RICE UNIVERSITY

GEOLOGY OF THE JOCOTÁN AND TIMUSHÁN QUADRANGLES, SOUTHEASTERN GUATEMALA

by

David C. Crane

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Thomas W. Donnelly

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David Edwin Crane

ABSTRACT

The Jocotán and Timushán quadrangles cover about six-hundred square kilometers in southeastern Guatemala adjacent to Honduras. They are located thirty to forty kilometers south of the Central Cordillera of Guatemala and thirty kilometers northeast of the Ipala Volcano, a late Tertiary or Quaternary cone belonging to the Volcanic Mountains Province of the Pacific Coast. Rock types and structural features of both provinces occur within the quadrangles.

The northwest third of the Jocotán Quadrangle is predominantly pre-Mesozoic phyllite and granite which belong to a zone of "basement" rocks exposed between the Motagua Valley-Bartlett Trough fault zone and a parallel fault crossing the Jocotán Quadrangle and extending north seventy-degrees east into Honduras. The age of the granite is not certain. The phyllites are tentatively correlated with the Permian Tactíc Formation (shales) of northern Guatemala.

The largest known occurrence of Cretaceous limestone in southern Guatemala crops out in a tightly folded anticline whose axis trends north seventy-degrees east across the center of the Jocotán Quadrangle. Approximately 1300 meters of thin-bedded Albian age limestone, shale and dolomite overlain by 200 meters of massive Albian age limestone are exposed in the rivers dissecting the anticline. A 200-meter-thick sequence of fanglomerate and sandstone separates the two units. These

clastics are evidence of movement along northeast-southwest fault trends during middle Albian time. There are no marine sediments in the area definitely younger than Cenomanian age. The limestone was probably folded in late Cretaceous time during the orogeny which affected all of Nuclear Central America.

Terrestrial redbeds similar to those of the Subinal Formation in the Motagua Valley developed on the folded and eroded Cretaceous limestone and exposed phyllite and granite during late Cretaceous or Tertiary time. These redbeds are composed of a mixture of volcanic fragments and fragments of the underlying rock type. The volcanic content generally increases toward the top of the redbeds. They are probably of Miocene or Pliocene age.

Late Tertiary (Pliocene?) block-faulting has affected the limestone and redbeds, particularly in the southwestern part of the Jocotán quadrangle. A later increase in volcanic activity blanketed the area in white, rhyolitic tuff. Basalt and laharic deposits developed around local fissures at about the same time. They are most abundant in the southern Jocotán Quadrangle, and in the regions to the south and west. Later Tertiary or Quaternary rhyolite flows and Quaternary basalt flows occur locally.

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INTRODUCTION

The geologic mapping of the Jocotán and Timushán quadrangles was undertaken in June, 1962, as a joint project between Rice University, the government of Guatemala and the government of the United States. A contract between Rice University and the United States AID Mission to Guatemala provided for financial support of two technicians (Rice University students) for a period of two years. Additional agreements between the U.S. AID Mission and various agencies of the Guatemalan government provided for logistical and technical help from those agencies.

The geologic mapping program in Guatemala was an outgrowth of a suggestion made by Dr. Ralph Miller of the U.S. Geological Survey (Miller, 1961, p. 43). Dr. Miller had just completed a minerals survey for the International Cocperation Administration in Guatemala (known now as the U.S. AID Mission to Guatemala) and recognized a need for systematic work.

This dissertation is the result of the work of one of the supported students. The other student, Burke Burkart, is concurrently completing his thesis entitled "The Geology of the Esquipulas, Chanmagua and Cerro Montecristo Quadrangles of Southeastern Guatemala." Field work by both students was accomplished during the months of June through October in 1962 and 1963.

ACKNOWLEDGMENTS

The author is indebted to many people and several agencies of the Guatemalan and United States governments. The U.S. AID Mission in Guatemala provided generous financial support for the project and the Industry Division of U.S. AID in Guatemala was very helpful in taking care of a number of administrative details during the field seasons.

During both field seasons the supporting technical agencies of the Guatemalan government provided invaluable assistance. Dirección General de Cartografía[1] and the Interamerican Geodetic Survey and especially Ing. Otto Bohnenberger of D.G. de C. are to be commended for their continuous efforts to lend both moral and material support. Dirección General de Cartografía arranged to supply the author with vehicle, driver, gasoline, maps, air photographs, field and camping equipment, office space in Guatemala City and storage space. The time and effort of Otto Bohnenberger and his associate Sam Bonis and the benefit of their field experience in Guatemala were greatly appreciated.

The geologists of Dirección General de Minería e Hidrocarburos, Ings. Oscar Salazar, Jorge Godoy and Marco Antonio Aceituno, devoted a great deal of time to the project. Their company in the field and their comments on the geology of Guatemala were very much appreciated.

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[1] Name recently changed to Instituto Geográfico Nacional de Guatemala.

The author is deeply indebted to Dr. B.F. Perkins of the Shell Development Company, Drs. A.H. Coogan and D.H. Jones of the Esso Production Research Laboratory and Dr. E.A. Pessagno of the University of California at Davis for fossil determinations. Dr. Gale Billings of the Sinclair Research Corporation was kind enough to do some chemical analyses.

The thesis was supervised by Dr. Thomas W. Donnelly. The writer is grateful for discussions in the field with Burke Burkart and Russell Clemons.

LOCATION

General Information

The Jocotán and Timushán Quadrangles are totally within and cover about twenty-five percent of the area of the Department of Chiquimula in southeastern Guatemala. Chiquimula is also the name of the capital city of the Department. The town has a population of about 30,000 and is located a few kilometers west of the Jocotán quadrangle. It can be reached by all-weather roads in three hours driving time from Guatemala City.

From the village of Vado Hondo, ten kilometers south of Chiquimula, a narrow gravel road leads eastward to the village of Jocotán and the Honduras border. This road and a southern branch from it to the village of Olopa provide access to the western half of the Jocotán quadrangle. The remainder of the area mapped is not accessible by road.

Topography and Vegetation

The elevations in the Jocotán-Timushán region range from 400 to 1,700 meters above sea level. The climate during the rainy season varies from hot and dry in the lowlands to cool and wet in the higher regions. When it rains in the valleys, it is usually only for a short period in the afternoon and the water runs off quickly.

Topographically, the region is a series of low pre-Tertiary mountain ranges composed of limestone, phyllite and granite

overlain by Tertiary extrusives and tuffs.

Late Tertiary or Quaternary block faulting, in some areas, has resulted in large flat valleys filled with Pleistocene gravels.

The phyllite and granite are in relatively high-standing areas with little soil cover and are agriculturally very poor except near the limestone outliers. The phyllite supports little more than pine trees at any elevation and is relatively unpopulated. The granitic area supports both pine trees and scrub brush but once the vegetation is removed the thin soil cover erodes away quickly.

Most of the limestone occurs in a tightly folded anticline whose axis trends northeast-southwest. The upper portion of the limestone sequence is a hard, massive limestone which weathers in large blocks and forms steep cliffs. The lower limestone is thin-bedded and shaly and has been exposed by erosion along the axis of the anticline. Soil develops rapidly on the limestone, especially the thin-bedded limestone, and is locally very deep. Even on the steep slopes there is usually enough soil trapped on the rock-strewn surface to enable the inhabitants to grow a respectable crop of maize and beans. As a result, only the most inaccessible limestone has a virgin growth of forest. The majority of the limestone is either under cultivation or has been allowed to revert to a dense covering of underbrush and fast-growing trees.

The southern half of both quadrangles are covered by a

variety of volcanic rocks, largely white rhyolitic tuff. The tuff has a very thin cover of poor soil except in scattered areas where the tuff has been removed by erosion and the underlying rock is exposed. The white-tuff-covered regions have little more vegetation than the phyllites; they are equally impermeable so that rain water runs off rapidly and except for some flat swampy areas covered with grass, the vegetation is pine trees and patches of scrub brush. Within the region of the rhyolite tuff, food is grown on local exposures of redbeds even though the crops are poor; the alternative is to cultivate the even less productive tuff.

The basaltic volcanic rocks weather to dark brown, clay-rich, fertile gumbo. Like the limestone regions, these areas are either under cultivation or have been allowed to revert to dense underbrush.

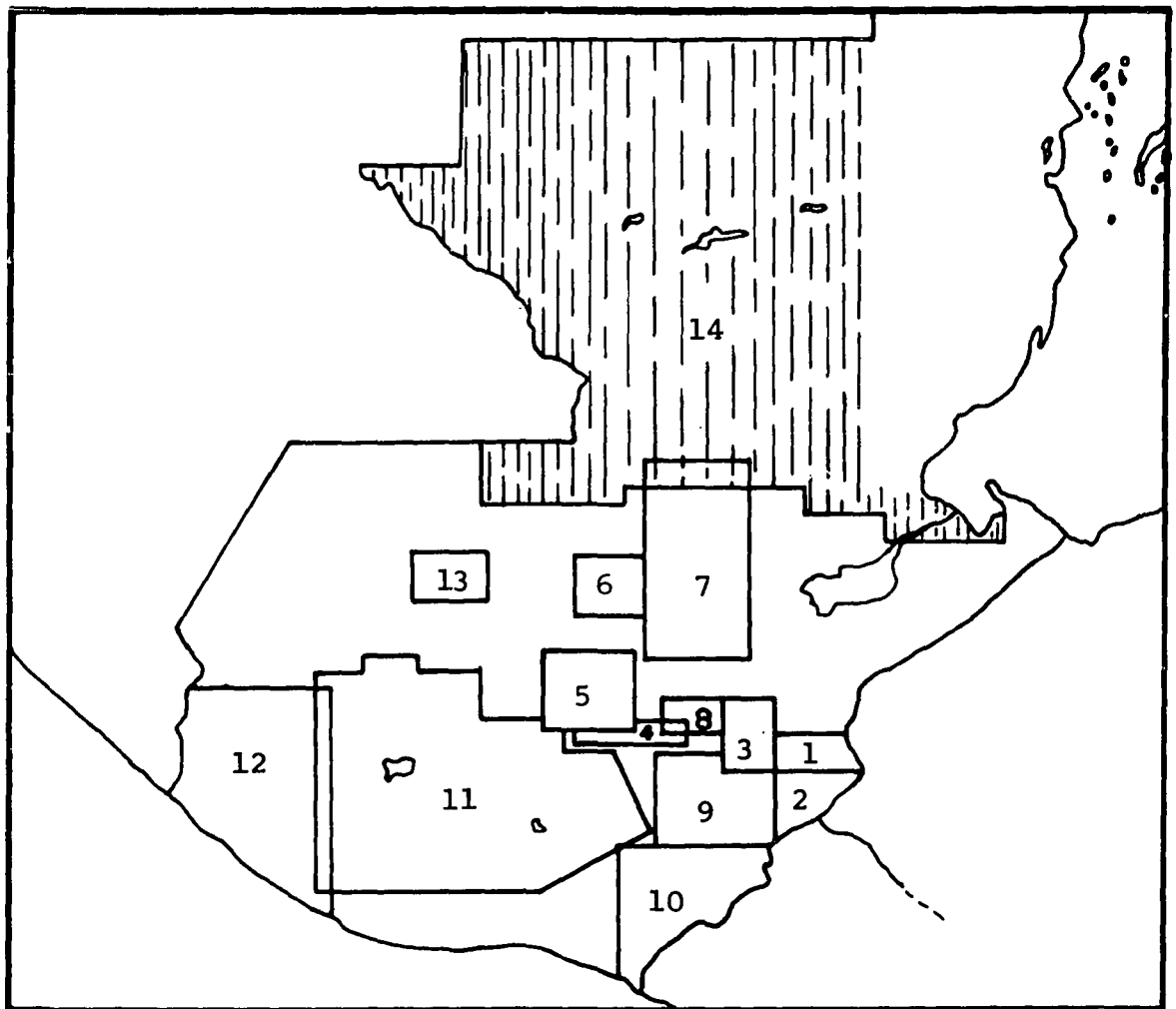
The central portion of the Timushán quadrangle is the most agriculturally productive and most inaccessible area of those described here. Most of the quadrangle is a relatively flat valley filled with alluvium derived from a wide variety of rock types. Water is abundant and the region is suitable for mechanical cultivation techniques. At present, crops of corn and beans are alternated seasonally with crops of tobacco, the latter being sent to market by crude roads via Copán in Honduras.

PREVIOUS GEOLOGIC WORK

The first geologic map of Guatemala was published in 1868 by the French geologists Dollfus and Mont-Serrat. Their map was largely based on their own reconnaissance geology but their knowledge of southeastern Guatemala was limited to reports made to them by a Jesuit priest. In 1899, the German geologist Karl Sapper published the results of his extensive reconnaissance work in northern Central America. The majority of his traverses in eastern Guatemala were confined to the Central Cordillera north of the Motagua Valley, but he also made a trip through southeastern Guatemala and was the first geologist to report on the nearby Metapán region of northwestern El Salvador.

Sapper's revised geologic map of Central America (1937) included some changes in the interpretation of Guatemalan geology resulting from the field work of Termer (1932) and a restudy of his own paleontologic specimens by Schuchert (1935), but it remained basically a reconnaissance geologic map. Subsequently, F.K.G. Mullerried (1939) and Dürr and Stober (1956) did reconnaissance mapping in southeastern Guatemala and adjacent El Salvador. In 1957, Roberts and Irving of the U.S.G.S. reviewed the geology of Central America and mapped some mineralized regions in detail.

In 1956, Jack Walper, a graduate student at the University of Texas, initiated the first intensive study of a quadrangle in Guatemala (Walper, 1960). He chose the Cobán-Purulhá



No.	Author & Date	Scale	Institution
1	Crane	1:50,000	Rice University
2	Burkart	1:50,000	Rice University
3	Clemons	1:50,000	Univ. of Texas
4	Hirschmann(1963)	1:60,000	Indiana Univ.
5	McBirney (1963)	1:75,000	Univ. of California
6	Walper (1960)	1:135,000	Univ. of Texas
7	Bonis (in prep)	1:100,000	D.G. de Cartografía
8	Bosc (in prep.)	1:50,000	Rice University
9	Williams, et al.	1:250,000	Univ. of California
10	Bohnenberger (in prep., photogeol.)	1:50,000	D. G. de Cartografía
11	Williams (1960)	1:585,000	Univ. of California
12	Bonis (1964)	1:250,000	D. G. de Cartografía
13	Bohnenberger (i.p.)	1:100,000	D. G. de Cartografía
14	Various (unpublished)	Various	Petroleum Companies

Locations of Areas Mapped Geologically in Guatemala
(After S.P.T.G.I.E.C., 1964)

Figure 1

region, an area of about 400 square miles in the Central Cordillera of Guatemala (figure 1). Walper's investigations covered the region in which Sapper concentrated much of his attention and his work was the first to help clear up the problems of nomenclature and correlation which occurred in the older literature. Subsequently, A.R. McBirney (1963) mapped the region between Purulhá and the Motagua Valley and further clarified the Mesozoic stratigraphy of Guatemala. Other recent workers in the Guatemalan Central Cordillera include Tomás Hirschmann (1963), Sam Bonis of L.S.U. (in preparation), and Eric Bosc of Rice University (in progress). Additionally, Russell Clemons of the University of Texas and Burke Burkart of Rice University are now completing theses with detailed geologic maps of areas in southeastern Guatemala adjacent to this report area. Their work will be referred to in this report simply as Clemons and Burkart, respectively.

Several U.S. petroleum companies have prospected in Guatemala in the last ten years but the only information published is the stratigraphic work by Vinson (1962). To date, the only detailed geologic mapping done in western Honduras is that of petroleum companies and they have not published their findings.

STRATIGRAPHY

General

Table 1 is a summary of the stratigraphic relationships between formations found within the Jocotán and Timushán Quadrangles.

Quaternary and Recent alluvium and travertine	
Quaternary basalt	
Padre Miguel Group* (Late Tertiary and Quaternary)	Rhyolite flow interbedded with and underlain by white rhyolitic tuff Soft white rhyolitic tuff, rich in biotite or pumice, generally massive but locally containing thin lacustrine beds. Basaltic volcanic rocks; interbedded lava flows, pyroclastics, and mud flows composed of a variety of basaltic fragments and ash. White, tuffaceous quartz and feldspar sandstone interbedded with white tuff and a few thin carbonaceous beds. Andesite flows.
Subinal Formation (Miocene-Pliocene?)	Red terrestrial sandstones and conglomerates
Cobán Formation (Albian)	Thick sequence of thin-bedded limestones and shales overlain by massive shallow water limestones.
Santa Rosa Group* (Pennsylvanian-Permian?)	Metasediments, largely phyllites, which are the oldest rocks exposed in the area. Probably Tactíc Formation equivalent.
Granite of uncertain age (Pre-Albian)	

*New designation.

Table 1. General Stratigraphy.

Granite

Granite and granodiorite crop out in the northwest quadrant of the Jocotán quadrangle in fault contact with phyllite. Williams et al. (1964, p. 12) consider this intrusive body to be a single pluton which, by slight variations of the alkali feldspar-plagioclase ratios, is locally graphic granite or quartz diorite. Field relationships substantiate this conclusion; the varieties of intrusive rock within the pluton grade imperceptibly into one another.

Anomalous outcrops of granite occur within the Chiquimula and Jocotán grabens. On the extreme western edge of the Jocotán quadrangle, within the Chiquimula graben, approximately 0.05 square kilometers of granite crops out. More granite is present but it is covered by Tertiary sediments and volcanic rocks. Two kilometers northwest of Jocotán, near the edge of the Jocotán graben, a similar but larger granite body is exposed in a window in the Tertiary volcanic rocks. This exposure extends over an area of approximately 0.15 square kilometers. Both of these granites are petrographically similar to the graphic granite of the pluton described above. They appear to be accumulations of large blocks of granite spalled from the nearby graben boundry-fault scarps.

Age of the Granite - The age of the granite is not certainly known. It is here considered to be pre-Albian age because one small outlier of Albian limestone was found on top of the granite/phyllite fault contact two kilometers

northwest of La Puente. However, the limestone may not be in place. The granite is certainly older than the Subinal Formation; fragments of the graphic granite occur within the La Puente facies of the Subinal redbeds.

Santa Rosa Group

The oldest rocks exposed in the Jocotán region are the phyllites underlying the Cretaceous limestone. Their composition and stratigraphic position suggest to this writer that they are metamorphosed Santa Rosa Group sediments (Tactíc Formation shales) though they may be older. In order to explain the correlation problems involved, it will be necessary to digress and define the Santa Rosa Group and the history of the name Santa Rosa.

In the past century, the name Santa Rosa has been applied to several different formations in Guatemala. As a result, the geologic literature contains some confusing usages of the formation name which should be abandoned. The author agrees with a suggestion (personal communication) of Otto Bohnenberger of Dirección General de Cartografía of Guatemala that the name Santa Rosa should be raised to group status in order to retain as closely as possible the original meaning of the name Santa Rosa at the type locality. Included in the newly designated Santa Rosa Group are the Pennsylvanian or Lower Permian conglomerates and arkoses of the Santa Rosa Formation (as revised by McBirney, 1963) and the Permian shales and thin limestones of the Tactíc Formation (Walper, 1960).

The name Santa Rosa was first applied by Dollfus and Mont-Serrat (1868, p. 272) to an unfossiliferous sequence of conglomerates, sandstones and shales exposed between Santa Rosa and Tactíc (Baja Verapaz and Alta Verapaz, Guatemala, respectively). Based on the section's similarity to the Triassic of Germany and their misidentification of the overlying beds as Jurassic, Dollfus and Mont-Serrat considered the Santa Rosa to be of Triassic age. According to Walper (1960, p. 1283), Karl Sapper compounded the error when he later incorrectly reinterpreted the section at the type locality, inverted the stratigraphic sequence, and assigned the Santa Rosa to the Carboniferous.

> "Unfortunately, Santa Rosa became widely used as a name for the Carboniferous shales when in reality it was originally applied to strata of Triassic to Lower Cretaceous age at its type locality. Thus has arisen the unusual situation wherein the name Santa Rosa is legitimate and usable everywhere except at its type locality." (Walper, 1960, p. 1286.)

Walper has reinterpreted the stratigraphy at the Santa Rosa type locality and assigned the rock units present to five different formations, the oldest of which is Upper Carboniferous. Walper does not use the name Santa Rosa for any of the formations present; he proposes the name Tactíc Formation for the approximately 500-meter-thick sequence of Upper Carboniferous and Permian shales and clastics interbedded with minor amounts of limestone.

Walper's stratigraphic interpretations have subsequently been confirmed by McBirney (1963), who studied a large area

south of Santa Rosa. However, McBirney points out that the base of the Tactíc Formation is better exposed in the area which he mapped and the entire formation can be subdivided into an upper shaly sequence equivalent to Walper's Tactíc Formation and a lower sequence of coarse arkosic sandstones and conglomerates which McBirney calls the Santa Rosa Formation (thickness not given). A similar sequence of Upper Carboniferous and Permian clastics and shales has been recognized elsewhere in Guatemala by Roberts and Irving (1957), by Thompson and Miller (1944) in Chiapas and by Dixon (1955) within the Macal Series of British Honduras (see figure 2).

The definition of the Santa Rosa Group suggested here has two distinct advantages; the original name Santa Rosa applies to the type locality as well as to the Carboniferous beds with which the original Santa Formation has since been miscorrelated and corresponds to the accepted "Santa Rosa Formation" in the Lexique Stratigraphique International (Hoffstetter, 1960). However, defining the lower formation of the Santa Rosa Group as the Santa Rosa Formation (McBirney) is not very satisfactory, both because McBirney failed to designate and describe a type section and because the name "Santa Rosa Formation" has already caused a great deal of confusion in the literature.

Distribution of Santa Rosa and older rocks in Central America - The most recent geologic map of Central America (Roberts and Irving, 1957) indicates that the oldest sediments

in Central America are of Permian age (Santa Rosa) and occur within and to the north of the Central Cordillera of Guatemala. South of the Central Cordillera, in Guatemala, Honduras and Nicaragua, pre-Triassic age rocks are classified as "rocks of Paleozoic age" (undifferentiated shale, limestone and sandstone and their metamorphic equivalents) or as pre-Cambrian metamorphic rocks (undifferentiated schist, gneiss, quartzite, marble and phyllite). The pre-Cambrian metamorphic rocks probably include metamorphosed strata of Paleozoic age and early Mesozoic age in places. However, because no sediments south of the Central Cordillera have been found to contain Paleozoic fossils, the ages of the sedimentary and metamorphic rocks are difficult to determine.

Occurrence in the Jocotán region - The major occurrences of phyllite in the area studied are in the west-central and north-central portions of the Jocotán quadrangle where they are in fault contact with Cretaceous limestones and with granite of uncertain age. Good representative exposures of the phyllite can be seen in the road cuts between San Jorge and San Juan Ermita, as well as east of Camotán on the road to Honduras. Most of the Timushán quadrangle has phyllite very near the surface as evidenced by the abundant Tertiary redbeds composed almost entirely of phyllite debris. However, only in the Quebrada de Monteros, one kilometer south of Monteros, was an outcrop of phyllite located.

Clemons and Burkart report outcrops of phyllite to the

west and south of the Jocotán quadrangle, respectively. In those areas, as in the Jocotán and Timushán quadrangles, the phyllites are either in fault contact with the Cretaceous and Tertiary sediments or those sediments unconformably overlie the phyllites.

Description - The phyllites of the Jocotán quadrangle range in degree of metamorphism from low-grade phyllites with relic sedimentary structures to low-grade schists, though the two extremes are rare. Typically, they are gray or reddish gray and lustrous on a fresh surface and weather to light orange or red. The individual mineral grains are generally not visible. The dominant fabric is a slightly contorted foliation with minor lineations, but it is not unusual to find lineations so prominent that the foliation is destroyed, resulting in a friable texture for the rock.

Small quartz stringers, one centimeter or less thick, are common throughout the phyllites. Locally, particularly in the vicinity of the Quebrada Negra, near San Juan Ermita, graphite and cubes of pyrite up to one centimeter across are abundant.

Fifteen samples representing a variety of sampling localities and phyllite colorations were analyzed by X-ray diffraction. Very little mineralogical variety existed between the samples. All the samples contained quartz and muscovite and most of them contained albite. Hematite, chlorite, talc or graphite were present in a few of the samples.

Origin of the phyllites - The phyllites appear to be

the metamorphosed equivalent of a thick sequence of pelitic sediments, very similar to those of the Tactíc Formation of the Santa Rosa Group. Their composition and stratigraphic position together suggest a tentative correlation with the Santa Rosa Group sediments. No other evidence for the age of these metasediments was found in the Jocotán and Timushán quadrangles.

Stratigraphically equivalent metasediments in the Chiquimula quadrangle (Clemons) may yield additional evidence on the origin and age of the phyllites.

Cobán Formation

The Cobán Formation was originally named by Sapper (1899) after the capital of Alta Verapaz, Guatemala. He described the Cobán Formation as the limestone, dolomite and limestone breccia occurring in Alta Verapaz between the Karbonkalke (the Chochal limestone, now known to be Permian age) and an unnamed overlying Upper Cretaceous limestone which he called the Kreidekalke. Later, Sapper (1937) referred the Upper Cretaceous limestone of Alta Verapaz as Rudistenkalke. Hoffstetter (1960, p. 60) summarizes the relationship between the various Cretaceous limestones as follows (translation by this writer):

> "There is no clear separation in the literature between the Cretaceous calcareous formations of northern Guatemala. The principal distinction made at present between the Cobán Formation and the younger limestones is the presence of abundant fossils (rudists and foraminifera) in the latter. The Cobán Formation contains very few fossils."

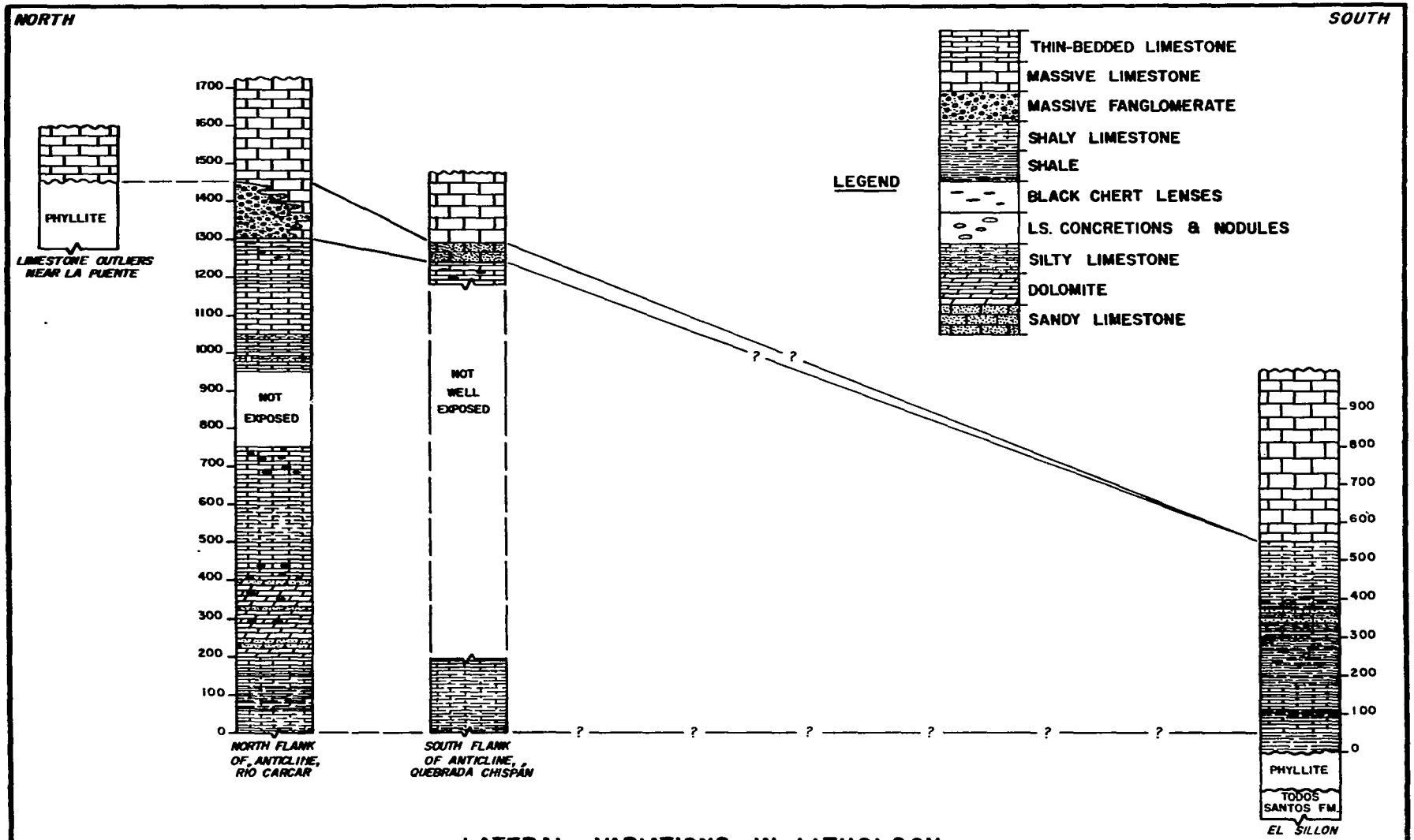
Later geologists in Guatemala have differed on the usage of the name; Walper (1960) redefines the Lower Cretaceous limestones of Alta Verapaz as the Ixcoy Formation (after Termer, 1932) and refers to the Upper Cretaceous limestones as the Cobán Formation. However, McBirney (1963) refers to the Lower Cretaceous limestones of Baja Verapaz as the Cobán Formation. The name Cobán Formation is retained here to refer to the limestones of Albian age which occur in southeastern Guatemala.

Occurrence - Cobán limestone occurs in the Jocotán and Timushán quadrangles as: 1) a large anticlinal structure

trending northeast-southwest, 2) outliers on the phyllites north of the anticline, and 3) horst blocks to the south and east of the anticlinal region. The majority of exposures occur in the central portion of the Jocotán quadrangle where the limestone anticline has been deeply incised by the Río Carcar and the Quebrada Torjá. The canyon of the Río Carcar, however, is the only area where extensive and continuous exposures of the Cobán Formation can be observed and the stratigraphic sequence determined.

Lithology - About 1,700 meters of Albian limestone has been measured and described from exposures in the Río Carcar and the Quebrada Chispán (see Appendix A for a complete description of the stratigraphic section). The section is divisible into an upper, 400-meter-thick sequence of massive, light gray limestone interbedded near its base with massive limestone conglomerate and sandstone and a lower, 1,300-meter-thick sequence of interbedded thin beds of limestone, dolomite and shale with minor amounts of black chert and sand in the limestone (fig. 3). The massive sequence contains abundant macrofossils of probable middle or upper Albian age. The thin-bedded sequence is relatively unfossiliferous but a few foraminifera of probable Albian age were found.

Figure 3 also shows some important lateral variations in the lithology of the Cobán limestone. The outliers on the phyllites north of the Jocotán road are massive limestone equivalent to the upper, massive sequence of the Cobán Forma-



LATERAL VARIATIONS IN LITHOLOGY OF THE COBÁN LIMESTONE IN SOUTHEASTERN GUATEMALA

FIGURE 3

tion. The lower, thin-bedded sequence is missing. No identifiable fauna were found in these outliers but Mulleried (1939) reported Toucasia cf texana Roemer (Albian age) from limestone outliers near Shupá, eleven kilometers northeast of Camotán. Immediately south of the Jocotán road fault zone a 200-meter-thick sequence of interbedded fanglomerate and massive limestone divides the massive and thin-bedded units of the Cobán limestone. The fanglomerate is composed of massive, unsorted beds of reworked limestone and contains a few thick green beds of altered, very fine-grained andesite fragments throughout. The andesite may be reworked from older Cretaceous or Jurassic beds but probably is contemporaneous. Seven kilometers farther south, on the south flank of the anticline, a 100-meter-thick series of siltstones and sandstones occurs between the massive and thin-bedded units. Thirty kilometers south of the Jocotán road fault zone Burkart reports no clastics between the two units at El Sillon.

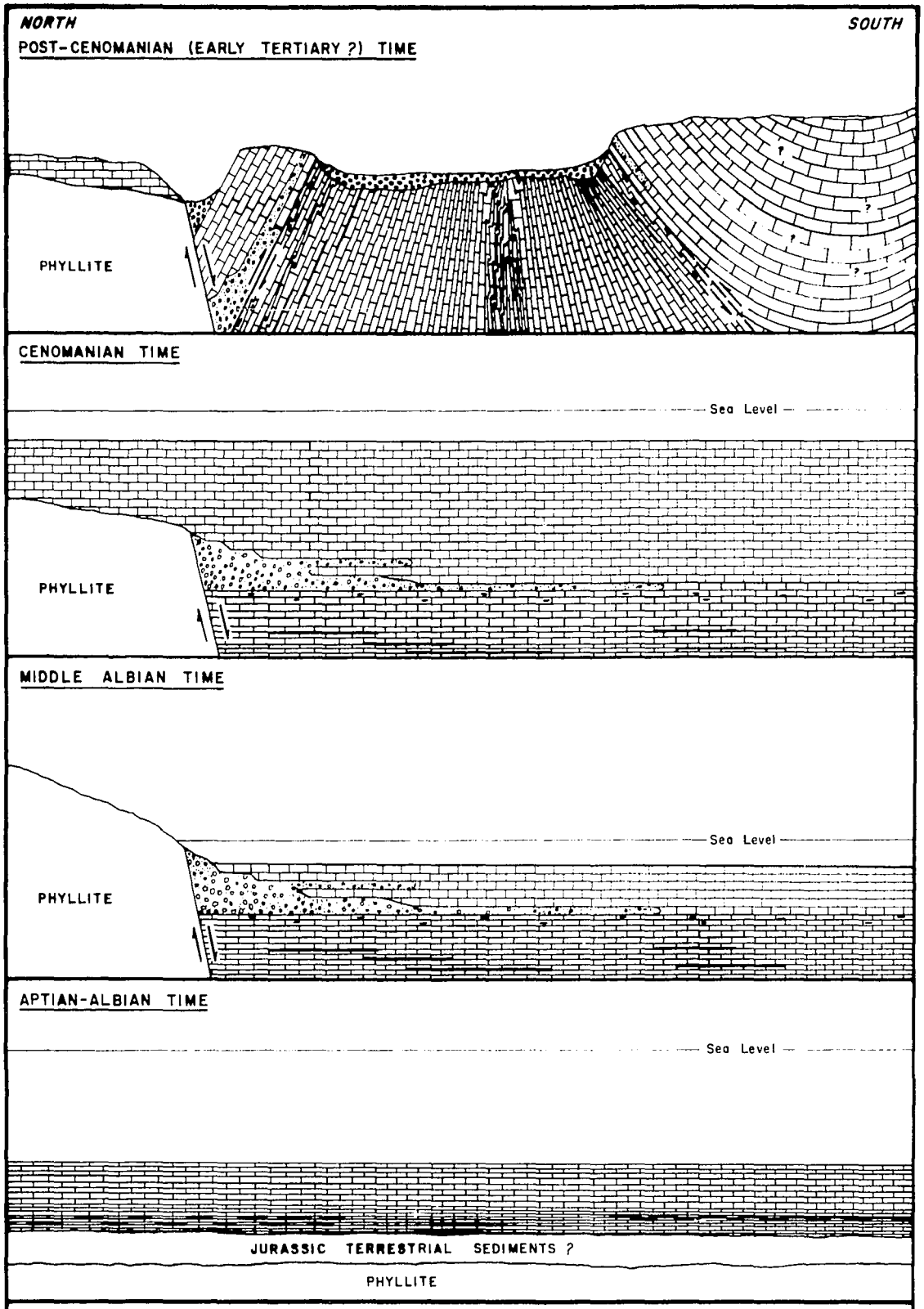
The lower, thin-bedded unit also thins to the south. The El Sillon exposures contain much more shale and shaly limestone than do the Río Carcar limestones. Precise correlations between the Río Carcar and El Sillon sections cannot be made because of the difference in facies and scarcity of fauna. The fanglomeratic facies of the Río Carcar section may correlate with either the erosional unconformity or the change in lithology from thin-bedded to massive at El Sillon.

Depositional History - Throughout northern Central

America, Jurassic terrestrial sediments (Todos Santos Formation) are succeeded by thin-bedded limestone and shale of Aptian-Albian age. Scattered outcrops of Albian limestone are reported as far south as Nicaragua (Hoffstetter, 1960) and to the west near Guatemala City (Vaughn, 1932). Thick sequences of Lower Cretaceous limestone overlying Jurassic terrestrial deposits are found to the north and east in Guatemala, southern Mexico, and western Honduras.

In southeastern Guatemala, a thick sequence of relatively unfossiliferous thin-bedded limestone and shale was deposited until middle Albian time when normal faulting produced local erosional unconformities. In the Jocotán quadrangle a thick fanglomerate of reworked limestone developed on the thin-bedded limestone south of the Jocótan road fault zone during middle Albian time. The fanglomerate is interbedded with massive limestone and sandstone containing rudists and other littoral zone fauna. Farther south, thinner beds of sandstones and siltstones containing similar fauna were deposited. Later Albian and Cenomanian massive rudist-bearing limestones were then deposited over most of the area. Figure 4 is a diagrammatic representation of the depositional and structural history of the Cobán limestone in southeastern Guatemala.

Northern Guatemala and north-central Honduras continued to receive marine limestone deposits throughout most of the Cretaceous but if those sediments were deposited in southeastern Guatemala they have been removed by later erosion.



DIAGRAMMATIC REPRESENTATION OF THE CRETACEOUS HISTORY OF THE COBÁN LIMESTONE IN SOUTHEASTERN GUATEMALA

Scale: Kilometers 0 1 2 3
Vertical Exaggeration 3:1

FIGURE 4

The only evidence for the existence of Cenomanian or younger limestone in the Jocotán region is the presence of a Durania fragment (Table 3) in a cobble from the younger (Tertiary ?) limestone conglomerate of the Subinal Formation. The Durania fragment is probably reworked from the underlying Cretaceous limestone.

Sapper (1899) reports finding an Upper Cretaceous rudist in nearby Copán, Honduras. This rudist may or may not be Upper Cretaceous in age; the stratigraphic ages of rudists have been revised considerably since 1899.

Paleontology - The thin-bedded limestones and dolomites are almost completely devoid of macrofossils. A few coarse-ribbed ammonites and some fish scales were found but none were well preserved enough to be identifiable. Seven samples which appeared to contain microfossils were examined by Dr. E.A. Pessagno of the University of California at Davis. His faunal determinations are listed in Table 2. Most of the identifiable fauna from the thin-bedded sequence are planktonic forms indicating a deep sea depositional environment or sterile bottom conditions during most of the period of deposition.

The faulting which occurred during middle Albian time caused a change in the depositional environment. Massive limestone, limestone fanglomerate and sandstones overlie the thin-bedded sequence and contain abundant littoral and neritic zone fauna. Coral, algae and mollusks, especially

Fauna from the lower (thin-bedded) sequence - determinations by E.A. Pessagno, Jr.

Sample No.	Location	Faunal Identification	Stratigraphic Determination
76	Olopa road outcrop, ½ km SSW of San Antonio Lajas (381284)	*Hedbergella washitaensis* (Carsey)	Albian-L. Cenomanian
79	Olopa road outcrop, ½ km NW of San Antonio Lajas (379294)	*Hedbergella* sp.	Not made
178	Río Carcar, 1 km east of San Antonio Lajas (393290)	*Hedbergella delrioensis* (Carsey)	Probably Albian-Lower Cenomanian
182b	Río Carcar, 1½ km north of San Antonio Lajas (between 383305 & 384305)	*Hedbergella* sp. Scattered benthonic forms Coccolith-like forms	Not made

Dr. Pessagno examined three other specimens from the thin-bedded sequence but found no determinate fauna. In his letter, dated October 14, 1964, he comments: "I suspect that most of your thin-bedded limestones are of Albian age... The lack of *Rotalipora sensu strictu* in your rather rich planktonic assemblages probably substantiates this. (*Rotalipora sensu strictu* seems to be restricted to the Cenomanian and certainly does not occur in the Albian)."

Table 2. COBÁN FORMATION FAUNAL DETERMINATIONS

Rudists from the upper, massive sequence - determinations by B.F. Perkins

Sample No.	Location	Faunal Identification	Stratigraphic Determination
144b	Quebrada El Vertiente vicinity (from debris on north face of hill) (near 435276)	Caprinuloidea sp.	Similar to caprinids of middle and upper Albian age
		Dasycladian algae and Petrophyton sp. (algae)	
238	Olopa road outcrop, 2 km NW of Olopa (455276)	Caprinuloidea cf undescribed Fredricksburg type	Middle Albian
218	Olopa road outcrop, 2 km NW of Olopa (454274)	Caprinuloidea fragments	Probably upper Albian
189	West of Olopa road, 2 km E of San Jorge (384303)	Undescribed Caprinid genus and Cladophyllia sp. (hexacoral) (see Fig. 5)	Found associated with sample #189c
189c	Same as 189	Caprinuloidid (similar to Coalcomana)	Upper lower Albian to lower middle Albian
Rudist from limestone cobbles in the Subinal Formation (Tertiary conglomerate?)			
276	Olopa road outcrop, 4 km due south of San Juan Ermita (379294)	Durania sp.	Cretaceous (Cenomanian or younger)

Table 3 COBÁN FORMATION AND SUBINAL FORMATION FAUNAL DETERMINATIONS

rudists, were found in the massive limestone sequence. Dr. B.F. Perkins of Shell Development Company and Dr. Alan Coogan of the Esso Production Research Laboratory examined various samples of the massive limestone and agreed that, while the rudists were not precisely like those described in the literature, they had strong affinities to Albian-age rudists of North America and the Caribbean region. Dr. Perkins' identifications are presented in Table 3.

Dr. Perkins noted one very unusual rudist in a sample from locality #189. (See Figure 5.) It is a caprinid similar to the Old World genus Caprinula in that all the accessory cavities are on the posterior side. However, it is not the same genus as any described in the literature. As soon as more

Actual Size

Undescribed caprinid genus from the Cobán Formation. Photograph also shows a patch of Cladophyllia sp. (lower right) and another caprinid fragment (upper right).

Figure 5

samples can be obtained, Dr. Perkins will name and describe the genus more completely.

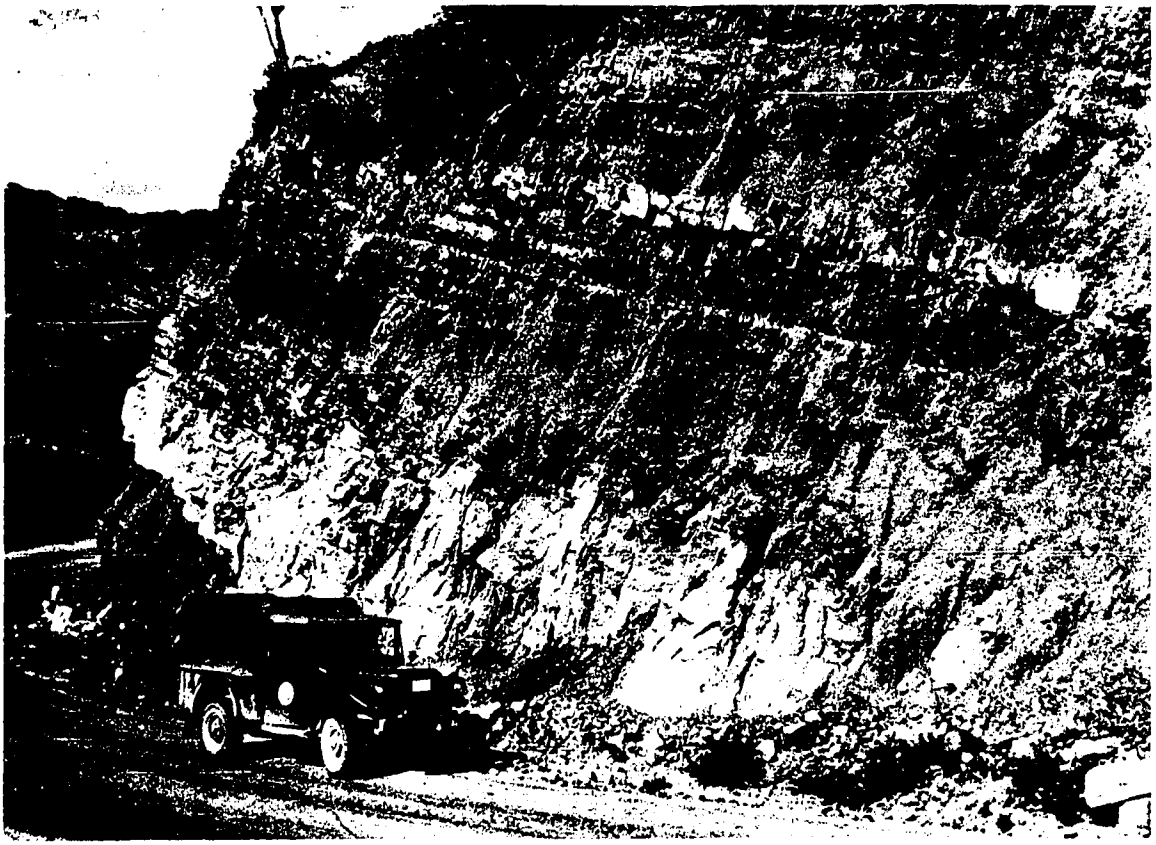
Tertiary and Quaternary Rocks

Terrestrial sediments and volcanic rocks overlie the rugged post-Cenomanian erosion surface throughout southeastern Guatemala. The lowermost sediments are generally conglomerates and redbeds composed of fragments of the underlying rock type and small amounts of volcanic rocks; higher in the section volcanic rocks become increasingly important constituents of the sediments and finally, near the top of the sequence, tuff, lapilli, bombs and flows form massive units containing very little reworked material.

By the time that most of the San Jacinto Formation had been deposited, the area was probably almost completely covered by ash. The later, final stages of vulcanism were less explosive; erosion locally exposed the older erosion surface and vulcanism was confined to rhyolite and basalt flows extruded along minor fissures.

Subinal Formation - The name Subinal Formation was first applied to a thick series of terrestrial redbeds in the Motagua Valley of Guatemala by Tomás Hirschmann (1963). An incomplete type section 754 meters thick was measured and described from a locality just north of the village of Subinal in the Department of El Progresso (Fig. 6).

> "The Subinal Formation consists predominantly of red and green poorly sorted conglomerates, sandstones, arkoses, siltstones and shales. The predominant color



Subinal Formation Exposed in Motagua Valley near Type Locality.

Figure 6

> of the weathered rock at the outcrop is brick-red, and the overall appearance is one of resistant sandstones and conglomerates with the shales and silty shales forming the intervening low areas. Throughout the formation, volcanic tuff is interbedded with the formation, and it appears in thin beds 5 to 15 centimeters (2 to 6 inches) thick, whereas locally the tuffaceous sediments cut across the strike of the Subinal beds." (Hirschmann, 1959)

Hirschmann was unable to date the formation exactly but concluded that it was younger than Cenomanian and at least as old as Miocene and that its most probable age was Miodene.

In this report, the name Subinal Formation has been applied to all of the Tertiary redbeds in the Jocotán-Timushán region.

Depositional Environment - In the area studied, as in the Motagua Valley type area, the Subinal Formation is a terrestrial intermontane sequence of interbedded conglomerates, sandstones, siltstones and shales. Varying amounts of tuff and other volcanic products occur throughout the formation. Nowhere, however, in the Jocotán and Timushán Quadrangles do the redbeds have a stratigraphic thickness as great as those in the type area, nor is there any evidence that they were ever as thick. The difference in formation thickness between the two areas can be attributed to the topography of the surface upon which the redbeds were deposited. In the type area, the Subinal Formation was deposited in a broad, relatively flat valley which drained a large area, probably not very different from the present-day Motagua Valley. The Jocotán-Timushán region, however, contained a series of narrow intermontane valleys oriented northeast-southwest which drained to the north (toward the present-day Motagua Valley) or to the south or both. Burkart has shown that the region south of the Jocotán-Timushán quadrangles contains very thick Subinal redbeds covering a large area and has postulated a depositional environment quite similar to the broad, flat valley suggested above for the Subinal region.

The erosion surface on which the Subinal Formation was deposited must have been quite rugged. Post-Cenomanian orogeny and subsequent erosion resulted in high-standing, parallel ridges composed of a great variety of rock types.

In the Jocotán-Timushán region, phyllites, limestones, intrusive rocks and perhaps some extrusive rocks were exposed before any significant accumulation of redbeds began. As a result, the composition of the clastic fraction of the redbeds is variable from one area to another; the basal units of the redbeds invariably contain large quantities of whatever rock type underlies them.

Throughout southeastern Guatemala the volcanic fraction of the redbeds increases toward the top of the section. It is not possible, however, to correlate between the various separated redbed outcrops on the basis of tuff content or percentage of volcanic products because the topography of the region during the deposition of the formation cannot be precisely reconstructed. Rates of erosion varied from place to place and time to time as a result of the difference in underlying rock type and contemporaneous faulting.

While the various redbed sequences in the area studied are sufficiently similar to justify considering them all part of the Subinal Formation, they have some differences worth noting. They have therefore been mapped as three different facies of the Subinal Formation distinguished on lateral and vertical changes in lithology.

Local Facies of the Subinal Formation

La Puente facies - Near the top of the ridge of phyllites, north of San Juan Ermita, several large outliers of massive Cretaceous limestone crop out. The outliers have

several hundred feet of relief above the underlying phyllites and form broad, white cliffs. Around the base of these outliers, particularly to the north and east sides, there is a thin (one to sixty (?) meters), nearly flat-lying, well-indurated, red terrestrial sediment. These redbeds occur as a down-faulted inlier in the south face of the phyllites. No bedding is evident. In outcrop they resemble a vesicular lava flow which has weathered dark red. The vesicles, however, only occur on the surfaces where soft constituents (pumice ?) have weathered out. On fresh surfaces and in thin section the sedimentary nature of the rock is apparent. It consists of a mixture of weathered andesite fragments, fragments of metamorphic quartz, and euhedral plagioclase laths in an argillaceous matrix. Additionally, small amounts of phyllite and granite are present. The granite fragments contain the typical graphic intergrowths of potash feldspar and quartz which characterize the nearby intrusive rocks. No limestone pebbles were found but small irregular voids filled with calcite are common.

The fact that no reworked limestone was found in any sample of the La Puente redbed facies means that these redbeds might be older than the limestone outliers. Contacts between the limestone outliers and the redbeds are difficult to find because there is always a broad fringe of limestone talus around the base of the outliers. After much searching, one good contact was located on the northeast side of the

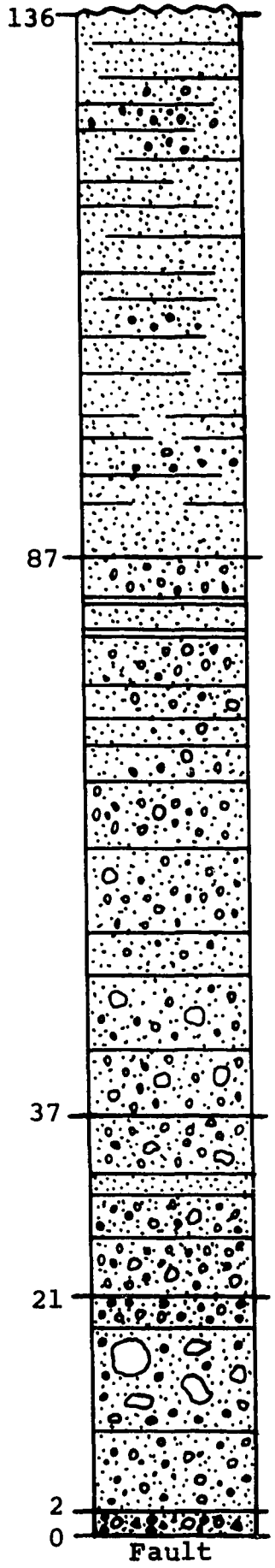
outlier at La Puente. There, the redbeds appear to lap onto the limestone because the contact is vertical, at least near the surface, and there is no evidence of faulting along the contact. Furthermore, several of the limestone outliers rest directly on the phyllite. Unfortunately, the situation is further complicated by the possibility that these limestone outliers are not in place.

Based on the one contact found at La Puente, the La Puente facies redbeds are considered to belong to the lowest part of the Subinal Formation.

San Jorge facies - The redbed outcrops along the road between San Jorge and San Juan Ermita exemplify many of the characteristics of the Subinal Formation. Figure 7 is a briefly described stratigraphic section measured in the redbeds near San Jorge. The specific details of the description are of no consequence for correlation purposes but a few general observations are worth noting:

1. The base of the sequence is in fault contact with phyllites on the north side of the valley. The strike of the redbeds is relatively constant (N 50 degrees E) and parallel to the valley. The dip of the redbeds decreases toward the top of the section, ranging from 55 degrees south near the base to 30 degrees south near the top. Minor faults are abundant because of the section's relationship to the fault zone (see Figure 25).

2. Reworked pieces of the phyllite are abundant in the



Erosion surface

Poorly sorted, poorly indurated, reworked redbeds and tuff. Bedding is not pronounced because of the friable nature of the sediment but most beds appear to be less than 25 cm thick. Maximum grain size is about 5 cm, average grain size is a few milimeters. Most of the constituent grains are reworked La Puente facies fragments, as are those in the remainder of the section described below.

Poorly sorted, interbedded conglomerates in beds 10-50 cm thick. Largest particles are cobbles in some beds, boulders in others. Average bed thickness decreases toward top of section and average constituent particle size is correspondingly smaller. A few beds of reworked tuff 1 to 3 cm thick are present near the top of this unit.

Poorly sorted conglomerates of reworked redbeds in beds 10-50 cm thick. Same composition as below.

5 to 20 cm beds of sand-sized reworked La Puente facies fragments containing some cobbles up to 6 cm in diameter and a red clayey matrix, interbedded with massive conglomerates of the same composition. Conglomerates contain some boulders up to 35 cm in diameter.

Phyllite conglomerate and breccia.

Redbed Section - San Jorge Facies

Figure 7

lower few meters of the section and occur in negligible amounts higher in the section.

3. The thickness of the beds and the size of the constituent particles decreases toward the top.

4. The degree of induration of the beds decreases toward the top.

5. The fraction of tuffaceous material increases toward the top.

6. Most of the section is reworked redbeds of the La Puente facies which now occur 600 meters above and five kilometers northeast of San Jorge.

7. There is an angular unconformity between the redbeds and the tuffaceous white sandstone above them.

These observations are generally true for all of the redbeds found near the road between Vado Hondo (one kilometer west of the mapped area) and Jocotán, although near Las Cruces there is some more recent alluvium composed of reworked redbeds.

San Antonio Lajas facies - The late Cretaceous or Tertiary terrestrial deposits which developed in the eroded core of the Cretaceous limestone anticline are limestone conglomerates. They are defined here as the San Antonio Lajas redbed facies. These conglomerates usually have a red sandy matrix and volcanic products are abundant only near the top of the section. A white, massive tuff unconformably overlies the conglomerates in the Jocotán quadrangle and angular unconformities are common in the Timushán quadrangle. The

contact between the two formations is generally gradational over a zone a few meters thick. This gradational zone is a reddish, tuff-rich limestone conglomerate at the base and a mixture of pink and white tuff toward the top. In rare instances, a thin zone of andesite-rich reworked tuff occurs within the contact zone.

One kilometer northwest of San Antonio Lajas, a one hundred-meter-thick section of the limestone conglomerate crops out on the Olopa road. There is no pronounced bedding but the attitude of the conglomerate (as determined by the trace of the limestone/limestone conglomerate contact and variations in the degree of sorting within the conglomerate) is relatively horizontal. Elsewhere in the Jocotán quadrangle the thickness of the limestone conglomerate varies from a few meters to over one hundred meters and with a few exceptions the bedding is nearly horizontal.

The writer believes that the San Antonio Lajas facies of the Subinal Formation is contemporaneous with or slightly older than the La Puente facies. Both facies are angularly unconformable conglomerates resting directly on top of the post-Cenomanian erosion surface, and they can be correlated with an overlying reworked redbed facies of much higher ash content; the La Puente facies has been reworked into the San Jorge facies and the San Antonio Lajas facies has been reworked within the overlying thin contact zone below the white, massive tuff. Accordingly, the gradational contact

zone between the San Antonio Lajas facies and the overlying tuff has been mapped as the San Jorge facies of the Subinal Formation.

The redbeds in the eastern half of the Timushán quadrangle are reworked phyllite debris mixed with pyroclastic material. They are poorly consolidated, poorly bedded and they are presumably underlain by phyllites. However, the only exposure of phyllite found was a small outcrop in the Quebrada de Monteros, south of Monteros. The phyllite content of these redbeds decreases westward toward Carboneras. They appear to be laterally equivalent to the San Jorge facies near Carboneras. Therefore, in the Timushán quadrangle, the Subinal redbeds have been mapped as the San Jorge and San Antonio Lajas facies only.

Age of the Subinal Formation - This study has developed no additional information concerning the age of the Subinal Formation. Future studies should concentrate on correlating the work of Hirschmann (1963) with that of Vinson (1962) in the lower Motagua Valley and attempt to find distinctive flora in the lignites of the San Jacinto Formation in order to date the Subinal Formation.

Hirschmann considered the Subinal Formation to be younger than Cenomanian and at least as old as Miocene. He states that the Subinal Formation in the type area contains cobbles of Cenomanian limestone and probably consideres the upper Armas Formation (Vinson, 1962), which is thought to be of

Miocene-Pliocene age (probably Pliocene), to be slightly younger than the Subinal Formation. However, the relationship between the Armas Formation and the Subinal Formation was not definitely known.

Figure 8 shows the Tertiary stratigraphic relationships of eastern and northern Guatemala as interpreted by Vinson. The type locality of the Armas Formation is near Bananera, 150 kilometers northeast of Subinal in the Motagua Valley. The upper unit of the Armas Formation is defined as the redbeds and overlying deltaic deposits exposed in the Motagua Valley between Bananera and the mouth of the Motagua River. This unit has a total thickness of about 1,400 meters. The lower unit of the Armas Formation is defined as the approximately 1,400 meters of unfossiliferous redbeds encountered in a wildcat oil well drilled near Bananera. Hirschmann was aware of some of Vinson's findings and apparently considers the upper unit of the Armas Formation to be younger than the Subinal Formation but the distinction between the two is not clear:

> "Near Los Amates, just past Quirigua, one can observe what appears to be the contact between a younger series of redbeds and the Subinal Formation. Even though I did not map that area in detail, I noted that just east of Quirigua the outcrop belt of the redbeds, which is about 1.2 kilometers (2 miles) wide at Los Amates, narrows to just a few hundred feet and then widens again to about 6 kilometers. At this narrow outcrop either a fault or a normal depositional contact brings the younger redbeds into contact with the Subinal Formation. The younger beds are much more loosely cemented, less well bedded, and higher in volcanic content. Identifiable foraminifera were found in these "younger" redbeds near Bananera by

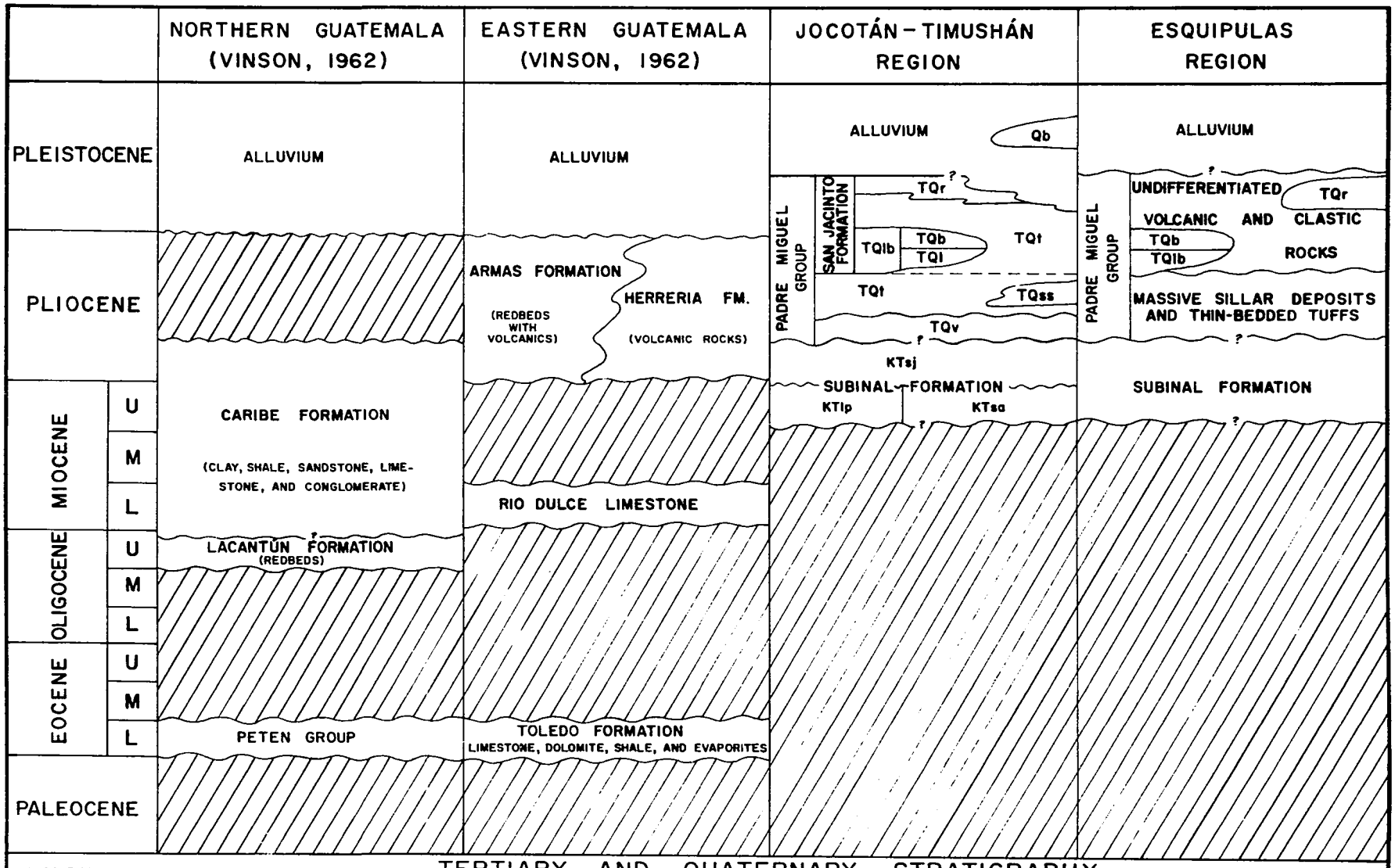


FIGURE 8 TERTIARY AND QUATERNARY STRATIGRAPHY OF NORTHERN AND EASTERN GUATEMALA

> Esso Standard (Guatemala) Inc. geologists, and the age of the rock has been determined to be Miocene to Pliocene. Hence, it is presumed that the Subinal Formation is at least as old as Pliocene." (Hirschmann, 1963, pp. 50-51)

The Esso Standard geologists undoubtedly included Vinson though Hirschmann does not mention him by name.

Vinson reports no volcanic rocks from Tertiary formations in the Motagua Valley older than Miocene in age. The Subinal Formation is always found to contain some volcanic fragments near its base so it is probably no older than Miocene age and may be as young as Middle Pliocene.

It is probably equivalent in part to the Armas Formation, perhaps to the lower, subsurface unit of the Armas Formation. More work should be done in the lower Motagua Valley to be certain of the relationships.

The age of the youngest member of the Subinal Formation is also difficult to determine. Burkart believes that the Subinal redbeds continued to accumulate until early Pliocene time and that most of the block-faulting of the Esquipulas region occurred during a later period of increased volcanic activity. Relationships in the Jocotán quadrangle also indicate that block-faulting occurred during and after the deposition of the Subinal Formation. Within the Jocotán quadrangle, the top of the Subinal Formation appears to be younger than the Jocotán graben and older than the lignites and ash at the base of the San Jacinto Formation. If the lignite could be dated, the upper limit of the age of the Subinal Formation could be determined. However, no identifiable flora has been found in the lignite.

Padre Miguel Group - The type and thickness of late Tertiary and Quaternary volcanic rocks varies from place to place in southeastern Guatemala. No single locality contains all the varieties of volcanic rocks nor are the relative ages of the various lithologies always certain. Rather than defining each lithologic type as a formation and attempting to correlate between scattered outcrops of similar lithology, the entire sequence of Tertiary and Quaternary volcanic rocks in these areas, except the morphologically distinctive Quaternary basalts, will be termed the Padre Miguel Group as defined by Burkart.

Near the type locality the Padre Miguel Group includes at its base a 450-meter-thick sequence of massive, white, rhyolitic sillar deposits overlain by almost 400 meters of bedded, reworked sillar and white rhyolitic tuff. In the Jocotán and Timushán quadrangles the base of the Padre Miguel Group contains no consolidated sillar deposits but instead is composed of less than 200 meters of white, massive rhyolitic tuff and tuffaceous sandstone. The difference in lithology is probably attributable to a difference in environment rather than age; the Padre Miguel region appears to have been closer to the centers of volcanic activity throughout Tertiary time. Additionally, the basins in which the thick Subinal redbeds had been deposited provided a depositional environment in which thick sequences of ash collected. The Jocotán and Timushán areas were relatively high-standing

regions composed mainly of Mesozoic and older rocks.

San Jacinto Formation - Overlying the reworked rhyolitic tuff, throughout southeastern Guatemala, are basaltic lahars, basalt flows and rhyolite flows, interbedded with small amounts of rhyolitic tuff. This sequence of volcanic rocks is well represented in the Jocotán and Timushán quadrangles, especially along their southern margins. The name San Jacinto Formation, as defined here, refers to the upper portion of the Padre Miguel Group, above the reworked tuff and sillars, and includes all of the basaltic volcanic rocks and rhyolite flows within the Padre Miguel Group and the rhyolitic tuff interbedded with them. The name is derived from the municipio San Jacinto which surrounds the aldea San Jacinto, a small village about five kilometers south of Santa Elena and just a short distance west of the southwest corner of the Jocotán quadrangle. All of the volcanic rocks within the San Jacinto Formation are well represented in the municipio San Jacinto and their relationships can be determined there.

Lithology - Figure 8 compares the types of lithologies in the Padre Miguel Group of the Esquipulas quadrangle (Burkart) and the types of volcanic rocks found in the Jocotán and Timushán quadrangles. Age correlations are based on similarities in lithology and lithologic sequence. In figure 8, as on plates 1 and 2, the different varieties of volcanic rocks within the Padre Miguel Group are distinguished

by different symbols. Units bearing the same symbol are not necessarily time equivalent; widely separated units of similar lithology have been identified with the same symbol unless they are suspected of being distinctly different ages. Figure 8 shows the most probable age relationships between the various lithologies of the Padre Miguel Group.

Six different varieties of volcanic rocks can be distinguished within the Jocotán and Timushán quadrangles:

1. Andesite Flow (TQv) - Found only at the top of the ridge north of San Juan Ermita, this heavily weathered flow is younger than all the formations with which it is in contact. No fragments of this flow were found within the San Jorge facies of the Subinal Formation and so the flow is presumed to be younger than the Subinal redbeds, though it may be the time equivalent of the upper Subinal Formation.

2. Tuffaceous Sandstone (TQss) - Interbedded rhyolitic tuff and tuff-rich quartz and feldspar sandstone unconformably overlies the Subinal Formation along the Jocotán road fault zone and within the Jocotán graben. One of the best exposures of this sandstone is in a road cut three kilometers west of San Jorge, just west of the edge of the Jocotán quadrangle. The base of the sequence contains a few fragments of reworked redbeds and rhyolitic tuff overlain by more than forty meters of thin-bedded lacustrine sediments including carbonaceous siltstone and shale, water-lain tuff, and thin beds of silty lignite. Overlying this lacustrine sequence is approximately

120 meters of interbedded tuff and sandstone. The top of the section is buried beneath the basalt flows to the south. A similar sequence of tuff, sandstone and lacustrine sediments crops out along the Río Jocotán, mostly west of Jocotán. Thin beds of silty lignite also occur near the base of this sandstone sequence. In both localities the lignites contain abundant but poorly preserved plant remains which are not identifiable. Dan Jones of the Humble Production Research Laboratory disaggregated several samples of lignite in search of identifiable pollen but reported that he found none, perhaps because the samples had been oxidized in outcrop. These are the same lignites from which Mullerried (1939) reported Middle Jurassic plant remains, "in part cycads, which are equivalent to those of El Consuelo, Oaxaca." In view of the structural and stratigraphic relationships of the area and the poor preservation of plant remains in the lignite, Mullerried's fossils were probably not Jurassic cycads.

The age of the lignite remains undetermined. A thorough search should be made for flora in the lignite in order to date the contact between the Subinal Formation and the Padre Miguel Group. Alternatively, radioisotope dates on the associated volcanic ash could be made to serve the same purpose.

To the south, in the area studied by Burkart, this sequence of thin-bedded sandstone and water-deposited tuff is probably represented by the sillar deposits and the over-

lying tuff and reworked sillar.

3. Rhyolitic Tuff (TQt) - Interbedded with and overlying the tuffaceous sandstone is a thick sequence of white, rhyolitic tuff. The white tuff is most abundant in the southern portion of the Jocotán and Timushán quadrangles where it is deposited on an erosion surface composed of tilted fault blocks of Tertiary redbeds and Cretaceous limestone. The tuff is generally massive with a few water-lain beds of tuff developed locally. Weathered pumice fragments, basaltic lapilli or slightly reworked quartz and feldspar sand may also be concentrated locally. Small euhedral biotite grains or small grains of magnetite are the most common mafic constituents of the tuff.

This white tuff occurs both in the San Jacinto Formation and within the underlying, basal unit of the Padre Miguel Group. The areas labelled TQt on plates 1 and 2 contain massive white tuff, some of which may be time equivalent to the sillars and reworked sillars of the Esquipulas region, others of which may be younger and associated with the laharic deposits.

4. Basalt (TQb), Lahar (TQl) and Undifferentiated Basalt and Lahar (TQlb) - Thick deposits of basaltic lahars and basalt flows overlie the tuffaceous sandstone and are intimately associated with the rhyolitic tuffs, particularly in the southern half of the Jocotán quadrangle. The lahars are poorly consolidated, unsorted, unbedded mixtures of a variety

of volcanic products including bombs, lapilli and ash. The basalts and lahars of the Jocotán quadrangle appear to be associated with three local eruptive centers: one a few kilometers northeast of Olopa, another 13 kilometers west of Olopa, near San Jacinto, and a third (minor center) within the Jocotán graben. Eruptions were probably associated with small cinder and spatter cones aligned along local fractures.

5. Rhyolite Flows (TQr) - Two major rhyolite flows occur within the Jocotán quadrangle. Both lie on top of an erosional surface composed of basalt and lahar. One large flow or composite flow of white rhyolite occurs in the southwest corner of the Jocotán graben, elongate northeast southwest along the Jocotán road fault zone and dissected by the Río Carcar (Figure 9). Zones of white rhyolitic tuff or altered rhyolite are common. Near the village of Las Cruces, on both sides of the Río Carcar, a few thin dikes of gray perlite glass cut across the flow laminations in this rhyolite.

In the southwest corner of the Jocotán quadrangle, near San Jacinto, white rhyolite flows cap the laharic basalts on either side of the road. These two flows are connected by a narrow rhyolite dike trending northwest-southeast across the Río Shutaque. An associated minor rhyolite flow occurs two kilometers south of San Jorge over the fault contact between the white Tertiary sandstone and Cretaceous limestone.

Rhyolite Flow in Southwest Corner of the Jocotán Graben (view to north). Foreground is limestone near the village of Carrizal.

Figure 9

Hot Spring Travertine Deposit in Quebrada Agua Caliente one Kilometer East of Camotán.

Figure 10

Quaternary Basalt (Qb) - In addition to the previously described weathered basalts and lahars of late Tertiary or Quaternary age there are other occurrences of basalt which are less weathered and are morphologically distinctive. Where possible, these basalts have been mapped as Quaternary basalt on criteria similar to those used by Williams *et al.* (1964, p. 20). All of the Quaternary basalts occur along the western border of the Jocotán quadrangle, aligned along the eastern boundry fault of the Chiquimula graben. Remnants of four Quaternary cinder cones are aligned along the graben boundry at the top of the basalt flow which extends to the west into the Pleistocene gravels of the Chiquimula Valley. Additionally, several small basalt flows and dikes of probable Quaternary age occur in the Río Shutaque north and south of Santa Elena.

Quaternary Alluvium and Travertine - The Quaternary deposits mapped on Plate 1 as Qal and Qcg are lithologically indistinguishable, poorly indurated conglomerates composed of a mixture of all the rock types of the surrounding area. They have been differentiated on structural criteria; the conglomerates Qcg are contained within a small tilted fault block on the eastern edge of the Jocotán graben (Figure 24). The alluvium Qal is undisturbed, flat-lying alluvium associated with present-day rivers and probably is younger than the conglomerate Qcg.

Large quantities of soft travertine (impure $CaCO_3$, mapped

as Qc) cap some of the hills in the Jocotán-Camotán vicinity. The travertine southwest of Jocotán is identical to the present-day deposits around the hot springs of the Jocotán-Camotán vicinity (Figure 10) and must have been the site of a thermal spring in relatively recent times. A similar, though much smaller body of travertine occurs in the canyon of the Río Carcar two kilometers south of San Juan Ermita. The travertine south of Camotán is much thicker and more weathered than the other travertines of the vicinity and more closely resembles caliche. This deposit is probably related to nearby cold-water springs in the Cobán limestone.

STRUCTURAL GEOLOGY

General

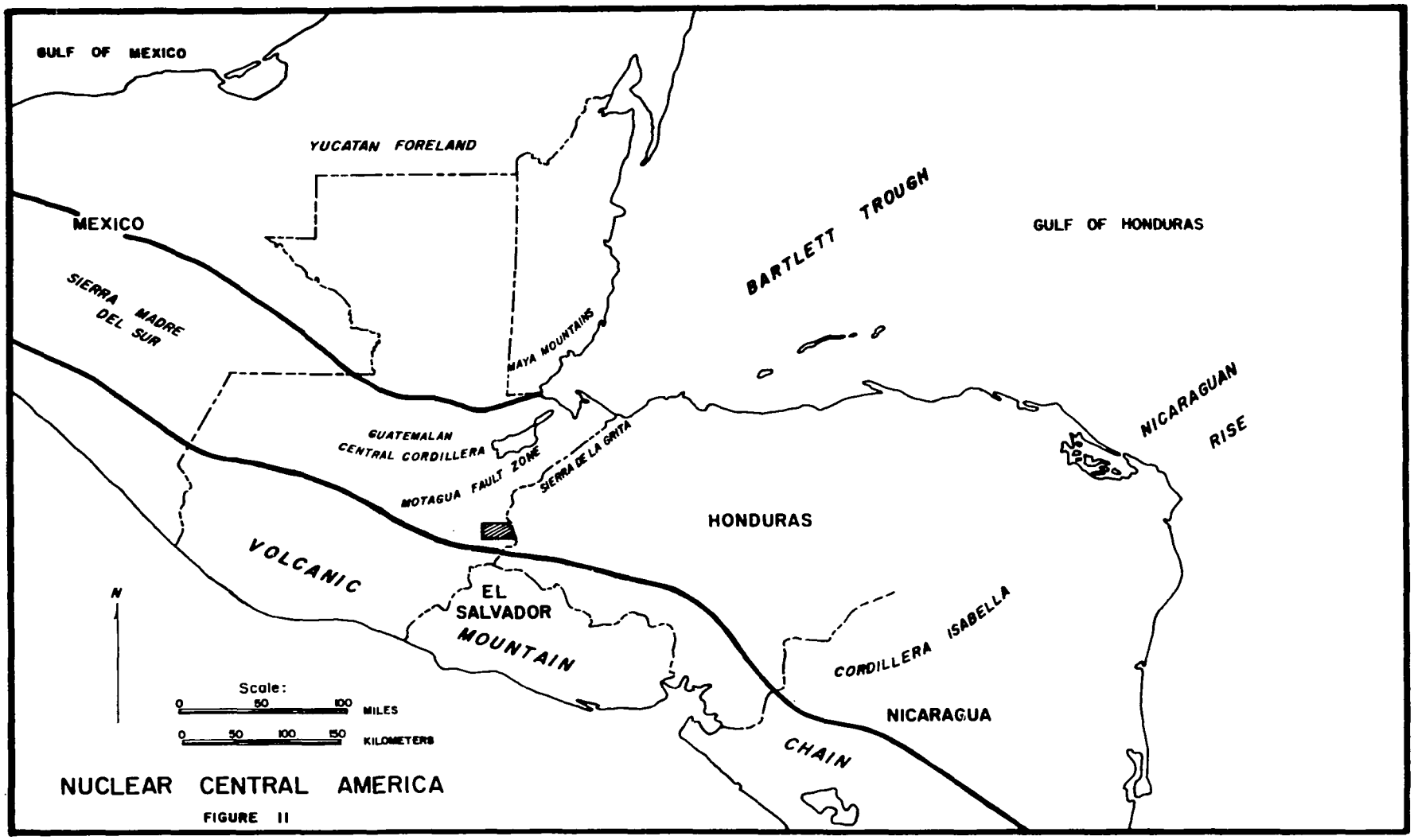
The Jocotán and Timushán quadrangles are located within the zone of contact between the Cenozoic Volcanic Mountains Province of Central America and the older provinces of Nuclear Central America (Figure 11).

> "The geologic nucleus of Central America combines the Governments of Chiapas, Guatemala, British Honduras, Honduras and northern Nicaragua. Together with the Greater Antilles they make the folded northern frame of the Caribbean basin." (Schuchert, 1935, p. 314).

This "folded northern frame" and its "young foreland" in Yucatan have been called Nuclear Central America since Schuchert's description of the region. Schuchert described the Volcanic Mountains Province as a "younger appendage" composed of younger, mainly volcanic mountains, parallel with the Pacific coast from southwestern Chiapas to Panama.

The northwest third of the Jocotán quadrangle contains structures and rock types associated with the Central Cordillera of Guatemala (the core of Nuclear Central America). It is predominantly phyllite and granite which belong to a zone of "basement rocks" exposed between the Motagua Valley fault zone and a parallel fault zone crossing the Jocotán quadrangle. These two fault zones trend approximately N 70°E in this part of Guatemala.

The southwestern quarter of the Jocotán quadrangle may be considered to be a part of the Volcanic Mountains Province of the Pacific coast. The exposed rocks are dominantly basaltic and rhyolitic flows and ash deposits which are



NUCLEAR CENTRAL AMERICA

FIGURE 11

probably contemporaneous with the late Tertiary to Recent volcanics of the Ipala Valley, twenty-five kilometers to the southeast. The Ipala Volcano, a well-formed cone rising over 700 meters from the floor of the Ipala Valley, may have been the source of some of the basaltic ash in the area, but the majority of the basaltic ash and bombs were produced locally from minor fissures. The volcanic rocks of the Jocotán quadrangle are unlike those of the volcanic mountains in their high content of rhyolitic material; here on the eastern edge of the volcanic province, thick sequences of rhyolitic tuff are common and within the Jocotán quadrangle alone there are two major rhyolite flows.

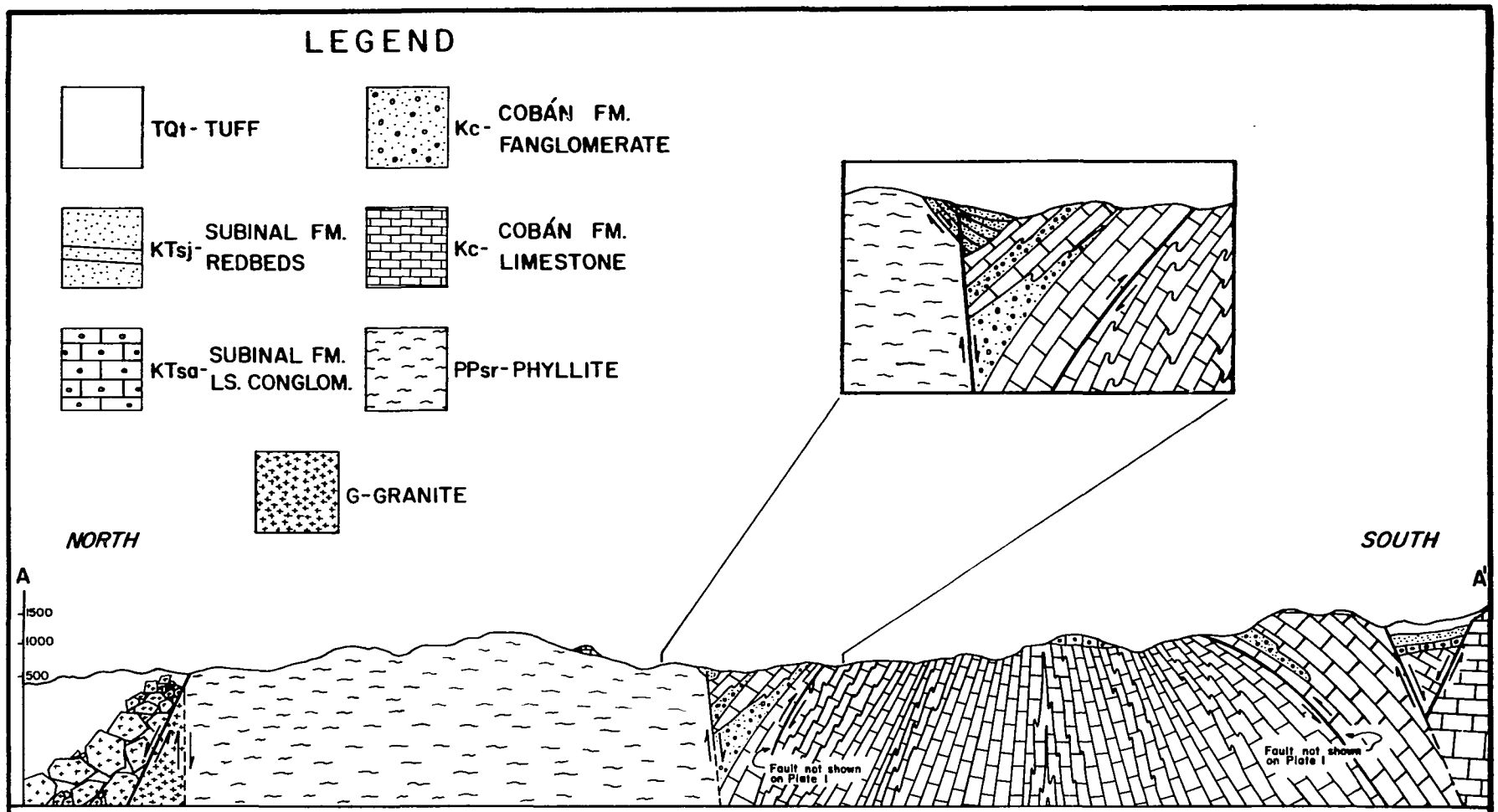
In addition to those areas of the Jocotán and Timushán quadrangles which are physiographically similar to the Central Cordillera and Volcanic Mountains, there is an intermediate zone south of the Jocotán road and east of San Juan Ermita which has some of the characteristics of both provinces. This region, which extends to the east into Honduras, is one of the few areas south of the Motagua Valley where a thick sequence of limestone is exposed in Guatemala. Approximately 1,600 meters of Cretaceous limestone crops out in a dissected, tightly folded anticline whose axis trends north seventy-degrees east, parallel to the structural trend of the Guatemalan Central Cordillera. The anticline, which measures about eight kilometers across strike, is bounded to the north by a pronounced fault parallel to the Motagua Valley. The

southern flank of the anticline is not as well defined because Tertiary cover and Tertiary block faulting obscure its margin. Minor faults are abundant within the anticline, particularly in the core where the thin-bedded limestones and shales are exposed, but these faults cannot be traced very far and appear to have very little displacement. Furthermore, a thick Tertiary limestone conglomerate developed on the breached core of the anticline and, with few exceptions, the limestone conglomerate is both in its original horizontal position and unaffected by subsequent faulting. Conversely, south of the anticlinal structure, the limestone, limestone conglomerate and overlying tuffaceous redbeds have been affected by Tertiary block faulting. Extrusives (flows and dikes) are also common in the block-faulted region though only a few were found within the anticlinal structure.

Local Summary

Figure 12 is a north-south cross-section of the Jocotán quadrangle and is a comprehensive summary of the structural relationships in the area. The normal fault at the north end of the section is the border of the Chiquimula Valley graben. Late Tertiary or Quaternary rhyolitic tuffs conceal the fault. A Quaternary basalt flow has been extruded from this fault zone into the Chiquimula Valley and several cinder cones are aligned along the fault.

The oldest rocks in the Jocotán quadrangle crop out between the Chiquimula graben fault and the Jocotán road fault



CROSS-SECTION OF THE JOCOTÁN QUADRANGLE

0 1 2 3 4 5
SCALE : KILOMETERS

FIGURE 12

zone. These rocks are pre-Cretaceous intrusives and phyllites. The intrusives are probably a single pluton and are separated from the phyllites by vertical or near vertical faults.

South of the Jocotán road fault zone Cretaceous limestone is faulted down against phyllite. The majority of the limestone is folded into a wide anticlinal structure whose axis trends north seventy-degrees east and crosses the Olopa road near San Antonio Lajas. Near the southern border of the Jocotán quadrangle the dominant structure is Tertiary block faulting. Within the block-faulted region, Tertiary terrestrial sediments and volcanics are abundant. Block-faulted Tertiary sediments and volcanics are even more prevalent in the adjoining quadrangle to the south.

On topographic highs throughout the Jocotán and Timushán quadrangles, Tertiary redbeds and tuff are common. In the eroded core of the anticline the redbeds are represented by a flat-lying limestone conglomerate with a red sandy matrix. All varieties of redbeds grade sharply upward into white massive tuffs.

Phyllite Structure

The deformational history of the phyllite is difficult to determine. Very little relic sedimentary structure exists. Elsewhere, notably in the Chiquimula quadrangle, thin stringers of marble permit tracing bedding planes short distances but in the area east of Chiquimula no lithologic variety was found. The phyllite is the metamorphosed equivalent of a

thick pelitic sequence of sediments similar to the Permian Tactic Formation described by Walper (1960). One good exposure of what appears to be relic sedimentary structure occurs in a road cut near San Juan Ermita (Fig. 13). The bedding planes are in an S-shaped fold striking north seventy degrees east. Foliations are poorly developed at this locality.

In general, the phyllites contain well-developed foliation planes and poorly developed lineations. However, the orientation of the foliation planes is quite variable. Local orientations have no obvious relationship to regional structures though presumably the fabric is related in some way to the deformational history of the phyllite.

Approximately one hundred foliation measurements on the phyllite of the Jocotán quadrangle are plotted on Figure 14. These measurements were made on phyllite outcrops throughout the region in which phyllite is exposed though approximately one-half of the measurements were made in road cuts along the Jocotán road. The total number of points plotted is small, but there appears to be a fabric to the phyllite. Most of the plotted values fall within a broad girdle trending northwest-southeast, and there is a concentration of values around the center of the plot. Similar fabrics result from overturned folds but in the Jocotán quadrangle most of the vertical foliation planes are associated with fault zones.

The northeast-southwest Jocotán road fault zone is the southern boundry of the phyllite. Figure 15 is a plot of

Relic Sedimentary Structure in Phyllite Exposed in Road Cut near San Juan Ermita.

Figure 13

Stereonets in figures 14, 15 and 16 contain plots of the pole to the plane of foliation. in the phyllite. All plots are on the lower hemisphere of a Wulff equal area net.

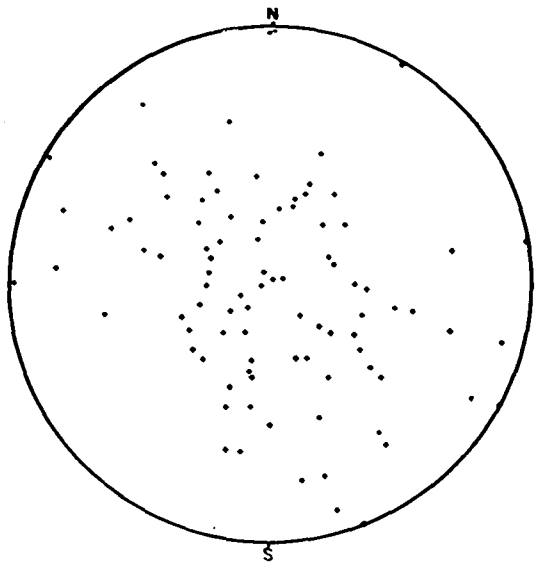


Figure 14 - Total of all foliation measurements made in the Jocotán quadrangle.

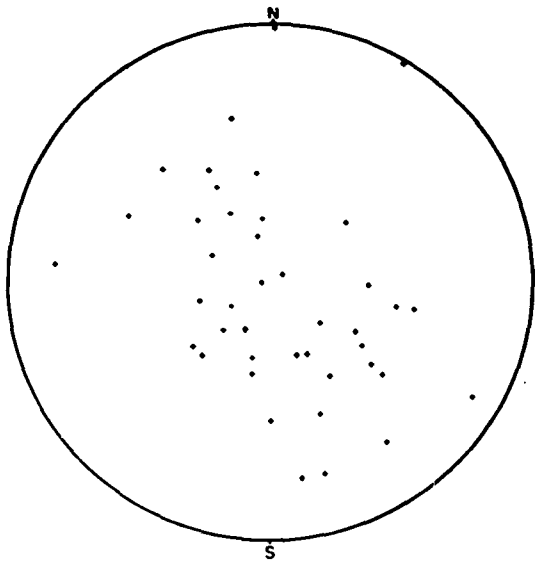


Figure 15 - Orientations of foliations measured away from the Jocotán road fault zone.

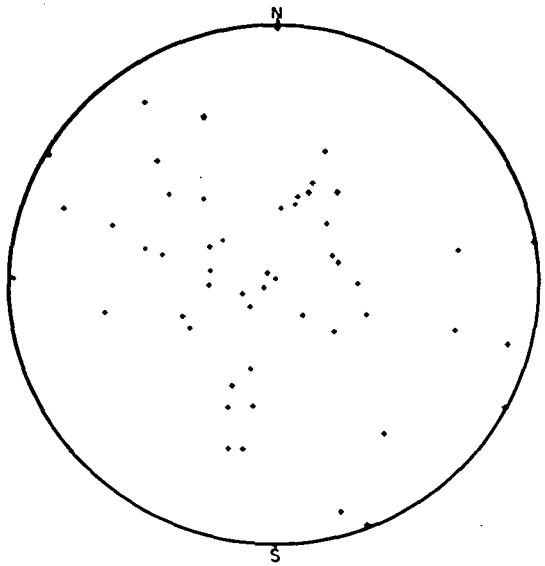


Figure 16 - Foliation measurements taken in the vicinity of the Jocotán road fault zone.

those foliation measurements obtained at least one kilometer away from the Jocotán road fault zone. The remainder of the measurements, taken largely from outcrops near the Jocotán road, are plotted on Figure 16 for comparison. Almost all of the near vertical foliation measurements were obtained in the vicinity of the Jocotán road[1] fault zone which suggests that the greatly contorted foliation planes visible in road cuts on the Jocotán road are atypical of the phyllite and are associated with the fault zone rather than the intense folding which has affected the younger limestones to the south. Burkart found very little folding of the phyllite foliations near El Sillon, and Clemons found very few vertical foliation planes in the phyllite of the Chiquimula quadrangle. From the limited amount of data available, a tentative conclusion is that, excepting those fabrics resulting from post-Aptian northeast-southwest faulting, the phyllite fabric of the area studied resulted from limited folding during Cretaceous time of previously horizontal foliations in the phyllites.

More work on the phyllite fabric in southeastern Guatemala and on the broad band of metamorphics to the east in Honduras

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[1]There is a possibility of bias in measurement resulting from vertical foliation planes being better exposed and therefore more frequently measured in road cuts. However, the foliation measurements away from the road were usually taken in ravines or on steep slopes in order to avoid a bias toward horizontal foliations. If there is a bias in this technique, it should affect both sets of measurements about equally.

would help in understanding the stratigraphy and deformational history of the region south of the Central Cordilleran core of Nuclear Central America.

Limestone Structure

The largest single structural feature of the Jocotán region is the tightly folded limestone anticline whose axis extends northeast-southwest across the Jocotán quadrangle. The cross-section of Figure 12 is drawn approximately perpendicular to the axis of the anticline. The lower part of the limestone section exposed in the core of the anticline is thin-bedded, interbedded limestone, shale and dolomite with a total stratigraphic thickness of 1,300 meters. Stratigraphically above and structurally on the flanks of the thin-bedded anticlinal core is a massive limestone about 400 meters thick.

This anticline appears to be a classic example of concentric folding. Wiess (1959) defines concentric folds as "folds in a layered body ... formed by flexure or buckling of individual competent layers combined with simultaneous slip of layer over layer." In the Río Carcar exposures, the amount of flexure or buckling of individual beds or members increases toward the axis of the anticline and the shaly members and other less competent members of the formation are locally more intensely deformed than the thicker bedded limestones and dolomites. Figure 17a illustrates the type of folding which has occurred in a few members of the

a. Quebrada Torjá, near Tunuco.

b. Río Carcar, near San Antonio Lajas.

Complex Structures within Cobán Limestone Anticline.

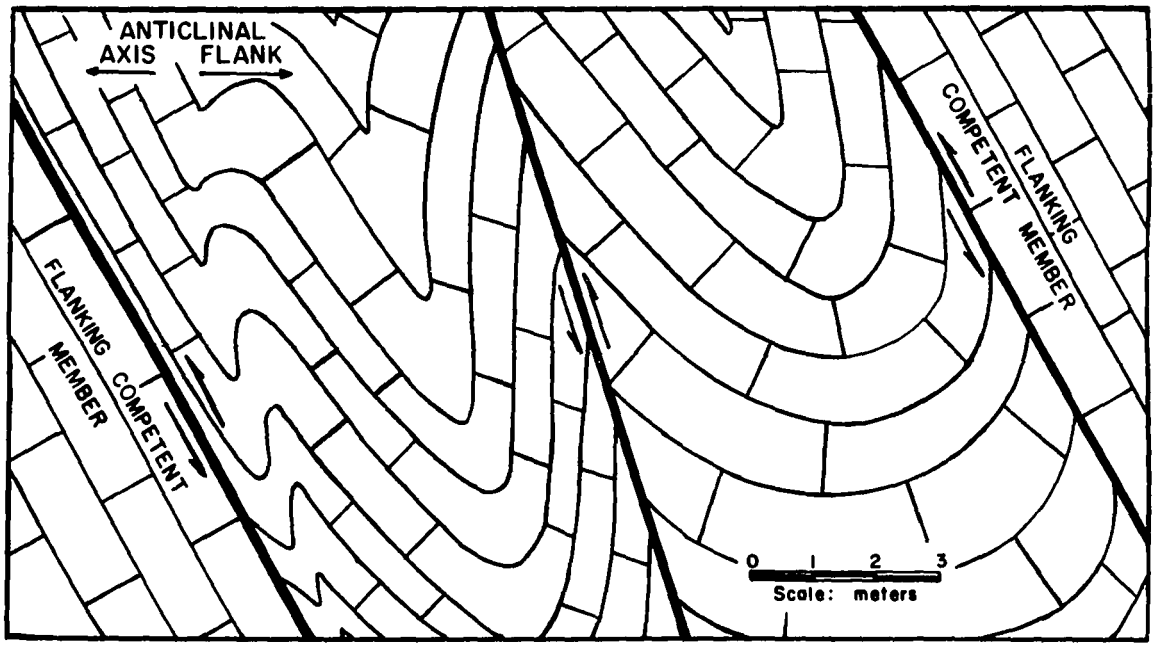
Figure 17

thin-bedded limestone sequence. In these instances, sections of limestone over twenty meters thick have been detached from the remainder of the section, presumably along incompetent flanking shale members, and folded into tight flexures resembling chevron folds. In some cases small shear planes developed along the axis of the chevron fold (Figure 18). The less competent shale-rich or thin-bedded limestone members were even more intensely deformed (Figure 17b). Figure 19 relates the various minor structures developed near the core of the anticline; buckling of semicompetent members has occurred between two more competent flanking members with slippage along the interfaces. The direction of folding has been interpreted to be largely the result of drag at the interface. In the field, the folding in places appears to be related to drag along faults and in other exposures the faults cut across the axis of pre-existing folds and produce no local drag effect. Both types of faults are represented in Figure 19.

Ideal concentric folds in a layered material require a change in thickness or volume of the individual layers. In rock, volume changes are too small to accommodate the change in geometry so the beds on the crests of the folds would be expected to thin (be extended) and beds near the core of the fold should thicken. These two processes are represented in the anticline by boudinage structures and deformed concretions and pebbles in the upper part of the thin-bedded sequence

Minor Faulting in Cobán Limestone. (North of the axis of the anticline, in Río Carcar, view to west.)

Figure 18



Diagrammatic Representation of Minor Structures within the Cobán Limestone Anticline.

Figure 19

(Figure 20) and by plastic-like flow in the less competent beds near the core of the anticline (Figure 17b).

The upper members of the Cobán Formation are massive limestones and very well cemented massive limestone conglomerates. They occur on the flanks of the anticline and are much more competent than the beds of the lower, thin-bedded sequence. Furthermore, the transition from thin-bedded to massive limestone is abrupt. Consequently, the upper, massive limestone section was detached during folding and all that remains of the top of the thin-bedded sequence is a zone of breccia about two meters thick. The detachment surface is best seen in the Río Carcar at 700 meters elevation on the north flank of the anticline, though it is also observable on the Olopa road southwest of Cerro El Cute (map coordinate 355296). In general, the massive limestone sequence is not folded and is highly resistant to erosion; Figure 21 is a photograph of the cliffs which are characteristic of outcrops of the massive limestone.

The base of the Cobán Formation is not exposed in the core of the anticline but farther south Burkart has shown that the lowermost Cobán sediments are thin-bedded marine shales overlying Jurassic shales of the Todos Santos Formation. Judging by the attitude of the beds in the core of the anticline and their intense deformation, it seems probable that these shales were the zone in which a <u>décollement</u> surface developed during the deformation of the

Approximate orientation of anticlinal axis.

Concretions Deformed Parallel to Bedding Plane in the Cobán Limestone (Río Carcar).

Figure 20

Cliff-forming Upper, Massive Cobán Limestone (view to northeast, toward Jocotán). The scarp is formed at the massive/thin-bedded limestone contact on the north flank of the anticline.

Figure 21

limestone. The relatively unfolded condition of the foliations in the older phyllites tends to confirm this hypothesis. The depth below the present surface to the decollement surface cannot be determined because the amount of Cretaceous section missing is not known.

Tertiary and Quaternary Structures

Block-faulting - Burkart has studied the well-developed block-faulting of the Esquipulas quadrangle (south of the Jocotán quadrangle) and shown that the orientation of the fractures bounding the block-faulted Tertiary sediments is related both to the orientation of the Central Cordillera of Guatemala and the more recent fault trends of the volcanic mountains to the west. The Tertiary redbeds were deposited in intermontane basins oriented approximately N 70° E, parallel to the pre-Tertiary structural trends, and have been subsequently affected by renewed movement along these fault directions and newer faults oriented at approximately right angles to them. The newer fault trends appear to be associated with the Ipala Valley; they are oriented tangentially to arcs whose center of radius is the Ipala Volcano, ten to twenty kilometers to the west of the block-faulted region of the Esquipulas quadrangle. The relationship is very well exhibited on the western edge of the Esquipulas quadrangle where some of the longer faults describe arcs with a radius of about ten kilometers.

The southern half of the Jocotán quadrangle contains

some block-faulting of a similar nature, particularly in the south-central area. Figure 22 summarizes the fault and fracture patterns in the Jocotán and Timushán quadrangles. West of Olopa, a strong pattern oriented N 10°W to N 30° W is apparent. The Ipala Volcano is 35 kilometers WSW of Olopa. Excepting the Jocotán graben, there is no significant block-faulting north or east of Olopa. Fractures and faults in the Timushán quadrangle are preferentially oriented about N 60° E.

Block faulting is a late Tertiary or Quaternary phenomenon in southeastern Guatemala. The grabens associated with the Chiquimula, Zacapa and Jocotán Valleys are probably late Tertiary structures. Block-faulting in the Jocotán quadrangle, as well as additional displacement of the Jocotán (road) fault zone, occurred after the deposition of the La Puente facies and prior to the deposition of the younger facies of the Subinal Formation.

Jocotán-Camotán Valley - The Jocotán-Camotán Valley is a small graben (see cross-section in Figure 23) which was initially formed in Mio-Pliocene (?) time contemporaneous with the block-faulting and graben formation elsewhere in southeastern Guatemala. Later accumulations of redbeds, volcanic ash, basalt and rhyolite flows obscure the margins of the original graben. The structure is further complicated by a smaller, tilted inlier of Pleistocene (?) gravels on the eastern edge of the graben (Qcg on Plate 1, not shown

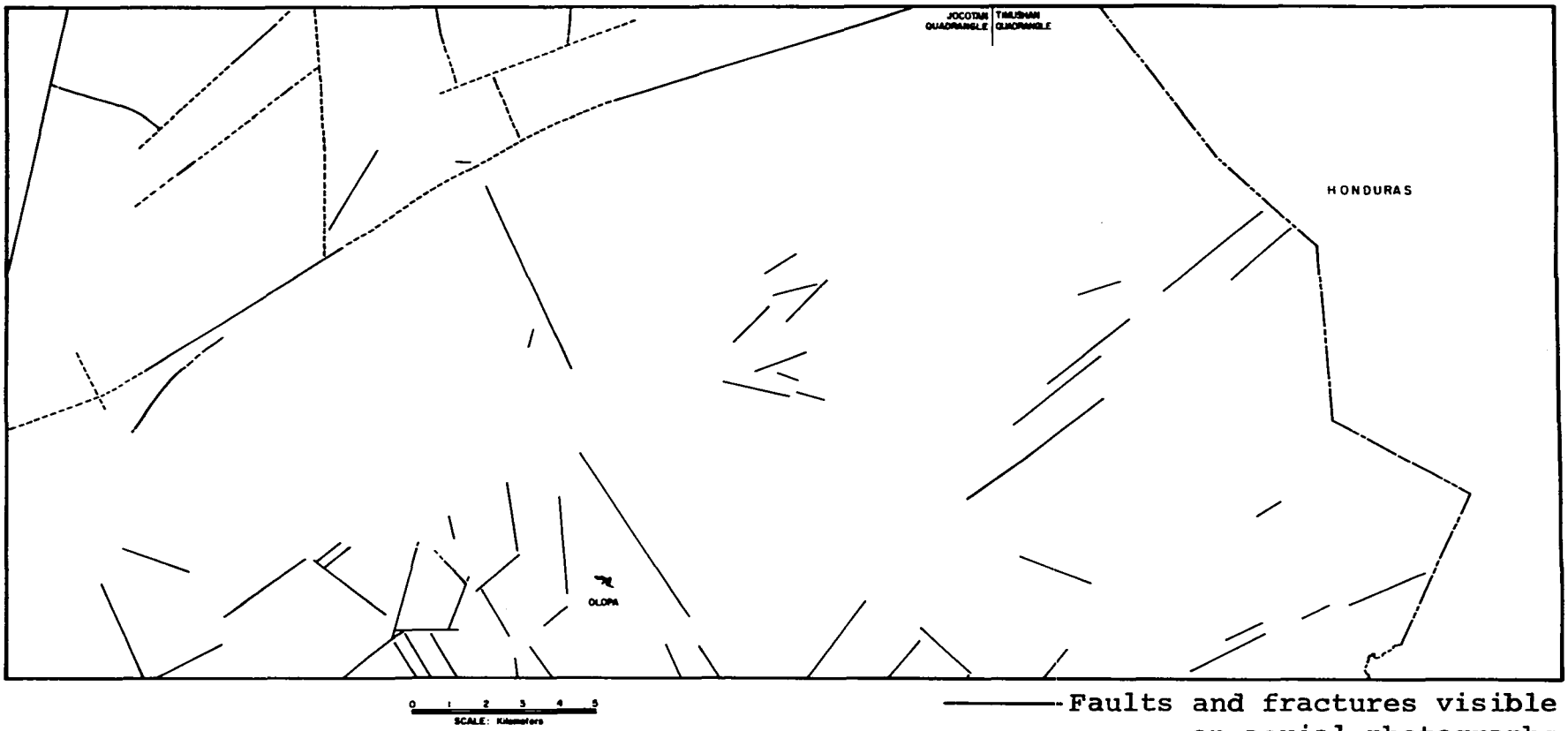
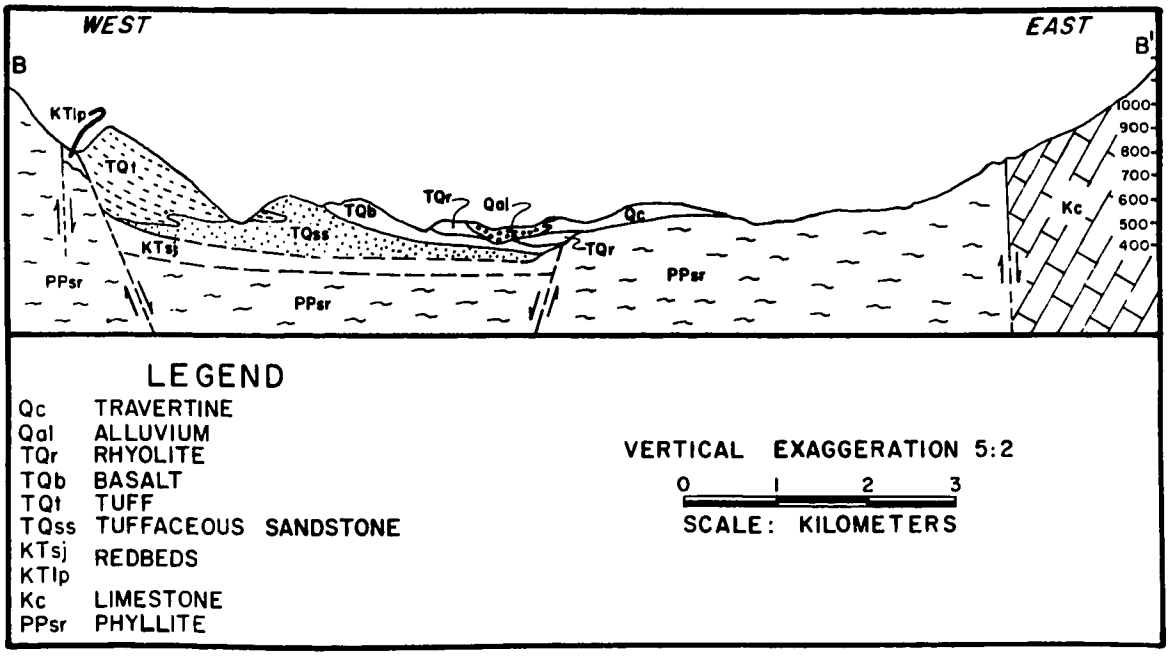


Figure 22

——— Faults and fractures visible on aerial photographs

- - - - - Faults not visible on aerial photographs

Fault and Fracture Patterns



Cross-Section of the Jocotán Graben. Section B-B'.

Figure 23

Tilted Fault Block of Quaternary Conglomerate (Qcg). (Exposed in the river north of Jocotán.) Hilltop is about 100 meters above river level. The face of the cliff is stained red with hematite derived from Subinal Formation cobbles within the conglomerate.

Figure 24

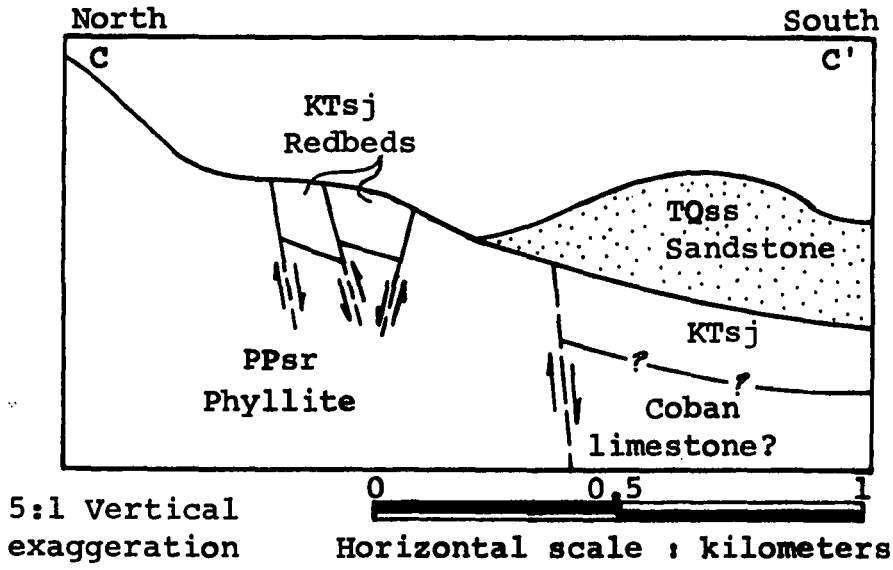
on Fig. 23). These gravels are well exposed only on the north bank of the Río Grande (Río Jocotán) where they crop out in a steep red cliff (Fig. 24). The faults bounding the inlier on the east and west are exposed in the river, the southern margin of the inlier is probably coincident with the aligned hot springs in the valley.

The faults bounding this inlier of conglomerate are the youngest faults in the Jocotán-Timushán region. They are probably contemporaneous with the latest movements of the Motagua Valley fault zone. Steeply dipping conglomerates of probable Quaternary age are also exposed in the Motagua River north of Zacapa. These structures, the thermal springs and severe earthquakes as recently as 1765 testify to the continuing tectonic activity of eastern Guatemala.

Jocotán Road Fault Zone - The Jocotán road parallels a major normal fault which can be traced across eastern Guatemala and into Honduras. Throughout its length the fault parallels the Motagua and Polochic fault zones. It disappears to the west beneath Quaternary volcanic rocks near Jalapa and may extend eastward into Honduras as far as San Pedro Sula. It has been active at various intervals since early Cretaceous time and perhaps longer. In general, the fault separates older, metamorphosed rocks to the north from younger Cretaceous and Tertiary sediments on the south but it is also the southern boundry of the Chiquimula and Jocotán grabens. In the Jocotán quadrangle, movement along

the fault occurred during Albian time, at the end of Cretaceous time and during late Tertiary or early Quaternary time. Minor movements along the fault may have occurred as recently as Middle Pleistocene time; late Tertiary or Quaternary basalt and rhyolite flows extruded along the fault are undisturbed but minor faults are abundant in the upper Subinal beds and lower Padre Miguel Group tuffs and sandstones. Figure 25 is a cross-section of the Jocotán road fault zone near San Jorge.

Further study of this fault zone in northern Honduras would probably be a useful method of obtaining information on the Mesozoic and Cenozoic history of the Cayman Trench, the Caribbean extension of the Motagua and Polochic faults.



North-South Cross-Section near San Jorge. Section C-C'.

Figure 25

GEOLOGIC HISTORY

The oldest rocks exposed in the Jocotán-Timushán region are metamorphosed pre-Mesozoic pelitic sediments. These metasediments (phyllites) are tentatively correlated with the Permian age Tactíc Formation of the Santa Rosa Group of north-central Guatemala. Late Paleozoic orogeny, accompanied elsewhere in Guatemala by igneous intrusions, probably accounts for the metamorphosed condition of these sediments. The granitic rock now found in fault contact with the phyllites of the Jocotán region may have been the metamorphosing agent.

No rock of definite Triassic or Jurassic age occurs in the quadrangles though Jurassic terrestrial sediments are known to occur in northern Guatemala and central Honduras.

A thick sequence of thin-bedded limestone, shale and dolomite was deposited on the post-Paleozoic erosion surface during Cretaceous time (Cobán Formation). The oldest exposures of these limestones in the Jocotán quadrangle are of Albian age. As deposition proceeded during Albian time, the calcareous sediments became progressively less shaly and more massive bedded until middle or upper Albian time when the underlying phyllites were faulted up with respect to the limestone and eroded, forming thick fanglomerate deposits near the fault zone and progressively finer conglomerates and sandstones interbedded with massive limestone toward the south. The granitic pluton may have been faulted

against the phyllite at the same time. Continued erosion and/or encroachment of the sea resulted in the deposition of a thick sequence of massive limestone above the fanglomerate and ultimately on top of the metamorphic terrain as well. There is evidence that limestone of Cenomanian age was deposited above the massive late Albian age limestone but if younger Cretaceous sediments were ever deposited, they have been completely removed by later erosion.

Post-Albian but pre-Miocene (probably late Cretaceous) orogenic movements folded the Cretaceous limestone into an anticline with a fold axis oriented north seventy-degrees east, parallel to the orientation of the Albian faults of the area and parallel to the present-day Motagua Valley structures. Subsequent erosion produced a series of ridges and valleys with the same orientation and exposed the pre-Cretaceous metamorphics and intrusives.

Late Cretaceous or Tertiary (probably Miocene) terrestrial redbeds, including limestone conglomerates, containing volcanic material were deposited in intermontane basins on top of the pre-Tertiary erosion surface. Block faulting and renewed faulting along the northeast-southwest trend may have begun to affect the area as early as Miocene time following which the redbeds were reworked into newly developed low areas including the Jocotán graben. The andesite flows and ash deposits of southeastern Guatemala were probably associated with this period of faulting.

During late Tertiary time, after the beginning of the period of block faulting, increasing volcanic activity inundated the redbeds with rhyolitic ash. Concurrently, local fissures, especially in the southern portion of the Jocotán quadrangle, produced basaltic flows and small cones of basaltic material. Local rhyolite flows, possibly of Quaternary age, later covered some of these basaltic volcanics. The youngest volcanics of the region are Quaternary basalt dikes, flows and cinder cones in the western part of the Jocotán quadrangle.

ECONOMIC GEOLOGY

The mineral resources of the Jocotán and Timushán quadrangles are few. Limestone and dolomite occur in large quantities but equally large amounts occur much nearer Guatemala City and other sites where they might be needed. No other industrial minerals and no metallic minerals were encountered in the area.

Because the silver deposits of the Concepción Las Minas area occur in hydrothermally altered Tertiary tuff, the possibility that the hot springs of the Jocotán-Camotán area might be depositing silver minerals and sulfides at depth was considered. Accordingly, several samples of travertine from the vicinity of Camotán were analyzed for trace elements. Dr. Gale Billings of the Sinclair Research Laboratories was kind enough to analyze the samples by emission spectrography. He reported that in addition to calcium and magnesium, minor amounts of sodium and strontium were present and only trace amounts of silicon, manganese, aluminum, copper and iron were found. The sensitivity of the method for detecting silver is 0.5 parts per million but none was detected.

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APPENDIX A

Stratigraphic Sections of the Cobán Limestone

1. Upper, massive unit measured in the Quebrada Chispán, (four kilometers west of Olopa).

2. Upper, massive unit measured in the Río Carcar.

3. Lower, thin-bedded unit measured in the Río Carcar.

Appendix A(1) - Upper unit of the Cobán Formation, measured in the Quebrada Chispán.

Base of section located at 1260 meters in the Quebrada Chispán, just above a large landslide (fault?). Top of section is top of Cerro Chispán.

Cumulative thickness (meters)	Description
250	Erosional surface
	Massive gray, cliff-forming limestone. Bedding planes are rare. A few unidentifiable rudists and other macrofossils present. Limestone is very recrystallized.
	Sample # 144b (see Table 3) containing *Caprinuloidea* and the hexacoral *Cylindroporella* is believed to belong in the lower part of this sequence.
23	Possible section missing, fault in the Quebrada Chispán.
	Tan massive sandy limestone, beds 15-90 centimeters thick.
18	
	Interbedded red and green clay containing lenses of *Ostrea*-rich tan sandy limestone.
15	
	Tan sandstone. Beds 15 to 80 centimeters thick.
10	
	Massive light gray sandy limestone and light gray fossiliferous limestone. Samples # 218 and 238 containing *Caprinuloidea* are probably from an equivalent horizon.
6	
	Massive greenish-gray calcareous siltstone with a few oyster shells.
0	

Appendix A(2) - Upper unit of the Cobán Formation, measured in the Río Carcar.

Base of the section located at about 720 meters elevation in the Río Carcar. Fanglomerate is exposed downstream from this point. Massive limestone exposed on hill east of the Río Carcar canyon.

Cumulative thickness (meters)	Description
430	Erosional surface
	Massive gray, cliff-forming limestone weathering light gray. Lithologically very similar to the massive limestone in the Quebrada Chispán section.
180	Interbedded massive gray limestone and fanglomerates. The fanglomerate is generally a pink limestone conglomerate with a green sandy matrix, contains 5-10 centimeter cobbles and pebbles of itself within itself, as well as slightly reworked and whole rudists. Sample # 189 containing Caprinuloidids of lower to middle Albian affinity is probably from an equivalent horizon.
	The thickness of this unit is an estimate. The actual thickness measured (assuming original horizontality, no repetition of section and constant strike and dip of N70E60NW) was about 600 meters.
80	Interbedded massive gray limestone and green sandy conglomerate. Pebbles and cobbles in the conglomerate are generally limestone but some reworked conglomerate is present.
20	Interbedded black silt and dark gray limestone weathering light gray. Black silt beds are six centimeters to one meter thick, limestone beds two to ten centimeters thick. Within this unit are some lenses of light gray or green coarse sand, one to five centimeters thick, weathering tan. The green color of this sand and the green sand above results from a high content of reworked, fine-grained andesite.
0	Fault contact with the lower, thin-bedded unit.

Appendix A(3) - Lower, thin-bedded unit of the Cobán Formation measured in the Río Carcar.

Cumulative thickness (meters)	Description
1290	Fault contact with the upper, massive unit of the Cobán Formation. Fault appears to be parallel to bedding of the upper unit.
	Dark gray, massive limestone weathering light gray. Black chert stringers indicate bedding was originally 5-10 cm thick. Tight folds abundant.
1260	Dark gray thin-bedded (5-10 cm beds) limestone weathering light gray, interbedded with light gray limestone containing very thin red or pink laminations (2 or 3 per cm). Light gray limestone (with laminations) parts along major bedding planes 2-10 cm apart. Small amount of black chert present near the top of the sequence. Pink-banded limestone more common toward the base of the sequence. Sample #182b containing Hedbergella, a planktonic Foraminifera, collected here.
1200	Dark gray limestone, beds 5-30 cm thick, weathering light gray, interbedded with dark gray to black silty limestone which occurs in beds 2-15 cm thick. Calcite veins commonly fill fractures.
1060	Alternating dark gray limestone and gray calcareous siltstone. Limestone weathers tan and light gray, occurs in beds 5-60 cm thick. Siltstone beds are 2-10 cm thick. Siltstone weathers light gray.
960	This 200 meters of section does not crop out to any significant extent. Debris on the slopes of the river bank generally fits the description of the sequence described above between 960 and 1060 meters. The slumping in this sequence indicates that it is at least as thin bedded as the overlying unit and may have a greater shale content. The 200-meter thickness is an estimate based on average strike and dip in the vicinity and taking into account probable repetition by

Appendix A(3), continued

Cumulative thickness (meters)	Description
	folding which is common on the area.
765	Dark gray thin-bedded limestone (2-15 cm beds) weathering light gray, interbedded with 2-5 cm beds (long lenses ?) of black chert. A few limestone concretions as below but not as abundant.
685	Dark gray thin-bedded limestone weathering light gray. Thick black chert beds (or large lenses) and light gray limestone concretions (10-15 cm in diameter) common throughout. In addition to the concretions, this unit contains 2-5 cm diameter spherical pebbles of limestone which are generally well rounded (one angular pebble found). Black chert is slightly more common toward the base of this unit.
625	Dark gray limestone weathering tan, beds 5-15 cm thick, interbedded with 2-15 cm beds of silty black shale. Shale beds constitute 25% - 30% of the unit.
605	Dark gray limestone weathering light gray interbedded with silty black shale. Limestone beds are 5-40 cm thick, thinner (2-10 cm) toward the top. Silty shale beds vary from 2 to 65 cm thick, are thickest and most abundant near the center of the unit. Overall, the unit is 60% limestone and 40% shale. The large quantity of shale makes this unit very incompetent.
525	Dark gray limestone weathering light gray, beds 5-40 cm thick, interbedded with 5 cm beds of black shale and siltstone. Shale and siltstone constitute no more than 5% of the sequence. One 20-cm-thick bed of brown-weathering calcarenite occurs near the center of the unit.
495	Dark gray thin-bedded (5-15 cm) limestone weathering light gray to tan. About 10% of the unit is 2 to 5 cm beds of dark gray silty limestone. Calcite veins (less than 2 cm thick) fill fractures.
435	Alternating gray and dark gray thin-bedded

Appendix A(3), continued

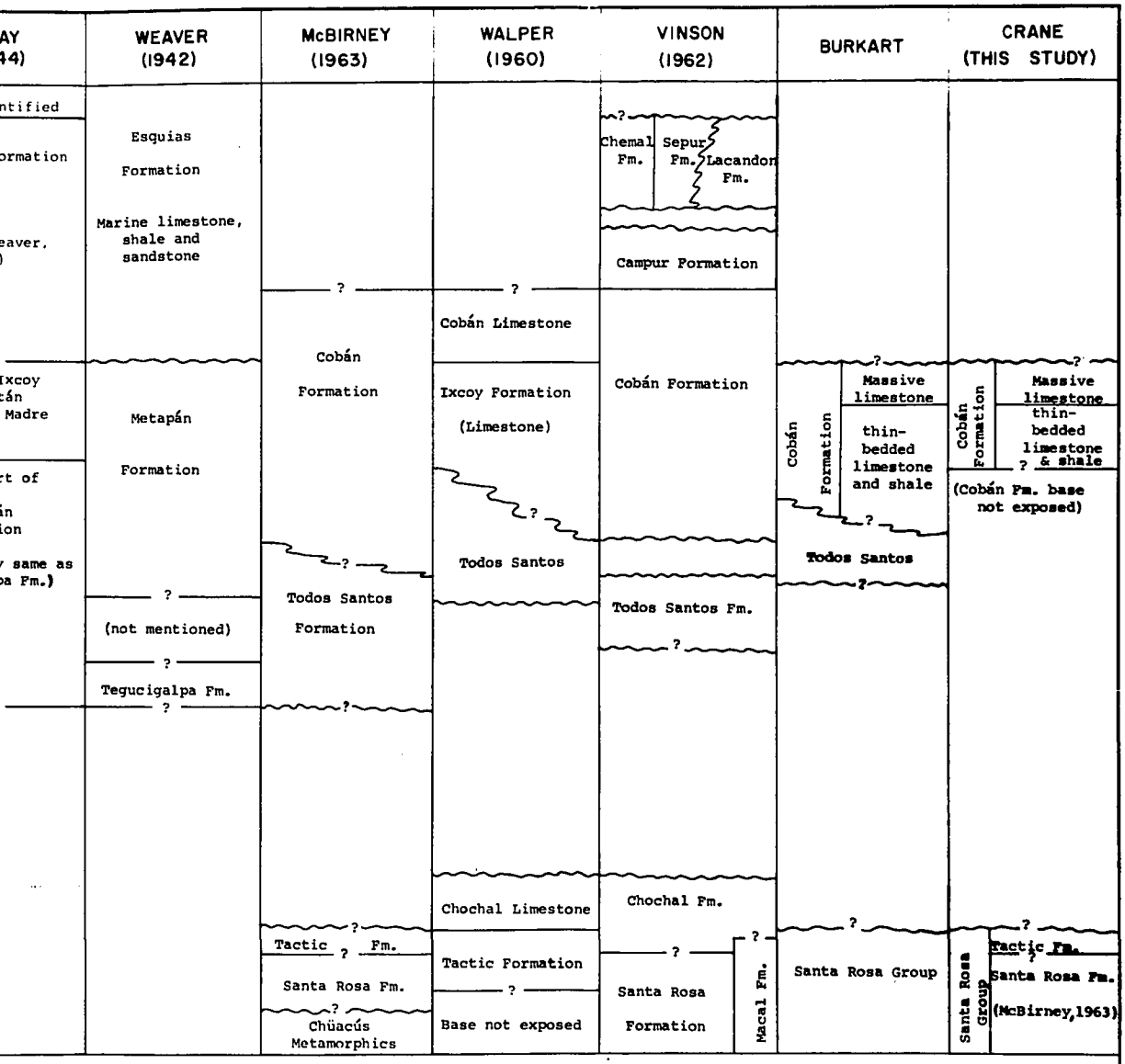
Cumulative thickness (meters)	Description
	limestone. Some of the thicker beds (10-20 cm) contain oval limestone concretions, 7 to 30 cm long, which are flattened along bedding planes. Concretions contain some pyrite but generally weather light gray. A few coarsely-ribbed, coiled, evolute ammonites occur in the concretions. The largest ammonite found measured 4 cm in diameter, all are poorly preserved. One centimeter beds (or long lenses) of black chert not uncommon. Concretions and black chert are more common toward the base of the unit. Calcite veins (less than 2 cm wide) fill fractures throughout the sequence. Sample #178 containing Hedbergella delrioensis collected from this unit. Sample #79, collected elsewhere, contains Hedbergella sp. and is thought to be from an equivalent stratigraphic position.
400	Thin-bedded alternately sandy and silty dolomite. Sandy dolomite is light gray, weathers light brown or tan, occurs in beds 2 to 10 cm thick. Near the center of the unit the bedding planes are pock-marked. These depressions are oval, measure 3 to 6 cm across and are generally less than one cm deep. Some are filled with iron or manganese-rich nodules, others with dolomite concretions but most have been weathered bare. One nodule was found to contain a mold of a coiled, coarse-ribbed ammonite $3\frac{1}{2}$ cm in diameter.
305	Gray-green to dark green sandy dolomite in 2 to 20 cm thick beds interbedded with gray to black silty dolomite beds 3 to 10 cm thick.
285	Same as below plus a few concretions of sandy dolomite. Concretions average about 10 cm wide by 25 cm long and are flattened along the plane of the bedding.
275	Gray sandy dolomite beds 2 to 20 cm thick, interbedded with gray to black silty dolomite beds 4 to 10 cm thick.
195	Gray limestone beds 2 to 10 cm thick weathering light gray. Very small amount of dark calcareous

Appendix A(3), continued

Cumulative thickness (meters)	Description
	shale present along some bedding planes. Sample #76 containing Hedbergella washitaënsis (collected elsewhere) is probably from a stratigraphically equivalent unit.
95	Gray limestone, beds 1 to 5 cm thick, weathering light gray and interbedded with tan sandy limestone beds 10 to 20 cm thick.
60	Dark gray to black fissile shale in beds 1 to 5 cm thick interbedded with dark gray limestone beds 2 to 10 cm thick. Limestone weathers tan or light gray. Bedding is tightly folded and slumping is common (see figure 17b). Thicker limestone beds smell or petroleum on fresh surfaces. One 50 cm bed of black limestone occurs which contains a few bright blue unidentifiable fish scales.
0	Bottom of the section is the lowest exposure of the Cobán Formation in the Río Carcar and corresponds to the point at which the anticlinal axis crosses the Río Carcar near San Antonio Lajas.

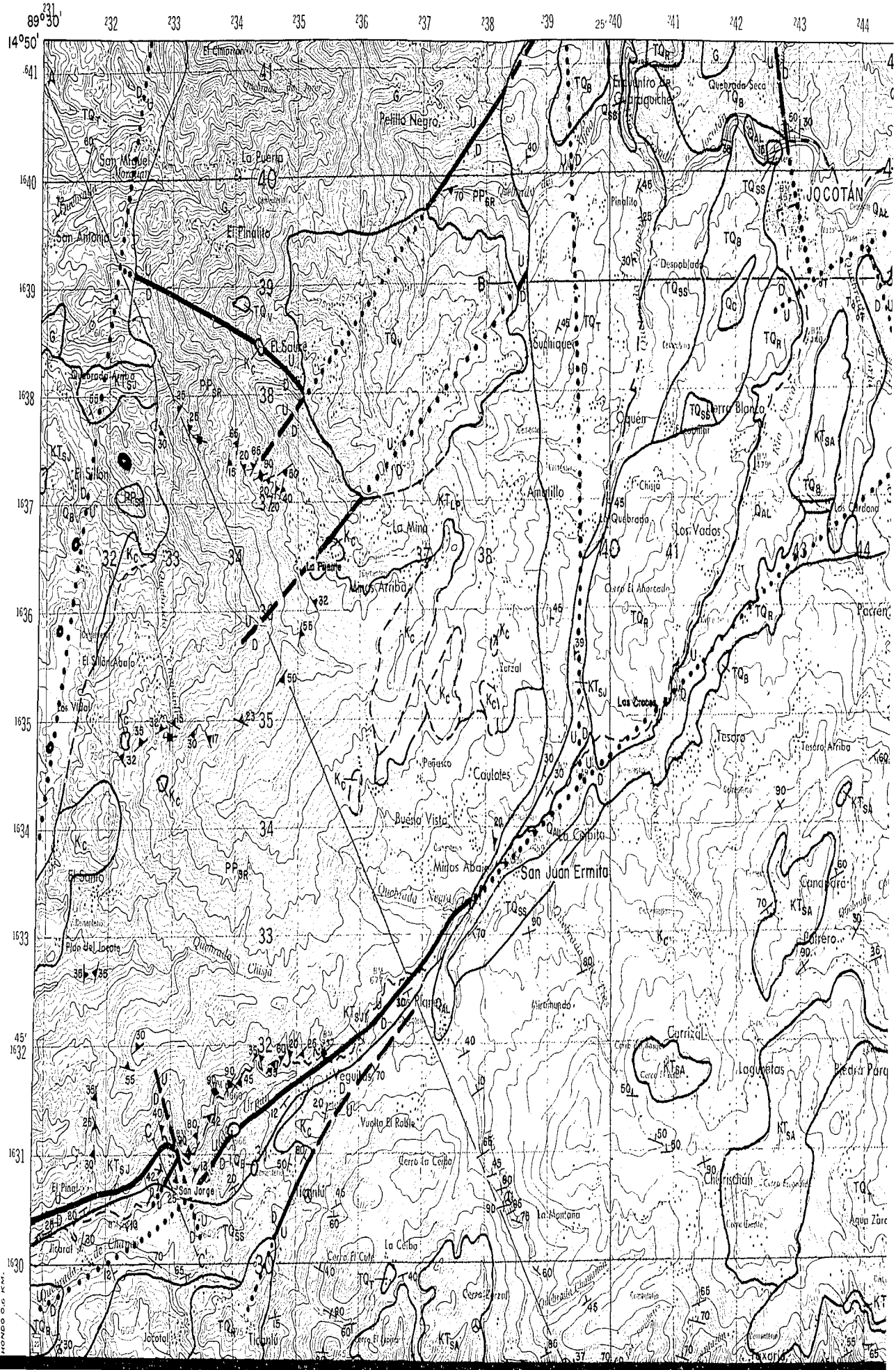
		LEXIQUE STRATIGRAPHIQUE INTERNATIONAL (1960)		ROBERTS & IRVING (1957)	THOMPSON & MILLER (1944)	IMLAY (1944)	WEAVE (1942)
CRETACEOUS	UPPER: DANIAN	?	?			Not Identified ?	
	UPPER: MAESTRICHTIAN	Esquias Fm. Marine limestone, shale and sandstone (Weaver, 1942)	Unnamed Fm. (Alta Verapaz) Limestone, rich in rudists and foraminifera (Kreidekalke of Sapper, 1937)	Unnamed limestones and clastics		Esquias Formation (After Weaver, 1942)	Esquias Formation Marine limes shale and sandstone
	UPPER: CAMPANIAN						
	UPPER: SANTONIAN						
	UPPER: CONIACIAN						
	UPPER: TURONIAN		? Ixcoy (?)				
	UPPER: CENOMANIAN		?	?		?	
	LOWER: ALBIAN	Metapán Fm. Largely terrestrial sediments	Cobán Fm. =Ixcoy Fm. (Barren limestone)	Metapán limestone	No mention of beds younger than Todos Santos	Cobán = Ixcoy = Comitán = Sierra Madre	Metapán Formation
	LOWER: APTIAN					? Upper part of Metapán Formation (Probably same as Tegucigalpa Fm.)	
	LOWER: NEOCOMIAN		Todos Santos Beds Terrestrial sediments and evaporites	?	?		
JURASSIC	UPPER	?	?	Todos Santos Formation	Todos Santos Formation		?
	MIDDLE						(not mentio
	LOWER			?	?	?	? Tegucigalpa ?
TRIASSIC	URPER		?				
	MIDDLE						
	LOWER						
PERMIAN	UPPER	?		? Chochal Limestone	? Paso Hondo limestone and shale		
	LOWER	Macal Series (Br. Honduras)	Chochal Limestone ? Santa Rosa Formation	? Santa Rosa Formation Grades from clastics at base to shales toward top	La Vainilla Ls. Grupera shale & ss.		
CARBON-IFEROUS	UPPER				Santa Rosa clastics ? Metamorphics		

UPPER PALEOZOIC AND MESOZOIC STRA



ESOZOIC STRATIGRAPHIC CORRELATION CHART

FIGURE 2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14°50'
El Chamorro
Petillo Negro
San Miguel
La Puerta
El Pinalito
San Antonio
El Sauce
Quebrada Arriba
El Sillón
La Mina
La Puerta
Minas Arriba
El Sillón Abajo
Los Vidal
Caulotes
Buena Vista
Minas Abajo
San Juan Ermita
El Santo
Plan del Loroto
Quebrada Chisja
Vegueta
Vuelta El Roble
Cerro La Ceiba
El Pinal
San Jorge
Ticanlú
La Montaña
La Ceiba
Cerro El Cule
Cerro Zarzal
Jocotal
Ticanlú
Encuentro Del Carriquiche
Quebrada Seca
Pinalito
Desnoblado
Sudhiques
Cerro Blanco
Amarillo
Chisja
La Quebrada
Los Vados
Cerro El Ahorcado
Los Cocos
Tesoro
Tesoro Arriba
Cerro Carrizal
Lagunetas
Cherischán
Agua Zarca
Canaguera
Carrero
Paraíso
JOCOTÁN

EL FLORIDO (FRONTERA CON HONDURAS) 22 KM.
JOCOTÁN
CAMOTÁN
Quebrada Seca
Tasilar
Pelenita
Tisipe
La Brea
Neurar
Pashapa
Portezuelo
Tisimle
Ocotoro
Cerro de Socorro
Cajón de
La Cumbre
Muyurco
Tierra Blanca
Cerro Pacayo
Dos Quebradas
Tulár
Timte
Limón
El Chorro
Marimba
Cantiquín
Los Cardona
El Roblar
Chiyó
La Arada
Changuís
Cerro de Tontoles
Loma Raja
Ojo de Agua
Pacren
Perican
El Ciucita
Naranjo
Tontoles
El Zapote
Cerro del Guayabo
Tesoro
Tesoro Arriba
Otumbla
Cruz de Charhal
El Limar
Tatutú
Trapichito
Cerro Quebracho
Tunucó Abajo
Canapará
Potrero
Lagunetas
Piedra Parada
Tunucó
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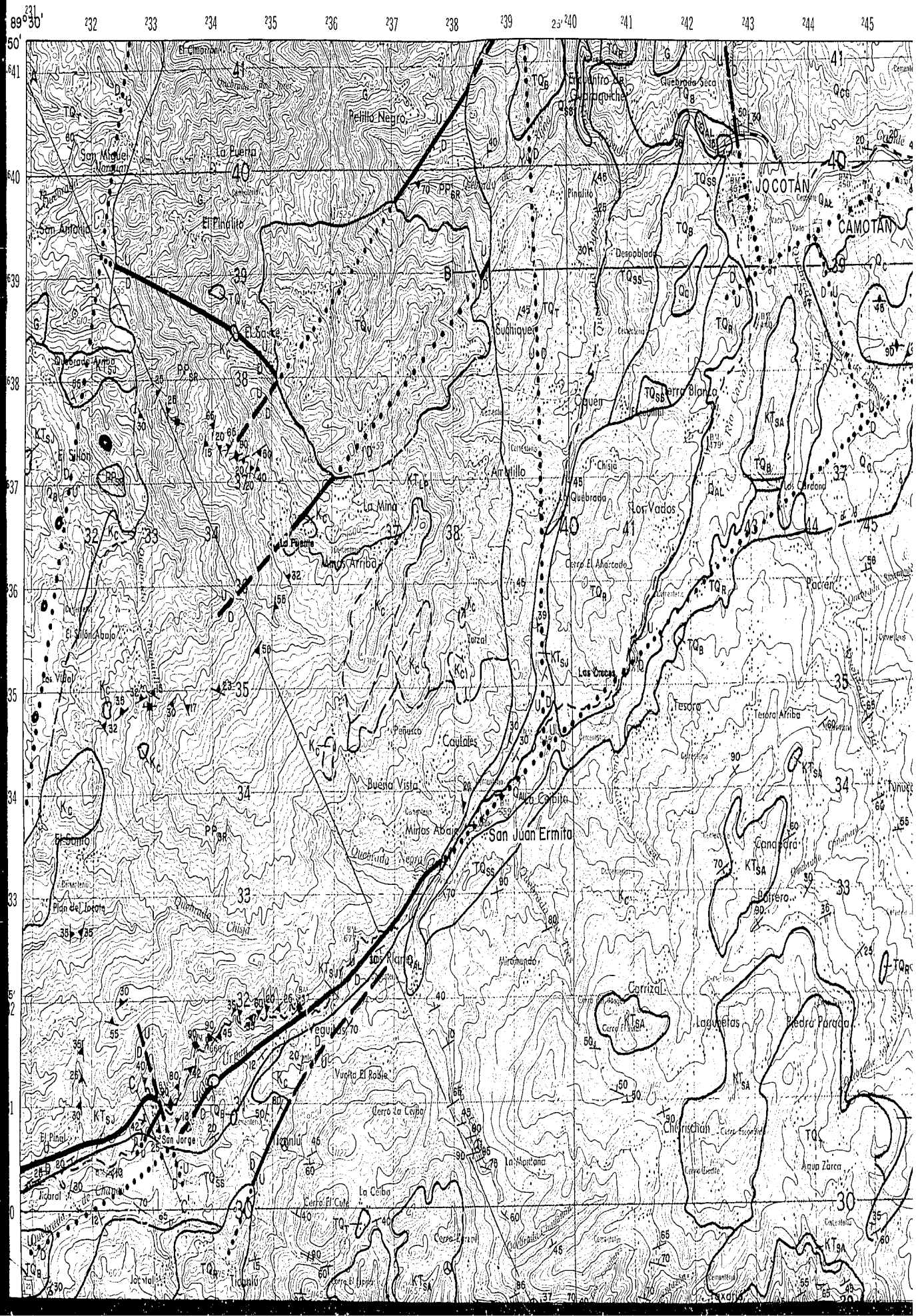
Chorischán
El Roblarcito
Caxoris
Camalote
Río Grande
Río Carcá


JOCOTÁN
CAMOTÁN
San Juan Ermita
Pelillo Negro
La Puerta
San Miguel Morazán
San Antonio
El Pinalito
El Sauce
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El Sillón
Despoblado
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La Mina
Minas Arriba
Los Vados
Cerro El Ahorcado
Los Cruces
Tesoro
Tesoro Arriba
Caulates
Buena Vista
Alta Capilla
Minas Abajo
Quebrada Negra
Quebrada Chisia
Plan del Tocote
El Sauro
Cerro Blanco
Los Cardona
Paciera
Canadera
Corrizal
Lagunetas
Piedra Parada
Cherischian
Agua Zarca
Vuelta El Roble
Cerro La Ceiba
La Montana
La Ceiba
Cerro El Cule
Cerro Ecarril
Cerro El Urraca
Tacuilo
Jocotal
Ticaral
El Pinal
San Jorge
Tecomán
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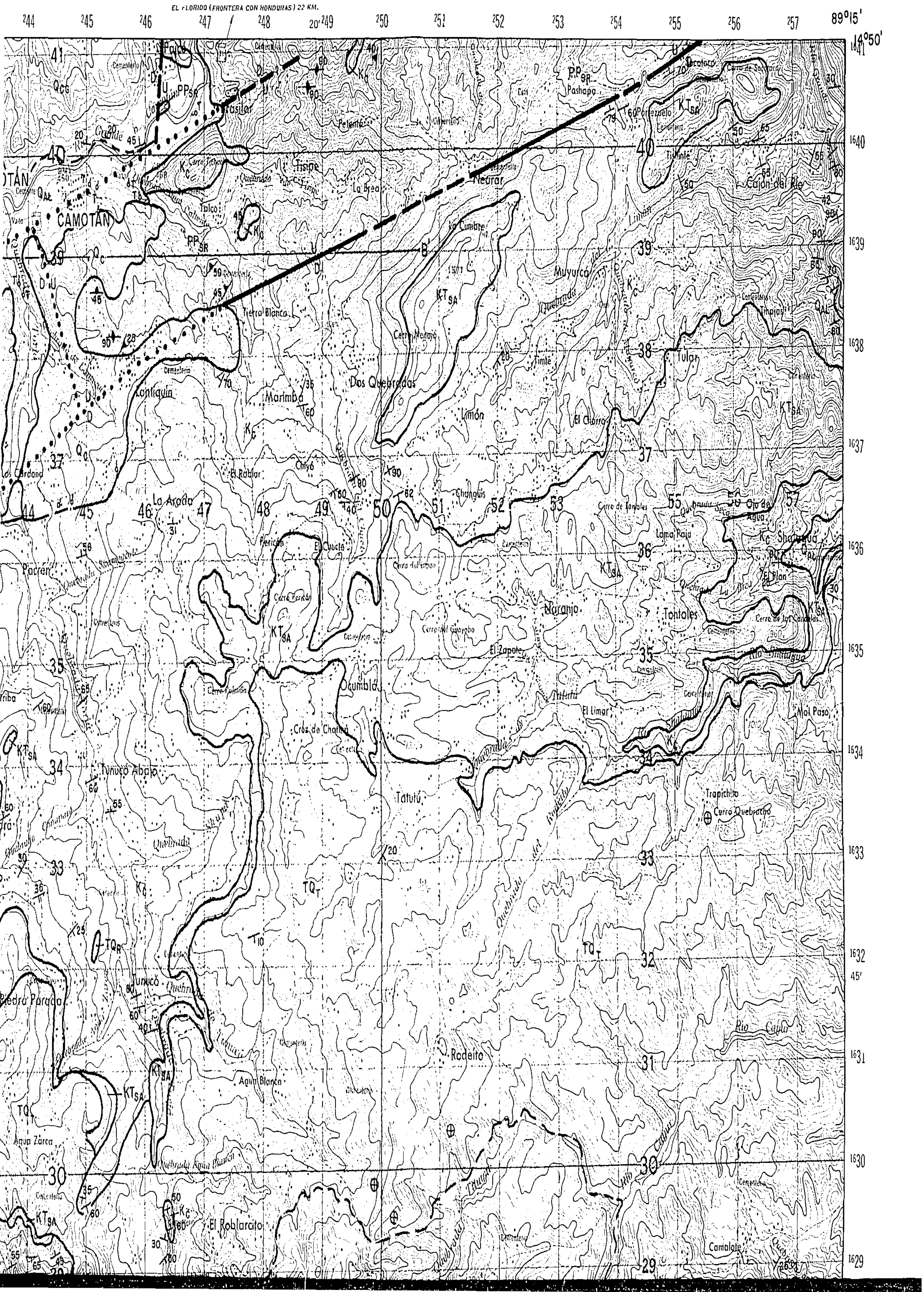
Chupa
Tunucó


EL FLORIDO (FRONTERA CON HONDURAS) 22 KM.
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45'
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Talco
Tierra Blanca
Cajón del Río
Muyurco
Tular
Timte
Dos Quebradas
Marimba
Limón
El Cloro
Conliquín
Los Cardona
La Aroda
El Rablar
Chiyo
Changüis
El Cuyte
Pacren
Cerro de Tontales
Loma Paja
Ojo de Agua
Shalagua
Naranjo
Tontoles
El Zapote
Rio Shalagua
Ocumbla
Cruz de Chalma
El Limar
Mal Paso
Tunuco Abajo
Tatutú
Trapichito
Cerro Quebracho
Piedra Parada
Rodeito
Agua Blanca
Agua Zarca
Río Caulin
El Roblarcito
Camalote
Quebrada Agua Blanca
La Cumbre
Cerro Pelón
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Q_{AL}
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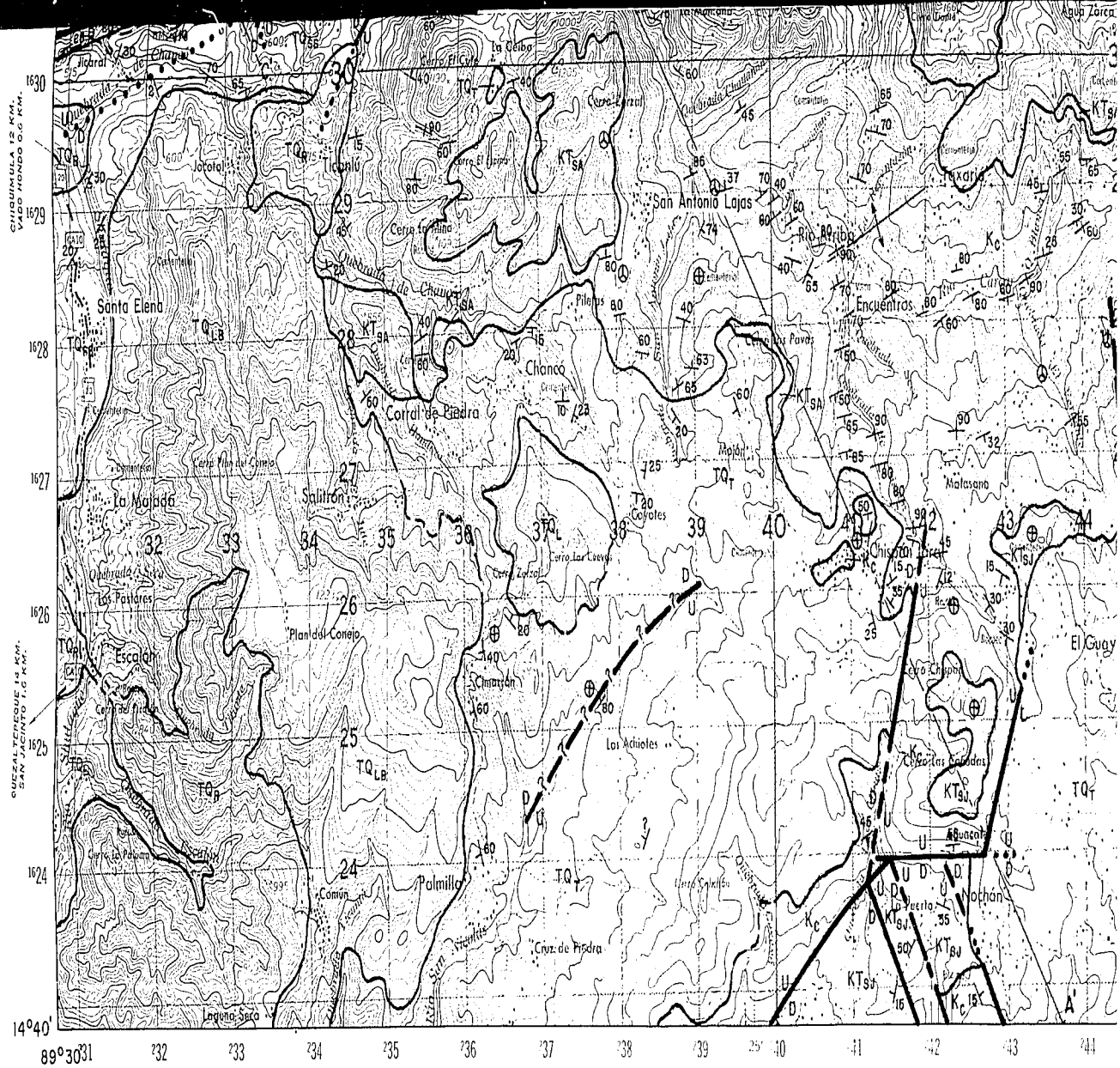

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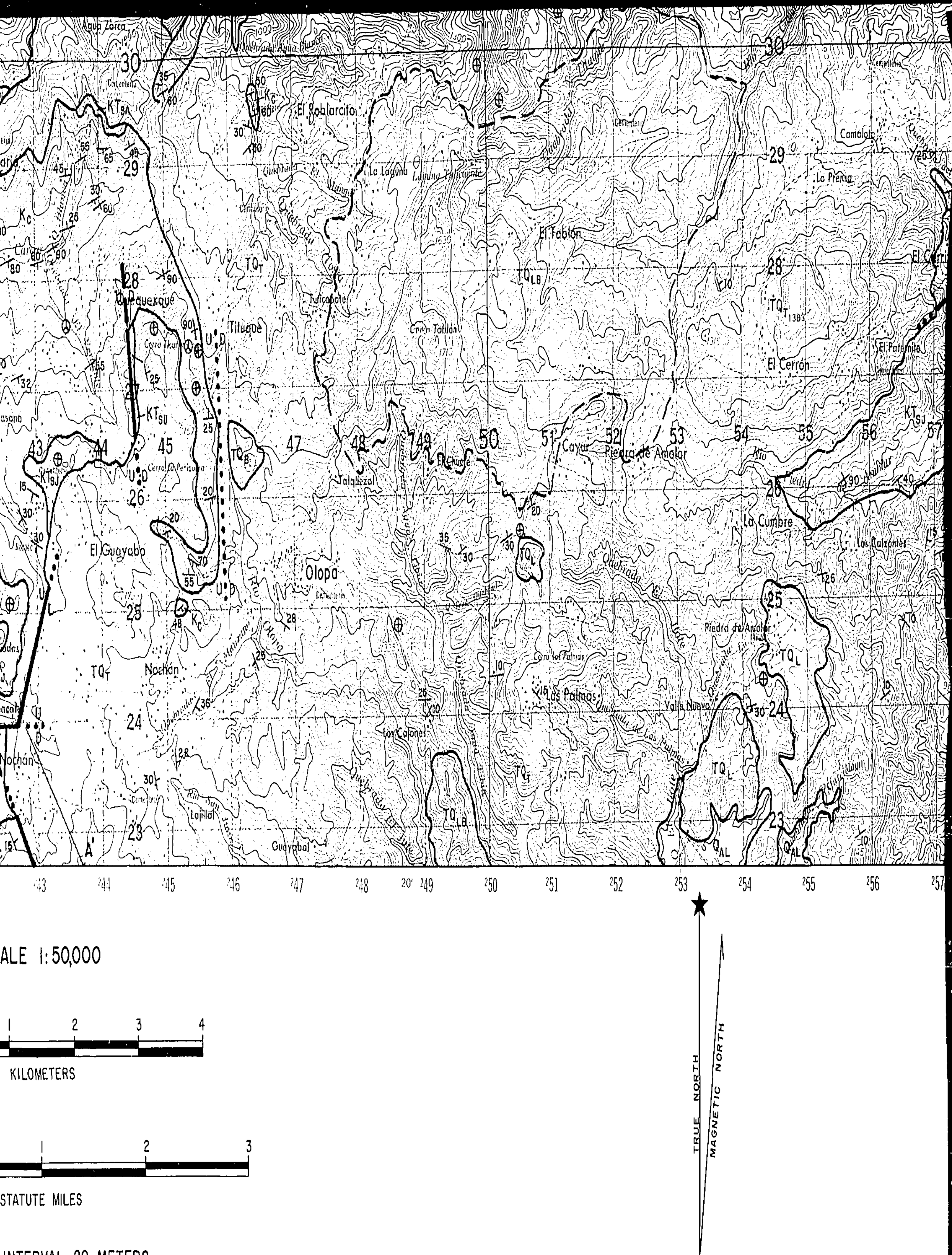
PLATE I

SEE PLATE 2 FOR GEOLOGIC LEGEND

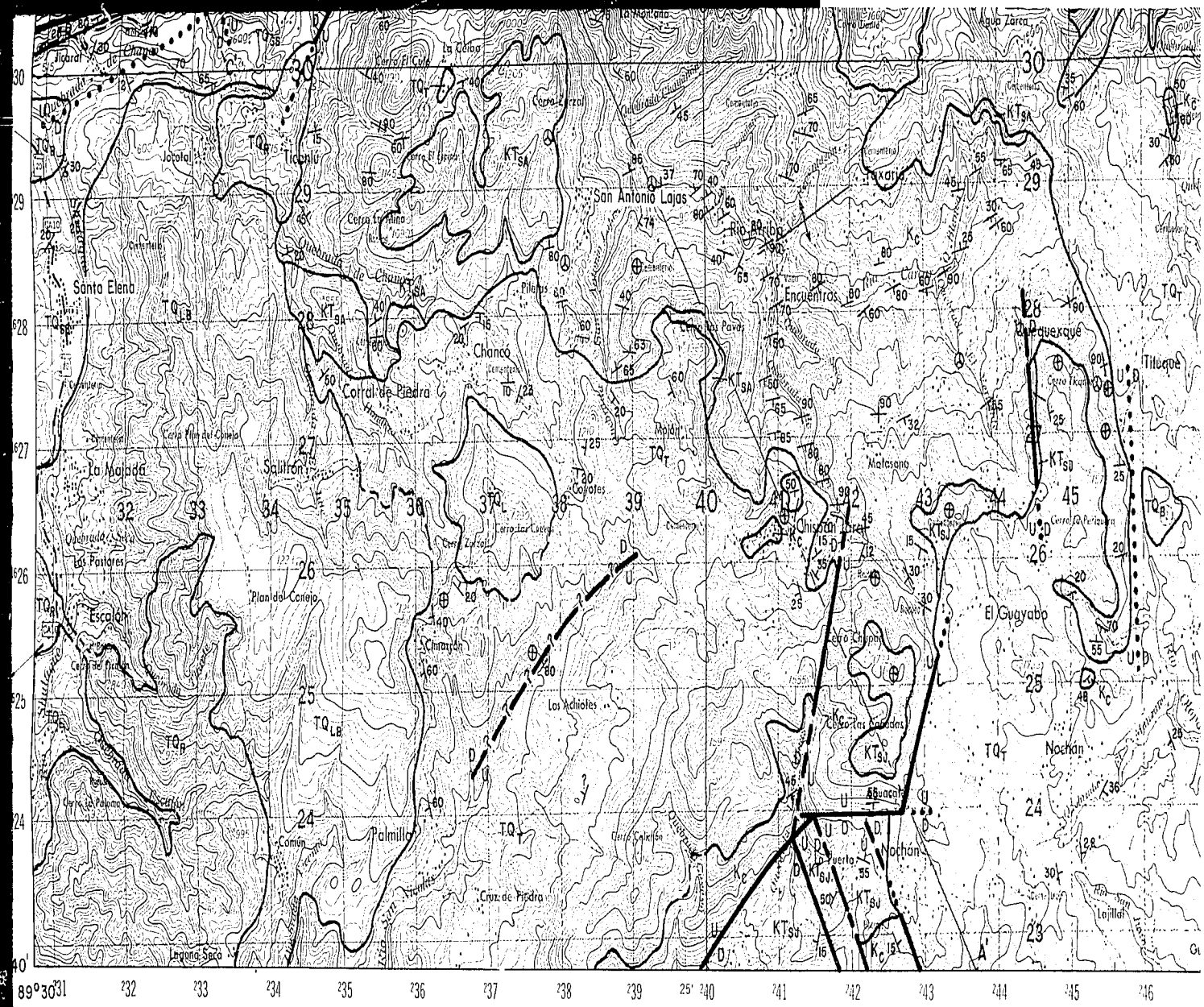
BASE MAP PREPARED BY INSTITUTO GEOGRÁFICO NACIONAL DE GUATEMALA, 1961



GEOLOGIC MAP OF THE JOCOTÁN QUADRANGL

SOUTHEASTERN GUATEMALA

GEOLOGY BY D. C. CRANE, 1962-1963
RICE UNIVERSITY, HOUSTON, TEXAS



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KILOMETERS

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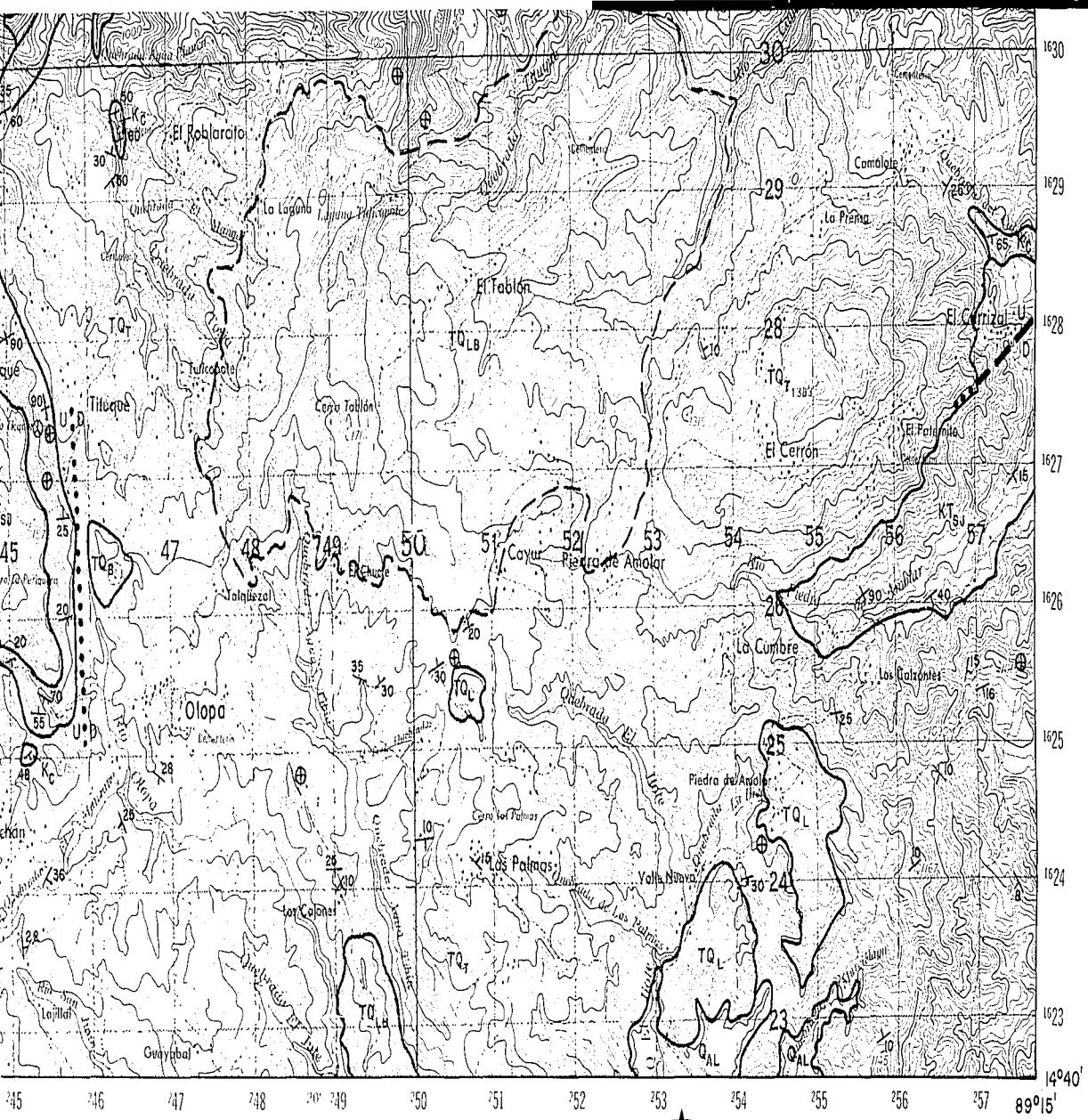
STATUTE MILES

CONTOUR INTERVAL 20 METERS

PLATE I

SEE PLATE 2 FOR GEOLOGIC LEGEND

BASE MAP PREPARED BY INSTITUTO GEOGRÁFICO NACIONAL DE GUATEMALA, 1961

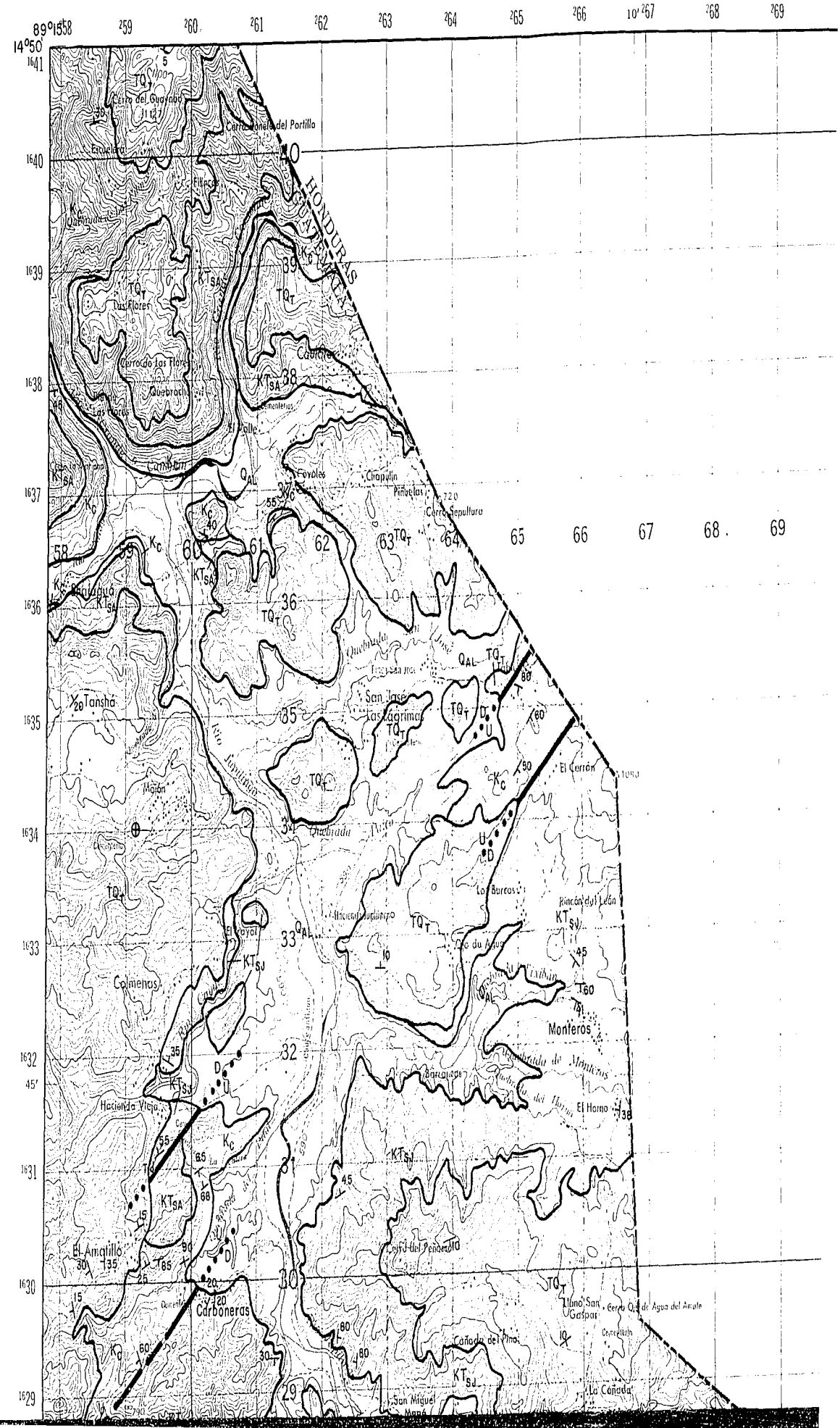


GEOLOGIC MAP OF THE JOCOTÁN QUADRANGLE

SOUTHEASTERN GUATEMALA

GEOLOGY BY D. C. CRANE, 1962-1963

RICE UNIVERSITY, HOUSTON, TEXAS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Cerro del Guayabo
Carboneras del Portillo
Las Flores
Cerrado Las Flores
Quebrada
El Valle
Cambern
Cerro Sepultura
Tansha
San José
Las Lagrimas
El Cerrón
Colmenas
Monteros
Hacienda Vieja
El Amatillo
Carboneras
El Horno
Cañada del Pino
La Cañada
San Miguel
Llano San Gaspar
Cerro Q. de Agua del Amate
Rincón del León
Las Burros
El Royal
Barranquera
Cerro del Pendenado
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Qal
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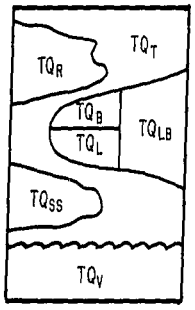
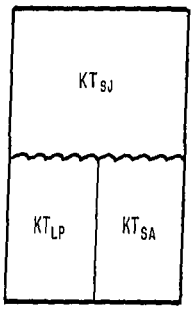
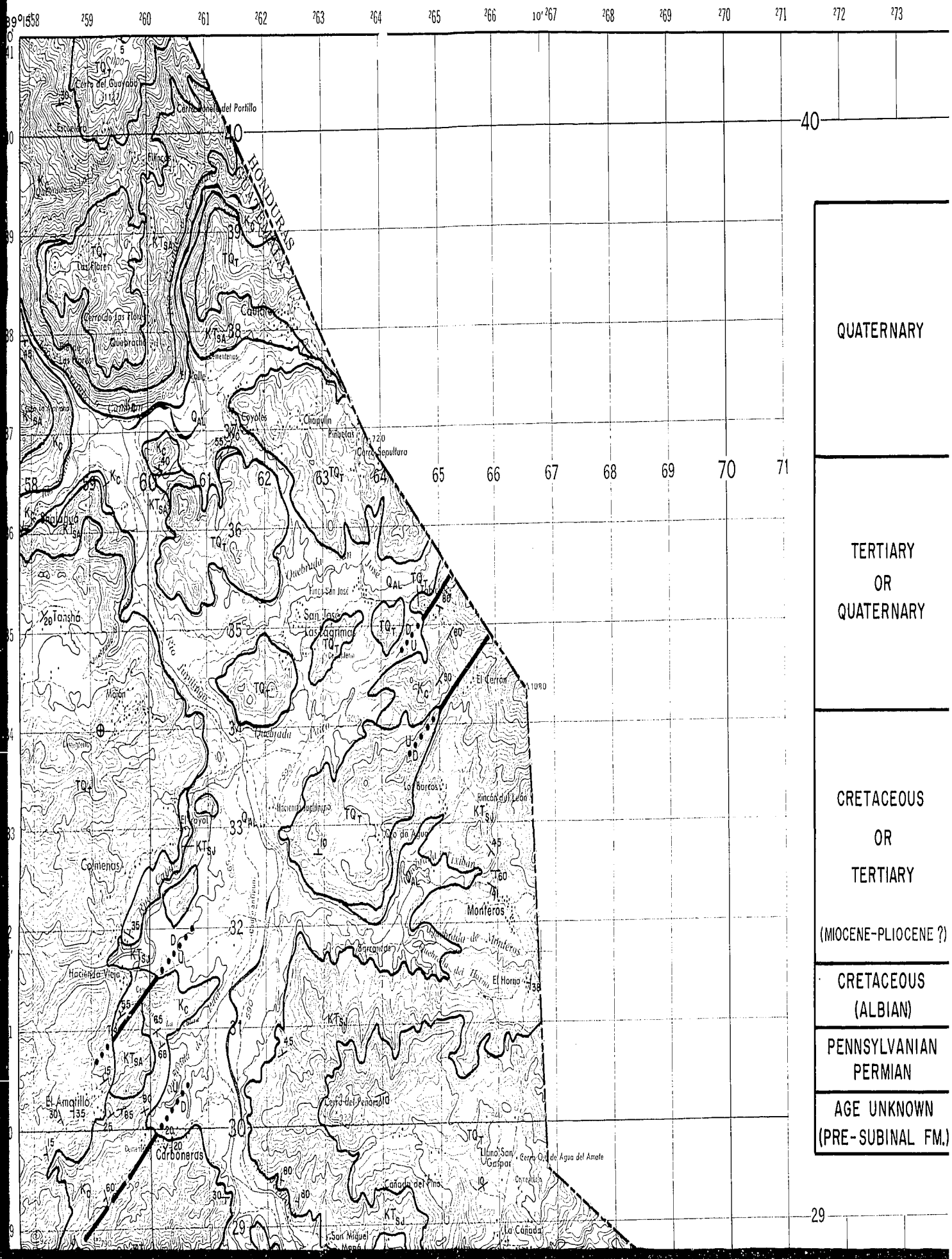
D
U

LEGEND

QUATERNARY	Q_C	TRAVERTINE	
	Q_{AL}	ALLUVIUM	
	Q_{CG}	CONGLOMERATE (JOCOTÁN GRABEN INLIER)	
	Q_B	BASALT	
TERTIARY OR QUATERNARY		TQ_T - RHYOLITIC TUFF TQ_R - RHYOLITE FLOWS TQ_L - BASALTIC LAHAR TQ_B - BASALT FLOWS TQ_{LB} - UNDIFFERENTIATED LAHAR AND BASALT TQ_{SS} - WHITE SANDSTONE TQ_V - ANDESITE FLOWS	SAN JACINTO FORMATION PADRE MIGUEL GROUP
CRETACEOUS OR TERTIARY (MIOCENE-PLIOCENE ?)		KT_{SJ} - SAN JORGE FACIES (REDBEDS) KT_{SA} - SAN ANTONIO LAJAS FACIES (LIMESTONE CONGLOMERATE) KT_{LP} - LA PUENTE FACIES (REDBEDS)	SUBINAL FORMATION
CRETACEOUS (ALBIAN)	K_C	LIMESTONE, SHALE AND DOLOMITE	COBÁN FORMATION
PENNSYLVANIAN PERMIAN	PP_{SR}	PHYLLITE	SANTA ROSA GROUP (TACTIC FORMATION?)
AGE UNKNOWN (PRE-SUBINAL FM.)	G	GRANITE	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Cerro del Guayabo
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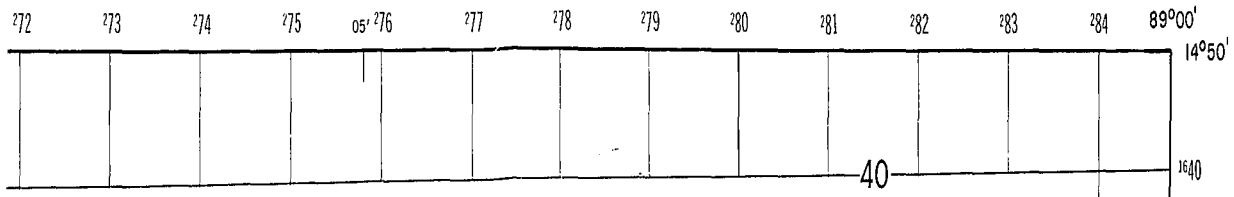
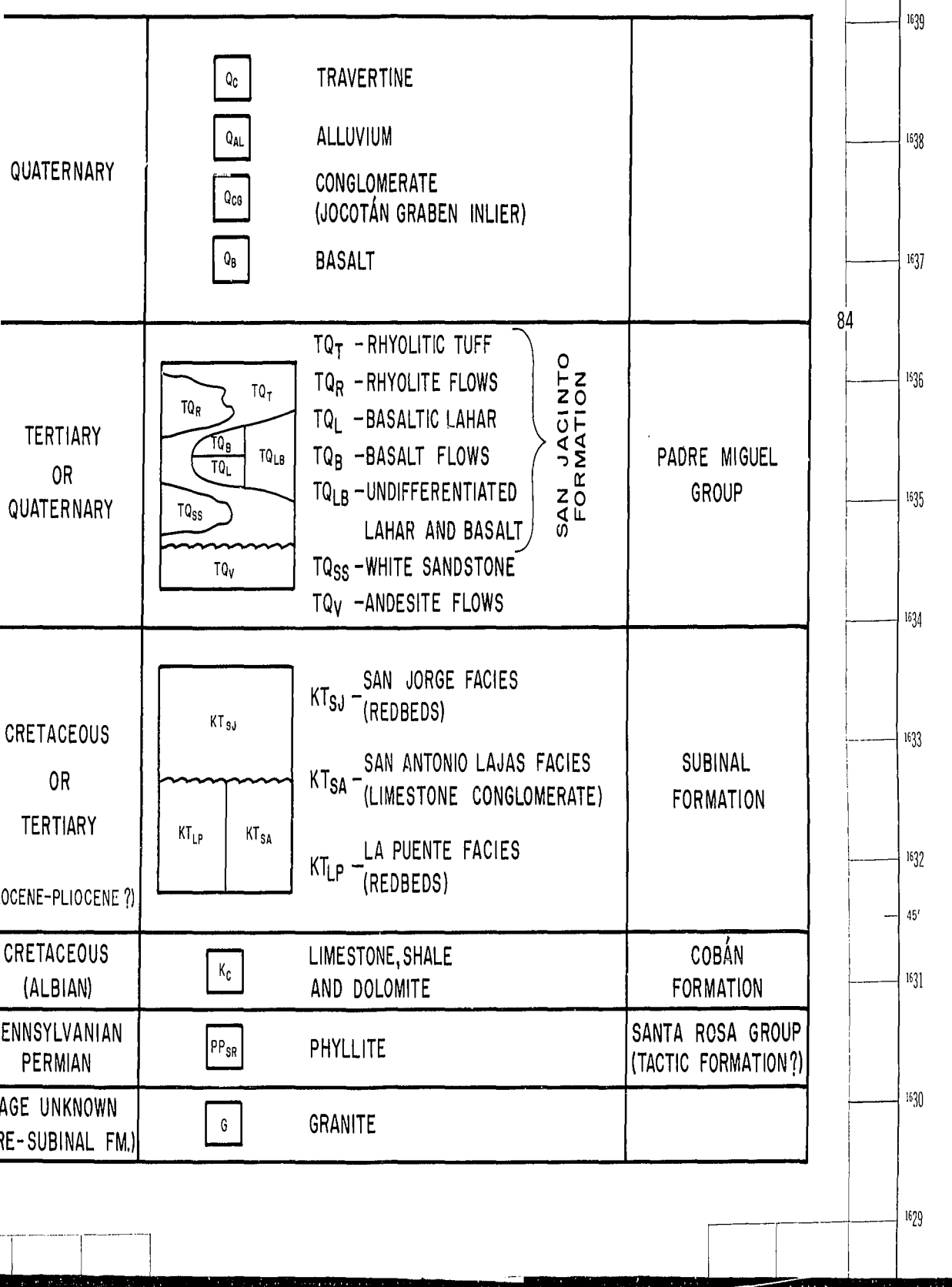
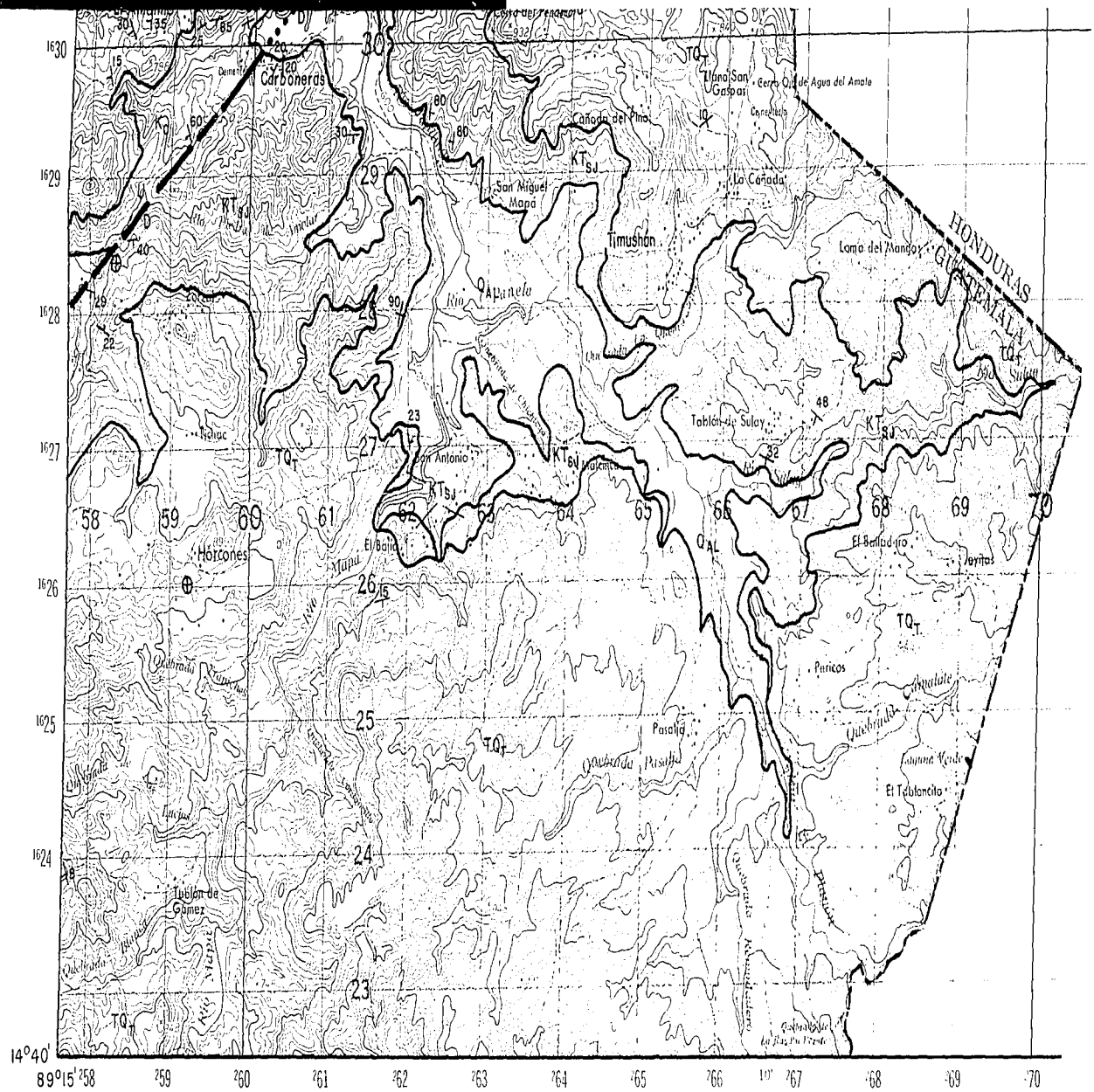
El Calle
Coyotes
Chaguilin
Pinuelas
Cerro Sepultura
Tansha
Motón
Quebrada
Finca San José
San José
Las Lagrimas
El Cerron
Los Barcos
Rincón del León
Hacienda Cuchinipa
Ojo de Agua
Colmenas
Monteros
Barranca
Quebrada de Monteros
El Horno
Hacienda Vieja
El Amarillo
Carbonera
Cerro del Peñascal
Llano San Gaspar
Cerro Ojo de Agua del Amate
Cañada del Pino
San Miguel
La Cañada
QUATERNARY
TERTIARY OR QUATERNARY
CRETACEOUS OR TERTIARY
(MIOCENE-PLIOCENE ?)
CRETACEOUS (ALBIAN)
PENNSYLVANIAN PERMIAN
AGE UNKNOWN (PRE-SUBINAL FM.)



LEGEND

QUATERNARY	Q_C	TRAVERTINE	
	Q_{AL}	ALLUVIUM	
	Q_{CG}	CONGLOMERATE (JOCOTÁN GRABEN INLIER)	
	Q_B	BASALT	
TERTIARY OR QUATERNARY	TQ_T, TQ_R, TQ_B, TQ_L, TQ_{LB}, TQ_{SS}, TQ_V	TQ_T - RHYOLITIC TUFF TQ_R - RHYOLITE FLOWS TQ_L - BASALTIC LAHAR TQ_B - BASALT FLOWS TQ_{LB} - UNDIFFERENTIATED LAHAR AND BASALT (SAN JACINTO FORMATION) TQ_{SS} - WHITE SANDSTONE TQ_V - ANDESITE FLOWS	PADRE MIGUEL GROUP
CRETACEOUS OR TERTIARY (OCENE-PLIOCENE ?)	KT_{SJ}, KT_{LP}, KT_{SA}	KT_{SJ} - SAN JORGE FACIES (REDBEDS) KT_{SA} - SAN ANTONIO LAJAS FACIES (LIMESTONE CONGLOMERATE) KT_{LP} - LA PUENTE FACIES (REDBEDS)	SUBINAL FORMATION
CRETACEOUS (ALBIAN)	K_C	LIMESTONE, SHALE AND DOLOMITE	COBÁN FORMATION
ENNSYLVANIAN PERMIAN	PP_{SR}	PHYLLITE	SANTA ROSA GROUP (TACTIC FORMATION?)
AGE UNKNOWN RE-SUBINAL FM.)	G	GRANITE	





SCALE 1:50

1 1/2 0 1

KILOMETER

1 1/2 0 1

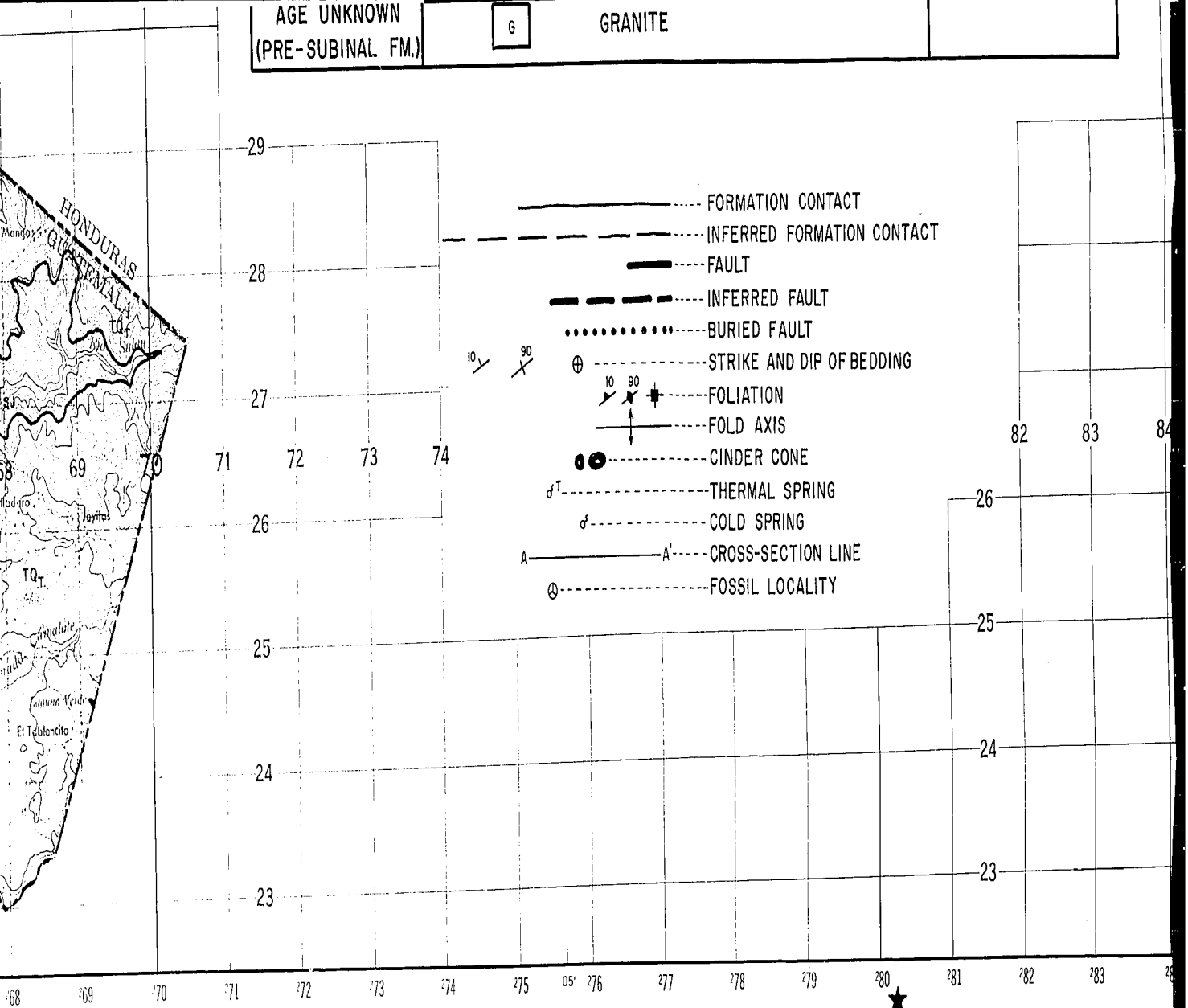
STATUTE MI

CONTOUR INTERVAL

PLATE 2

BASE MAP PREPARED BY INSTITUTO GEOGRÁFICO NACIONAL DE GUATEMALA, 1961

AGE UNKNOWN (PRE-SUBINAL FM.)	G	GRANITE



SCALE 1:50,000

1/2 0 1 2 3 4

KILOMETERS

0 1 2 3

STATUTE MILES

CONTOUR INTERVAL 20 METERS

TRUE NORTH

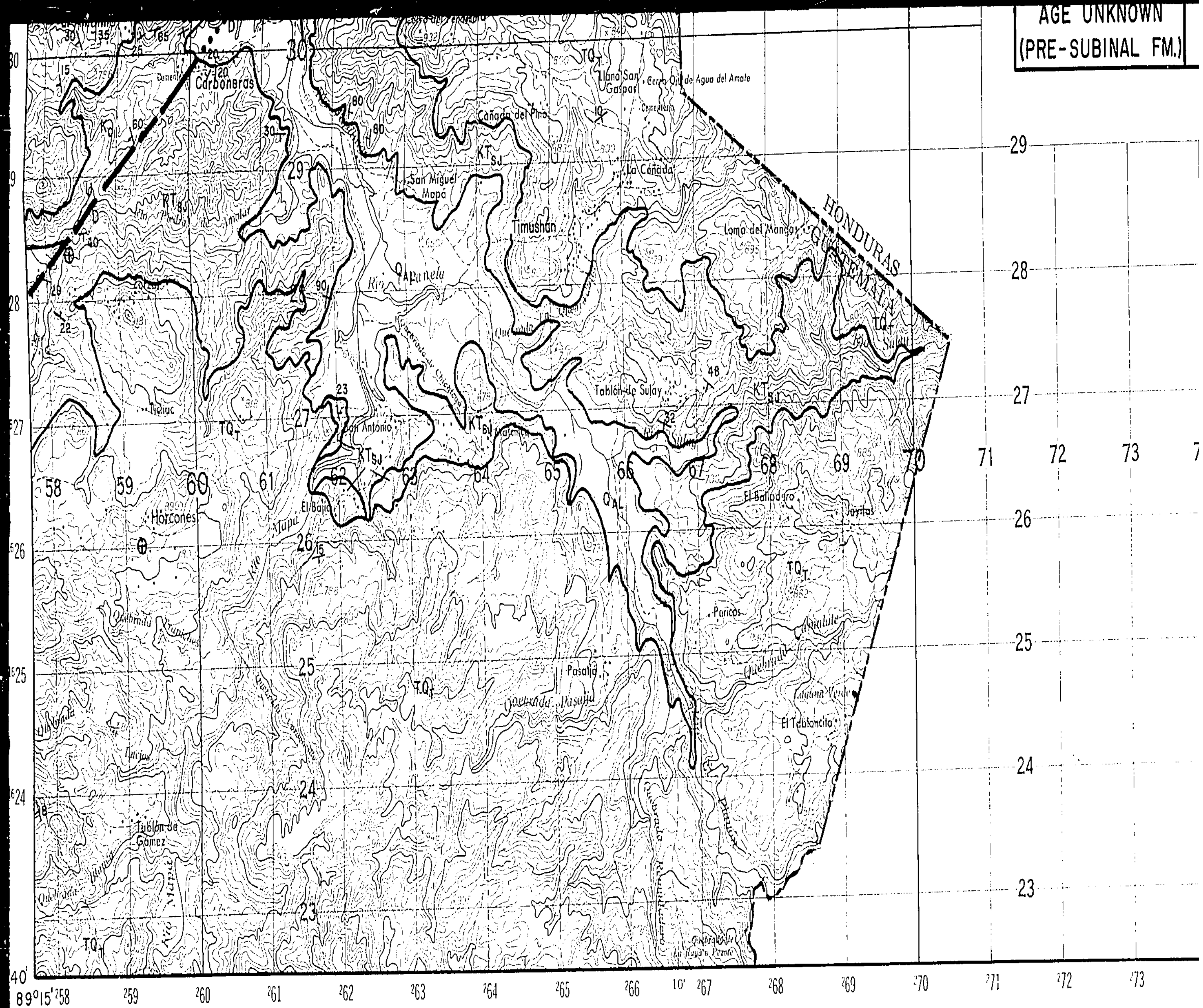
MAGNETIC NORTH

GEOLOGIC MAP OF THE TIMUSHÁN QUADRANG

SOUTHEASTERN GUATEMALA

GEOLOGY BY D. C. CRANE, 1962-1963

RICE UNIVERSITY, HOUSTON, TEXAS



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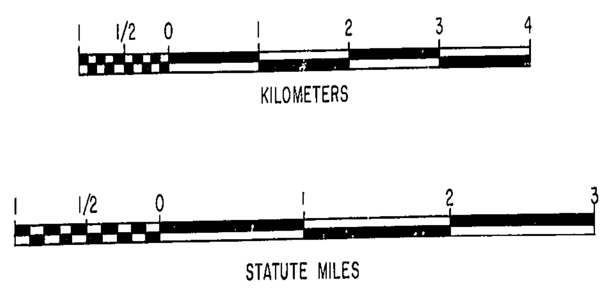
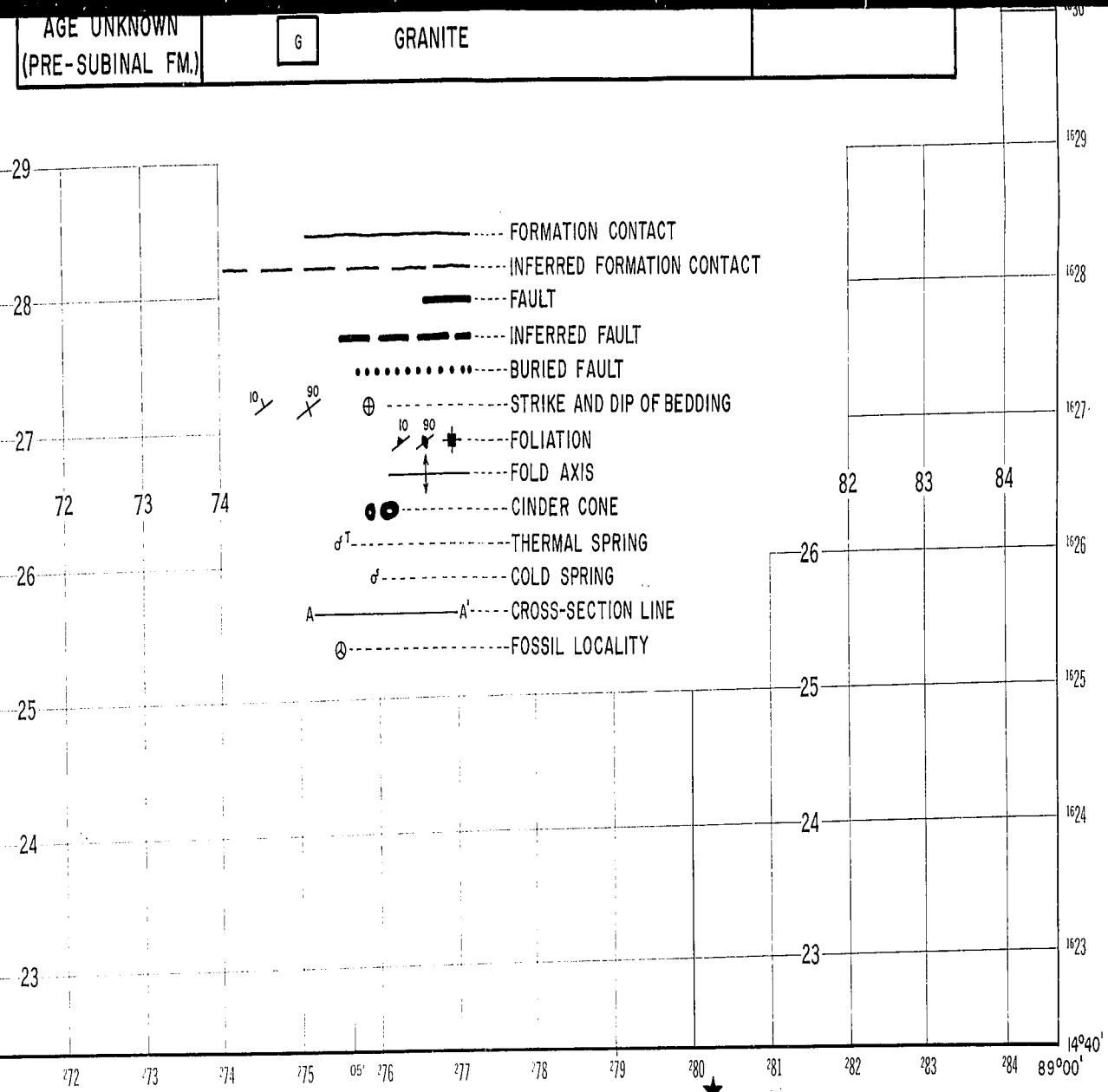


CONTOUR INTERVAL 20 METERS

PLATE 2

BASE MAP PREPARED BY INSTITUTO GEOGRÁFICO NACIONAL DE GUATEMALA, 1961

AGE UNKNOWN (PRE-SUBINAL FM.)	G	GRANITE



GEOLOGIC MAP OF THE TIMUSHÁN QUADRANGLE

SOUTHEASTERN GUATEMALA

GEOLOGY BY D. C. CRANE, 1962-1963

RICE UNIVERSITY, HOUSTON, TEXAS