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GEOLOGY OF THE ESQUIPULAS, CHANMAGUA AND CERRO MONTECRISTO QUADRANGLES, SOUTHEASTERN GUATEMALA.

Rice University, Ph.D., 1965
Geology

University Microfilms, Inc., Ann Arbor, Michigan
RICE UNIVERSITY

GEOLOGY OF THE ESQUIPULAS, CHANMAGUA AND CERRO MONTECRISTO QUADRANGLES, SOUTHEASTERN GUATEMALA

by

Burke Burkart

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Doctor of Philosophy

Thesis Director's Signature:  

Thomas W. Donnelly

Houston, Texas
May 1965
ABSTRACT

In southeastern Guatemala the sedimentary sequence is strikingly similar to that north of the Motagua valley, with phyllites of the Santa Rosa group (new designation) overlain by continental clastics of the Jurassic-Lower Cretaceous Todos Santos formation and limestones of the Albian Cobán formation. Red beds of the Tertiary Subinal formation are found in bands parallel to the tectonic fabric of the fold mountains of the Sierra, the locus of Tertiary volcanic activity as well. Post-Subinal pyroclastics and water-deposited tuffs, basalts and rhyolites form thick blanket deposits throughout the region.

The Esquipulas area is particularly important because of the insight that can be gained into the complex Late Cretaceous to Recent tectonics, where the pre-Tertiary rocks were folded and later block faulted into basins that paralleled the major fold mountains of Guatemala. The area was an important site of Tertiary volcanism centered almost wholly within an elongate graben basin parallel to the trend of the Motagua fault zone and the axes of the fold mountains. The graben was a basin of deposition for a thick (1000 + meters) sequence of Subinal red beds, composed almost entirely of Tertiary volcanic material. Distribution of Tertiary red beds along major fault zones of Guatemala is the result of volcanism along the zones of weakness and subsequent accumulation of volcanic (largely) detritus in basins that were controlled by normal faulting.
Pyroclastic activity increased throughout the period of deposition of the Subinal in the Tertiary. A thick blanket of tuff was deposited throughout the map area on top of all but the most prominent peaks of pre-Tertiary rocks at the margins of the Subinal basins. A sequence newly designated here as the Padre Miguel group is composed of massive and thin-bedded pyroclastics, the water-deposited facies controlled by deposition in graben basins that developed on an essentially north-south trend, transecting the older Subinal graben basins. Siliceous flows, basalts, lahars and pyroclastics which are the uppermost part of the Padre Miguel group dominated in the Pliocene and Pleistocene.
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INTRODUCTION

Purpose of Investigation

This study is intended to clarify the complex stratigraphy and structure of southeastern Guatemala which has previously been known only generally, from the works of a few prominent and, for the most part, early geologists. Relatively detailed field studies have been made in recent years in the region north of the Motagua valley, but southern Guatemala has received no such attention.

The Esquipulas area of southeastern Guatemala has a sedimentary sequence of over 2000 meters, exclusive of pyroclastics. The area includes possibly the thickest sequence of Tertiary red beds in southern Guatemala. They are blanketed over much of their extent by volcanic rocks, yet exposures reveal vertical and lateral variations in lithology and relationships to other rocks that reflect the tectonic control over their deposition. They are not the only red beds in the area, for a sequence of Early Mesozoic red clastics is also present. How and when each was deposited, and ways of distinguishing between the two, are major problems.

Pre-Tertiary formations include limestones, continental red beds and phyllites and quartzites. Correlation of these formations with established units to the north of the Motagua valley is thought to be desirable. The nomenclature of north of the Motagua is preferable to that of "equivalent" units outside of Guatemala which have received little study. In addition to being a most prominent
feature of topography, the Motagua valley has been the southern margin for the stratigraphic nomenclature established in the Central Cordillera.

The tectonic history of the region is complex. Folding and block faulting occurred near the end of the Cretaceous and during much of the Tertiary, accompanied at many stages by volcanism. Changes in character and direction of tectonism in time are grossly indicated by the divergence of the Central Cordillera and the volcanic mountains of the Pacific Cordillera. At the scale of the map area this divergence is also discernable.

Previous Work

The earliest important work which discussed southeastern Guatemala is that of A. Dollfus and E. de Mont-Serrat (1868), which included the first generalized geologic map of Guatemala and El Salvador. In 1899 Karl Sapper published his first of several studies of Central American geology, a collection that has been the unrivaled authority until recent years. R. J. Roberts and E. M. Irving (1957) published a compilation of their field studies and summarized the geology of Central America with emphasis on mineral resources. This work remains the most important modern summary.

Two studies in the Guatemalan highlands to the north of the Motagua valley were made by J. L. Walper (1960) and A. R. Mc Birney (1963). T. S. Hirschmann (1963) studied the El Progreso area of the Motagua valley and specifically the Subinal formation. Howel Williams (1960) reported on the volcanic highlands of Guatemala, and Williams,
McBirney and Gabriel Dengo (1964) have made a reconnaissance study in southeastern Guatemala. This latter study includes a reconnaissance of the western part of the Esquipulas area.

Graduate students from universities in the United States who are currently doing field studies in Guatemala include the following: Mr. Russell Clemons from The University of Texas is studying the Chiquimula area; Mr. D. C. Crane from Rice University is studying the Jocotán area; Mr. Eric Bosc from Rice University is studying the San Agustín Acasaguastlán area; Mr. Samuel B. Bonis from Louisiana State University is studying the area around Senahú.

Messrs. Otto H. Bohnenberger and Jorge Godoy of Dirección General de Cartografía\(^1\) have made recent field studies in Guatemala.

**Acknowledgements**

The author wishes to thank the United States AID Mission in Guatemala for their sponsorship under contract 520-29, and particularly Mr. Raymond H. Luke of the Industry Division and Mr. Kenneth W. Davidson, formerly of that division. The assistance of Mr. L. Schlesinger, Director of Centro de Fomento and Productividad Industrial and of Messrs. Julio Montano and Alfonso Rosales Valle, past and present directors of Dirección General de Minería, respectively, is gratefully acknowledged. Mr. Alfredo Obiols, Director of Dirección General de Cartografía, provided excellent

\(^{1}\)Recently redesignated Instituto Geográfico Nacional de Guatemala.
support for the fieldwork by furnishing equipment and services of his organization, and his help is greatly appreciated.

The Interamerican Geodetic Survey in Guatemala was quite helpful in furnishing equipment and in providing two aerial flights over the map area.

Mr. Otto H. Bohnenberger of Cartografía was coordinator of the project for the Guatemalan government, providing excellent assistance and advice for which the author is very greatful. Mr. Bohnenberger, Mr. Samuel B. Bonis and Mr. Jorge Godoy of Cartografía spent time with the author in the field and were helpful in explaining their work and other work in Guatemala. Mr. Marco Antonio Aceituno accompanied the author in the field on several occasions. His help as well as that of Mr. Oscar Salazar of Minería was graciously offered. The author spent several valuable days in the field with Dr. Howel Williams of The University of California, Berkeley, and with Dr. Alexander Mc Birney of Scripps Institute of Oceanography. Discussions with Dr. Gabriel Dengo of the Organization of American States on the geology of Guatemala were very enlightening. Mr. Tomás Hirschmann of INDE is to be thanked for the time he spent discussing his work on the Subinal formation.

Dr. Fred M. Bullard of The University of Texas gave helpful advice during the early stages of the project.

Mr. R. C. Douglass of the United States National Museum identified foraminifers and Mr. P. M. Kier of the Smithsonian Institution identified an echinoid specimen. Dr. Dan Jones of the Esso Production Research Laboratories, Houston, Texas, made a pollen analysis.
In the Department de Chiquimula the former governors, Colonel Alfonso Algara Piloña and Colonel Marco Antonio Asturias Sobral were very helpful. The late Don José Iten, owner of the Finca San José and the San Vicente mine, was a reliable source of information and gracious host. In Esquipulas the author had the good fortune of knowing and living with the Benedictine Fathers of the Basílica de Esquipulas.

Dr. T. W. Donnelly of Rice University originated the project, supervised the thesis and was of great help in the field and laboratory stages of the work. The author also wishes to thank Dr. J. Cl. De Bremaecker and Dr. Riki Kobayashi of Rice University for reading the manuscript.

Mr. David C. Crane, graduate student from Rice University, worked simultaneously in the area adjacent to the north ("Jocotán"). Mr. Russell Clemons, a graduate student from The University of Texas, mapped the area to the northwest ("Chiquimula"). Both were helpful and able colleagues. The author has benefitted from discussions with Mr. Eric Bosc, graduate student from Rice University, who is studying the San Agustín Acasaguastlán area.
GEOGRAPHY

Location

The Esquipulas area is in the Department of Chiquimula in southeastern Guatemala adjacent to the republics of Honduras and El Salvador (see Figure 1). The area is defined by three ten by fifteen minute quadrangles published by Dirección General de Cartografía de Guatemala at a scale of 1:50,000. These three sheets are entitled the "Esquipulas Sheet" (2359IV), the "Chanmagua Sheet" (2359I) and the "Cerro Montecristo Sheet" (2359III). The area comprizes approximately 650 square kilometers.

Topography

Terrain of the region ranges from mountainous to essentially flat. Mountains and high plateaus, the "central highlands", span the central portion of the area, trending in a general north-south direction with the continental divide running along the ridges. The lowest elevation is approximately 500 meters, encountered in the extreme northwest corner of the area. The highest point in the area and in the Departamento de Chiquimula is Cerro Montecristo (2416 meters), whose summit is the point of intersection of Guatemala, Honduras and El Salvador.

An area of significantly low elevation is found to the west of the road from the town of Quezaltepeque to Ermita and to the
GEOGRAPHIC SETTING

POTEN LOWLANDS

CIAFAPAS MEXICO

CENTRAL CORDILERA

Río Motagua

PACIFIC CORDILLENA

PACIFIC OCEAN

HONDURAS

EL SALVADOR

GUATEMALA CITY

MAP AREA

FIGURE 1
border with El Salvador. The area extends westward beyond the limits of the Esquipulas area in the Ipala and Asunción quadrangles. Referred to as the "western graben area" in this study, it is characterized by numerous hills of low relief whose elevations are below 1000 meters.

The "central highlands" is a mountainous belt extending southward to Cerro Montecristo from the center of the northern border of the area. The southern portion of the highland area extends from the village of Apantes to Cerro Montecristo. It is highly dissected, exhibiting a typical mountainous topography. From Apantes northward the topography is high but less dissected. Due north of Apantes is the "Cebollas plateau" which is the least dissected portion.

A major valley area is found directly to the east of the Cebollas plateau. It is referred to as the Esquipulas valley after the town of Esquipulas in its southwest corner. The valley is a striking topographic feature which is relatively flat and almost enclosed by high terrain that rises abruptly from the valley floor. Drainage here is into the Río Olopá which flows southeast to the Pacific Ocean through the Río Lempa of El Salvador. All other drainage in the Esquipulas area goes into the Río Shutague which flows northward into the Río Motagua and the Caribbean.

Climate

Guatemala is within the tropical climatic zone, ranging from 14° to 18° north latitude. As in most tropical zones temperatures are primarily a function of elevation within any given season, and
seasonal variations are not great. At sea level the climate is generally hot, while the higher elevations enjoy cool climate during the rainy season, and only slightly warmer climate during the dry season. The rainy period in this part of Guatemala is from early June through October.

In the Esquipulas area of southeastern Guatemala the range of elevation of almost 2000 meters produces a climate varying from hot and arid in the lowlands to cool and wet in the mountains. Areas of high elevation have a longer rainy season than the valleys, with mountains such as Cerro Montecristo being shrouded in clouds for all but a few months of the year (February, March and April). There are occasional rains during the dry season and these are generally in the mountains and high plateaus. No accurate rainfall studies are known for this area, but it is estimated that the low elevations receive about one meter (40 inches) of rainfall per year, and the mountainous areas a larger amount which increases with elevation. There is rain almost every afternoon during the wet season, though it is of short duration. In the middle of the rainy season there is often a period of from two to three weeks with little or no rain referred to as the "canicula".

Access

The Esquipulas area has two major roads that give good access. "Route 18" begins at the extreme northwest corner of the area and extends southeastward to the town of Esquipulas and beyond to the Honduras border. This is referred to as the "old road", as a
new route to Esquipulas is currently under construction. The new road will follow the old route for much of its length, crossing the highlands near Apantes, just south of the Cebollas plateau instead of at "La Cumbre" to the north as before. The other major road, Route 20, runs from the town of Ipala into the northwestern part of the area and intersects Route 18 near the village of Río Grande. It extends to Quezaltepeque and goes southward to Concepción las Minas and Ermita. At Ermita a primitive continuation of this road runs to the El Salvador border. It is generally passable in the rainy season with a four-wheel-drive vehicle. In the dry season there is a vehicle trail that can be negotiated from just north of Esquipulas, across the valley to Olopita and north to the village of El Rodeo.

Trails are numerous in all parts of the area except in the high, mountainous rain forest of Cerro Montecristo and the adjacent mountains to the north. Trails are used for most travel.

Map Coordinates

The geologic map included with this study was made on a topographic base provided by Dirección General de Cartografía of Guatemala at a scale of 1:50,000. In addition to standard latitude and longitude references, the map bears a rectangular grid system, the Universal Transverse Mercator Grid (UTM), also referred to as "military grid". This system divides the area into 1 kilometer squares, each of which is identified by two numbers, the first being the UTM "easting" (abscissa) and the second the UTM "northing" (ordinate). By including a decimal, a position is defined to
within 100 meters in easting and 100 meters in northing. Thus, the
cemetery at Quezaltepeque which is in the (37, 19) kilometer square
is more precisely located by (37.3, 19.1).
STRATIGRAPHY

This is the first study to correlate pre-Tertiary rocks in southeastern Guatemala with what is substantially the entire sequence of lithologies from north of the Motagua valley. Earlier workers have suggested such correlations without having formally used terminology from Guatemala in their mapping studies (see below). Thus the phyllites of the area have been previously considered equivalent to the Santa Rosa formation, the Metapán formation has been correlated with the Todos Santos formation and the Cretaceous limestones have been suggested as equivalent to the Cobán formation. These previous correlations were based upon an "absolute" lithologic equivalence, but with current knowledge of the succession of lithologies it can be seen that there is sequential equivalence as well.

Santa Rosa Group

The oldest rocks found in the area are phyllites and minor quartzites of the Santa Rosa. The phyllitic shales and quartzites are uniform over their limited extent (around 19 square kilometers) within the map area. Mineral constituents are quartz, muscovite and chlorite, with occasional layers rich in graphite. The phyllites are brown in overall color with a shiny silver and brown appearance in hand specimen. Quartzite layering is parallel to foliation planes
and it is suspected that foliation represents original bedding throughout these low-grade metamorphic rocks. Quartz veins are prevalent in these rocks.

Sapper (1899) mapped these rocks with others he thought to be of pre-Cambrian age, calling them merely gneiss, mica schist and phyllite. Roberts and Irving (1957) refer to a progressive sequence of metamorphism of rocks which flank the crystalline ("anticlinal") core of early Paleozoic rocks. Thus they believe the Santa Rosa shales are metamorphosed to phyllite and schist near Puerto Barrios, in eastern Guatemala and Honduras, although they refer to the phyllites near Concepción las Minas merely as "Paleozoic schist". Hirschmann (1963) in his study of the Subinal near El Progreso, mapped the phyllites and the included carbonates as Santa Rosa, which is the first mention of this unit south of the Central Cordillera.

Mr. Russell Clemons, who is working in the Chiquimula area immediately to the northwest, states in a personal communication that he believe that the metasedimentary sequence in his area belongs to the Santa Rosa. The sequence contains marble and in general is much more varied in that area, though the section from San José la Arada southward along the Ipala road to Las Vegitas is rather uniform and identical in appearance to the rocks of the Esquipulas area.

Much discussion has centered on the name "Santa Rosa", which was first used by Dollfus and Mont-Serrat (1868, p. 270F) for a series of shales, sandstones, conglomerates and limestones in the
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<td>Conglomerates and sands</td>
<td>Recent</td>
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<td>Basalt, rhyolite flows, lahars, conglomerates, massive and thin-bedded tuffs</td>
<td>Late Tertiary through Pleistocene</td>
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<td>Subinal Fm. (0-1000 m)</td>
<td>Red beds: red sandstones, shales and conglomerates, chiefly of volcanic origin</td>
<td>Miocene-Pliocene?</td>
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<td>Cobán Fm. (950 m)</td>
<td>Limestones and shales with some sandstones</td>
<td>Albian</td>
</tr>
<tr>
<td>Todos Santos Fm. (100+ m)</td>
<td>Red sandstones, shales with some pebble conglomerates</td>
<td>Jurassic to Albian</td>
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<td>Phyllites and minor metaquartzites</td>
<td>Pennsylvanian-Permian?</td>
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Department of Alta Verapaz near the village of Santa Rosa. Table 2 gives a breakdown of stratigraphic names used by various workers for portions of the original Santa Rosa Series of Dollfus and Mont-Serrat (1868). Localities where the Santa Rosa as defined by Dollfus and Mont-Serrat (1868) occurs are known in most recent literature (cf. Mc Birney, 1963) by the names Santa Rosa, Tactic, Chochal and Todos Santos. The name Santa Rosa was applied to the oldest of two broad sedimentary divisions, the younger of which contained part of the Todos Santos as defined today, the Cobán formation and the Sepur formation. Sapper (1899) correlated beds of this younger division with beds occurring in the Department of Huchete, and according to Walper (1960, p. 1287) and Mc Birney (1963, p. 201) he did so erroneously. The new term, Todos Santos formation was applied to beds that are the uppermost part of the Santa Rosa as defined by Dollfus and Mont-Serrat (1868), and with its widespread acceptance came ambiguity in the meaning of Santa Rosa, the name no longer applying to the part of the type locality near the village of Santa Rosa.

Walper (1960, p. 1287) introduced the name Tactic for the Permian shales and minor limestones that lie beneath the Permian Chochal limestone, a unit named by Roberts and Irving (1957, p. 16). Walper (1960) applied the name Tactic to the remainder of the original Santa Rosa, which was the sedimentary sequence beneath the Chochal limestone. The lowermost part of this sequence is not exposed in the Cobán-Purulhá area of Walper (1960). Mc Birney (1963), noting that there were two distinct lithologies, re-defined Tactic to apply to the fine clastic upper sequence as described by Walper (1960), and
<table>
<thead>
<tr>
<th>AGE</th>
<th>LITHOLOGY</th>
<th>DOLLFUS &amp; MONT-SERRAT (1868)</th>
<th>SAPPER (1899)</th>
<th>ROBERTS &amp; IRVING (1957)</th>
<th>WALPER (1960)</th>
<th>McBIRNEY (1963)</th>
<th>THIS STUDY</th>
</tr>
</thead>
<tbody>
<tr>
<td>JURASSIC-ALBIAN</td>
<td>Shale, sandstone conglomerates</td>
<td>&lt;br&gt; Santa Rosa Series</td>
<td>&lt;br&gt; Todos Santos Fm.</td>
<td>&lt;br&gt; Todos Santos Fm.</td>
<td>&lt;br&gt; Todos Santos Fm.</td>
<td>&lt;br&gt; Todos Santos Fm.</td>
<td>&lt;br&gt; Todos Santos Fm.</td>
</tr>
<tr>
<td>PERMIAN</td>
<td>Limestone</td>
<td>Karbonkalke</td>
<td>&lt;br&gt; Chochal Fm.</td>
<td>&lt;br&gt; Chochal Fm.</td>
<td>&lt;br&gt; Chochal Fm.</td>
<td>&lt;br&gt; Chochal Fm.</td>
<td>&lt;br&gt; Chochal Fm.</td>
</tr>
<tr>
<td>PALEOZOIC</td>
<td>Fine Clastics</td>
<td>Santa Rosa Fm.</td>
<td>&lt;br&gt; Santa Rosa Fm.</td>
<td>&lt;br&gt; Not recognized</td>
<td>&lt;br&gt; Santa Rosa Fm.</td>
<td>&lt;br&gt; Santa Rosa Fm.</td>
<td>&lt;br&gt; Tactic Fm.</td>
</tr>
<tr>
<td></td>
<td>Coarse Clastics</td>
<td>&lt;br&gt; Unnamed Fm.</td>
<td>&lt;br&gt; Tactic Fm.</td>
<td>&lt;br&gt;</td>
<td>&lt;br&gt;</td>
<td>&lt;br&gt;</td>
<td>&lt;br&gt;</td>
</tr>
</tbody>
</table>

1These lithologies do not occur in the areas mapped in the references cited, but texts include discussion of terminology listed.
resurrected the name Santa Rosa for the lower coarse arkosic sandstones and conglomerates exposed to the south near Salamá.

Mr. Otto H. Bohnenberger in a personal communication has suggested that the two-fold division of the Pennsylvanian-Permian clastic sequence of McBirney (1963) be retained, but that it be made more flexible by defining the Santa Rosa as a "group", composed of a lower, as yet un-named formation of coarse clastics, and the upper, Tactic formation of fine clastics. In the Esquipulas area the two-fold division of this sequence has not been noted, and although the phyllites are very likely the equivalents of the Tactic, enough doubt exists to warrant the use of a more general term. Thus Santa Rosa is a group name in this study. This should provide a suitable terminology for mapping when field distinction is unclear or unnecessary.

The probable age of metamorphic rocks studied by Williams et al. (1964) in southeastern Guatemala is Middle or Late Paleozoic. This author has correlated these rocks with the Late Paleozoic low grade metasedimentary rocks on the north of the Sierra de las Minas, of which the upper unit, the Tactic formation, is thought to be Permian by McBirney (1963).

Todos Santos Formation

Overlying the metasedimentary rocks of the Santa Rosa group is a sequence of sandstones, shales and conglomerates believed to correlate with the Todos Santos formation of the Central Cordillera. No contact between the Todos Santos and Santa Rosa has been found in
this area. The upper contact of this formation is seen in the El Sillón section (see Appendix 1), where thin-bedded lower Cobán limestone lies apparently conformably above it. This part of the sequence consists of alternating thin to thick-bedded sandstones and shales, with minor pebble conglomerates at the base of the exposed section. Some of the indistinctly bedded red sandstones and siltstones have both calcite and silica cement and are seen in thin section to have undergone extensive pressure solution (see Appendix 5, sample BB-28). Metaquartzite fragments are believed to come from the underlying Santa Rosa metasedimentary rock.

The Todos Santos is believed to be exposed near the village of Quesera (35, 03) where variegated shales are poorly exposed in the road cut. The section suffers from a large amount of distortion toward the top where it has been intruded by a small stock or dike. The base of the section is not exposed here as it is faulted against phyllite to the north. A red bed conglomerate of phyllite fragments appears to be near the fault at the base of the Todos Santos section, but close examination reveals fresh volcanic rock fragments, including euhedra volcanic quartz. The section appears to be overlain by the thin-bedded member of the Cobán limestone just southeast of the road at Quesera (35.6, 03.6).

An exposure of pebble conglomerates and hard quartz sandstones is seen on the road near El Sillón at (36.5, 0.25), where the conglomerates are faulted against the Cretaceous limestone. At the contact of the small intrusive and the limestone near the village of Limones there is another inclusion of pebble conglomerates and hard
sandstone which appears to be Todos Santos, but large exposures are not present in the area. Dürr and Stober (1956) report exposures of this pebble conglomerate in the Metapán area to the south in El Salvador.

The thickness of the Todos Santos formation is not known. In the El Sillón Section 100 meters of partially covered section was measured beneath the Cobán limestone.

The Todos Santos formation of this area appears to be continental, derived from underlying sedimentary and possibly granitic rocks. The uppermost beds of the Todos Santos possibly are marine, for it grades upward into limestones that bear a marine fauna (see below).

The "Laramide" age of metamorphism suggested by some authors appears to be too late an estimate. An age at least as early as Jurassic is required to explain the lithology of the Jurassic (in part) Todos Santos, which is frequently made up of reworked phyllites and other metamorphic rocks of the Santa Rosa group. Conglomerates found on the Atlantic Highway at kilometer marker 34 contain reworked phyllite, and are believed by Hirschmann (1963) to be Todos Santos. Todos Santos beds along the Cobán road at kilometer 165 and 166 contain conglomerates of the same composition. In south-eastern Guatemala the Todos Santos beds are composed of metamorphic rock fragments to a large extent, and the surface of unconformity above the Santa Rosa and overlying rocks, referred to as "Cretaceous sediments", bears large quantities of metamorphic fragments and vein quartz from the metamorphic sequence. (Williams et al., 1964).
The reworked metasedimentary rock content of the Todos Santos is, perhaps, evidence for Triassic metamorphism of the Santa Rosa sediments, presumed of course that the Todos Santos Jurassic-Lower Cretaceous age has been rightly ascertained. The Triassic was a likely time of metamorphism as it was a period of uplift and according to some authors, a period of intense orogeny (see e.g., Roberts and Irving, 1957).

Roberts and Irving (1957, p. 21), whose work was done before the knowledge of Tertiary red beds in this region, report that the Metapán formation near Concepción las Minas includes volcanic tuff. They mapped beds as Metapán which now are known to belong to the Subinal formation and Padre Miguel group. Their map (Plate No. 8 of their study) shows areas north and west of the Río de Concepción that are listed as Metapán sandstone, shale and conglomerate. This sequence is a poorly-bedded water deposited tuff containing fragments of metamorphic quartz. The same lithology can be seen 2 kilometers southeast of Ermita where the tuff is concordantly above the Subinal conglomerates of limestone, metaquartzite and andesite flow fragments. This lithology is common to other parts of the map area and has been seen near los Cimientos in the Chiquimula area (map number 2260 II; coordinates 16, 26). The red beds mapped by them as Metapán along the Río las Minas are mostly Subinal, though there is some doubt that they are entirely Subinal, because the Subinal here consists of reworked metamorphic material which could belong to either clastic sequence. Here the two formations could be expected to be in contact since the base of the El Sillón section
contains Todos Santos beds and it is close by and on strike with the beds in question. Furthermore, the river east of Ermita is the northern limit of the southern Subinal belt. The presence of occasional fresh volcanic fragments or limestone fragments is the deciding factor in mapping them all as Subinal, as was done in this study.

Sapper (1899, p. 65) designated the sedimentary series of northwestern El Salvador as the Metapán strata, and in the original designation restricted the name to the clastic sequence that underlies the limestone, which he mapped separately only as "Kreidekalk". Later Sapper (1937, p. 27) considered the clastic sequence correlative with the Todos Santos formation of Guatemala and very likely with the upper part of the Tegucigalpa formation of Honduras. Mullerried (1942, p. 129) also makes this correlation. Stirton and Gealey (1949, p. 1740) present a summary of the stratigraphy of the Metapán area in which they leave the limestone unnamed. Sapper's (1899) original "Metapán-Schichten" has since been variously interpreted to mean "Metapán series", "Metapán beds", "Metapán formation", and even "Metapán limestone". "Metapán formation" is a valid formation name for the lower clastic sequence as it was originally used in that manner by Sapper (1899, p. 65) and continued by Sapper (1937), Mullerried (1942), Stirton and Gealey (1949) and Roberts and Irving (1957). Roberts and Irving (1957) distinguish between the Metapán formation and overlying limestone, but include the two together on their map (Plate 1).
In spite of the nearness of the rocks that have been called the Metapán formation, it is desirable in the Esquipulas area to use the name Todos Santos formation, for it has a clearer meaning, wider acceptance and comes from the same region as the rest of the nomenclature of this study.

Albian limestone overlies the Todos Santos in the map area (see below), placing an upper limit on its age. Mullerried (1942, p. 129) considers the age of the Todos Santos strata to be Jurassic and Early Cretaceous. Walper (1960, p. 1295) tentatively assigned an age of Jurassic-Cretaceous to these rocks in the Cobán Purulhá area. McBirney (1963, p. 203) as well believes that they may be Jurassic and partly Cretaceous in age. With the understanding that these rocks may not be everywhere the same age, and that a reliable earliest possible date has not been established, the Todos Santos formation will be listed as Jurassic to Albian in this study, on the basis of the reasonable estimates of Walper (1960) and McBirney (1963) and the established Albian age of the overlying limestones.

**Cobán Limestone**

A few kilometers north of the town of Ermita a 950 meter section of limestone has been measured which correlates with the Cobán formation of Alta Verapaz, named by Sapper (1899, p. 65). The section divides into a lower thin-bedded, dense limestone of around 400 meters thickness (see "El Sillón Section", Appendix 1). The limestones appear to lie conformably above sandstones and shales of the Todos Santos formation.
The lower boundary of the Cobán limestone in this area is placed at the position of appearance of the first thin-bedded limestone above the Todos Santos clastics. This relationship does not exist to the north in the Jocotán area where Crane has found that the Todos Santos formation did not develop or was removed prior to the limestone's deposition. Stirton and Gealey (1949, p. 1740) have noted an apparent conformable relationship between the lower clastics (Metapán beds) and the overlying Albian limestone. In the Metapán area as in the El Sillón Section, onlap is suggested by the transition from sandstone and shale to alternating thin-bedded limestone and shale.

Dürr and Stober (1956, p. 46) present the limestone sequence near Metapán as having two interfingering facies, massive-bedded and thin-bedded. This writer believes that such a relationship is only apparent, being the result of juxtaposition by block faulting.

The sequence of rocks described by Dürr and Stober (1956) from the region around Metapán includes three major divisions, namely (1) a lower conglomerate series, (2) a series of limestones and (3) an upper conglomerate sequence. These correspond to the units this writer has called (1) the Todos Santos, (2) the Cobán and (3) the Subinal in the Esquipulas area. Dürr and Stober (1956) did not assign formation names to any of these units, and the term "Metapán beds" as they use it simply refers to the sedimentary rocks found in the vicinity of Metapán.
The limestone of the Metapán area was separated by Sapper (1899) on his geologic map from the Metapán beds, referring to it merely as "Kreidekalk". Weaver (1942, p. 179-180) called a part of the overlying limestone the Esquías formation. Stirton and Gealey (1949) give no name to the limestone, but recognize that it is separate from the underlying Metapán formation. "Metapán limestone" is not a valid stratigraphic term.

The Cobán limestone is moderately fossiliferous though few definite identifications have been made because of poor preservation. Recrystallization in the limestone portions of the section makes identification difficult. Identifiable fossils have come from marly parts of the section exclusively.

There is no doubt that the limestone of the Esquipulas area is stratigraphically equivalent to the limestone of the Metapán area. Inliers of limestone occur at intervals of no greater than 6 or 7 kilometers from El Sillón southward to Metapán. The limestone of the Metapán region has been dated as Middle Albian by Mullerried (1939) on the basis of Toucasia cf. texana Roemer from the massive-bedded limestone one kilometer north of Metapán. Roberts and Irving (1957, p. 22) report that Exogyra arietina Roemer was found in the limestone near Metapán, signifying an early Late Cretaceous age.

In the Esquipulas area fossils found in the lower part of the limestone of the El Sillón Section by the author have been identified as Orbitolina cf. parva Douglass by Mr. R. C. Douglass (personal communication) which are Albian in age. Q. parva, a species closely related to Q. texana, has been recently described by Douglass (1960, p. 39). Walper (1960, p. 1299) reports that Q. cf. texana was found
in the Ixcoy, the lower of the two units of Cretaceous limestone that are present in the Cobán-Purulhá area. These fossils from the Santa Rosa Section were given an age of Early Albian. An Orbitolina similar to *O. texana* was found by Vaughan (1932) from the vicinity of Guatemala City. Thus three Orbitolinas from areas far apart in Guatemala have been described as being similar to *O. texana* Roemer, namely, the *O. cf. texana* of Walper (1960), the *O. cf. parva* of the El Sillón Section and the Orbitolina from near Guatemala City of Vaughan (1932). These fossils are all found in limestone sections and it would be interesting to know if they are in reality the same species.

Although the lower, thin-bedded sequence of the Cobán limestone of the map area has proven to be Albian in age, the massive-bedded limestone that lies above is not dated conclusively. There is evidence for a post-Albian age in the Metapán area, for as stated above an early Late Cretaceous age is signified by *Exogyra arietina* (Roberts and Irving, 1957, p. 22). At 596 meters in the El Sillón Section a badly preserved echinoid was found that was identified as *Hemiaster?* by Mr. P. M. Kier of the Smithsonian Institution, (personal communication), who judged that it was probably from the Upper Cretaceous. In contrast, the massive-bedded limestone near Metapán contains fossils dated by Mullerried (1939) as Middle Albian, as stated above. Until more information is available the age of the massive-bedded section will have to be listed as Albian.
Subinal Formation

The Subinal formation is a continental basin deposit composed of sandstones, claystones, siltstones, conglomerates, shales and very minor fresh-water limestones, derived to a large extent in this area from volcanic rocks. The name Subinal was first used by Hirschmann (1963) in his study of the continental red beds found in the Motagua valley near El Progreso and Sanarate. There is no indication that Subinal beds of the Motagua area are contiguous with the continental deposits of the Esquipulas area; it is, in fact, likely that they never were. But the two deposits have clear similarities in general lithology, apparent environment of deposition, and probably in geologic age, that suggest their correlation. Furthermore there are many specific parallels in lithology, such as a vertical decrease in certain clastic components that indicate kinship. As will be mentioned below, the red beds of these two areas also share similar tectonic settings.

The Subinal formation of the map area is made up principally of volcanic rock fragments, yet locally contains fragments of the Cobán limestone or phyllite and metaquartzite from the Santa Rosa group. Conglomerates within the Subinal that are rich in limestone or metamorphic rock fragments are found at the margins of the suspected basins of deposition.

There are two belts of Subinal in the map area that trend in an east-northeast direction. Figure 2 shows the distribution and trend of Subinal beds in this area. Something of the character of
Subinal basins can be discerned from the rapid lateral variation in lithologies and bedding characteristics of these rocks, which will be discussed in some detail for the rocks of the northern belt of the area.

At the margins of the northern belt, which is some 15 to 20 kilometers wide, the Subinal has measurable thicknesses of less than 100 meters, while at least 1000 meters of Subinal may be found near the center of the belt. Only at the margins has the lower contact been seen. Along the northern margin red sandstone of the Subinal is underlain by massive-bedded limestone of the Cobán formation, and along the southern margin it is underlain by phyllites of the Santa Rosa group. Boulder conglomerates are found at both margins of the belt. The northern margin is marked by boulders of limestone whereas both limestone and andesite flow are found as boulders in breccias along the southern margin. Exposures at the center of the belt are of much higher textural maturity than at the margins, with the size range of the clastics much lower, the conglomerates less abundant and of finer and more uniform size. (See Table 3 and Figure 3.)

The southern belt of Subinal red beds in this area is extremely rich in conglomerates with a high percentage of limestone and metasedimentary rock fragments. This is a narrow belt measuring only 7 or 8 kilometers across the regional east-northeast strike; perhaps the narrowness explains why it does not exhibit the features of increasing clastic maturity towards its axis as does the northern belt.
### Table 3

**Character of Conglomerates and Breccias of the Northern Subinal Basin**

<table>
<thead>
<tr>
<th></th>
<th>North Margin (La Calera)</th>
<th>Basin Center (Tierra Colorada)</th>
<th>South Margin (Cruz Alta)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Largest clastic size</strong></td>
<td>Boulder</td>
<td>Pebble</td>
<td>Boulder</td>
</tr>
<tr>
<td><strong>Percent limestone fragments</strong></td>
<td>50</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td><strong>Percent volcanic flow fragments</strong></td>
<td>30</td>
<td>60</td>
<td>35</td>
</tr>
<tr>
<td><strong>Percent metamorphic rock fragments</strong></td>
<td>5</td>
<td>20</td>
<td>35</td>
</tr>
<tr>
<td><strong>Percent other constituents, mainly chert</strong></td>
<td>15</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td><strong>Bedding</strong></td>
<td>Poor to absent</td>
<td>Graded; distinct to indistinct; continuous; cross-bedded weakly</td>
<td>Poor to absent</td>
</tr>
</tbody>
</table>
SUBINAL BASIN TREND

Post Subinal Tuffs, Flows
Subinal Fm.
Cobán Fm.
Todas Santos Fm
Santa Rosa Gp.

Metapán
Medium bedded, brick red, silty, fine-grained volcanic sandstone and red clay alternating with 1 meter thick conglomerate containing pebbles up to 1 cm. in diameter. Some pebbles are angular, most are round. Pebbles are composed of brown chert, biotite-rich violet tuff, metamorphic quartz, andesite flow and rarely, limestone fragments. Ripple marks are seen in clay beneath sandstone layers. Sandstone is faintly cross-bedded.
Volcanic rock fragments of the Subinal in this area include andesite and basalt flow, rhyolitic and rhyodacitic tuff. The andesite flow seen in vast quantity in the breccias southwest of Esquipulas appears in many conglomerates of the formation as the most abundant constituent. This is a distinctive type of fragment, with relatively large (several mm) plagioclase phenocrysts and with a grayish-pink or violet groundmass. Few rhyolite flow or shallow intrusive fragments have been noted in red beds known to be Subinal in this area. Sand and silt-size clastics of the Subinal are often entirely reworked tuff, though many specimens examined show no signs of having been abraded in stream transport. Sample BB-29 (see Appendix 5) is representative of Subinal which is dominantly tuff and whose texture suggests little or no transport after deposition. This sample is from the road cut near San Isidro (34.8, 03.3). It is several tens of meters stratigraphically above a conglomerate of phyllite and volcanic rock fragments which rests atop the Santa Rosa phyllites. Most samples that appear to be un-worked do exhibit bedding, and though it is often poor, it is reasonable evidence that the deposits formed in water from slow ash falls. Such poorly-bedded deposits are seen from Quezaltepeque to Salfate along the road, where they are interbedded with minor conglomerates composed of andesite flow and to a much lesser extent, limestone.

The andesite fragments that make up the breccias near Esquipulas (for example at 44.0, 11.6) have not been traced to the flows they came from. It is on the evidence that the breccias
contain angular fragments as large as boulder size and are un-diluted by other constituents over a wide expanse, that flows are thought to have been abundant here. In other parts of the area andesite flows are found interbedded with the red beds, for example, east of La Cumbre 1.5 kilometers (44.5, 18.8) and just north of the Río Anguiatú (37.0, 95.0). Most of the small dikes of andesite and basalt that intrude the Subinal appear to be younger than the overlying tuffs. One possible exception is the dike along the Río La Conquista near La Calera (39, 22). This dike was emplaced along a major fault which separates Subinal from Cobán limestone.

Figure 4 is a diagrammatic representation of a north-south section through the northern Subinal basin during deposition of the formation. The relationships of flows and coarse clastics to basin geometry is presented from field evidence.

Hirschmann (1963) lists volcanic rocks, rhyolite and andesite, as relatively abundant constituents of the Subinal of El Progreso area, occurring in greater amounts than limestone, schist, or plutonic rock fragments. Mr. Eric Bosc, currently studying the San Agustín Acasaguastlán area, reports personally that the Subinal of that area characteristically bears andesite fragments. The author has noted that andesite fragments are abundant in red beds on the Río San José near the Hacienda San Miguel of the Metapán area. There is evidently a greater proportion of volcanic rock in the Subinal of the Esquipulas area than any other area mentioned; but volcanic rock is characteristic of all of these Tertiary beds, and andesite appears to be the most common type.
DIAGRAMMATIC CROSS-SECTION OF SUBINAL BASIN
PRIOR TO DEPOSITION OF PADRE MIGUEL GROUP

SUBINAL Fm.
COBÁN LS.
TODOS SANTOS FM.
SANTA ROSA GR.
ANDESITE FLOW

DIAGRAMMATIC SEQUENCE OF POST-SUBINAL FAULTING
AND DEVELOPMENT OF CONGLOMERATES AND FLOWS

FLOWs (SAN JACINTO Fm.)
PADRE MIGUEL THIN-BEDDED TUFF
PADRE MIGUEL SILLARS
SUBINAL Fm.
COBÁN LS.
A limestone conglomerate or "pudding stone" described by Dürr and Stober (1956) lies on top of the limestone of the Metapán area. A thick sequence of limestone conglomerate is also reported by Crane in the Jocotán area, developed upon thin-bedded Cobán limestone. No mappable expanses of limestone conglomerate are found in the Esquipulas area, though they occur in isolated patches as a mantle on Cerro El Sillón. The conglomerates are made up of well-rounded limestone fragments cemented by calcite, limonite, red clay or as Dürr and Stober note (1956), by silica. The diameter of the pebbles is up to 20 cm.

Dürr and Stober (1956) recognize a unit referred to as "conglomerates of limestone with sand" (writer's translation) which lies above the limestone conglomerates. This is a unit which contains more sandstone than the underlying conglomerates and is gradational into them. Grading upward from the conglomerates of limestone with sand is a unit called "sandstone with conglomerates". This is the more typical Subinal lithology of the Esquipulas area. Limestone fragments decrease in size and quantity upward through these three units. Hirshmann (1963) notes that limestone decreases upward in the Subinal section of El Progreso, which is also observed in the Esquipulas area, though there is not as well defined a vertical sequence of reworked limestones. Only in isolated localities could the base of the Subinal be called a limestone conglomerate (as on Cerro El Sillón). However, a basal conglomerate of reworked phyllite fragments is common in the map area close to the metamorphic rocks, and a similar sequence to that of Dürr and Stober (1956) could be defined, but
on a metamorphic rock fragment basis instead of limestone fragments. But the Subinal so closely reflects local provenance that neither of these descriptive systems could be carried far from the immediate area of the source rock.

The Subinal is in places overlain by pyroclastics that have been partially altered through transport or deep weathering. They are generally non-bedded and conglomerate-free, representing a transition between the well-worked Subinal and the massive-bedded Padre Miguel group sillars (see below). These volcanic sediments are commonly seen between the Subinal and Padre Miguel in the hills east of Quezaltepeque. Apparently these sediments were deposited at about the time the tectonic basin was filled and their contacts with older rocks probably wandered up ravines on the marginal lands. They indicate that a large amount of material was deposited in a relatively short time, for even in a wide and shallow basin environment, slowly accumulating sediments could become bedded and water-worn. These rocks are more reasonably identified with the Padre Miguel group than the Subinal and have been mapped as such.

Tuff increases upwards in the Subinal, grading finally into the intermediate deposits discussed above. In areas where the Subinal is missing through non-deposition, the older rocks are often overlain by thick deposits of tuff with vein quartz pebbles derived from the Santa Rosa group phyllites. These deposits are generally adjacent to exposed phyllites or overlying them, being equivalent in time perhaps to parts of the Subinal of this area. These rocks may be seen near Ermita (35, 99), San José (38, 03) and Esquipulas (45, 09).
Hirschmann (1963) estimated that the Subinal of El Progreso area is Middle Tertiary in age. It was determined to be younger than Cenomanian on the basis of Upper Cretaceous fossils in limestone fragments found in the sequence. Sapper (1937) dated the Motagua valley red beds as Miocene, apparently on the basis of andesite fragments which he believed to have erupted in the Tertiary. Williams et al. (1964, p. 15) are confident of a Tertiary age for the oldest of the red beds, favoring a Middle or Late Tertiary estimate.

This author feels that the exact age of the Subinal of the Esquipulas area is still an uncertainty. Although a late Cretaceous age cannot be ruled out at this time, a Middle to Late Tertiary age is believed to be more probable.

**Tectonic Setting of the Subinal**

Aerial distribution, thickness, and direction and character of lithologic variation of the Subinal have an important bearing on interpretation of post-Cretaceous tectonics. The Subinal appears to have been deposited in relatively narrow (for the northern basin from 15 to 20 kilometers) elongate graben basins, whose axes are parallel to the Motagua fault trend, which is around N70°E at this longitude. Fault and fracture patterns as well as distributions of pre-Tertiary rocks also lead to this interpretation.

The great bulk of the Subinal red beds in this region was derived contemporaneously from volcanic rock, with andesite flow fragments and tuff as dominant material. Volcanism that accompanied trough development was apparently active along marginal faults where
today one finds andesite boulder breccias. Evidence of this relationship also exists a short distance to the south in the Metapán area where limestone is found overlain by thin andesite flow and an andesite and limestone fragment conglomerate is the Subinal lithology (Stirton and Gealey, 1949, p. 1740). This exposure appears at what is probably the margin of a similar Subinal basin, whose northern limit is defined roughly by the Río San Miguel, but which has been covered by Cenozoic volcanics that blanket the entire region to the south. Andesite flows have been found by the writer well inside of the Subinal basins, interbedded with clastics.

Related Tertiary Deposits

The pattern of distribution of Tertiary red beds and conglomerates in Guatemala is such that they appear to be related to the structure of the Central Cordillera, but more specifically to the major faults north and south of this mountain system. Their linear distribution along the Motagua, Polochic and Jocotán faults and in patches along the westward extension of the Jocotán fault into the Chiquimula area and beyond, as well as between the zones of major east-northeast faulting of the Esquipulas area, is more than an accident of Tertiary topography. These were the belts of Tertiary volcanism. The relationship of the Sepur formation of northern Guatemala to Polochic faulting is not known, yet its linear east-west outcrop belt and mountain-bounding position suggest an analogous relationship to the Subinal of the Motagua fault zone.
The Sepur and Subinal formations are made up of a diverse but similar group of components. Terrestrial conglomerates of the Sepur contain andesitic volcanic rocks as does the Subinal of the Esquipulas area and to a lesser extent, the El Progreso area. Table 4 lists these similarities. Absence of Tertiary continental deposits in the Cordillera (with possible exception of two small areas in the Cuchumatanes mapped by Sapper (1899) has been noted by Williams et al. (1964). Tertiary volcanic flows also are missing in this region, in the low mountainous region between the Motagua and Jocotán faults and in the mountains of the Esquipulas area. Thus flows and continental clastics are absent in the zones between major faults. One might explain this absence by a rather thorough erosion of the three or possibly four mountainous areas in consideration. But experience in southern Guatemala has led the author to conclude that neither the flows nor clastics existed there, except possibly very near the margins. The Cobán limestone of the Jocotán area is shrouded by a limestone conglomerate, believed by Crane to be equivalent in age to the earliest Subinal of the basin areas. This conglomerate is not substantially eroded away and neither would one expect the red beds or flows to have been completely removed by erosion, had they existed there.

A genetic relationship among continental deposits of Guatemala, parts of southern Mexico, El Salvador and Honduras is strongly suggested. Not enough is known of the ages of these deposits to determine whether basin development was parallel in time as it appears to be in space. In the northern part of Guatemala near Cahabón village
<table>
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</table>

^1 Hirschmann (1963).

^2 Sapper (1937).

^3 Vinson (1962).

^4 Dürr and Stober (1956); this writer's correlation.
(Alta Verapaz) the Sepur formation was estimated by Sapper (1937, p. 31) to be of Eocene age and later Vinson (1962) suggested it to be Late Cretaceous, probably Turonian. The Subinal of the Motagua valley area as discussed above is estimated to be Middle Tertiary. Ages of other interesting continental clastics can be compared in Table 4, where agreement is good for the ages of all formations with the exception of the Sepur, estimated to be older than the other formations listed.

**Tertiary Topography**

Tertiary topography was, from all evidences, generally rugged. Williams et al. (1964, p. 19) speak of a rugged pre-volcanic surface in southeastern Guatemala which existed prior to Tertiary volcanism. It is this author's opinion that the land surface at the onset of volcanism was probably not as rugged as the great thicknesses of Tertiary red beds would at first indicate, as they appear to have deposited in basins controlled more by gradual, active tectonics than of tectonic controlled erosion; they are in at least one belt, across the northern Esquipulas area, a true graben basin (see below).

The earliest sedimentary rocks that are believed to be Tertiary in this part of Guatemala are the limestone conglomerates that lie above Cretaceous Cobán limestones. They have been studied by Crane who finds they make up a discrete mappable unit of some 30 meters thickness, composed of well-rounded and generally well-sorted cobble-sized limestone fragments with a red sand matrix. He finds that they contain volcanic ash. Similar conglomerates are found on
El Sillón in the Esquipulas area and in the Metapán area (Dürr and Stober, 1956). Metamorphic rock fragments appear to be lacking in these rocks, which could indicate that the Santa Rosa phyllites were not yet exposed. Crane believes the Jocotán area limestone conglomerates formed mainly in the eroded center of an anticline, where the exposed rocks were the thin-bedded lower Cobán limestones. The topography of the pre-volcanic surface in the Tertiary or possibly late Cretaceous was probably a limestone topography, with an erosion produced relief controlled at least partly by Late Cretaceous-Early Tertiary folding and thrusting. The Subinal basins developed after the limestone conglomerates formed, as near the northern margin of the Esquipulas area the Subinal is composed of boulders of this conglomerate.

The topography at or near the end of the Tertiary was of low relief, with thick sequences of tuff filling the remaining space in the Subinal basins. Tuff covered all but the highest peaks of pre-Tertiary rocks on adjacent horst blocks.

Hirschmann (1963) notes that serpentine is one of the major components of Subinal conglomerates of the El Progreso area, second only to quartzite and vein quartz in abundance. Serpentine has not been found in Subinal conglomerates of the Esquipulas area, allowing speculation as to a northern drainage during the development of the basin deposits. With the knowledge that the nearest known source of serpentine is near the Montagua valley in the Chiquimula area to the northwest, one can assume there was no drainage into the basins of the Esquipulas area by rivers coming from the north. It is likely
that the Motagua valley was almost as pronounced a feature as it is today, being the deepest valley and the most prominent drainage course of the region.

**Differentiation of Red Beds**

Beneath the Cobán formation and in some places overlying it are clastic beds that bear a striking resemblance to each other. The Todos Santos and the Subinal both contain conglomerates, sandstones, shales and siltstones in colors generally red or reddish brown. Neither of these formations has been found to contain fossils in this area.

The most important criterion for distinguishing between these two formations has been the presence or absence of volcanic rock fragments. The Subinal contains volcanic rock fragments in abundance whereas the Todos Santos exposures in the area appear to be devoid of volcanic rock. This criterion was followed by Williams et al. (1964, p. 17) though they subsequently found from microscope study that spilitic and keratophyre occur in the Mesozoic as well as the Tertiary sandstones. They conclude that fresh volcanic rock fragments including basalt, andesite, dacite or rhyodacite is indicative of the Tertiary beds.

The Subinal in the Esquipulas area occasionally contains shales, clays and fine silt beds for which this criterion is difficult if not impossible to apply in the field. Though pebble conglomerates are frequent and usually contain volcanic rock fragments, where such fragments are lacking or where exposures are poor, it is
difficult to be certain which sequence is present. Near the village of Apantes along the route of the new road there are thick sequences of dark reddish-brown and violet-brown shales, siltstones and sandstones that are devoid of conglomerates. These rocks overlie the Santa Rosa phyllites, which crop out just beneath the capping tuffs on the mountain immediately south of Apantes. The entire phyllite and clastic sequence dips northward. There is a basal conglomerate of phyllite fragments in these sands and shales, but this could belong to either of the red bed sequences. Under the microscope one can see that the fine clastics are primarily fresh volcanic glass which could hardly be as old as the Jurassic sequence.

The solution applied to the red bed problem in the Esquipulas area may not apply far away from the area, but the following criteria were used to distinguish between the Subinal and the Todos Santos:

(1) The Subinal is presumed to contain a much greater proportion of volcanic rock fragments than the Todos Santos. If these fragments are fresh reddish-purple, violet or gray andesite fragments or glass, they are almost certainly indicative of the Subinal.

(2) The Subinal is apparently the only red bed sequence with limestone fragments. Fresh water limestone beds have been found in the Subinal in the Esquipulas area, but are quite distinctive and restricted.
Since the Subinal formation is locally made up of older sedimentary rocks, the possibility exists that it was derived in some places from the Todos Santos. This is a problem in the vicinity of Ermita where red beds of the Subinal are in contact with red beds of the Todos Santos. Distinction between the two here must be made by microscope.

**Padre Miguel Group**

A thick sequence of siliceous massive-bedded tuffs, waterlain tuffs, sandstones, volcanic flows and laharic deposits occurs as the youngest rocks of the region. Referred to by the new name Padre Miguel group, this sequence overlies the Subinal formation and covers pre-Subinal Mesozoic and Paleozoic rocks of the highlands adjacent to Subinal basins. The name comes from the village of Padre Miguel, which is on the road midway between Quezaltepeque and Concepción las Minas. Figure 6 shows relationship between massive tuff, thin-bedded tuff, volcanic flows and laharic deposits of this group.

In terms of aerial distribution the tuffs and tuff-derived rocks are the most widespread of the map area, and blanket a vast portion of western Honduras, northwestern El Salvador and southeastern Guatemala. Thicknesses are quite variable, the maximum determined for the Esquipulas area being 450 meters. Dürr and Stober (1956) report a thickness of some 400 meters of tuff near San Miguel village in the Metapán area. Meyer (1961) notes that 450 meters of tuffs are found in the mountains of Honduras bordering El Salvador.
**STRATIGRAPHIC SECTION OF PADRE MIGUEL GROUP**

LAHARIC DEPOSITS, ASH DEPOSITS, BASALT AND RHYOLITE FLOWS, SANDSTONES AND CONGLOMERATES; FORMATION DEFINED ON APPEARANCE OF FIRST BASALT FLOWS OR BASALTIC LAHARS.

BEDDED WATER-LAIN TUFFS: BEDDED TUFFS, SHALES, SANDS AND CONGLOMERATES WITH INTERBEDDED THICK, PUMICEOUS NON-BEDDED TUFF; COLORS WHITE, CREAM AND YELLOW.

MASSIVE SILLARS: MASSIVE-BEDDED, VITRIC, CRYSTAL AND LITHIC TUFFS; RHYOLITIC SILLAR DEPOSITS SOME OF WHICH ARE CLIFF FORMING AND SLIGHTLY WELDED; INDIVIDUAL UNITS UP TO 90 METERS THICK; CONTACT WITH UNDERLYING (IN PLACES) RED BEDS IS GRADATIONAL, WITH RED-BROWN TO YELLOW POORLY-BEDDED TUFFACEOUS CLAY AND SAND INCLUDED AS THE BASE OF THE SECTION.
It is thought that the combined thickness of both massive and thin-bedded tuff will exceed 450 meters in the areas where the massive tuffs have been downfaulted and water-deposited sediments have accumulated above (see below). Massive tuffs are thinnest where they lie above pre-Tertiary rocks on the old marginal lands to the Subinal depositional areas. They are thickest to the east and west of the central highland area, where down-faulting enabled the thick sequence of well-bedded tuffs to accumulate. The thickest sequence of massive tuffs is above the Subinal formation, where the tuff was deposited within the depositional basin.

Massive bedded sills\(^1\) are the dominant rocks of the Cebollas plateau, forming high, steep cliffs to the southeast above Quezaltepeque. Exposures along the trails from the village of Pata de Buey to the village of Cebollas and Tierra Colorada to Cebollas are selected as typical of the massive-bedded sequence. Some of the deposits in this sequence are distinctive enough in lithology to provide a basis for local determination of structure. One distinctive lithic tuff found on the Cebollas plateau (40, 15) is also present in the western graben area (31.9, 13.7). In general the poor exposures and extensive faulting make subdivision of the tuffs impractical for large areas.

\(^1\)Poorly indurated tuff. The name given to rhyolitic tuffs of the Arequipa region of Peru (see Fenner, 1948; Jenks and Goldich, 1956).
Included in the Padre Miguel group is a wide-spread sequence of thin-bedded sandstones, shales, conglomerates and interbedded pumice deposits found east and west of the central highlands. These strata are primarily water deposited, having accumulated during or after block faulting which limited their distribution. These deposits formed from the re-working of tuffs from adjacent highlands and from contemporaneous ash falls. The thickest of these deposits is seen in the northeast part of the area in the cliffs north and east of the town of Chanmagua. From the village of Rodeo on the north end of the Esquipulas valley into the hills to the southeast one sees a sequence of around 400 meters of bedded tuffs, unbedded tuffs and conglomerates. It is thought that angular unconformities may be numerous within the sequence of bedded tuffs, because the youngest are without exception dipping the most gently into the Esquipulas valley, which is the major structural feature to have developed after the sedimentary sequence had begun to deposit.

Atop the Cebollas plateau and on other high tuff-blanketed terrain one finds red and yellow clays that may be the decomposed remnants of the more recent ash falls, at least in part. These clays are indistinguishable from badly decomposed older tuffs, which weather badly in the high moist mountains.

In this area it would be possible to map the two recognizable tuff divisions of the Padre Miguel separately if greatly detailed mapping were desired. The sedimentary section is predominantly bedded, yet some massive tuffs are included. The massive-bedded older tuffs include occasional well-stratified tuffs as well.
Where vegetation and soil cover is abundant the two divisions are essentially indistinguishable, for they support the same soils and vegetation. The dense faulting adds to the difficulty in distinguishing between the two. In the plateau areas tuff debris at the base of steep cliffs not only conceals, but can be confused with badly weathered Padre Miguel.

The uppermost part of the Padre Miguel group consists of interbedded pyroclastics, basalt flows, laharc deposits and conglomerates, included as a whole as the San Jancito formation by Crane. The age of these deposits is not known with certainty, although it is suspected that they are of a Pliocene-Pleistocene age range.

Near the village of Palmitas (58, 20) fossil wood is found in the sedimentary tuff sequence.

It has been mentioned that thicknesses range widely in these tuff deposits. The massive-bedded sequence is known to be thinner in the eastern part of the area. The lower contact was never seen and it can only be estimated that the section is perhaps half as thick in the vicinity of Chanmagua as near Padre Miguel, making it around 225 meters thick. The sedimentary sequence here is several hundred meters thick, while in the Cebollas plateau it is entirely missing.

A pink crystalline tuff is found northeast of Pata de Buey (36, 13) which is similar to the white tuff previously described from Río Lucia Sazo. The red coloration is the result of hematite staining that is concentrated along tiny fractures and in pores.
Just north of Quezaltepeque the Río La Conquista cuts through a ridge of high hills, the eastern part of which is made up of an accumulation of vitric rhyolitic tuff agglomerate. These lapilli-sized fragments are extremely soft and angular, and contain no other fragments, which suggests they fell into place without reworking. They are intruded a kilometer to the east by a small rhyolite stock. This was probably an important eruptive center for the latest tuffs of the Padre Miguel group.

The new road from San Jacinto to Quezaltepeque passes through cuts in very young volcanic flows and sediments, mapped as the uppermost part of the Padre Miguel group, called the San Jacinto formation by Crane. These are predominantly river deposits with interbedded pumice, basalt flows and bombs and conglomerates. They differ from the lower water-lain tuffs that are included with the Padre Miguel group in that they contain rhyolite flow, basalt flow and material derived from basalt. These deposits are restricted to the zone of basalt flows in the western garden area. The sequence is composed mainly of channel conglomerates, lahars, flows, bedded tuffs, and pumice deposits. Conglomerates are made up of rhyolite and perlite flow fragments, basalt flow and rhyolitic tuff fragments. The exposed section shows some relatively recent faulting quite clearly. This portion of the Padre Miguel formation is estimated to be Pleistocene in age.

Near the village of Bujorjes (54.0, 12.0) one finds large, generally well-rounded boulder-sized fragments of gray, pumice-rich tuff which are contained in white, poorly consolidated water-lain
tuffaceous sediments of the Padre Miguel. These clasts are up to 4 meters in diameter with the majority smaller, but gravel-size fragments and smaller are absent (see photograph, Figure 7). Some of these show evidence of welding, with flattened pumice fragments (see photograph, Figure 8). Sparsely distributed in the tuffaceous sediment, they are seen over a wide area along a line parallel to the Esquipulas valley margin from the above locality to the intersection of the road and the Quebrada de Mal Paso (53.3, 09.5) several kilometers distant. In postulating a means of emplacement for these clasts one must take into account the following facts:

(1) they have not indented the underlying sediment as by falling in shallow water or on land in soft sediment
(2) they are not fractured as though they might have fallen on a hard surface
(3) they represent a narrow range of sizes, from large cobble to boulder
(4) they are rounded and not angular
(5) some have characteristics of welded flow fragments, with flattened pumice and higher density than others

Rock with an identical appearance is seen on the road southeast of Quebrada de Mal Paso (53.9, 09.0) as a flow. The possibility that these may be volcanic ejecta is discounted because of the flattened pumice, which is not preferentially oriented now with respect to surrounding bedding. Furthermore there is a lack of smaller lapilli-size fragments. Although rounding could be an original characteristic
Gray pumice-rich tuff clast in water-lain yellowish-white tuffaceous sedimentary rock. Absence of fine clastic material suggests sliding as a method of emplacement.

Figure 7

Partially welded tuff with flattened pumice fragments.

Figure 8
of the fragments were they ejected from a fissure, they could as well have attained it by weathering in place. This is believed to have occurred, with subsequent sliding, gliding or for the more pumice-rich, floating for short distances, all being possible means of transport.

The Padre Miguel group is in part time equivalent to the Subinal, for it was being deposited on the highlands at the time of formation of the tuff-rich red bed sequence most characteristic of the younger Subinal. How successfully it was removed by erosion prior to the deposition of the Padre Miguel tuffs is not known. Certainly one cannot assume that the tuff sequence is everywhere younger than the Subinal in the Esquipulas area, though the vast number of exposures are obviously younger. The sequence of sedimentary tuffs and flows is younger than the Subinal throughout the area. The entire Padre Miguel sequence is thought to range in age from Late Tertiary through Pleistocene. The sedimentary facies with interbedded volcanics (San Jacinto formation) is possibly Pliocene-Pleistocene.

**Alluvium**

Recent alluvium forms thick deposits in the major rivers of the area and in the Esquipulas and Chanmagua valleys. The most extensive and the thickest alluvial deposits are in the Esquipulas valley, where white and yellow conglomerates, principally of tuff from the Padre Miguel formations, are flat-lying over most of the valley. Older conglomerates, possibly Pleistocene, are exposed as inliers near
the eastern margin of the valley from Boyeros northward a few kilometers, presumed much older because they are indurated and are dipping at about 15 degrees to the west. The Recent valley alluvium is composed of reworked red beds from the Subinal formation in the vicinity of Esquipulas, where tributaries of the Río Zepoctún have deposited it. The Río las Minas and Río Brujo have accumulated vast thicknesses of gravel where they have meandered after reaching the low relief of the western graben area.

Steeply inclined Recent red alluvium is found along a fault zone near Casa Quemada (36.8, 09.8; see photograph, Figure 16).
STRUCTURAL GEOLOGY

Two distinct tectonic patterns are recognizable in southeastern Guatemala, mirroring on a local scale major features of the Central Cordillera and the Pacific Cordillera. Divergence in the tectonic pattern is seen to have occurred after Tertiary block faulting which followed late Cretaceous or early Tertiary folding and thrust faulting. Through an unknown span of the Tertiary there was normal faulting and graben development parallel to the ancient "Motagua trend" or the trend of the Central Cordillera, but near the end of the Tertiary after the thick accumulation of tuffs had begun, the direction of faulting shifted to more northerly, forming a transecting set of grabens and horsts. Faulting parallel to the Motagua trend persisted during the time of this transection, but it is restricted to the zones of Tertiary faulting and is presumably associated with the old fault zone. Both Tertiary and Quaternary faulting were attended by volcanism, and as will be discussed below, there were notable differences in the volcanism of the two periods.

Early Tectonics

One can say little about the Paleozoic or Mesozoic tectonics in this part of Guatemala, for strong deformation of the late Cretaceous or early Tertiary has likely re-shaped any non-aligned fabric
from earlier times. The degree to which Paleozoic rocks were folded prior to the formation of the Mesozoic sedimentary sequence is not known, yet it is the author's opinion that the phyllites of the Santa Rosa group received most of their metamorphic alteration prior to the deposition of the Todos Santos formation. It is likely that metamorphism occurred during emergence at sometime prior to the Jurassic, as postulated by Roberts and Irving (1957, p. 34) and others.

Exposures of pre-Tertiary rocks in the Esquipulas area are few and one must go to adjacent areas to see the degree to which Cretaceous limestones are folded. The Jocotán area adjacent to the north, for example, has anticlinal structures mapped by Crane. These structures are folded along axes parallel to the regional Motagua trend.

Foliation of metasedimentary rocks of the Esquipulas area is parallel to bedding planes, and in the small area where they are best exposed near the town of Concepción las Minas, their strike is exclusively parallel to the regional trend. No major structure can be seen in these rocks, but on a scale of a few meters one finds abundant small folds with axes along the regional trend.

In the Jocotán area Crane has found evidence for faulting during the deposition of the Cretaceous limestones.

**Tertiary Faulting**

Tensinal deformation was a final stage in the series of tectonic events that accompanied the orogeny of the late Cretaceous
or early Tertiary. The major Tertiary faults of the Esquipulas area bound a graben basin filled with red beds of the Subinal formation (see above), an accumulation of over 1000 meters of volcanic debris, reworked limestone and phyllite. Other major faults of southern Guatemala are zones of accumulation of thick sequences of continental clastics. The Subinal formation appears along the Jocotán fault which trends east-northeast, and along its apparent extension to the west, mapped by Williams et al. (1964, Figure 2). Wherever the Subinal is exposed in the eastern part of the area depicted on the small scale geologic map of Figure 9, there are major faults parallel to the Motagua structure. These faults separate limestone from Subinal just north of Quezaltepeque and phyllites from Subinal near Esquipulas.

The largest concentration of east-northeast faults occurs in the Tertiary red beds of the Esquipulas area. In the area mapped by Williams et al. (1964), which is west of the Esquipulas area though it includes the westernmost part of it, faults along the older east-west trend are rare. Most faults of this trend bear in a north-south and northwest-southeast direction. Apparently the Motagua trend is Tertiary or older.

Faults in the Subinal are more difficult to find than in the overlying tuffs; there are several indicators used in combination with one another that aid in their location, mainly the following: anomalous strike and dip of strata, hydrothermal alteration of strata, springs, thermal springs, igneous dikes and anomalously straight-coursed streams which have located themselves along zones of weakness.
Stereographic projections of the attitudes of Subinal beds indicate that there has been drag-faulting along the margin of the basin of deposition, with a likelihood that some occurred during the time of deposition of the Subinal (See Appendix 3). Subinal basin subsidence was probably periodic, occurring along with red bed deposition.

It is the author's belief that the Subinal belt of red beds of the Esquipulas area along with its dense system of Tertiary faults extends beneath the volcanic cover of the Ipala graben complex, trending east-west in the subsurface across the Ipala quadrangle and possibly beyond. Small isolated patches of red beds are found with the limestones at the margins of the projected basin (see map, Figure 9). No doubt the belt extends under the tuffs into Honduras on the east as well.

The exact age of graben formation like the age of the Subinal formation itself is conjectural. As stated above, Hirschmann (1963) and Mc Birney (1963) estimate that the Subinal of the Motagua valley area is Middle Tertiary. Mc Birney has suggested an Eocene age for uplift and reverse faulting of the Central Cordillera. It is reasonable that tensional features developed soon afterward, but no closer estimate than Middle Tertiary can be made from information at hand.

**Late Tertiary-Quaternary Faulting**

Block faulting began again after the sills of the Padre Miguel group were deposited, but the faults were transverse to the
east-northeast Tertiary faults. This later transverse trend includes north-south faults, some of which bound prominent graben valleys of the region. Williams et al. (1964) make note of a large number of north-south faults found in their reconnaissance mapping.

Prominent features that run transverse to the older regional structure are the western graben area and the central highlands. Cross-sections A-A', B-B' and C-C' (Figures 10, 11 and 12) show the nature of the structure in the central highland area, which is a horst block that contains the most diverse geology in the area, upon which red beds of the Subinal as well as inliers of Paleozoic and Mesozoic rocks are exposed. The Western graben area is part of the Ipala graben complex, a feature which is internally faulted into smaller tilted blocks.

The above prominent features are separated by a complex fault zone which runs in an arc through the western portion of the area, extending into El Salvador on the south. Chapman (1957) has mapped an area in northwestern El Salvador that includes Lake Güija in which he finds faulting with several hundreds of meters displacement on a generally north-south trend. This may be a continuation of the arcuate fault zone to the north. The western graben area (or the Ipala graben complex) is delimited by the arcuate fault zone. It is marked by a narrow band of basalt flows with interbedded basalt bomb layers, that are a part of the San Jacinto formation. The bombs attest to a close source of eruption.

Late-Tertiary Quaternary faulting can be thought of as having occurred in two stages as follows: (1) a stage of graben development
to the west of the present highlands and probably to the east, forming
the three major topographic divisions of the map area (see Figure 5);
this faulting was followed or in part accompanied by basalt flows,
(San Jacinto fm.) and (2) a later stage of further movement, speci-
fically of tilting in the direction of the central highlands. Basalt
flows and basalt bomb layers are concordant to the underlying tuffs,
thus the tilting which is as much as 40 degrees to the northeast
must have occurred after the extrusion of basalt. This tilting was
accompanied or followed shortly by rhyolite and perlite flows and
shallow intrusives.

On top of the Cebollas plateau and the rest of the central
highlands the sedimentary sequence of the Padre Miguel group is
absent. These deposits formed in the western graben after its de-
velopment had begun, and they have obscured sections of the fault.
To the east of the Cebollas plateau in the hills around the Esquipulas
valley, one finds a thick sequence of water-deposited tuffs, identical
to those in the western graben area even to the lithologic character
of interbedded ash deposits. This part of the area has had a similar
history of downfaulting, though the faults were complex and have very
likely been obscured by waterlain tuffs.

The following general statements can be made about the char-
acter of the faults that developed during the Quaternary with refer-
ence to different parts of the area:

(1) In the western graben area Late Tertiary-Quaternary
faults are oriented strongly in a near north-south
direction (see Figures 9 and 13). Here the faulting is apparently part of the Ipala graben complex.

(2) Late Tertiary-Quaternary faulting in the central highlands is directed more to the north-northeast or east-west, with a smaller proportion on a north-south trend.

(3) Faults that seem to be part of the arcuate Ipala north-south trend are prominent east of the central highlands. The Motagua trend in this part of the area is strong, reflecting movement along older faults.

Fault traces are relatively straight even as they cut across rugged topography, confirming measurements of the fault planes, indicating that they were high angle faults close to the surface. Graben faults are usually multiple, parallel step faults which give an exaggerated view of the thickness of the Padre Miguel by distributing the total throw. This step faulting is unusually well displayed at the southern margin of the Esquipulas graben (see below).

The block faulting that occurred after the Padre Miguel sillars were deposited is thought to be Pliocene-Pleistocene in age, as it controlled deposition of the thin-bedded tuff sequence of that probable age. The age of Volcán Ipala and volcanic rocks within the Ipala graben is considered by Williams et al. (1964, p. 27) to be Quaternary. Fault patterns and distribution of flows in the Esquipulas area show a geometric relationship to Ipala volcanism and faulting (see Figure 9 and Plates 1, 2 and 3). Faulting is known to have followed basalt and rhyolite flows of the map area, thought
Fault trends in the Esquipulas area

Fault magnitudes represent cumulative lengths of faults in areas depicted (see Appendix 4).

Figure 13
to be Quaternary in age, though a possible Late Tertiary age as well is indicated on the geologic map of Plates 1, 2 and 3, by symbols (TQₜ and TQᵣ).

Shales, sands and intermixed plant material from the Esquiplas valley (52.1, 12.7) which are dipping westward at from 8 to 10 degrees have been determined to be Miocene or younger from plant spore analyses (see Appendix 2). It is likely that the faulting and tilting of the water-lain Padre Miguel tuffs was Pleistocene, but Recent faulting cannot be ruled out. Some indications of Pleistocene and Recent faulting are the following:

(1) High areas are often swampy with very poorly developed drainage. Even such areas in which the rock is easily erodable show extremely immature drainage patterns and are swampy (see "Geomorphology", below).

(2) Alluvial deposits that lie on top of young volcanic rocks such as the perlites have been tilted. These deposits are believed to be Pleistocene (see "Alluvium", above).

(3) Dip slopes are still very much apparent even on easily erodable tuffs and red beds.

(4) Active hot springs are found along faults.

(5) Recent earthquakes have occurred in the area (Gutenberg and Richter, 1949).
View of El Sillón looking southwestward from Socorro; small normal faults in the Cobán limestone are clearly seen in this photograph.

Figure 14
Limestone fault breccia from near Quesera (Cobán fm.)
(35.7, 03.9)

Figure 15

Recent tilted "red beds" from near Casa Quemada
(36.8, 09.8)

Figure 16
faults are transected by a set of north-northwest faults normal to the first. Few of these numerous faults have a displacement of over 25 to 50 meters, yet combined they make the tuff sequence appear to be more than 1100 meters thick from the valley floor to the mountains on the south (43, 02). Normal faulting has exposed the Subinal formation for a short distance along a fault scarp on the west of the Esquipulas valley (44, 13). Here the throw has exceeded the thickness of the Padre Miguel group (about 450 meters) and has exposed the underlying Subinal formation. Only the major faults of a suspected large number in the conjugate system south of the valley have been mapped. Numerous parallel faults which step the tuffs downward into the valley are evident on the north end of the valley where they form scarps.
Aerial view of southwest corner of the Esquipulas valley showing the town of Esquipulas and several faults marginal to the graben. Fault ABC runs east-northeast parallel to southern margin of the valley. A set of faults normal to this is best seen by trace along DB in the photograph.

Figure 17
Structural History of the Esquipulas Valley

The Esquipulas valley is the most prominent result of final stages of faulting in the Late Tertiary and Quaternary. The valley is a graben feature of almost equant proportions, some 40 square kilometers in area. It is a remarkable feature of topographic contrast which appears to be completely enclosed when viewed from high surrounding areas, though it opens narrowly to the southwest and northeast where it is drained by the Río Olopa. The valley is the largest expanse of relatively flat terrain in the map area. Hills east of the valley are composed of water-lain tuff interbedded with pumice layers. These deposits dip in the direction of the valley at generally low angles. Apparently there are several major unconformities within these strata as the result of intermittent graben development with sedimentation. In the sequence between El Rodeo (54, 22) and hill number 1150 about 2 kilometers southeast, the dip changes from 8 to 40 degrees in about one kilometer across strike. From (55, 15) the dip is 50 degrees to the south yet one finds the strata to be dipping at only 10 degrees south some 3 kilometers south at Bojarjes (54, 10). It should be noted that almost without exception the tuffs surrounding the valley have been drag-faulted downward in the direction of the valley at angles less than 20 degrees. The only horizontal bedded tuffs that have been found in this part of the area are in the valley proper, representing the most recent, unconsolidated alluvium.

South of the Esquipulas valley, step faults parallel the southern margin of the valley (see photograph, Figure 17). These
faults are transected by a set of north-northwest faults normal to the first. Few of these numerous faults have a displacement of over 25 to 50 meters, yet combined they make the tuff sequence appear to be more than 1100 meters thick from the valley floor to the mountains on the south (43, 02). Normal faulting has exposed the Subinal formation for a short distance along a fault scarp on the west of the Esquipulas valley (44, 13). Here the throw has exceeded the thickness of the Padre Miguel group (about 450 meters) and has exposed the underlying Subinal formation. Only the major faults of a suspected large number in the conjugate system south of the valley have been mapped. Numerous parallel faults which step the tuffs downward into the valley are evident on the north end of the valley where they form scarps.
GEOMORPHOLOGY

Topographic relief of the Esquipulas area was shaped primarily by block faulting that occurred after the deposition of the Padre Miguel group. This is seen on the largest scale by the division of the area into major graben and horst sections, represented mainly by the western graben area, the central highlands and the presumed eastern graben area. Within the major sections there has been further faulting and tilting, which controlled location and shape of smaller features such as streams and hills.

In the western graben area a drainage pattern developed in which the rivers and streams carved out numerous small generally equant hills which have dip slopes eastward. The village of Palmar (31, 14) is situated on the largest of these blocks which are bounded generally by faults and fractures that are the primary control for drainage. There is a rather restricted range of elevations of about 500 meters in this part of the area, with the maximum elevation reaching about 1100 meters.

The central highlands area runs southward through the map area, with the maximum elevation north of the Cebollas plateau reaching 1904 meters and south of the plateau rising to 2416 meters on Cerro Montecristo. The Cebollas plateau is a small feature (12 to 15 square kilometers) with a dip slope to the west. Some of its westward slope is the result of erosion. The highest elevations run along the east and southeast margins as erosion remnants, many of which are silicified
View to the west from the headwaters of Río las Minas. Distant low hills are in the western graben area.

Figure 18

Banded rhyolite flow from near El Carrizal (31.5, 21.8)

Figure 19
along faults or fractures at the margin of the fault block. Some of the resistant cliff-forming tuffs of the map area are unsilicified, dense and hard crystal tuffs, but silicification of fault scarps is probably responsible for the resistance of otherwise soft and easily erodable tuff.

Three valleys within the area are relatively flat: the Esquipulas, Chanmagua and Quezaltepeque valleys are the results of faulting. The Esquipulas valley alone is a graben valley. The Quezaltepeque and Chanmagua valleys are erosional features in the Subinal formation, but their development was controlled by the convergence of a large number of faults.

In the Esquipulas valley some rivers are degrading ancient alluvial sands and gravels. The degradation is proceeding eastward as the Río Olopa cuts into the low hills on the east of the valley, and it proceeds southward as the Río Atulapa attacks the more abrupt topography of the valley's south margin. Several sections of up to 30 meters thickness are noted within the valley that are cut through by the Río Zepoctún and the Río Atulapa. The Río Zepoctún and its tributaries are removing material from the northwest part of the valley. A low ridge of Padre Miguel bedded, consolidated tuff lies between the Río Olopa and the Río Zepoctún. Recent alluvium forms a broad slightly elevated terrace deposit between the Río Zepoctún and the Río Atulapa.

All of the drainage cutting across the southern part of the valley runs east-northeast, the direction of the boundary faults along the southern margin of the valley.
The town of Chanmagua sits on an ancient terrace deposit of the Río Chanmagua, at the center of an intermontaine basin of almost equant proportions. The Río Chanmagua flows to the northwest across this portion of the map area and there are a few limited expanses of relatively low relief along its course where the river has meandered widely. Tributaries fan out into the dissected, tuff-capped plateaus that have a maximum elevation of 1800 meters at Cerro San Isidro (66, 12) southeast of Chanmagua. Drainage has carved out a bowl-shaped basin some 7 to 10 kilometers across and 1000 meters deep, exposing the Subinal formation in the center. The physiographic setting is much like that of the area around Quezaltepeque, where faulting has influenced drainage, but erosion has been the leading agent in establishing relief.

Mountainous topography exists to the south of Apantes in the central highland region of the map area. Here a significant amount of dissection of tuff-covered plateaus has occurred. In the area near El Brujo village intrusive rocks have contributed to the rugged relief by piercing the plateaus, and along with faults, have created an erosional advantage. Most of the deeply incised rivers of the high plateau region show evidence of being fault controlled.

The entire area has an immature drainage pattern brought about by the relatively recent faulting. Drainage is poorly established in the plateaus and mountains with few exceptions. One finds swampy conditions even at high elevations in the area, as for example at La Cumbre, where the old road crosses the highest part of its traverse to
Esquipulas. Here the meadows are very poorly drained. Slumping and landslides are additional signs of immaturity that are found throughout the area.
INTRUSIVE ROCKS

There are three major groups of intrusive rocks within the area mapped. Granitic textured rocks of intermediate composition are found in the central highlands where they intrude the thick sequence of Padre Miguel sills. The basalt-andesite rocks are most common though not limited to the sectors of Subinal formation exposure, and are apparently older than the Padre Miguel. Finally, the perlite-rhyolite and basalt association occurs in the major downfaulted areas, namely the western graben area and the north end of the Esquipulas graben.

Granitic Textured Rocks

Granitic rocks of the central highlands are exposed in three localities: in the vicinity of Río las Minas, near El Sillón at Limones and along the Río Brujo near its headwaters. These rocks (TQ₁ on Plates 1, 2 and 3) are generally intermediate in composition, being diorites, monzonites, syenites and their fine-grained equivalents. Large grain size is a result of intrusion into the deeply buried Subinal or lower part of the Padre Miguel. The relationship of grain size to depth of burial is close in several dikes, notably one exposed at the headwaters of the Río las Minas where one finds fine-grained rocks contiguous with granitic rocks intruded into the lower lying Subinal downstream.
Along the Río El Brujo is the area of greatest exposure of intrusive rocks. These are similar to the Río la Minas intrusives and to rocks from one small intrusive the author has sampled from near Metapán, El Salvador. The geometries of the intrusives of the El Brujo area are difficult to know because of cover. At the few contacts seen the rocks were gray-green trachytes. The coarsest textured rocks are syenites that were observed along the trail that leads from El Brujo village to partway up Cerro Montecristo, which is near the center of a small pluton of some 5 or 6 square kilometers of exposed extent. Southwest of the village of El Brujo there are fine-grained gray dike rocks that follow the river intruding Subinal formation conglomerates. These intrusives appear at intervals in the Río El Brujo almost as far as Anguiatú, where the river turns northwestward. A similar dike goes northward from the small pluton. It is suspected that others extend radially outward from this body and are lost in the rain forests of the ridges of Cerro Montecristo and Cerro El Brujo.

**Basalt-andesite Dikes**

Dikes of basalt and andesite occur throughout the area, but are densest in the outcrop areas of the Subinal formation. These dikes are thought to be Tertiary in age and related to the flows that are interbedded with Subinal volcanic sandstones and conglomerates. The dikes are found in the principal fault zones of the northern red bed belt. One such basalt dike runs along the Río la Conquista fault (see map, Plate 1) north of Quezaltepeque for a
short distance. It is typical of basalts found in dikes and flows within the Subinal belt, being a fine-grained, pyroxene basalt (see Appendix 5, sample BB-79).

**Rhyolite-perlite Intrusive Rocks**

The western graben area has small intrusions of rhyolite and perlite scattered from north to south, some too small to be recorded on the geologic map. These are associated with faults and appear to have been intruded at about the same time the sub-blocks were tilted in this graben complex. They are all cryptocrystalline to glassy rocks whose fine texture is the result of rapid solidification near the surface (see Appendix 5, sample BB-23).

In the hills above San Jacinto these intrusives are difficult to distinguish from rhyolite flows which they fed, except where banding is prominent. Rhyolites intrude laharic deposits near San Jacinto but more commonly are found along faults in the Padre Miguel group. Though these intrusives are found with contact zones of perlitic rhyolite (commonly called "perlite"), large masses of perlite of several square kilometers extent are found which lack the essentially non-glassy, non-perlithic rhyolite (see below).

Williams *et al.* (1964) believe that the small bodies near San Jacinto may be feeders for ignimbrites. This is quite likely, though they would have to be some of the latest tuffs to have been erupted. The age of the rhyolite flows and shallow intrusive rocks is post-Padre Miguel thin-bedded tuffs (Pliocene-Pleistocene?), and the rhyolites are younger than at least some of the basalt flows
along the western graben margin. This relationship is clearly seen on the hill above the new road near the village of Río Grande (32.7, 19.6). Evidence that some of the basalt is definitely younger than one of the large perlite masses is seen on hill #1150 north of the Esquipulas valley (49, 19). The rhyolite rocks were evidently contemporaneous or nearly so with the basalts of this area. They have been included by Crane in his study of the Jocotán area with the rocks he has called the San Jacinto formation, the uppermost part of the Padre Miguel group. This author believes they are Quaternary in age, but a Late Tertiary age is not ruled out.

**Perlite Origin**

At the north end of the Esquipulas valley and near the village of El Caracol in the northwestern corner of the area there are two exposures of shallow intrusive perlite, each of which covers several square kilometers. These exposures appear to be made up entirely of perlite, with little or no non-glassy rhyolite in association. The origin of the perlite is linked with the origin of the water it contains—the essential question is whether the water was original to the rhyolitic magma or was introduced on emplacement. That the perlite cooled at or near the surface is evident from field relationships and from the almost complete absence of crystalline material in the rock.

An insight into the problem of origin of the larger bodies might be gained from the smaller intrusives, and one in particular which is in the extreme northwest corner of the map area (30.9, 22.8).
There the perlite occurs as a chill-zone selvage to small rhyolite intrusives, possibly stocks or dikes. This shallow intrusive is banded vertically, with bands parallel to the contact surface. Banding is an alternation of water-poor rhyolite and water-rich perlite, with an increase in the perlite percentage in the direction of the contact. Data on concentrations of Na and K in samples from this intrusive show a definite increase in $K_2O$ outward in the rock in the direction of the contact, paralleling a rise in $H_2O$ concentration. $Na_2O$ decreases toward the contact (see Tables 5 and 6). These distributions are the ones expected for an intrusive for which the volatiles moved out of the magma. Orville (1963) has shown experimentally that there are gradients of Na and K concentration in feldspars formed hydrothermally across a temperature gradient. Na concentrates in the higher temperature and K in the lower temperature phases. If water had been absorbed by the melt from the environment of emplacement, it is doubtful that such Na and K trends would hold. The chill zone developed at the margin of the small bodies, trapping water. The still molten, slowly cooling interior remained a path of escape for volatiles, depleting the melt in water.

It is thought that the larger perlite masses were emplaced by multiple injections and were able to retain high concentrations of water because of rapid cooling in an analogous fashion to the chill zone described above. The process of fast chilling is difficult to envision for bodies of several square kilometers extent or more as are found in the map area. At the village of El Caracol
### TABLE 5

**Na₂O AND K₂O IN RHYOLITE-PERLITE INTRUSIVE CONTACT ROCKS; FROM LOCALITY (30.0, 22.8)**

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>%Na₂O</th>
<th>%K₂O</th>
<th>%H₂O (+)</th>
<th>%H₂O (−)</th>
<th>Distance from Contact</th>
<th>Rock Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>204-A</td>
<td>3.68</td>
<td>4.83</td>
<td>0.23</td>
<td>0.48</td>
<td>1.8 meters</td>
<td>rhyolite</td>
</tr>
<tr>
<td>204-B</td>
<td>3.65</td>
<td>5.05</td>
<td>1.10</td>
<td>0.54</td>
<td>1.2 meters</td>
<td>rhyolite-perlite</td>
</tr>
<tr>
<td>204-C</td>
<td>3.16</td>
<td>5.37</td>
<td>1.71</td>
<td>1.68</td>
<td>0.6 meters</td>
<td>rhyolite-perlite</td>
</tr>
<tr>
<td>204-D</td>
<td>3.58</td>
<td>6.14</td>
<td>3.14</td>
<td>1.67</td>
<td>0.0 meters</td>
<td>perlite</td>
</tr>
<tr>
<td>204-E</td>
<td>2.90</td>
<td>1.60</td>
<td>n.d.</td>
<td>n.d.</td>
<td>--</td>
<td>laharcic country rock</td>
</tr>
</tbody>
</table>

Analyses by atomic absorption spectrophotometry (by the author).

### TABLE 6

**Na₂O AND K₂O IN RHYOLITE-PERLITE FROM A SHALLOW DIKE; FROM LOCALITY (30.5, 99.0)**

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Rock Type</th>
<th>%Na₂O</th>
<th>%K₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>296-B</td>
<td>rhyolite</td>
<td>4.83</td>
<td>3.90</td>
</tr>
<tr>
<td>297</td>
<td>perlite</td>
<td>4.70</td>
<td>5.45</td>
</tr>
</tbody>
</table>

Analyses by atomic absorption spectrophotometry (by the author).
one can see separate perlite dikes by viewing El Caracol, the small mountain, from the west along the old road.

**Age of Intrusives**

The intrusive rocks of this area are no older than the Padre Miguel tuffs and most of them are younger. Exceptions to this are the dike rocks along faults in the Subinal formation, which are thought to be Tertiary in age. The vast majority of the dikes of the perlite-rhyolite association which cut the tuffs are believed to be substantially younger, and are perhaps feeders for the most recent ash deposits. Feeders for the thick blanket of Padre Miguel tuffs would have been expected within or at the margins of the zone of Tertiary volcanic activity (the belts of red bed deposition). There is no reason to believe that pyroclastic eruption was from zones different from the zones of Tertiary flows. Note again that the Tertiary red beds of this part of Guatemala contain vast amounts of reworked tuff as well as flow fragments.

The rhyolite dikes of the western graben area around El Caracol are, as Williams et al. (1964) believe, likely feeders from which the tuff issued. Their intrusion into lahars that are younger than the Padre Miguel water-deposited tuffs precludes their being feeders for the entire Padre Miguel sequence. As stated above (see "Stratigraphy") there were probably late ash falls at frequent intervals in the area, some of which may be represented by the deeply weathered tuffaceous soils of the high plateaus, having been removed from steeper slopes.
Granitic textured rocks of the Río Las Minas and Río El Brujo areas are found cutting the Padre Miguel tuffs. The Río las Minas intrusives have given rise to hydrothermal silver deposits in veins in the tuffs. The veins are of importance economically (see below). These intrusives, though intermediate in composition for the most part, are probably contemporaneous with the siliceous dikes and stocks of the western graben area. All are post Padre Miguel massive and thin-bedded tuffs which would make them Late Tertiary, a possibility raised by Williams et al. (1964), p. 10) or Quaternary. There is doubt as to the age of the Padre Miguel tuffs themselves, and thus these intrusives are listed as Late Tertiary-Quaternary.

No rocks were found in the area which would correspond to the "Laramide" plutonic rocks discussed by Williams et al. (1964, p. 10, 11).
EXTRUSIVE ROCKS

The extrusive rocks are difficult to separate in the field from the shallow intrusives to which they are related. The intrusives discussed above are associated with petrographically identical flows in the same areas, with the exception of the intermediate granitic textured rocks, for which no such equivalents are known. Thus the rhyolitic-perlitic rocks are emplaced as flows, dikes and stocks as are the basalt andesite rocks. Extrusives are segregated into the same geographic zones as the intrusives that were discussed above. Though the Padre Miguel tuffs were treated above as a stratigraphic unit, they will be included here in a brief discussion of petrographic character.

Pyroclastic Rocks

The Padre Miguel tuffs are composed of sills and waterlain tuff which is generally of rhyolitic or rhyodacitic composition. Most of the non-bedded tuffs are sills of approximately 100 meters thickness which are siliceous, light colored, low density vitric tuffs, some with pumice, some with abundant crystals and some with abundant lithic fragments. There are few of these rocks that are welded, most being soft and porous. Lithologic integrity is known to exist for some of these units for several kilometers, but correlation becomes difficult for greater distances because of complex faulting. One densely crystalline tuff is traceable for several
kilometers along the western margin of the fault block of the central highlands, seen best at exposures near the waterfall on Río Lucia Sazo (31.8, 11.8).

The most common mafic constituent of these tuffs is biotite. Biotitic tuff \( (n = 1.499 \pm 0.002 \text{ for the glass}) \) is exposed near Salitre (34, 21), extending to near Río Grande about 2 kilometers to the southeast. A bedded, water-deposited biotitic tuff is exposed in the new road cuts near El Caracol (32, 21). A biotitic tuff is found north of Concepción las Minas just north of the river in road cuts (35, 07).

The tuffs, despite their vast thicknesses and expanse, are surprisingly uniform in several respects. They have a restricted range of glass indices \( (n = 1.499 \pm 0.002) \) which is the same as the indices for glass of the rhyolitic dikes and flows. This would indicate a silica percentage of around 72. The tuffs are mainly glassy, and there are only a few units that contain large amounts of crystals or lithic fragments.

**Flows**

Williams *et al.* (1964, p. 19) state that the Tertiary lavas and pyroclastics were erupted from fissures predominately as there is no indication of large volcanic cones. This view is shared by the author, however with some reservation. The areas that were the likely sites of Tertiary volcanism also were likely areas of graben development, erosion and sediment accumulation, which would remove or obscure evidence of their existence.
Basalt and andesite are by far the most important flow rocks of the area (see thin-section descriptions, Appendix 5). Interbedded andesites are found in the Subinal formation in the map area and in the Metapán area of El Salvador (see Stirton and Gealey, 1949). Andesite rubble is indicative of important flows along the southern margin of the northern Subinal outcrop belt as noted above.

The rhyolitic flows are found associated with the shallow intrusives, occurring primarily in the northwestern corner of the area. Some of the flows are extremely well banded (see Figure 20). The rhyolite flows are predominately cryptocrystalline and glassy rocks with very fine-grained feldspar phenocrysts (see Appendix 5, sample BB-145). The rhyolitic flows are some of the latest rocks formed.

Siliceous rocks seem generally to have been erupted at a late time, evidenced by the increased percentages of tuff vertically in the Subinal formation and by the thick Padre Miguel rhyolitic tuff sequence and rhyolite flows.
EL SILLÓN SECTION

COBÁN FM.
Albian (975 M.)

COBÁN FM.

COBÁN FM.

TODOS SANTOS FM.
Jurassic - Lower Cretaceous (100+ M.)

FIGURE 20
GEOLOGIC HISTORY

Too little is known about the oldest rocks in the area for an accurate evaluation of their depositional history. The phyllites, here called the Santa Rosa group, are pelitic and quite uniform throughout the Esquipulas area and in the southern parts of the Chiquimula and Jocotán areas. Some changes have been found in the sequence between San Pedro Pinula and Cabañas by Williams et al. (1964), the most notable being the presence of interbedded igneous rocks. The Santa Rosa phyllites were probably Late Paleozoic geosynclinal deposits, corresponding to the Tactic formation (see "Stratigraphy" above), the uppermost part of the sequence of low grade metamorphic rocks believed by McBirney (1963) to be Permian.

Succession by continental clastics of the Todos Santos formation followed a period of uplift in the Triassic. During the Early Jurassic or perhaps Late Triassic clastics of the Todos Santos formation were first deposited. The formation is composed to a large measure of detritus from the Santa Rosa which was by now at least partly metamorphosed. In southeastern Guatemala the thickness of this formation seems to range widely, and the unit is entirely missing between the phyllites and Cretaceous limestones of the Jocotán area, but whether through erosion or non-deposition is not known. The uplift in the Triassic marked the end of deep water sedimentation up to the Recent, for the sedimentary sequence
deposited from Jurassic to Recent times has been continental to shallow marine exclusively.

Transgression during the Albian left a thick deposit of limestone, the Cobán, across southern and central Guatemala. Crane has found evidence of faulting during the deposition of the Cobán limestone. It is indicated that there was normal movement downward to the south on the Jocotán fault. The accumulation of the thin-bedded facies of limestone was limited to south of the fault. Although the Albian Cobán limestone is probably marine throughout the map area, one unconformity in the El Sillón Section (just beneath the Orbitolina zone) suggests shallow water conditions.

During the Late Cretaceous or Early Tertiary there was uplift and an erosional reduction of the Cretaceous limestone was accompanied by folding and thrust faulting. The author is in agreement with Mc Birney (1963) that the intensity of "Laramide" folding and faulting was less to the south of the Motagua valley than to the north in the Sierra. A mantle of limestone conglomerate developed on the Cobán limestone in southeastern Guatemala and western El Salvador, controlled by the structure. The final stage of Late Cretaceous or Early Tertiary activity appears to have been longitudinal block faulting, where long and narrow grabens developed parallel to the structure of the fold mountains. Volcanic activity occurred along with these late tensional features, probably in the Middle Tertiary. This was the first important volcanism of the Cenozoic and was mainly restricted to the graben basins. Lavas were erupted along with pyroclastics, probably from fissures rather than
cinder cones (Williams et al., 1964); both flows and pyroclastics contributed the bulk of the sediment that filled or almost filled the Subinal graben basins. Tuff deposited on the lands marginal to the basins was largely eroded into the basins.

Great pyroclastic outpourings occurred after the Subinal formation was deposited, blanketing the entire area except for occasional high ridges of Cretaceous limestone. Eruptive centers for the earliest tuffs are not known accurately, but they appear to have originated from within the Esquipulas area as fragment sizes decrease in all directions but southward, where in nearby Honduras and El Salvador, coarse pyroclastics reach the same thicknesses as the sillaric deposits of the Esquipulas area (around 450 meters). The age of this volcanism is not known with certainty, but was possibly Late Tertiary and may have continued intermittently along with renewed graben development until as late as the Pleistocene, as discussed below.

The latest trend of faulting was transcurrent (north-south) to the Motagua trend. This faulting is related to the Ipala faulting to the west. The map area was broken into three major blocks separated by two generally north-south fault zones. The grabens that developed were sites of accumulation for tuffaceous sediments which are the upper part of the Padre Miguel tuff sequence, probably during the Pliocene-Pleistocene. Basalt flows were erupted along the arcuate fault zone separating the central highlands from the western graben area, and these flows were later tilted as the western graben area broke into smaller fault blocks. Rhyolite flows and small intrusives
as well as intermediate granitic textured rocks were contemporaneous with the basalt flows. Faulting is known to have involved some of the more recent laharian deposits, alluvial sands and gravels.
ECONOMIC MINERAL DEPOSITS

Non-metallic Mineral Deposits

Subsurface Water

Groundwater is an important resource in this part of Guatemala since the rainy season lasts only half a year and there are water shortages in the remaining months in places away from the permanent streams. Even during the rainy season some parts of the area such as the Esquipulas valley often suffer from lack of water. The rainfall for the year is more than sufficient to meet foreseeable needs, either by extending the usefulness of surface water with surface reservoirs or by utilizing the subsurface water.

Springs are abundant throughout the area at elevations which permit distribution to communities without pumping. For some isolated villages local groundwater may be obtained less expensively by means of wells. The conditions under which phreatic water occurs in the area are discussed below.

The Esquipulas area as well as adjacent portions of southeastern Guatemala, Honduras and El Salvador must be considered in their separate parts with regard to sub-surface water because of widely ranging topographic and geographic conditions. Throughout the area there is a possibility of finding small quantities of near surface water for local domestic use, although the valley areas where the thickest alluvial deposits are found are the more likely places
to encounter large quantities of phreatic water. The most obvious water-bearing material is the recent alluvium of the major valleys and along major rivers, but ancient alluvial deposits have been mapped that should serve as reservoirs (see above, "Alluvium").

The most important of the large valleys is the Esquipulas valley which contains thick deposits of Recent alluvium on top of older conglomerates and sands of the Padre Miguel group, all of which should prove to be ideal for water storage. Locally there are thick deposits of gravel and sand in the Chanm agua valley that would suffice for water storage, but by-and-large this valley must depend upon the Subinal formation for phreatic water. The Quezaltepeque valley lacks alluvial deposits except along some of the rivers such as the Río la Conquista.

The widespread Subinal formation contains porous and permeable conglomerates and sandstones that would provide good storage for phreatic water. The margins of the Subinal belt of red beds are the best places for finding thick conglomerate and breccia sequences, but rocks in the central portions of the northern belt appear to be well suited as reservoir rock, and the formation is quite thick there.

Massive-bedded Padre Miguel tuffs are not highly permeable in places where they are not abundantly fractured. Fortunately, fractures are common in the map area, especially near the faults in the western graben area. The Padre Miguel group to the north and east of the Esquipulas valley contains thick sequences of conglomerates and sands which would be ideal for phreatic water so long as topography admits to the establishment of a water table.
Aquifer water is considered to be too unpredictable and restricted in extent to be valuable. Certain portions of the Subinal and Padre Miguel might contain water under aquifer conditions, but rarely would these conditions be predictable from surface evidence.

Perlite

Large quantities of perlite, a hydrated volcanic glass, are found in the Esquipulas area. The largest of these deposits is located about 2 kilometers north of the village of Valle de Dolores (48, 17) on the north side of the Esquipulas valley, and it occurs perhaps almost as abundantly in two areas near the village of El Caracol (33, 20) and hill number 795 (34, 19).

The perlite is rather uniform in composition in the areas listed above where it is a rhyolite with a silica percentage of around 72.8 ($n = 1.499 \pm 0.002$). The glass expands several times its original volume when placed in contact with open flame, a property which should make it valuable for use as a building material in light weight concrete or as an insulation.

Advantages in exploitation of perlite from these deposits are its abundance, absence of overburden and proximity to roads.

Gravel

Gravel is abundant in the major rivers throughout the map area, notably in the Olopa, Chanmagua, Shutague, Brujo and Las Minas rivers. Of these the Río las Minas and Río Brujo carry lower percentages of soft tuff gravel than the others and should provide
better suited gravel for use in concrete. The Río las Minas and Río Brujo\(^1\) carry mainly detritus from the intrusives, andesite and limestone fragments reworked from the Subinal formation. The Río Olopa gravel has been used with apparent success in making concrete used in construction of the new road to Esquipulas and the Honduras frontier.

**Limestone**

Limestone from Cerro El Sillón is used locally for making cement for road construction. The nearest modern calcining plant is at El Ronco about 20 kilometers to the south in El Salvador. Limestone of El Sillón is an inexhaustible supply that is well exposed. Completion of a proposed new road to Metapán from Quezaltepeque would make the El Sillón limestone of potential export value.

**Clay**

There are two possible sources of clay with potential commercial value in the map area: the Subinal formation and the weathered surface of tuff deposits, which is composed of red, yellow and brown tuffaceous clay that is believed to come from the most recent ash deposits or from deeply weathered Padre Miguel (see geologic map, Plates 1, 2 and 3). The weathered tuffs are the most widespread and are more uniform in quality.

\(^1\)Also called Río Anguiaútú, Río Negro or Río Frío.
Metallic Mineral Deposits

The Esquipulas area contains silver mines belonging to the Alotepeque district\(^1\), studied in some detail by Roberts and Irving (1957). Currently the San Vicente mine near San José is the only mine in operation. It produces small amounts of argentiferous galena.

The important commercial mineralization of silver-bearing sulfides is of hydrothermal origin. The author has found that contact metamorphic deposits of sulfides are small and irregular, and there is no indication that mining has been successful in any but the hydrothermal veins. Historical evidence bears this out, with the important mines of the past following veins parallel to the major east-west fault trend in the district. It is the author's opinion that hydrothermal fluids came from and extension of the small intrusive at Limones (35, 03) or from a larger, deeper body of the same age. As seen below the attitudes of veins from once-successful mines in this district suggest relationship to this intrusive and the east-west fault which bounds it to the north.

<table>
<thead>
<tr>
<th>Mine</th>
<th>Strike of Veins</th>
<th>Dip of Veins</th>
</tr>
</thead>
<tbody>
<tr>
<td>San Pantaleón</td>
<td>N75°W</td>
<td>steeply S</td>
</tr>
<tr>
<td>Santa Rosalía</td>
<td>E-W</td>
<td>60° to 70° S</td>
</tr>
<tr>
<td>San José Grande</td>
<td>N80°W</td>
<td>75° SW</td>
</tr>
</tbody>
</table>

(from Roberts and Irving, 1957)

\(^1\) The district was named after the town of Alotepeque, which is now called Ermita.
Mineralization in the currently producing San Vicente mine has taken place along a fault which runs roughly east-west. The host rock is tuff and fault-brecciated tuff. The major vein is faulted and an attempt was being made in 1963 to relocate it, while mining at the same time from a smaller vein. Galena is the major silver-bearing mineral in the gangue of calcite, sphalerite and tuff breccia.

Contacts between the Limones intrusion and adjacent rock exhibit oxide mineralization near the village of Limones. Magnetite, hematite, limonite and manganese oxides are principal minerals at the small iron prospect on the road at Limones. Oxides of iron, manganese and copper also formed at contacts between the dike rocks at the headwaters of the Río las Minas and the host rock, which here is limestone and tuff. As stated above, these contacts have proven to be poor zones for silver mineralization. In contrast, the most productive mine in the history of the district, the San Pantaleón mine, produced pyrite, galena, sphalerite, stibnite, tetrahedrite, arsenopyrite and silver sulfides in a gangue of quartz with some calcite (Roberts and Irving, 1957).

Future exploration for silver in the area should be directed toward finding hydrothermally deposited sulfides in the tuffs. Orientation of productive veins from the old mines on a nearly east-west strike and dip to the south fits the pattern that would be predicted from the intrusives and faults mapped in the area adjacent to the district.
REFERENCES CITED


APPENDIX 1

EL SILLON MEASURED SECTION

The following section was measured along the road between the towns of Concepción las Minas and Ermita, beginning at the first road cut to the north of the first small stream at the north edge of Ermita. The base of the section begins with a sequence of sand and siltstones and clays, believed to be of the Todos Santos formation. This sequence is faulted against Subinal red beds in the vicinity of the base of the measured section. The section terminates at the town of Limones, where the uppermost unit of massive-bedded Cobán limestone is in intrusive contact with a small pluton. The sequence has a consistent strike and dip of around N80°E, 55°N and is cut by several small faults, which probably have added about ten per cent in added thickness through repetition of massive-bedded limestone.

<table>
<thead>
<tr>
<th>Meters from base of section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-100</td>
<td>Alternating beds of red sandstone and siltstone, claystone and shales; bedding highly variable from well-bedded alternating sandstone and siltstone to poorly bedded sandstone and siltstone; at the base of this section quartz pebbles are thinly distributed in sandstone layers; outcrop color is red or reddish brown; the center part of this unit is covered.</td>
</tr>
<tr>
<td>100-123</td>
<td>Thin-bedded, dense, black limestone interbedded with thin layers of yellow shale; limestone ranges from 0.3 cm. to 2.5 cm. in thickness; outcrop color is yellowish brown.</td>
</tr>
<tr>
<td>123-171</td>
<td>Dense black limestone in beds 8 to 15 cm. in thickness alternating with thin interbeds of yellow shale; weathers yellow.</td>
</tr>
</tbody>
</table>
171-187 Dense, black limestone in beds up to 20 cm in thickness; yellow shale interbeds a few cm in thickness; limestone veined with calcite; yellow weathering.

187-201 Non-calcareous, thin-bedded light-gray to cream colored shale.

201-203 Non-calcareous clayey siltstone interbedded with claystone; beds 2 to 3 cm thick.

203-209 Non-calcareous, thin-bedded light gray to cream colored shale.

209-215 Light gray limestone in beds 10 to 30 cm thick; bedding irregular; no shale partings; yellow weathering with karst features.

215-244 Covered

244-252 Thin-bedded light gray to yellow shale with scattered limestone nodules at the base of the unit.

252-306 Thin-bedded, light gray to dark gray nodular calcareous shale; nodules are limestone; weathers red brown and yellow.

306-323 Gray, shaly limestone; weathers yellow.

323-357 Very thin-bedded, nodular, yellowish brown silty shale; Mn dendrites and stain; upper three meters is a poorly bedded more silty claystone.

357-364 Yellow brown, silty nodular claystone; limestone nodules.

364-370 Massive fine-grained, gray limestone unconformably atop the nodular claystone.

370-374 Fossiliferous, calcareous gray shale; abundant large forams, Orbitolina parva.

374-383 Light gray, fine-grained, dense limestone in beds 10-20 cm thick.
383-385  Yellowish green, nodular claystone; weathers to reddish brown.

385-395  Thin-bedded, light gray shaly limestone; weathers yellow and brown.

395-399  Indistinctly bedded, gray fossiliferous limestone; fossils are molluscs.

399-415  Yellow claystone and shale grading upward into silty and sandy claystone and red sandstone; bedding indistinct.

415-417  Nodular yellow silty claystone; bedding indistinct.

417-418  Red silty claystone and shale; beds 0.3 to 8 cm thick.

418-422  Very hard, well-cemented fine to medium-grained yellow-brown sandstone; beds 0.3 to 0.6 cm thick; graded within each bed; red stained on exposed surfaces.

422-435  Red silty claystone with occasional fine to medium yellow sandstone layers with bedding from 2 to 3 cm; grades upward into yellow silty clay.

435-443  Yellow silty sandstone with beds from 0.3 to 1.4 meters in thickness; grades upward into thinner-bedded sandstone of same lithology.

443-451  Covered

451-470  Thin-bedded, fossiliferous light gray shaly limestone; weathers yellow; fossil fragments are recrystallized pelecypods.

470-485  Yellow weathering calcareous shale and thin-bedded gray limestone; some limestone layers contain molluscs.

485-541  Covered

541-548  Dark gray shaly limestone with beds from 2 to 5 cm in thickness; limestone is nodular, dense and fine-grained, veined with calcite; weathers yellow.
548-562  Light gray, shaly nodular limestone; weathers yellow.

562-566  Dark gray to black, very thin-bedded, shaly limestone; limestone is fine-grained and weathers yellow.

566-641  Medium gray, nodular, thin-bedded shaly limestone; fossil molluscs and Hemiaster? found at 596m; weathers yellow.

641-649  Gray, very thin-bedded platy limestone.

649-1075 Light gray, massive-bedded, dense limestone; bedding variable from distinct to non-bedded; beds 3 to 4 meters thick are common; weathers yellow to reddish yellow; karst topography; heavily veined with calcite.
APPENDIX 2

Pollen Analysis

Sample BB-225 Padre Miguel group; near the Olopa River in the Esquipulas valley.

Abundant Gramineae pollen
Advanced type woody tissues
Compositae polle (two types, long and short spines)

Juglans
fungal spores
Laevigatosporites
Latosporites
Punctatosporites
Deltoidospora
Pityosporites
Triporopollenites
Triatriopollenites
Tricolpites
Tricollopollenites

Age is Miocene or younger

This sample is a lignitic shale on the landing strip road 1/2 km west of Río Olopa in the Esquipulas valley (S2.1, L2.7). Esso Production Analysis was by Dr. Dan Jones, Research Laboratory, Houston, Texas.
APPENDIX 3
ATTITUDE OF BEDS

Each of the stericographic projections (Schmidt net, lower hemisphere projection) in Figure 21 is a compilation of poles to bedding planes of either the Subinal formation or the Padre Miguel group in a specific part of the area. The diagrams present information that is on the geologic map in a form that aids in interpretation of dominant structural trends in the areas selected.

Figure 21 is a plot of the poles to bedding planes of the Padre Miguel strata in the western part of the area west of easting 236. The greatest concentration of points is in the southwest quadrant, reflecting the attitudes of beds in the western graben area. Points in the northeast quadrant represent the attitudes of strata that adjoin the arcuate fault zone on the east. They are not as numerous because attitudes of the Subinal beds were not included. The remaining prominent concentrations in the southeast and northwest quadrants are representative of bedding whose strike is parallel to the axis of the Subinal basin (around N70°E).

Figure 21b presents attitudes of strata of the Subinal formation where it appears as an inlier near the village of Apantes (40, 09). The pole concentration is in the southeast
quadrant indicating that the beds dip in the direction of the Subinal basin axis.

Figure 21c presents a composite of two effects, namely, (1) drag faulting along a northeast-southwest strike at the northern margin of the red bed basin and (2) the southwestward tilting of strata toward the arcuate fault zone. Note that some red beds dip to the northwest. These strata are near some of the many faults that strike N70°E on the complex northern margin of the Subinal basin.

Figure 21d shows the attitudes of the Padre Miguel group in the vicinity of Esquipulas. There is a pole concentration in the center of the projection, representing a slight amount of drag faulting and perhaps some initial dip into the Esquipulas graben basin.
ORIENTATION OF BEDDING IN FOUR PARTS OF
THE MAP AREA

(a) WESTERN GRABER AREA—
PADRE MIGUEL GR.

(b) MAPANTES AREA—SUBINAL FM.

INDEX MAP

POLES TO BEDDING PLOTTED ON
SCHMIDT EQUAL-AREA NETS
(LOWER HEMISPHERE)

(c) QUEZALTEPEQUE AREA—SUBINAL FM.

(d) ESQUIPULAS AREA—PADRE MIGUEL GR.

Figure 21
APPENDIX 4

FAULT ORIENTATIONS IN FOUR SECTORS OF MAP AREA
(See Figure 13)

Figure 22
APPENDIX 5

THIN SECTION DESCRIPTIONS

Quartzite from Santa Rosa Group phyllites.

Sample BB-219B This sample is from a thin layer of quartzite interbedded with phyllite, from the metamorphics on the finca of the late Don José Iten (38, 04).

Composition: This rock is a very fine-grained metaquartzite, with grains up to 0.25 mm. The rock is almost entirely of unstrained quartz, with a few percent plagioclase (albite) and orthoclase. Grading is excellent, with grain sizes quite uniform within distinct beds. Numerous thin quartz veinlets cut perpendicular to bedding.

Todos Santos Formation

Sample BB-28 This is a very fine-grained orthoquartzite from a roadcut at the river just north of Ermita (01, 35).

A. Texture:

1. This specimen is composed almost entirely of terrigenous material in the form of quartz sand and some clay. Secondary calcite and quartz cement are also present.

2. Bedding is distinguishable in thin section as an alternation of grain size between relatively homogeneous and well sorted beds. Porosity is about 2 percent. Elongate grains are oriented generally parallel to the bedding planes.

3. Grain size: Extreme (100%) is 2.0 Ø
   Range 16-84% is 2.0 Ø
   Size class (Wentworth) is very fine sandstone to coarse siltstone.
   Major texture: well-sorted silty, very fine sand.
   Graphic standard deviation (approximate) Ø84-Ø16/2 = 1Ø.

4. Grain shape: pressure solution has compacted grains such that original shape is not reliably determinable. It is estimated that grains were originally well rounded.
   Sphericity: most grains are roughly equant, though elongate grains are found parallel to bedding; original sphericity not accurately determinable.
5. Textural maturity for this sandstone is high, as the high sorting and apparent roundness would indicate.

6. Cements:
   calcite 3%
   quartz (overgrowths) 3%
   fine, granular interstitial quartz 2%
   clay 2%

B. Mineral composition:
   1. quartz 85%
   2. feldspar 2%

C. Rock fragments:
   metaquartzite 3%

D. Additional characteristics:

   Quartz grains have straight extinction and some have optically continuous quartz overgrowths. Occasional grains have zircon inclusions. There is a low percentage of metamorphic quartz and no chert.

E. Discussion:

   The overall high textural maturity, essentially monomineralic character and high degree of compaction are considered the most revealing characteristics of this rock. Additionally the presence of metaquartzite is believed to be of importance, suggesting that the Santa Rosa phyllites and quartzites contributed to the rock. A second source area, possibly contributing most of the quartz is also a possibility. Though the straight extinction would suggest a metamorphic quartz area, plutonic quartz is not ruled out.

   The high textural maturity of this rock rules out the Subinal formation as does the lack of volcanic rock fragments, chert and high clay content. Pressure solution effects would also not be expected in the Subinal beds, as they are young and were never deeply buried.

Cobán limestone

Sample BB-27 Thin-beded, gray fossiliferous limestone from the road cut at the foot of Cerro El Sillón, (35.0, 02.0). This sample is from the upper, massive-beded section of the formation.
Composition: This limestone is composed of 50% microcrystalline calcite and 50% fossil mollusc shells, measuring up to 1 cm. Shell material has recrystallized to sparry calcite, which also fills the shells.

Subinal formation

Sample BB-58 This is a brick red, granular tuffaceous sandstone. Bedding is poorly developed.

Texture:

This specimen is a very poorly sorted sandstone composed almost entirely of volcanic rock fragments.

Bedding is distinguishable in thin section. Graded distribution of coarse and fine material is characteristic of a waterlain sediment.

Size range is from coarse silt with grains of around 0.05 mm to very coarse sand with grains up to 2 mm.

Grains are all angular and some, notably quartz, have perfect euhedral crystal features.

This sandstone is highly immature as poor sorting and angularity of fragments would indicate.

This rock has clay, limonite and hematite cements.

Composition of finer material:

1. glass and devitrified glass; Approximately 40% very fine-grained glass fragments, pumice and devitrified glass, some as small as 0.025 mm.

2. quartz; 5% subhedral to euhedral quartz up to 1 mm in size.


4. rock fragments; 20% grains of an aphanitic siliceous volcanic rock.

5. cements 20%; hematite, clay

Composition of granules:

1. Plagioclase; 50% of grains are euhedral laths in matrix

2. K-feldspar 15%; zoned euhedral crystals
3. Sanidine 5%
4. Ore minerals 4%
5. Quartz 1% euhedral, bipyramidal form
6. Sericite replacements 25%

Additional characteristics:

Included in the matrix is altered biotite in a very small percentage, and fragments of tridymite.

Discussion:

This rock is a very immature granular sandstone which apparently has not to have been transported far by water. It is bedded sufficiently to have been deposited in water, as in a lake.

Subinal formation

Sample BB-29  This is a reddish-brown sandstone with a high content of volcanic rock fragments.

A. Texture:

1. This specimen contains abundant tuff fragments and pumice. It contains quartz, sanidine, plagioclase, and hematite grains. Clay, sericite, hematite and limonite are secondary alterations.

2. Bedding exists but it is not distinct. There is a homogeneous distribution of grains and clay. Grains are dominantly angular. Porosity is approximately 10 per cent.

3. Grain size ranges from less than 0.01 mm in diameter to 4 mm. (3.3 to -2 mm).
   Size class (Wentworth) is very fine sand.
   Major texture: poorly sorted, granular, clayey, very fine sand.

4. Grain Shape: a large percentage of quartz and feldspar grains are perfectly euhedral and unabraded showing hexagonal bipyramidal form. Some quartz is partially rounded, but most quartz and other grains are angular or sub-angular.
Composition: This limestone is composed of 50% microcrystalline calcite and 50% fossil mollusc shells, measuring up to 1 cm. Shell material has recrystallized to sparry calcite, which also fills the shells.

Subinal formation

Sample BB-58 This is a brick red, granular tuffaceous sandstone. Bedding is poorly developed.

Texture:

This specimen is a very poorly sorted sandstone composed almost entirely of volcanic rock fragments. Bedding is distinguishable in thin section. Graded distribution of coarse and fine material is characteristic of a waterlain sediment.

Size range is from coarse silt with grains of around 0.05 mm to very coarse sand with grains up to 2 mm. Grains are all angular and some, notably quartz, have perfect euhedral crystal features.

This sandstone is highly immature as poor sorting and angularity of fragments would indicate.

This rock has clay, limonite and hematite cements.

Composition of finer material:

1. glass and devitrified glass; Approximately 40% very fine-grained glass fragments, pumice and devitrified glass, some as small as 0.025 mm.

2. quartz; 5% subhedral to euhedral quartz up to 1 mm in size.


4. rock fragments; 20% grains of an aphanitic siliceous volcanic rock.

5. cements 20%; hematite, clay

Composition of granules:

1. Plagioclase; 50% of grains are euhedral laths in matrix

2. K-feldspar 15%; zoned euhedral crystals
3. Sanidine  5%
4. Ore minerals  4%
5. Quartz  1% euhedral, bipyramidal form
6. Sericite replacements  25%

Additional characteristics:

Included in the matrix is altered biotite in a very small percentage, and fragments of tridymite.

Discussion:

This rock is a very immature granular sandstone which appears not to have been transported far by water. It is bedded sufficiently to have been deposited in water, as in a lake.

Subinal formation

Sample BB-29 This is a reddish-brown sandstone with a high content of volcanic rock fragments.

A. Texture:

1. This specimen contains abundant tuff fragments and pumice. It contains quartz, sanidine, plagioclase and hematite grains. Clay, sericite, hematite and limonite are secondary alterations.

2. Bedding exists but it is not distinct. There is a homogeneous distribution of grains and clay. Grains are dominantly angular. Porosity is approximately 10 per cent.

3. Grain size ranges from less than 0.01 mm in diameter to 4 mm. (3.3 Ø to -2 Ø).
   Size class (Wentworth) is very fine sand.
   Major texture: poorly sorted, granular, clayey, very fine sand.

4. Grain Shape: a large percentage of quartz and feldspar grains are perfectly euhedral and unabraded, showing hexagonal bipyramidal form. Some quartz is partially rounded, but most quartz and other grains are angular or sub-angular.
5. Textural maturity for this sandstone is quite low.

6. Cements:
   clay
   hematite and limonite
   calcite

B. Mineral composition

   quartz
   plagioclase (andesine)
   calcite
   sanidine
   hematite

C. Rock fragments
   andesite (andesine, Ab 60-70)
   pumice

D. Additional characteristics

   Some of the quartz grains are volcanic and euhedral, exhibiting unabraded bipyramidal forms. Some feldspars have altered partially to sericite. Most of the plagioclase and quartz fragments are angular, showing no signs of abrasion through transport.

E. Discussion

   This rock is texturally immature, with poor sorting and angularity of grains indicating little or no transport. It is probably a water-deposited tuff with little or no reworking.

Subinal Formation

Sample BB-213  In hand specimen this is a fine-grained, faintly bedded, well-cemented red-brown to maroon sandstone. It contains calcite or calcite cement. The locality is north of Ermita, (35, 00).

A. Texture:

   1. This specimen is composed of calcite grains, quartz, chlorite grains and metaquartzite, with abundant interstitial calcite and hematite cements
2. Bedding is indistinct in thin section. Grains are homogeneously distributed as to mineral type. Grains are dominantly angular, with one notable exception being quartz grains, some of which are round. Calcite cement and hematite rich clay occupy up to 25 per cent of some areas of the thin section, but average around 10 per cent.

3. Grain size is variable among all of the major constituents. Maximum size of grains is approximately 0.25 mm. (2.0 Ø). Size class (Wentworth) is fine sandstone to coarse siltstone.

4. Grain shape: all grains are angular with the exception of some quartz grains which show some rounding.

5. The rock is extremely immature. It is poorly sorted with a large clay content and silt and fine sand-sized grains.

6. Cements:
   calcite
   clay
   hematite and limonite

B. Mineral composition

1. quartz
2. calcite
3. K-feldspar
4. plagioclase

C. Rock fragments

1. metaquartzite
2. chlorite
3. andesite

D. Additional characteristics:

   There is a considerable variation in clay content in different parts of this rock. Bedding which is seen in hand specimen results from differing amounts of clay. In some areas the sand and silt size particles are not in contact and the clay is the supporting material.
Calcite appears as fragments and as cement. A large quantity of hematite cement and hematite or limonite stained clay is present.

E. Discussion:

This rock is texturally immature as there is a large amount of clay, silt and fine sand and the majority of the grains are angular. Calcite grains are angular and of roughly the same size range as quartz grains. The presence of metaquartzite and chlorite grains indicates a metasedimentary source area probably the Santa Rosa, either directly or through the Todos Santos. Calcite grains indicate a limestone source area. There is a small percentage of andesite which suggests that the rock is a part of the Subinal sequence. The rock is distinctively rich in reworked, terrigenous material and low in volcanic rock fragments. It is not typical of the Subinal lithology.

Subinal formation

Sample BB-76 This is a specimen of andesite from the Subinal formation from near Quezaltepeque (37, 21). The pebble-sized, grayish-pink fragment is imbedded in a matrix of fine red sandstone.

Texture:

This specimen cryptocrystalline to very finely crystalline with small phenocrysts of andesine.

Phenocrysts:

**Plagioclase** Andesine phenocrysts (Ab60) around 0.4 mm in length. Phenocrysts are euhedral.

**Magnetite** Euhedral crystals up to 0.3 mm.

Groundmass:

The groundmass of this rock is composed of cryptocrystalline material and minute (0.05 mm) crystals of andesine (Ab60) and opaques. The matrix is partly sericitized.
Tuff

Sample BB-55  This is a rhyolitic tuff from a locality between Quezaltepeque and Esquipulas on the old road at bench mark 1285 (42, 18).

Texture:

This specimen is a lithic vitric tuff which is composed of devitrified glass with phenocrysts of biotite, orthoclase and quartz. Lithic fragments are abundant.

Phenocrysts: 10%

K-feldspar  8%; euhedral to subhedral crystals, some of which are partially altered; up to 0.3 mm in size.

Biotite  2%; euhedral and subhedral crystals of up to 1 mm in size.

Quartz less than 1%; subhedral to anhedral crystals up to 0.15 mm.

Groundmass:  90% Composed of glass and cryptocrystalline devitrified volcanic glass.

Lithic fragments: 25 to 30% of the entire rock (their percentage not figured above); these fragments are composed of very fine-grained rhyolite with phenocrysts of K-feldspar and plagioclase.

Rhyolite dike

Sample BB-204A  This rock is a white rhyolite from the dike at the northwestern corner of the map area (31, 22).

Texture:

The rock is cryptocrystalline with numerous vesicles. The only identifiable crystals in the rock are vesicle-filling grains of tridymite (verified by X-ray diffraction).

Groundmass:  The groundmass is cryptocrystalline but X-ray diffractograms indicate the presence of quartz and sanidine.
Rhyolite flow

Sample BB-145  This specimen is a violet colored well-banded rhyolite from a dike-flow complex 0.5 km east of hill #789 in new road cut (32.0, 21.4).

Texture: Alphanitic texture with fewer than 1% phenocrysts of k-feldspar. Pronounced fluidal structure.

Phenocrysts: 1% Size range is from 0.05 to 2.5 mm.

- Alkali feldspar 90% (of phenocrysts)
- Plagioclase 9%
- Hematite 1%

Groundmass: The groundmass is predominantly cryptocrystalline, though very fine-grained k-feldspar is present. There is less than 1% magnetite present in euhedral and subhedral crystals. Finely divided hematite is responsible for color banding which is pronounced in hand specimen.

Perlite

Sample BB-23  This specimen is a perlitic rhyolite glass from a locality on the old road from San Jacinto to Quezaltepeque (33.7, 19.3), 0.6 km due southeast of hill #795. In hand specimen it is a waxy, light blue-gray perlitic glass with large biotite and k-feldspar crystals. Spherulites of devitrified glass that are gray to brown in color are present.

Texture: porphyritic glassy (perlitic); fluoidal

Phenocrysts 5%

- K-feldspar; euhedral to subhedral up to 1.2 mm in size.
- Biotite; microlites of biotite and subhedral crystals up to 0.6 mm are present.
- Magnetite; euhedral magnetite up to 0.12 mm in size.
Groundmass: The groundmass is perlitic glass with a refractive index of 1.499 (± 0.002), and which is entirely clear in thin section except for zones that show flow structure. Flow structure is well developed and marked by the following:

1) Flow bands contain a high concentration of microlites—far higher than any non-banded areas.

2) Elongate phenocrysts are aligned to the direction of flow banding.

3) Flow bands are zones of greatest devitrification; patches of optically continuous cryptocrystalline material are most frequent along these bands.

4) Flow bands are bands of color segregation; color is evidently finely divided hematite.

Andesite dike

Sample BB-211 This is a pyroxene andesite from along a fault southwest of Esquipulas at San Joaquin (45, 07).

Texture: This rock has a trachytic texture, with well-developed flow structure.

Phenocrysts: 8%

Plagioclase: 6% zoned and unzoned plagioclase phenocrysts have a composition of around An30-An40.

Sanidine: 1% phenocrysts and glomerocrysts of euhedral sanidine.

Pyroxene: 1% most pyroxene in this specimen is altered to calcite; inclusions of magnetite are common.

Magnetite: <1% subhedral magnetite forms relatively large (0.3 mm) phenocrysts, though they are not abundant.

Groundmass: 92%; Plagioclase laths are around 0.12 mm in length and forming about 50% of the total rock. Euhedral magnetite makes up about 5% of the total rock in small crystals (less than 0.05 mm) spread throughout the matrix. Altered pyroxenes and altered feldspar account for the remaining percentage of the rock (about 37%).
Andesite flow

Sample BB-175  This specimen is of andesite, from a flow interbedded with Subinal red beds from 1 km east of La Cumbre at (44, 18).

Texture: This rock has a trachytic texture, with the largest plagioclase lath 0.15 mm in length.

Phenocrysts: 10% of total rock

Pyroxene: 10% of total rock; phenocrysts of up to 1.0 mm all of which have been replaced by calcite or chlorite

Plagioclase: (andesine) less than 1% of total rock

Groundmass: Plagioclase accounts for 60% of the total rock. All pyroxene is now altered to chlorite or calcite, but originally it amounted to about 30% of the rock.

Basalt flow

Sample BB-127  This is a very fresh sample of pyroxene basalt flow from hill #97, west of Concepción las Minas (33, 07).

Texture: This rock has a trachytic texture, with a matrix which includes fine, dusty looking interstitial glass, but primarily extremely fine to fairly large (0.75 mm) plagioclase.

Phenocrysts: around 2% of total rock

Augite: some grains have altered to chlorite

Plagioclase: Labradorite (around An60)

Sanidine

Groundmass: Plagioclase makes up about 70 per cent of the matrix, with augite, opaques and glass the remainder. Largest plagioclase laths are around 0.75 mm. The majority are less than 0.2 mm in length. Range of An values is from around An54 to An68, in the andesine range.
Basalt flow

Sample BB-82  This specimen is an augite basalt with a very small percentage of olivine, mostly altered to iddingsite, hematite or chlorite. It is from the flow in the vicinity of the "Puente Piedras Azules" (32, 20).

Texture:  This rock has a subophitic texture, with a small percentage (6%) of phenocrysts, mostly consisting of augite.

Phenocrysts:  6%

Augite:  2% (of total rock)

Plagioclase:  less than 1%, partially altered to nontronite; Ca labradòrite (around An 70)

Orthoclase:  2%; zoned

Olivine:  less than 1%; altered to iddingsite, chlorite and hematite.

Groundmass:  Plagioclase laths make up about 50% of the total rock, with augite around 40%. Ore minerals, principally magnetite, are present as around 3 per cent of the rock. Plagioclase in the matrix ranges from An55-An70 (labradorite).
GEOLOGIC MAP OF THE ESQUIPULAS QUADRANGLE
SOUTHEASTERN GUATEMALA

GEOLGY BY B. BURKART, 1962-1963
RICE UNIVERSITY, HOUSTON, TEXAS
<table>
<thead>
<tr>
<th>Layer</th>
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<tbody>
<tr>
<td>Quaternary</td>
<td>Recent alluvium</td>
</tr>
<tr>
<td></td>
<td>Quaternary alluvium</td>
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<tr>
<td></td>
<td>Cover, deeply weathered ash and tuff</td>
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<tr>
<td>Tertiary or</td>
<td>Intrusive rocks:</td>
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<tr>
<td>Quaternary</td>
<td>Intermediate composition</td>
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<tr>
<td>(Pliocene-Pleistocene)</td>
<td>Rhyolite-perlite flows and shallow intrusives</td>
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<tr>
<td></td>
<td>Basalt flows</td>
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<tr>
<td></td>
<td>Undifferentiated lahar and basalt</td>
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<tr>
<td></td>
<td>Undifferentiated volcanics and volcanic clastics</td>
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<td>San Jacinto formation</td>
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<td>Padre Miguel group</td>
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<tr>
<td>Late Cretaceous</td>
<td>Massive-bedded tuff (sillars); thin-bedded tuff</td>
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<tr>
<td>? Tertiary (Miocene</td>
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<tr>
<td>Pliocene)</td>
<td>Red beds: sandstones, shales, conglomerates, volcanic detritus</td>
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<td>Interbedded flows</td>
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<tr>
<td>Cretaceous (Albian)</td>
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<td></td>
<td>Limestone, shale, minor sandstone</td>
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<td>Jurassic to Albian</td>
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<td>Sandstone, shale, conglomerate</td>
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<td>Permian</td>
<td>Santa Rosa group</td>
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<td></td>
<td>Phyllite</td>
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GEOLOGIC MAP OF THE CERRO MONTECRISTO QUADRANGLE
SOUTHEASTERN GUATEMALA

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