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GEOLOGY OF THE EL OCOTITO-IXCUINATOYAC REGION AND OF LA DICHA STRATIFORM SULPHIDE DEPOSIT, STATE OF GUERRERO

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A study carried out in cooperation with the Cía. Minera del Río Murga, S. A., the Geologisches Institut of the Technische Hochschule of Munich, and the Instituto de Geología the of Universidad Nacional Autónoma de México

RESUMEN

El presente estudio se refiere a un área de la Sierra Madre del Sur, que está en la parte central del Estado de Guerrero, al sur de la Ciudad de México, cerca del poblado de Ixcuinatoyac y comprende unos 500 km².

Las sierras más altas del área sobrepasan los 2.000 m de altura; el nivel de base local está cerca de 600 m y está formado por el valle del Río Papagayo que desemboca en el Océano Pacífico. El área ya alcanzó en alguna época la etapa de madurez en el ciclo geomórfico pero ha sido rejuvenecida.

El Complejo Xolapa es la unidad estratigráfica mas antigua y consiste de esquisto de biotita. Los sedimentos originales clásticos son de edad precámbrica o paleozoica. Esta unidad está cubierta discordantemente por la Formación Ixcuinatoyac, de 400 m de espesor, que consiste de filitas y cuarcitas probablemente paleozoicas y que contiene un cuerpo estratiforme de pirrotita-troilita-chalcopirita. Esta unidad, a su vez, está cubierta discordantemente por la Formación Chapolapa, de edad triásico-jurásica, que consiste de unos 1,000 m de rocas volcánicas y sedimentarias de color principalmente verde y púrpura. Las rocas volcánicas son de composición intermedia a ácida y pertenecen al área limítrofe entre los grupos de rocas que se clasifican como alcali-cálcicas y calcio-alcalinas. Las rocas sedimentarias consisten de conglomerados, brechas, subgreywackes, cuarcitas, greywackes y algo de filitas. A esta unidad sobreyace discordantemente la Formación Morelos, que consiste de 500 a 1,000 m de caliza y dolomita cretácita tardío-temprana plegada. Encima de la superficie de erosión post-cretácica, se depositaron rocas volcánicas terciarias que han sido incluidas en la Formación Agua de Obispo (800 m de latita de cuarzo, latita y rocas epiclásticas) y en la Formación Alquitrán (800 m de piroclásticos riodacíticos) que la cubre discordantemente. Las formaciones volcánicas son de edad oligocénica y miocénica, respectivamente.

Las rocas intrusivas del área pertenecen a dos generaciones; un intrusivo granítico del Cretácico Tardío y gabros y dioritas del Terciario medio.

Los procesos del Cretácico Tardío, que emplazaron el tronco de granito en la parte central del área, determinaron también la estructura de la región. El rumbo de la

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foliación y el de los ejes de los pliegues en las unidades más antiguas rodean el cuerpo granítico sintectónico. El rumbo de una foliación anterior se puede reconocer solamente en el Complejo Xolapa. Esa foliación tiene un rumbo E-W, igual al de la estratificación y se desarrolló simultáneamente con la facies de almandina-anfibolita como resultado de una orogenia precámbrica o paleozoica. El metamorfismo retrogrado a la facies de epidota-anfibolita debe su origen a la intrusión del granito. Existen rasgos que sugieren la existencia de un rumbo de foliación diferente en la Formación Ixcuinatoyac originado por una orogenia paleozoica (?) Los patrones actuales de la foliación y de los pliegues junto con el desarrollo de la facies de esquistos verdes resultaron, tanto en la Formación Ixcuinatoyac como en la Formación Chapolapa, del mismo proceso que emplazó el granito y de la Orogenia Hidalgoana, que también plegó a la Formación Morelos. El patrón de las diclasas en el granito está de acuerdo con el patrón regional de los pliegues en la Formación Morelos (NNW-SSE). Los sistemas de fallas con rumbo NNE-SSW y WNW-ESE, que constituyen otro rasgo tectónico importante de la región se les consideran como del Mioceno tardío-Plioceno y deben su origen al cabalgamiento del continente sobre el Pacífico.

Los dos yacimientos minerales del área los constituyen el prospecto de barita denominado La Esperanza y la mina de cobre abandonada denominada La Dicha. El prospecto de barita La Esperanza consiste de una veta que se encuentra todavía en vías de exploración y desarrollo. La mina abandonada La Dicha estaba en explotación a principios del presente siglo y su producción consistió en cobre supergenético de alta ley. Recientemente, sus menas de sulfuro han llamado la atención para nuevas operaciones. Sin embargo, al reconocer la naturaleza realmente estratificada y plegada del cuerpo mineral, se ha perdido, por lo pronto, su valor económico.

ZUSAMMENFASSUNG

Diese Arbeit bezieht sich auf ein Gebiet der Sierra Madre del Sur im zentralen Teil des Staates Guerrero. Das Gebiet liegt südlich von Mexico City, in der Umgebung des Dorfes Ixcuinatoyac. Es umfasst etwa 500 km^2.

Die höchsten Gebirgsketten des Gebietes sind über 200 m hoch. Das Tal des Papagayo Flusses —der in den Pazifik entwässert —bildet das lokale Basis-Niveau mit einer Höhe von ungefähr 600 m über M. N. Im geomorphen Zyclus hatte das Gebiet das Stadium der Reife erlangt und erfuhr dann eine Verjüngung.

Der Xolapakomplex ist die älteste stratigraphische Einheit. Er besteht aus biotitschiefern. Die zugrundeliegenden klastischen Sedimente haben präkambrisches oder paläozoisches Alter. Die Einheit wird durch die 400 m mächtige Ixcuinatoyacformation diskordant überlagert. Diese besteht hauptsächlich aus Phylliten und Quartziten von wahrscheinlich paläozoischem Alter. Sie enthält eine Magnetkies-Troilit-Kupferkies lagerstätte. Die Ixcuinatoyacformation wird ihrerseits diskordant überdeckt von der triassischjurassischen Chapolapaformation. Diese stellt eine 1000 m mächtige Folge vulkanischen und sedimentären Gestein dar, das verwiegend gründ und violett gefärbt ist. Die vulkanischen Gesteine haben eine intermediäre bis saure chemische Zusammensetzung und gehören einer Gesteinssippe des subalkalischalkalischen Grenzgebietes an. Die sedimentären Gesteine sind: Konglomerate, Brekzien, Subgrauwacken, Quarzite, Grauwacken und einige Phyllite. Diskordant folgt die Morelosformation mit 500 bis 1000 m mächtigen, gefalteten Kalken und etwas Dolomit der oberen Unterkreide. Auf der nachkretazischen Erosionsoberfläche wurden tertiäre Vulkanite abgelagert. Diese werden zusammengefasst in der Agua de Obispoformation (800 m Quarzlatite, Latite und klastische Sedimente) und in der diskordant darüberliegenden Alquitránformation (800 m Pyroklastika rhyodazitischer Zusammensetzung). Diese vulkanischen Formationen haben oligozänes bzw. Miozänes Alter.

Zwei Generationen von Intrusivgesteinen kommen im Gebiet vor: ein oberkretazischer Granitpluton und mitteltertiäre Diorite und Gabbros.

Die spätkretazischen Vorgänge, durch die der Granit im zentralen Teil des Gebietes intrudiert wurde, bestimmten auch den tektonischen Aufbau des Gebietes. Die Streichrichtung der Schieferung und der Faltenachsen aller älteren Einheiten Verläuft um den syntcktonischen Granitkörper herum. Die Streichrichtung einer früheren Schieferung Lässt sich mit Sichereheit nur im Xolapakomplex erkennen. Diese Streichrichtung verläuft (wie die Schichtung) E-W und wurde zur gleichen Zeit wie die Almandin-Amphibolitfazies durch eine präkambrische oder paläozoische Orogenese geschaffen. Die retrograde Metamorphose zur Epidot-Amphibolitfazies erfolgte zur Zeit der Granitintrusion. Es bestehen Hinweise, dass auch in der Ixcuinatoyacformation vor der Granitintrusion andere Streichrichtungen vorherrschten; diese sind einer paläozoischen (?) Orogenese zuzuschreiben. Das gegenwärtige Bild von Schieferung und Faltenstrukturen, sowie die Grünschiefenfazies in der Ixcuinatoyac—und Chapolapaformation sind auf die Vorgänge zurückzuführen durch, die dar Granit intrudiert wurde, und auf die Hidalgoische Orogenese; durch diese wurde auch die Morelosformation gefaltet. Die Klüftung im Granit steht mit der regionalen Streichrichtung der Faltenachsen des Morelos-Kalkes (NNW-SSE) in deutlicher Beziehung. Eine weitere wichtige tektonische Erscheinung im Gebiet ist das System von Verwerfungen. die NNE *und WNW streichen. Ihr Alter wird als spätmiocän und pliocän* angesehen und ihre Entstehung der Ueberschiebung des Kontinents über den Pazifik zugeschrieben.

Die beiden Minerallagerstätten des Gebietes sind das Barytvorkmmen von La Esperanza und das aufgegebene Kupferbergwerk von La Dicha. Das Barytvorkommen von La Esperanza ist eine Ganglagerstätte, die sich noch im Stadium der Erforschung und Entwicklung befindet. Das verlassene Bergwerk von La Dicha wurde zu Beginn dieses Jahrhunderts betrieben, wobei supergenes, hochgradiges Kupfererz gewonnen wurde. Vor kurzem fanden die Sulfiderze neuerdings Beachtung. Mit der Erkenntnis, dass sie kein mächtiges Gangvorkommen sind, sondern dass sie synsedimentär entstanden waren und dann nur örtlich stark gefaltet wurden, ging jedes weitere wirtschaftliche Interesse an ihnnen verloren.

Das wichtigste petrographische Belegmaterial liegt in den Archiven des Instituts für Geologie der Tchnischen Hochschule München.

ABSTRACT

This study concerns an area of the Sierra Madre del Sur, in the central part of the State of Guerrero, south of Mexico City, around the village of Ixcuinatoyac. The area comprises about 500 km^2.

The highest mountain ranges of the area have elevation greater than 2,000 m. The local base level is around 600 m and is formed by the valley of the Papagayo River, which drains into the Pacific Ocean. The area once had reached the stage of maturity in the geomorphic cycle and became rejuvenated.

The Xolapa Complex is the oldest stratigraphic unit and consists of biotite schist. The original clastic sediments are of Precambrian or Paleozoic age. The unit is unconformably overlain by the 400 m thick Ixcuinatoyac Formation, made up mainly of phyllites and quartzites of probable Paleozoic age and containing a pyrrhotite-troilite-chalcopyrite mineral bed..

This unit. in turn, is covered unconformably by the Triassic-Jurassic Chapolapa Formation, which consists of about 1,000 m of volcanic and sedimentary rocks of mainly green to purple colours. The volcanics are of intermediate to acidic composition and belong to a rock suite that falls in the alcali-calcic and calc-alcalic border area. The sediments are *conglomerates, breccias, subgreywackes,* quartzites, greywackes and some

phyllites. Unconformably follows the Morelos Formation, consisting of 500 to 1,000 m thick folded, upper Lower Cretaceous limestone and some dolomite. Over the post-Cretaceous erosional surface Tertiary volcanics were deposited, which are included in the Agua de Obispo Formation (800 m of quartz-latite and epiclastics) and in the unconformably overlying Alquitrán Formation (800 m of rhyodacite pyroclastics). The volcanic formations are, respectively, of Oligocene and Miocene age.

Two generations of intrusives exist in the area; an Upper Cretaceous granitic intrusive and middle Tertiary diorites and gabbros.

The Late Cretaceous processes that emplaced the granite stock in the center of the area, determined also the structure of the region. The strike of foliation and the strike of fold axes of all older units are aligned around the syntectonic granite body. The strike of an earlier foliation can be ascertained only in the Xolapa Complex. This foliation trends, as the bedding, E-W and was developed at the same time as the almandine-amphibolite facies, by a Precambrian or Paleozoic orogeny. The retrograde metamorphism to the epidote-amphibolite facies was brought about at the time of the granite intrusion. There are suggestions that there also existed a different strike of foliation within the Ixcuinatoyac Formation due to the influence of a Paleozoic (?) orogeny.

The present foliation and fold patterns together with the development of the greenschist facies in both the Ixcuinatoyac and Chapolapa Formations resulted from the same granite emplacing process as well as from the early Tertiary Hidalgoan Orogeny, which also folded the Morelos Formation. Jointing in the granite harmonizes with the regionally recognizable strike of fold axes of the Morelos Limestone (NNW-SSE). The system of faults striking NNE and WNW, considered as mainly of late Miocene and Pliocene age and due to the overthrusting of the continent over the Pacific, is also and important tectonic feature in the area.

The two mineral deposits of the area are the barite prospect of La Esperanza and the abandoned copper mine of La Dicha. La Esperanza barite propect is a vein deposit, still in the stage of exploration and development. The abandoned La Dicha mine was worked at the beginning of this century, producing supergene, high-grade copper. Lately, its sulphide-ores became attractive for new opertions. With the recognition of the true bedded, and hence folded, nature of the ore, it lost further economic interest.

INTRODUCTION

Location and extent.—The area to which this study refers lies in the central part of the State of Guerrero, south of Mexico City, in the Sierra Madre del Sur physiographic province, to the southwest of Chilpancingo, in the area of Ixcuinatoyac —El Ocotito (Figure 1). The area comprises about 500 km².

There are two dirt roads on which vehicles with high clearance can travel during the dry season (Plate 1). One of these goes from El Ocotito toward the west-northwest, to Jaleaca de Catalán. The course of the road has changed not long ago in the vicinity of Tlahuizapa, where it now runs through this village instead of west of it, as it was the case when the map was made. Near the junction of the Alcaparrosa River with the Papagayo River, there is a short side road leading north to Ixcuinatoyac. From this point downstream along the Papagayo River another road [illegible]anches off to the southwest and then to the west, leading to Santa Rita. This road is almost never in drivable condition for any kind of vehicle. Somewhat west of the Potrero River ("Caida del Potrero") a road goes from the main road northward up to Coacoyulillo. The other major road connects El Ocotito with La Esperanza.

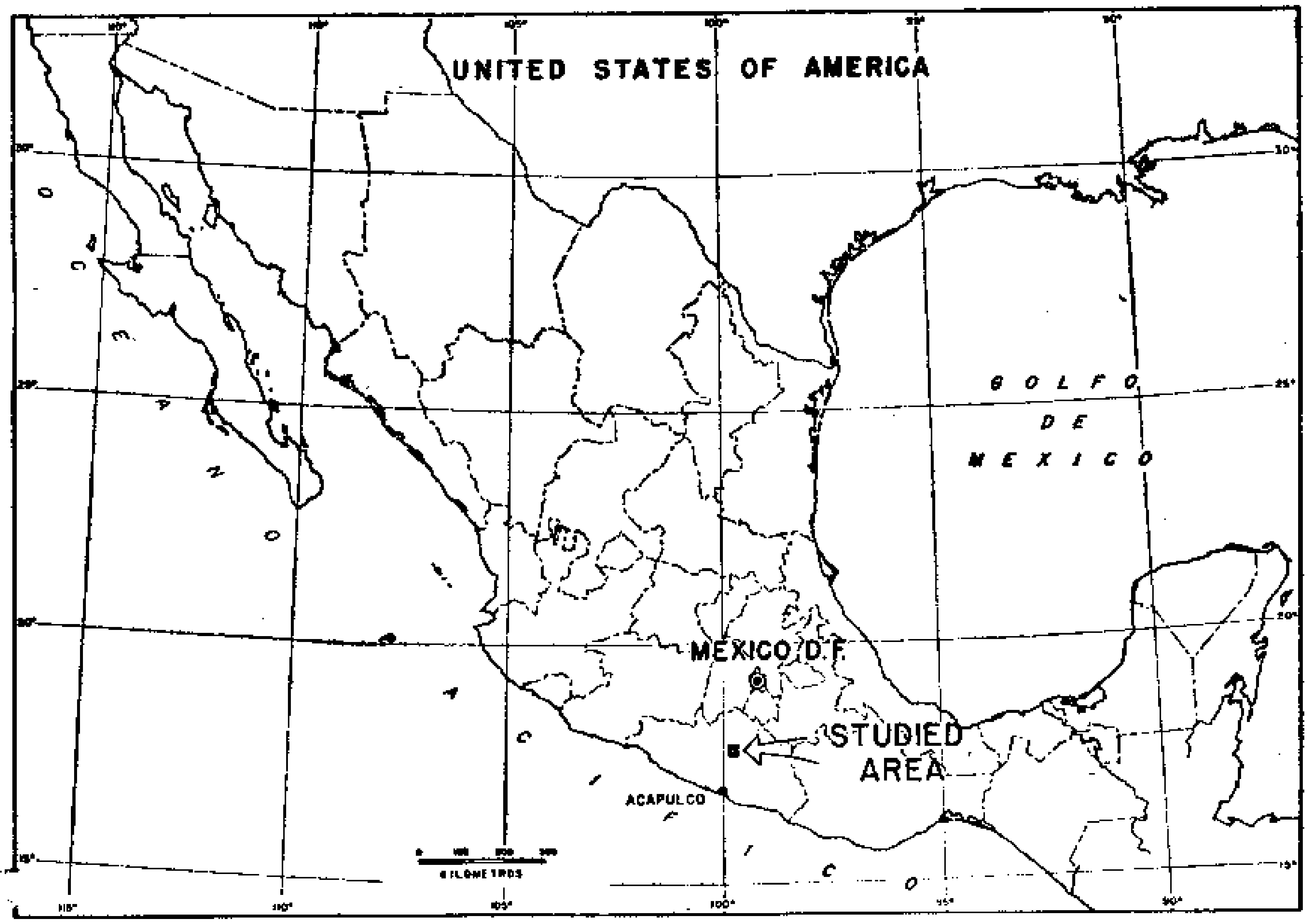

FIG. 1.—Index map.

Villages existing in the area have been mentioned above. Other small settlements are Agua Hernández and Rincón de Alcaparrosa, to be reached on foot trails going northward from Ixcuinatoyac ("El Pueblito"). The villages are all small rural settlements.

PHYSIOGRAPHY.—The area belongs to the southern slope of the Sierra Madre del Sur (Raisz, 1959) and is framed from the north, northeast and east by a mountain range which is throughout over 2,000 m above sea level. It consists of Cretaceous limestones in the north and in the northeast (highest elevation: Cerro del Burro) and of Tertiary volcanics in the east (highest elevation: Cerro Cabeza del Toro). The ranges to the south, where there seems to exist also a cover of Tertiary volcanics, and to the southwest do not reach thes ealittudes. Much lower are the ranges in the center of the area, consisting of Paleozoic or Precambrian schists, intruded by a Cretaceous granite stock, which uparched the area. Once the uplifted limestone had been eroded away, the underlying crystalline rocks, under the ruling climate quickly fell prey to erosion ("inversion of topography").

The local base level, at an average of 600 m, is formed by the Papagayo River. This crosses the southwestern corner of the area, flowing roughly from the northwest to the southeast. Farther outside the map area, it turns to the south-southwest and flows near Acapulco into the Pacific Ocean. The main affluents of the Papagayo River in the area come predominantly from north and northeastern directions, forming correspondingly elongated valleys and ridges. Only the Caracol River, in the southeastern portion of the map area, flows from an eastern direction. Shortly above the crossing of the El Ocotito-Ixcuinatoyac road, it takes up the Soyatepec and Tlahuizapa Rivers. The other main affluents, cited from east to west, are the Potrero and Alcaparrosa Rivers. The Potrero River between the El Ocotito-Ixcuinatoyac road captures the Esperanza River and up stream from Coacoyulillo it is split up into the Barranca de Nehapilla and the Barranca del Reparo. The Alcaparrosa River flows into the Papagayo River near Ixcuinatoyac.

The courses of the Alcaparrosa and Potrero Rivers with their respective affluents, are steep only where they enter the Chapolapa Formation, and form there many high waterfalls. Nevertheless, in their lower courses, as in the Papagayo River itself, there are also numerous cataracts and rapids. In terms of the geomorphic cycle, as explained by Thornbury (1954, p. 137), the "cataracts and rapids are most typical of early youth and will have disappeared before maturity is attained". This does not appear to harmonize with the fact that most "stream divides are sharp and ridge-like resulting in a minimum of interstream uplands" (Plate 2, figure 1), which is a typical sign for attainment of maturity in the geomorphic cycle (Thornbury, 1954, p. 138). Thus it is concluded that the area had already reached maturity, when it was rejuvenated by taphrogenetic processes in Miocene-Pliocene times. The Soyatepec River probably was affected by such faulting processes. Southwest of the village of Soyatepec it was united with a barranca, that follows a fault from the east, and then was deviated towards the west by the fault which dammed up the Soyatepec valley to the south; the Soyatepec River then cut its way somewhat westward in a huge, steep, V-shaped gorge through the Chapolapa and Morelos Formations.

Except for control by faults, there is not much structural control of the courses of the rivers. These originated mostly on a former sedimentary or volcanic cover. To the south, the Papagayo River today crosses very conspicuous bedding and foliation in quite random superposed courses. One could make a case for antecedence, where the stream bed has been cut into an upfaulted block of granite.

The Alcaparrosa River also has a typical superposed course, where it cuts much of its way through the granite, instead of through the nearby much softer phyllites.

The drainage pattern in the area is mostly dendritic. Just occasionally, as in the southern part of the map area where biotite-schists underlie the terrain, there is a notable influence of the strike of bedding and foliation on the course of the rivers. A small area around the Barranca de Nehapilla shows a more or less rectangular pattern, caused by jointing. Very conspicuous is the angular pattern in the eastern Tertiary volcanic area.

In the limestone areas, which show the signs of karstic features, such as caves, sinkholes, etc., the water courses, at least superficial ones, are scarce. Consequently hills of limestone often show a rounded, lumpy form (Plate 2, figure 2). The units below the limestone are intensely dissected. The overlying Tertiary volcanics are also strongly dissected (along their joints). However, one can still recognize in many places their original, close to horizontal position, by the mesetas they form. These break down in sharp cliffs and in many places have subsequently been tilted, which give them a stepped aspect.

The climate is tropical with rain in the summer. The annual amount of precipitation ranges between 1,000 and 1,300 mm. Some typical trees or brushes are: carnicera, otate, cugiote, cocoyul; on dry hillsides: pine, oak.

Previous work.—The area studied has not been treated geologically before. Santillán's (1929) mining geological report which covers the western part of the State of Guerrero could not be used for the study of the area, because it was too general. González-Reyna (1856) in his compendium of Mexican mineral deposits did not recognize the true nature of La Dicha sulfide deposit and gave misleading indications as to its dimensions. De Cserna's (1965) study and geologic map of the region between Chilpancingo and Acapulco, east of the area studied, provided fundamental information as to the possible geological make-up of the Ixcuinatoyac area. In that area, comprising about 1,600 km², he defined the Xolapa Complex and the Chapolapa, Agua de Obispo and Alquitrán Formations.

Purpose of study.—The present study was undertaken as a cooperative project with Cía. Minera del Río Murga, S. A., Mexican affiliate of Texas Gulf Sulphur Company, to establish basic geological relations of the region between El Ocotito and Ixcuinatoyac, where a massive sulphide ore body, known as La Dicha, is located. In order to reach this goal, it was necessary to carry out geologic mapping.

As the region in covered only by a 1:100,000 scale topographic map which was not suitable for this purpose, a planimetric base map was prepared by the writer from vertical aerial photographs. On the photographs and on this base map the geology was mapped which resulted in the first map of this kind that covers this region of Mexico.

In previous literature and mining reports this massive sulphide ore body together with the nature of the enclosing rocks were described in widely different ways. From these, its true nature and origin were rather doubtful, namely whether it was a vein of hydrothermal origin or an orebed of syngenetic nature. The study of the rock sequence revealed the presence of a heretofore unknown stratigraphic unit, the Ixcuinatoyac Formation, of probable Paleozoic age, and the genetic relation of the orebed to this stratigraphic unit.

This study constitutes the doctoral dissertation of the writer at the Technische Hochschule of Munich, Germany; an undertaking sponsored by the Instituto de Geología of the Universidad Nacional Autónoma de México with the purpose of strengthening academic exchange relations between these two Institutions.

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For the overall arrangements that made possible the study, the writer is very grateful to Prof. Dr. P. Schmidt-Thomé, Director of the Goelogical Institute of the Technische Hochschule of Munich.

No less gratitude is due to Ing. Guillermo P. Salas, Director of the Instituto de Geología and Messrs. Velásquez Spring and Allan H. Juhas, both of Cía. Minera del Río Murga, S. A., for their personal interest and constant support in every phase of this study.

The actual directing and supervising of this study was by Dr. Zoltan de Cserna, of Instituto de Geología, who suggested this study, accompanied the writer to the field on several occasions, offered guidance, both in the field and laboratory, and reviewed the manuscript. Mr. Juhas in addition offered helpful suggestions in the field and in the solution of some petrographic problems. Both staff members and technicians of the Instituto de Geología readily assisted the writer in specific problems on numerous occasions. The field work was carried out with a jeep and camping equipment of the Instituto de Geología, which was placed at the disposal of the writer. The office and laboratory work was carried out at the main Institute building in México, D. F. To all these persons the writer is very grateful.

STRATIGRAPHY

The area mapped is underlain by metamorphic, sedimentary and volcanic rocks. They have been mapped in six stratigraphic units, whose names and correlation are shown on Figure 2.

PALEOZOIC OR PRECAMBRIAN.—*Xolapa Complex.*—This is the lowermost stratigraphic unit recognized in the area studied (de Cserna, 1965, p. 15). It consists essentially of a strongly metamorphosed biotite schist. Considering the great area it underlies, a thickness of 1,000 m could be visualized as a minimum, although the actual thickness probably is decidedly greater.

The Xolapa Complex may be separated into two subunits; a coarser-grained one of a very uniform character, and a fine-grained one which shows bands and especially lenses of lighter coloured material (quartz, feldspar, epidote), alternating with biotite-rich parts. In general, the fine-grained subunit is the predominant one in the northern part of the main biotite schist area (Plate 1).

The main mass of the biotite schist together with the large granite area form the central part of the region studied. It lies south and east of the main granite terrain and is pierced in places by minor granite intrusives. The easiest accessible and at the same time most typical outcrops of the coarse-grained subunit are in the valley of the Potrero River, between Puente Potrero (where the El Ocotito-Ixcuinatoyac road crosses the Potrero River) and Coacoyulillo (Plate 1), along which the road passes for a short distance. Another very typical occurrence of the coarse-grained subunit is at 2 km south of the village of La Esperanza, where it is very well exposed in a ledge forming a 100 m high cascade of the Esperanza River (Plate 1). Unfortunately, this locality is not of easy access and may best be reached from the south along the river. Smaller patches of the schist outcrop abundantly to the west in the valley bottom of the

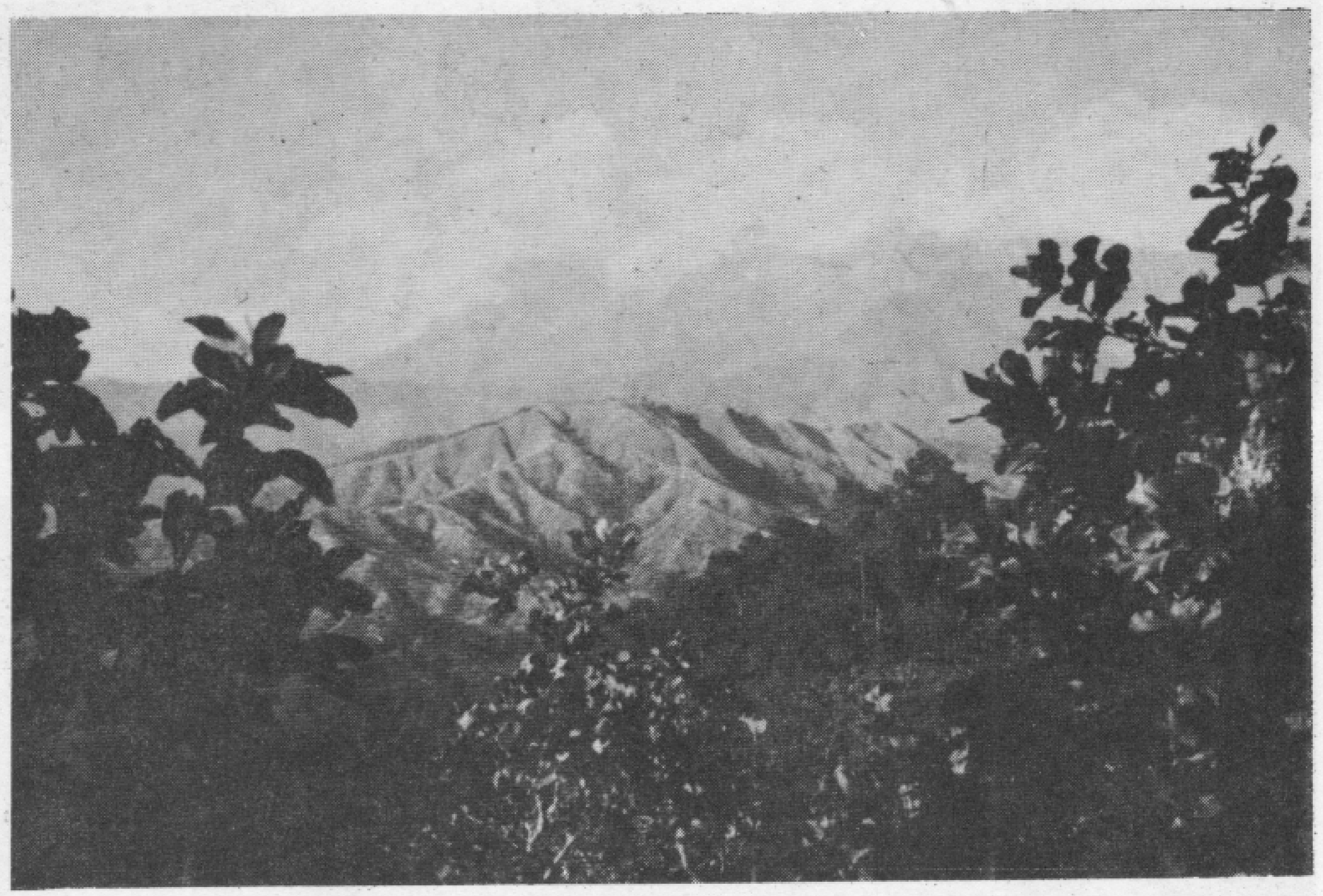


Fig. 1.—Sharp stream divides show attainment of maturity in the geomorphic cycle. The dissected massive in the center is formed by the Xolapa Complex (biotite schist), the mountain range in the background by the Morelos Formation (limestone).

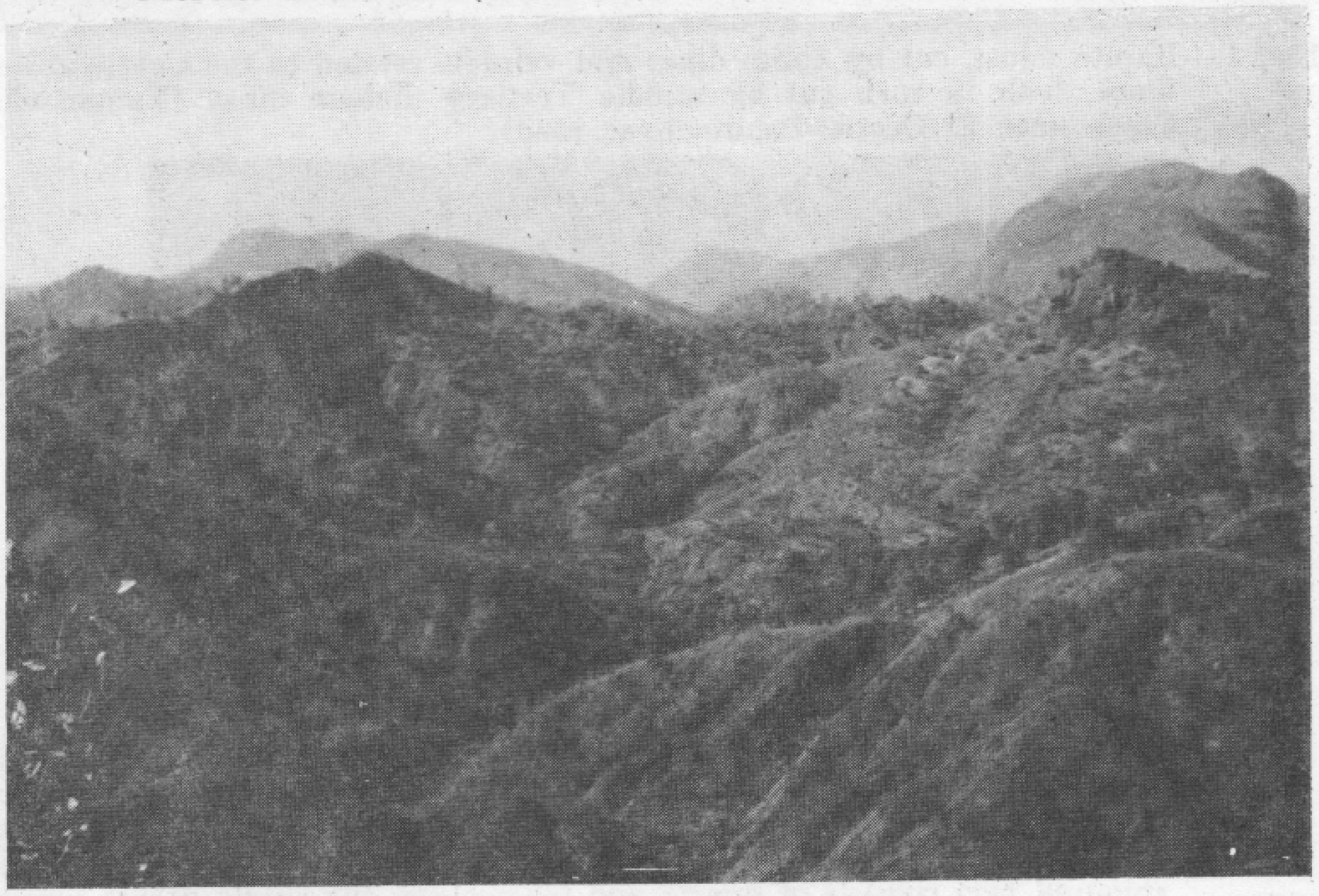


Fig. 2.—In the left part volcanics of the Chapolapa Formation; in the right center somewhat tilted volcanics and epiclastics of the Tertiary Agua de Obispo Formation; in the right background the rounded, lumpy form of a limestone hill.

LANDFORMS IN THE AREA STUDIED

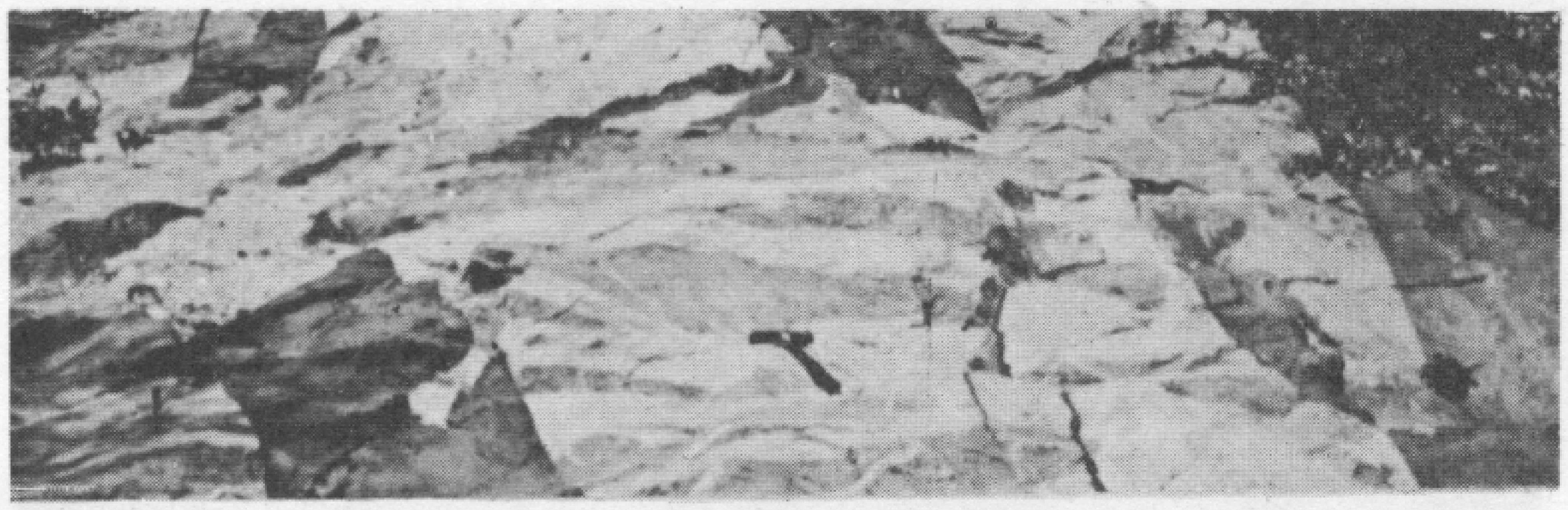


Fig. 2.—Detail of Figure 1.

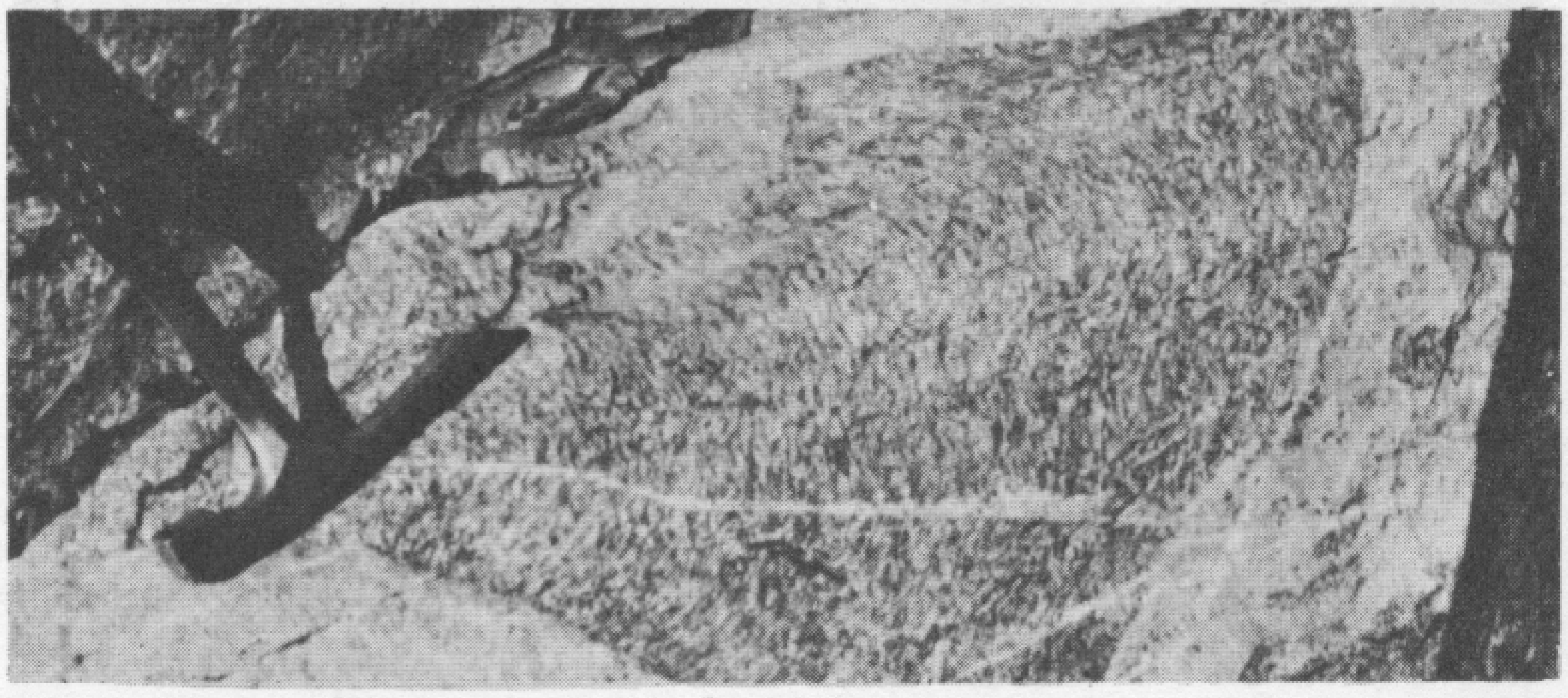


Fig. 1.—Biotite schist, cut by aplite dikes and veinlets related to the Coacoyulillo Stock, both in turn cut by middle Tertiary diabase dikes (Tamarindo Creek near El Ocotito-Ixcuinatoyac road).

Fig. 3.—Photomicrograph (o.100) of biotite schist. Dark part of photograph shows a large grain of original hornblende; of this relics can be seen in the slightly lighter coloured middle part of the grain. The darkest parts of the grain are biotite replacing the hornblende. The light coloured part consists of quartz and plagioclase; the single grains cannot be distinguished because the photograph is taken without crossed Nicols. The small grains with high relief are epidote; they formed especially along the borders of hornblende and plagioclase in a process of retrograde metamorphism from the almandine amphibolite facies to the epidote amphibolite facies..

DETAILS OF XOLAPA COMPLEX

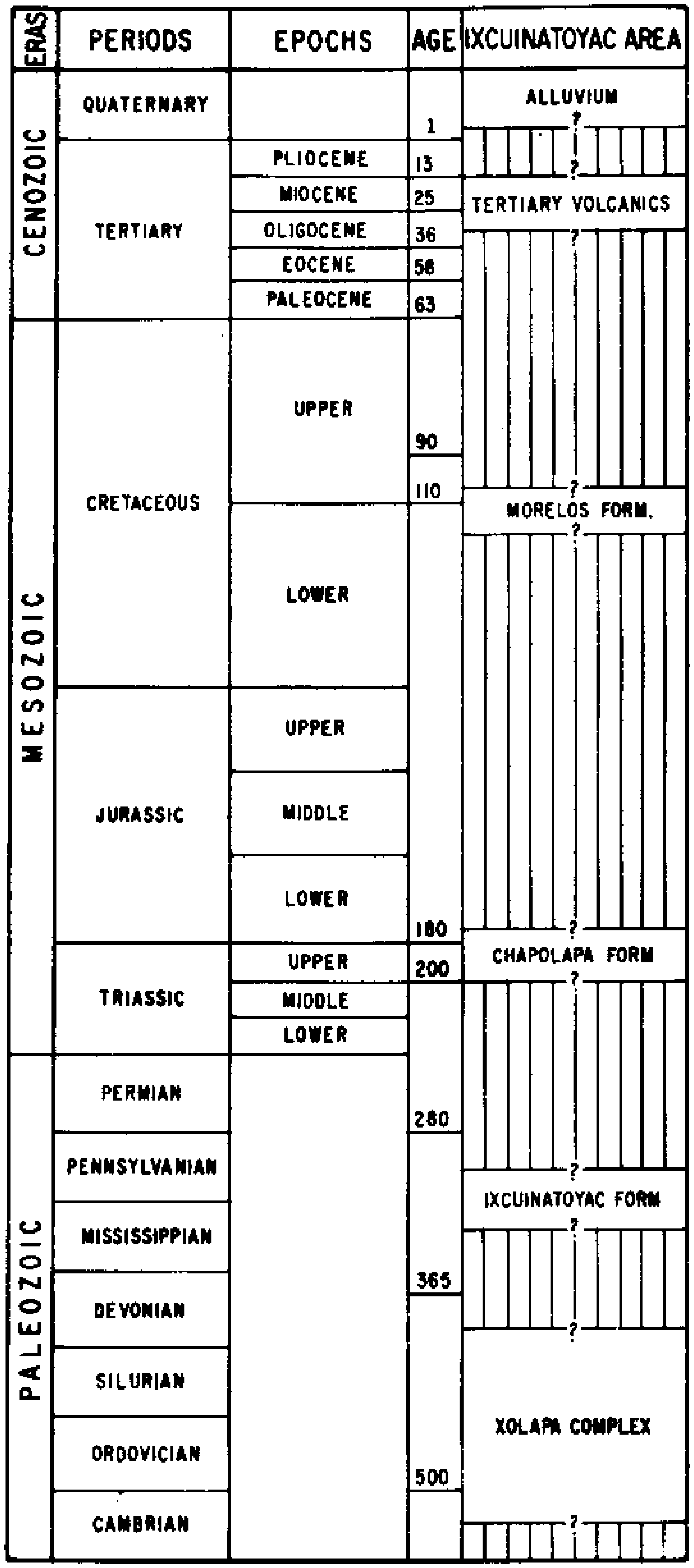


Fig. 2.—Correlation table.

Papagayo River and the Barranca Hedionda, northwest of the village of Ixcuinatoyac.

The fine-grained, banded subunit of the Xolapa Complex is best exposed along the Barranca del Reparo and the Barranca de Nehapilla, north of Coacoyulillo; to reach these exposures requires hard and long walks over mountainous country on foot trails. In general, it is difficult to move around in the area underlain by the biotite schists as these are thickly overgrown by vegetation and highly dissected by watercourses.

In places the schists are densely cut by dikes and veinlets of aplitic or granitic composition (Plate 3, figures 1, 2). The coarse-grained bitite schist consists almost completely of quartz and biotite, in the proportion of 3:1. There is also some granulated plagioclase, hornblende, fairly numerous grains of epidote, a few grains of garnet (almandine) and sphene. The shattered and rehealed quartz grains vary in size from 0.01 to 0.8 mm. The biotites have an average size of 0.2 mm. The fabric is lepidoblastic. The flaky minerals are fairly concentrated in very irregular streaks and bands.

The fine-grained subunit sometimes resembles macroscopically, at a first glance, certain greenschists. The microscope clearly shows, however, mineral and facies relations similar to the coarse-grained biotite schist. The quartz is the prevalent constituent (82%), followed by plagioclase (5%), biotite (5%), epidote (6%), hornblende (1%), and almandine (1%). The grain size of the quartz ranges from 0.001 to 0.2 mm, the biotite averages around 0.07 mm. The epidotes occur in grains of up to 0.1 mm, or in extremely fine-grained aggregates. The garnets are around 0.05 to 0.08 mm in size. The quartz grains are also very irregular in size, with finer grains predominating. Sometimes, however, the quartz grains show a banding clearly due to distinct grain size.

The original sediment was an argillaceous and somewhat arkosic sandstone that suffered metamorphism reaching the almandine - amphibolite facies. Later retrograde metamorphism followed and converted these rocks to the epidote-amphibolite facies. In Winkler's system, (1965, p. 99-102) this facies corresponds to the quartz-albite-epidote-almandine subfacies of the greenschist facies. The stable mineral assemblage of the almandine-amphibolite facies had been hornblende-plagioclase-almandine; there still are relics of it to be seen. The new coexisting minerals of the lower facies are epidote-biotite-albite-almandine. Both epidote and biotite, the latter clearly replacing the hornblende, occur very abundantly between plagioclase and hornblende; the biotite neccessarily is associated with the hornblende and obtained from it its iron and magnesium requirements. Epidote, according to its formula, is richer in calcium than its main originator plagioclase; it took advantage of the calcium released by the decomposition of the hornblende (Plate 3, figure 3).

Southeast of the mapped area, north of Xaltianguis, occurs biotite schist of the greenschist facies; south of Xaltianguis the degree of metamorphism increases to the epidote-amphibolite facies, typified by the biotite gneiss of that area (de Cserna, 1965, p. 17). The notable increase of metamorphism encountered to the west should also be mentioned here.

As to the age of the Xolapa Complex, de Cserna (1965, p. 19) considered it to be Paleozoic, as in most places the overlying rock sequence is of probable Triassic age, rather than to relate it to the Precambrian rocks of Oaxaca which were supposedly metamorphosed about 950 million years ago and belong to the amphibolite and granulite facies (Fries *et al*, 1962). There could be a relation to the Cordilleran eugeosyncline of North America of the early Paleozoic era (Kay, 1955, 1957, 1960; Roberts *et al.*, 1958; Kay and Crawford, 1964). The metamorphism might be due to a middle Paleozoic orogeny. A Precambrian age, however, cannot be excluded from consideration.

PALEOZOIC.—*Ixcuinatoyac Formation.*—The rocks of this formation, in part strongly folded and moderately metamorphosed, and which underlie the area west of the principal granite intrusive are named here Ixcuinatoyac Formation. They consist mainly of impure quartzites and phyllites, the phyllites making up the bulk of the formation. The realtively less resistant nature of the phyllites is responsible for the exposure of this formation mainly in the bottom of the valleys of the Papagayo and Alcaparrosa Rivers. Schistosity and bedding coincide in most places, although locally there is a wide divergence between the two (Plate 4, figure 1).

The relation of the Ixcuinatoyac Formation to the underlying Xolapa Complex is discordant. The rocks of the Ixcuinatoyac Formation show slump structures and cross bedding which indicate normal position over the Xolapa Complex. The unconformity at the base of the Ixcuinatoyac Formation is evidenced by the superposition of different types of rocks of the respective units in different places. Even though a direct contact could not be seen, the units crop out in several places sufficiently close to each other, as to be strongly suggestive of the relationship. In the valley of the Papagayo River, where the road to Santa Rita branches off from the Ixcuinatoyac-El Ocotito road, phyllites lie over the Xolapa Complex which, in this area, approach a somewhat gneissic appearance. Here the quartz grains are mostly squeezed flat and in places begin to migrate and to concentrate in greater lenses. The strike of bedding and foliation is in both units about the same. However, the dip in the Xolapa Complex changes frequently around the vertical, whereas in the phyllites it remains for a rather long distance to the north with medium values. Slightly farther north in the river bed, quartzites of the Ixcuinatoyac Formation lie over the above described rock type of the Xolapa Complex. In other places it is the coarse-grained biotite schist that is overlain by the Ixcuinatoyac Formation. The biotite schist to the south-southwest of the village of Ixcuinatoyac is covered in places by tuffaceous green banded argillites or by quartzites of the Ixcuinatoyac Formation. In the Barranca Hedionda, the schists are covered by quartzites.

The type-section of the formation lies in the Barranca Alcaparrosa and farther west in the valley of the Alcaparrosa River, in the Barranca Hedionda and in the Barranca de Lima that lies father north (Plate 1). The thickness of the section is about 400 m. Generally it consists if phyllites and quartzites in a proportion of about 3:1, the phyllites being in the middle part of the section. The basal part of this formation in the east is cut by a granite intrusive. To the west of the granite contact, there is a sequence of some 80 m of impure quartzite. The rock is often finely laminated, due to original differences in the composition of the sediments. The quartzites possess anywhere from dark-grey to very light colours. Typical is a light-blue type with dark-blue spots of about 1 mm in diameter. These spots, under the microscope, turned out to be flat accumulations of tiny muscovite flakes, 0.03 mm in size. The quartz grains are, more or less, equigranular, averaging 0.02 mm in diameter. Quartz and muscovite make up the bulk of the rock; they occur in a proportion of about 50:50. The rock consists of 3% biotite porphyroblasts, which measure 0.3 mm in diameter (Plate 5, figure 1).

In the dark grey type, the muscovite is slightly less abundant (40%; grain size 0.06 mm). It is also oriented parallel to the bedding plane, but more or less uniformly dispersed through the rock, without forming the spots. Certainly, the quartz grains (50% of the rock) are often concentrated in pure bands, sometimes in lumps, with exceptional grain sizes up to 0.2 mm. The average size of the quartz grains is 0.03 mm. In the groundmass of quartz and muscovite, there are disseminated biotite prophyroblasts in random orientation; some of them are partly altered to chlorite. There are also some grains of epidote and pyrite.

Upward in the section, the quartzites become purer and the quartz grains larger and less well sorted. There are a few meters of conglomerate, made up of flat squeezed pebbles of sandstone. Slightly above the conglomerate lies a sulphide mineral bed about 2 m in thickness, and which consists mainly of iron sulfides. The conglomerate and the mineral bed are more intensely folded than the remainder of the section, due to disharmonic folding. Cross-bedding (Plate 5, figure 2) and slump structures in the conglomerate show the true position of the bedding. With fair certainty the true position of the beds can be followed through the folds to the east, and it can be concluded that the lower part of the section is exposed there. In some places a quartz conglomerate is also present.

Some distance to the north of the mouth of the Barranca Alcaparrosa, the quartzites contain two sills of highly altered periodotite which appear as talc schist (Table 1, Sample 51), One of these layers is about 0.75 m thick and can be followed along strike for some 5 m. The high limonite content in this rock is probably due to the leaching of iron from the above-lying sulphide ore bed. Talc schists are formed in purely metasomatical ways (Barth, *et al.*, 1939, p. 402). The original rocks of the present talc schists are considered to be ultrabasic in composition (*i. e.* peridotites). Certainly, there is a considerable body of geological evidence that, in eugeosynclinal environment, intrusions and extrusions of lavas with ultrabasic composition do take place; the bodies normally are not of very large dimensions, are mostly lenticular in shape and aligned along the strike of the enclosing rocks. This type of peridotites (called generally ophiolites in the European geologic literature) represents the initial magmatism in orthogeosynclinal belts.

Approximately 10 to 20 m above the conglomerate, the quartzites contain more and more interbeds of phyllite, until finally the major part of the sequence consists of phyllites. The phyllites are light to predominantly dark grey and show the silky luster of sericite. Some quartzite bands are intercalated in which the quartz makes up 80% of the rock and has an average grain size of 0.08 mm. The other minerals are mainly chlorite and muscovite in about equal proportions. The bulk of the phyllite is made up of 96% sericite (grain size 0.02 mm), and about 3% quartz (0.01 mm in diameter). Clinozoisite is present and, again as

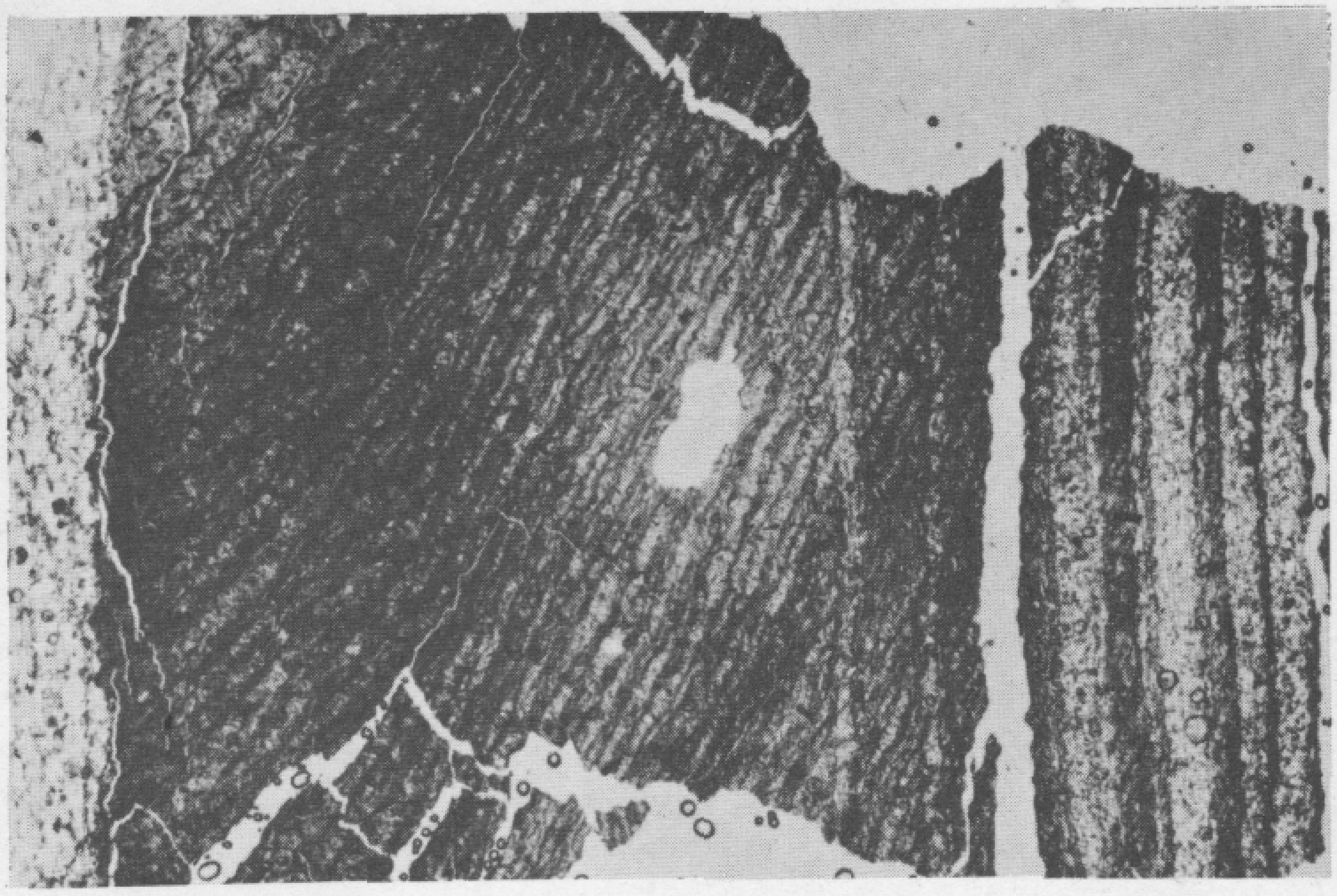


Fig. 1.—Photomicrograph without crossed Nicols (X 7). Foliation and bedding in different directions.

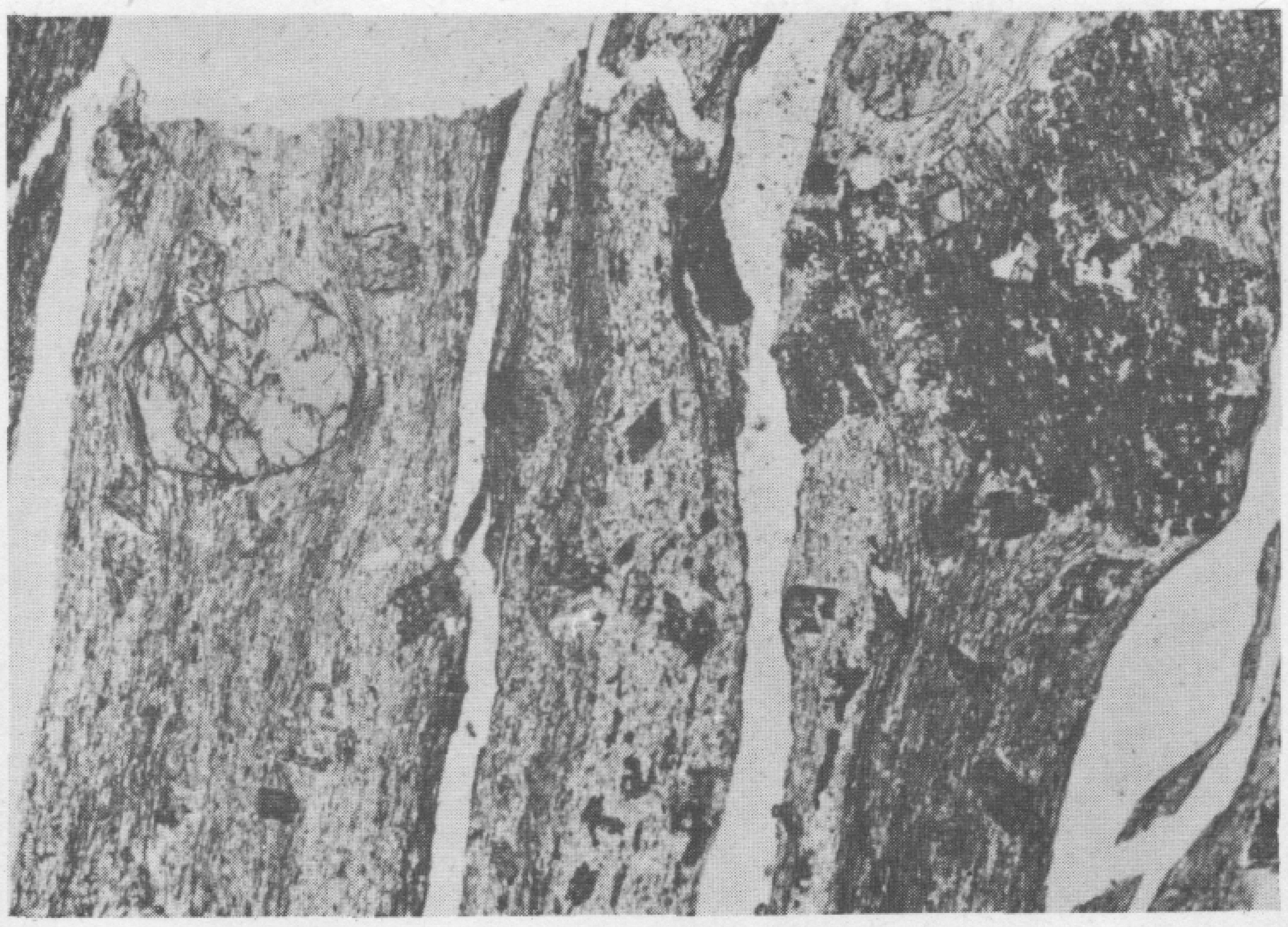


Fig. 2.—Photomicrograph without crossed Nicols (X 10). Foliation and bedding coinciding. Light coloured porphyroblast in upper part of photograph is almandine; dark coloured large porphyroblasts in right lower corner *are staurolites.*

FOLIATION IN THE IXCUINATOYAC FORMATION

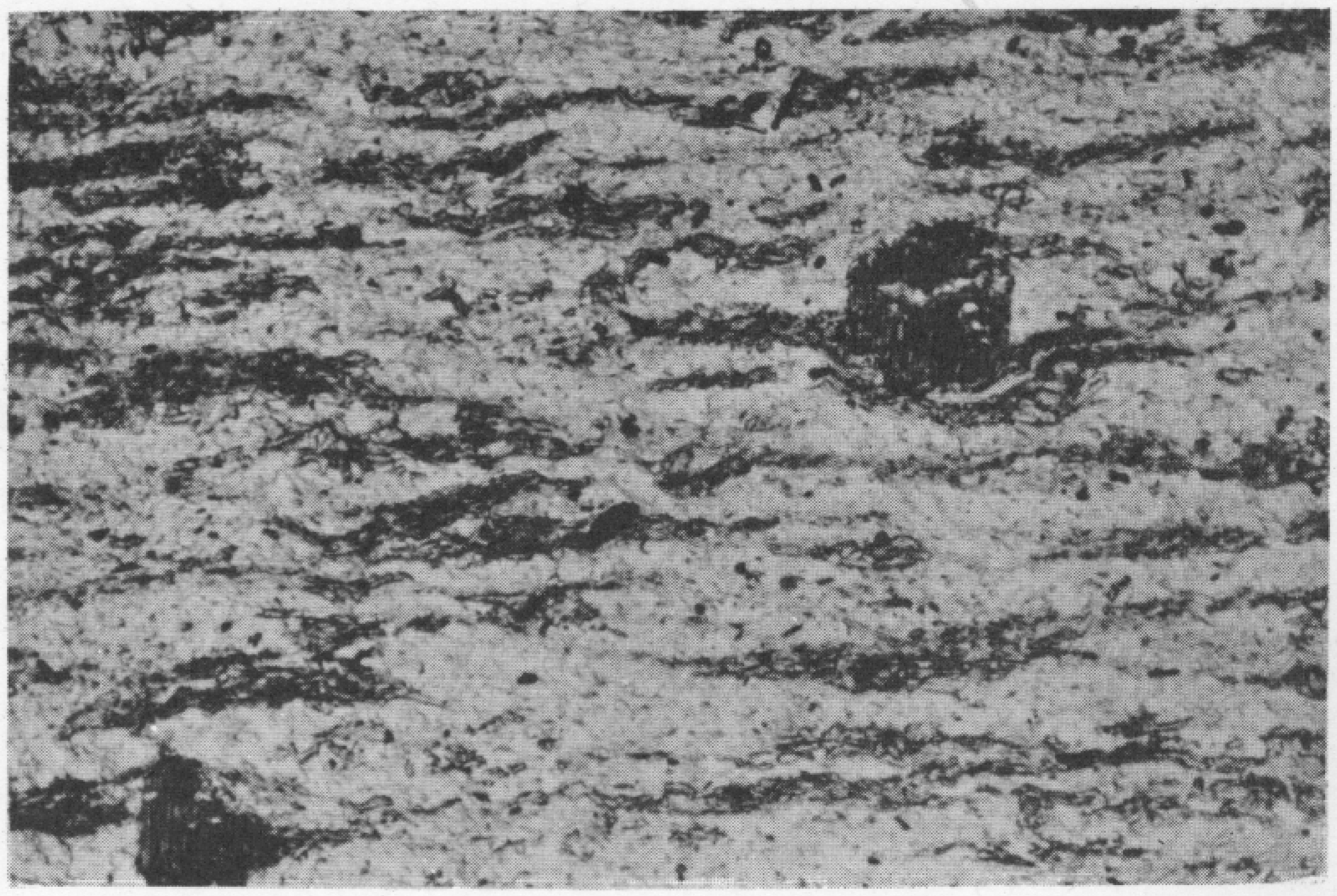


Fig. 1.—Photomicrograph without crossed Nicols (X 30) In a groundmass of quartz and muscovite flat accumulations of tiny muscovite flakes. Porphyroblasts of biotite.

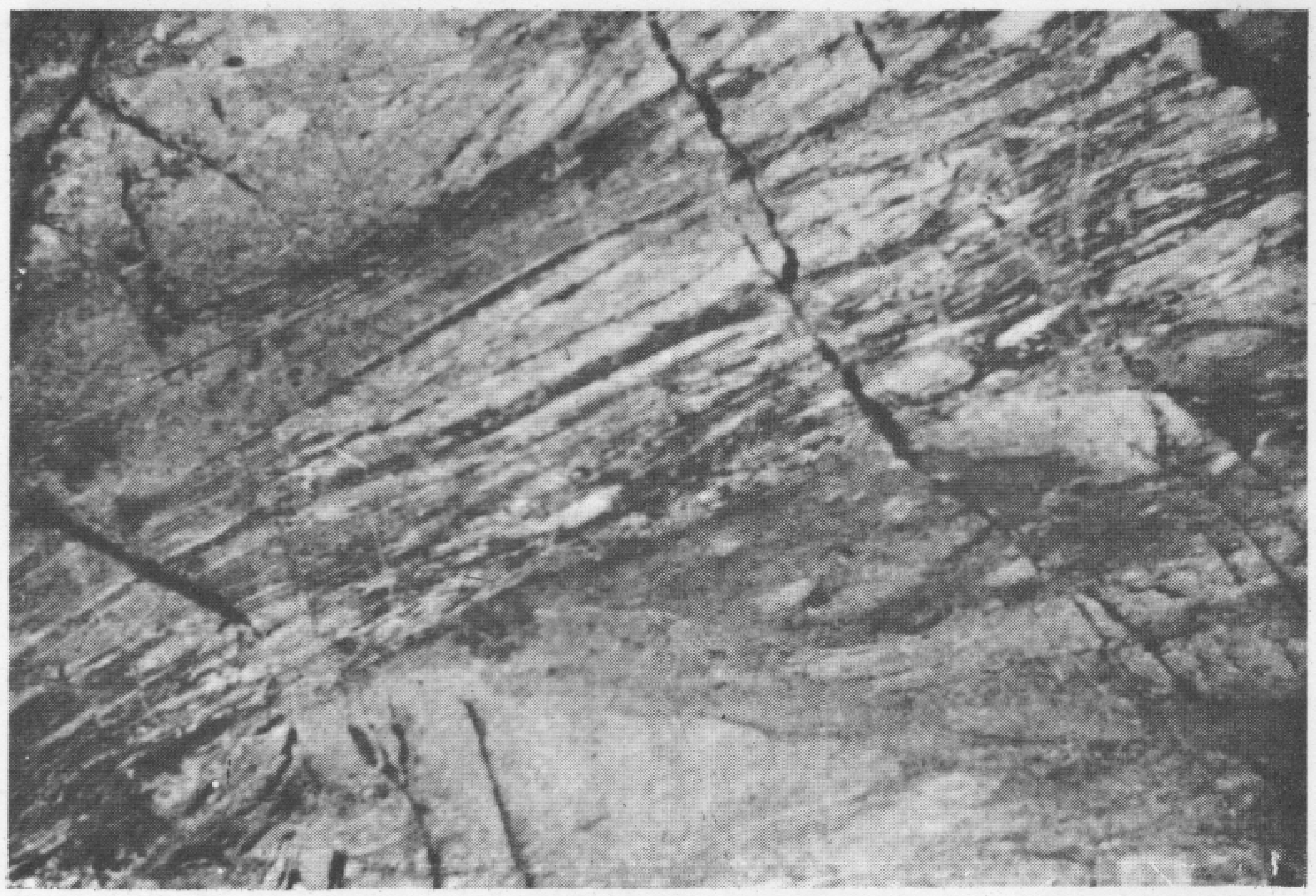


Fig. 2.—Crossbedding. Width of photographs represents 50 cm.

DETAILS OF IXCUINATOYAC FORMATION

in the quartzites, epidote and chlorite. Quartzites overlie the phyllites in the area of the village of Ixcuinatoyac.

Going from the Alcaparrosa River area that lies north of Ixcuinatoyac, to the Papagayo River valley west and south of Ixcuinatoyac (Plate 1), a lateral change of facies may be observed. In the Alcaparrosa River area north of Ixcuinatoyac (*e. g.* shortly south of Rincón de Alcaparrosa), the presence of volcanics in the Ixcuinatoyac Formation is uncertain. However, from Ixcuinatoyac towards the Papagayo Valley, there seems to be an increase of tuffaceus material in the formation. Light and dark-green banding, in many instances very fine, suggests the accumulation of shales rich in subaqueous tuffs that may be called "argillaceous tuffs" (A. Juhas, personal communication). A thin section of a coarse-banded sample taken from the bed of the Alcaparrosa River slightly north of Ixcuinatoyac, shows the presence of quartz, sericite, very abundant chlorite and large feldspar crystals with or without twinning. In part these have been identified as oligoclase and probably were originally phenocrysts. Magnetite is rather common. Calcite occurs in small aggregates of micrite or as filling of veinlets. It is probably derived from calcium-rich plagioclase.

In the Papagayo valley, there is a transition from these "argillaceous tuffs" into green, obviously volcanic rocks with feldspar phenocrysts of several millimeters in length. Finally, it should be mentioned also the presence of coarse — and finely— banded rhythmic deposits, especially in the Papagayo valley, in which quartz sand layers alternate with argillaceous ones (Plate 6, figures 1, 2).

The rocks of the Ixcuinatoyac Formation belong to the greenschist facies. Widespread, though often incomplete, retrogressive replacement of biotite by chlorite shows a change from the "quartz-albite-epidote-biotite subfacies" to the lower temperature "quartz-albite-muscovite-chlorite subfacies"; this was brought about by the intrusion of the granite. In the higher grade epidote-amphibolite facies, almandine should appear instead of iron— bearing chlorite. However, in the Ixcuinatoyac Formation almandine is confined to an arae 100-200 m from the granite contact. Approximately 50 m distance from the granite contact, in the western part of the Barranca de Lima area, a staurolite-almandine-rock (Plate 4, figure 2) was found, obviously also a product of contact metamorphism. The porphyroblastic chlorites are the products of alteration of biotite. Staurolite-almandine rocks occur exceptionally as contact metamorphics if a very special chemical composition in the rock exists, and only in the hornblende hornfels facies (Turner and Verhoogen, 1960, p. 513). Though belonging to a hornfels facies, there is a foliation present which suggests that the Ixcunatoyac Formation acquired a foliation before the granite was intruded ("Foliation is not present in a hornfels unless the rock developed schistosity prior to thermal metamorphism."; Moorhouse, 1959, p. 427).

Although some rather intensely folded parts, including isoclinal folds in the quartzite-phyllite-quartzite sequence of the Alcaparrosa River area are present, in general, the bedding planes dip constantly to the west. The possibility that the sequence is a part of a huge overturned isoclinal fold can be discarded. Detailed examination of the sequence together with samples collected along the section did not reveal an overturned repetiton of the lower half of the section. Geochemical studies of samples taken in the western quartzites did not show the slightest trace of iron or copper sulfide mineralization (Cía. Minera del

Río Murga, S. A., oral communication), which should be expected, since the sulfides are of sedimentary nature. Thus the quartzite-phyllite-quartzite sequence probably represents a transgression and a regression. From the underlying biotite schist, first was derived the impure sandstone of the Ixcuinatoyac Formation. Once the sinking of the basin stopped, the region became exposed to subaerial erosion which resulted in the deposition of an intraformational conglomerate composed of this material. In some places streams brought quartz pebbles derived from the nearby metamorphic terrain into the conglomerate. Shortly after the formation of the conglomerate, the sulfides were deposited, also in a band paralleling, more or less, the shoreline. With the deepening of the basin it became enlarged and in it the shaly material was deposited. The upper sandstone probably marks a period of regression. In the Ixcuinatoyac Formation thus the components of the underlying biotite schists are present in reworked form as sands and clays.

The age of the Ixcuinatoyac Formation is thought to be Paleozoic; this is suggested by the underlying Xolapa Complex of presumably early Paleozoic (possibly Precambrian) age and the overlying Chapolapa Formation of Triassic-Jurassic age. The overlying Chapolapa Formation probably represents the taphrogenic stage pertinent to an orogenic phase which had previously affected the Ixcuinatoyac Formation. As to this orogenic phase one could think of a correlation with the Mississippian Antler Orogeny (Roberts, 1949, p. 65) in the North American Cordilleran Geosyncline. Thus, an early or medial Paleozoic time of deposition for the Ixcuinatoyac Formation may be assumed.

TRIASSIC-JURASSIC.—*Chapolapa Formation.*—This formation comprises a variety of rocks, ranging from mainly volcanic to sedimentary in origin (de Cserna, 1965, p. 19). These rocks are interbedded and nowhere, in the highly folded terrain, is an identical section that one could trace over long distances. The volcanic rocks consist of lava flows (Plate 7, Figure 1) and schistose tuffs; the sediments, mostly coarse clastics, are made up mainly of conglomerates, breccias, subgreywackes, quartzites, greywackes and contain some phyllites. The Chapolapa Formation is up to 1,000 m in thickness. The colour of the rocks that make up this formation ranges from green (due to abundance of chlorite and epidote) to purple.

The Chapolapa Formation overlies unconformably the Xolapa Complex and the Ixcuinatoyac Formation (Plate 1) . In several places, lavas of the Chapolapa Formation (up to 200 m in thickness) flowed over rocks of the Ixcuinatoyac Formation, on a very irregular erosion surface that cuts clearly and sharply the bedding planes.

The outcrops along the eastern part of the "El Ocotito-Ixcuinatoyac" and "El Ocotito-Esperanza" roads are not very good and provide a unilateral picture of only the volcanic part of the sequence. The sedimentary components of this formation are more abundant in the western part of the area. The best section of this formation may be observed in the "barrancas" that come down from the mountain ranges on both sides of the upper Papagayo valley (Plate 10), where the very irregular intercalated volcanics, conglomerates and quartzites are all well exposed.

The chemical analyses of the volcanics of the Chapolapa Formation are shown in Table 1. One can readily see the intermediate to acidic composition

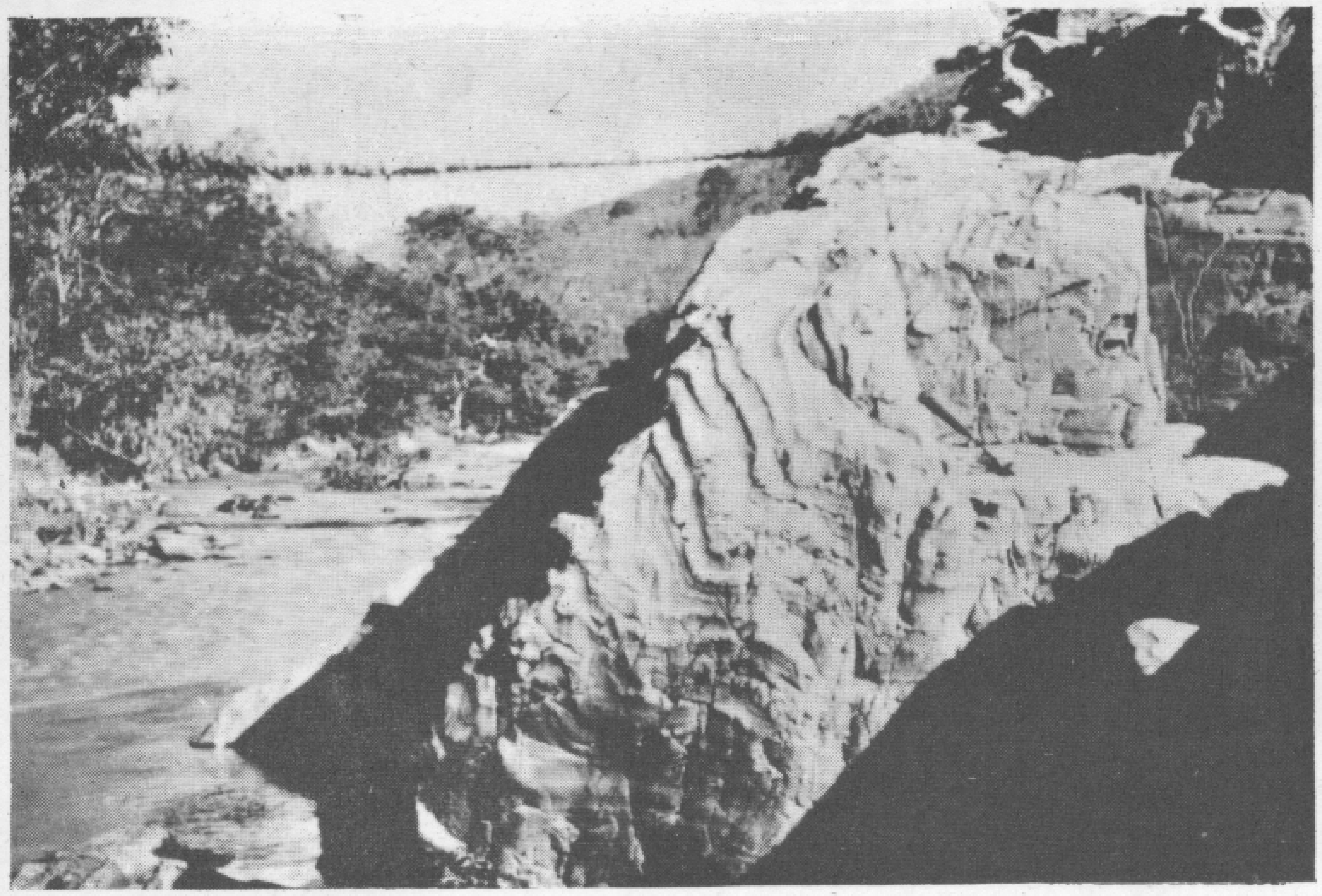


Fig. 1.—Coarse-banded rhythmic deposits near foot-bridge over the Alcaparrosa River north of Ixcuinatoyac.

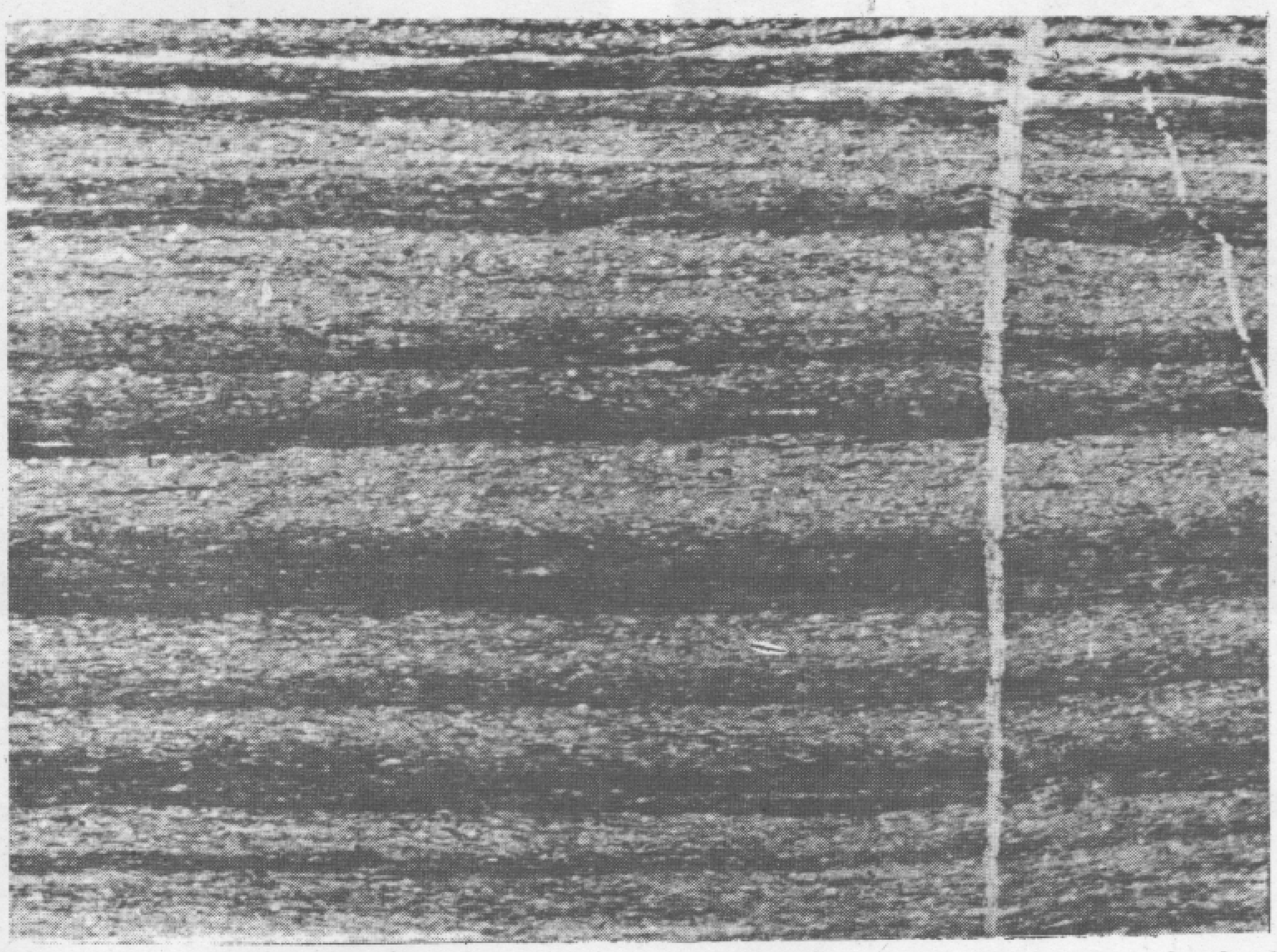
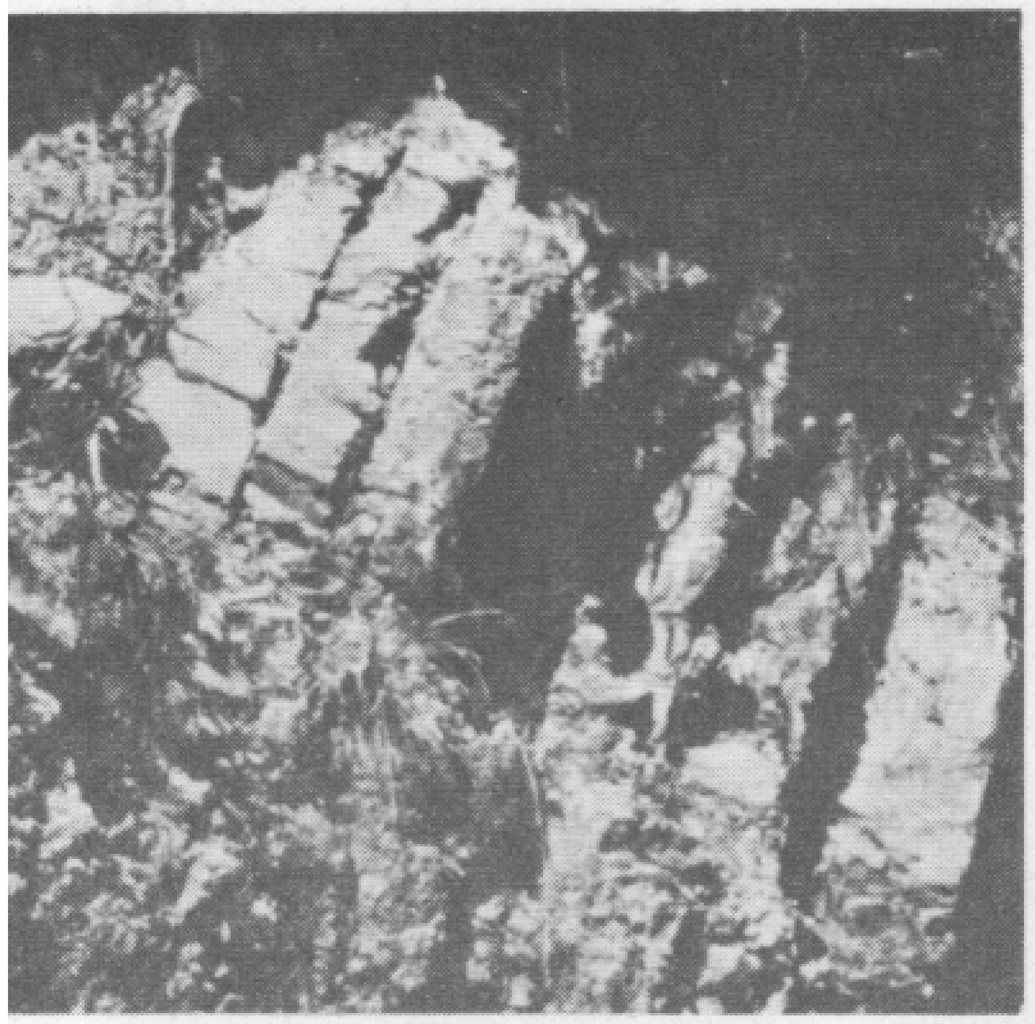


Fig. 2.—Photomicrograph without crossed Nicols (X 10). Finely-banded rhythmic deposits: alternation of quartz sand and argillaceous layers.

RHYTHMIC DEPOSITS IN IXCUINATOYAC FORMATION



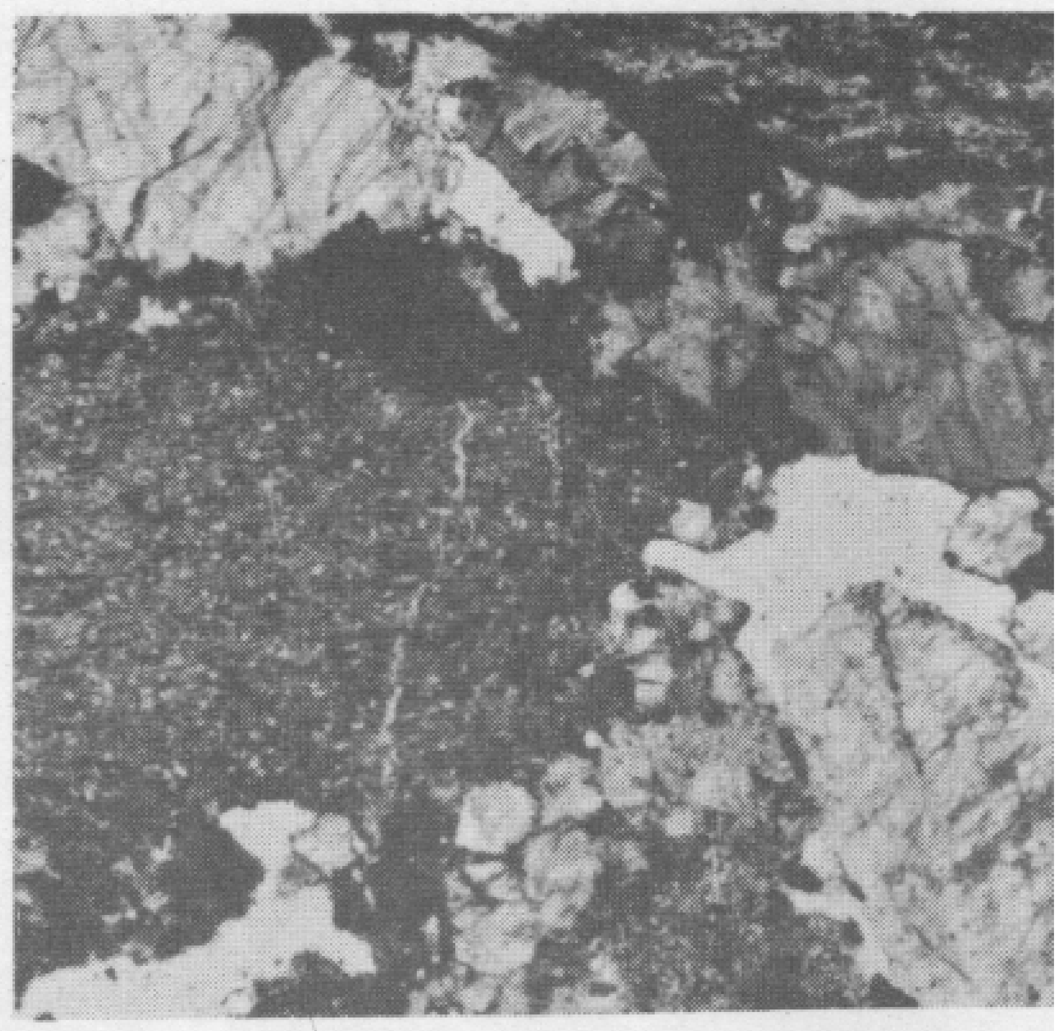
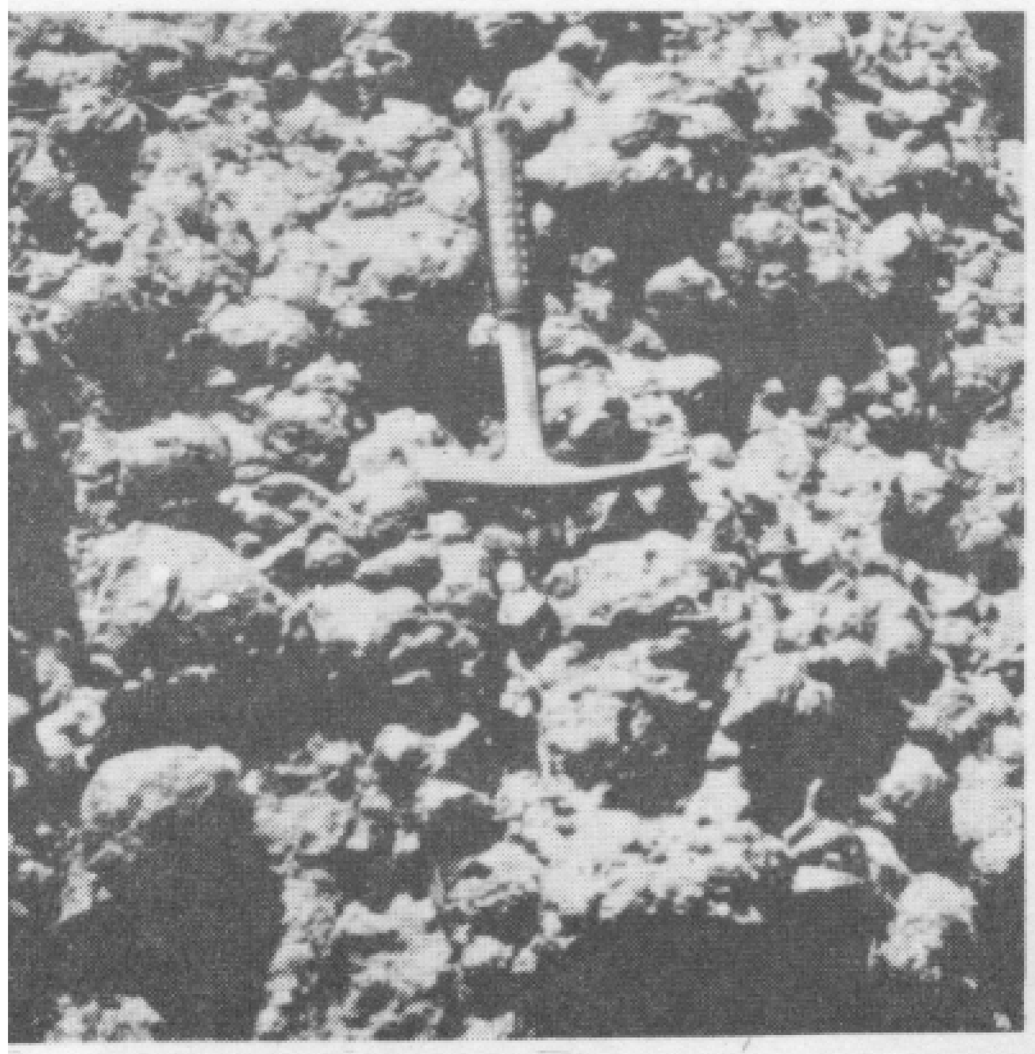


Fig. 1.—Columnar jointing in rhyolites along the El Ocotito-Ixcuinatoyac road.

Fig.. 2.—Photomicrograph without crossed Nicols (X 25). Subgreywacke; aggregate of fragments of quartz, feldspar, siltstones, phyillites. Chapolapa Formation.



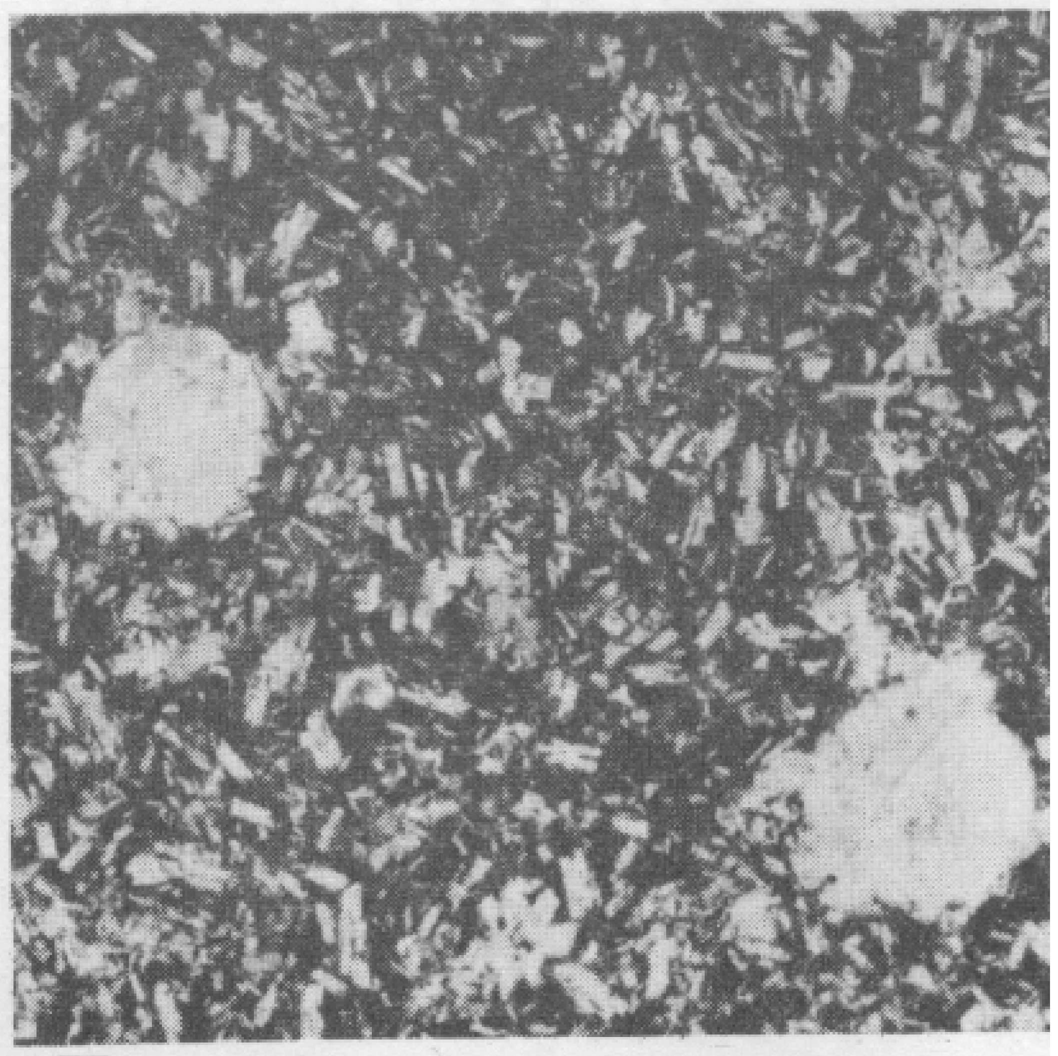


Fig. 3.—Geode-like structures of volcanic origin (quartz - latite), filled with quartz and calcite; locality at "El Pozo" near El Ocotito-La Esperanza road. Agua de Obispo Formation.

Fig. 4.—Photomicrograph without crossed Nicols (X 10). Latite: pilotaxitic textured groundmass of feldspars; vesicles filled with calcite and quartz. Agua de Obispo Formation.

DETAILS OF CHAPOLAPA AND AGUA DE OBISPO FORMATIONS

TABLE 1. Chemical Analyses of roces from the El Ocotito-Ixcuinatoyac region
All analyses performed by Ing. Quim. Alberto Obregón

Sample	21	32	N-51	N. 104	122
SiO_2	75.17%	72.03%	28.37%	71.19%	40.06%
TiO_2	0.06	0.10	0.00	0.10	1.85
Al_2O_3	13.95	15.25	0.69	15.00	13.30
Fe_2O_3	0.03	1.04	44.75	2.38	6.09
FeO	1.79	1.79	4.39	0.46	6.04
MnO	0.03	0.03	0.10	0.01	0.10
MgO	0.50	0.25	11.20	0.97	9.18
CaO	1.40	2.24	0.00	0.00	4.94
Na_2O	3.42	4.00	0.03	0.13	1.63
E_2O	3.45	2.52	0.15	5.70	1.85
P_2O_5	0.08	0.09	0.00	0.00	0.57
SO_3	0.00	0.00	0.00	0.00	0.00
CO_2	0.00	0.00	0.00	0.00	2.27
H_2O-	0.25	0.69	9.98	3.31	4.11
H_2O+	0.01	0.04	0.20	0.06	0.21
TOTAL	100.14%	100.07%	99.86%	100.11%	100.14%
Clasificación:	Granite	Granite	Talc schist	Rhyelite	Poeneite
Stratigraphical único:	Coacoyulillo granite stock	Coacoyulillo granite stock	Ixcuinatoyac Formation	Chapolapa Formation	Morelos Formation
Location:	Barranca de Alcaparrosa	Barranca de Lima	Alcaparrosa River near the Barranca de Alcaparrosa	Crest of mountain northwest of Ixcuinatoyac.	Upper Papagayo valley, left bank of the Papagayo River opposite "Huertas"

TABLE 1.—Chemical Analyses of roces from the El Ocotito-Ixcuinatoyac region
All analyses performed by Ing. Quim. Alberto Obregón

Sample	155	182	185	190	235
SiO_2	59.09%	73.19%	70.79%	59.67%	75.24%
TiO_2	1.22	0.15	0.25	0.84	0.76
Al_2O_3	11.47	15.04	15.58	16.98	12.03
Fe_2O_3	6.10	0.28	1.65	3.05	2.05
FeO	3.74	1.30	0.35	3.60	3.09
MnO	0.12	0.02	0.00	0.06	0.01
MgO	2.70	0.08	0.51	1.91	1.19
CaO	5.39	0.00	1.54	3.53	0.13
Na_2O	5.92	3.88	3.67	4.34	0.61
E_2O	0.47	3.73	4.78	2.48	2.00
P_2O_5	0.17	0.02	0.02	0.20	0.13
SO_3	0.00	0.00	0.00	0.00	0.00
CO_2	1.78	2.03	0.00	2.11	0.00
H_2O-	1.77	0.07	0.90	1.00	2.74
H_2O+	0.10	0.11	0.22	0.34	0.15
TOTAL	100.04%	99.90%	100.26%	100.11%	100.13%
Clasificación:	Epidote greenschist	Quartz latite	Rhyolite	Rhyoducite	Subgreywacke
Stratigraphical únit:	Chapolapa Formation	Chapolapa Formation	Chapolapa Formation	Chapolapa Formation	Chapolapa Formation
Location:	Alcaparrosa River. 1.500 m above sea level; 4 km northeast of Rincón de Alcaparrosa	El Ocotito-Ixcuinatoyac road at crossing Caracol River (Paraje Palo Morado).	Mountain west of El Ocotito-La Esperanza road; 5 km north northeast of Tlahuizapa.	1 km east of La Esperanza, at road.	Barranca del Limón

TABLE 1.—Chemical Analyses of roces from the El Ocotito-Ixcuinatoyac region
All analyses performed by Ing. Quim. Alberto Obregón

Sample	328	336	373	377	404
SiO_2	56.86%	49.84%	70.68%	56.46%	71.94%
TiO_2	1.21	1.87	0.15	1.17	0.27
Al_2O_3	18.08	16.05	15.70	16.46	16.06
Fe_2O_3	2.41	2.76	2.56	5.27	1.66
FeO	4.68	7.05	0.00	2.08	0.50
MnO	0.07	0.10	0.01	0.07	0.02
MgO	2.15	5.38	1.07	1.31	0.12
CaO	6.03	8.54	0.32	6.36	0.96
Na_2O	4.96	3.68	2.20	4.23	3.28
E_2O	1.15	1.42	4.24	3.53	3.93
P_2O_5	0.23	0.41	0.40	0.54	0.06
SO_3	0.00	0.00	0.00	0.00	0.00
CO_2	0.57	0.00	0.00	1.95	0.00
H_2O-	1.73	2.65	2.36	0.56	1.33
H_2O+	0.13	0.14	0.54	0.27	0.14
TOTAL	100.26%	100.09%	100.23%	100.25%	100.27%
Clasificación:	Diorite	Gabbro-diorite	Quartz latite	Latite	Quartz latite
Stratigraphical unit:	small intrusive	small intrusive	Agua de Obispo Formation	Agua de Obispo Formation	Chapolapa Formation
Location:	0.5 km west of El Ocotito - Ixcuinatoyac road crossing Potrero River, some 50 m below road in the creak bed.	somewhat less than 1 km east northeast of El Ocotito - Ixcuinatoyac road crossing Potrero River	"El Pozo" Caracol River, somewhat less than 1 km beyond the El Ocotito - La Esperanza road where it enters the mountain area from El Ocotito.	1 km before the El Ocotito - La Esperanza road leaves the Tertiary volcanic terrain toward the north.	5 km southeast of La Esperanza; on the road El Ocotito - La Esperanza.

of these rocks belonging to the same rock suite. The samples for analyses were collected from points equally distributed over the entire area. It is interesting to note the different appearance that chemically similar rocks may have, such as sample 132 (El Ocotito-Ixcuinatoyac road at Caracol River crossing; Plate 1) and Sample 404 (near La Esperanza; Plate 1) that is often just due to weathering; Sample 132 represents fresh rock collected from the valley bottom, whereas Sample 404 is from the least altered part of a large kaolinite area high in the mountains. The fact that there are samples with different degrees of acidity allows the construction of approximate variation diagrams in the sense of Peacock, as is shown by Barth (1951/62, p. 171-2). The alkali-lime index corresponds roughly to an SiO_2 value of 66%. This means that the volcanics of the Chapolapa Formation belong to a rock suite that falls in the alcali-calcic and calc-alcalic border area, which terms, in the former usage, correspond to the "Atlantic" and "Pacific" suites of Becke, Harker and Niggli.

Few meters below the Morelos carbonates an extrusive rock was found, that, because of its volcanic nature and green colour, was considered in the field to belong to the Chapolapa Formation. This extrusive rock is exposed in the upper Papagayo valley, on the left bank of the Papagayo River opposite "Huertas" (Plate 10). No contact with the surrounding rocks could be observed. This type of rock has not been seen in any other place. The chemical analysis (Table 1, Sample 122) showed that it did not fit into the rather sharply outlined picture given by all the other Chapolapa volcanics; it is basic in composition and belongs to a special rock suite marked by a high content in alkalies.

The application of the values of the chemical analysis, according to Rittmann's method (1959), gave an "olivine trachybasalt"; however, no olivine is visible either macro —or microscopically. The microscope shows just one outline of what may have formerly been an olivine phenocryst. The hollow is filled with secondary, finely granulated quartz and some secondary sparry calcite. It seems that the olivine originally present has been decomposed and its constituents entered into the abundantly present secondary minerals. Further attention is called by the high content of potash, which in average basalts is only around 0.5%. The rock is regarded as a potash spilite ("poeneite"). The now missing, originally present olivine is a characteristic for spilites. Slavik (1908, p. 130) in his extensive microscopic investigation of spilites found that "the olivine is never preserved, only the outlines of pseudomorphs in few rocks suggest its original presence". Under the microscope a felty-textured-feldspar groundmass with medium — size augite phenocrysts is observed. There are numerous vesicles, filled in quite irregular varying proportions with secondary quartz, chlorite and calcite. Quartz and chlorite crystallized contemporaneously, and calcite later. The variety of chlorite present is very pale green and is mostly fine grained. Under crossed Nicols, it seems almost opaque because of the very small birefringence. Remarkably, the augite phenocrysts are concentrated around the borders of the vesicles. This observation was also made by Slavik (1908, p. 82) in many spilites.

The potash spilites are much less frequent than the soda spilites, but they are formed in a similar geosynclinal environment. Apparently, an "adularization" of the plagioclase took place in the originally basaltic lavas, instead of an "albitization". Potash spilites are known from the Parmian of Timor (De Roever, 1942(p. 209-289), where they mark the early igneous activity in the first stages of geosynclinal evolution. This is in accordance with the basal position of the potash aplites of the studied area with respect to the geosynclinal deposits that accumulated during the Jurassic and Cretaceous.

Among the sediments the quartz conglomerates are the most conspicuous; they reach thicknesses of up to 100 m. In the barrancas of the northeastern part of the upper Papagayo valley, such as the Barranca del Limón, or the upper part of the Barranca Hedionda, the conglomerates quickly thin out to the south-southeast within some hundred meters of distance to a thickness of about 5 m. Farther south, a conglomerate appears in the Barranca de Las Huertas, at an elevation of 900-1000 m above sea level. About 500 m along the strike to the northeast of this point, in the Barranca de Carrizal, only 10 m of this same unit are present. Cross-bedding is common. Part of the conglomerates, and of the also frequently occurring breccias, is polymict (pebbles of quartz quartzite, phyllite, etc.). Another part consists mainly of predominantly subangular vein—quartz pebbles, derived probably from metamorphic areas. The fact that the conglomerates are not especially mature, is shown also by the very frequent association with polymict fine conglomerates, breccias and subgreywackes. The coexistence of semimature conglomerates and the, by definition, very immature subgreywackes is known to be possible.

> "A gravel achieves maturity much more rapidly than does a sand under the same conditions. The gravels become founded and compositionally mature as a result of short transport. Hence even mature *gravels may be associated wiht immature sands. The Mississippian* Pocono, for example, contains quartzitic conglomerates and subgreywackes" (Pettijohn, 1948/56, p. 253)."

Sorting is poor. All these characteristics, but especially the wedge shape of the conglomerate bodies, suggests a fanglomerate nature. The conglomerate composed of flat carbonate pebbles, deserves special mention because of the scarcity of carbonates prior to the Morelos Formation in the area. The pebbles are seldom in contact with each other and are oriented in the plane of foliation of the rock. The groundmass consists, to a large extent, of micas and of angular quartz grains and feldspars which, in part, attain considerable sizes; fragments of micritic calcite are also present. The groundmass throughout is deep violet in colour. The locality of the limestone conglomerate is in the lower part of the Barranca de la Peña Colorada, at an elevation of 650 m above sea level.

In the north-northeast of the area studied, the top of the Chapolapa Formation is exposed under the overlying Morelos Formation. The unconformable contact between these two units is partly made up of a predominantly violet coloured breccia composed of fragments of quartz. This breccia reaches a thickness up to 50 m, but is completely missing in many places along the contact. This would suggest that the breccia occurred irregularly over the entire area before the limestone was deposited.

A very frequent type of rock, and commonly rather intimately associated with the conglomerates and breccias, is the subgreywacke. These rocks are often interbedded. The chemical analysis of Sample 235 (Table 1) shows the typical values of this type of rock. Under the microscope, it consists of an aggregate of very poorly sorted fragments of quartz, feldspar, siltstones and phyllites. A groundmass does not exist (Plate 7, figure 2).

South of Rincón de Alcaparrosa, on the east bank of the Alcaparrosa River is encountered, over one kilometer length, a feldspathic quartzite. Minor occurrences are found throughout the formation. It is very massive, hard and tan-coloured. The angular grains are very poorly sorted. Chlorite and sericite are fairly abundant.

In places the terrigenous subgreywacke grades into a greywacke, considered to be a subaqueous product. This greywacke, which is a green hard rock, does not reveal any features to the naked eye. The microscope shows a groundmass made up of micas, chlorite and quartz; it contains highly angular grains of quartz, feldspars, some heavy minerals, especially zircon and some fragments of aggregates of mica and chlorite; also some euhedral biotite. Occasionally graded bedding can be observed. In the Barranca del Zapote, at 600 m above sea level, easily accessible, is an especially fine example of a sequence showing many-times-repeated graded bedding.

Included with the subaqueous sediments is an interval of phyllites which are always accompanied by a few beds of quartzites. These quartzites are completely different from those of the Ixcuinatoyac Formation; they are dark grey to black and occur in beds of 20 cm average thickness. Between these beds occur predominantly thin layers of variably sandy black phyllites. Occasionally, blocks of rock have slipped into the sandy phyllite sequence, such that it reminds of a *Wildflysch.* These can be seen especially in the Barranca del Guarumbo (Plate 1), at an elevation of about 800 m above sea level, where a block of conglomerate, at least 10 m in diameter, has slumped into black shales.

One might think of a pre-Cretaceous orogeny affecting the Chapolapa Formation considering its greenschist facies, and that the Morelos Formation, immediately above the Chapolapa Formation does not show any sign of metamorphism; thin sections do not show the slightest recrystallization of the micritic limestones. However, the mineral assemblage of the greenschist facies has not neccesarily to be caused by metamorphism. Deuteric alterations in this case cannot be made solely responsible, since epidote is abundant in many Chapolapa rocks. Hydrothermal alteration can be considered as a satisfactory explanation. It is true that the thin section of a sample of the Chapolapa rock produced some doubt about this problem. In this probably originally trachytic rock with frequent feldspar phenocrysts set in a fine —grained groundmass, in addition to the usual greenschist minerals there occur two minerals of the epidote family, epidote and clinozoisite. This could suggest two causing events, (*e. g.* hydrothermalism and metamorphism). However, the differences in the minerals, whose alteration products they represent, can also account for them; only the clinozoisite is seen to come forth from feldspars. Also the unconformity with the overlying Morelos Formation could suggest a pre-Morelos deformation. However, the unconformity is not conclusive in this respect. The relief on the Chapolapa Formation was from the beginning irregular. As the formation to a great extent is continental, its rocks were subjected to erosion from the moment of their formation. Further, part of the rock types of the Chapolapa Formation had a primary inclination (vulcanites, fanglomerates).

It can hardly be thought of an orogeny that would have affected the largely

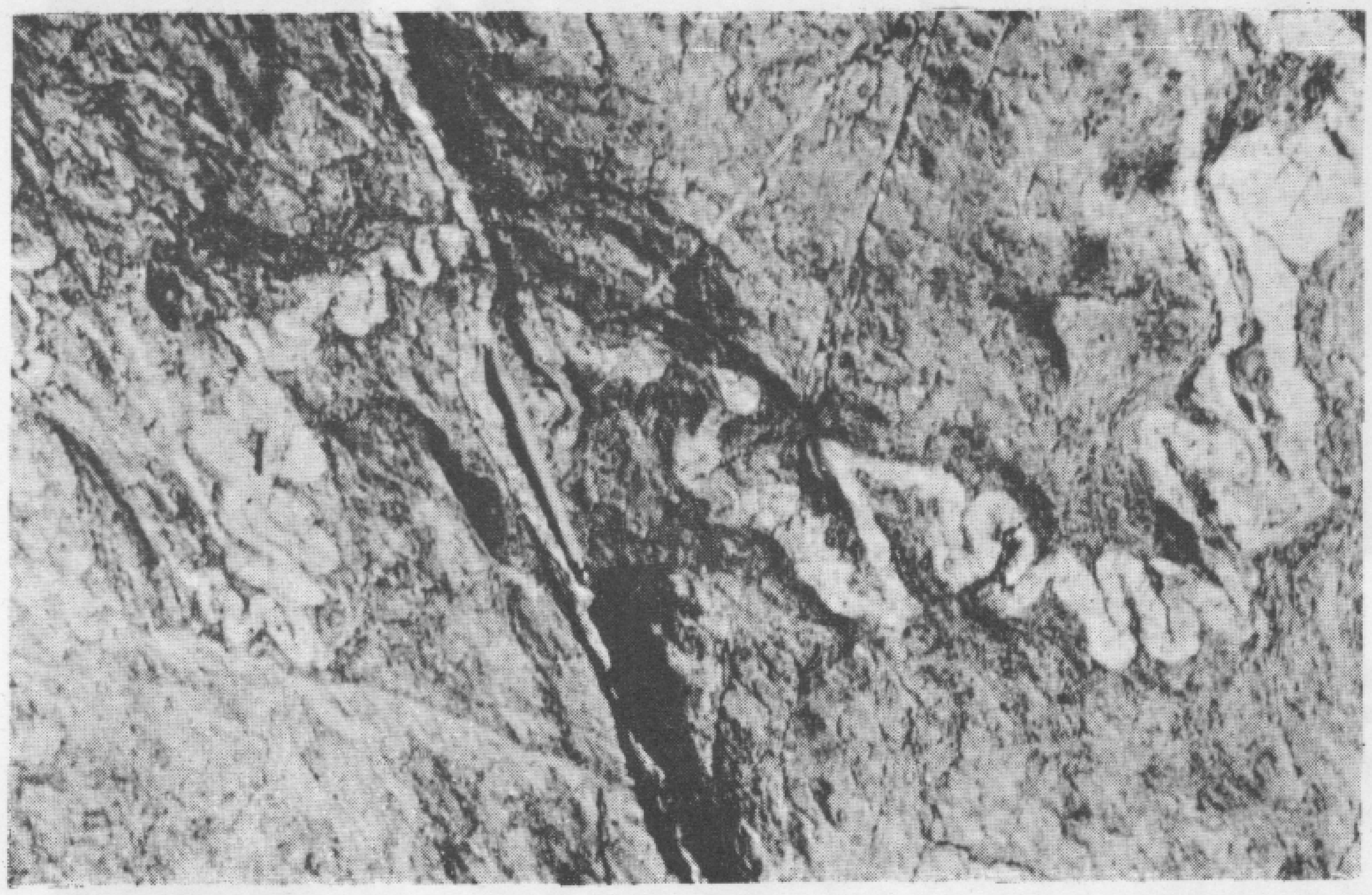


Fig. 1.—Ptygmatic folds of quartzo-feldspathic veinlet in aplitic rock.

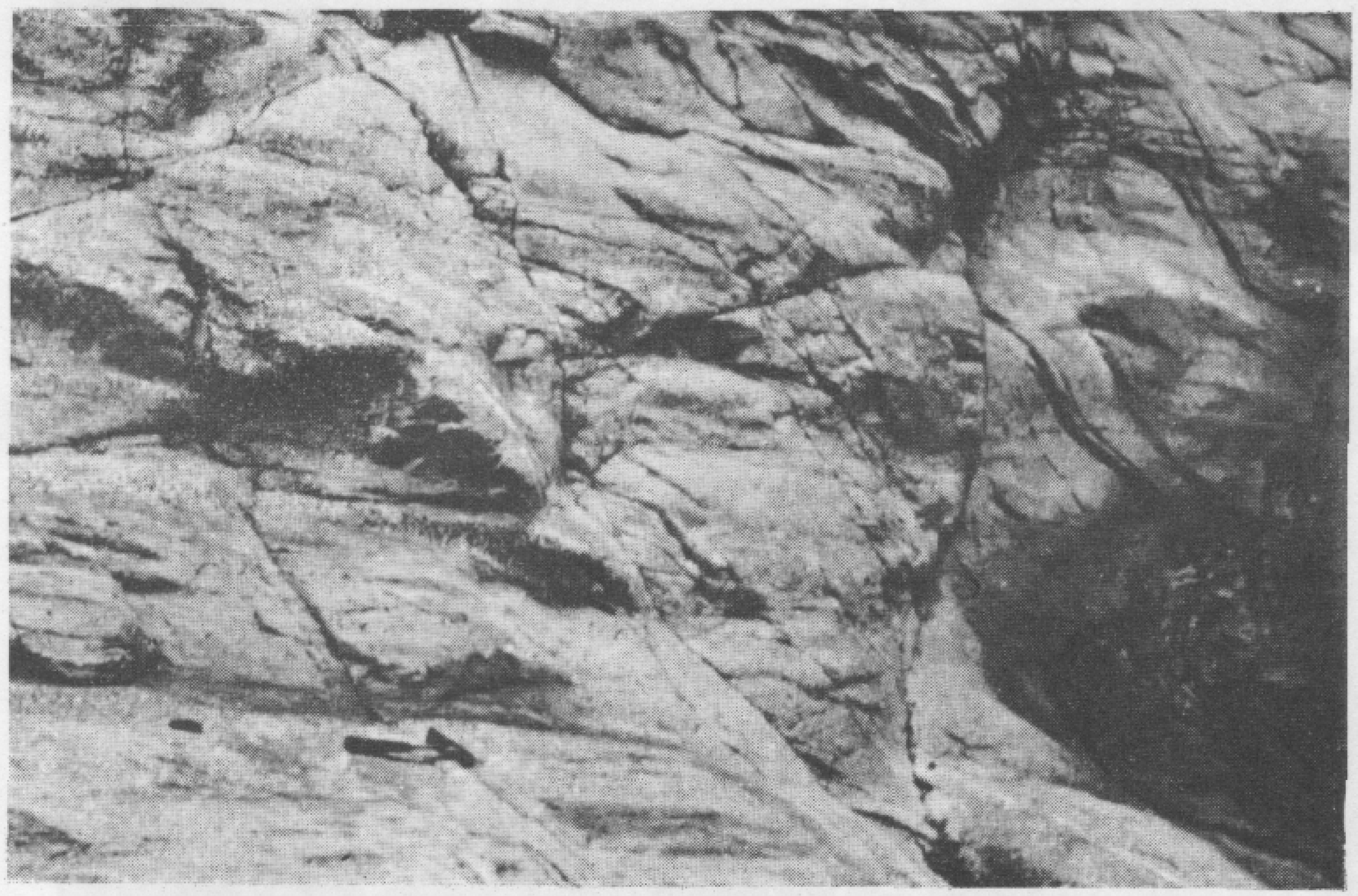


Fig. 2.—In part "digested" phyllites (somewhat darker shaded rock), which form roof pendants in a small granite intrusive.

STRUCTURAL DETAILS OF INTRUSIVES

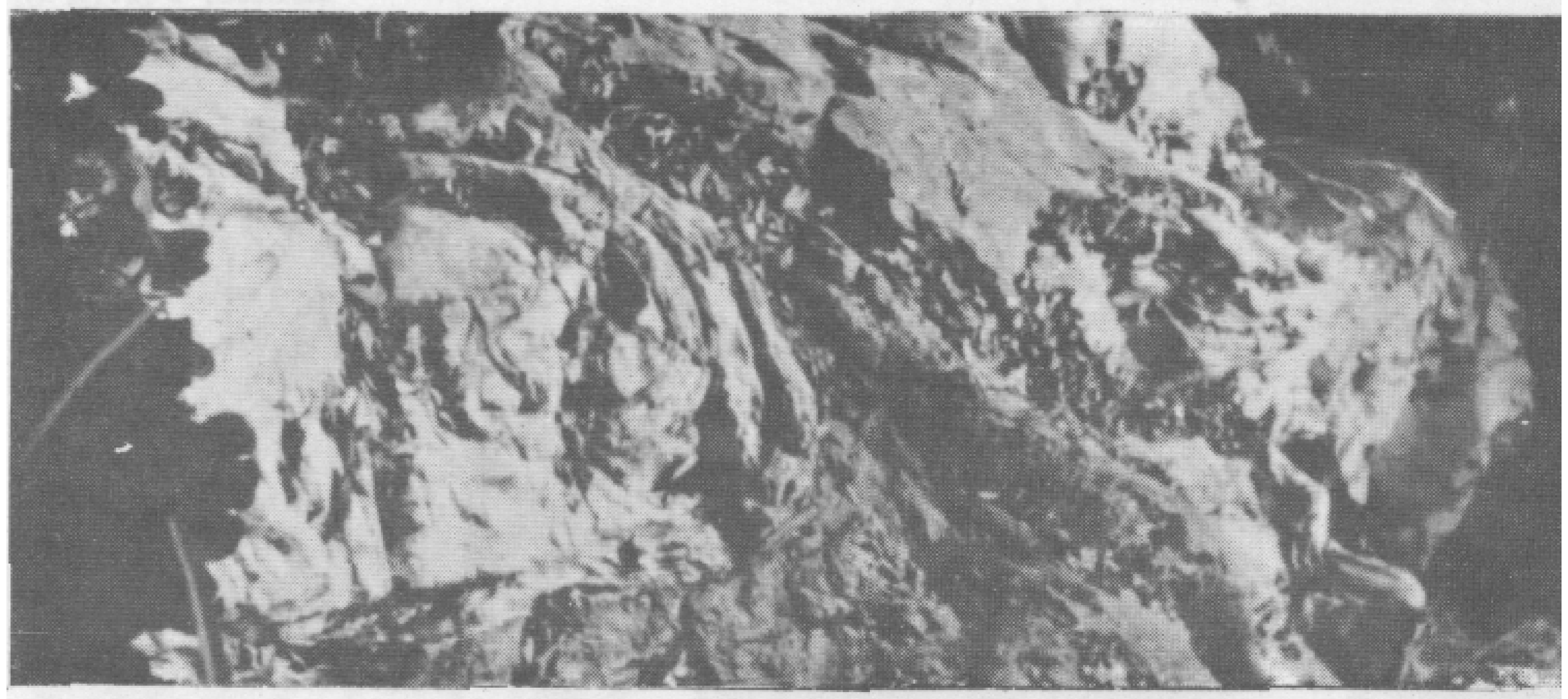


Fig. 1.—Isoclinal fold in quartzites of Ixcuinatoyac Formation.

Fig. 2.—Zig-zag folds in quartzites of Ixcuinatoyac Formation.

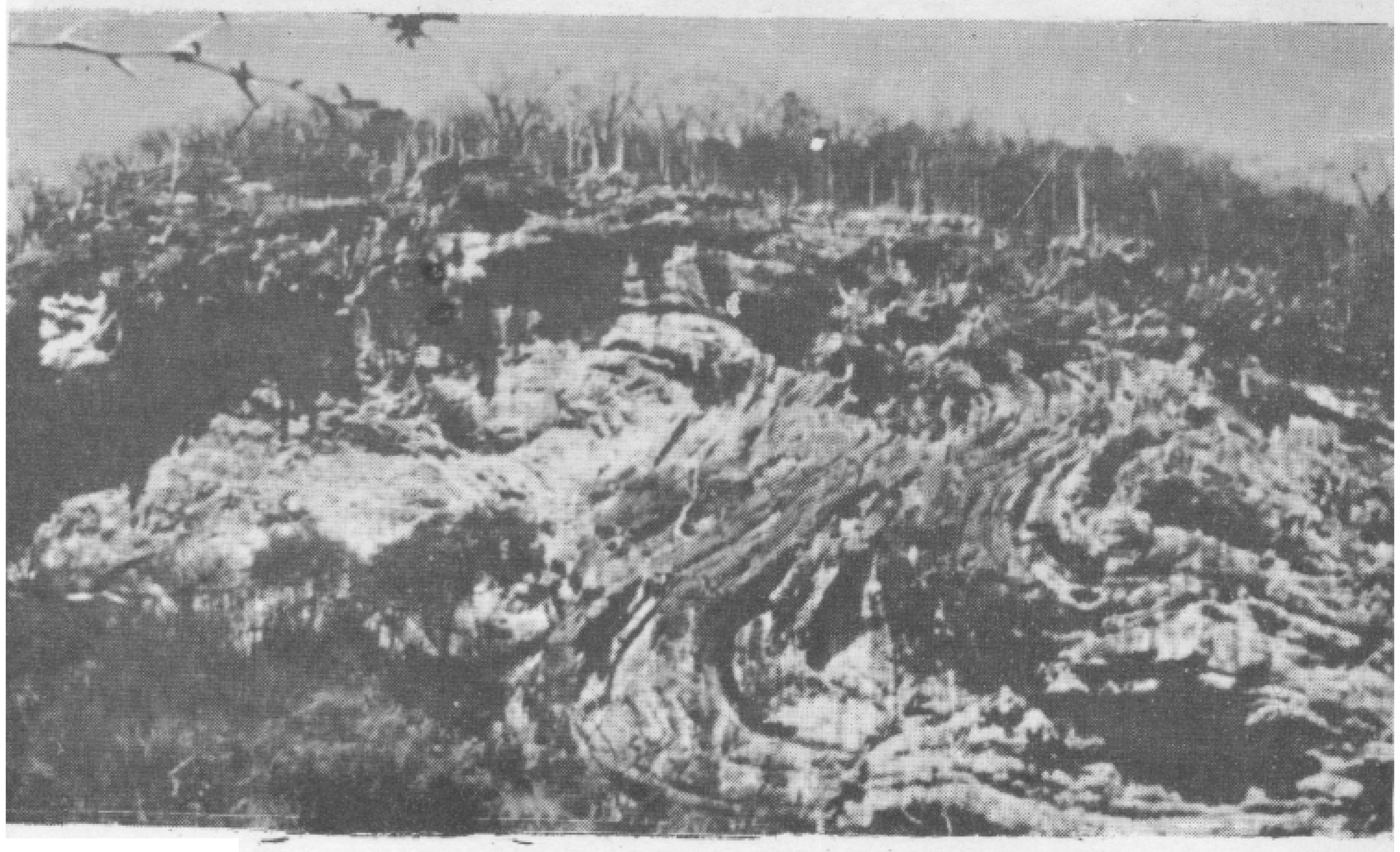


Fig. 3.—Overturned fold in Morelos Formation.

TYPES OF FOLDS

continental deposits in pre-Morelos times. Therefore, the granite emplacing events preceding the Hidalgoan Orogeny, and the orogeny itself, are thought to have caused the development of the greenschist facies and the folding and foliation of the Chapolapa Formation. These two events probably caused also a second period of folding and the development of incipient foliation in the underlying Ixcuinatoyac Formation.

Inferences as to the age of the Chapolapa Formation can be made by comparison with similar rocks of other parts of Mexico. Comparable green volcanic rocks have been found in the central, western and southwestern parts of Mexico. These are interstratified with marine sediments of Carnian age (Burckhardt and Scalia, 1906); furthermore they were identified below Upper Jurassic beds (Pantoja, 1959). The violet-coloured quartz breccia, which shows up in the northeast of the area studied, below the limestone contact, is comparable to similar rocks reported by Salas (1949, p. 85-92) in the northwest of Oaxaca and by Guzmán (1950, p. 108-116) in the northeast of Guerrero; at this latter locality they are definitely older then Middle Jurassic. Thus, de Cserna (1965, p. 22), with a certain elasticity, assigned to the Chapolapa Formation a Late Triassic — Early Jurassic age.

All thin sections corroborate the Chapolapa Formation belonging to the greenschist facies.

CRETACEOUS.—*Morelos Formation.*—This formation consisting of limestones and dolomites is well known all over south-central Mexico (Fries, 1960, p. 44). Thus, the description of these carbonates will be brief. The formation was deposited in Albian-Cenomanian times. In the area studied it crops out mainly in the north-northeast and in the east. In the northeast in forms the high mountain tops of the Cerro del Burro, with impressive escarpments facing towards the area studied, while in the other direction it warps gently downwards. The thickness of the formation is 500 m in the east and southeast and over 1,000 m in the north and northeast. In the west it occurs on both sides of the Papagayo valley as a less conspicuous, relatively thin cover, locally forming the top of down-faulted blocks.

The Morelos Formation in the area consists mainly of limestones of light to dark grey colours and occurs in generally thick beds. It is a micrite (calcilutite) with an average grain size of 0.001-0.002 mm. The thin section often shows a diffuse dark banding. Some badly preserved oysters and debris of pelecypods were found. Exceptionally, some chert nodules are present. Horizons of dolomite and dolomitic limestone are dispersed irregularly throughout the formation and seem to change laterally over short distances. The dolomite presents itself in thick beds and generally has a sugary texture and a dark grey weathered surface.

For paleontological reasons and based on regional correlation, de Cserna (1965, p. 25) ascribed to this unit, in the region between Chilpancingo and Acapulco, a medial Albian — early Cenomanian age.

TERTIARY.—The Tertiary rocks in the area studied are volcanics that overlie discordantly all older formations. They consist of two units, which were not mapped separately; de Cserna (1965) named these units as the Agua de Obispo and Alquitrán Formations. They are exposed in the east and in the southeast of the area, forming highlands with steep escarpments. There are many excellent and easily accesible outcrops of the volcanics along the El Ocotito-La Esperanza road, between the El Ocotito valley and where the road enters the Chapolapa Formation, near the bridge over the Soyatepec River (Plate 1). A very good outcrop of the acidic part of the volcanic rocks can be observed at "El Pozo", slightly less than one kilometer beyond the point where the El Ocotito-La Esperanza road enters the mountain area from the El Ocotito valley. There, the Caracol River forms a cascade, below which there is a large natural pool, showing lava flows and welded tuffs of varying thicknesses; these in places show flow-layering and the presence of numerous, up to 20 cm in diameter, macrospherules (geode-like structures of volcanic origin), now filled with quartz and calcite (Plate 7, figure 3). An easily accesible outcrop of the latites is on the side of the road about one kilometer before the El Ocotito-La Esperanza road leaves the Tertiary volcanic terrain towards the north. Both previously mentioned exposures belong to the Agua de Obispo Formation, whereas the Alquitrán Formation, which overlies the Agua de Obispo Formation, has no readily accesible outcrops.

Agua de Obispo Formation.—This formation in the area has a thickness of about 800 m and consists in part of lava flows of quartz-latitic composition in the lower part and latitic composition in the thicker, upper part (Table 1, Samples 373 and 377), Further a fair amount of epiclastics, mainly conglomerates, is interstratified.

The rock kindred of this formation, which represents the subsequent volcanism following the early Eocene Hidalgoan Orogeny (de Cserna, 1960), is again intermediate between alcali-calcic and calc-alcali, as in the subsequent volcanics of the Chapolapa Formation.

The quartz latites are red coloured, the latites dark grey, in places black. Under the microscope the latite shows pilotaxitic texture. The feldspars are in part potash feldspar, in part andesine; there are further some diopside needles and rather abundant hypersthene. The hypersthene is altered to a very great extent to antigorite. Other secondary minerals are calcite and quartz, mainly occurring in vesicles. Calcite has crystallized first because, where occurring together with quartz, it forms an exterior layer in the vesicles, quartz occupying the center. In other vesicles quartz fills one half, calcite the other half: in this case calcite first precipitated at the bottom part of the vesicle thus indicating the normal position of the unit (Plate 7, figure 4).

In the formation are also included tuffs of the same composition as the lava flows.

Occasionally obsidian-like densely welded glassy fragments were found, that had fallen down from the escarpments . Quite frequently volcanic conglomerates are also found, with pebbles of considerable size.

De Cserna (1965, p. 30) assigned to the formation a late Oligocene and possibly early Miocene age, on the basis of its stratigraphic position.

Alquitrán Formation.—This formation is of approximately the same thickness as the Agua de Obispo Formation (about 800 m) and overlies it discordantly. The upper step of the conspicuous Cabeza del Toro Peak, is formed by rocks of this formation. It consists of pyroclastic flows, of varying degrees of welding. The rock is light-grey coloured and contains phenocrysts of quartz, feldspar, biotite and hornblende, together with lithic fragments. Its composition is that of a rhyodacite. There are only a few tuff horizons, which are soldified to a small degree. The formation as a whole is more resistant to weathering than the underlying Agua de Obispo Formation with its great amount of epiclastics. Thus the lower formation is sheltered by the upper one, which relation produces the stepped topography.

De Cserna (1965, p. 31-2) considered the Alquitrán Formation to be of Miocene age.

QUATERNARY.—There are only very few alluvial deposits, as the area is presently in the stage of very active erosion. The alluvium of the El Ocotito valley may be mentioned here, accumulated probably due to structural reasons. The deposits in the Soyatepec valley owe their existence probably to a fault, which dammed up the valley south of Soyatepec. Similar conditions may have caused the accumulation of the alluvial deposits northwest of Rincón de Alcaparrosa which cover a rather small area. This alluvium, covered by garden cultures, is about 40 m thick and is exposed on its east and west sides by the rivers which cut their way through the deposits forming, in part, vertical walls. These alluvial deposits are somewhat spectacular for the huge boulders they contain. Further upstream along the Alcaparrosa River, occasionally limestone blocks up to 70 m in diameter are found, which probably are remants of mountain slides that originated on the high escarptment of the Cerro del Burro highland in the east.

INTRUSIVES

There exist two generations of intrusives in the area; an older granitic and a younger gabbroic and dioritic one.

GRANITE.—The main granite intrusive of the area is the Coacoyulillo Stock. It covers an area of about 50 km^2. Including some minor apophyses around it, this intrusive lies roughly in the center of the area. It is elongated in form and stretches from the El Ocotito — Ixcuinatoyac road northward almost to Rincón de Alcaparrosa. The contact in the northeast is formed by the Chapolapa Formation, whereas in the southeast by the Xolapa Complex; the entire western border is in contact with the Ixcuinatoyac Formation. All three units have been intruded by the granite.

Two chemical analyses of the granite are illustrated in Table 1 (Samples 21 and 32). Under the microscope the granite shows a hypidiomorphic to allotriomorphic granular texture. It contains mainly quartz, orthoclase, oligoclase and only a small percentage of biotite, which, especially in the border phases of the granite stock, is arranged parallel to the contacts.

The effects of thermal metamorphism were investigated in the Ixcuinatoyac Formation. In this formation, in the vicinity of the granite contact a staurolite-almandine hornfels was found. Almandine occurs frequently all along the granite contact, whereas staurolite forms only when very special chemical conditions exist (abundance of iron and aluminium, deficiency of magnesium calcium and of alcalies; Winkler, 1967, p. 64). Furthermore numerous pseudomorphs of biotite after hornblende were found in the proximity of the granite.

Thus, the contact metamorphism in the Ixcuinatoyac Formation has reached the degree of the amphibolite hornfels facies; the pyroxene hornfels facies was nowhere reached. A foliation is present, which, as has been pointed out in discussing the Ixcuinatoyac Formation, must be due to a previous orogeny.

A pressure between 500 and 2,000 bar is the normal range in terms of contact metamorphism and these values can be regarded as extremes. The amphibolite hornfels facies forms under these pressure values with the corresponding temperature values between 500 to 650°C (Winkler, 1967, p. 69-72). This agrees with the presence of the δ-chalcopyrite in the La Dicha sulfide bed, which lies near the granite contact. Normal chalcopyrite can be transformed into the magnetic δ-chalcopyrite when it is heated over 550°C. Thus, within the immedite vicinity of the granite, the amphibolite-hornfels facies was attained in the temperature range of 550-650°C.

To a rather subordinated degree, the intruding granite made way for itself by assimilation of the surrounding rock; this is shown by the fact that the granite has different shades of colour adjacent to the different rock types it has intruded. In the Barranca Alcaparrosa, where the granite intruded quartzites, it is light grey to white coloured; in the Barranca de Lima, where it intruded phyllites, a darker greenish-grey tint is obvious. The effect of the granite intrusion on the intruded rock is discussed in the chapter on structure. It shall be noted here, however, that the retrograde metamorphism, observed both in the biotite schists of the Xolapa Complex and in the Ixcuinatoyac Formation, is thought to be due to the intrusion of the granite.

The occurrence of aplites is rather widesrpread, forming irregular, often quite large masses in the granite body itself or dikes that swarm through the granite body and its surroundings. Occasionally ptygmatic folding can be observed (Plate 8, figure 1). In instances, as in the Caida del Potrero area, located at the crossing of the Potrero River (Plate 1), the aplitic masses are so abundantly mixed with the surrounding rock that to make a clear cut delineation of the intrusive body is practically impossible.

Diorite and gabbro.—Several small dioritic and gabbroic intrusives were found; however, these are not shown on the geological map, as its scale is too small; also their locating on the aerial photographs was extremely difficult. A typical, easily accessible locality of the diorite (Table 1, Sample 328) is some 500 m west of Caida del Potrero, where quite fresh outrops are present in the creek bed, some 50 m below the El Ocotito-Ixcuinatoyac road. Regarding the gabbroic rocks, this same road crosses an area of exfoliation boulders of gabbro-diorite (Table 1, Sample 336) at less than one kilometer east-northeast of Caida del Potrero.

The thin section of the same gabbro-diorite shows a hypautomorphic granular texture; there are a few orthoclase grains which are very rich in sodium; the bulk of the feldspars are plagioclases ranging in composition from andesine to labradorite. Some of the plagioclases are zoned; in their center epidote is present as a product of epidotization of the early formed calcium rich plagioclase. The augites are altered to a great extent to uralite; further secondary minerals are antigorite, chlorite and epidote; apatite is a very common accessory mineral; iron oxides and ilmenite occur as opaque minerals.

A few hundred meters downstream from the place where the El Ocotito-Ixcuinatoyac road crosses the Tamarindo Creek, there is a small intrusive stock (20-30 m in diameter) of gabbro, which is unusually rich in interstitial, disseminated pyrite. Numerous dikes radiate from this body; these dikes cut the surrounding biotite schists of the Xolapa Complex and the aplitic-granite dikes, which are probably related to the major granite intrusive (Plate 3, figures 1, 2). All the basic intrusives are probably related to the diabase dikes, which are widespread throughout the area. These cut the quartzites of the Ixcuinatoyac Formation as well as the granite. Although the diabase dikes are relatively resistant to erosion, they are frequently encountered along creek beds. This is likely, because the dikes have been introduced into zones of structural weakness. De Cserna (1965) considered nearly all these generally small, basic intrusive bodies of medial Tertiary age, as they intrude middle Tertiary and older formations and are covered by upper Tertiary rocks.

STRUCTURE

THE EMPLACEMENT OF THE GRANITE AND ITS EFFECTS ON THE STRUCTURE OF THE AREA; FOLIATION AND FOLDING.—The structure of the area is primarily controlled by the large, central Coacoyulillo Stock of granite. Its form is elongate, roughly in a N-S direction, which suggests a connection with the strike of the fold axes in the Morelos Formation, which is NNW-SSE. The granite intrusion caused an uparching of the overlying formations, including the Morelos Formation. The Morelos Formation frames the area, part of it lying outside of the map area. In the north, and in the northeast, the base of the Morelos Formation lies at an elevation of 1,800 m above sea level, and in the east and in the southeast, its base lies at 600 m above sea level. Similar relations are observed in the west, in the upper Papagayo valley, where the base of the limestone is at an elevation of about 600 m above sea level. Thus, the base of the limestone slopes gently downward away from the granite. The underlying Chapolapa Formation encircles the intrusive completely. In the stratigraphically deepest part of the area, the Ixcuinatoyac Formation and the Xolapa Complex are present, and were most affected by the intrusion. These rocks were partially dragged up from the depth, contorted and a second set of incipient foliation was imposed upon them, aligned roughly in a concentric fashion around the circular contact. In the Chapolapa Formation, the strike of the foliation and of the fold axes also coincides well with that of the underlying stratigraphic units, as long as the distance from the granite contact is not too great. The concordant relation of the granite to the intruded rocks suggests, that it made its way up by lifting and shouldering aside the rock in its way, rather than by assimilation (Cloos, 1963, p. 79). An exception is a small granite stock that outcrops in the bed of the Alcaparrosa River, west of Rincón de Alcaparrosa, which shows a striking example of assimilation; this stock has "digested" to a great extent the intruded phyllites, which form roof pendants (Plate 8, figure 2). These are still seen in the granite with measurable attitudes, which are the same as those of the surrounding phyllites that were unaffected by the intrusion. A fine example of uparched roof rock can be seen near the granite contact in the Barranca Alcaparrosa, where quartzites have been domed up. An intrusive body with concordant contacts reveals that it has been emplaced during crustal deformation (Longwell, 1939, p. 256). Thus, the granite stock of the area, the writer considers to be a "syntectonic granite". This explains also the gneissic aspect of the granite, seen throughout the entire granite area (Cloos. 1963, p. 73), brought about by the parallel arrangement of its components, chiefly the biotite flakes.

The retrograde metamorphism observed in the Ixcuinatoyac Formation and in the Xolapa Complex is thought, at least in part, to be also an effect of the granite intrusion, as has been mentioned previously. The almandine-amphibolite facies of the Xolapa Complex was imported on these rocks during an earlier deformation. The granite intrusion brought a new influx of heat and gases, while the metamorphic rocks were dragged up at the same time to a higher elevation. The possibility, that also the Ixcuinatoyac Formation formerly belonged to a higher metamorphic facies (*i, e.* the epidote-amphibolite facies) and that its lithologic make-up was more easily accessible to retrograde metamorphism cannot be discarded.

The approximate E-W strike of foliation and folding in the Xolapa Complex south of the granite area has been extensively measured in the field and corroborated by the aerial photographs. That the strike of foliation and of folding coincide, at least in this southern area, is shown by a banding that is thought to reflect the bedding. The strike cuts somewhat across the contact of the southernmost granite area. Possibly the conspicuous appearance of the strike in this southern area on the aerial photographs, is due to the reinforcement of foliation rather than to a change during the intrusion of the granite. The N-S and NNW-SSE strikes of foliation in the small areas of the Xolapa Complex west of the Coacoyulillo Stock date back to the time of the granite emplacement as do the N-S strikes in the schists, east of the Coacoyulillo Stock. It could not be ascertained whether or not the E-W lineation in this eastern area, as seen on the aerial photographs, represents bedding or jointing. The E-W strike in the Xolapa Complex is original, which is supported also by the observations in the area north of Xaltianguis, where a general E-W strike exists (de Cserna, 1965).

In the Ixcuinatoyac Formation, the strike of foliation and the bedding follow most closely the granite contact. The present attitude of foliation and geometry of folds is related to the granite emplacing event. Over large distances often there is no evidence of folding to recognize; nevertheless, there exist many gentle folds, as well as isoclinal and zigzag folds (Plate 9, figures 1, 2).

However, there are features that support the presence of a former foliation in the Ixcuinatoyac Formation. On a field trip in the company of Mr. A. Juhas, it was observed in the conglomeratic quartzites on the east bank of the Alcaparrosa River (north of the mouth of the Barranca Alcaparrosa), that in addition to the bedding there existed two directions of foliation with different strikes. A further suggestion to a former foliation, concerning the staurolite-almandine hornfels, is discussed in the stratigraphic section of this paper.

The Chapolapa Formation does not show so intense folding as the Ixcuinatoyac Formation. As it is a stratigraphically higher unit, it was submitted to less intense P-T conditions and reacted more by fracturing than by folding. As an example may be cited the chaotic fracturing of the Chapolapa rocks in the

Barranca del Espinazo del Diablo, westernmost barranca heading from the north into the upper Papagayo valley, that has been included in the mapping; (Plate 1). However, essentially it was affected to the same degree by the granite intrusion as was the underlying unit. Plate 10 shows well the same stlye of folding in the Chapolapa and Ixcuinatoyac Formations. The fold axes generally plunge slinghtly to the NNW in the are covered by Plate 10. They have been measured directly or determined by measurement of bedding planes dipping in different directions, as is shown, for example, by the contact area of both units in the Barranca de la Peña Colorada (Plate 10).

The Morelos Formation shows, in general, a gentle undulation with strong inversed folding being the exception (Plate 9, figure 3).

MESOZOIC FAULT.—From purely paleogeographic and sedimentary facies considerations the writer infers the existence of a fault with a N-S strike and the downthrown side to the west that cut across during Triassic-Jurassic times the middle part of the area. As has been pointed out earlier, the sedimentary part of the Chapolapa Formation is almost lacking in the east half of the area. The fanglomerates are especially indicative of a fault scarp. The rising of the granite magma could have been favoured by such a scarp. Of course, these conclusions are highly hypothetical.

TERTIARY FAULTS AND JOINTS.—*Eastern Tertiary volcanic area.*—The aerial photographs of this area show a very conspicuous conjugate joint system with its acute angle, in contrast to that of the granite joint system, pointing to a NNW-SSE direction (Plate 1). Compressive forces that acted in this line, until now have not been known in the Cenozoic in this region. Therefore, a late Tertiary uplift is tentatively made responsible for this joint system with its mayor axis in a ENE-WSW direction, that coincides with the direction of the obtuse angle of the before mentioned conjugate joint system.

Regionally extended fault system.—Distributed over the entire area, there exists a fault system with planes striking NNE-SSW and WNW-ESE (Plate 1). Field observations show that they are steeply inclined to vertical. These faults cut all formations present in the area. De Cserna observed that they do not cut the Pliocene Chilpancingo Formation, therefore these faults have been formed during the later part of the Tertiary, before the deposition of the Chilpancingo Formation. De Cserna (1965, p. 52-56) showed that the faults resulted from the same megatectonic process (the thrust faulting of the continent over the Pacific Basin in a SSW direction) that facilitated the formation of the Trans-Mexico Volcanic Belt and the Acapulco Trench.

JOINTS IN THE COACOYULILLO STOCK.—From the aerial photographs, it was possible to detect a joint pattern in the Coacoyulillo Stock. There are longitudinal, cross and diagonal joints (Plate 1). The correlation with a regional pattern is obvious. The diagonal joint system has its acute angle divided by a line which runs about ENE-WSW. This line coincides with the maximum stress direction. According to the law of Hartmann, as can be seen from the regional NNW-SSE strike in the Morelos Formation, the major compressive forces of the Hidalgoan Orogeny acted in ENE-WSW direction.. Thus the orogenic tress imposed the diagonal joint system on the solidified rigid granite body in Tertiary times.

GEOLOGIC HISTORY

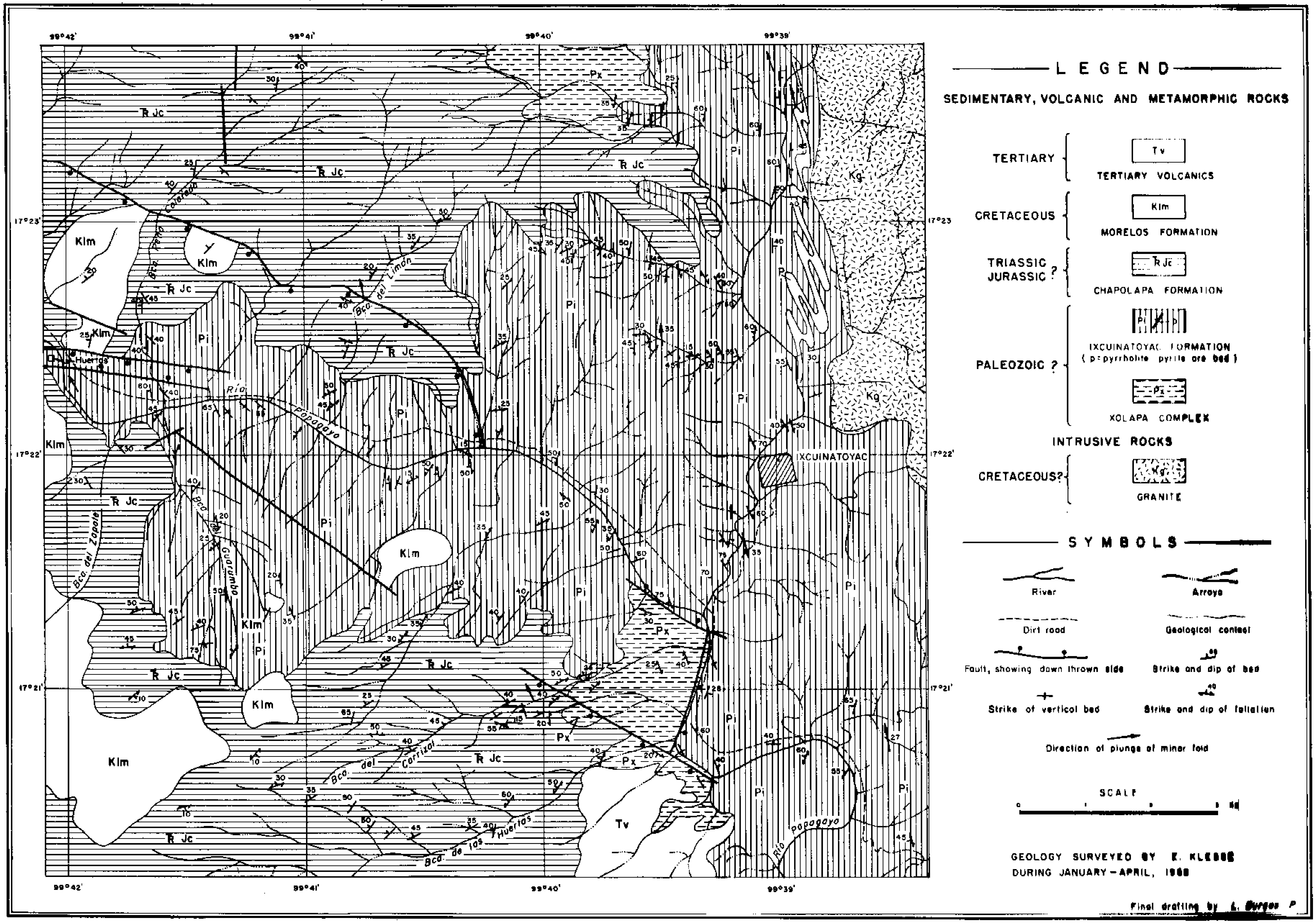
Many details have already been described in the final parts of the stratigraphic descriptions. This chapter shall give some supplements and serve as a summary.

The eugeosynclinal sediments that make up the Xolapa Complex were deposited in Precambrian or Paleozoic times. Their metamorphism, reaching the almandine-amphibolite facies could have taken place during early Paleozoic times. However, the possibility of a Precambrian deformation and metamorphism cannot be excluded from consideration.

This structural belt became deeply eroded and covered by the sediments of the Ixcuinatoyac Formation. These sediments comprise impure sandstones and shales, which contain also tuffaceous material towards the southwest. There are also rhythmic deposits of shales and sands. The sediments could have formed part of a miogeosyncline or accumulated in the transition zone from a miogeosyncline to a eugeosyncline (Stille, 1941); to be sure, carbonates in great quantities have not been found. The present picture of folding and foliation is essentially due to the processes which resulted in the emplacement of the Upper Cretaceous granite body of the area. But there are some, even if weak, hints to a former Paleozoic (?) orogenesis, which might have somewhat affected the sediments. The retrograde metamorphism, if it really only took place from one subfacies to another within the greenschist facies, is not very significant. Two active stages during the granite emplacement could have been responsible for the two metamorphic processes. The folding of the sediments during the Paleozoic orogeny created a foliation. Indications to this former orogeny are the foliation present in the staurolite-almandine hornfels and the two foliations with different strikes in the quartzite. The folded rocks were eroded before they suffered faulting and fracturing and were covered unconformably during Triassic-Jurassic times by the Chapolapa Formation. This formation could represent the red bed or taphrogenic stage following the orogeny that affected the Ixcuinatoyac Formation. In this latter case here could be thought of a connection with the Mississippian Antler Orogeny in the North American Cordilleran Geosyncline.

The sediments of the Chapolapa Formation fit into a red bed environment; the Chapolapa volcanics belonging to an alcali-calcic to calc-alcali rock suite and in their intermediate to acidic composition could be regarded as constituting the product of subsequent volcanism.

The formation, with its volcanics and its terrigenous and subaqueous sediments, shows to have originated under the semicratonic conditions of a red bed environment, comparable to the Triassic Newark Group formed after the Appalachian Orogeny or to the Late Precambrian Keweenawan, which includes also felsitic lavas. After the orogenesis, which is probably correlated with the Antler Orogeny, erosion was very fast and isostasy kept the mountains rising. As the crust of the earth is not homogenous enough to adjust itself to such an uplift without breaking into segments, faulting gives rise to a high relief horst- and graben-structure and allows the lavas to ascend, often causing blockage of the drainage. In the western part of the area studied, there seems to have been a basin, probably a graben, as sediments in the east are lacking. The wedge-shaped bodies of the rather immature fanglomerates, consisting to a great extent



GEOLOGIC MAP OF THE IXCUINATOYAC - PAPAGAYO VALLEY AREA of polymict breccias, are indicative of the fault scarps of the red bed environment. Another suggestion to fault scarps is the limestone conglomerate. "Such deposits must record unusual conditions which permitted the erosion of limestone as gravel rather than the usual removal by solution. This implies sharp uplift and locally high relief best achieved along a fault scarp" (Pettijohn, 49/57, p. 257). But, in general, limestone is absent which is another characteristic of the red bed facies (Pettijohn, 1949/57, p. 629). Typical for the facies is also the tannish-reddish arkosic quartzite, which is very poorly sorted.

The subgreywackes are also characterized by an abundance of unstable materials, as feldspars and especially rock fragments accumulated without, or almost without, a matrix. Subgreywackes are no rare sediments; they are thought to form roughly one-third of all sandstones (Pettijohn, 1949). According to Pettijohn (1949/57, p. 321) they appear late in the orogenic cycle. They seem to be a product of paralic sedimentation (*i. e.* they accumulated mainly in floodplains and deltas).

All these above rock types appear to have been formed under oxidizing conditions, represented by the deep red to violet colours. The transition from red to green is by no means bound to stratification, but occurs quite irregularly in vertical as in lateral direction in both the volcanic and the sedimentary rocks. The partial reduction with the formation of chlorite and epidote occurred later.

The greywackes are commonly considered to be geosynclinal sediments, products of deposition from turbid media. But the essential nature of the greywackes is expressed by Pettijohn (p. 313) in the following manner: "They are the earmark of sedimentation in tectonically unstable regions... They require only an environment in which erosion, transportation and deposition are so rapid that complete chemical weathering of the materials does not take place." If the deposition occurred in marine or lacustrine environment is not essential. So the red bed environment can well be a proper place for the formation of greywackes. Intermontane basins, filled with sea, or more probably fresh water, were formed by the swift tectonic movements assisted by lava flows and the rapid accumulation of alluvial fans. Earthquakes account for the mixed and very badly sorted nature of the greywackes as well as for the graded bedding.

The probably lacustrine black shales and banks of black and grey quartzites occur throughout the sequence though subordinate in their quantity. In all known examples of red bed facies they form a small, but characteristic part of the sequence. The occasionally occurring slump-blocks again testify the unquiet environment.

The age of theChapolapa Formation has been referred to as Late Triassic-Early Jurassic in describing this unit..

The carbonates of the Morelos Formation were deposited in a shallow, clear, miogeosynclinal sea during late Early Cretaceous times, over the erosional surface that developed on the Chapolapa Formation and older rocks. In early Late Cretaceous times the granite intrusion took place and was followed by the folding of the Morelos carbonates during early Eocene times (Hidalgoan Orogeny, approximately correlative with the Laramide Orogeny of the western United States). Highly suggestive reasons for the Cretaceous age of the granite intrusion are the concordance of granite contact with all units formed prior to Cretaceous times and the fact that the Chapolapa Formation was intruded by the granite. An additional slight suggestion is, that in the conglomerates and breccias of the Chapolapa Formation, even in the polymict ones, there have not ben found fragments of granite.

Over the Morelos Formation and the older rocks an erosion surface developed, which became covered by the products of the Tertiary (Oligocene-Miocene) subsequent volcanism, made up of the Agua de Obispo Formation (latites) and the Alquitrán Formation (rhyodacites).

The regionally distributed system of faults striking NNE-SSW and WNW-ESE was formed mostly in late Miocene — early Pliocene times and is due to the thrusting of the continent over the Pacific Basin. At present the area is undergoing intense erosion.

MINERAL DEPOSITS

La Dicha sulphide deposit.—The mineralized body runs from somewhat south of the suspension-bridge (north of Ixcuinatoyac) in a narrow strip for about 2.5 km northwards, until several hundred meters north of the mouth of the Barranca Alcaparrosa (Plate 1). From a point somewhat south of this mouth northwards it is sufficiently well exposed to show its constant stratigraphical position near the conglomerate, somewhat below the phyllites, in the Ixcuinatoyac Formation. After an interruption of about 1.5 km, the ore reappears along strike in the Barranca de Lima, again situated stratigraphically somewhat under the phyllites. The same is true of a last rudimentary showing over 2 km north-northeastwards along strike from the outcrop in Barranca de Lima, in the Barranca de Ipoxtelite (Plate 1); again the conglomerate horizon is present. It could not be ascertained if the mineral bearing solutions came from submarine volcanic emanations or from another source; they seem to have followed a narrow band along a shore-line which allowed the appropriate changes in "pH" and "redox-potential" to precipitate them.

The other evidence for synsedimentary nature of the deposit is the fact that the mineralization follows, in general, the folded beds. There are, however, some small cross-cutting offshoots, but these must be expected with the strong metamorphism which the easily mobile sulphides had to suffer. As a general rule, the major effect of metamorphism on the mobilization of the ore has been a flowage from the fold limbs to the crests, where the sulphide bed thickens.

Small scale zigzag folding that the sulphide ore bed suffered is well shown in the quartzites in the Barranca de Ipoxtelite area (Plate 9, figure 2). Especially the larger folds with their gently NNW dipping axes (Plate 1) gave rise to misleading exaggerations about the reserves of the sulphide bed in former reports (Santillan, 1929; González-Reyna, 1956). González-Reyna (1956 p. 163), classifying the deposit as a vein, ascribed to it an average thickness of 21 m and a maximum thickness of even 39.5 m, whereas the real average thickness of the deposit is around 2 m.

The abandoned La Dicha mine, had been worked at the beginning of this century, producing supergene, high-grade copper. The interpretation as an exceedingly thick vein extending to great depths, as described in the reports, lately presented an attractive target for new exploration. As it is recognized now, as a result of geologic mapping, the very local thickening of the deposit was produced by localized strong folding of a sedimentary horizon; the bed itself is too thin to have economic importance. Thus, La Dicha deposit has lost further economic interest for the time being.

The chemical analysis of the major constituents of a representative mineral sample is shown in Table 2.

TABLE 2.—Chemical analysis of the main constituents of Sample 520. The sample was collected from the mineral bed, where it crosses the Barranca de Alcaparrosa. The analysis was made by Ing. Quím. Alberto Obregón.

Fe	54.37%
S	35.93%
Cu	1.50%
Insoluble	7.80%
	99.50%

An x-ray fluorescence test, in addition, showed the possible presence of zinc in a quantity less than 0.5%.

The investigations performed mainly under the direction of Ing. Eduardo Schmitter of Instituto de Geología de la Universidad Nacional Autónoma de México, gave interesting results. Sample 520 was prepared for the chemical and the x-ray diffraction tests; it was ground, mortared, sieved and washed in alcohol and a fraction of approximately 0.2 mm in diameter sized material was obtained. The weak magnetic reaction of the material called attention, as the sample seemed to consist mainly of pyrrhotite, normally strongly magnetic. By means of an isodynamic separator several fractions of different magnetic intensity were obtained which are shown in Table 3.

TABLE 3.—Fractionation of Sample 520 by means of isodynamic separator. Note that increase in value of amperes means a decrease of the magnetic properties of sample.

No. of the fraction	Percentage of weight	With the separator in a vertical position. Magnetic intensity, expressed in *amperes*
520-8	4.95	0.2
520-9	22.14	0.5
520-10	46.51	0.7
520-11	20.67	1.0
520-12	3.57	1.7
520-13 (non-magnetic)	2.16	1.7 (1.7 amperes is the maximum value of amperes that can be reached with the separator)

Four of the above fractions were subjected to partial quantitative, chemical analyses, shown in Table 4.

TABLE 4.—Quantitative chemical analyses of four of the fractions shown in Table 3.

No. of fraction (cf. Table 3)	% Fe	%Cu
520—9	57.92	0.04
520—10	61.43	0.02
520—11	57.90	0.09
520—12	36.75	30.66

The theoretical value for the proportion Fe:S in the combination FeS is 63.53: 36.47. Pyrrhotite in most cases approaches a proportion of approximately 58:42, as it is characterized by iron deficiency. The theoretical value 63.53: 36.47 is almost realized in the mineral troilite, a non-magnetic variety of FeS; troilite of the meteorite of Casas Grandes (Palache *et al*, 1944, p. 233) has iron and sulfur percentages of 63.40% and 36.21%. Among the fractions of Sample 520, the fraction "520-10" most approaches the theoretical value, referred to above (*cf.* Table 4). This fraction shows, among the first three that are listed in Table 3, the weakest magnetism. The microscopic study of the fraction 520-11 showed a considerable content of pyrite, which is non-magnetic and contains less fron; therefore, no greater percentage of iron can be expected in this fraction. In conclusion, both the relatively weak magnetism and the high value for the iron/sulfur proportion found in fraction 520-10 suggest that this fraction mainly consists of troilite. Troilite, in intimate association with pyrrhotite, can be estimated to make up 1/3 to 1/2 of the Sample 520. The x-ray diffracton confirmed the presence of troilite in the sample.

In an attempt to explain the iron and copper percentages of fraction 520-12 (Table 4), x-ray diffraction also was applied. As a result, the presence of δ-chalcopyrite was revealed ("Index -inorganic- to the Powder Diffraction File" 1964, ASTM, Card No. 11-570). Also δ-chalcopyrite should be present in the sample in considerable amounts besides normal chalcopyrite.

δ-chalcopyrite is a variety of chalcopyrite that is deficient in sulfur and is formed above a temperature of approximately 550°C.

Microscopic studies of polished sections of the sample did not distinguish either pyrrhotite from troilite, or normal chalcopyrite from δ-chalcopyrite. The bulk of the minerals is composed of pyrrhotite-troilite showing xenomorphic texture. Pyrite exhibiting spheroidal texture is arranged along fractures. Small quantities of magnetite, hematite and goethite are present and sphalerite to a very subordinate degree.

Concerning the occurrence of the mineral troilite, Dana (1944, p. 234) cites only one terrestrial showing: "Troilite has been found in serpentine in Del Norte Country, California." It should be reminded here, that a talc schist was found near the La Dicha mineral bed which is also thought to have been derived by alteration from a peridotite (*cf.* stratigraphical part, Ixcuinatoyac Formation). Commonly troilite is found in meteorites.

LA ESPERANZA BARITE DEPOSIT.—In addition to the La Dicha mine, there exists a deposit of barite, that contains some hematite, mainly in form of

specularite. This is the usual combination in barite veins (Schneiderhöhn, 1962, p. 172). The minerals occur as vein deposits from hydrothermal solutions, these being related to the granite intrusion. The vein is in the upper part of the Chapolapa Formation about 50 m below the Morelos limestone contact; a green and red coloured quartz breccia is frecuent in the surroundings. The topographic position is about 4 km to the north-northeast of the village of La Esperanza (Plate 1) at an elevation of around 1,500 m above sea level. A road has recently been built to the prospect, However, early in 1968, there were still very little workings on the prospect and the reserves were unknown. The barite is relatively clean and devoid of hematite; where, however, hematite occurs, it is in large solid blocks not affecting its easy separation from the barite.

LITERATURE CITED

BARTH, T. F. W., 1962, *Theoretical petrology*: John Wiley, New York, 416 p.

BARTH, T. F. W., CORRENS, C. W., and ESKOLA, PENTTI, 1939 *Die Entstehung der Gesteine*: Springer, Berlin, 422 p.

BURCKHARDT, CHARLES and SCALIA, SALVADOR, 1906, *Géologie des environs de Zacatecas*: Cong. Géol. Internal., 10, Mexico, Guide des Excurs, 16, 26 p.

CLOOS, HANS, 1963, *Einführung in die Geologie*: Borntraeger, Berlín, 503 p.

CSERNA, ZOLTAN DE, 1960, *Orogenesis in time and space in Mexico*: Geol. Rundschau, v. 50, p. 595-605.

——1965, *Reconocimiento geológico en la Sierra Madre del Sur, entre Chilpancingo y Acapulco, Estado de Guerrero*: Univ. Nal. Autón. México, Inst. Geología, Bol. 62, 76 p.

DE ROEVER, W. P., 1942, *Olivine basalts and their alkaline differentiates in the Permian of Timor*: Geol. Expedition Lesser Islands (H. A. Brouwer), v. 4, p. 209-289.

EARDLEY, A. J., 1951, *Structural geology of North America*: Harper & Bros., New York 624 p.

FRIES, CARL, JR., 1960, *Geología del Estado de Morelos y de partes adyacentes de México y Guerrero, región central meridional de México*: Univ. Nal. Autón. México, Inst. Geología, Bol. 60, 236 p.

FRIES, CARL, JR., SCHMITTER, EDUARDO, DAMON, P. E. and LIVINGSTON D. E., 1962. *Rocas precámbricas de edad grenvilliana de la parte central de Oaxaca, en el sur de México*: Univ. Nal. Autón. México, Inst. Geología, Bol. 64, p. 45-53.

GONZÁLEZ-REYNA, JENARO, 1956, *Riqueza minera y yacimientos minerales de México*: Cong. Geol. Internal., 20, México, Monogr., 497 p.

GUZMÁN, E. J., 1950, *Geología del noreste de Guerrero*: Bol. Asoc. Mex. Geol. Petroleros, v. 2, p. 95-156.

KAY, MARSHALL, 1955, *Paleozoic of the northern Toquima Range, central Nevada*: Bull Geol. Soc. America, v. 63, p. 1269-1270 (abstract).

——1960, *Paleozoic continental margin in central Nevada, western United Statse*: Cong. Geol. Internal., 21, Copenhagen, Mem. pt. 12, p. 93-103.

KAY, MARSHALL, and CRAWFORD, J. P., 1964, *Paleozoic facies from the miogeosynclinal to the eugeosynclinal belt in thrust slices, central Nevada*: Bull. Geol. Soc. America, v. 75, p. 425-454.

KING, P. B., 1959, *The evolution of North America*: Princeton Univ. Press, Princeton, 190 p.

LONGWELL, C. R., KNOPF, ADOLPH, and FLINT, R. F., 1939, *A. textbook of geology*: John Wiley, New York, 543 p.

MOORHOUSE, W. W., 1959, *The study of rocks in thin section*: Harper & Row, New York, 514 p.

PA ACHE, CHARLES, BERMAN, HARRY, and FRONDEL, CLIFFORD, 1944, *Dana's system of mineralogy*: John Wiley, New York, v. 1, 834 p.

PANTOJA-ALOR, JERJES, 1959, *Estudio geológico de reconocimiento de la región de Huetamo, Estado de Michoacán*: Cons. Rec. Nat. no Renovables (México), Bol. 50, 36 p.

PETTIJOHN, F. J., 1949/57, *Sedimentary rocks*: Harper & Bros., New York, 718 p.

RAISZ, ERWIN, 1959, *Landforms of Mexico*: Cambridge, Mass., map. with text, approx. scale 1:3,000,000.

RITTMANN, ALFRED, 1959, *Nomenclature of volcanic rocks proposed for the use in the Catalogue of Volcanoes and key-tables for the determination of volcanic rocks*: Bull. Vulcanol., v. 12, p. 75-102.

ROBERTS, R. J., 1949, *Geology of Antler Peak Quadrangle, Nevada*: U. S. Geol. Survey, report on open-file.

ROBERTS, R. J., HOTZ, P. E., GILLULY JAMES, and FERGUSON, H. G. 1958, *Paleozoic rocks of north-central Nevada*: Bull. Am. Assoc. Petrol. Geologists, v. 42, p. 2813-1857.

SALAS, G. P., 1949, *Bosquejo geológico de la cuenca sedimentaria de Oaxaca*: Bol. Asoc. Mex. Geol. Petroleros, v. 1. p. 79-156.

SANTILLÁN, MANUELA 1929, *Geología minera de las regiones norte, noroeste y central del Estado de Guerrero*: Inst. Geol. México, Bol. 48, p. 47-102.

SCHNEIDERHÖHN, HANS, 1962, *Erzlagerstätten*: Gustav Fischer, Stuttgart, 371 p.

SLAVIK, FRANTISEK, 1908, *Splilitische Ergussgesteine im Präkambrium zwischen Kladno und Klattau*: Kommisionsverlag von F. Rivnác, Prag. 176 p.

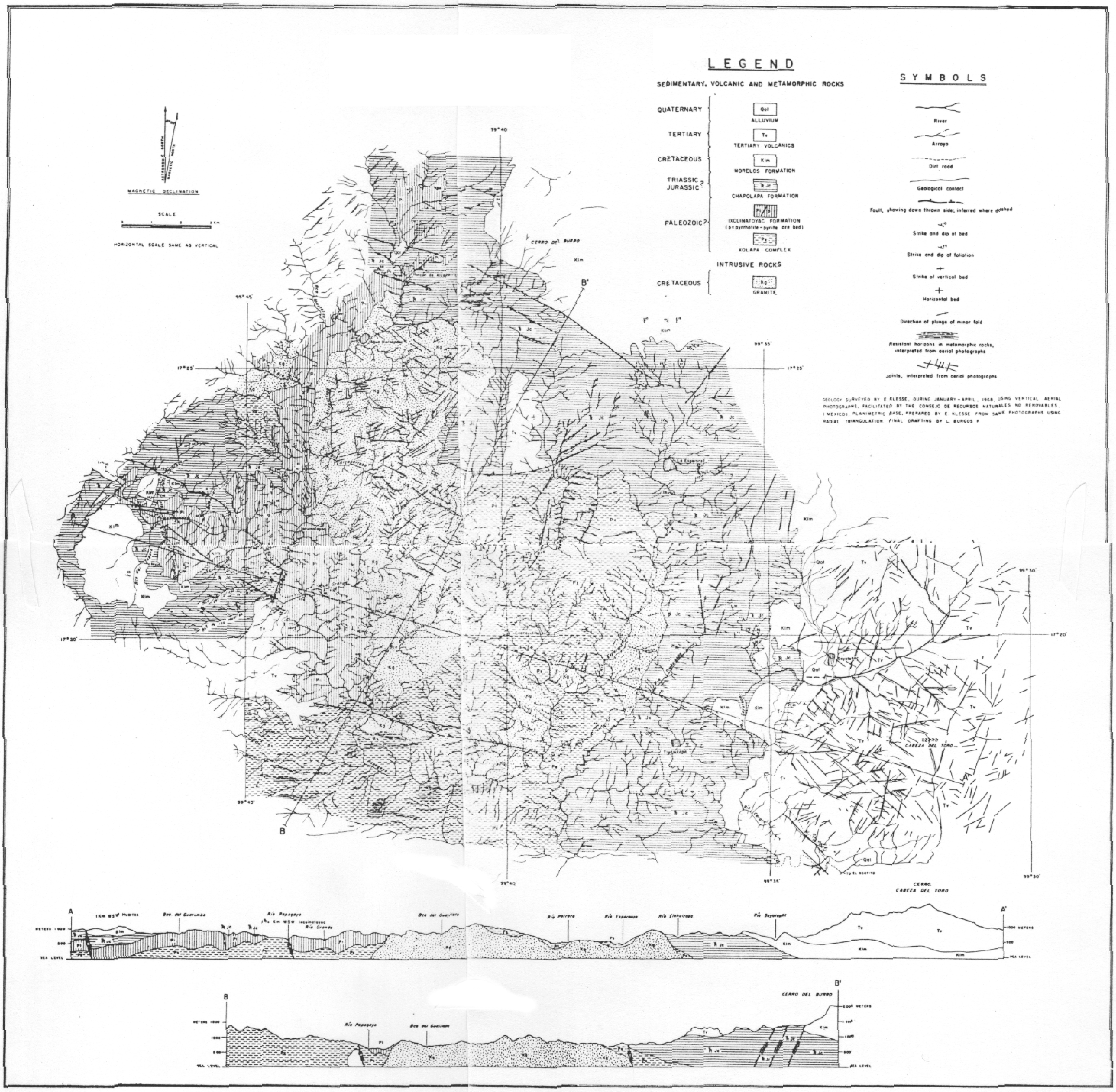
STILLE, HANS, 1941, *Einführung in den Bau Amerikas*: Borntraeger, Berlin, 717 p.

THONBURY, W. D., 1954, *Principles of geomorphology*: John Wiley, New York, 618 p.

TURNER, F. J., and VERHOOGEN, JOHN, 1960, *Igneous and metamorphic petrology*: McGraw-Hill, New York, 694 p.

WEYL, RICHARD, 1961, *Die Geologie Mittelamerikas*: Borntraeger, Berlin, 226 p.

WINKLER, H. G. F., 1967, *Die Genese der metamorphen Gesteine*: Springer, Berlin, 237 p.



GEOLOGICAL MAP AND STRUCTURE SECTIONS OF THE EL OCOTITO-IXCUINATOYAC AREA, STATE OF GUERRERO