side arroyo, the grade of which is directly contrary to that of the Aros, we found basin conglomerate and sandstone 140 to 150 m. thick. Above the basin deposits dense and amygdaloidal andesite flows were present from about 1600 m. to 1780 m. above the sea. At 1780 m. we encountered the lower portion of the whitish or light colored rhyolite above referred to, which we found to be not less than 100 m. thick.

Here the trail drops somewhat into the head of a small arroyo, passes through a grove of large, handsome pines and within two or three hundred meters comes out suddenly upon the point of a salient jutting out into the main cañon of the Aros. My aneroid gave the elevation of the pinnacle as 1780 m. above tide, or about 550 m. above the boiling flood of the river in plain sight below us and apparently almost at our feet. A magnificent scene was spread out before our eyes, as we looked into the maze of cañons and arroyos. The bright reds of some of the rhyolite beds contrasted strongly with the dull reds of others, the light gray or white of the tuffs, the browns of the low-lying andesites, the various greens of grass-grown slopes, live-oak woods and pine forests and the brilliant yellow of an occasional lichen-covered cliff. From this view-point we could look into the upper portions of the great cañon of the Chico river, a tributary of the

FIG. 3
GUAYNOPITA DISTRICT, CHIHUAHUA, MEXICO.
Geology by E. O. HOVEY.
Based on topographic sheet by R. T. HILL



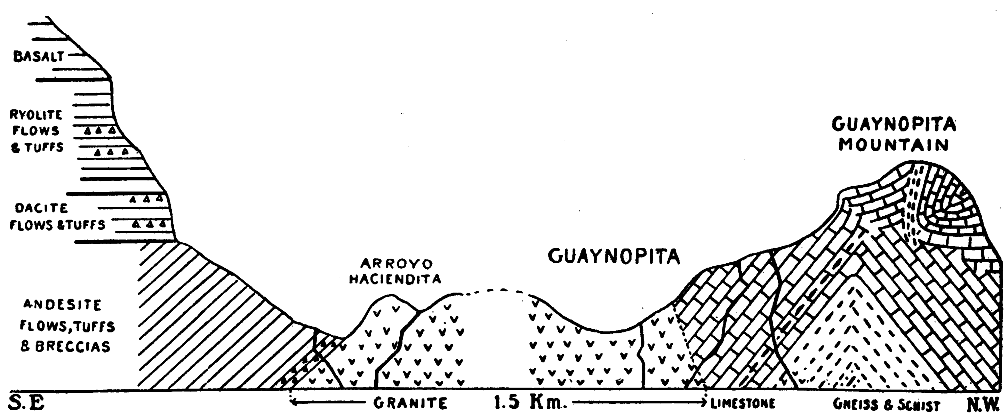


Fig. 4. Idealized section across Guaynopita district from S. E. to N. W. Heavy black lines are diabase porphyrite dikes. Proportions are entirely schematic. Determination of dacite is provisional and should have been so indicated in figure.

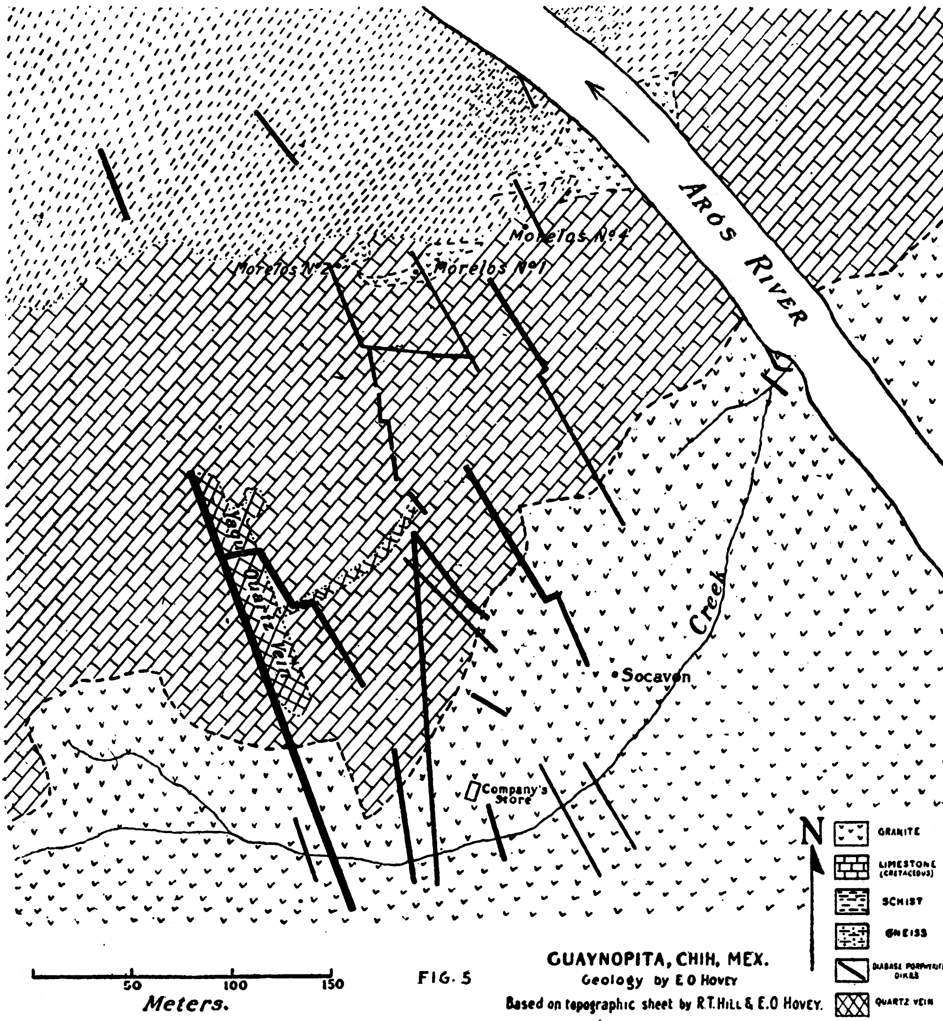


FIG. 5

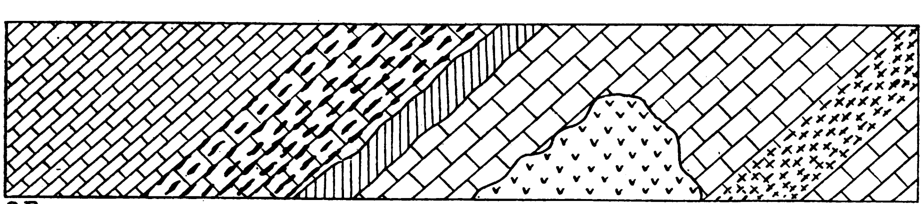


Fig. 6. Section along trail east of Morelos No. 2. tunnel, Guaynopita. Looking S. W. 1. Heavy bedded limestone 25 to 30 m. 2. Heavy bedded limestone, 4 m. thick, containing many bands of chert 10 to 15 cm. thick. 3. Diabase porphyrite dike 1.5 m. thick. 4. Heavy bedded limestone; silicified near the dike. 5. Granite apophysis 9 m. wide at base of section. 6. Calcareous chloritic schists 2.5 m.

Aros, where there are said to be many ruins of pre-Columbian habitations in caves or on vantage points.

The trail winds for nearly a kilometer along the edge of the plateau overlooking the river, and then descends rapidly into the portion of the gorge in which the mining operations of Guaynopita and Monterey are carried on. The Aros cañon widens considerably through the entry of the Arroyo Haciendita and its tributaries from the south together with some other minor affluents of the main stream, but the extent of the little Guaynopita district is comprised within an area scarcely 4 km. square.

The geology of this district has been discussed by the author in another

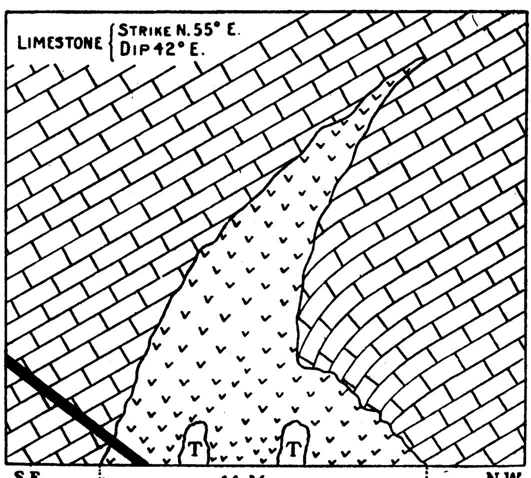


Fig. 7. Granite apophysis in limestone at Morelos No. 1 tunnel (T), Guaynopita. Looking S. 55° W.

place,[1] so that a mere summary of facts and conclusions will be given here. At Guaynopita the Aros River has cut its cañon down into the granite core of the Western Sierra Madre region. The granite, however, is intrusive in and therefore younger than a bluish crystalline and semi-crystalline limestone which is most probably of Cretaceous age (*fide* R. T. Hill), and marine origin.[2] The granite is also younger than andesite flows and breccias (tuffs) which seem to be unconformable with the limestone also. The limestone strikes N. 55° E., has been greatly elevated, tilted, contorted, overthrust, faulted and metamorphosed by the mountain-making forces which have raised the general region, and which here seem to have acted

[1] Festschrift, Harry Rosenbusch, pp. 77–95. Stuttgart, 1906.

[2] The fact of the occurrence of post-Cretaceous intrusive granite in Mexico seems to have been made known first by E. Ordoñez, *Vid.* Bol. Inst. Géol. de Mex., Nos. 4, 5 and 6, p. 76.

from the west. Impure clayey layers within the limestone have been altered by regional metamorphism into schists. Gneiss is closely associated with the schist. Dikes of diabase porphyrite intersect granite and limestone alike, and they also cut across the great quartz veins which traverse the granite and limestone. Above the old andesite there are flows and tuffs of dacite (?), rhyolite and basalt. The order of sequence is, beginning with the oldest rock exposed at Guaynopita, Cretaceous limestone, andesite, granite, quartz veins, diabase porphyrite dikes, dacite (?), rhyolite and latest of all basalt, agreeing essentially with the sequence made out by W. H. Weed for his section across Chihuahua and Sinaloa from Parral to Bacubirito some hundreds of kilometers south of Guaynopita.[1] From the evidence observed in the east side of the Aros cañon and elsewhere the

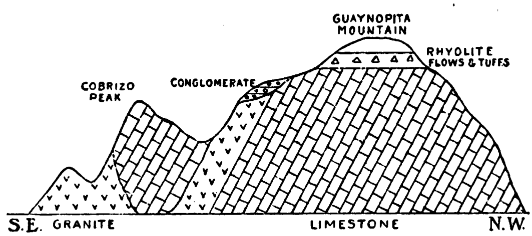


Fig. 8. Section from east to west through Cobrizo Peak and Guaynopita Mountain. The proportions are entirely schematic.

author is obliged to insert younger andesites also among or above the dacite (?) flows and tuffs, and basalts in the older part of the series. Guaynopita mountain is composed mostly of the upturned limestone, upon which the rhyolite seems to lie directly without any intervening andesite or dacite. The granite is a biotite granitite of medium coarseness of grain associated with hornblende granitite and muscovite-biotite granite.

The granite carries chalcopyrite in considerable amount and this has supplied the copper ores (chalcopyrite, tetrahedrite and oxidized ores) to the contact zones and the great veins. The ores carry commercially important values in gold and silver. Contact phenomena are comprised mostly in the serpentinization and marmorosis of the limestone and the garnetizing and epidotizing of the granite. Local enrichment, or secondary concentration, of lead and copper sulphides and oxidized ores has occurred in connection with some of the dikes.

The cañon of the Aros is strongly V-shaped at Guaynopita, evidencing a youthful stage of development. The more rapid cutting done by the great stream is shown by the presence of "hanging valleys" along the sides of the

[1] Trans. Am. Inst. Min. Eng., XXXII, p. 458.

FIG. 1. AROS CAÑON AT GUAYNOPITA.

Lower part is cut partly through granite. The upper salient at the left is of Cretaceous limestone. Volcanic rocks form the background.

FIG. 2. AROS CAÑON AT GUAYNOPITA.

Old (left) and new (right) channels of the river in granite.

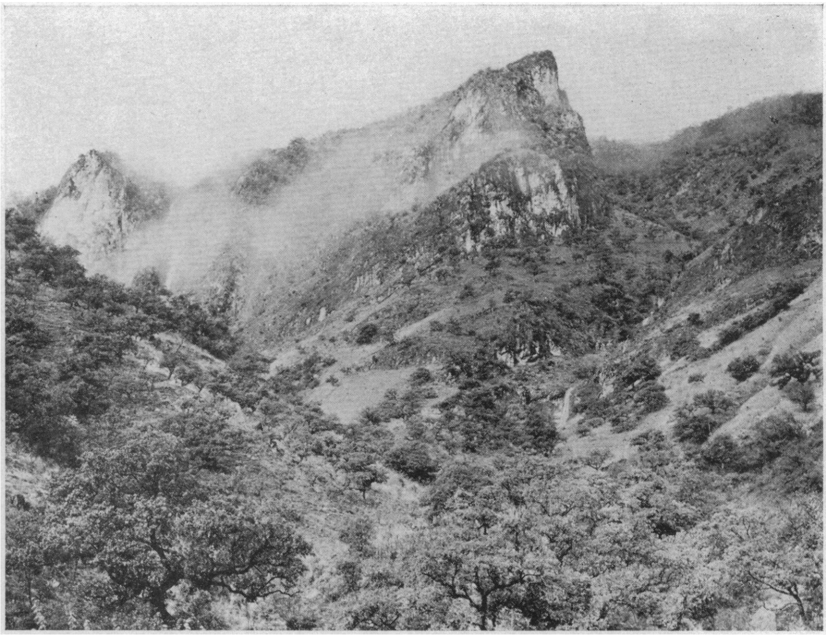


FIG. 1. GUAYNOPITA. THE COBRIZO PEAKS.

Outliers of Cretaceous limestone resting upon an intrusive granite. Mineralization has gone forward along the contact zone.

FIG. 2. GUAYNOPITA.

Cretaceous limestone showing an overthrust fault. View looking north-northwest from near the northern (right) of the Cobrizo Peaks as seen in Fig. 1.

FIG. 1. GUAYNOPITA. ORDOÑEZ BUTTE.

Southwest face showing limestone and associated schist, overlain by volcanic rocks. Intrusive granite is at the bottom of the section.

FIG. 2. OCAMPO.

The Santa Juliana vein about 5 meters wide (right half of view) cuts a heavy bed of diabase and its underlying Navosaigame conglomerate.

FIG. 1. NEAR GUAYNOPITA.
Contact of granite (left) with andesitic breccia. About 1.5 km. east of the mining camp.

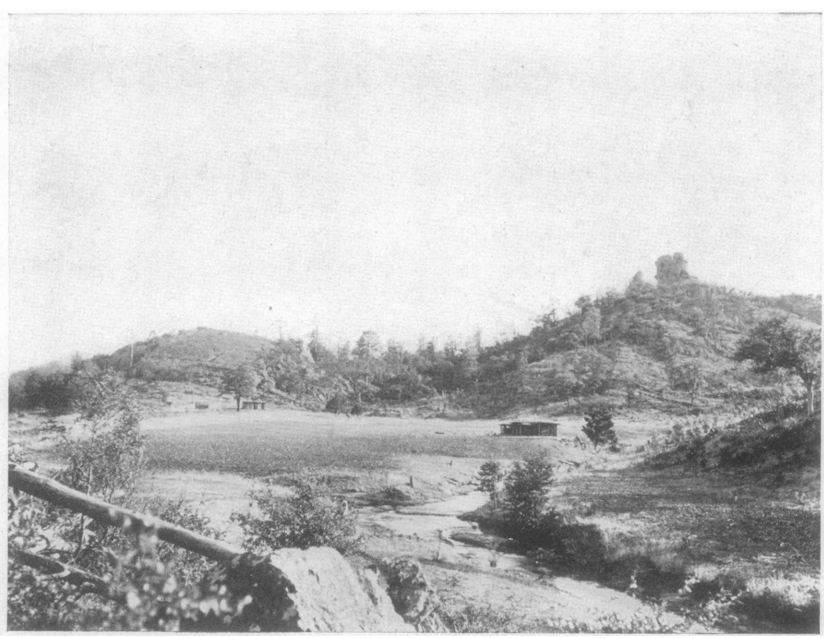


FIG. 2. RANCHO LAS ANIMAS.
Rounded knob of trachyte (left). A brecciated flow.

great gorge, some of which show picturesque waterfalls. High level (550 to 600 m. above the river) benches of conglomerate and sandstone show the former position of some of the basin deposits of the old inclosed basin. Directly across the Aros from Guaynopita a strong butte rises from the river. The point is really an outlier of the Candelaria mountain mass, but it shows so typically the whole important history of Guaynopita and therefore of the Western Sierra Madre that it seems worthy of a definite name, and Professor Hill and the author have taken the liberty of dignifying it by naming it Ordoñez Butte after Ezequiel Ordoñez, the Mexican geologist. The face of the butte is shown in Plate XXV, fig. 1.

Leaving Guaynopita 11 March our trail led us up a steep ascent of nearly 1100 m. to the top of the high mesa (2350 m. A. T.), where we encountered andesite and basalt. Looking backward to the north across the Aros cañon we had an impressive view of the profile of the great cuesta sloping gently at an angle of 3° southeastward from the great mass culminating in the Candelaria peaks. The elevated plateau is indeed the "Mother Range" (Sierra Madre), for most of the present relief of the mountains is due to the extensive erosion that has taken place in the great landmass. Westward of Guaynopita the stage of erosion is more advanced, and the resulting relief is more complex and rugged.

For four days our course lay somewhat east of south along the high mesa, 2200 to 2460 m. above the sea, forming the watershed between the Aros river on the east and the Tutuaca, an important tributary of the Aros, on the west. The general slope of the mesa is gentle toward the south of east, and the eastward slope is much longer than the western. The southward flowing drainage is consequent in character, and as has been intimated above enters the "inverted" stream of the Aros in an upstream sense. The westward slopes are very steep and the meagre inverted drainage is slowly capturing the consequent drainage. The mesa varies greatly in width, from a mere ridge, when the two drainage systems come sharply together, to the broad Mesa Venado which is more than 1.5 km. wide at its widest part. The timber of the high mesa, 2100 m. and higher, is the long-leafed pine, and it is abundant, though the forest is not dense.

The vegetation grows in zones dependent upon the altitude above the sea. The best-marked of these zones are perhaps those of the live-oaks and the pines. The live-oaks flourish between altitudes of about 1220 m. and 1830 m., gradually becoming more scrubby on the higher slopes, where an oak coppice looks like an old New England apple orchard. Between 1800 m. and 2100 m. above the sea the live-oaks give place to the jack pine, while above about 2100 m. the long-leafed pine is in its prime. The full grown pines are 45 to 55 m. high and 1.5 to 2 m. in diameter at the butt.

The lowest branches are often 15 to 18 m. above the ground. The timber of the high mesa is the real incentive for pushing forward the railroads which are trying to make their way from the central plateau down to the Pacific Ocean.

The rock of the surface of the mesa over which we rode for 60 km. or more is mostly of dull brownish andesite, rather than the rhyolite which characterizes most of the Mexican plateau. This andesite contains few phenocrysts and has a very coarse-grained groundmass. It would be classed as an augite andesite. There is much more of this rock in the make-up of the surface of the high plateau in western Chihuahua, than has been supposed; and furthermore the andesite occurs at more than one horizon, as is shown in the section in the Aros Cañon from near Dedrick to the ferry on the trail to Guaynopita and elsewhere.

About 60 km. southeast of Guaynopita we reached the old Chihuahua-Dolores trail. For days we had been traversing the trackless forest, hence the well-worn mule-paths of the old route across the Mesa Venado looked like a great highway. For many years this was the road traversed by the thousands of pack-trains needed for the transportation of supplies from

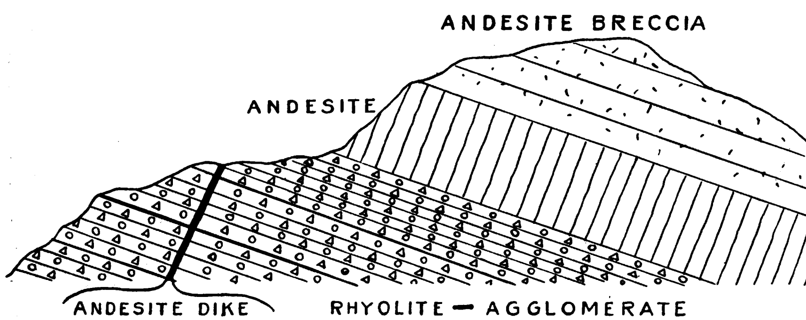
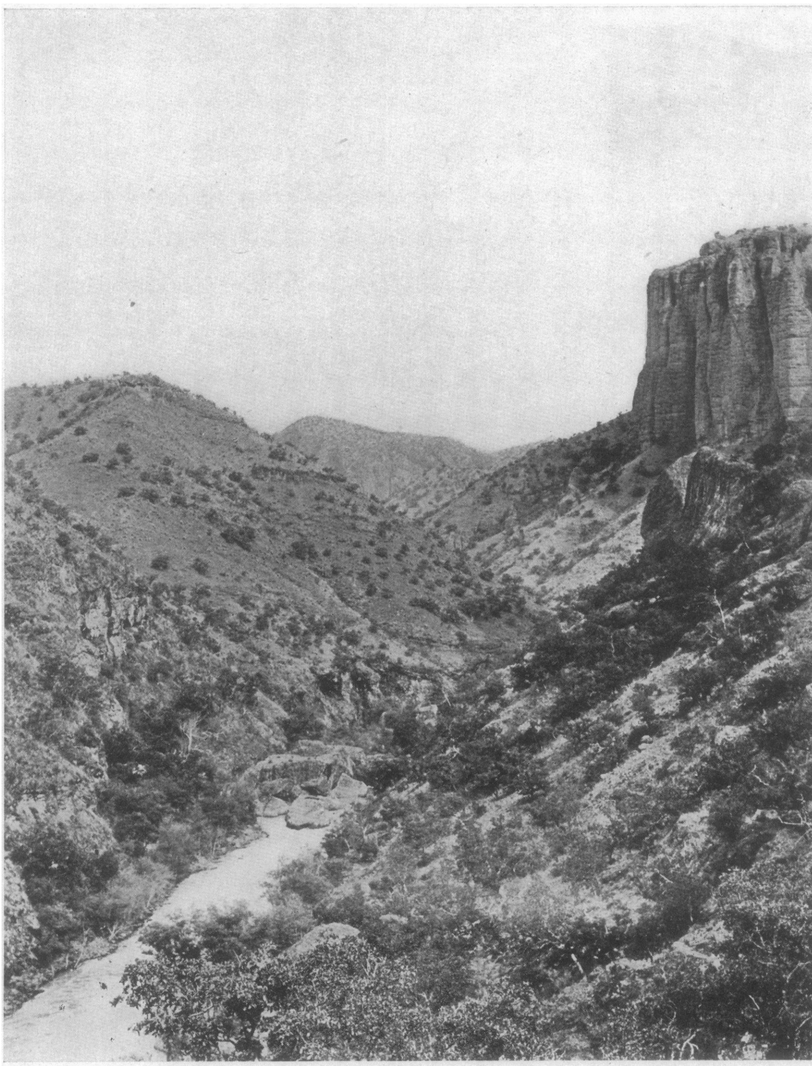


Fig. 9. Arroyo Calaveras in the Tutuaca valley. Heavy bed (150 m. thick) of rhyolite breccia, or agglomerate, cut by an andesite dike and overlain by andesite and andesite breccia.

Chihuahua to Dolores and other mining districts of the Western Sierra Madre and the return of ore and bullion to the capital. Recently, however, a new trail with gentler grades leading to the Chihuahua and Pacific railway at Temosachic has been established south of the Mesa Venado through the enterprise of American capitalists.

Turning abruptly westward from this plateau we plunged into a deep tributary ravine of the Tutuaca river and made a complete cross section of the district included within the Tutuaca cañon to the high mesa west of and above Dolores. The series exposed in the edge of the Mesa Venado was, in descending order: andesite about 80 m., rhyolite 40–50 m., andesite



TUTUACA CAÑON, NEAR DOLORES.

Lower gorge about 300 m. deep. Basin sandstone and conglomerate in massive formation about 120 m. thick lie upon flows of andesite and basalt.

(dacite ?) 150 m., rhyolitic or dacitic flows and tuffs 200–225 m. Below this series there is lithoidal and glassy rhyolite in massive flows, evidently of great extent, whose thickness could not be determined. Some obsidian was noted. An occasional basic dike is to be seen cutting the lower rhyolite.

We made noon camp on 15 March in Arroyo Calaveras in the midst of the Tutuaca Valley at an altitude of 1520 m. at the foot of a north-facing bluff formed by a heavy bed of extremely coarse rhyolitic agglomerate with gentle dip to the southwest. This agglomerate overlies a flow of rhyolite and is conformably overlain by andesite and a thick bed of andesitic breccia. The rhyolite agglomerate is cut by a strong dike of andesite. North of this noon camp the volcanic beds dip northward and eastward, indicating the probability of the existence of an ancient volcano or at any rate a volcanic vent in the vicinity. (See Fig. 9.)

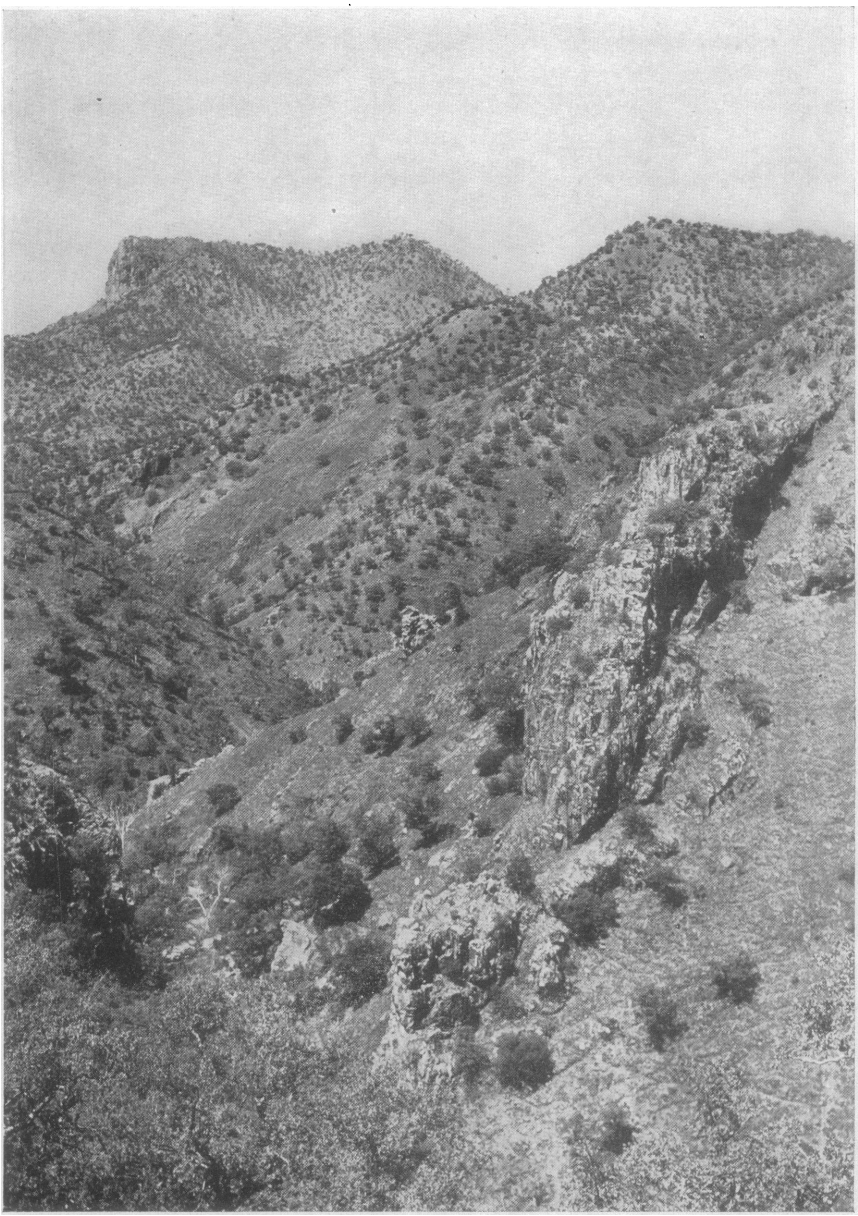
The lower hills are capped by remnants of basin conglomerates and sandstones, the outliers of the great Mesa San Augustin farther north. This mesa has a gentle dip of 2° to 3° eastward. All stages of the gradual dissection and removal of the basin deposits are to be seen in this section across the Tutuaca cañon, from table-topped mountains, typical "mesas" in the original sense of the word with flat tops many acres in extent, to shaft-like pinnacles upon rounded bases, and even to entirely denuded volcanic mounds, presenting an extremely billowy topography. Approaching the Tutuaca river we descended by an arroyo through these basin deposits and found them about 120 m. thick by aneroid measurement, but the thickness is naturally a variable factor.

The Tutuaca flows northward through the western portion of its drainage basin, with the result that its tributaries coming in from the east are more important than those coming in from the west. This position of the river gives it a particularly thick section through the basin deposits, being near the bordering mountains from which the supply of material came. As we neared these mountains, the component parts of the conglomerate were seen to be coarser. Many boulders 30 cm. or more in diameter of vesicular basalt (andesite ?) and smaller subangular fragments of other lavas were observed in a yellowish or brownish sandy matrix. About 80 m. above the river, *i. e.*, 1190–1230 m. above tide, there is a 40 m. bed of basalt, showing again the unwisdom of laying much stress upon the sequence of the beds of different kinds of lava in a large district. This fresh looking horizontal basalt at Dolores is at the same altitude above the sea as the old, tilted andesite at Guaynopita, only 50 km. distant to the north-northeast. At Guaynopita, on the other hand, basalt is the uppermost rock, 1000 m. higher than this lowest Dolores basalt. Above the basalt at Dolores there are many beds of less basic lavas, some of them rhyolites, through a vertical section of 1300–1400 m.

About on a level with the basalt flow (1250 m.) the Dolores arroyo cuts through a vertically laminated chloritic schist with northeasterly strike which is evidently a result of extreme regional metamorphism. Time was lacking for the investigation of this exposure, but it should be noted in passing that this zone strikes approximately in the same direction with the zone of metamorphosed rocks (limestones and schists) at Guaynopita, but probably lies somewhat to the east of the axis of that zone.

Following the arroyo upward through the overlying basalt and breccia, at 1460 m. above the sea, or 210 m. above the exposure of schist in the bed of the stream, we came upon the lower portion of the great bed of diabase 140 m. thick in which occur the veins that are being exploited by the mines of the Dolores Company. The veins or dikes cutting the diabase are highly siliceous in character and are strong, wall-like affairs, sometimes 6–8 m. thick, which can be readily distinguished standing above the less resistent country rock north and south of the diabase area. The general course of these veins or dikes is somewhat east of north. They are mineralized with argentite and free gold and silver, and considerable profitable mining was done along some of them in the crude native Mexican fashion before English and American capitalists took hold of the region in systematic manner. Within the mine the diabase becomes more and more fractured and more and more altered and silicified as it approaches the main vein, the "Alma Maria," so that it is not always easy to distinguish the bounding walls of the vein. The zone of fracturing and decomposition may be set down as being 20 to 25 m. wide on either side of the vein, making a total width of 45 to 60 m. including the vein. The alteration of the diabase consists in kaolinizing the feldspar and serpentinizing the augite, resulting in a rock that looks like a porphyrite.

Another series of siliceous dikes forms an extremely interesting feature of the Dolores region. The rock is strongly marked with bright red bands parallel with the walls of the fissure. The rock is a highly acid igneous rock which is to be classed with the rhyolites. The dikes are possibly the feeders of the rhyolite cap which lies over the sheet of diabase. If this be true, the diabase is to be considered an extrusive flow. Direct evidence, however, as to the intrusive or extrusive character of the diabase sheet was not observed. The unaltered diabase showed no special peculiarities. The upper surface of the diabase sheet was determined to be about 1600 m. A. T. Above this is at least 100 m. of rhyolite, including both lithoidal and obsidian flows. These beds have a pronounced dip toward the southwest. They are overlain unconformably by beds of acid tuffs which aggregate 200



ARROYO DOLORES AND DOLORES MOUNTAIN.

Strong siliceous veins cut beds of tuff and breccia and are brought into prominence by superior resistance to erosion. Dolores Mountain is about 3,000 m. high and is one of the higher elevations of the Western Sierra Madre.

meters in thickness, the upper portion of which beds shows a dip somewhat north of east.

The journey southward from Dolores was first over the cap of rhyolite flows and tuffs and then southward down a small consequent stream in a broad valley known as the Arroyo Amplio. The stream breaks across the divide on the east and flows in an inverted sense into the Tutuaca. At an altitude of 1800 meters we came to the base of another massive flow of basalt, which proved by aneroid measurement to be 120 meters in thickness. The position of this bed of basalt therefore is the same as that of the rhyolite just mentioned in the Arroyo Dolores, and shows a horizontal alternation between lavas of extreme divergence in chemical composition. This bed of basalt evidently is composed of several flows, since farther south and

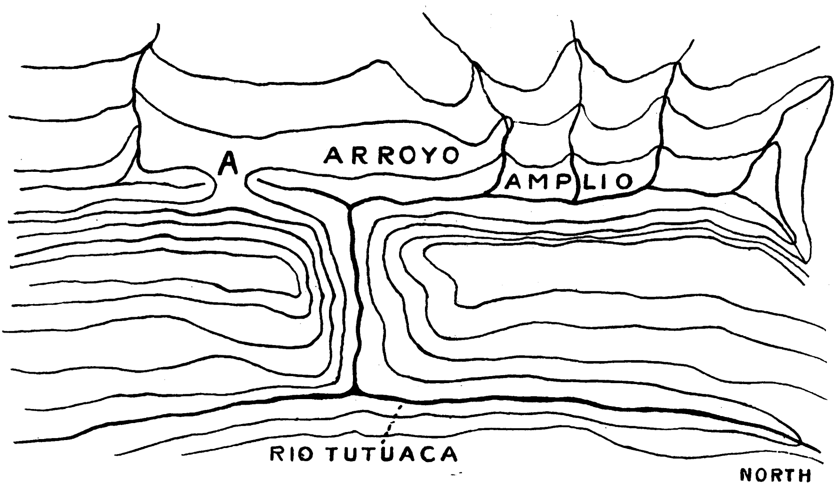


Fig. 10. Arroyo Amplio. A tributary of the Tutuaca south of Dolores. A "wash" of gravel at A has checked the capture of the drainage of the southern part of the arroyo. The sketch lies with north at the right and is about 2 km. from north to south.

apparently continuous with it there are four individual sheets of basalt one above another. The beds dip south of west, or in an opposite direction to those upon the east side of the Tutuaca cañon.

The arroyo here shows considerable stream conglomerate though it may be difficult to distinguish these beds from the basin formations which play such an important part in the eastern portion of the cañon. The stream conglomerate, however, seems to be composed more largely of well-rounded, apparently water-worn pebbles and to be even more local in its development than are the basin formations. The Arroyo Amplio shows high-level terraces of gravel indicating former positions of the stream.

The drainage of the arroyo has been captured by a stream cutting back from the Tutuaca, but a divide of gravel south of the break through the eastern ridge causes the southern part of the arroyo to preserve its consequent southward drainage for a considerable distance farther, until the main stream finally discharges into the Tutuaca and the arroyo comes to an end.

The valley to the west of the Arroyo Amplio is known as the Arroyo Charamusca, in which likewise coarse stream conglomerate and high-level terraces are in evidence. The drainage here too is consequent, *i. e.* toward the south, and like that of the Arroyo Amplio has been captured by the Tutuaca. High up on the western side of the arroyo the rhyolite cap is exposed in several precipitous cliffs 30–40 m. in height one above another with débris slopes between.

The country is intersected with veins of quartz and other minerals, some of which are of great persistence. The largest of these, known as the "Veta Grande," begins about 25 km. south of Dolores in the second north-south arroyo to the west of Arroyo Charamusca. It consists of quartz and calcite somewhat mineralized and rises like a wall above the softer country rock for a distance of 12–15 km. in a north-south direction. Some prospecting has been done on the Veta Grande, but no mining as yet.

Continuing south-southeast from the hamlet of Veta Grande we ascended a long arroyo with inverted (north-flowing) drainage which has been carved out of a tuff bed that dips 15° toward S. 30° W. Our noon camp was made on a bed of vesicular andesite showing beautiful flow structure. This was overlain by the tuff, above which was a flow of basalt lying upon the irregular surface of the tuff. The tuff showed the indurating effects of contact metamorphism for 15 to 20 cm. from the basalt. This arroyo headed abruptly in a cirque-like amphitheatre with extremely steep walls which were hard to scale. The pass between this arroyo and the next longitudinal ravine shows an altitude of 2040 m. (aneroid) above tide. The beds of lava and tuff in the view southward from this divide show the same gentle dip south of west, while those east of the Tutuaca dip toward the east or southeast. Whether this opposition of dip was due to an anticlinal arching of the beds or to the position of original deposition from volcanic vents was not determined, but the uniformity and persistence of the opposing dips would argue for the existence here of a broad, simple anticline with the Tutuaca river flowing near the zone of fracture along a general course about N. 15° W. The surface of the longitudinal (north-south) ridges bordering the arroyos is formed of small, somewhat lenticular mesas diminishing in altitude toward the south. These mesas slope toward the south-southwest in accord with, but to a less degree than, the dip of the component beds of lavas and tuffs.

Our descent to the stream in the next arroyo to the west took us over four flows of columnar, amygdaloidal basaltic lava with intervening beds of tuff or breccia. The fertile cattle ranch occupying this arroyo is known as Agua Caliente on account of some hot springs occurring here. Two kilometers south of the ranch house there is in the bed of the stream at an altitude 1500 m. a flow of rhyolite overlain by a bed of andesite or basalt.

Three or four kilometers farther south at an altitude of about 1680 m. we came upon the scanty remains of an ancient inclosed basin. The basin sandstone and conglomerate here showed evidence of the presence of water during its deposition in the ancient mud cracks and mud-flat surfaces of the former and the numerous well-rounded (waterworn) basaltic boulders in the latter. Underneath the basin deposits there were, in descending order, basalt, perlitic obsidian and rhyolite. The basin deposits show some remarkable erosion forms in the fragments from the cliffs, but these are surpassed by the erosion of the tuff beds.

The next point of interest was Las Animas ranch about 40 km. due south of Dolores, where a squatter has taken up a little arable land in a creek bottom. The low hills in the vicinity are capped by remains of coarse and fine basin deposits, which overlie tuff beds with a general southwesterly dip. The unconformity between the two is strongly marked. This open swale is limited on the south by a nearly symmetrically rounded dome-like hill composed of breccia made up of large angular blocks of extremely dense, fine-grained trachyte with prominent phenocrysts of biotite and hornblende. The hill is really the northern end of a ridge which stretches away to the south for an undetermined distance. (See Plate XXVI, fig. 2.) The rounded form is due to erosion of the beds, which strike N. 10–15° W. and dip 8–10° W. The "breccia" is composed entirely of angular fragments of solid and platey trachyte in a pasty matrix of the same material and is therefore a brecciated flow. The rock in the fragments is unaltered in appearance and is reddish gray in color on a fresh fracture.

After paying a visit to the Cinco de Abril gold-silver prospect in the Arroyo Colonna (so named on account of the columnar forms left by erosion in a heavy quartz vein), 2 or 3 km. west of Las Animas, we traversed for 3 or 4 km. the Arroyo Largo. Here was probably the most northern exposure of a series of peculiar basins in which the basin sandstones and conglomerates rest upon a heavy bed of almost pure white rhyolite tuff. The basin deposits are harder, or more compact, than the tuff, with the result that the latter has been worn away more rapidly than the former and great fragments of the basin rocks have slid or fallen to lower positions, where they frequently form caps on pedestals of the softer rock. All show the effect of eroding agencies, particularly of wind. In the rather fine-grained, homogeneous white tuff the wind has produced a cornice-like undercutting at the upper edge beneath the harder basin deposits. The strange effects of this style of erosion were observed from the Arroyo Largo southward for several kilometers through the "Tierra Blanca" district nearly to Yepachic and in other places to the east and south. Besides plain capped pillars there are many masses remotely suggestive of animal forms in their grotesque features of development.

Below the white tuff there is a coarse yellowish rhyolite (?) tuff which is exposed in the lower portions of the Arroyo Largo and again at the southern edge of the Tierra Blanca region where we crossed it. At the latter place the beds of coarse tuff are sharply upturned against a massive bed of hornblende andesite similar in character to the component fragments of the breccia at Las Animas ranch. The strike of these upturned tuff beds is about N. 90° E. and the dip about 45° N., contrasting strongly with the N. 30° W. strike and 10°–15° W. dip of the overlying beds of tuff. It would seem that the position of the tuff beds indicated an intrusive origin for the great bed of andesite, but no contact metamorphism was noted in the con-

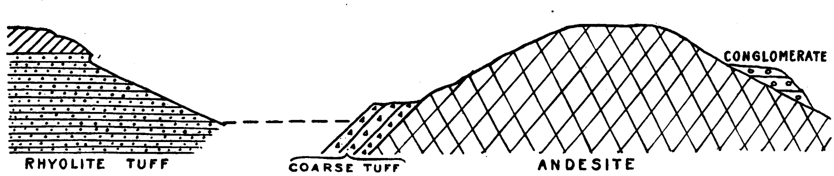


Fig. 11. Section from north to south 4 or 5 km. north of Yepachic showing cornice erosion in fine tuff (see also Plate XXIX, fig. 1) beneath harder basin conglomerate and drag in a coarse yellow tuff upon the surface of a heavy bed of andesite. The conglomerate at the right of the section is a remnant of the old filling of a basin which has been dissected by a tributary of the Mulatos river. The rock lying upon the rhyolite tuff seems to be basin conglomerate.

tiguous tuff, and to assign the local unturning of the beds to drag of the settling tuff strata against the persistent and nonshrinking mass of solid lava seems to accord better with the other facts observed in the region. Under the microscope too flow structure is very pronounced in the groundmass of this rock, — a character unusual in intrusive sheets.

Crossing the mass of andesite at an altitude of about 1850 m. above tide we noticed on the south side coarse well-bedded conglomerate forming a terrace 50–75 m. high above the tributary of the Yepachic river which flows at the base of the bluff. Within a few hundred meters of the andesite bed, and at essentially the same elevation, there is an extensive flow of rhyolite. The section exposed by the river is 60–75 m. thick and shows beds with strong flow structure mingled with those presenting curved columnar parting. The general relations of these rocks is shown in Fig. 11. These horizontal alternations between lavas of greatly varying basicity are of interest in considering the vulcanism of the region.

The little Indian village of Yepachic (2060 m. above tide) straggles along

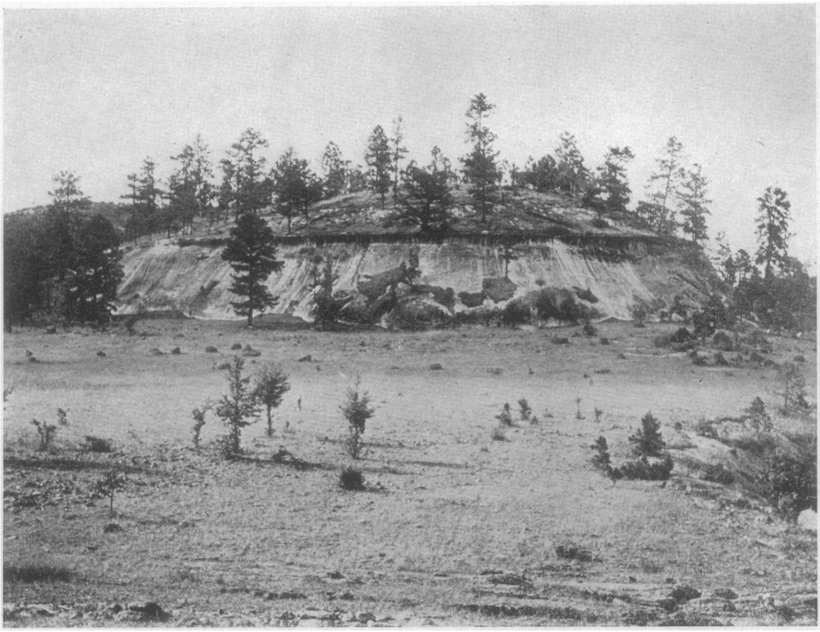


FIG. 1. "CORNICE" EROSION.

In rhyolite tuff near Yepachic under a bed of basin conglomerate. A phenomenon of wind action. See also Fig. 11, p. 430.

FIG. 2. PINOS ALTOS.

A capped pillar of basin sandstone on rhyolite tuff. Such forms are characteristic of many portions of this part of the Sierra Madre region.

two or three streets on the west side of a fertile inclosed basin, the drainage of which has been captured by the Mulatos river, a tributary of the Aros. The villagers belong for the most part to the Tarahumare tribe. They gain their livelihood by tillage and by caring for pack trains and travelers, the village being located at the junction of important trails through the mountains. The Yepachic basin is bordered by lava flows and tuff beds. Toward the west, beds of red and white tuff with strike of N. 40° E., dip 10° W. are traversed by the trail. The tuffs contain occasional beds of devitrified lava. Looking northward from a point about three miles west of Yepachic we could see tuff (?) beds in the western face of the Santa Barbara ridge with distinct dip toward the east. Such variable dips are to be expected of course in beds of fine volcanic ejecta. The Sierra de Santa Barbara bounds upon the east the valley of the Mulatos river, which is an important tributary of the Aros.

The general aspect of the topography of the head-waters of the Mulatos river system is one of greater maturity than that shown in the Tutuaca basin. Mesas are conspicuous by their absence and buttes with sharp or rounded tops rising to a general level are the present indication of the former extent of original and secondary flat lands. Cañons with precipitous walls seem to be lacking, their places being taken by valleys with more sloping sides, though still with V-shaped cross-section.

Four or five miles west of Yepachic we traversed the picturesque Arroyo de la Cueva, the course of which is east and west. Here we found evenly bedded sandstones at least 150 m. thick with strike about N. 60° E. and dip 20° E. The rock is composed entirely of volcanic materials considerably decomposed. Many of the little pebbles in the gravelly layers are distinctly water-worn in appearance. In color the rock is white, red, yellow and pistach green. In spite of its thickness this sandstone seems to be of rather local development, and on the south side of the arroyo within a quarter of a mile west of the greatest thickness of the sandstone there is a heavy bed of rhyolite. It is probable that the sandstone overlies the rhyolite, but the relation of the two formations was not determined.

Passing to the south over a low divide showing white tuff (or the sandstone ?) upon the rhyolite, we entered the Arroyo San José, another east and west ravine. We found ourselves entering a mineralized belt. The walls of the arroyo are of rhyolite flows and tuffs intersected by strong veins of quartz, which are prominent features of the country on account of their superior resistance to disintegration from weathering. In this arroyo is the producing gold mine called "Dios te guie"; at the mouth of the branch arroyo leading down from Cerro Boludo we saw the ruins of a Mexican 5-stamp mill with its arrastre.

Cerro Boludo (or "Bald Mountain") is a residuary mountain composed of rhyolite and andesite flows and tuffs, capped with a bed of reddish white rhyolite 50–60 m. thick which dips gently toward the north. Its top is at an altitude of about 2400 m. above the sea. A mineralized vein, or aggregation of veins, of white quartz 17–19 m. thick cuts through the mountain from west to east (course N. 80°–90° E.) and has been greatly instrumental in preserving the eminence. It is reported to have been traced across country for 8 or 10 km. The vein is much brecciated and contains many cavities lined with drusy quartz crystals. Seams of kaolin, some of which are beautifully slickensided, occur in the vein and show that some differential movement has taken place since the filling of the fissure.

Continuing southward from Cerro Boludo we traversed the Arroyo San Francisco in which at about 1760 m. above the sea lies the small Mexican mining camp of the same name with its little two-stamp mill and primitive arrastre. Gold-bearing quartz carrying copper and nickel is treated here. A great bed of lithoidal rhyolite characterizes this arroyo, giving great bluffs forming the walls of the ravine in places. This arroyo is tributary to the Rio de Mayo. The trail to Ocampo (Jesus Maria) leads out of this arroyo over a divide 280 m. above the San Francisco camp, drops into the small well-wooded Arroyo Paragatos, which joins the San Francisco a few miles to the west, and then passes over another divide into the great cañon of the Rio de Moris, which is the principal tributary of the Rio de Mayo.

The country rock of the upper portion of the great Moris cañon is rhyolite and rhyolitic tuff intersected by many basic dikes. Below this (at about 1900 m. above tide) lies an enormous thickness of dark blue or bluish-green coarse conglomerate which is likewise cut by many dikes, some basic and some apparently acid (rhyolitic). With this conglomerate, or rather alternating with the beds thereof, are associated beds of whitish, finer-grained, hard conglomerate and beds of dark red sandstone. All of these beds seem to be composed entirely of materials of originally igneous origin. Where the trail from San Francisco to Ocampo (Jesus Maria) crosses the Moris cañon the beds dip rather gently toward the east or northeast, but looking toward the west down the cañon one could see the dip gradually diminishing and finally becoming distinctly westerly. The thickness of the detrital beds was not determined for lack of time, but it must be measured in scores of meters even when considerable allowance for possible faulting has been made. The rhyolite forming the cap-rock of the cañon walls was poured out on the eroded upturned edges of the beds of sandstone and conglomerate. This sedimentary series seems to be of sufficient importance to require special designation, and Professor

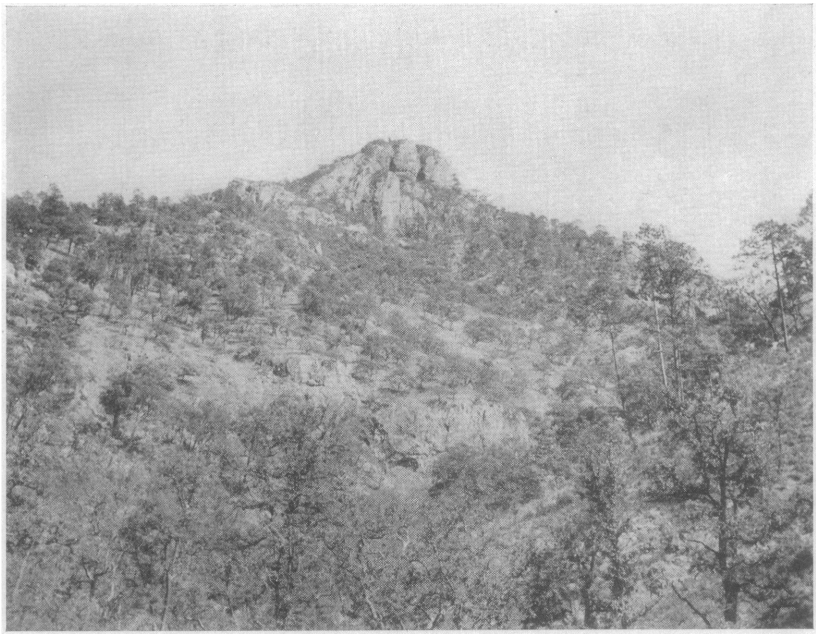


FIG. 1. CERRO BOLUDO, NEAR YEPACHIC.

From the southwest. Altitude 2150 m. above tide. An erosion remnant of indurated rhyolite tuff traversed by a great quartz vein.

FIG. 2. CAÑON OF THE RIO DE MORIS, 1,200 M. DEEP.

Rancho Navosaigame. Lower part of gorge is in the dark-blue coarse conglomerate called the Navosaigame formation; upper part is in andesite, rhyolite tuff and rhyolite.

Hill and the author[1] have proposed to call it the Navosaigame formation, for convenience, from the name of the ranch in the Moris cañon where it is typically developed and where we first observed it. Plate XXX, fig. 2 gives a view of the entire northern slope of the Cañon of the Rio de Moris at the Hacienda Navosaigame. The Navosaigame beds are exposed at Ocampo (see pp. 434 and 435) and Pinos Altos (pp. 436 and 439), according to the author's observations, and probably elsewhere. They underlie an area, therefore, more than 20 km. in diameter.

No limestone boulders were seen in the Navosaigame beds, but exhaustive examination could not be made. In the south wall of the Moris cañon opposite the hacienda house a great dike of basic igneous rock rises far into the Navosaigame and may penetrate it. The rock appears to be diabase, but is too much decomposed for satisfactory determination. About 2 km. east of this dike a porphyrite dike with large square or rectangular phenocrysts of feldspar cuts the Navosaigame beds and rises through the caprock of white rhyolite. Here again as usual the basic rock has suffered decomposition to a much greater degree than the more acid lavas. Siliceous veins, however, are not lacking from the region, and a noteworthy example of one crosses the Moris cañon like a great pinnacled wall about 3 km. east of the Hacienda Navosaigame. In appearance from a distance this vein was like the Yaqui vein at Guaynopita, the Veta Grande south of Dolores, the Veta Colonna at the mine "Cinco de Abril" west of the ranch Las Animas, and several great veins at Pinos Altos, besides doubtless many others.

In this region the Moris cañon is not less than 13 km. wide and 1200 m. deep. No basin conglomerates or sandstones were seen, this part of the cañon lying in the zone of more advanced erosion than the district farther east, but river gravels were observed at several altitudes. These gravels contain an occasional pebble or boulder of the blue Cretaceous limestone, evidencing the occurrence of this rock *in situ* farther to the east (upstream).

The trail from Hacienda Navosaigame to Ocampo leads over the Cumbre Potrero at an altitude of 2120 m. above the sea into the Arroyo Rosario which is a tributary of the great Candameña cañon, in another branch of which lies the town of Ocampo. The cap rock of the Cumbre is rhyolite in great development, about 340 m. of the rock by aneroid measurement lying in practical horizontality upon the eroded upturned edges of the beds of the Navosaigame formation. The highest points rise to an altitude of 2320 m. above the sea, or 200 m. above the trail crossing of the old Combre Potrero.

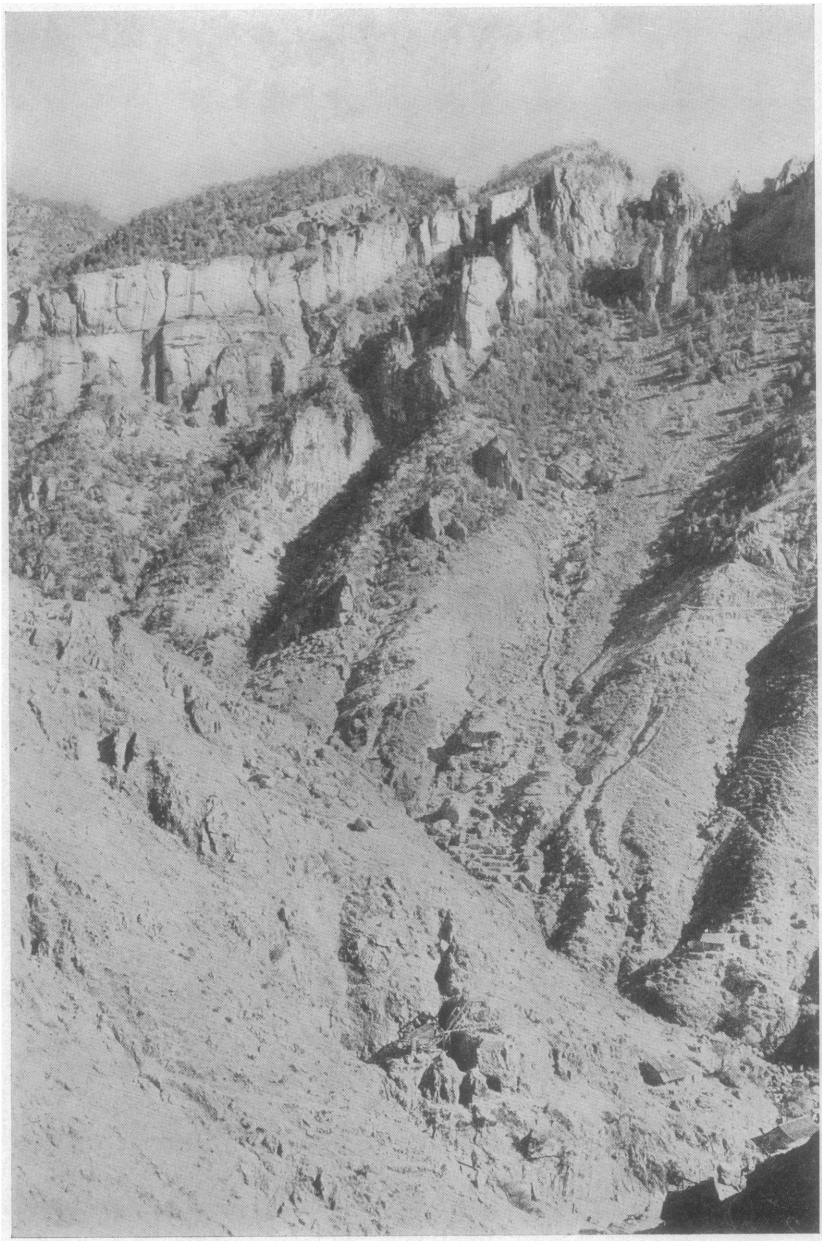
The rocks exposed along the trail in the Arroyo Rosario are decom-

[1] Hovey, E. O. The Western Sierra Madre of the State of Chihuahua, Mexico. Bull. Am. Geog. Soc., Vol. 37, p. 539. Sept., 1905.

posed rhyolitic tuffs and flows lying unconformably upon the beds of the Navosaigame formation, which dip rather gently (about 15°) toward the southeast. Many large and small dikes of apparently rather basic igneous rock intersect both the Navosaigame and the overlying rhyolitic beds. Well-rounded boulders of disintegration are abundant and no fresh rock was seen.

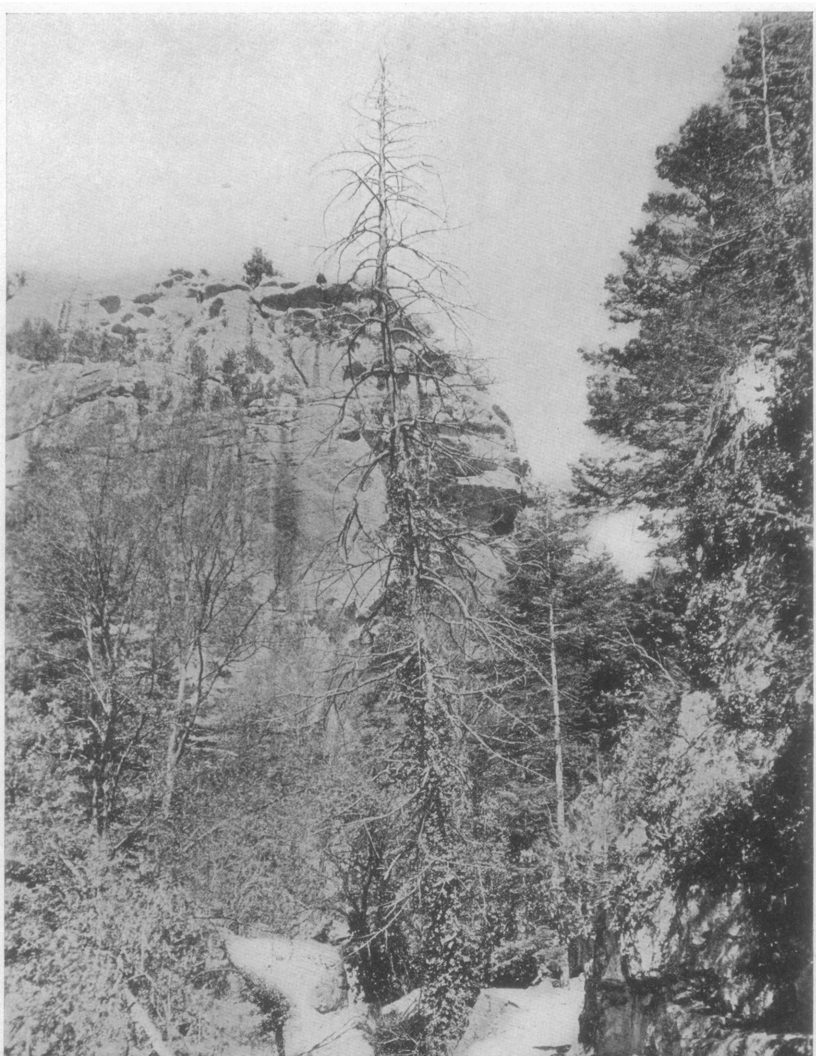
After passing over another divide at an elevation of about 2130 m. above the sea, the trail descends rapidly into the branch of the Candemeña cañon in which Ocampo is situated. Ocampo is a celebrated mining camp, better known, perhaps, by its old name of Jesus Maria. Several mines are, or have been, in operation here, and from one of them alone, the Santa Juliana, more than $100,000,000 worth of silver bullion was taken by its owners during about fifty years of active work in the nineteenth century. The cañon is so deep, narrow and crooked that one does not see the town resting in its bottom, a kilometer below the rim, until he is fairly upon it. The population of Ocampo varies greatly with the prosperity or adversity of the mines, but it is said to average 5,000 inhabitants. It is hard, however, to see where so many people can be stowed away in the dwellings which are in sight, even with the crowding common among the Mexican peons. The town lies at an altitude (Balvanera Mining Co's. office) of about 1800 m. above the sea. Its position according to Lieut. H. O. Flipper, manager of the mines at the time of our visit, is lat. 28° 12′ N. and long. 107° 6′ 40″ W. (Greenwich).

The Santa Juliana mine may be taken as typical of all the mines at Ocampo. A great composite quartz vein 5 to 10 m. thick cuts almost vertically (hade 4° or 5° toward N. W.) through a heavy bed of diabase and the underlying conglomerate (Navosaigame). The contact between the diabase and the conglomerate is exposed in and beside the Providencia tunnel. The quartz is of course entirely secondary in origin and together with its mineral contents seems to have been derived from below. Where the Providencia tunnel enters the bluff the Santa Juliana vein strikes N. 50° E., but about 61 m. from the mouth the vein and, consequently, the tunnel turn more to the north. Plate XXV, fig. 2, shows the relation of the great quartz vein, known locally as the Santa Juliana vein, to the inclosing diabase at the Providencia tunnel. At the lower left hand corner of the photograph the conglomerate of the Navosaigame formation comes into view. The Rincon tunnel, which is near by, follows a thick secondary quartz vein that lies nearly at right angles to the southern (Providencia) end of the Santa Juliana vein and hades strongly (30°) toward the southwest. Other heavy quartz veins in the district run parallel to and at considerable angles with the Santa Juliana. Time was lacking for an in-



OCAMPO. CAÑON BELOW TOWN.

Navosaigame conglomerate overlain by diabase, above which are andesite and rhyolite flows and tuffs.



OCAMPO. ARROYO SAN JUAN.

Cliffs of rhyolite tuff showing effects of wind erosion.

vestigation as to any system upon which the veins and joints might be arranged.

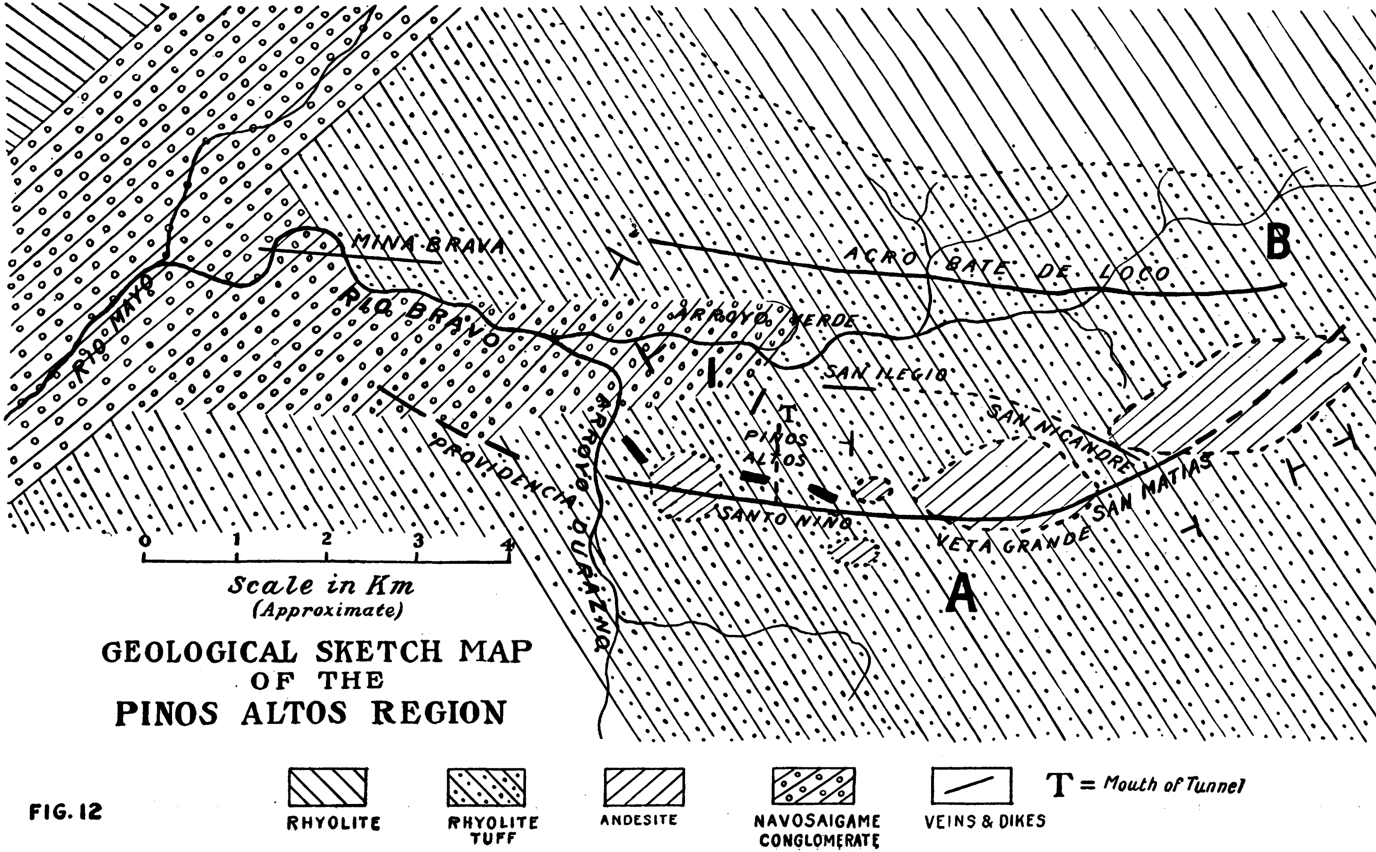
The diabase has highly baked the conglomerate beneath it for 0.60 to 1.2 m. from the plane of contact. The principal effects of the metamorphism are: the change of color to dark purple and the production of a shaly and hackly structure with consequent obliteration of the bedding planes. In places the sandstone or conglomerate has been rolled up into the base of the diabase sheet for several inches or even a foot (30 cm.) from the contact. The extrusive character of the diabase is further indicated macroscopically by the occurrence of an occasional scoriaceous mass in it near the lower contact. Such a mass is a fragment of the original upper or front crust of the stream which has been rolled over to the under portion of the stream. Along the planes of incipient cracks or joints in the diabase and at uniform distances therefrom hematite has segregated, producing narrow zones of red which traverse the rock interruptedly in every direction. Similar zones of hematite occur in the Triassic diabase near New Brunswick, N. J. (and probably at many other localities). The Ocampo diabase shows a beautiful variolitic facies, the spots often being 1.25 cm. or more in diameter and being scattered profusely through the rock. They are darker in color than the groundmass.

Microscopically the diabase presents no peculiarities.

Leaving Ocampo for Pinos Altos one traverses first the Arroyo San Juan in a northeasterly direction, following the Ocampo-Miñaca trail for 4 to 4.5 km. to the "combre" or divide 740 m. above the plaza of the town, where the two trails part company. An approximate section along this arroyo gives, in descending order:

Rhyolite flows and tuffs probably 200 m. thick or more.
Andesitic tuffs and flows (to divide) 160 m. and more.
Coarse, dark-red, cross-bedded conglomerate and sandstone (dip E.), 80 m.
Diabase, 120 m.
Andesite flows, 20 m.
Rhyolite tuffs and flows, 140 m.
Gray conglomerate and dark, thin-bedded sandstone (tuff ?) (dip E.), 55 m.
Diabase-agglomerate, 15 m.
Diabase sheet or sheets, 150 m.
Navosaigame conglomerate at 1800 m. above the sea and below.

The section shows at least three horizons of heavy-bedded conglomerates and coarse sandstones, all dipping eastward or southeastward and covered unconformably by lava flows and tuffs. The fragmental rocks seem to be composed entirely of volcanic materials. The presence of numerous rounded boulders was the feature relied upon to distinguish them from tuffs. To this feature, in the case of the upper sandstone member, was added marked cross-bedding. Pending further investigation these beds



GEOLOGICAL SKETCH MAP OF THE PINOS ALTOS REGION

FIG. 12

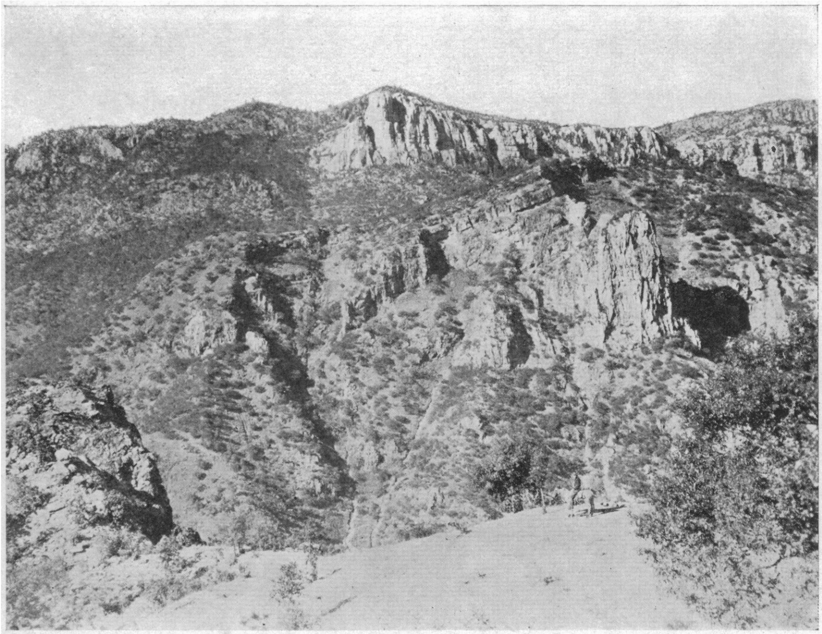


FIG. 1. PINOS ALTOS. NORTH WALL OF ARROYO VERDE.

Navosaigame beds at bottom with interbedded diabase. Lying unconformably upon the Navosaigame are beds of rhyolite tuff, above which is a heavy bed of rhyolite.

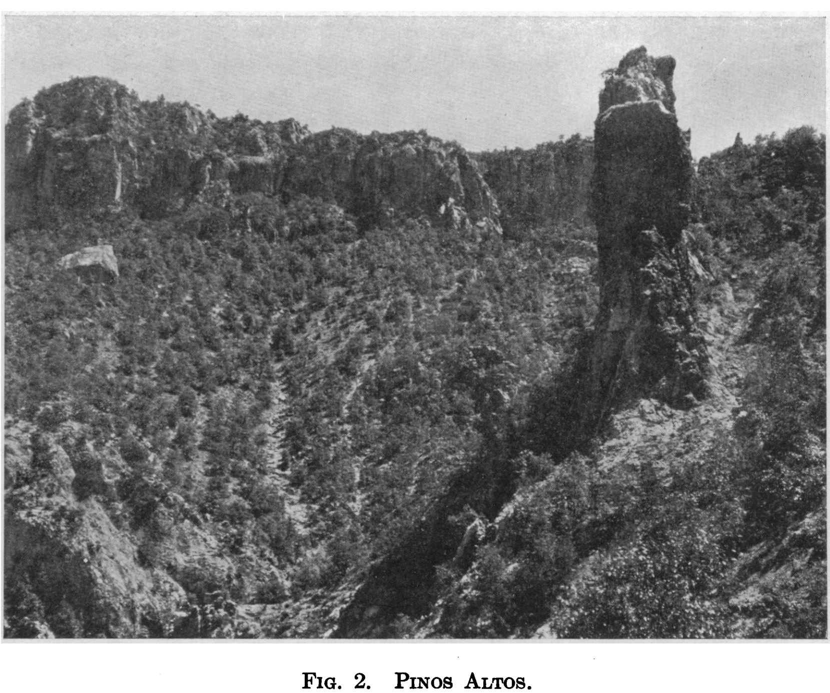


FIG. 2. PINOS ALTOS.

San Ilegio vein, or zone, of quartz with associated silicified country rock. The softer including rhyolite tuff has been removed by erosion.

are taken to be of rather local development and not necessarily a proof of extensive subsidence and re-elevation.

Pinos Altos is a mining town lying 15 or 16 km. north-northeast of Ocampo. The intervening country shows andesite and rhyolite flows and tuffs as the surface rocks. About half-way between the towns there is an area of yellowish sandstone dipping rather moderately south of east. The gently incised plateau which the trail traverses slopes gradually toward the north. Heavy forests of hemlock and pine characterize the region. Pinos Altos lies in the more rugged and deeply cut portion of the plateau between the Arroyo Durazno and the Arroyo Verde near where they join to form the great cañon of the Rio Bravo. The Bravo joins with the Concheña to form the Rio de Moris.

The region has derived its importance as a mining district from a network of strong silicious veins and silicified zones which intersects a complex consisting of basic igneous (probably diabase) dikes and sheets, andesite flows or sheets, acid igneous (rhyolitic) flows and tuffs and a basal conglomerate composed of waterworn igneous materials. Being little known, the district merits rather extended descriptions on account of its interesting features.

The strongest veins, or silicified zones, are three in number and run in a general easterly and westerly direction. They are the Mina Brava and its probable extension the Acrobate de Loco, north of the Rio Bravo and the Arroyo Verde; the San Ilegio and its continuation the San Nicandre in and near the southern wall of the Arroyo Verde, while farther south is the largest vein of all, which is known in its different parts from west to east as the Providencia, the Santo Niño, the Veta Grande and the San Matias. There are many trans-

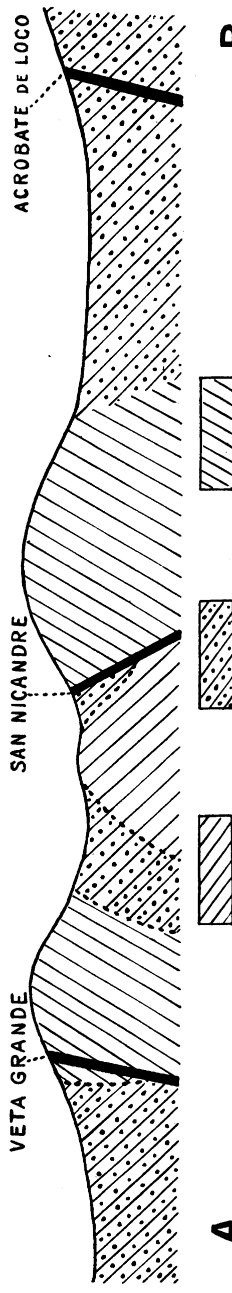


Fig. 13. Schematic cross section from A to B on the map, fig. 12. Scale is only approximate, but the line represented is about 4 km. long.

verse veins of small size which, however, seem to have had an important bearing upon the mineralization of the region. The largest of these cross veins is the Transvaal, 1.5–2 km. northeast of the Mina Brava. The relation of the principal veins to one another and to the country rock is indicated on the accompanying sketch map (Fig. 12), important data for which were supplied by Mr. R. S. Brooks, a mining engineer in the field who was thoroughly familiar with the district. The author did not visit the veins north of the Arroyo Verde.

At several points the veins, or zones, are prominent features of the landscape on account of their superior resistance to the subaërial erosion which has cut deeply into the associated tuffs. The action of the erosive agencies has been much quickened during recent years by the removal for mine timbers of the "lofty pines" which gave the district its name. All the veins are alike and therefore a description of the Santa Niño will suffice for all. This vein has been exploited by the workings of the Pinos Altos Mining Company and access to it 400 m. below the surface is easy by the main mine tunnel, which is 1050 m. long, entering from the south wall of the Arroyo Verde. The rock through which the tunnel has been driven is entirely rhyolite tuff, with three or four quartz veins about 1 m. wide and several silicified zones. The Santo Niño vein is considered to be from 10 to 15 m. wide, and much drifting and stoping has been done upon it. It is reported that at the point of intersection of the tunnel with the vein the ore ran about $4 in gold per ton.

The so-called "vein" does not have well-defined walls, and it seems to be a closely set network or zone of veins rather than a single vein. The amount of sulphide ores (pyrite and chalcopyrite) present gradually diminishes with distance from the most definite siliceous vein. The diminution is probably secondary and due to the oxidation of the pyrites. Fractures abound in the immediate country rock, which is an indurated (silicified) rhyolite tuff, and slickensided surfaces show that differential movement has taken place within the mass. Ferruginous brecciated zones occur in the tuff beside some of the smaller quartz veins composing the Santo Niño network. The veins are essentially vertical in position and intersect the whole series of rocks exposed, with the possible exception of the highest cap-rock of rhyolite, which is exposed only north of Arroyo Verde.

Examination of the country rock westward of the mine tunnel (at T on the map, fig. 12) as far as the Arroyo Durazno shows that beds of highly inclined (strike, N. 20° W., dip 35° E.) dark-blue and dark-red conglomerate and sandstone underlie discordantly the partly silicified rhyolite and tuff in which the mine occurs. A long period of erosion occurred after the tilting of the conglomerate-and-sandstone beds before the deposition of the tuff beds. The materials making up the conglomerate and sandstone seem to have been derived entirely from ancient basic igneous rocks, and the beds are referred to the Navosaigame formation. Interbedded with the conglomerate are beds of diabase, and diabase dikes intersect the stratified rock and the overlying rhyolite tuff. The baking effect of contact metamorphism is more evident perhaps in the beds of rhyolite tuff than in the Navosaigame conglomerate. The passage of these basic dikes through the rhyolite tuff as well as the Navosaigame indicates the probability that the intercalated diabase sheets in the latter are intrusive in character, and that they were subsequent in origin to the tilting of the conglomerate. In the north wall of the Arroyo Verde a heavy bed of rhyolite lies upon the tuff beds.

The region is one favorable to mineralization. Early igneous activity, during which rather basic rocks were produced, was followed by quiet times when the dark blue Navosaigame conglomerate was laid down, possibly in inland basins formed after the manner of the present mesas of the country. Then followed some regional deformation, as is shown by the rather high dip of the conglomerate. This period of deformation was followed by one of renewed activity, resulting in the outpouring of great quantities of rhyolitic lavas and the ejection of accompanying ashes. The ash formed the major portion of the ejecta, and it now shows strong stratification. The general dip of the ash beds is about 10° W. by S., but there are many variations. After the eruptions of acid materials came the intrusion and possible outpour of andesitic and even diabasic lavas.

The nature of the region between Pinos Altos and Miñaca can be described in only the most casual manner, since the 115 to 130 km. of trail were passed over in about two days of travel. The trail first passes over a great area of the yellowish, reddish and whitish rhyolite tuff. Nine kilometers from Pinos Altos near the road to Concheño there is a stream half a kilometer across of rhyolite showing flow structure beautifully and associated with much perlitic obsidian.

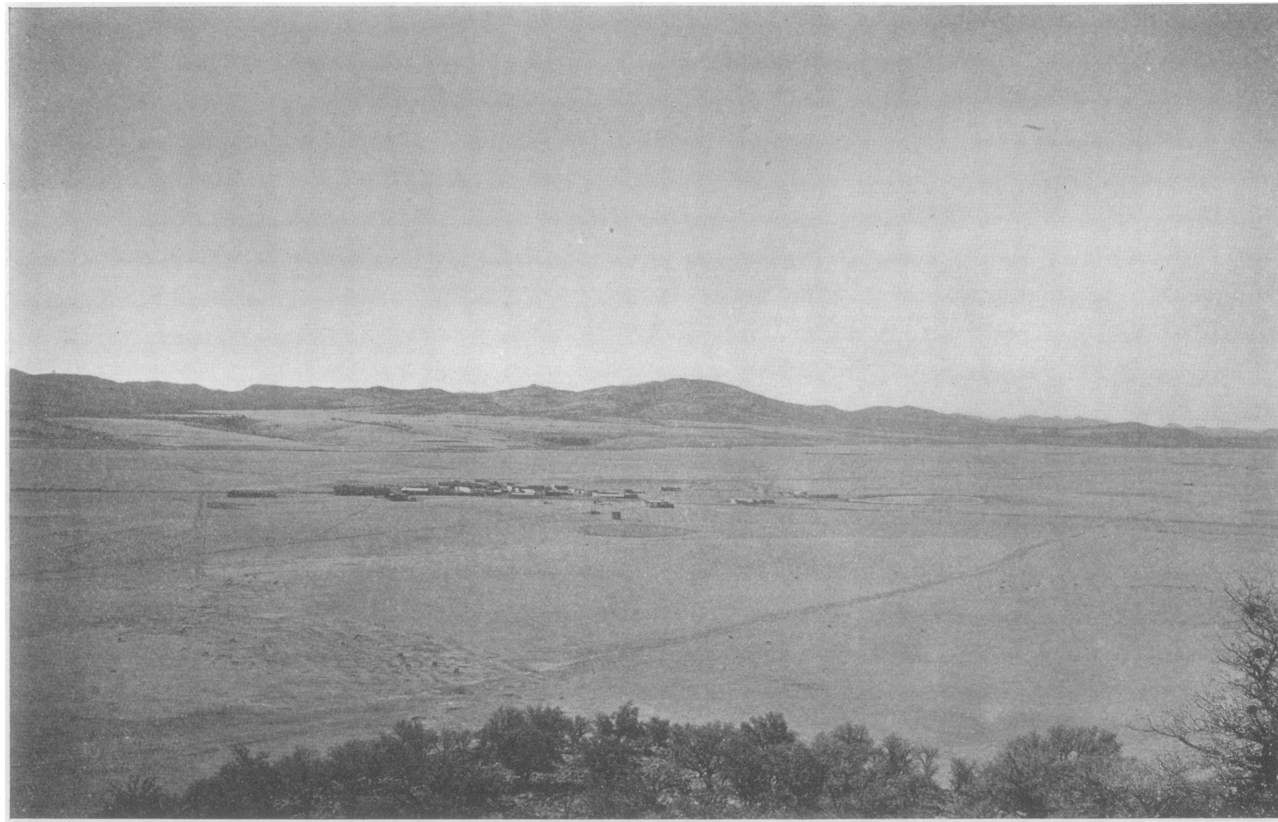
The trail keeps for the most part on the areas of tuff, but occasionally traverses a gorge in a flow of rhyolite or crosses the surface of an area of andesite. About 40 km. east of Pinos Altos the trail drops into a vertical-walled gorge perhaps 50 or 60 m. deep in sandstone. The beds seem to be horizontal in position; they contain rounded grains and pebbles, and they show some cross-bedding. This probably is a strong development of basin sandstone. In color the rock is light yellow or whitish, but red pebbles were observed. The erosion phenomena shown in the gorge just mentioned are remarkable, and the numerous pinnacles, crags, grottoes and archways which have been carved out of the rather soft material make the views in every direction most picturesque. The hour of my visit was so late that I could not stop to examine the rock closely or take photographs.

The little Indian (Tarahumare) hamlet of La Cueva Humada is in the midst of this area of sandstone and is about 12 km. west of the village of Temochic. The Temochic river, a tributary of the Rio Verde and thus of the Aros, traverses the sandstone area from southwest to northeast and is bordered by vertical cliffs of the rock 40 or 50 m. high. In the near distance can be seen the mountains of andesite and rhyolite that inclose the sandstone.

The regularity of the sandstone beds is sharply disturbed near the river 3 km. west of the village of Temochic. The beds on both sides of the Temochic river suddenly turn sharply upward, changing within a few yards from a horizontal position to a dip of 30° or more toward the W. N. W. on the west side of the river and toward the opposite direction on the other side. The disturbing factor was probably an igneous intrusion, but the question could not be investigated on account of a heavy snowstorm that was raging at the time of my visit.

The Tarahumare village of Temochic lies in a typical inclosed basin six or eight kilometers in diameter, the drainage of which has been captured by the Aros drainage system. The elevation of the village as determined by aneroid, average of two readings, is 2110 m. above the sea. East of this basin the trail rises over an extensive flow of andesitic lava, reaching an altitude of 2310 m. upon it. At La Junta, 12 km. east of Tomochic, basalt is encountered at 2200 m. above the sea. Three kilometers beyond La Junta the Rio Verde, which flows northward into the Aros, cuts down to 2150 m. A. T. in this sheet of basalt, and east of the river the trail rises to 2340 m. on the basalt, giving a thickness of at least 190 m. for this flow or series of flows. The basalt apparently covers an area of many square kilometers and dips gently toward the west. It has been considerably dissected by the Rio Verde and its tributaries.

The eastern limit of this basalt plateau is sharply defined near a little hamlet called Agua Caliente about 18 km. east of Tomochic. The bottom of the valley here is 2160 m. above tide and the section shows basalt, rhyolite and obsidian (bed 30 m. thick), andesite tuff and andesite in descending order from the west. East of Agua Caliente the trail rises rapidly again to the top of a basalt plateau, which may well be part of that to the west of the hamlet. After quickly regaining the altitude of 2360 m., the trail crosses for 6 or 7 km. an almost uniform slope of basaltic lava, some of which is scoriaceous, which gradually rises to the altitude of 2420 m., at its eastern border. This plateau or part of the great plateau, extends for many kilometers north and south. It has not suffered dissection to the extent shown



MIÑACA BASIN.

A great inclosed basin the drainage of which has been partly captured by the Aros river. Shallow depressions retain ponds in varying stages of desiccation.

MIÑACA BUTTE.

Remnant of an andesite flow, illustrating the process of filling inclosed basins through disintegration of rock beds and the transportation and distribution of the resulting fragments.

by that portion west of the Rio Verde, thus maintaining the observation made farther north that erosion is advancing from the west eastward. The great basalt mesa, or plateau, is bounded on the east by a strong, deeply serrated cordon rising 300 or 350 m. above it and extending in a general N. N. W.–S. S. E. direction. The trail crosses the cordon through a notch at an altitude of 2510 m. above tide.' The material of the cordon is augite andesite, dark purplish gray in color, weathering to a deep red.

The descent to the basin east of the great cordon is rather gradual, and the floor of the basin may be said to begin at an altitude of 2300 m. It continues to descend more gently for two or three kilometers from the western edge, when the barometer reads about 100 m. less, and this (2200 m. A. T.) is essentially the level of the broad flat plain forming the bottom of the basin. The basin is one of the largest encountered upon the route described in this paper, being 15 to 18 km. wide from east to west and 35 to 40 km. long. In the middle of it on the Aros river lies the old Tarahumare village of Pahuirachic, not more than 2 km. distant from the new railroad town of Miñaca, which at the time of my visit was the passenger terminus of the Chihuahua and Pacific railway toward the west.

The basin contains many lagunas, large and small, some of which appear to be permanent in character, while most are periodic. Much of the drainage is still internal, although the Rio Aros (here called the Rio Guerrero) has made its way completely across the area. Here and there is to be seen the top of an almost buried mountain. Most of these knolls are of rhyolite, some are of andesite, some of trachyte and those of basalt are not absent.

About 1.5 km. east of Miñaca the peculiar hill known as Miñaca Butte rises 200 m. above the level of the plain. The eminence receives its name from the Mexican hero, General Miñaca, who lies buried on the top, having been killed there with his followers while making a stand against the attacks of hostile Indians.

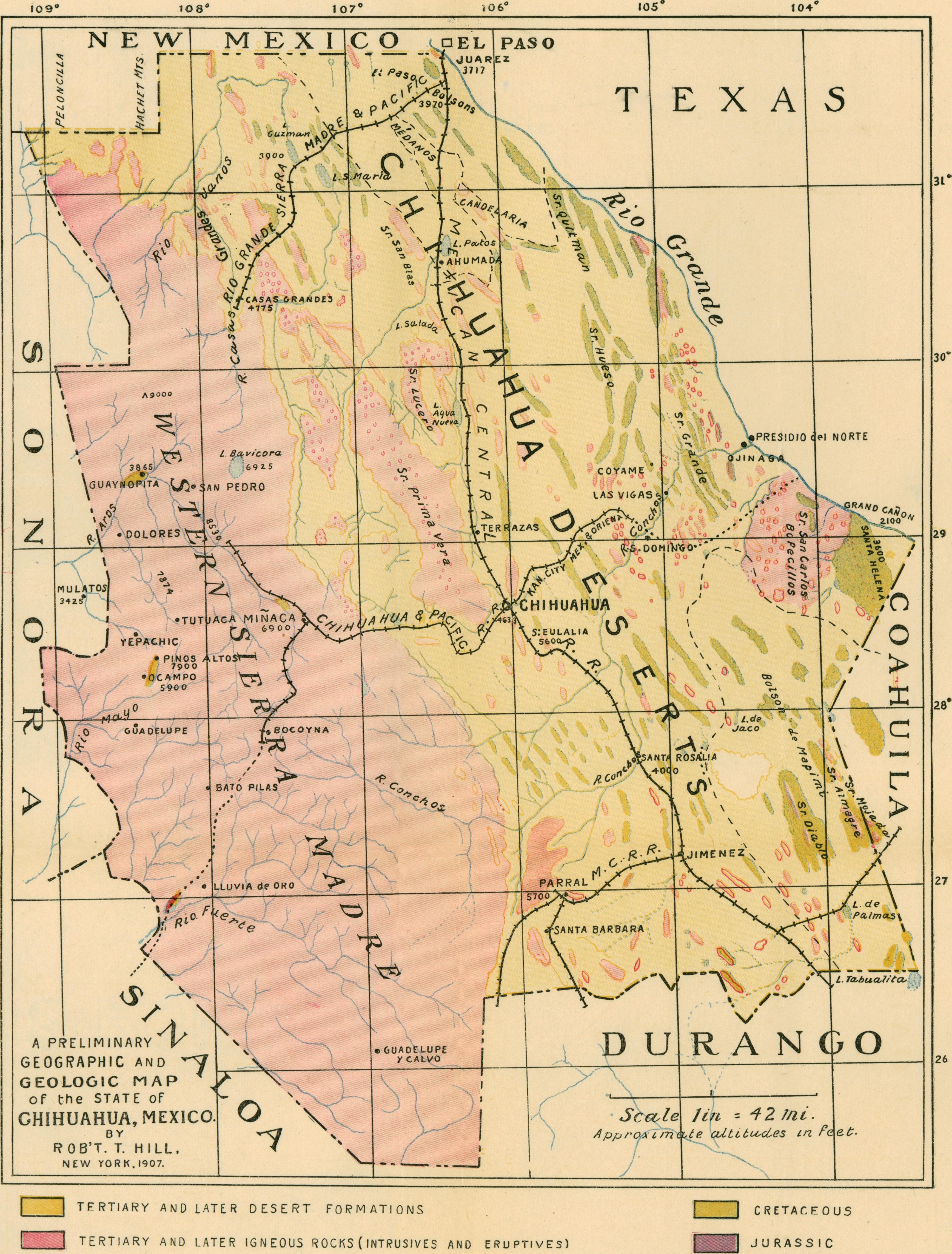
The Butte is a double cone (a small steep one upon a broad low one), the residue of a sheet of extremely glassy biotite-andesite. Devitrification and weathering have gone so far as greatly to obscure the microscopic characters of the rock. The upper and more glassy portion of the hill is decidedly more columnar in structure than is the lower, while in the lower part the bedding is more pronounced. The less glassy lower part of the hill has resisted disintegration more successfully than the upper. The whole process of disintegration and consequent basin filling is beautifully shown from the columnar structure and horizontal jointing due to contraction from cooling, through the great subangular blocks and the smaller rounded masses, boulders, pebbles and sand to the fine soil of the plain, resulting from the constantly acting strains arising from diurnal and secular variations in temperature.

About 2 km. south of the railway station at Miñaca a group of low knolls marks the top of a buried mountain of andesite. Black glassy lava occurs around the outside of the circle, the rock being rather dense, with flattened vesicles. Within this zone is a zone of cryptocrystalline andesite with strongly marked platey parting, while the center of the group is of fine-grained dark-gray rock. Streams of boulders extend out on all sides into the basin, the boulders uniformly decreasing in size with distance from the knolls. Under the microscope the rock is seen to be typically hyalo-pilitic in texture and to be practically free from phenocrysts, except for an occasional lath of plagioclase which is larger than its fellows. Minute black grains, apparently of iron oxides, are scattered rather uniformly through the mass.

The section along the railroad east of Miñaca to the edge of the Chihuahua basin seems to be wholly in volcanic rocks, among which the basic varieties greatly predominate.

Conclusions.

The structure of the Western Sierra Madre of the State of Chihuahua, as shown in the sections seen upon this journey, is not complicated. A foundation of marine Cretaceous limestones has been raised to an altitude of at least 1800 m. above the level of the sea. This elevation was accompanied by extreme regional metamorphism, as is evidenced by the limestone schists of Guaynopita and Dolores, the pressure coming from the west. An ancient andesite was associated with the limestone, being poured out upon it before or during the elevation just referred to. Post-Cretaceous intrusive granite occurs in great masses in and beneath the limestone and andesite. More recently there have been innumerable flows of basalt, andesite, dacite (?), trachyte and rhyolite, and ejections of the corresponding tuffs, burying the older terranes. Here and there sandstones have been laid down, while in the numerous inclosed basins among the mountains the original relief of the surface has been largely obliterated by the accumulated wash forming the basin sandstones and basin conglomerates. Erosion has advanced more rapidly from the west than from the east, and the resulting enormous cañons account for the present relief of the mountain peaks and ranges.



A PRELIMINARY GEOGRAPHIC AND GEOLOGIC MAP of the STATE of CHIHUAHUA, MEXICO. BY ROB'T. T. HILL, NEW YORK, 1907.