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GEOLOGY OF THE PUNO-SANTA LUCIA AREA,

DEPARTMENT OF PUNO, PERU

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in partial fulfillment of the
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1964

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I hereby recommend that the thesis prepared under my supervision by Jorge A. Portugal

entitled GEOLOGY OF THE PUNO-SANTA LUCIA AREA, DEPARTMENT OF PUNO, PERU

be accepted as fulfilling this part of the requirements for the degree of Doctor of Philosophy

Approved by:

William F. Jenks

Form 668—Grad. Sch.—1M—4-61

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Geology of the Puno-Santa Lucia Area, Department of Puno - Peru by Jorge A Portugal

ABSTRACT

The Puno-Santa Lucía area covers 6750 square kilometers in the higher parts of the Andes in southern Peru.

The main objectives of the present study were to determine the stratigraphic, volcanologic and structural history of the area through Mesozoic and Cenozoic time.

A geologic map of the area on the scale of 1:100,000 was prepared during 15 months of field work.

The oldest rocks in the area are quartzites and shales of the Lower to Middle Devonian Cabanillas Group, more than 2000 meters thick. The Jurassic Lagunillas Group has been divided by the author in three units, with an aggregate thickness of 1050 meters. The Middle Cretaceous rocks are included in the Huancané Group and the Moho Group, the combined thickness of which is 410 meters. The Ayavacas Limestone, upper member of the Moho Group, contains fossils of Cenomanian age. Trachytes of Cretaceous age occur near Juliaca and on the Capachica Peninsula. Red beds (Cotacucho, Vilquechico and Muñani formations), mapped by Newell within the Tertiary Puno Group, are here considered to be Upper Cretaceous on the basis of their stratigraphic position. Apparently these formations were deposited in a closed basin

between eastern and western ranges. The Puno Group, of probable Tertiary age, consists of two units: the Saracocha Formation and the Tacaza Formation. The Saracocha Formation, made up mainly of conglomerates, is widely distributed in the southwestern portion of the map-area, but is absent towards the northeast. The Tacaza Formation is a thick volcanic sequence in the southwestern portion of the area, roughly paralleling the western range; it thins towards the east. Olivine basalt flows and tuffs of the Sillapaca Formation unconformably overlie the Puno Group.

Small stocks of granodiorite, diorite, monzonite and syenite are irregularly distributed throughout the area. The composition of these generally ranges from granodioritic in the cores to dioritic or monzonitic at the margins. These stocks were emplaced during the Lower Tertiary.

Rhyolite intrusives, of probable Miocene or Early Pliocene age, intrude the uppermost beds of the Tacaza Formation.

Lack of age determination for most of the formations made the reconstruction of the structural history of this area difficult. The Paleozoic tectonic evolution is little known. Two Mesozoic orogenies have been recognized. The

Lagunillas Group was folded and faulted in Late Jurassic time, producing structures with east-west trend. Chaotic structure everywhere present in Ayavacas Limestone is believed to have been caused by gravity sliding. Folding at the end of the Cretaceous affected all rocks of the region, but was most intense toward the west, near Vilque and Mañazo, where two major thrusts were mapped. The writer reinterpreted Newell's Maravillas overthrust as an unconformity.

Intrusion of the stocks of intermediate composition, and faulting of the lower beds of the Puno Group, are evidence of a Lower Tertiary orogeny.

Normal faulting, intrusion of the rhyolite, and tilting of the Puno Group towards the southwest, characterize the end of the Tertiary. This movement is tentatively dated as Pliocene.

Epeirogenic movement which in a general way caused the present elevations of the Andes, was accompanied by late normal faulting. Graben-like depressions of this late age are partly filled by Quaternary sediments. One such depression is occupied by Lago Titicaca.

CHAPTER I

INTRODUCTION

Purpose and Scope of Investigation

The Andes, which form a nearly continuous mountain chain from Tierra del Fuego to Panama, Colombia and Venezuela have been studied in many places and for many purposes. The Republic of Peru affords many opportunities for detailed geologic work which leads to a better understanding of the early history and final development of a young mountain chain. Unfortunately, few accurate geologic maps have been published except around the oil fields and some mining districts.

Two zones in Peru are especially favorable for analyses of Andean history, central Peru and southern Peru. In both places accessibility is good by rail from the Pacific up through the Western Cordillera, thence on eastward by road through the Eastern Cordillera to the low jungle country east of the Andes. In both places some areal mapping has been accomplished, so that the nature of the numerous unsolved problems of Andean history in each has been partly determined.

Southern Peru has been the subject of various studies (Jenks 1945, 1946, 1948, 1953; Newell 1945, 1946, 1949, 1953;

Douglas 1920; Bowman 1916) which outlined some of the major problems. It was therefore decided, in consultation with Jenks during the Spring of 1962, that the writer would undertake a detailed study, within the region of fairly easy accessibility of a structural and stratigraphic problem in southern Peru. The initial plans called for a detailed analysis of the tectonic and epeirogenic movements affecting Cenozoic sedimentary and associated igneous rocks along the Pacific slope of the Andes in the Department of Arequipa.

In June 1962, the Empresa Petrolera Fiscal (E. P. F.), a Peruvian government organization, through the good offices of Mr. Pedro Verástegui, offered to sponsor the field studies, provided that the work could be integrated with that of the E. P. F. already under way in the vicinity of Lago Titicaca.

The specific objectives of the revised program were:

1) To map an area extending westward from the shore of Lago Titicaca on the scale of 1:100,000
2) To determine the stratigraphic and volcanologic history of the mapped area through Mesozoic and Cenozoic time
3) To determine the structural relationships of the various rock units, and

4) To make such recommendations concerning the exploration for petroleum in the region as might seem appropriate. (The Empresa was engaged in the search for oil in the Lago Titicaca region.)

The location of the Puno-Santa Lucía area, mapped during the field study, is shown on Fig. 1. It is in the Department of Puno, southern Peru, between 15° 30' and 16° 00' south latitude and 69° 30' and 70° 48' west longitude, an area of approximately 6750 square kilometers (2606 square miles). Except for the southwestern corner, the map-area is within the Lago Titicaca drainage basin.

Field work in the area was carried out from July 1962 to September 1963. All the trips were made accompanied by a driver who also acted as a field assistant. The party was equipped with a four-wheel drive jeep. Stratigraphic sections were measured with tape and compass.

A base map on the scale 1:100,000, prepared from the topographic sheets (scale 1:200,000 and 1:100,000) of the Peruvian Army, served for the compilation of the geological data. The geology of the Peninsula de Capachica and the Juliaca, Caracoto and Puno areas was plotted on vertical air photographs. The scale of the photographs is approximately 1:40,000, taken by the Servicio Aerofotográfico Nacional.

Several trips beyond the limits of the map-area were made to study stratigraphic, structural and petrologic relationships.

Previous Work

Until 1949 very little geological work had been done in the Titicaca region. The Pirin oil field, the highest in the world (3991 meters), attracted most of the geological attention, although this field was never of importance. It lies 25 kilometers northeast of Juliaca, beyond the border of the present map-area.

In 1920 Douglas published the results of one of his three pioneering geological traverses across the Andes. These traverses followed the route of the Southern Peru Railway from the coast, passing through the area which is the subject of the present report. Cabrera and Petersen (1936) discussed petroleum possibilities of the region with particular reference to the Pirin area.

The major contribution to the geology of the Lago Titicaca region came in 1949, when Newell published the results of his field studies, carried out between 1942 and 1945. The publication included a geologic map, on the scale of 1:500,000, of about 58,000 square kilometers in southern Peru and adjacent parts of Bolivia. Considering the scale of the map, the complex geology of this region, and the limited time available for actual field work, Newell's work will surely be known as a landmark in the history of geologic study in this part of South America, even though some errors have been detected.

The present map-area is wholly within the boundaries of Newell's geologic map.

As the present, more detailed mapping and analysis proceeded numerous deviations from Newell's mapping and conclusions have been discovered. Among the most significant are reinterpretation of Newell's Maravillas overthrust, revision of the Cretaceous and Tertiary stratigraphic sequences, and new data on the volcanic history of the Western Cordillera. Nevertheless, the framework of the geology of the Puno-Santa Lucía area was established by Newell, without whose earlier study the present one would have been far more difficult and time-consuming.

ACKNOWLEDGMENTS

The writer is deeply indebted to Mr. Pedro Verástegui of the Empresa Petrolera Fiscal. Through his good offices the cost of the field work was entirely covered by the E. P. F.

Dr. W. F. Jenks gave guidance and support during the preparation of this thesis. He spent three weeks in the area during August 1963 to review and discuss the field problems.

Also it is pleasure to thank Ing. Oswaldo Zevallos of the Empresa Petrolera Fiscal for his continuous assistance and valuable discussion and comments in the field.

The writer extends his sincere thanks to Dr. Victor Benavides of International Petroleum Company for his advice. He made short trips to the area in August 1963.

Dr. Ralph Imlay of the U. S. National Museum kindly identified the ammonite fauna of the Lagunillas Group.

The hospitality of Ings. Moisés Hinojosa and Fidel Alvarez of Lampa Mining Company and Sr. Aníbal Avila of Hda. Sacanagachi is acknowledged with appreciation.

Miss Virginia L. Wayman typed the manuscript.

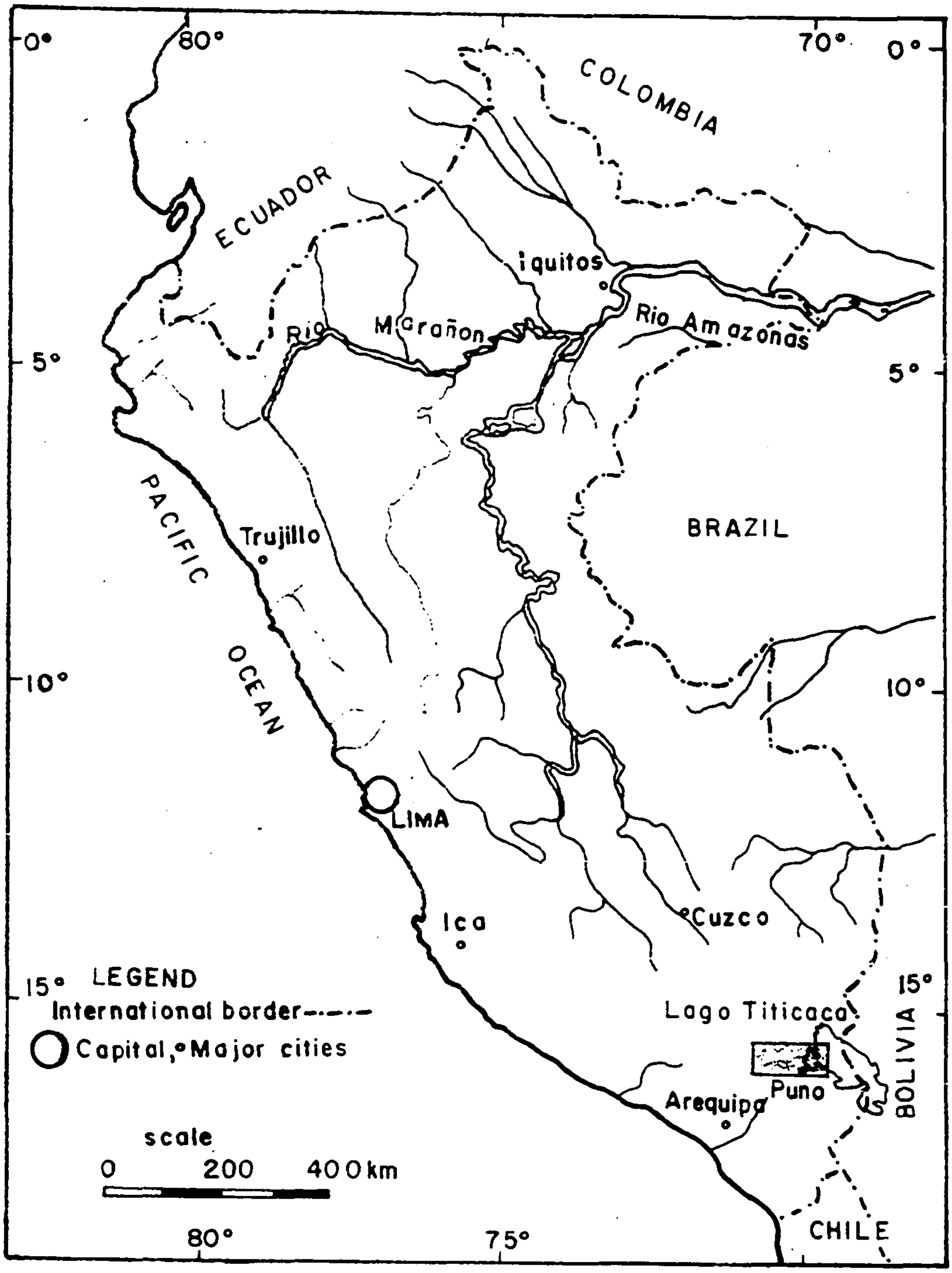


Figure 1. Map showing location of the Puno-Santa Lucia area

CHAPTER II

GEOGRAPHY

Regional Setting, Relief and Drainage

The region to be described in the present work lies in the higher parts of the Andes in southern Peru.

The location of the mapped area, approximately 6750 square kilometers, is shown in Fig. 1. It includes part of the eastern slope of the western range and part of the Titicaca plateau. Towards the west we find the western range, or "Cordillera Occidental," which forms an unbroken range with peaks up to 5243 meters in elevation in this region. To the east the high topography breaks away to smooth hills and grassy pampas of the Titicaca plateau.

The divide between the Titicaca and the Pacific drainage passes through the highest portions of the western range, Co. La Vera, Co. Livina, Co. Saihuani, Co. Tocruyo and Co. Chacutanta.

The central part of this area is traversed by the broad Cabanillas and Coata Rivers; which flow eastward toward Lago Titicaca.

The streams and rivers running towards the Pacific side are torrents, flowing with steeper gradients, like Charamayo, Quemillene and Tincopalca Rivers; they are in the southwest portion of the area.

The smooth hills and flat terrains of the Titicaca plateau are grassy and support fairly large herds of sheep; the highest portions in the western range are bare rock. In the low areas eucalyptus is cultivated.

An interesting feature in this area is the presence of Lago Titicaca, the highest navigable lake in the world. The height above sea level is about 3804 meters.

Climate

Two seasons are strongly marked; the wet season corresponding to the summer and the dry season corresponding to the winter. The dry season is more appropriate to carry on field work. The Andean grass "ichu" is dominant, though shorter grasses are present between the ichu. In the highlands precipitation is either hail or snow. Storms are very frequent during the wet season. In the lower parts precipitation is mainly as rain, from November to March. Winter nights are frosty and the days sunny.

Below is some meteorological information, furnished by the "Gran Unidad Escolar San Juan Bosco" from their records at Salcedo.

For The Period 1950-1962

	Monthly Av. Rainfall	Av. Max. Temp. (°C)	Av. Min. Temp. (°C)
January	135.65 mm.	18.7	2.09
February	141.93	17.9	0.96
March	108.26	18.5	0.70
April	34.51	18.3	-1.27
May	10.37	17.2	-4.95
June	4.80	17.1	-6.47
July	1.54	17.1	-6.41
August	4.87	18.3	-5.63
September	30.85	19.2	-2.60
October	32.68	19.8	-1.40
November	42.54	19.6	-1.75
December	93.02	19.6	-0.36

Accessibility and Culture

Much of the farmlands belong to few landowners, whose residences are in Lima or Arequipa. The communities and many Indian families depend on a small scale farming on mountain sides and terraces preserved in some hills.

Ruins of tombs of the ancient Inca are found at "Cillustani" on the shore of Laguna Umayo.

The main highway from Arequipa to Juliaca crosses the area from west to east. Fifteen kilometers west of Laguna Saracocha a road branches to Puno, passing through Mañazo, Vilque, and Tiquillaca villages. Side roads penetrate to the northwest end of Laguna Lagunillas to Lagunillas station, and others to Tacaza, Jornoni and San Antonio de Esquilache mine. A network of trails exists in some regions where

PHOTOGRAPH 1: A small volcanic cone in the western range. View taken along the road to San Antonio de Esquilache mine.

farms are present; many of these trails are passable to four-wheel drive vehicles. Travel away from these roads and trails has to be done on foot.

The southern railroad of Peru ascends the Andes from the seaport of Mollendo to Puno; its highest point is at Crucero Alto, 4468 meters (14,666 feet) above sea level, 14 kilometers west of the western edge of the map-area. From Santa Lucia to Puno it has an easy gradient; from Juliaca there is a branch to Cusco. Small vessels in Lago Titicaca transport passengers and cargo from Puno to Guaqui, Bolivia.

Two fairly large cities are in the region: Puno the capital of the Department, and Juliaca a railway junction city. These obtain their living from scattered pastoral and agricultural communities and trade with Arequipa and Bolivia, the neighboring country. The main crops are barley, potatoes, quinua, and oca.

Mining at present is not an important activity. The work of Lampa Mining Company, Cia. de Minas del Peru, and several other small mines supports a small population.

CHAPTER III

STRATIGRAPHY

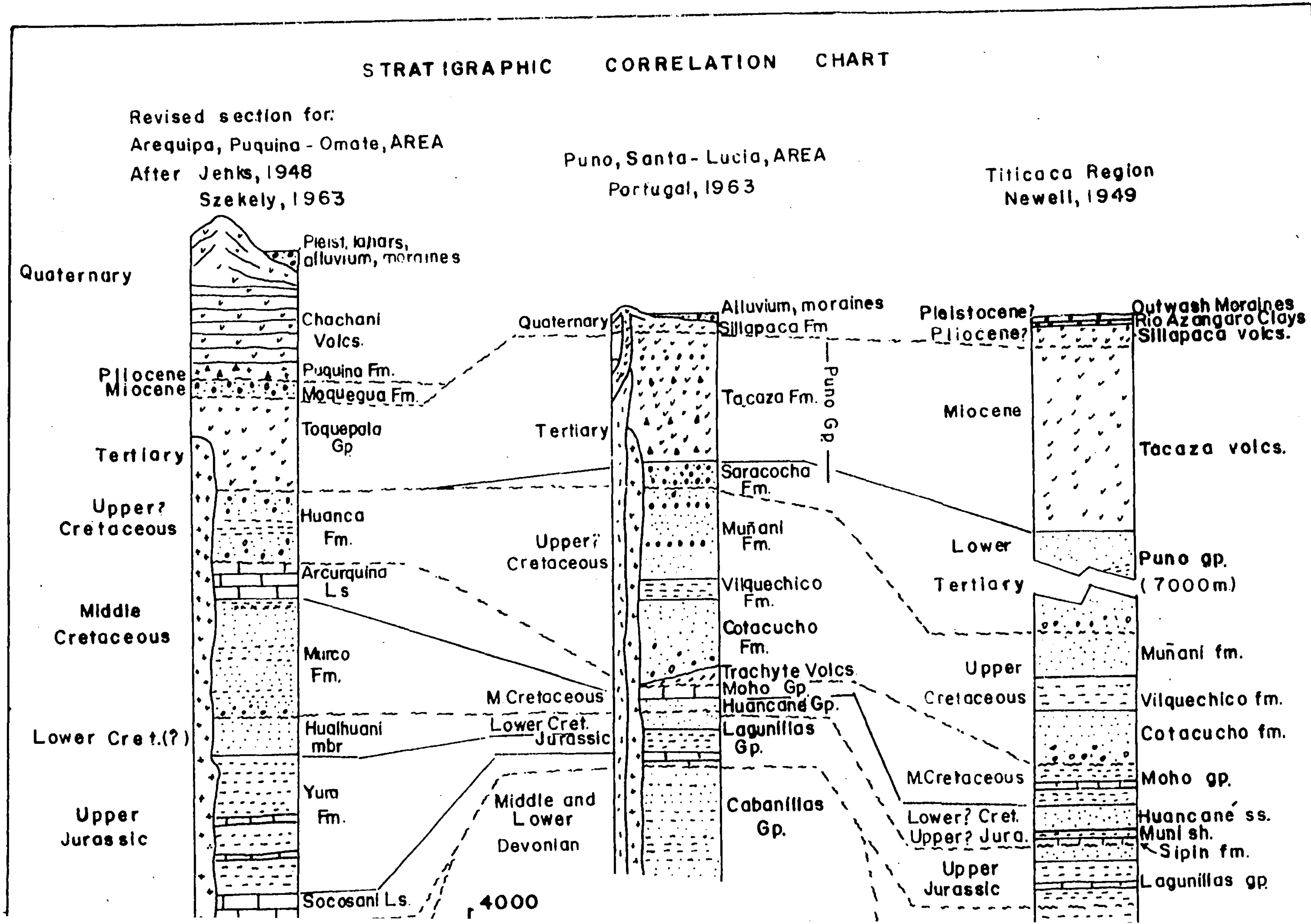
General Statement

The stratigraphic sequence within the map-area includes rocks of Devonian, Jurassic, Cretaceous, Tertiary and Quaternary age.

The Devonian rocks are represented by the Cabanillas Group, a sequence made up of sparsely fossiliferous shales and quartzites with a thickness of more than 2000 meters. Upper Paleozoic rocks have not been found within the map-area, Newell describes Permian sediments at the Peninsula de Copacabana, 110 kilometers southeast of Puno; and also at Muñani, north of the Lago Titicaca. Triassic rocks are not known anywhere near the area.

The Jurassic is represented by the Lagunillas Group. Three units have been recognized, with an aggregate thickness of 1050 meters. The uppermost member of this group, composed of white quartzites, is probably of Early Cretaceous age.

The Middle Cretaceous shallow water sediments have been included in the Huancané Group and the Moho Group with an aggregate thickness of 410 meters. The uppermost unit


STRATIGRAPHIC CORRELATION CHART
Revised section for:
Arequipa, Puquina - Omate, AREA
After Jenks, 1948
Szekely, 1963
Puno, Santa-Lucia, AREA
Portugal, 1963
Titicaca Region
Newell, 1949
Quaternary
Pleist. lahars, alluvium, moraines
Chachani Volcs.
Pliocene
Miocene
Puquina Fm.
Moquegua Fm.
Tertiary
Toquepala Gp
Upper? Cretaceous
Huanca Fm.
Arcurquina Ls
Middle Cretaceous
Murco Fm.
Lower Cret.(?)
Hualhuani mbr
Upper Jurassic
Yura Fm.
Socosani Ls.
4000
Quaternary
Alluvium, moraines
Sillapaca Fm
Tertiary
Tacaza Fm.
Puno Gp.
Saracocha Fm.
Upper? Cretaceous
Muñani Fm.
Vilquechico Fm.
Cotacucho Fm.
Trachyte Volcs
M.Cretaceous
Moho Gp.
Huancané Gp.
Lower Cret.
Jurassic
Lagunillas Gp.
Middle and Lower Devonian
Cabanillas Gp.
Pleistocene?
Outwash Moraines
Rio Azangaro Clays
Pliocene?
Sillapaca volcs.
Miocene
Tacaza volcs.
Lower Tertiary
Puno gp. (7000m)
Upper Cretaceous
Muñani fm.
Vilquechico fm.
Cotacucho fm.
M.Cretaceous
Moho gp.
Lower? Cret.
Upper? Jura.
Huancané ss.
Muni sh.
Sipin fm.
Upper Jurassic
Lagunillas gp.

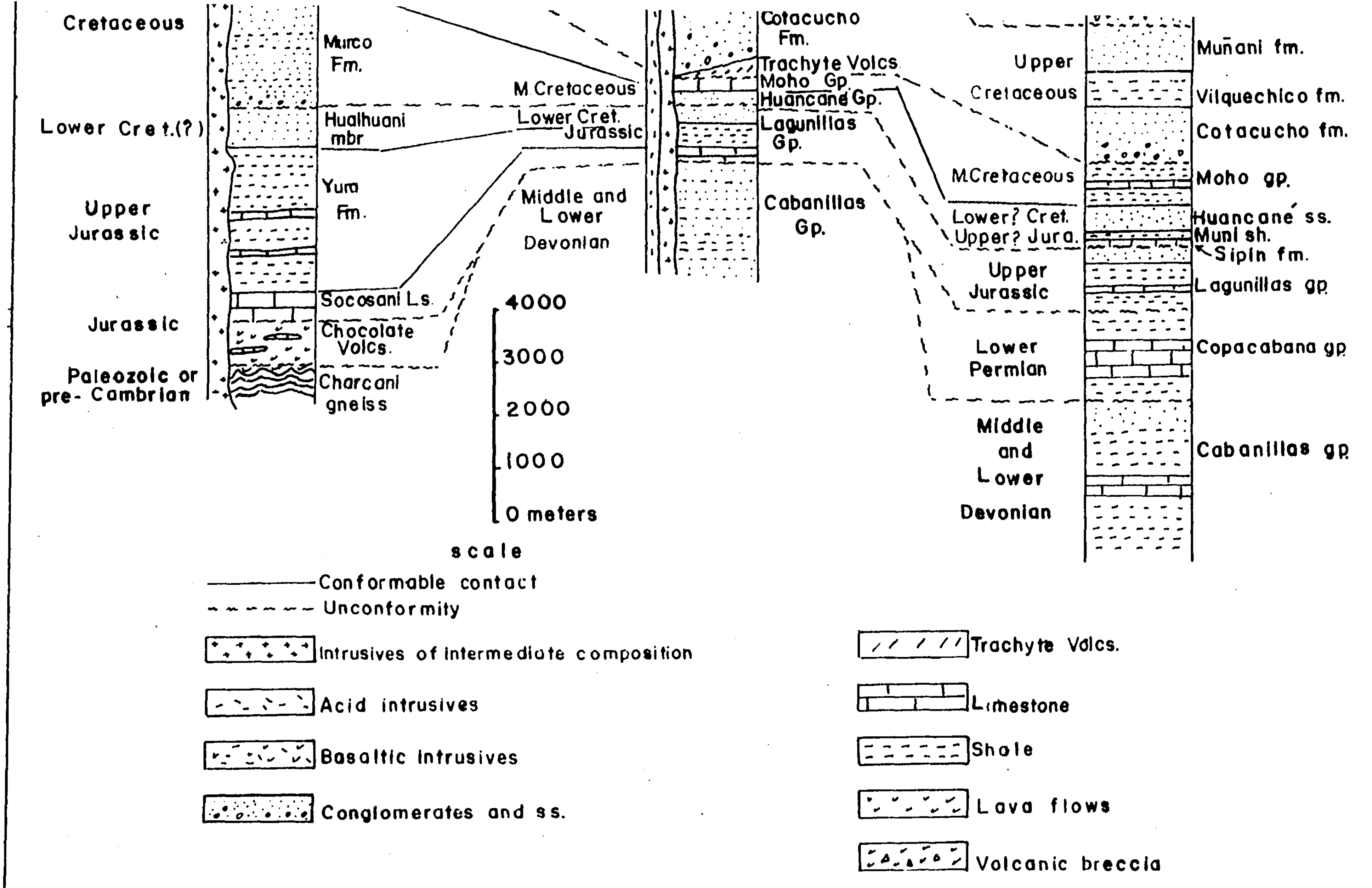

Cretaceous
Murco Fm.
Lower Cret.(?)
Hualhuani mbr
Upper Jurassic
Yura Fm.
Socosani Ls.
Jurassic
Chocolate Volcs.
Paleozoic or pre-Cambrian
Charcani gneiss
M.Cretaceous
Lower Cret.
Jurassic
Middle and Lower Devonian
Cotacucho Fm.
Trachyte Volcs
Moho Gp.
Huancane Gp.
Lagunillas Gp.
Cabanillas Gp.
4000
3000
2000
1000
0 meters
scale
Upper Cretaceous
M.Cretaceous
Lower? Cret.
Upper? Jura.
Upper Jurassic
Lower Permian
Middle and Lower Devonian
Muñani fm.
Vilquechico fm.
Cotacucho fm.
Moho gp.
Huancané ss.
Muni sh.
Sipin fm.
Lagunillas gp.
Copacabana gp.
Cabanillas gp.
Conformable contact
Unconformity
Intrusives of intermediate composition
Acid intrusives
Basaltic intrusives
Conglomerates and ss.
Trachyte Volcs.
Limestone
Shale
Lava flows
Volcanic breccia

Figure 2

of the Moho Group (Ayavacas Limestone) is sparsely fossiliferous, bearing fossils of Cenomanian age.

The trachytic flows around Juliaca and the Capachica Peninsula and the red beds of continental origin (Cotacucho, Vilquechicho and Muñani formations), mapped by Newell within his Puno Group of Tertiary age, are here placed in the Upper Cretaceous.

The restricted Puno Group of the present work consists of the Saracocha Formation, made up of conglomerates and sandstones, and the Tacaza Formation, made up entirely of volcanics. During the field work it was found that this group thins out towards the east and northeast and thickens towards the western range, which is covered in great part by the Puno Group.

The basalt and tuffs unconformably overlying the Puno Group and older rocks have been included within the Sillapaca Formation. The name Umayo Basalts has been introduced for some local flows at Tiquillaca and at Laguna de Umayo.

Six major unconformities have been studied, four of them are related to major orogenies.

The total measured thickness is 11,265 meters.

Igneous intrusions took place intermittently during Tertiary time. These plutons are related to orogenesis and volcanism.

TABLE 1

Stratigraphic Succession, Puno-Santa Lucía Area

Geologic Age	Formation and Description	Meters
QUATERNARY	Terrace and river gravels Moraines, outwash, peat	150
	Unconformity	
TERTIARY	Uplifting of the Andean block	
	Sillapaca Fm: Basalts and basaltic andesites	15-240
	Unconformity	
	Puno Group	
	Tacaza Fm: Pyroxene basalts, flow breccias, dacites, rhyolites, tuffs and conglomerates	2375
	Slight disconformity	
	Saracocha Fm: Conglomerates and feldspathic sandstones	0-550
	Unconformity	
CRETACEOUS	Muñani Fm: Sandstone reddish-brown arkoses, tuffs and conglomerates	2300
	Vilquechico Fm: Shale, brick-red, with intercalations of reddish sandstone	90-400
	Cotacucho Fm: Massive sandstone, reddish-brown, and conglomerates	1740
	Unconformity	

TABLE 1 (continued)

Geologic Age	Formation and Description	Meters
	Moho Group: Limestone, fossiliferous, bluish-gray; shale, brick-red and feldspathic sandstone	195
	Huancané Group: Orthoquartzites, coarse and x-bedded; limestone reddish-gray, and conglomerates made up of sub-angular fragments; both of them lenticular	215
	Unconformity	
	Lagunillas Group: Made up of the following three units:	
CRETACEOUS(?)	Quartzites, white, fine to very coarse-grained, massive, non-fossiliferous	300
	Shale, black, fissile, with intercalations of thin bituminous ls., highly fossiliferous	150
JURASSIC	Limestone, black to dark-gray, bituminous, fossiliferous, well bedded. Basal contact not seen.	600
	Unconformity	
DEVONIAN	Cabanillas Group: Shale, black to greenish-gray, highly micaceous. Sandstones and quartzites; fossiliferous. Base not exposed.	2000+
	Aggregate measured thickness	11,265

DEVONIAN ROCKS

General Statement

The oldest rocks in the Puno-Santa Lucía area are of Devonian age. Neither the top nor the base of this Paleozoic sequence has been recognized during the field work.

Around Cabanillas and north of the map-area a thick sequence of dark shales and phyllites, interbedded with quartzites, bearing a few fossils of Middle and Lower Devonian age was described. No division of the Devonian has been done; consequently all the rocks cropping out northwest of Cabanillas were mapped as the Cabanillas Group.

Folding and metamorphism of the Devonian formations in this region was moderate to weak.

Cabanillas Group

Name, Age, and Distribution

Newell (1945, p. 46) applied the term Cabanillas Group to all the rocks cropping out along the Cabanillas River, where excellent exposures are seen. No effort has been made to divide the sequence.

Newell points out that the Icla or Lower Devonian, and the Sicasica of Middle Devonian age of Bolivia, are similar in lithology to the Cabanillas Group.

Newell (1949, p. 33) mentions the following fossils found at Quebrada Jarajache, between Pirin and Taraco, 25 kilometers northeast of Juliaca, of Middle Devonian age:

Conularia sp.

"Cryphaeus" australis var. tuberculata Kozlowski

"Cryphaeus" cf. pentlandi Salter

Homolonotus noticus? Clarke

Paleoneilo pondeana Hartt and Rathbun

Diaphorostoma furmanianum Kozlowski

The lower beds of the Devonian at Cabanillas contain crinoid stems, casts of bryozoa and abundant brachiopods; Leptocoelia, Tropidoleptus, Spirifer, Chonetes, etc. (Douglas, 1920). The upper beds are made up of shales which yielded Conularia and trilobites. Douglas (1920, p. 36) described the fauna collected by him at Cabanillas which " . . . clearly shows that these Devonian beds of Taya-Taya correspond to the upper part of Steinmann's Icla Schiefer of Bolivia characterized by Leptocoelia flabellites; and, from the abundance of the genus Conularia."

Douglas (1920, p. 36) mentions that the Lower Devonian beds of Bolivia appear to be unrepresented in this part of Peru, and that the Taya-Taya beds probably represent a somewhat higher horizon. The Lower Devonian in Bolivia is

PHOTOGRAPH 2: Quartzites and argillites of the Cabanillas Group, beds up to 60 cm. thick. Picture taken north of Hda. Taya-Taya, looking north.

PHOTOGRAPH 3: Closer view of the Devonian quartzites and argillites. Photograph at the same place as one on preceding page.

defined by Leiorhynchus bodenbenderi, Leptocoelia acutiplicata, and Scaphiocoelia boliviensis.

Composite section of the Cabanillas Group in the vicinity of Cabanillas.

Unit		Meters
	Top	
	Cretaceous Conglomerates	
	Unconformity	
	Cabanillas Group	
5	Quartzite, greenish-gray, thick-bedded, argillaceous, fossiliferous	400
4	Shale, olive-gray, micaceous, interbedded with thin quartzites; ripple marks	150
3	Quartzites interbedded with black shale, bearing brachiopods	150
2	Shale, dark-gray to greenish-gray, highly micaceous, fossiliferous, beds up to 15 cm. thick, interbedded with greenish-gray quartzite, silty and argillaceous, quartzite beds up to 40 cm. thick ridge-forming; containing trilobites, brachiopods and Conularia sp.	1200
1	Shale, black, micaceous, iron concretions, thin-bedded, scarcely fossiliferous	100
	Bottom not exposed	
	Total	2000+

An erosion surface of moderate relief cuts folded Devonian rocks southwest and northwest of Cabanillas. The Devonian rocks are overlain by Cretaceous rocks with an angular unconformity at Co. Chicurmaco and at Las Huertas. Newell (1949, p. 34) mentions that these rocks are overlain disconformably by Lower Permian rocks in the Copacabana and Muñani areas.

The shales and argillites consist mainly of muscovite, quartz and iron oxide. There is a strong tendency for the mica flakes to be oriented parallel to the bedding; the muscovite is probably of sedimentary origin. This feature has been used to identify some non-fossiliferous argillites cropping out along the Puno-Acora Road as of Devonian age. The shales and argillites contain organic material. Ripple marks in sandstones are particularly common around Cabanillas. The black shales contain minor amounts of quartz.

Rocks of this group show little recrystallization and no cleavage.

JURASSIC ROCKS

General Statement

The area of the present work contains extensive zones of Upper and Lower Jurassic rocks with an abundant ammonite fauna. All these sediments have been included in the Lagunillas Group.

Collections of ammonites were made at Hda. Queirani, 12 kilometers south of Vilque; at Co. Zapana, 25 kilometers south-southeast of Santa Lucia railway station, near the Puno-Arequipa Road; at Co. Quimsachata, 20 kilometers southwest of Vilque. All of them were sent to Dr. Ralph Imlay of the U. S. National Museum who kindly furnished identifications and age determinations. The specimens are now in the collections of the National Museum.

Extensive outcrops have been mapped south of the Vilque and Mañazo villages. Jurassic rocks were also mapped south of Laguna Lagunillas along the north shore of Laguna Saracocha; these are considered by Newell (1949, p. 44) as the type section for the Lagunillas Group. To the south the Jurassic rocks are overlain by Tertiary volcanics. North of the areas mentioned above, the Jurassic is missing.

No volcanics have been found in these Jurassic formations; the Chocolate Formation described by Jenks near Arequipa (1948) has not been recognized in this part of the Andes.

Probably folding and thrusting took place at the end of the Jurassic. This orogeny might be correlated with the

Nevadian orogeny of western North America.

Neither top nor bottom of the Jurassic have been found.

Lagunillas Group

Name, Age, and Distribution

The group was named by Cabrera and Petersen (1936, p. 35) after Laguna Lagunillas. In the present report the name has been kept to avoid confusion in the literature, realizing that the name does not fulfill the requirements of a type locality.

Newell (1949, p. 46) described some conglomerates, at Las Huertas overlying Devonian rocks with angular unconformity, which he considered the base of the Jurassic sequence. During the present field work it was found that the lenticular conglomerates and limestone at that locality are the base of the Middle Cretaceous sequence.

Composite section of the Lagunillas Group in the area southwest of Mañazo:

From top to bottom.

Unit	Meters
Puno Group	
Conglomerates	
Unconformity	

Unit		Meters
	Lagunillas Group	
8	Quartzite, white, sugary, cross-bedded, beds from a few cm. up to one m. thick	150
7	Quartzite, same as above, with a great amount of quartz pebbles up to 3 cm. diameter; some thin conglomerate beds	100
6	Quartzite, white, interbedded with siltstone and black shale	50
5	Shale, black, interbedded with quartzite and thin-bedded limestone	30
4	Shale, black, fissile, carbonaceous concretionary, bearing ammonites	100
3	Shale, black, carbonaceous interbedded with thin limestone	20
2	Limestone, black to dark-gray,argillaceous, thin-bedded, bearing ammonites	500
1	Limestone, dark-gray, interbedded with thin black shale beds up to 15 cm. thick, fossiliferous	100
	Base is not exposed	
	Total	1050+

In spite of being complexly folded and faulted, the section can be subdivided into three formations, an upper quartzite, a middle dark shale, and a lower limestone. The three formations from top to bottom are:

1) White, nonfossiliferous, locally cross-bedded, fairly well sorted quartzite. This formation has beds up to 1 meter thick, interbedded with thin conglomerate beds made up of rounded quartz pebbles. Because it is highly disturbed, the true thickness has not been obtained. It is estimated to be about 300 meters. The quartzites include units 6, 7, and 8 of the composite section.

On the basis of their stratigraphic position these quartzites are tentatively correlated to the Hualhuani Member of the Yura Formation of the Arequipa region (Jenks, 1948, p. 146). Jenks pointed out that the Hualhuani Member may be of lowermost Cretaceous age in its upper part.

2) Black, concretionary, fissile shale with a rich ammonite fauna in numerous horizons. The ammonites are locally associated with concretions. This black shale formation is 150 meters thick and includes units 3, 4, and 5 of the composite section. Near Laguna Lagunillas the black shale occurs with light-gray quartzites in places showing rhythmic sedimentation. East of Co. Zapana the black shale shows some slump structures. The formation has a weak slaty cleavage in many places, and ammonites in it have been strongly deformed. They have an oblate form with the long axis more or less parallel to the cleavage.

From collections made in the black shales at Hda. Queirani and Co. Zapana, Dr. Ralph Imlay determined the following ammonite fauna:

Reineckeia cf. R. paucicostata Tornquist

R. (Reineckeites) cf. R. (R.) eusculpta Till

R. (Reineckeites) cf. R. (R.) stuebeli Steinmann

R. (Reineckeites) cf. R. (R.) multicostata Stehn

Eurycephalites sp.

Reineckeia cf. R. brancoi Steinmann

Eurycephalites parvus Stehn

Posidonia ornati Quenstedt

Reineckeia sp. Juv. cf. R. brancoi Steinmann

According to Imlay, this is a characteristic Callovian assemblage. Also some pelecypods occur with the ammonite fauna.

Although the upper contact of the black shale with the quartzites has not been observed clearly, it appears to be conformable.

This unit of black shales is correlative with the Yura Formation of the Arequipa region (Jenks, 1948). He assigned an Upper Jurassic age for this formation, based on ammonites and pelecypods collected near Tiabaya. Newell, quoted by Jenks, (1948, p. 145), considered the fauna of probable

Callovian age.

3) Dark-gray, bituminous, thin-bedded limestone, interbedded with black shale. Some horizons are highly fossiliferous. The limestone is folded and thrust which makes it impossible to get the true thickness. It is estimated to be 600 meters thick, and includes units 1 and 2 of the composite section. Some beds are locally dolomitized.

Dr. Ralph Imlay of the U. S. National Museum made the identification and age determinations of the ammonites. He found them mostly of Early Jurassic (Sinemurian) age as shown by the presence of the ammonites listed below:

Vermiceras cf. *V. stübeli* Tilmann

Metophioceras? sp.

Crucilobiceras? sp. Juv.

The Socosani Formation of the Arequipa quadrangle (Jenks, 1946, 1948) is considered of Toarcian and Bajocian age by Benavides (personal information, 1964). The limestone unit of the Lagunillas Group, because of its stratigraphic position, is considered to be correlative with the Socosani Formation (see Fig. 2, Stratigraphic Correlation Chart).

Its upper contact towards the black shale is transitional.

The Early Jurassic (Sinemurian) sediments in this area, do not show any evidence of a regressive sea, instead they seem to grade into the black shale unit of Callovian age (Lower and Middle). However, a better search might give some clues to a disconformity between these two units.

Douglas (1914, p. 8) described Callovian fauna in sediments interbedded with basic flows at the Morro de Arica, Chile. Callovian beds with a volcanic facies have also been recognized at the Quebrada Guaneros northwest of Arequipa by Bellido (in Wilson, 1962), but in the Puno-Santa Lucía area the volcanics are absent. They appear to be localized along the southern coastal portion of Peru; extending into Chile and northern Argentina.

One important fact is that the thickest sections of the Upper Jurassic rocks are in the Arequipa, Omate and Pachía-Palca region. Towards the east, in the Puno-Santa Lucía area, the equivalent of the Yura Formation (Upper Jurassic) thins out and the volcanic facies is absent. It still shows the characteristics of near shore sediments, with some carbonaceous shales interbedded with thin dark limestone and black shales containing ammonites. Its approximate thickness in the Puno-Santa Lucía area is 750 meters.

In the Pachía-Palca quadrangles the Yura Group is 1600 meters thick and it is made up from top to bottom, of quartzites, sandstones interbedded with dark shales containing plant remains, and limestones of neritic waters (Wilson and García, 1962, p. 28).

The Yura Formation, in the Puquina-Omate area, consists of fine-grained sandstone alternating with dark carbonaceous shale, siltstone, argillites and shelly limestones, which are probably of shallow marine origin. Its approximate thickness is 2900 meters (Szekely, 1963, p. 28).

In the Arequipa region (Jenks, 1946; 1948, p. 140), the Yura Formation is 3500 meters thick, of which the lower 3000 meters is a monotonous alternation of dark grey to black shales and light green quartzites. The upper 500 meters contain thick, fine grained brown quartzites. The shale strata are characterized by the abundance of fragments of plants. Marine fossils, pelecypods and ammonites were found in some shale and quartzite beds.

The thinning of the Upper Jurassic rocks towards the east is clearly inferred. But at the present time is impossible to suggest the direction of transgression of the sea during the deposition of the Lagunillas Group.

The age of the orogeny, which produced tight folding and metamorphism in the Lagunillas Group, still remains uncertain. It seems that it took place before the deposition of the Neocomian? Huancané Group, which lacks the strong folding and metamorphism shown by the Jurassic sediments.

CRETACEOUS ROCKS

Middle Cretaceous Rocks

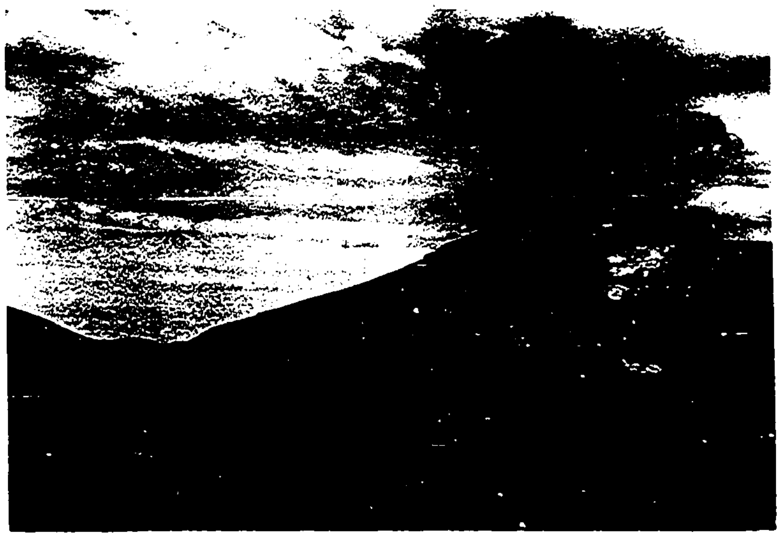
General Statement

A fairly thick sequence of conglomerates, sandstones, shales and limestones of shallow marine origin transgress rocks of Devonian age on a surface of moderate relief. This unconformable contact is easily followed and recognized from southwest of Cabana village through Las Huertas to Cerro Chicurmaco, and also northeast of Hda. Cayachira. At the last locality the surface has been domed producing a suitable slope for the gliding of the Ayavacas Limestone.

These rocks are of special interest since they mark a major break between Jurassic and Cretaceous conditions. They might be related to the main Cretaceous overlap in central and northern Peru. These Middle Cretaceous rocks are of economic interest because most of the indications of petroleum are found within them. Furthermore, they represent the last shallow marine fossiliferous sequence within the Titicaca region.

Fossils suggest that the uppermost formation, the Ayavacas Limestone, is of Cenomanian age (Newell, 1949, p. 51) and for convenience the whole sequence is classed as Middle Cretaceous, since no breaks have been observed within it. Newell (1949, p. 50) suggests the possibility that the Huancané sandstone is of Neocomian age; no fossils have been reported from this sandstone.

Heim (1947, p. 20) in his brief summary of the Geology of the Pirín oil field disagrees with Newell, among some other conclusions, with regard to the position of the Sipín Limestone, considered by Heim as probably Tertiary overlapping Cretaceous and Devonian rocks. Newell (1949, p. 6) considers it as lying at the base of the Mesozoic sequence " . . . having locally been displaced from its original position by extensive overthrusting." During the present work a limestone was found 25 meters above the base of the Mesozoic (unit 2 of the Huancané Group). It has a lenticular character and was deposited over a surface of moderate relief. This might be equivalent to the Sipín Limestone. It is here considered as part of the Huancané Group.



PHOTOGRAPH 4: Showing the Huancané sandstone, in the upper right, unconformably overlying Devonian rocks. View taken at Co. Chicurmaco looking SW.

PHOTOGRAPH 5: Showing the angular unconformity between the Cabanillas Gp. of Devonian age (right hand) and the Huancané Gp. (center of the picture). Further left a small stock intrudes the Huancané Gp. View taken at Co. Lacarimpo NE of Maravillas, looking north.

Table 2

Sequence of the Cretaceous rocks in the Puno-Santa Lucía area.

Upper Cretaceous	
	Meters
Muñani Formation	2300
Vilquechico Formation	90-400
Cotacucho Formation	1740
Unconformity	
Middle Cretaceous	
Moho Group	195
Huancané Group	215
Total	4850

Huancané Group

Name, Age, and Distribution

Newell (1945, p. 46) describes an orthoquartzite, conformably overlying the Muni Formation, and named it the Huancané sandstone after the town of Huancané, located at the northwest shore of the Lago Titicaca.

In the Puno-Santa Lucía area, there are some lenticular limestones and conglomerates conformably underlying the sandstone. All these units, for mapping purposes, have been included in one group and named the Huancané Group.

The group is made up of the following units, from top to bottom:

1) Sandstone, reddish-white, rounded to well rounded, medium to very coarse-grained, conglomeratic in places; the lower part is interbedded with a few conglomerate beds, made up of quartz pebbles up to 2 centimeters in diameter, the upper part is finer, cross-bedded, and iron spotted. Feldspar is generally not present; only very subordinate amounts have been observed in the upper part. Its upper contact towards the Moho Group is transitional.

At Cerro Infiernillo (see Plate 3) this unit conformably overlies the lenticular limestone; but to the northwest, at Co. Chicurmaco the sandstone rests directly on Devonian rocks with angular unconformity; it has a light-gray, thin, tuffaceous sandstone bed near its base.

2) Limestone, reddish-brown, sandy, with a few conglomerate beds; beds are up to 15 centimeters thick. This limestone and the underlying conglomerate are of lenticular character filling out small troughs in a surface of moderate relief; both of them pinch out. The thinning out of these two units is seen southwest of Las Huertas. Newell (1949, p. 52,54) described at the base of the Mesozoic some limestones and red shales of local development, the Sipín

Limestone and the Muni shale respectively. The lenticular conglomerates and limestones observed by the author at Co. Infiernillo, underlying the Huancané Formation are considered, for their stratigraphic position, equivalent to the Sipín and Muni formations of Newell.

Search for fossils in these units in the Puno-Santa Lucía area has been unsuccessful. Newell (1949, p. 54) reports pelecypods from the Muni Formation. These did not prove to be adequate for age determinations.

The thickness of the limestone is 55 meters at Co. Infiernillo.

3) Conglomerate is sub-angular, made up of quartzite, siltstone, granite; poorly sorted, sandy matrix. The greatest diameter of the cobbles is about 15 centimeters. At Co. Infiernillo it unconformably overlies Devonian rocks. Its thickness ranges from a few centimeters up to 20 meters.

According to Newell (1949, p. 57) the Huancané Formation gets coarser towards the west. He describes a conglomerate, the "Saracocha conglomerate," at Laguna Saracocha. This conglomerate, made up of quartzite, limestone and andesite fragments, is considered in the present work as the base of the Puno Group of probable Tertiary age.

No volcanic activity has been registered during the deposition of the Huancané sandstone in the Puno-Santa Lucía area. Igneous rocks are represented by very few pebbles of red granite and gneiss.

Some dips taken on the cross-bedding show that the source of sediments for the Huancané Group was to the northeast.

A section measured at Co. Chuncallama northeast of Puno does not show the bottom, but it becomes shaly towards the base with a few beds of red shale.

The age of the Huancané Group is not known with certainty due to the absence of fossils. Newell suggests a Neocomian age, since it conformably underlies the Moho Group containing Cenomanian fossils (Ayavacas Limestone). The Huancané Group is correlative with the Murco Formation of the Arequipa region (Jenks, 1946, 1948), which overlies the Yura Formation of Callovian age (see Fig. 2, Correlation Chart).

The aggregate thickness is 215 meters. No fossils have been found in the Huancané Group. The descriptions of the sections measured during the field work are given in the appendix.

Moho Group

Name, Age, and Distribution

A widely distributed sequence of red and non-red Middle Cretaceous beds was named by Newell (1945, p. 46) as the Moho Group after Moho, a village located on the northeast shore of Lago Titicaca, (and Newell mapped this group in many places covered by the present study). The name is kept in the present work for the Puno-Santa Lucía area.

The Ayavacas Limestone, named by Cabrera and Petersen (1936, p. 40) for the outcrops in the village of the same name located 10 kilometers northeast of Juliaca is the uppermost unit of the Moho Group in the Titicaca basin.

The lower contact of the Moho Group is transitional into the Huancané Group; its upper contact is marked by an unconformity, which is very clear west of Lake Lagunillas, with the Ayavacas Limestone unconformably underlying the Upper Cretaceous formations. Within the Titicaca basin this contact is commonly obscure due to the lack of good exposures; however, at Co. Katavirco due east from Juliaca, there is an excellent exposure of the Ayavacas Limestone unconformably underlying the basal conglomerate of the Cotacucho Formation.

Locally, at Co. Infiernillo, the Moho Group has two limestones, one at the base directly overlying the Huancané Group, and the Ayavacas Limestone at the top. They differ because the lower limestone is less massive, sandy and of brownish-gray color; the Ayavacas Limestone is dark-gray, massive, and highly disturbed.

At Hda. Ilpa a sandy limestone overlies the Huancané sandstone. In all probability this is the lower limestone of the Moho Group.

Four units of the Moho Group have been recognized in the Puno-Santa Lucía area with an aggregate thickness of 195 meters. The lowermost limestone has been observed only at Co. Infiernillo and at Hda. Ilpa. These units are from top to bottom:

1). Limestone, dark-gray, massive, with cherty bands and nodules developed locally, up to 40 meters thick, exceedingly persistent throughout the mapped area, known as the Ayavacas Limestone. It is folded, refolded and thrust. This disturbance does not affect the lower units of the Moho Group. It is sparsely fossiliferous. Newell (1949, p. 51) mentions Gryphaea, and corals identified by Dr. John Wells as Epistreptophyllum. Dr. C. Wythe Cooke identified the following echinoids: Orthopsis titicacana Cooke, and

<u>Tetragramma</u> sp. indet.

2) Shale, brick-red, interbedded with red siltstone and gypsum. Its thickness ranges from 30 to 70 meters.

3) Sandstone, reddish-brown, with angular to sub-rounded grains, feldspathic, non-fossiliferous; 40 meters thick.

4) Limestone, brownish-gray, sandy, lenticular, non-fossiliferous; 45 meters thick.

Newell (1949, p. 59) describes some shales, northeast and east of the Lago Titicaca, conformably overlying the Ayavacas Limestone as belonging to the Moho Group. These upper units are missing in the map-area.

Newell (1949) considers the Arcurquina (600 meters thick) of the Arequipa region as probably Aptian-Albian in age, based on some pelecypods and echinoids. Benavides considers it as of Albian-Cenomanian and Turonian age (written communication, 1964). The Ayavacas Limestone, uppermost unit of the Moho Group of the Puno-Santa Lucía area, contains fossils of Cenomanian age. On stratigraphic position, and considering facies change, the whole Moho Group is considered, in the present report, to be correlative to the Arcurquina Limestone (see Fig. 2).

Upper? Cretaceous

General Statement

A sequence of red beds was mapped by Newell (1949) within the Tertiary Puno Group in the Puno-Santa Lucía area. In the present work they were found to be equivalent to the Upper? Cretaceous formations (Cotacucho, Vilquechico and Muñani) of the northeast shore of the Lago Titicaca described by Newell.

Along the Putina-Poto road Newell (1949, p. 62) describes the Cotacucho Formation, the basal unit of the Upper? Cretaceous, resting on Permian and Devonian rocks. West of Laguna Lagunillas the base of the Cotacucho Formation is made up of a coarse conglomerate and sandstone and it rests on the Cretaceous Moho Formation. Within the Titicaca basin the basal contact is poorly exposed, faulted, or intruded.

This very thick sequence of red, tuffaceous sandstone, shales and conglomerates unconformably overlies Middle Cretaceous and older rocks; bounded at the top by a regional unconformity. Locally at Juliaca, and Peninsula de Capachica, volcanic flows of trachytic composition were found at the base of these beds.

The unconformity at the base of this sequence is taken as the boundary between the Middle Cretaceous and the Upper? Cretaceous. No macrofossils have been found in these red beds.

The identification of these formations is based entirely on structural and stratigraphic relationships and on their persistent lithologic characters.

These units, extremely persistent within the Titicaca region (see Plate 4), are missing in the eastern range, and also so far are missing in the western range.

For these reasons it appears that this whole sequence was deposited in a closed basin, bounded by the Cordillera Oriental and by an uplifted area in today's western range. Figure 3 shows the approximate limits of the basin; information for the eastern portion was taken from Newell, confirmed by short trips made by the writer to the Putina area.

Trachytic Volcanics

The basal conglomerate of the Cotacucho Formation at the northwest side of the Peninsula de Capachica near the Coata River, is made up of a great amount of trachyte cobbles and boulders and monzonite-diorite, limestone, quartzite and sandstone pebbles. At the same locality two trachytic flows occur near the base of the Cotacucho Formation.

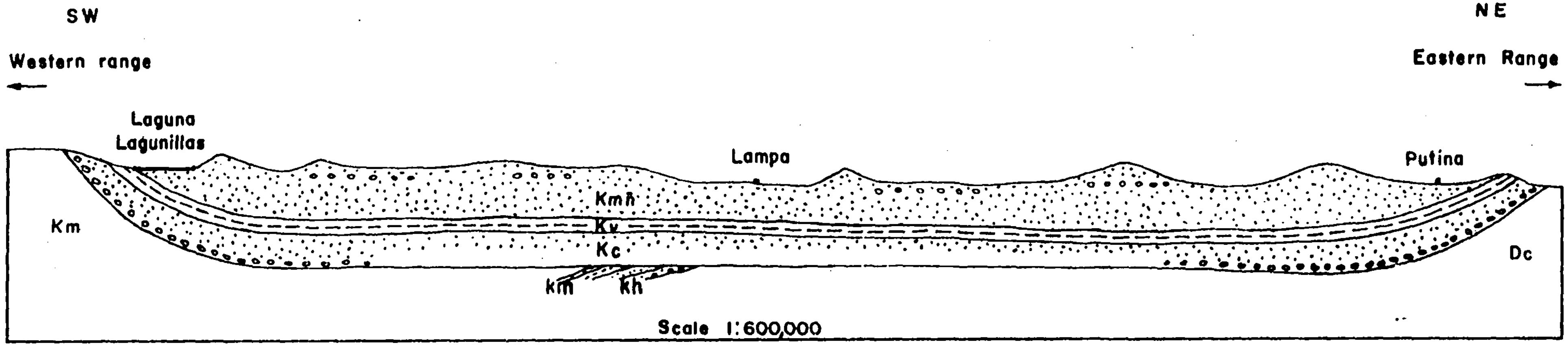


Figure 3. Diagrammatic section showing the limits of the depositional basin of the Upper Cretaceous red beds (Cotacucho, Vilquechico and Muñani formations), along a SW - NE line; from Laguna Lagunillas to Putina.

Dc, Cabanillas Group; Kh, Huancané Group; Km, Moho Group; Kc, Cotacucho Formation; Kv, Vilquechico Formation; Kmñ, Muñani Formation.

Several trachytic flows west of Juliaca, overlie Devonian argillites and quartzites and sandstones of the Huancané Group. The age relationship of the trachyte is difficult to study in this place because the upper contact is not exposed. Its maximum aggregate thickness is 350 meters.

Some trachyte fragments were observed in the basal conglomerate of the Cotacucho Formation in the outcrop west of Laguna Lagunillas.

These volcanic outbreaks took place during the deposition of the lower part of the Cotacucho Formation. If this formation is of Upper Cretaceous age, as inferred, the age of the volcanics would also be Upper Cretaceous.

Further indication of the widespread volcanic activity at this time are tuffs which occur at the base of the Cotacucho Formation along the Putina-Sandia road, some 75 kilometers northeast of the Puno-Santa Lucía area.

Petrography

The trachytes are brownish-red and porphyritic.

Microscopic studies of three specimens of the flows west of Juliaca indicate a trachytic composition with gradation to trachyandesite. There are abundant sanidine phenocrysts altering to sericite. The plagioclase phenocrysts

PHOTOGRAPH 6: Cretaceous trachyte outcrop at Juliaca. View taken looking southeast.

range in composition from oligoclase (An 26) to andesine (An 42), some feldspar tablets appear to have more calcic cores. All phenocrysts are generally idiomorphic; some grains exhibit corrosion phenomena. Groundmass is finely crystalline, made up of potash feldspar and quartz. Accessory minerals are apatite and magnetite. Sericite replaces feldspars; calcite occurs in the groundmass and fills cavities in irregular masses.

Cotacucho Formation

Name and Distribution

The unit was named by Newell (1945, p. 45) after Cotacucho, on the north shore of Lago Titicaca. Its base rests unconformably on the Moho Group west of Lagunillas. According to Newell on the eastern shore of Lago Titicaca, outside of the mapped area, it rests on Permian and Devonian formations. Its upper contact is transitional into the Vilquechico Formation.

At Ticalacaya the basal part of the Cotacucho Formation is a thick-bedded conglomerate made up of quartzite, quartz diorite, quartz monzonite, trachyte, and limestone fragments. The upper sandstones are brownish-white to light-gray, tuffaceous and feldspathic, with some frosted quartz grains.

The basal conglomerate is well exposed at Co. Ticalacaya (see Plate 4). Within the Titicaca region it is faulted or intruded. A thickness of 940 meters was measured at Co. Ticalacaya (thickest section of the Cotacucho Formation in this area). No fossils have been found in this formation and it appears to represent a non-marine deposition.

The unconformity beneath the Cotacucho Formation represents a major break in the sequence, in the Puno-Santa Lucía area. It is taken as the limit between the Middle Cretaceous (by fossils) and the Upper? Cretaceous rocks. The fence diagram of Plate 4 shows the unconformity clearly exposed at Co. Ticalacaya, at the western edge of the map-area. In the other localities it is faulted or intruded.

One important characteristic of the Cotacucho Formation, and generally of all the Upper Cretaceous formations, is the persistent lithology throughout the area. The description of the sections shown in Plate 4 is given in the appendix.

Vilquechico Formation

Name and Distribution

In this area the Vilquechico Formation is composed almost entirely of brick-red shales, with intercalations of sandstone about 10 centimeters thick; towards the contact with the overlying Muñani Formation there are a few thin beds of marl bearing charophytes. Newell (1949, p. 64) mentions Chara ovalis Fritzsche, C. perlata Peck and Recker, which have Upper Cretaceous affinities.

The formation was named by Newell (1945, p. 45) after the village of Vilquechico, located on the north shore of the Lago Titicaca.

It is very persistent throughout the area (see Plate 4). Its lower and upper contacts are transitional. Its thickness is variable: at the Peninsula de Capachica it is 220 meters and at the Peninsula de Chucuito it is about 400 meters. The formation thins out westward, and at Co. Queraya it is 90 meters thick.

Below there is a section measured at the Peninsula de Chucuito, which is considered as a standard section for the Puno-Santa Lucía area.

Section of the Vilquechico Formation at Co. Chullumpe, Peninsula de Chucuito.

Unit	Meters
Muñani Formation	
Sandstone, brick-red, medium grained, feldspathic	

Unit		Meters
	Vilquechico Formation	
4	Shale, brick-red, flaggy, beds up to 15 cm. thick, silty; interbedded with sandstone, reddish-white, feldspathic, medium-grained, x-bedded	80
3	Sandstone, reddish-white, medium to very coarse-grained, angular to rounded, conglomeratic in places, feldspathic, tuffaceous, some frosted quartz grains, x-bedded; beds up to 30 cm. thick	35
2	Shale, brick-red, silty, flaggy, interbedded with red siltstone	165
1	Sandstone, brick-red, fine-grained, angular, x-bedded, feldspathic, beds up to 20 cm. thick	120
	Total	400
	Cotacucho Formation	

There are excellent outcrops of the Vilquechico Formation on the Peninsula de Capachica, south of Vilque, west of Co. Yaurichampe and west of Hda. Andamarca.

Muñani Formation

Name and Distribution

The Muñani Formation was named by Newell (1945, p. 45) after the village of Muñani, approximately 50 kilometers northwest of Huancané, where a section of 900 meters of this formation is exposed.

Its lower contact with the Vilquechico Formation is transitional and its upper contact is marked by a regional unconformity with the overlying Tertiary Puno Group.

The Muñani Formation is considered by Newell (1949), and in the present report, as the uppermost formation of the Mesozoic sequence. It is made up of sandstone, reddish-brown, fine to medium-grained, angular to sub-rounded, feldspathic and highly tuffaceous and interbedded with conglomerates and siltstones, with the conglomerates being more abundant towards the top (see Plate No. 4). Fossils have not been found in the Muñani Formation.

This formation, which on the north shore of Lago Titicaca, outside of the map-area, is typically fine to medium grained sandstone and somewhat arkosic (Newell, 1949, p. 66), becomes coarser towards the west and at Co. Chullumpe, shown in fence diagram (Plate 4), the uppermost part of it contains abundant lenticular and thin conglomerate beds. At Co. Queraya (same diagram) it is almost 90 per cent conglomerates. Also the volcanic tuff, the pebbles and cobbles of andesite increases in amount westwards.

The uppermost beds of the Muñani Formation are softer, friable and easily eroded, forming depressions covered by

Recent deposits, which made it impossible to get a complete thickness of this formation. Its thickest measurement, about 2300 meters, was obtained at Co. Yaurichampe.

The descriptions of the section shown in Plate 4 are given in the appendix.

The samples of sandstone, of the upper part of the Muñani Formation, studied in hand specimen and microscopically, are in general a mixture of sediments and tuffaceous material. They are approximately 60 per cent sand, 30 per cent silt and 10 per cent clay (by volume).

The sand is 20 to 60 per cent quartz. Plagioclase, K-feldspar and a small amount of biotite partly altered to hematite comprise the rest of the particles. Hematite and clay make up the matrix and coat the sand grains. Pyrite, epidote, hornblende and calcite also occur in the sand and coarse silt size. Rock particles include vein quartz, quartzite, chert, andesite rocks, limestone and shale.

Newell mapped all these Upper Cretaceous formations within the Puno Group in the Puno-Santa Lucía area. He did not recognize the presence of the Cotacucho, Vilquechico and Muñani formations in this region. During the field work an angular unconformity was discovered between the Upper Cretaceous and the Puno Group due west of Mañazo village.

Also at Co. Putina, southeast of Puno, the Puno Group overlies the Muñani Formation with an angular relationship. On these structural and stratigraphic evidences the Upper Cretaceous red beds have been separated from the Tertiary sequence.

Newell tentatively correlated the Cotacucho, Vilquechico and Muñani formations with the Huanca Formation of the Arequipa quadrangle (see Fig. 2). This correlation is accepted in the present report.

Age Relations

The age of the red beds is not known with certainty. Newell (1949, p. 64) mentions Charophyta of Upper Cretaceous affinities in the Vilquechico Formation. Also, these beds overlie unconformably the Ayavacas Limestone of Middle Cretaceous age (Cenomanian). This unconformity has been observed by the author at Co. Ticalacaya northwest of Laguna Lagunillas and east of Putina, and at Co. Katavirco due east of Juliaca. In general it is poorly exposed within the Titicaca region. As pointed out by Newell, an Upper Cretaceous age in all probability is most accurate for the Cotacucho, Vilquechico and Muñani formations.

TERTIARY ROCKS

Puno Group

General Statement

The Puno Group was named by Cabrera and Petersen (1936, p. 45), after the city of Puno. It consists of two units: the Saracocha Formation and the Tacaza Formation.

The thickest section of this group in the Puno-Santa Lucía area is 2405 meters, and it becomes thicker towards the west and southwest of the map-area.

No adequate fossils for age determinations have been found in this sequence. The classification of formations is entirely based on structural, lithologic, and stratigraphic characters.

The Saracocha Formation is made up of conglomerates and sandstones. A study of the variation and distribution of the type of material in this conglomerate, leads to the conclusion that it was deposited in independent tectonic basins. This formation is widely distributed along the southwest portion of the map-area, towards the northeast it is absent. The presence of this conglomerate, roughly paralleling the western range, is taken as evidence of an orogeny at the end of the Cretaceous or beginning of the Tertiary.

The Tacaza Formation which overlies the conglomerates, consists of pyroxene basalt flows, flow-breccias, agglomerates, and tuffs. This formation thins out towards the east.

Newell (1949) included a very thick sequence of red, arkosic, tuffaceous sandstone and red shale in the Puno Group. During the present field work it was discovered that those sandstones and shales are equivalent to his Muñani, Vilquechico and Cotacucho formations of the northeastern shore of Lago Titicaca.

Measured sections of the Puno Group are presented in Appendix IV, and plotted on the fence diagram of Plate 5.

<u>Saracocha Formation</u>

<u>Name and Distribution</u>

Jenks (in Newell, 1949, p. 57) suggested the name of Saracocha conglomerate for a conglomerate cropping out at Laguna Saracocha. Newell believed this to be a coarser facies of the Cretaceous Huancané sandstone. Stratigraphic relationships of the conglomerate now prove it to be the base of the Tertiary Puno Group (see Photo 8).

In the present work the term "Saracocha" is still applied to the conglomerate in its revised stratigraphic position.

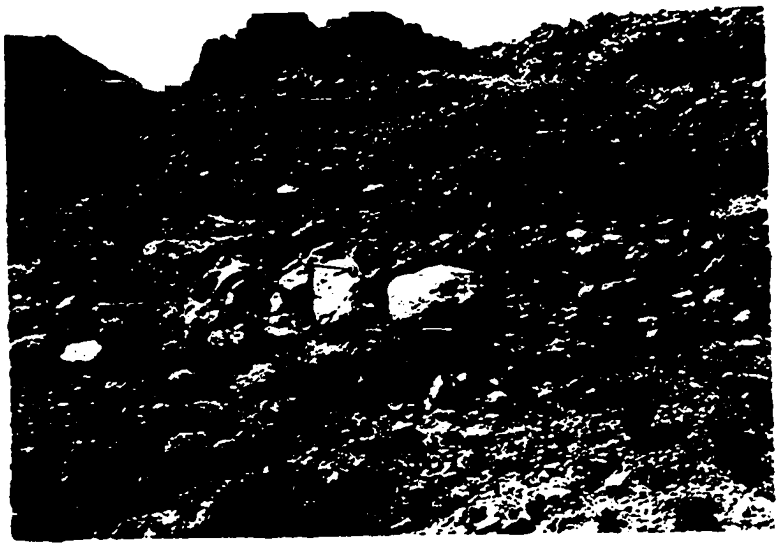
The conglomerate is reddish-gray, thick-bedded, with sub-angular to sub-rounded boulders. Fragments range from a few centimeters up to 1 meter in diameter; towards the top it becomes finer. The amount and composition of the components varies horizontally and vertically. In general it is made up of quartzite, limestone, diorite, andesite, basalts, trachyte and sandstone. There is an increase in the amount of volcanic fragments towards the west and south-west. Most of the material is derived from the underlying local older rocks.

The Saracocha Formation, well developed in the western and southwestern parts of the map-area (see Plate 5), disappears towards the north; from Santa Lucía to Cerro Coachico, at the extreme north of the fence diagram, the volcanic sequence directly overlies older rocks.

Because of the variation in size and shape of boulders, this conglomerate appears to have been laid down in structural valleys near fairly steep slopes; bounded at the bottom by a regional erosion surface.

This conglomerate rests unconformably on Jurassic and Cretaceous rocks.

The thickness of this formation ranges from 0 to 550 meters; the thickest section was measured at the Saracocha Lake.



PHOTOGRAPH 7: Conglomerate of the Saracocha Fm., base of the Puno Gp., showing boulders of diorite up to 1 m. diameter, at Cerro Viscachane, SE of Puno. Hammer was used for scale.

PHOTOGRAPH 8: Conglomerate of the Saracocha Fm., base of the Puno Gp. at Laguna Saracocha, looking east.

Tacaza Formation

Name and Distribution

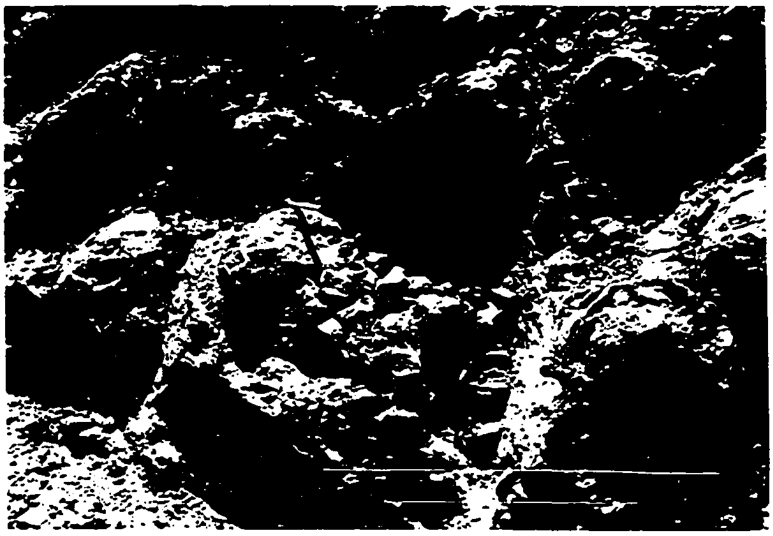
This formation was named by Jenks (in Newell, 1945, p. 48) after Tacaza mine 15 kilometers northwest of Santa Lucía railroad station. Because only a very small fraction of the formation is represented at this locality, it does not fulfill the requirements of a type locality. Nevertheless, due to the circumstance that the name has become very well known in the literature, it was advisable to preserve it for the pyroxene basalts, flow-breccias, agglomerates and tuffs, with intercalations of lenticular red conglomerates of volcanic origin, overlying the Saracocha Formation with a slight disconformity.

The western range is made up almost entirely of rocks of the Tacaza Formation.

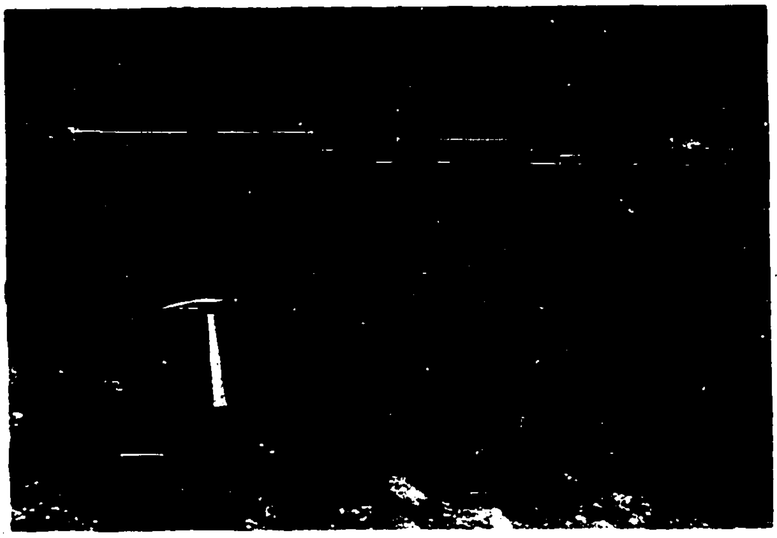
The Tacaza Formation comprises rocks of extrusive origin, widely spread in the west and southwest portion of the mapped area, from Puno to the west and north of Santa Lucía.

At Co. Coachico, extreme north of the map (also see Plate 5), the Tacaza Formation is made up mainly of andesite and augite basalts flows, with minor intercalations of tuffs, flow-breccias and conglomerates of volcanic origin, directly overlying quartzites of the Devonian Cabanillas Group. In this section the Saracocha conglomerate so predominant at the base of the Puno Group along the south and southwest portion of the map, is missing.

At Co. Auquirane (see Plate 5), a massive rhyolitic tuff rests at the top of the Tacaza Formation. These tuffs are massive, not welded, and show different degrees of cohesion, porosity and permeability. Its distinctive name in southern Peru is "sillar." They originated as <u>nuées ardentes</u> or "incandescent tuff flows" (Fenner, 1940, 1948a; Jenks, 1945, 1946, 1948; Jenks and Goldich, 1956). The tuffs are white to yellowish gray, and contain andesite and pumice fragments up to 8 centimeters diameter. Sanidine, quartz and biotite are identifiable megascopically, and ash-size particles are always present. Its thickness is variable and at Co. Auquirane it is approximately 85 meters. Good outcrops have been observed by the author 15 kilometers west of Puno along the Puno-Moquegua road. At Hda. San Miguel 17 kilometers southwest of Puno the sillar underlies the Umayo Basalts. Pyroclastic flows also occur north and northwest of Santa Lucía in thick massive beds of fine tuff breccia and lapilli tuff. They seem to be the product of large eruptions of pumice, lapilli and ash, with some lithic



PHOTOGRAPH 9: Andesite flow of the Tacaza Formation, showing the formation of boulders by exfoliation. View SE of Puno, along the road to Moquegua.



PHOTOGRAPH 10: Tacaza Formation: Andesite flow breccia with inclusions of andesite, limestone and quartzite fragments in an andesitic matrix. Outcrop SE of Puno along the Puno-Moquegua road.

fragments.

Nonwelded tuffs (Ross and Smith, 1960) of this type are known to be abundant in southern Peru to the Chilean and Bolivian border. Underlying these tuffs at Co. Auquirane there are andesite and basalt flows with thin intercalations of conglomerates and tuffs. This section is intruded by a diorite stock.

The sections at Co. Saihuani show an increase of tuffs and tuffaceous sandstones. An arkose 110 meters thick was observed near its base (unit 3 of the stratigraphic section), interbedded with andesite, basalt and flow-breccias. Tuffs at Hda. Tincopalca northwest of Co. Saihuani, along the Arequipa-Puno road, are thin bedded and the individual beds have very little variation in thickness. The uppermost beds contain silicified gastropods, suggesting that these tuffs were deposited by ash falls into water. Near Co. Zorrillo these thin bedded tuffs show small slump structures. The thickest partial measurement (2405 meters) of the Puno Group, within the map-area, was obtained at Co. Saihuani.

The Tacaza Formation at Co. Tacahuapata and at Co. Putina is made up mainly of andesite, basalt and flow-breccias. These breccias contain inclusions of andesite, basalt and also of foreign material, i.e., quartzite, sandstone, limestone and plutonic rocks. Volcanic breccias (see photograph 10) are characteristic of the Tacaza Formation and are very abundant throughout the mapped area. In places they are rather coarse, but finer flow-breccias have been observed by the author towards the northeast of the map-area, along the Arapa-Azángaro road. The fragments of the breccias are angular, but some rounded cobbles have also been observed particularly 4 kilometers northeast of Jornoni mine, suggesting an amount of transportation before deposition; rounded fragments have been observed especially in those flows with a high amount of sedimentary material.

The flows exhibit a wide range in composition, but andesitic varieties predominate and in some places they grade into basalts. The basalts range from vesicular to amygdaloidal. They are always porphyritic. Some have a deep maroon color caused by a high content of hematite, distributed throughout the groundmass or as pseudomorphs after amphiboles and biotite crystals. Epidotization and chloritization are the most common hydrothermal alterations causing some characteristic green patches. The flows of the Tacaza Formation are also characterized by occasional copper stain, which appears to represent " . . . copper indigenous to the flow." (Jenks, 1944, private report on Santa Lucía).

Dacites (unit 4 of the section measured at Co. Coachico) and rhyolites have also been found, but in very subordinate amounts.

In the contacts with stocks of granodiorite, the Tacaza Formation has suffered intensive thermal metamorphism. At Co. Jornoni and at Co. Coachico epidotization, sericitization and silicification are related to plutonic invasion.

In general the Puno Group shows an increase in thickness towards the west and southwest; 2405 meters were measured at Co. Saihuani within the map-area, becoming thicker towards the Cordillera Occidental. The thinning out of the volcanic sequence is seen towards Co. Auquirane and northeast of Santa Lucía and at Co. Coachico, extreme north of the fence diagram, it is 625 meters thick. One important conclusion is that the thickest sections of the Puno Group roughly parallel the western range.

<u>Petrography</u>

The microscopic study of the specimens of the Tacaza Formation reveals mainly an andesitic to basaltic composition.

Some of the thermally metamorphosed rocks show such degree of alteration that the study of the thin sections give little idea of their original composition.

The feldspar phenocrysts and the feldspar in the groundmass of the flows belonging to the Tacaza Formation are microscopically recognizable.

In andesites and in basaltic andesites the feldspars are represented by andesine (An 46). Towards the borders there is a sharp change to a clear rim of more sodic composition, these rims of course indicate peripheral growing. The phenocrysts are idiomorphic; but some of the grains exhibit corrosion phenomena. Reddish-brown biotite and hornblende are irregularly distributed in small grains. The groundmass is made up of plagioclase, orthoclase, biotite and small amount of quartz. In most of the thin sections the phenocrysts of ferromagnesian minerals are not well preserved, but aggregates of chlorite, magnetite, hematite and carbonates are considered to represent original phenocrysts of pyroxene, olivine or hornblende. The groundmass is microcrystalline and partially glassy in some thin sections.

In basalts the plagioclase ranges in composition from andesine to bytownite. Plagioclase phenocrysts are zoned from bytownite at the cores to clearer sodic plagioclase borders. The hornblende is the pale-green variety. Some aggregates of magnetite and chlorite are formed by replacement of original pyroxene and olivine phenocrysts. In some specimens augite and olivine phenocrysts are clearly observable. Some of the basalt flows are highly amygdaloidal, with hyalite, calcite, quartz and clay minerals in the amygdules.

Some tuffs have a dacitic composition with quartz, andesine and biotite grains in a groundmass made up of shard glass altering to hematite and carbonate.

Age Relations

The information for dating the Puno Group is not conclusive. The volcanic sequence overlies sediments of Middle Cretaceous and Upper Cretaceous age with a regional angular unconformity. In the Titicaca basin the Puno Group was not affected by the folding affecting the Upper Cretaceous beds. Around Santa Lucía and in the neighborhood of Puno the lower part of the volcanic rocks has suffered hydrothermal alteration at the contact with the intrusives. This means that the deposition took place after Steinmann's Peruvian folding (1929) of Late Cretaceous age; thus a Tertiary age for the Puno Group is the most probable but not conclusive. The age of the "sillar" is even less conclusive. I am inclined to tentatively place these tuffs in the uppermost Tertiary. Whether the "sillar" belongs to the Tacaza Formation still remains uncertain.

Sillapaca Formation

Name, Age, and Distribution

The term Sillapaca was applied by Jenks (in Newell, 1945, p. 48) to a group of andesite and basalt flows, after the Cordillera de Sillapaca, which lies north of Laguna Lagunillas. He also included the volcanic cones of the western range within this formation.

The Sillapaca Formation at the Sillapaca locality, northwest corner of the Geological map, rests horizontally on tilted beds of the Tacaza Formation. It is approximately 400 meters thick and made up of agglomerates, tuffs and basalt flows. Large areas of more or less horizontal basalt flows have been mapped in the Puno, Umayo, Tiquillaca areas, overlying in angular unconformity rocks of Tacaza and older formations. Some of these last basalt flows were traced to one volcanic center located at Co. Arboleda, on the south shoreof Laguna Umayo. I propose here the name of Umayo Basalts for all the more or less horizontal flows of basaltic composition, cropping out at Laguna Umayo and Tiquillaca. Further field work may show the existence of similar feeders for the basaltic flows south of Chucuito, Acora and southwest of Puno.

Because of their structural relationships, the Umayo Basalts are considered equivalent to a part of the Sillapaca Formation of Jenks. The age of these basalts is not known with certainty, but physiographic relationships show a pre-Pleistocene age.

The thickness of the Umayo Basalts ranges from 15 to 240 meters. Towards the Cordillera Occidental, it is less well defined.

Figure 4 shows a section of the Umayo Basalts 6 kilometers southwest of Puno. It is 78 meters thick and shows a bedded tuff at the base followed by three highly vesicular flows, vesicles are of irregular orientation. At Hda. San miguel the Umayo Basalts directly overlie rhyolitic pyroclastic flows.

In the Puno-Tiquillaca and Laguna Umayo region, the extensive Umayo basalt flows lie upon a fairly flat surface, which is tentatively correlated with the "Puna" erosion surface. West of Tiquillaca these flows plunge down the slope beneath the alluvium deposits. An olivine basalt neck at Co. Arboleda, rises above surrounding bedded tuffs associated with the flows, and is apparently the source of the Umayo Basalts (see Fig. 5). On the gentle slopes of Co. Arboleda near the neck the rock is made up entirely of tuffs

UMAYO BASALTS - SW. of PUNO

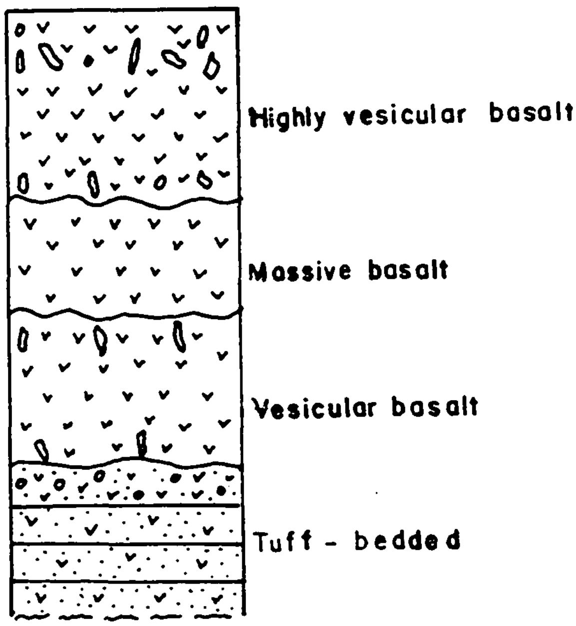
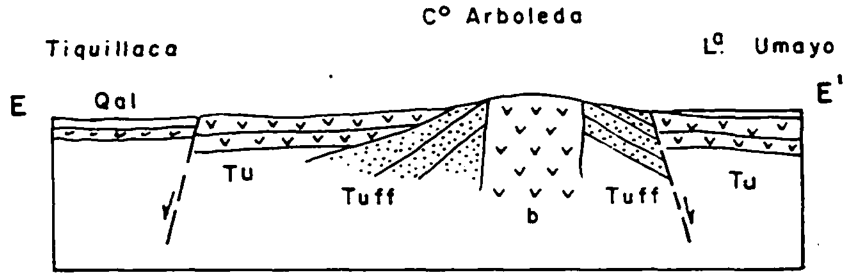


Figure 4. Columnar section of the Umayo Basalts, 6 kms. southwest of Puno. The section is 78 meters thick.



scale 1:100,000

Figure [illegible]. Feeder neck of the Umayo Basalts at Co. Arboleda. Probably there are more volcanic necks which acted as feeders for these basalts; which have not been observed during the field work.

Tu, Umayo Basalts; b, basalt; Qal, Alluvium.

PHOTOGRAPH 11: The Umayo Basalts with a bedded tuff at the base (hammer) followed by basalt flows. Road cut NW of Puno, looking NW. It rests on shales of the Moho Group.

and highly vesicular basalts. Probably there are more volcanic necks, southwest of Puno, which acted as feeders for these basalts, which the author has not observed during the field work.

Petrography

The flows at Tiquillaca and the flows southwest of Puno, at Hda. San Miguel are dark-gray to black vesicular olivine basalts. The phenocrysts of olivine are partly altered to brownish iddingsite, there are some augite and labradorite phenocrysts in a microcrystallitic to glassy groundmass. Augite is altering to a red-brown hematite.

Calcite is also present along small fractures.

A remnant of basalt flows much like the other basalts described at Laguna Umayo is present at Co. Pachacote (southwest of Mañazo). The rock is black and contains olivine in a very fine to glassy groundmass, containing also some andesine-labradorite and augite grains.

The microscopic analysis of other basalts of the Sillapaca Formation shows them to be almost identical with the Umayo Basalts. They have in the matrix augite granules, magnetite grains and tiny apatite needles. The labradorite phenocrysts are zoned from calcic to sodic; augite, partly altered to hematite, is also present as phenocrysts.

Olivine altering to iddingsite makes up approximately 2 per cent of the section.

QUATERNARY

Moraines, Mud Flows and Alluvium

Some mud flows have been observed in this area. They were caused by heavy rainfall on slopes covered by loose material. These deposits may attain a length of 4-6 kilometers like the one southwest of Tiquillaca along the road to San Antonio de Esquilache, which consists of coarse gravels of older rocks, the matrix is unsorted tuffaceous sand to clayey material. Its thickness locally exceeds 100 meters.

Around Cerro Coallaca there is a mixture of what might be a moraine from a small mountain glacier, and mud flows. This deposit is made up of coarse and angular to sub-angular gravels; the finer particles have been washed out towards the lower levels. It is at an elevation of 4800 meters.

On the Geological map, outwash, alluvium and stream deposits have been grouped together. Recent running waters have cut all these deposits. Evidence of strong glaciation in this area is lacking except for small cirques around the highest peaks, generally above 4600 meters. The absence of strong glaciation in the western range during the

Pleistocene may have been due to smaller precipitation. Also Early Pleistocene moraines on steep slopes might have been removed leaving no recognizable remnants.

Although no glacial striae were observed, small U-shaped hanging valleys are present in the southwest and northwest portions of the map. These have been modified by recent streams and talus deposits.

Along the Cabanillas River there are two well defined terraces, approximately 10 meters apart and more than 1 kilometer wide, extending several kilometers along the valley. The development of these terraces might be ascribed to variations in climatic conditions. They consist of an unsorted and unstratified accumulation of sub-rounded pebbles, cobbles and boulders of older rocks. The river has locally cut through these gravel deposits into the Devonian basement. The deepening and channeling is probably due to unloading of the streams in Recent times.

CHAPTER IV

INTRUSIVE ROCKS

General Statement

The diorites, granodiorites, monzonites and all the intrusive bodies of intermediate composition of the Puno-Santa Lucía area, were emplaced during the Lower Tertiary orogeny (Incaic orogeny).

The Upper Cretaceous folding (Peruvian folding of Steinmann) did not have an intrusive phase in this part of the southern Andes.

Around the intrusives thermal metamorphism is shown by the Tacaza Formation, which unconformably overlies Cretaceous sediments. Evidences of folding are absent in the Tacaza and in the plutonic rocks. These evidences strongly support the idea of emplacement of the plutons after the Upper Cretaceous folding.

Crushed zones and mylonitization in the intrusives and volcanics are common, especially west of Puno and southwest of Santa Lucía. These disturbances, the rhyolite intrusives, and the tilting of the Puno Group towards the southwest might be related to the Upper Tertiary Quechuan orogeny of Steinmann. Quechua is the name of the language spoken by the Incas.

Generally the core of the intrusives is granodioritic in composition; towards the sides they change to monzonites and diorites. Some of these stocks have acted diapirically on the Ayavacas Limestone, which by the effect of the intrusions was pressed out and glided over flows of the Puno Group (see chapter on Structure).

In the mapped area small stocks are irregularly distributed. It is in the area between Santa Lucía, Cabanillas and Vilque where they have their largest extension. Though they superficially seem to be independent, the amount and distribution of thermal metamorphism in the lower part of the Tacaza Formation and the similarity in composition between these intrusives suggest that they have one magmatic origin, in other words they represent the topmost part of a large batholith. Unfortunately in the area there are no deeply eroded valleys to offer an opportunity to the study of the continuation of these stocks in depth. At Co. Chiro the contact seems to dip towards the intrusive (see Photo 20).

These intrusives vary in composition from granodiorite to acid rhyolite. I have not observed foliation in them, but chilled zones are common, indicating that the intrusion took place at relatively shallow depths. Both the igneous and country rock show a narrow metamorphic zone.

Emplacement of Intrusive Rocks

The largest outcrops of diorite, granodiorite, and monzonite and other intrusives are in the southwest portion of the mapped area. In the east and towards the eastern range the rocks exposed are exclusively Mesozoic and Paleozoic sediments.

Several small stocks of fine to medium grained diorite, west and southwest of Puno, are highly altered, their contacts with the flows of the Tacaza Formation are indefinite. The field relationships seem to indicate that these stocks are related to the volcanics in space, time and tectonics.

The stocks are of small size and discordant to the country rock, this is taken as a major evidence in favor of the intrusive origin. They are emplaced in non metamorphic rocks.

Many plutons have produced a deviation of the strike of the sedimentary country rock along the contact zone, due to the dragging action of the intrusives. This is especially notable at Co. Coallaca, where besides the change in strike, there are numerous radial faults in the Muñani Formation.

The most likely processes of emplacement seem to be the

PHOTOGRAPH 12: In the center is a xenolith of red shale of the Moho Group surrounded by a syenite intrusive; the diameter of the xenolith is approximately three meters. View taken at Peninsula de Ccotos, east of Capachica village, looking southwest.

forceful injection and stoping of the country rock during the magmatic intrusion, but evidence is scarce. The presence of a few shale fragments from the roof in a syenite body at the Peninsula de Ccotos is considered as suggestive of the stoping process. Here the size of the fragments is up to about three meters diameter (see Photo 12).

Melting and assimilation does not seem to have been an important process of emplacement in this area.

In concluding, I would say that in this part of the Peruvian Andes the emplacement of the plutonic bodies have taken place in two principal processes varying in importance in different stocks. Field evidence shows that forceful injection was very important; stoping probably had also a role in the emplacement, though evidences for the latter are very scarce.

Petrography

A petrographic study was carried out on 62 thin sections of the intrusive and volcanic rocks of this area. The igneous rocks were classified according to the classification followed by Williams, Turner and Gilbert (1958).

A decrease in quartz and orthoclase content, from the center towards the outside of some of the intrusives, has been observed during the present work.

The mode of some of the different specimens is shown in Table 3, pages 73 to 75.

Light grey, medium-grained intrusives at Co. Coallaca, Co. Chosicane, west of Saracocha and some other small intrusives south of Tiquillaca are made up of granodiorite with a quartz diorite to diorite border facies.

The main accessory minerals of the granodiorite are magnetite, ilmenite, zircon and apatite.

The secondary constituents are chlorite, sericite and epidote.

In all the specimens of granodiorite, especially in the one taken from Co. Chosicane, east of Maravillas, some of the crystals tend towards idiomorphic development. The plagioclase feldspar ranges from oligoclase (An 28) to andesine (An 44), the cores being more calcic. Myrmekitic intergrowths are common, alteration to sericite and epidote was observed in all the slides. The quantity of potash feldspar varies in different specimens. Perthitic intergrowths are of general occurrence in samples taken near the contacts. The potash feldspar never shows crystal faces. Interstitial quartz shows strain shadows. The amphibole is green hornblende in prisms with poorly developed crystal faces. Biotite is yellowish-brown color and never exceeds the amount of hornblende. In some of the slides magnetite is totally or partially replacing hornblende. Epidote is formed at the expense of calcic feldspar in the sample taken from Co. Chiro.

The quartz diorite specimens are a more basic border facies of granodiorite intrusives. In these slides the plagioclase is strongly zoned and ranges in composition from andesine (An 32) to labradorite (An 56). Albite twinning is very general; Carlsbad and Pericline twinning is also common. In general the plagioclase crystals show an idiomorphic development. The size of the tablets varies considerably within a single slide. In some of the specimens the plagioclase crystals are strongly kaolinized and sericitized and a few of their cores contain epidote. Most of the potash feldspar is microcline and also some orthoclase is present. Quartz is irregularly scattered throughout the rock as a late product of recrystallization; many grains are badly fractured. The biotite is light brown. The quantity of this mineral varies, but does not surpass the amount of hornblende. Some crystals are idiomorphic. Partial chloritization of biotite accompanied by production of magnetite and occasionally of ilmenite is a common phenomenon. At the boundary with feldspar some micas show a vermicular development. Hornblende is a characteristic rock forming mineral of this quartz diorite. It is the green variety showing a prismatic habit, though the crystal faces are not well developed. Some of the larger hornblende crystals are associated with brown biotite. The amphibole shows some chloritization. Apatite is a very abundant accessory mineral, it usually forms small prisms within the ferromagnesian minerals. Idiomorphic crystals of zircon are common in some biotite grains. The plagioclase tablets of the specimens of diorite taken from the Puno-Moquegua road are sericitized, some of the cores are altered to epidote. The quartz diorites contain abundant pseudomorphs of hematite after hornblende and biotite.

A few specimens of monzonite porphyry from Co. Jornoni were studied microscopically. This gray, medium grained quartz monzonite weathers light brown. The core of the plagioclase crystals is epidotized and some of them are strongly kaolinized and sericitized. The potash feldspar is microcline. This rock seems to be a border facies of the granodiorite pluton at Co. Chiro. The modal composition of the examined slides is given in Table 3, p. 74. The plagioclase is strongly zoned and varies in composition from oligoclase (An 26) to andesine (An 48). Quartz is present

Table 3 MODAL ANALYSIS OF THE INTRUSIVES OF THE PUNO-SANTA LUCIA AREA

Minerals, %	Sample Nos.						
	SL - 40	JP - 159	JP - 147	JP - 306	JP - 149	JP - 125	JP - 114
Quartz	9	14	7	10	15	2	10
K-Feldspar	15	20	12	6	16	15	22
Plagioclase	48	44	50	51	49	54	49
Hornblende	7	8	12	10	10	14	6
Biotite	7	4	6	4	3	2	5
Augite	2	-	-	4	-	-	-
Chlorite	5	4	5	3	3	1	1
Other Accessories	7	6	8	12	4	12	7
Type of Plagioclase	Andesine - Labradorite	Oligoclase Andesine	Andesine Labradorite	Andesine Labradorite	Oligoclase Labradorite	Oligoclase Andesine	Oligoclase Andesine
Alkali feldspar to total feld-spar ratio	0.23	0.31	0.19	0.10	0.24	0.23	0.31
Rock name	Quartz diorite	Grano-diorite	Quartz diorite	Quartz diorite	Grano-diorite	Diorite	Grano-diorite
Locality	Co. Chosicane	Co. Chosicane	Co. Chocorose	Co. Coallaca	Co. Coallaca	Co. Queraya	Co. Quiviane

Table 3 (continued) MODAL ANALYSIS OF THE INTRUSIVES OF THE PUNO-SANTA LUCIA AREA

Minerals, %	Sample Nos.						
	SL - 48	JP - 250	SL - 61	JP - 169	JP - 181	JP - 212	JP - 203
Quartz	5	13	9	11	8	2	4
K-Feldspar	46	8	25	26	20	6	12
Plagioclase	15	52	43	41	56	66	58
Hornblende	4	12	3	14	5	5	6
Biotite	5	5	5	4	3	8	8
Augite	-	-	-	-	2	2	2
Chlorite	20	4	8	1	3	7	6
Other Accessories	5	6	7	3	3	4	4
Type of Plagioclase	Oligoclase	Oligoclase Labradorite	Oligoclase Andesine	Oligoclase Andesine	Oligoclase Andesine	Andesine Labradorite	Andesine Labradorite
Alkali feldspar to total feld-spar ratio	0.75	0.13	0.36	0.38	0.26	0.08	0.17
Rock name	Syenite Porphyry	Grano-diorite	Monzonite Porphyry	Quartz Monzonite	Grano-diorite	Diorite	Diorite
Locality	Co. Yaurichampe	Co. Chiro	Co. Jornoni	Co. Jornoni	Co. Changarani	Limón Verde	Co. Coquen-cora (Li-món Verde)

Table 3 (continued) MODAL ANALYSIS OF THE INTRUSIVES OF THE PUNO-SANTA LUCIA AREA

Minerals, %	Sample Nos.					
	JP - 201	JP - 83	JP - 54	JP - 312	JP - 344	JP - 345
Quartz	12	3	8	2	4	10
K-Feldspar	20	12	54	11	11	20
Plagioclase	49	50	26	68	60	47
Hornblende	9	12	2	1	3	5
Biotite	4	3	5	2	1	12
Augite	-	6	-	4	5	-
Chlorite	2	4	2	5	7	2
Other Accessories	4	10	3	7	9	4
Type of Plagioclase	Andesine Labradorite	Andesine Labradorite	Oligoclase	Andesine Labradorite	Andesine Labradorite	Andesine Labradorite
Alkali feldspar to total feldspar ratio	0.28	0.20	0.67	0.14	0.15	0.29
Rock name	Granodiorite	Diorite	Syenite	Diorite	Diorite	Granodiorite
Locality	West shore of Laguna Lagunillas	Hda. Totorane	Península Ccotos	6 kms. S. of Puno, road to Moquegua	Co. Putina Puno	Co. Ccota

in an amount between 9 and 11 per cent. Albite twinning is very common; Carlsbad twinning is also present. Hornblende is very characteristic mineral of this rock, its prismatic habit being persistent throughout the slides investigated. The amphiboles show strong chloritization, biotite is altered to hematite, magnetite and carbonates. The accessory constituents are apatite and zircon.

At the Peninsula de Ccotos a small stock of syenite cuts the Moho Group. The mode of the sample is shown in Table 3. The plagioclase feldspar is oligoclase; some of the tablets are highly zoned. The crystals are altered to sericite and calcite with epidote in their cores. Most of the potash-rich feldspar is orthoclase. Quartz is scattered in small phenocrysts throughout the rock and in the groundmass as interstitial quartz. Biotite and hornblende grains are altered to chlorite with some hematite and magnetite. The accessory constituents are tourmaline and zircon.

Age Relations

During the course of the present work strong emphasis has been given to the probable relation between the Steinmann's second orogeny "The Incaic folding," which he considers to have taken place in the Lower Tertiary (Eogene) and-the intrusions of plutons of intermediate composition in this area.

Crosscutting relationships of the stocks with the lower beds of the Tacaza Formation at Co. Jornoni and southeast of Puno, of probable Lower Tertiary age, have been observed. The Tacaza Formation where intruded shows intensive contact metamorphism.

There is no information for the exact dating of the Incaic orogeny. Gerth (1955, p. 239) suggested an Early Miocene age.

The relations between these intrusives and the coastal batholith have not been worked out. The batholith in the Punta de Bombón quadrangle is older than the Camaná Formation of Oligocene age (Szekely, 1963, p. 86); in the Arequipa quadrangle the batholith is older than the Huanca Formation of probable Upper Cretaceous age (Jenks, 1948, p. 173). A Miocene age is suggested in the present report for the intrusives of the Puno-Santa Lucía area.

<u>Rhyolite Intrusives</u>

A few conspicuous rhyolite intrusives are scattered throughout the mapped area. They are characteristically small and clearly discordant to the country rock.

A 12 kilometer long by 1.5 kilometer wide rhyolite intrusive south of Vilque (see Photo 13), clearly intrudes

PHOTOGRAPH 13: Showing a rhyolite pluton to the left of the picture, intruding flows of the Tacaza Fm., shown in the right. View taken southeast of Hda. Queirani looking south.

flows of the Puno Group with a strong breccia zone and some silicification at the contacts. It shows some small and unaltered roof pendants made up of volcanic breccia and conglomerates belonging to the Tacaza Formation at the top.

The position and elongated shape of this intrusive indicate that it is located along a fault which might be related to the thrusts (see Plate 1). At the contacts the composition of this rhyolite intrusive grades into dacite.

Megascopically the rhyolite is a white rock with conspicuous quartz phenocrysts (up to 6 milimeters diameter) in a white matrix. Under the microscope the quartz shows small cracks and a few strain shadows. The crystals tend to be rounded or of an irregular shape and show sharp edges. Sanidine phenocrysts are less common than those of quartz and their boundary with the matrix is vague. Oligoclase is scarcer. The phenocrysts are twinned according to the Carlsbad law. The groundmass is a fine aggregate of quartz, feldspar and biotite. Biotite, in the reddish-brown variety, is always present though in small amounts. In some of the slides the phenocrysts are in a banded glass matrix.

Other occurrences of rhyolite are as dikes, north of Hda. Cayachira and at Tambillo, northeast of Laguna Saracocha. In the last mentioned locality a dike 20 meters wide and more than a thousand long is a rhyolite porphyry with phenocrysts of quartz and sanidine. The quartz and sanidine make up about 40% of the rock. Some other intrusive bodies include the one at Co. Yanaorco, which is a sanidine porphyry neck with phenocrysts up to 4 centimeters long. It contains occasional small quartz and hornblende phenocrysts; abundant biotite, quartz and potash feldspar in the groundmass. The neck at Co. Zorrillo is a sanidine porphyry with some quartz and biotite phenocrysts, in a crystallitic to glassy matrix. In Co. Llanquire, on the road to San Antonio de Esquilache mine, a dike of rhyolite porphyry is very well exposed.

A granite occurence west of Hda. Cornaviri intruding along the thrust plane seems to have the same relationships in time and tectonics as the rhyolite. The orthoclase tablets are up to 1 centimeter long and the quartz grains are made up by a cluster of small crystals. Some feldspar grains are highly sericitized. Biotite is present in small quantities and altering to hematite and magnetite.

Age Relations

The rhyolite intrudes the uppermost beds of the Tacaza Formation along the road to San Antonio de Esquilache and at Co. Zorillo, and seems to be post-Late Tertiary faulting. This rhyolite nowhere intrudes the Sillapaca Formation.

South of Vilque and northeast of Hda. Cayachira the rhyolite bodies seem to be cut by the Puna erosion surface (Pliocene?). The rhyolites are therefore younger than the Tacaza Formation and older than the Puna surface and Sillapaca Formation, perhaps Miocene or Early Pliocene.

Thermal Metamorphism

The rocks invaded by the plutonic bodies show a narrow zone of thermal metamorphism.

The Huancané Formation made up of orthoquartzites has been recrystallized, but outlines of small pebbles are still recognizable. This formation in the neighborhood of the plutons consists almost exclusively of quartz but subordinate amounts of biotite are common. The more impure arenaceous sediments like the Devonian Cabanillas Group, some beds of the Moho Group, the Cotacucho and Muñani formations contain important amounts of biotite; the mica is of reddish-brown color in minute grains.

A distinct example of contact metasomatism occurs in the Peninsula de Ccotos, along the contact between a syenite body and the Moho Group. Here, there is a narrow zone bearing hornblende in elongated prisms, closely associated with brown to black euhedral tourmaline, with some sericite.

The sediments at this contact show an enrichment of feldspar taking the form of plagioclase that can be recognized even megascopically. In this place there are partly assimilated xenoliths of red shale of the Moho Group in a syenite body, Quartzites and arenaceous sediments bearing biotite are more common.

At Hda. Ilpa, along the contact of the granodiorite and dolomitic limestone of the Moho Group, long colorless prisms of tremolite are typically developed in a calcite-quartz matrix.

The volcanic flows of the Tacaza Formation seem to have suffered a very extensive thermal metamorphism. In basalts of this formation the main product of metamorphism is chlorite accompanied by some biotite. Chlorite forms aggregates by replacement of original pyroxene phenocrysts. In some cases aggregates of magnetite and ilmenite are the product of replacement of ferromagnesic minerals. The plagioclase which ranges in composition up to labradorite, has retained its original habit; however, in a few tablets the original structure has been destroyed; some are crowded with inclusions which seem to be biotite. The plagioclase phenocrysts have borders of more sodic composition. These rims might indicate peripheral growth during metamorphism.

Andesites carry a great amount of chlorite as the principal product of metamorphism. A reddish-brown biotite irregularly replaces hornblende. In some slides former phenocrysts of ferromagnesian minerals are now an aggregate of biotite, chlorite and magnetite. The groundmass forms a mosaic of quartz, plagioclase and mica. The plagioclase of the phenocrysts and also the plagioclase of the groundmass retains its igneous habit.

The grade of metamorphism in the Tacaza Formation is variable, in places it is very slight and in some others the igneous structures have disappeared, and many of the plagioclase phenocrysts are granulated and are very vaguely discernable.

In samples taken from the contacts between the intrusives and the Tacaza Formation silicification has been observed. The groundmass is chalcedony; granular epidote is distributed both within the phenocrysts and within the groundmass, other secondary minerals are sericite and chlorite. In some cases alteration has been so intensive that the specimen consists mainly of epidote, hematite, carbonate and quartz.

CHAPTER V

STRUCTURE

General Statement

In the Puno-Santa Lucía area there were two different orogenies in Mesozoic time. The Paleozoic structural history is little known, since the scattered Devonian outcrops have been inadequately studied for purposes of regional correlation. Devonian rocks are overlain without a visible angularity by Lower Permian rocks in the Copacabana and Muñani areas (Newell, 1949, p. 34). Ahlfeld (1960, p. 31) describes a disconformity between the Devonian and the Upper Paleozoic in Bolivia. The Upper Paleozoic rocks are missing in the Puno-Santa Lucía area due to the presence of an epi-Devonian erosion surface.

The record beginning with Jurassic time is more complete. The geosynclinal sediments of the Lagunillas Group were tightly folded at the end of the Jurassic.

The Lower Cretaceous transgressive seas deposited on a surface of moderate relief several hundred meters of clastic sediments. During the Middle Cretaceous time the uplifting of the area produced the retreat of the sea and sliding of the Ayavacas Limestone and associated Moho red beds.

Although an unconformity is recognized between the Middle and Upper Cretaceous in slopes of both the eastern and western ranges, it appears to be relatively slight within the Titicaca area. The Upper Cretaceous internal basin was folded up at the end of the Mesozoic.

Over the whole area the unconformity between the Mesozoic and Tertiary rocks ranges between 10° and 35° and the units have an entirely different geographic distribution. The Upper Cretaceous beds are limited to the Titicaca area and eastern foothills of the western range, and the Tertiary Tacaza Formation to the western range mainly.

Small stocks of intermediate composition intrude the lower part of the Tacaza Formation. These intrusives and faulting in the lower beds of the Puno Group are evidence for a Lower Tertiary orogeny, tentatively correlated with Steinmann's Incaic folding.

At the end of the Tertiary normal faulting, and also the intrusion of the rhyolite, took place in this area. This movement is correlative to Steinmann's Quechuan orogeny.

Epeirogenic movement took place after the deposition of the Sillapaca Formation.

Folding of Devonian Rocks

Since no detailed work has been done on Devonian rocks it is inappropriate to undertake here a separate analysis of the folding and faulting, which has affected the Devonian Cabanillas Group. However, reconnaissance work done close to the contact of the younger rocks indicates rather gentle folds of prevailing east-west and north-south directions. These actual directions of folding do not necessarily represent their original trends, since the Cabanillas Group has been affected by later orogenies.

Newell, et. al., (1953, p. 10) mention the scarcity of evidence of pre-Mississippian orogeny in southern Peru. Evidently the structural history of the Paleozoic in this area still remains open to new investigations.

Folding of Devonian rocks has not produced indications of rock flowage. Where quartzites are present the folds are broader and more open, with rounded crests. The folded Devonian beds were subjected to long erosion in pre-Jurassic time. Because of this long period of erosion the thick Permian formations, so predominant in Copacabana and Muñani areas and east of the Lago Titicaca, are absent between Santa Lucía and Puno. Triassic strata are not known in the area.

Upper Jurassic Orogeny

The two cross-sections of Figure 6 show a tight folding in the Jurassic Lagunillas Group and thrusts bringing this group against the Upper Cretaceous formations. On the right side of the sections at Co. Huañulaya, the Upper Cretaceous Muñani Formation is folded up in a wide open syncline. Some of the major Jurassic anticlines and synclines have sheared off.

The mapping of Jurassic rocks shows that the major folds, thrusts and transverse faults do not continue into the younger formations, on the contrary a syncline and anticline and several other minor structures are covered, in the south, by the Tertiary volcanic sequence (see Plate 1). Unfortunately the contact between the Jurassic and Cretaceous rocks has not been observed within the limits of the map-area. However, it is expected to find the Cretaceous overlapping the folded Jurassic rocks somewhere in southern Peru.

The Cretaceous Huancané Group at Las Huertas, 15 kilometers north of the thrust bringing the Jurassic into contact with Cretaceous rocks, is not affected by folding or thrusting. This is additional evidence for Late Jurassic disturbance.

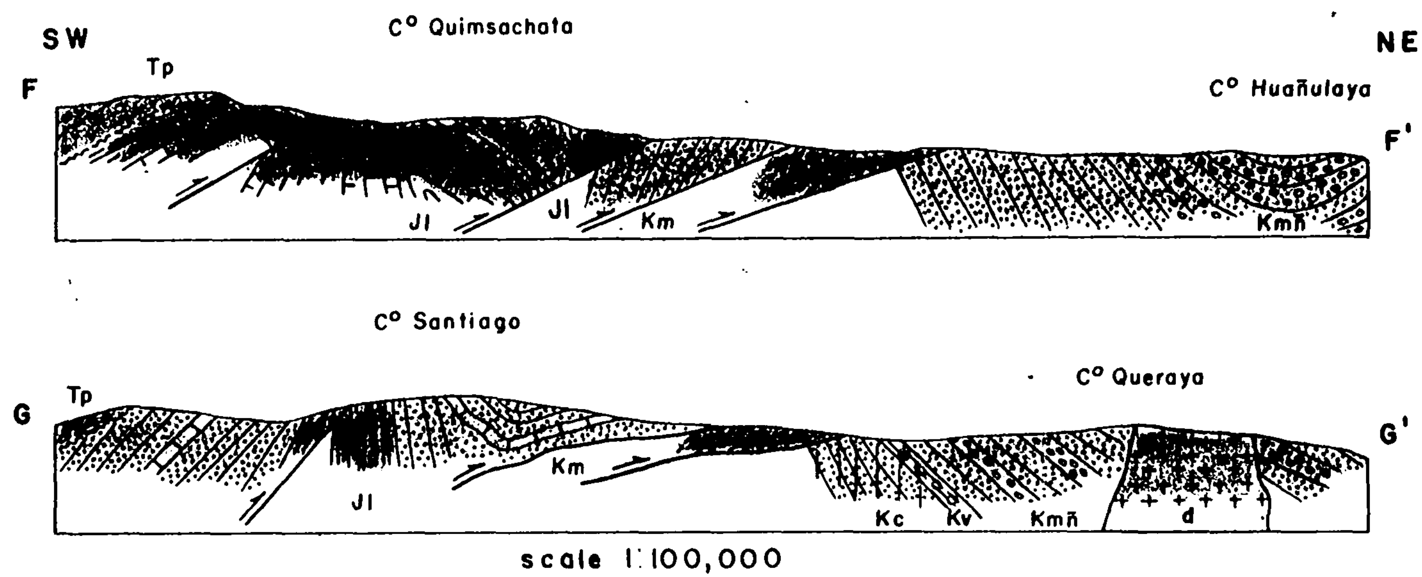


Figure 6. These two sections show the tight folding of the Jurassic Lagunillas Group (left), associated with thrusts; in contrast to the open folding shown by the Upper Cretaceous formations at Co. Huañulaya and at Co. Queraya (right).

Jl, Lagunillas Group; Km, Moho Group; Kc, Cotacucho Formation; Kv, Vilquechico Formation; Kmñ, Muñani Formation; Tp, Puno Group; d, diorite.

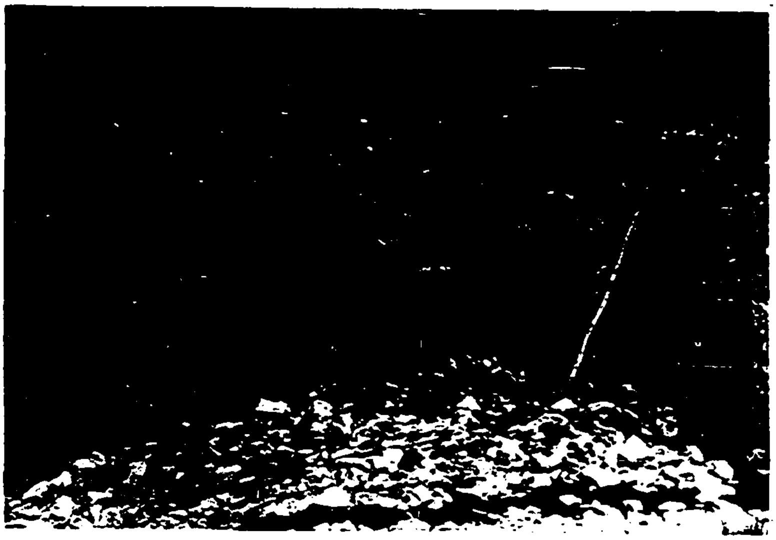
The folded limestone and shales of Jurassic age at Co. Quimsachata show weak slaty and fracture cleavage. The fossils are highly distorted with their longest axes perpendicular to the compressional stresses. Cretaceous and Tertiary formations do not have slaty or fracture cleavage, showing a different degree of intensity of deformation.

The anticline on the lower limestone west of Co. Quimsachata trends eastward and is slightly overturned to the south.

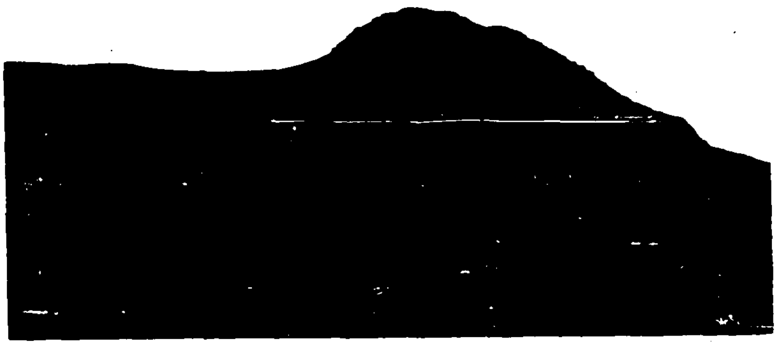
West of the granite porphyry intrusion (see Plate 1) the quartzites, upper unit of the Lagunillas Group, are sharply folded and some sections overturned to the south. These relations are most easily explained by assuming that the intrusion, of Tertiary age, followed the plane of the thrust with some pressure producing minor movements.

Gentla and very moderate plunges have been observed in almost all the folds as shown by their crests and troughs, and in some cases, by the intersection of bedding and foliation planes. The average plunge is about 10^{o}, steeper incilnations are rare.

No igneous activity during Jurassic time has been detected.



PHOTOGRAPH 14: Showing in the center of the picture, limestones (Lower unit of the Lagunillas Gp.) thrust over black shale (Middle unit of the same Gp.). Both of these units are highly fossiliferous. View taken west of Co. Pucara looking west.



PHOTOGRAPH 15: Recumbent syncline in quartzites, (Upper unit of the Lagunillas Gp.). View taken southwest of Hda. Queirani (Co. Sucanaya) looking northeast.

The structure of the Jurassic differs from structures mapped on younger rocks, because the folds are associated with thrusts, small tear faults and higher metamorphism.

Apparently the effect of the Upper Cretaceous folding in these early formed folds was mild. The author has observed in no place superimposition of structures on the flanks of the Jurassic flexures, which might indicate strong effects of later movements. However, the two major thrusts shown on Plate 1 may have been initiated in Jurassic time and reactivated in the Upper Cretaceous folding. Also over wide areas the Jurassic folds differ from the Cretaceous folding in the trend of the axial planes; southwest of Mañazo the trend of the Jurassic structures is roughly east-west. Southeast of Puno Upper Cretaceous folds strike northwestwards, northwest of Puno, almost due north. At the Peninsula de Capachica there is a syncline in the Cotacucho Formation with its axial plane striking northwest-southeast.

In central Chile, an orogenic movement in the Upper Jurassic time has not been established yet, but in Tarapacá Province (northern Chile) an angular unconformity separates Jurassic from Lower Cretaceous sedimentary rocks (Cecioni and García, 1960, p. 1616). In Atacama Province an angular unconformity separates marine sediments of Callovian age and rocks of Tithonian and Neocomian age (Harrington, 1961, p. 176). South of Nazca Rüegg (1956a), discovered Tithonian sediments lying unconformably over the Río Grande Formation of Dogger age.

It seems that, in the Puno-Santa Lucía area, the Late Jurassic Orogeny (Nevadian) took place at the end of Callovian time, as established by the ammonite fauna in the black shale unit. There was no intrusive phase The orogeny appears to have been followed by an epeirogenic uplift until the deposition of the Huancané Group, of probable Neocomian age.

Middle Cretaceous

Sliding of the Ayavacas Limestone

In the Puno-Santa Lucía area the Ayavacas Limestone is highly disturbed, it is thrust and folded. The disturbance on the Ayavacas Limestone is also observed north and south of the map-area. In these folds the limestone has moved differentially over the unit of red shale beneath it. One important fact is that the depth of the pile up folding is roughly equal to the sum of the stratigraphic thickness of the limestone. This was clearly observed at Río Chacalaya (see Photo 16).

Three kilometers north of Hda. Cayachira there is a doming up of the erosion surface above the Devonian rocks (see Photo 17). This is probably the cause of the piling up of the Ayavacas Limestone, by the effects of gravity, towards the southwest in what Harrison and Falcon (1936, p. 92) call cascade folds, like those exposed at the Cayachira River (see Photo 16). Gravity sliding is considered here as a nonorogenic process.

The following evidence, found during the field work, strongly supports the gliding tectonics idea:

1) The presence of an appropriate slope for the gliding recognized especially north of Hda. Cayachira.
2) The absence of cleavage in the inverted limb.
3) The chaotic structure of the limestone showing that the blocks have moved independently one from the other.
4) Cascade folding.
5) The preservation of unthinned limbs, and
6) The Ayavacas Limestone has clayey red beds above and below. The lithologic aspect is equally important.

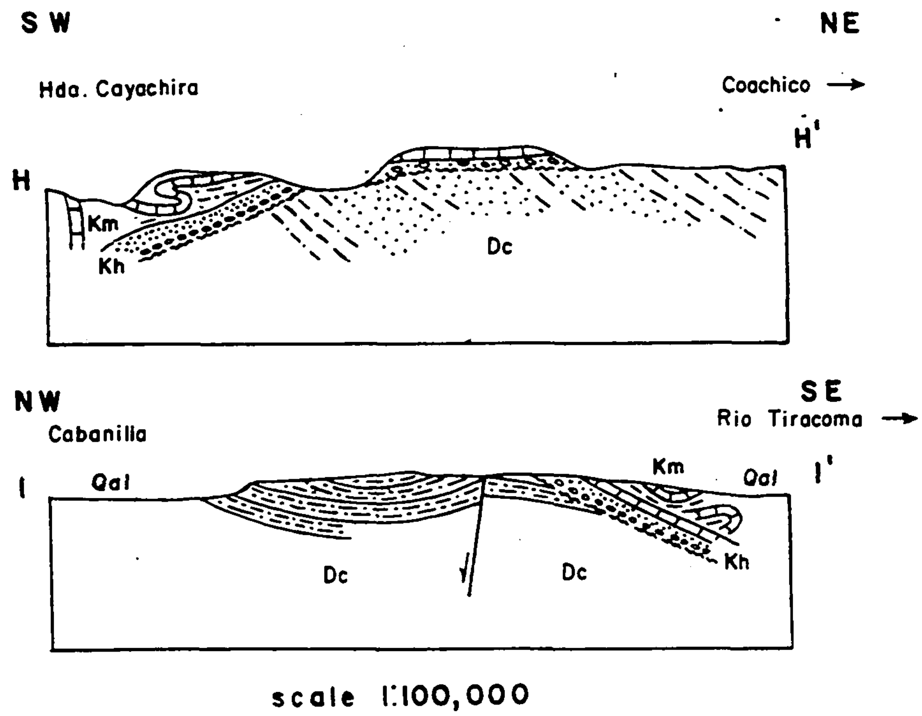


Figure 7. The upper section shows the erosion surface cutting Devonian rocks, domed up. The doming probably produced the gliding of the Ayavacas Limestone towards the southwest (Hda. Cayachira). The lower section shows the same limestone glided down towards the southeast of the same uplifted area. Also see Figure 8.

Dc, Cabanillas Group; Kh, Huancané Group; Km, Moho Group; Qal, Quaternary Alluvium.

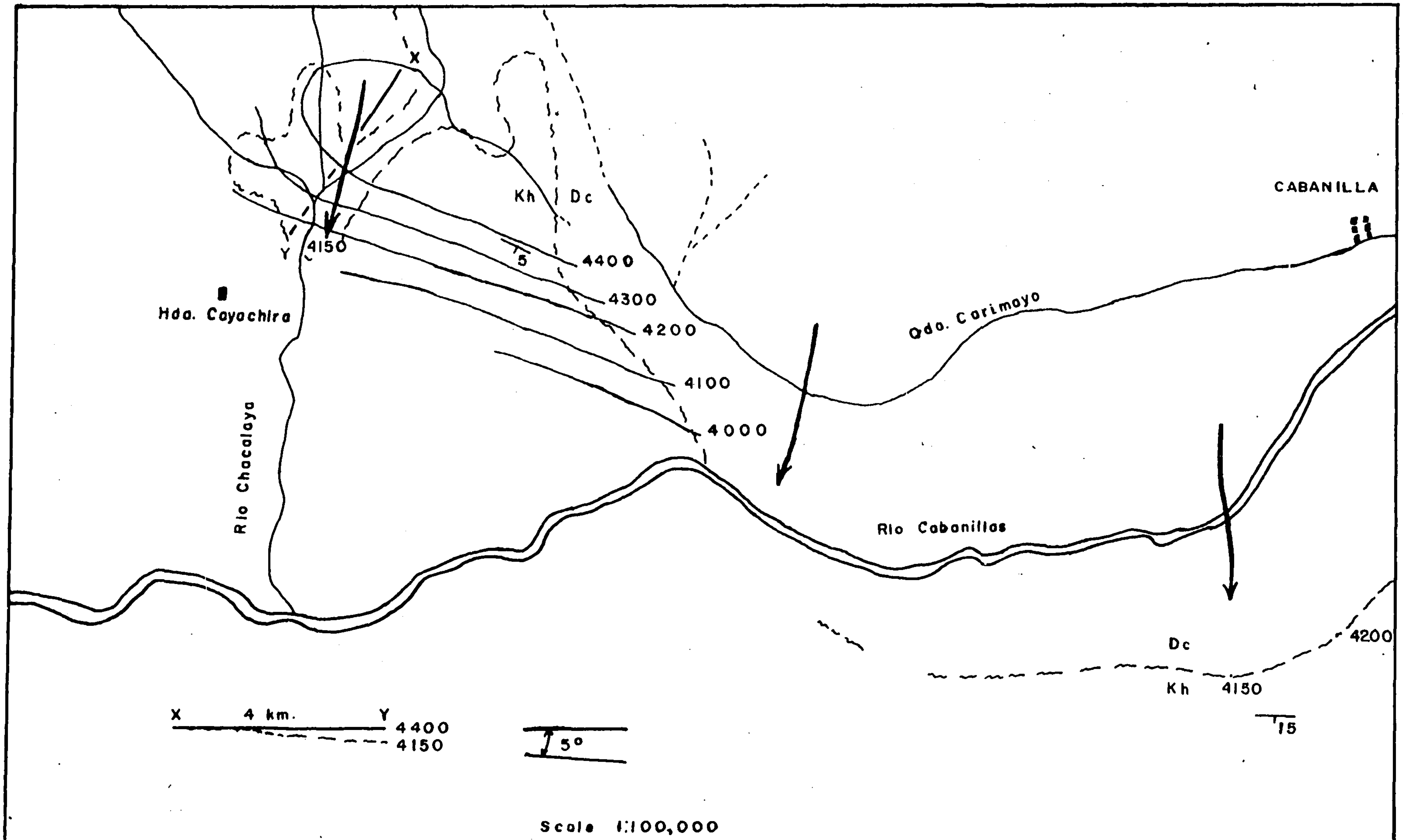
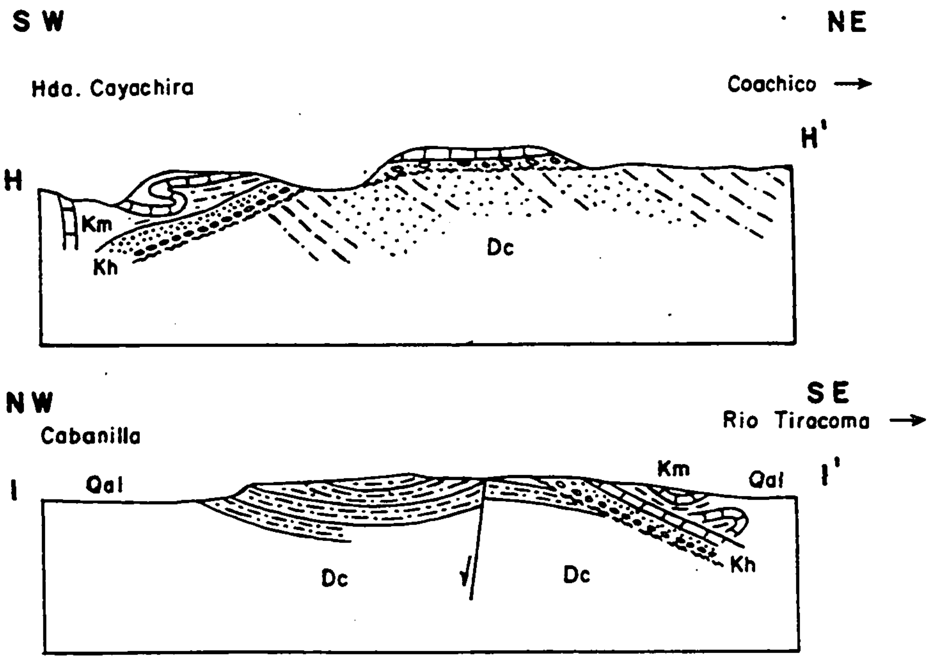


Figure 8. Map showing partial configuration of the epi-Devonian surface on which gravity sliding of the Moho Group is postulated. The arrows on the map show the apparent direction of sliding of the Ayavacas Limestone. The profile at the bottom indicates a drop of 250 meters in four km. in the elevation of the erosion surface.

Dc, Cabanillas Group; Kh, Huancané Group; —— 4200 ——, form lines on the erosion surface; — — —post-Devonian, pre-Huanca erosion surface.



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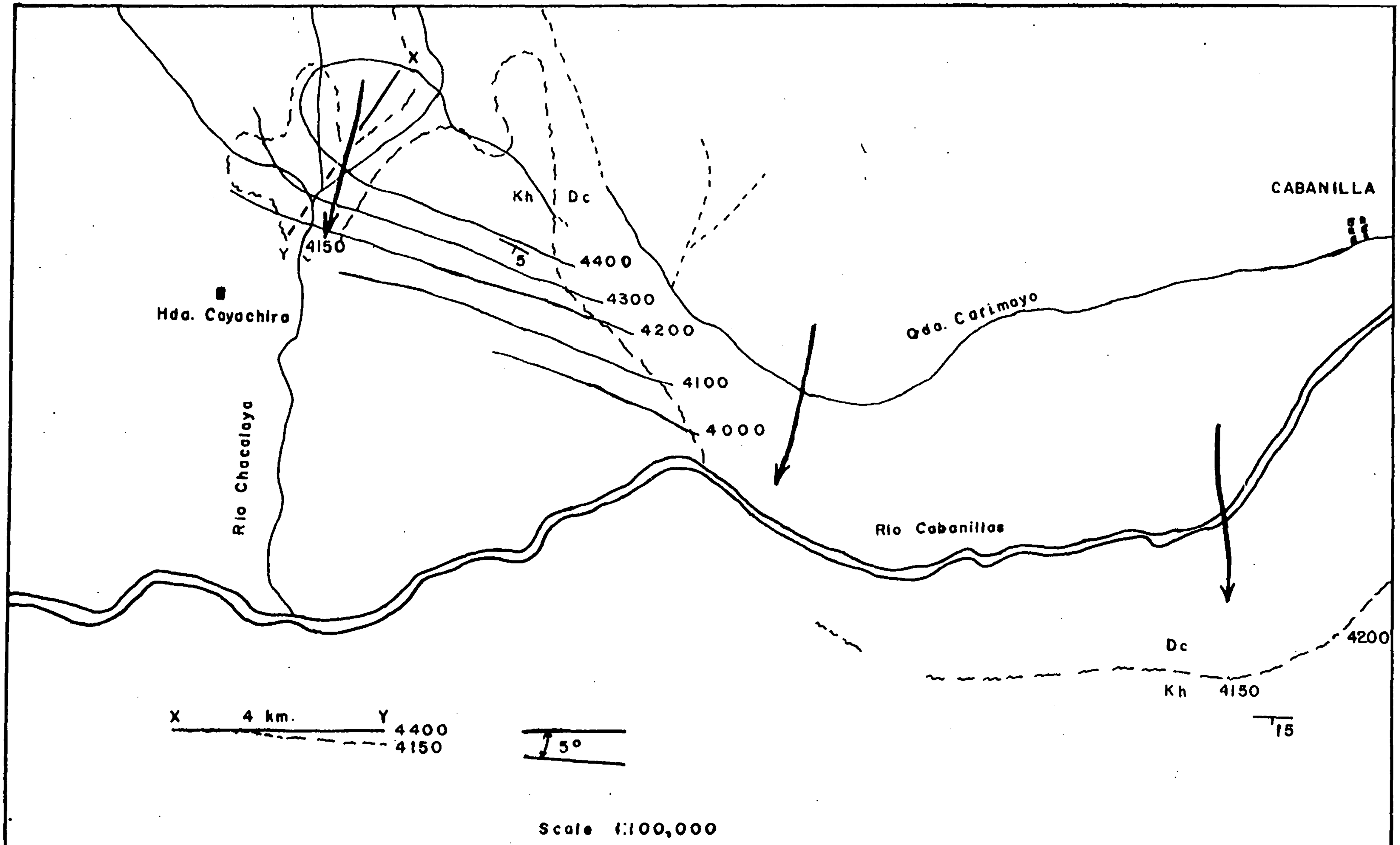

Figure 8. Map showing partial configuration of the epi-Devonian surface on which gravity sliding of the Moho Group is postulated. The arrows on the map show the apparent direction of sliding of the Ayavacas Limestone. The profile at the bottom indicates a drop of 250 meters in four km. in the elevation of the erosion surface.

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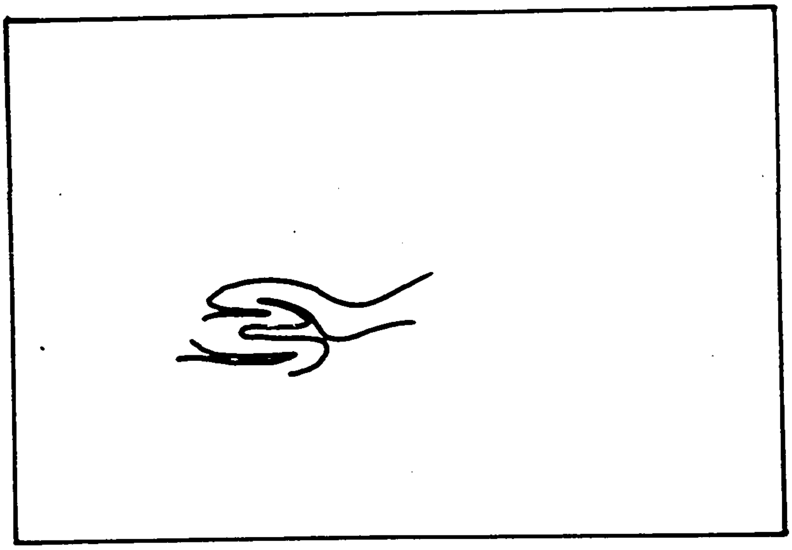
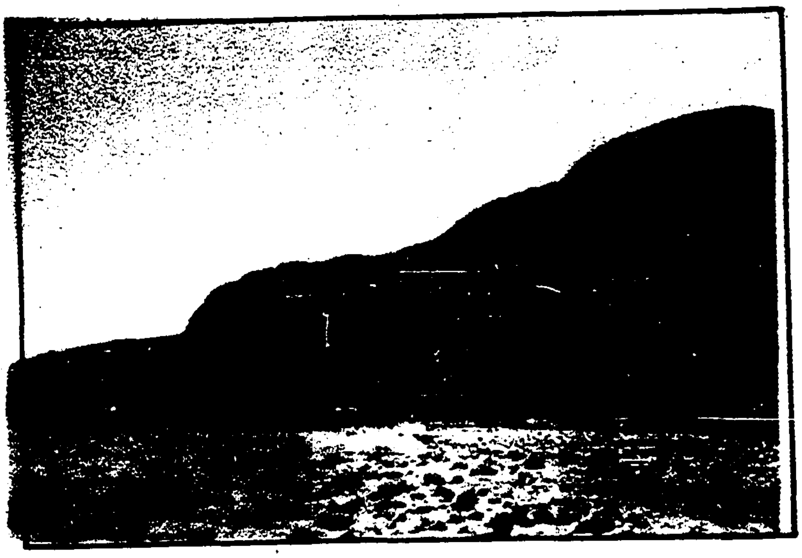


Overlay, Photograph 16

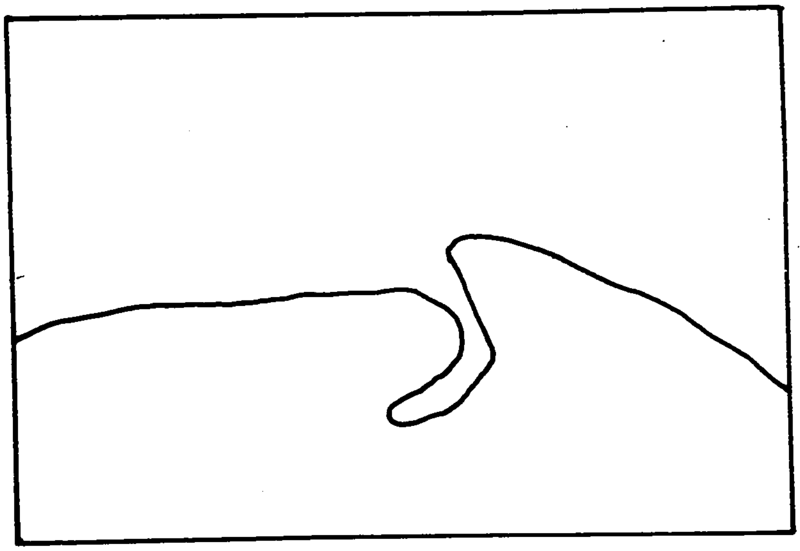
PHOTOGRAPH 16: Piling up of the Ayavacas Limestone, upper member of the Moho Group. The depth of the recumbent folding here is approximately equal to the sum of the stratigraphic thickness of the limestone. Note the lack of thinning of the inverted limbs. View taken at Rio Chacalaya looking west.



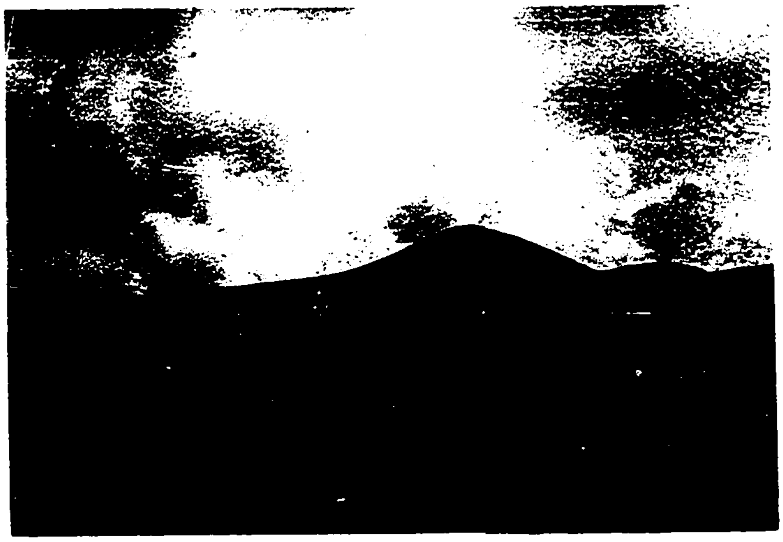
Overlay, Photograph 16

PHOTOGRAPH 16: Piling up of the Ayavacas Limestone, upper member of the Moho Group. The depth of the recumbent folding here is approximately equal to the sum of the stratigraphic thickness of the limestone. Note the lack of thinning of the inverted limbs. View taken at Rio Chacalaya looking west.

PHOTOGRAPH 17: Erosion surface, cutting Devonian rocks, domed up; creating a suitable slope for the gliding of the Ayavacas Limestone. View taken 3 km. north of the Cayachira Hda. looking northeast.



Overlay, Photograph 18



PHOTOGRAPH 18: Vertical and recumbent folds in Ayavacas Limestone. View northwestward from west of Hda. Cayachira.

Overlay, Photograph 18

PHOTOGRAPH 18: Vertical and recumbent folds in Ayavacas Limestone. View northwestward from west of Hda. Cayachira.

It must be understood that I am speaking of gravity sliding or gravitational tectogenesis of an uplifted area in which the sediments have slipped down-slope and became compressed, folded and overthrust in areas of lower level, with the assumption that the nonconsolidated limestones have yielded plastically. van Bemmelen (1955) generalizes gravity tectonics and considers it as a reaction to endogenetic causes; a primary tectogenesis (uplift) is followed by a secondary tectogenesis of gravitational character.

The form lines of Figure 8 show the local configuration of the epi-Devonian erosion surface on which the gravity sliding of the Ayavacas Limestone is postulated. The profile X-Y at the bottom of the same figure shows an approximate southwesterly drop of the surface of 250 meters in four kilometers, a slope of approximately 5°. Such a slope could initiate the sliding of the limestone, which here has a thickness of about 40 meters. This direction of movement is also determined from the direction of overturning of the folds in the excellent exposures at río Chacalaya (see Photo 16).

The sliding affecting the Ayavacas Limestone, on the west side of the Lago Titicaca, around Laguna Saracocha and elsewhere in the Puno-Santa Lucía area, took place at the end of the deposition of this limestone of Cenomanian age. The sliding movement has been a regional phenomenon, reaching the areas north and south of the Geological map. Newell (1949) describes the limestone highly folded and contorted southwest of Santa Rosa, 120 kilometers northwest of the map. Also south of Juli, approximately 80 kilometers south of Puno, he mentions the same type of disturbance in the limestone. The last locality was visited also by the writer.

The Cotacucho Formation of probable Upper Jurassic age, unconformably overlies the highly disturbed Ayavacas Limestone at Co. Katavirco, 7 kilometers due east of Juliaca and at Co. Ticalacaya west shore of Laguna Lagunillas (see Plate 4).

Upper Cretaceous Folding and Faulting

Folding

Folding after the deposition of the Muñani Formation in the Titicaca trough was relatively gentle. In the areas located south of Vilque, south and west of Mañazo, folding and thrusting appear to have been more intense than the folding in the Titicaca trough, possibly because complications were introduced by southern pressures along this belt. The greatest angular unconformity observed between these beds and the overlying Puno Group is about 35° at Co.

PHOTOGRAPH 19: An open syncline in the red sandstones of the Upper Cretaceous Muñani Fm. Photo taken at Co. Huinuyo, Peninsula de Chucuito, looking northwest.

Tacaraca, due west of Mañazo village.

The Upper Cretaceous formations have been deformed into broad folds. They are approximately symmetrical, with the axial plane inclinations close to vertical (see Photo 19).

The folding of the Huancané Group north of Puno and at Hda. Ilpa is very gentle and may have occurred at this time. The trend of the folding north of Puno is northeast-southwest. The folding at Hda. Ilpa follows a direction northwest-southeast.

Folds of lower magnitude were mapped south of Chucuito and at the southeast end of the Peninsula de Chucuito (limit of the map), in the Upper Cretaceous Muñani Formation (see Photo 19). These folds strike roughly northwest-southeast. Southeast of Capachica an open syncline has been mapped in the Cotacucho Formation, also striking northwest-southeast. No tear faults were observed in these folds.

Faulting

Two major thrusts have been mapped; the upper one bringing the Jurassic Lagunillas Group over the Cretaceous Moho Group; and a lower one bringing the Moho Group into contact with the Upper Cretaceous, Cotacucho and Vilquechico formations.

Both of them strike east-west and dip gently to the south. In places the thrusts seem to have an alternation of gently and steeply dipping planes which may indicate movement under light load. It is also difficult to determine to what extent such irregularities are due to later warping.

Towards the west and southwest these thrusts are covered by the volcanic rocks of the Puno Group; to the east they are cut off by a rhyolite intrusive.

The thrust planes are exposed south of Hda. Taracumilla. Here the fault plane dips 10° to 15° to the south and is marked by no more than 20 centimeters of gouge. In general the plane itself is inconspicuous but it can be followed along the north slope of Co. Santiago. Towards the west a granite porphyry separates the Moho Group from the Lagunillas Group and was evidently intruded along the thrust plane. The same thrust apparently crops out again in the southwestern part of Co. Niñachilla, to be covered again by volcanics of the Puno Group.

Newell (1949) mapped four regional overthrusts in the region of Lago Titicaca. He named the most westerly of these faults the Maravillas overthrusts; which he followed, with some interruptions, from Maravillas through Mañazo to to Acora, projecting it to Ilave; with a length of approximately 150 kilometers. Field evidence now shows that the structure mapped by Newell as an overthrust at Maravillas and north of Hda. Cayachira is an unconformity between the Middle Cretaceous and the Devonian Cabanillas Group. South of Mañazo the zone of thrusting described in the previous paragraphs occupies the position of Newell's Maravillas overthrust, but with two major thrusts and several minor ones. Evidences of the continuation of this zone of thrusting eastwards have not been observed.

Southwest of Vilque and near the overthrust, the sandstones of the Cotacucho Formation are vertical or dip steeply north. They resume a lower angle attitude a short distance from the fault.

The elongated shape and position of the rhyolite north and east of Hda. Queirani, suggest that it follows the plane of a fault, which may be related to the thrusts, because the thrusts and Jurassic rocks could not be traced eastwards. The rhyolite exhibits none of the shattering, which could characterize a pluton older than the faulting.

The folding and thrusting affecting the Upper Cretaceous and older sediments in this area and also the angular unconformity between the Upper Cretaceous and the Puno Group, of probable Tertiary age suggest that the disturbance took place at the end of the Cretaceous and might be correlative to the Peruvian folding of Steinmann (1929), which is expressed mainly in the Cordillera Occidental region of Peru.

Depression of small structural basins by normal faulting probably continued along the axis of the Cordillera Occidental, as indicated by the presence of the limestone and andesite conglomerate of the Saracocha Formation.

Tertiary Orogeny

The structural history of the Puno Group is shown by the intrusion of plutons of intermediate composition, tilting towards the southwest along the western range and the faulting in the Titicaca trough.

Two main orogenic movements have been distinguished in Tertiary time in this region, which might be correlative to Steinmann's Incaic and Quechuan foldings.

Steinmann (1929) distinguished three periods of folding in Peru. They are:

Quechuan Folding - Pliocene

Incaic Folding - Paleocene-Oligocene

Peruvian Folding - Upper Cretaceous

During the field work it was possible to distinguish these three periods of deformation in the Puno-Santa Lucía area.

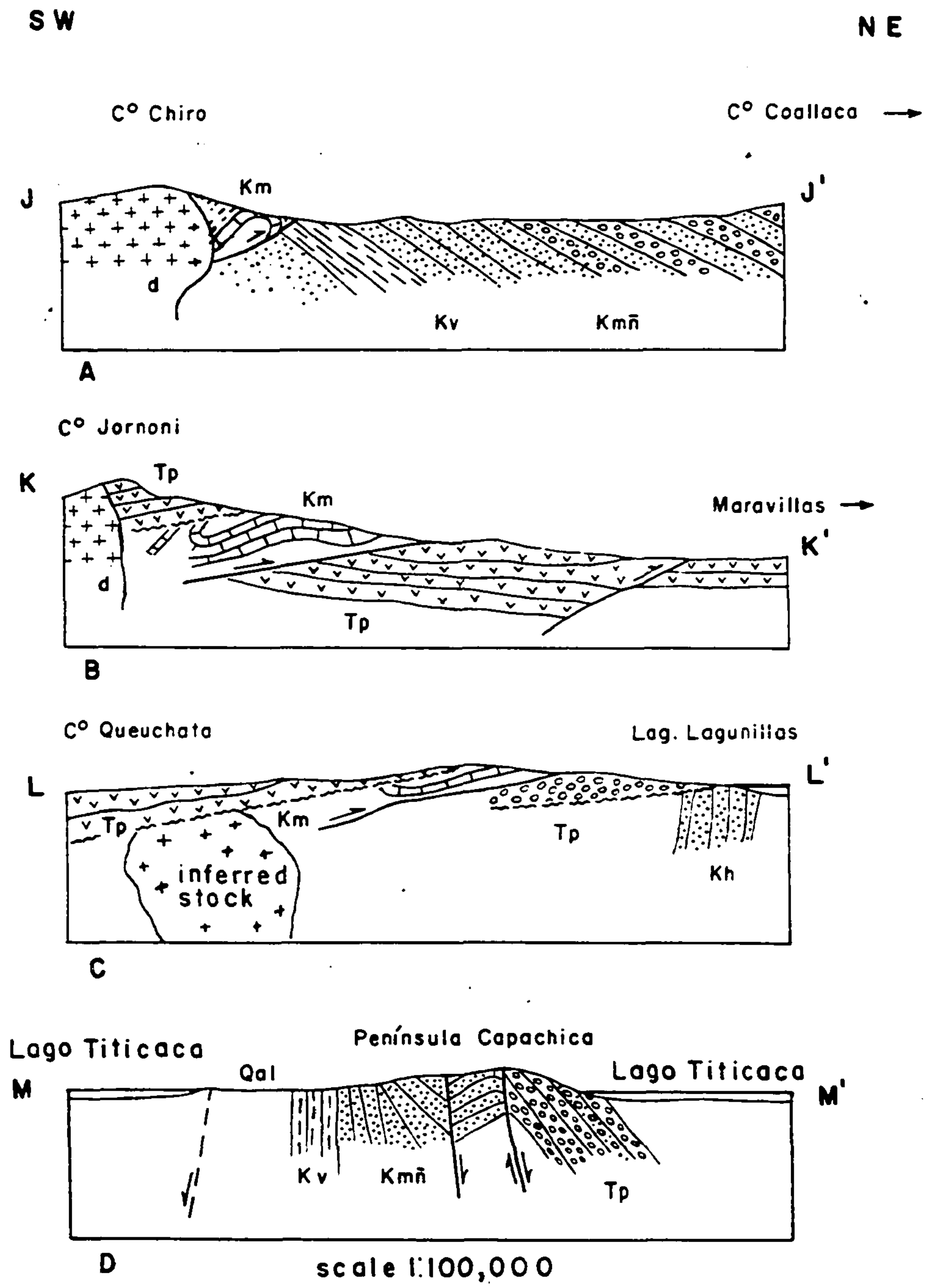


Figure 9. Sections showing structural relations of Ayavacas Limestone and Puno Group (sections A-C), and the horst of the Capachica Peninsula (section D). Section A and B show inferred diapiric structure as a result of the intrusion of the Co. Chiro and Co. Jornoni stocks. Section C shows the inferred origin of the faulted and contorted Ayavacas Limestone wedge within the Puno Group.

Kh, Huancané Group; Km, Moho Group; Kv, Vilquechico Formation; Kmñ, Muñani Formation; Tp, Puno Group; d, diorite; Qal, Alluvium.

At Co. Chiro and south of Hda. Larepata and also southwest of Laguna Lagunillas, large blocks of Ayavacas Limestone have been thrust over lava flows belonging to the Tertiary Puno Group. The same type of structure is observed south of Laguna Saracocha.

It seems that in all the places mentioned above, the intrusives of intermediate composition have acted diapirically on the Ayavacas Limestone, which by the effect of the intrusions was pressed out and glided over rocks of the Tacaza and older formations (see Photo 20). Probably the thrust planes became lubricated by the shales underlying the limestones. The result is a structure in which the Cenomanian Ayavacas Limestone in some places covers flows and conglomerates of the Tertiary Puno Group and in others is covered by younger lavas belonging to the upper Puno Group (see Figure 9). This intrusion and faulting is evidence of a third orogeny, which as stated before might be correlative with Steinmann's Incaic orogeny.

At the end of the Tertiary there was strong normal faulting in the central and northern portions of the map. Most of the faults are of very high angle between 70° and 90° and in some places, as in the Peninsula de Capachica, they appear to be high angle thrusts.

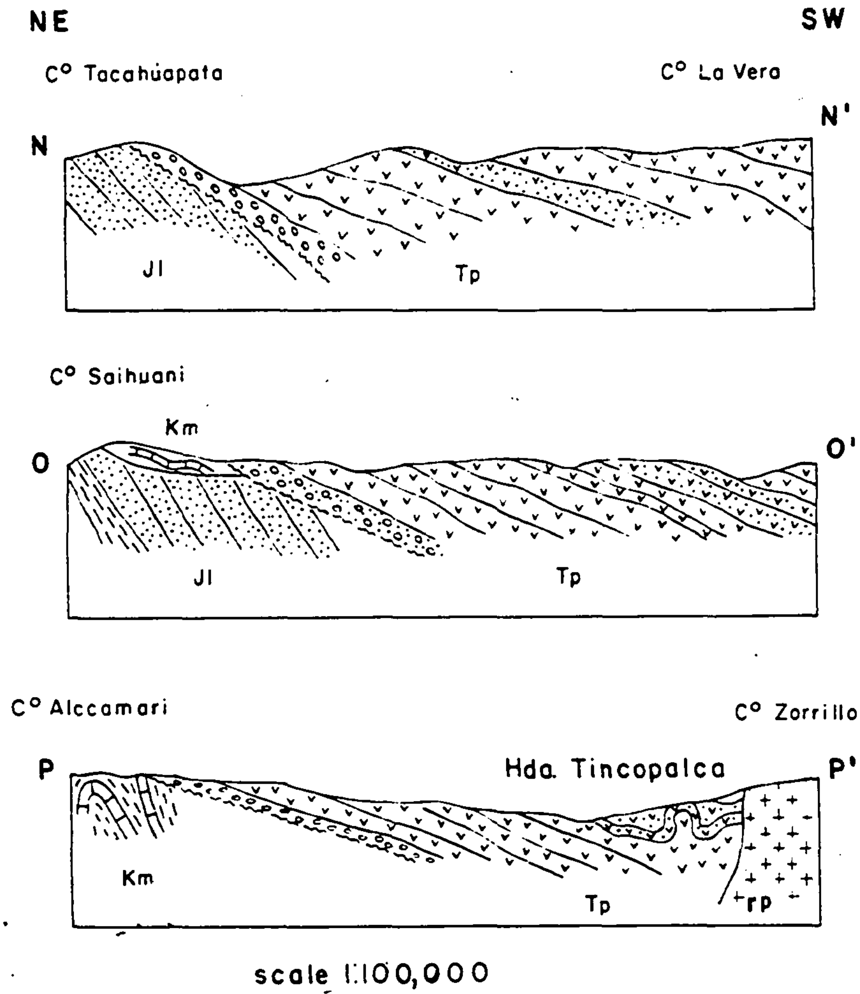


Figure 10. These sections show the Tertiary Puno Group tilted towards the south and southwest along the Pacific divide, forming a persistent homocline. The lower section in the right hand shows a rhyolite porphyry intruding the upper part of the Puno Group.

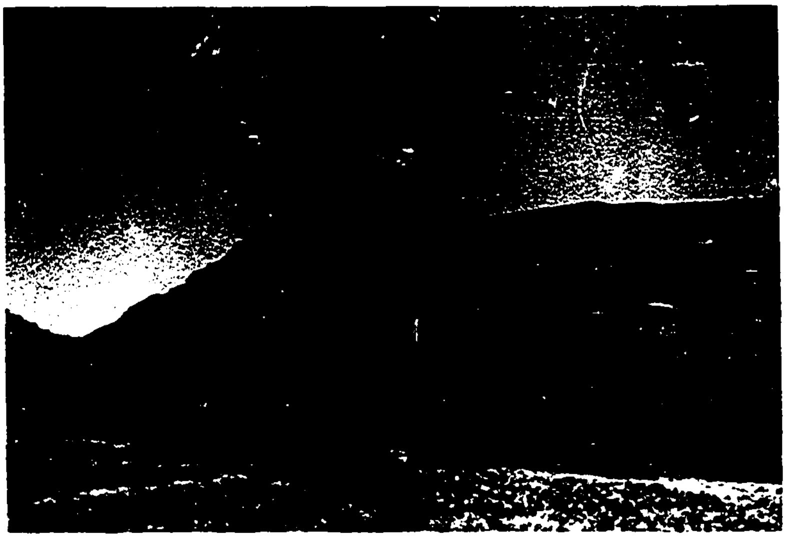
Jl, Lagunillas Group; Km, Moho Group; Tp, Puno Group; rp, rhyolite porphyry.

Only the major and more striking normal faults were mapped during the field work. One of these is a fault which brings the Muñani Formation into contact with the Puno Group, northeast of Co. Jornoni. It strikes roughly N. 50° E. and dips 80° northwest. Its southwestern end dies out in a diorite intrusive at Co. Chiro and its northeastern end in the Muñani Formation. Because of the absence of the Cotacucho and Vilquechico formations, a stratigraphic separation of 600 meters is suggested for this fault.

Two other major faults have been mapped at Hda. Añavili making a small graben. Both of them strike northeast and are almost vertical. The northern fault brings the Moho Group into contact with conglomerates and sandstones of the Puno Group; the southern fault puts these Tertiary red beds into contact with black shales of the Lagunillas Group (see Plate 2, cross-section AA').

Southwest of Tambillo a normal fault brings the Moho Group into contact with the Tacaza Formation.

In the northwestern part of the Peninsula de Capachica there is a great normal fault, bringing the Upper Cretaceous Muñani Formation into contact with the Cretaceous Moho Group, it strikes N 48° W. and dips 80° to 85° to the southwest; this fault goes further north off the map. On the



PHOTOGRAPH 20: Cerro Chiro stock and adjacent contorted Ayavacas Limestone. The structure of the limestone is inferred to have been produced by the diapiric injection of the granodiorite. Direction of photograph is northwest.

northeast shore of the Peninsula there is another great normal fault of very high angle, which puts the Puno Group into contact with the Muñani Formation.

At Co. Chullumpe southeast of the Peninsula de Chucuito a nearly vertical normal fault has been detected. This fault shows the scarp in the downthrown block, that is to say, the scarp is a fault line scarp. It brings the shales of the Vilquechico Formation and sandstones of the Cotacucho Formation into contact with shales of the Moho Group. The Capachica and Chucuito peninsulas are horsts.

The uplifting of the Cordillera Occidental produced the tilting of the Puno Group, along the Pacific divide (see map, Plate 1, and Figure 10). At Co. Pichocollo, Co. Chichillape, Co. Quechata, Co. Saihuani, Co. Acero, the Puno Group is uniformly tilted towards the south and southwest forming a homocline. Also all these peaks mark the divide between the waters running into the Pacific Ocean from the waters forming the Titicaca drainage.

One last orogenic movement has been called upon to explain the faulting and the rhyolite intrusions, which might be correlative to Steinmann's Quechuan orogeny of Pliocene age (Steinmann, 1929).

The Tertiary volcanics described by Harrison (1943) in central Peru are affected by thrusts. In the southern Andes of Peru, however, the Puno Group does not show evidence of compressional stresses, instead it is normal faulted, warped and tilted towards the southwest along and near the Pacific divide.

Structural Analysis

During the Jurassic time, as indicated earlier in this paper, the relatively narrow geosyncline receiving sediments had a northwesterly direction nearly parallel to the present Andean trend. In southern Peru maximum thickness of marine sediments, mostly clastics, are recorded to the southwest of the present continental divide (Jenks, 1946, 1948). To the southwest in the coastal zone, thick accumulations of volcanic rocks (Douglas, 1914) were essentially contemporaneous with these sediments.

The northeastern limit of marine Jurassic sediments passes in a northwesterly direction through the Puno-Santa Lucía map-area. Lack of pronounced stratigraphic variation of the Jurassic sequence of the area suggests that this "disappearance of the Jurassic" is due to erosion at some post-Jurassic period of disturbance.

Folding and thrust-faulting of the Jurassic Lagunillas Group in the Puno-Santa Lucía area, trends east-west. Folds are overturned toward the north and thrusts dip south. Metamorphism of the Jurassic shales is somewhat stronger than that of younger strata.

The east-west structural trend, local as it is, is anomalous for the Andean region as a whole. While it is not yet possible to indicate positive evidence for any one reason for the deviation from usual northwest trends in this part of the Andes, the following ideas may be advanced.

1) During Late Jurassic time the Devonian massif, now evident as a great dome at and to the north of Cabanillas, may already have become a positive element. Tectonic stresses generally directed northeast and southwest for the Andean region as a whole may here have been deflected around a swell in the Paleozoic basement.

2) The Puno-Santa Lucía area is just to the north of the sharp bend of the Andes and the coast from a northerly direction in Chile to a northwesterly direction in Peru. If this abrupt change in direction dated back as far as the close of the Jurassic, it may well have influenced the

direction of compressional stresses leading to the northerly thrusting and overturning of the Lagunillas Group.

The fact that Upper Cretaceous rocks from near Vilque, west past Mañazo also show east-west structures essentially parallel to those of the Jurassic rocks suggest that the same stress relations continued, in that area, at least as late as the close of the Cretaceous. Elsewhere northwesterly trends or northerly trends of principal folds prevail. Chaotic disturbance of Ayavacas Limestone and Moho red beds is not tectonically significant, being related to sliding and slumping of an unusually incompetent formation as slopes developed in Cretaceous time. Distribution of the volcanic rocks of the Tacaza Formation suggests that the eruptive centers were in the vicinity of the continental divide. Weaknesses may have developed, due either to shear or to tension, parallel to the divide, providing access to the surface for the volcanic materials.

Late Normal Faulting

The structural pattern of the Umayo Basalts is one due to the late history of the Puno-Santa Lucía region. Newell (1946; 1949, p. 81) pointed out the strong geomorphic effect of normal faulting on the configuration of the Titicaca

Basin. The Umayo Basalts have clearly been warped and displaced by faults, probably normal and vertical, in the vicinity of Vilque and Tiquillaca to the west of Puno and also in the vicinity of Puno.

By reference to the geologic map, Plate 1, it may be seen that the Umayo Basalts east of Tiquillaca, dip westward and, just to the west of the village, disappear below a cover of alluvial gravels. To the west (southeast of Vilque) the same flows are exposed once again, essentially horizontal, above the remarkably plane surface truncating Late Cretaceous tilted strata, and some 200 meters above the Quaternary gravel plain. Clearly there must be a fault below the alluvium.

The structural pattern shown by the Umayo Basalts is characteristic of epeirogenic movements.

Fault scarps produced during this late period of normal faulting remain in fairly well preserved condition southeast of Vilque and at the Peninsula de Capachica.

All these faults are recognized by their scarps as the result of vertical displacements. The maximum visible vertical displacement is about 300 meters.

As indicated by Newell (1949) most of the Quaternary alluvial depressions, and the depression occupied by the

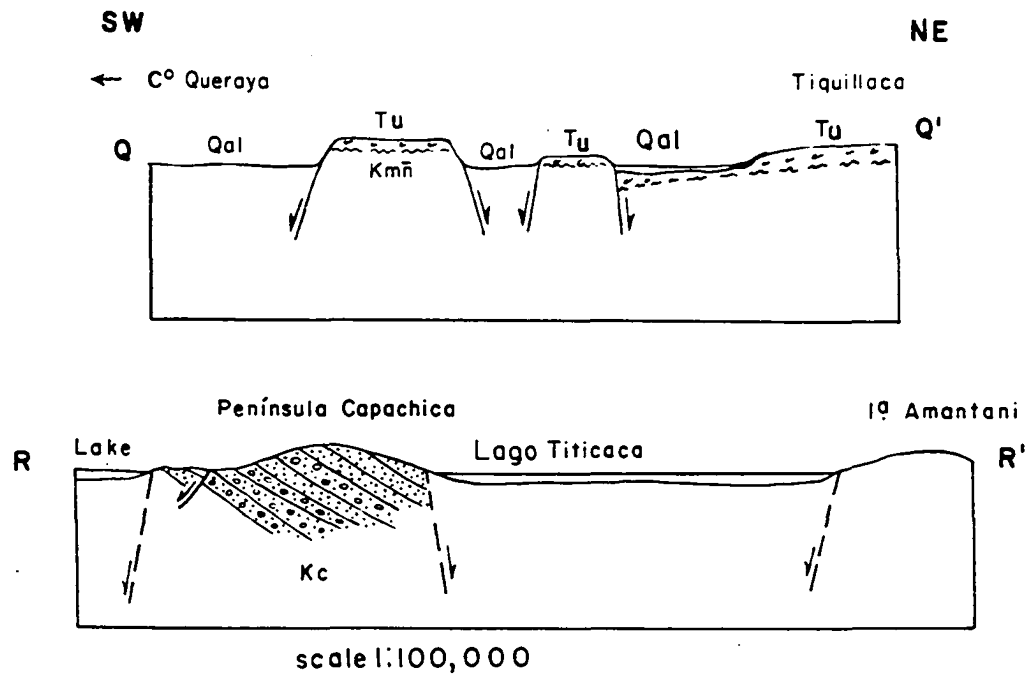


Figure 11. These sections show late normal faulting, after the deposition of the Umayo Basalts. This normal faulting formed structural basins, one of which is occupied by Lago Titicaca (lower section).

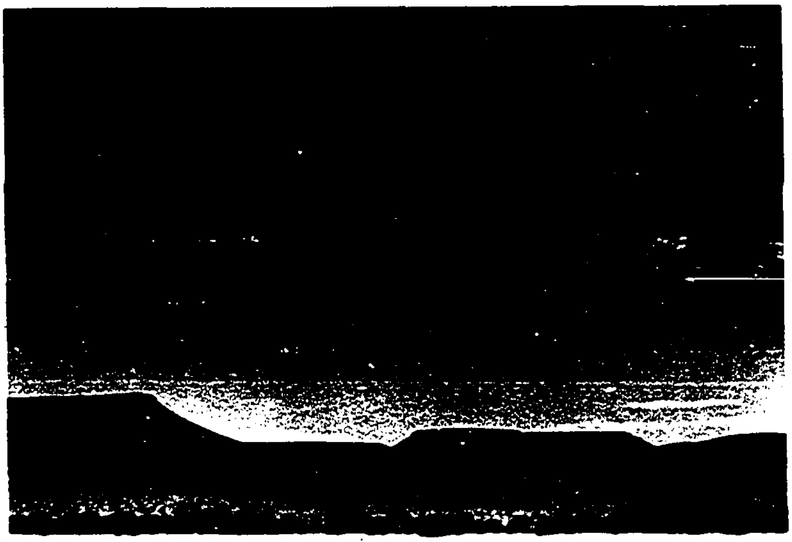
Kc, Cotacucho Formation; Kmñ, Muñani Formation; Tu, Umayo Basalts; Qal, Quaternary Alluvium.

Lago Titicaca are bounded on either one or both sides by a normal fault (see Figure 11). The present relief within the Titicaca region was caused in part by this late normal faulting.

Because many of the faults are concealed by the gravel and valley filling accumulated in these small Quaternary basins, it has frequently been necessary to call upon physiographic evidences to determine the presence of a fault. Most of the normal faults are vertical or nearly so, the scarps are linear and straight, with the exception of the southwestern side of the Capachica Peninsula where some irregular fault planes are exposed.

Stratigraphic evidence of this late normal faulting is difficult to recognize, because alluvium and valley filling conceals the downthrown block.

The time during which this normal faulting occurred is difficult to establish, because of the lack of age information on Tertiary and Quaternary formations within the Titicaca Basin. Probably it was intermittent and the movement completed in the Pleistocene time. No evidence of Recent movements was found.



PHOTOGRAPH 21: The "Puna" erosion surface leveling the upturned sequence of the Tacaza Fm., and preserved by flows of the Umayo Basalts. Photo taken south of Hda. Malcuamayo, looking south.

PUNA EROSION SURFACE

An erosion surface that levels the upturned volcanic sequence of the Tacaza Formation, and which has been preserved below the Umayo Basalts in the Puno, Tiquillaca and Vilque region has been observed by the author during the field work (see Photo 21).

At Hda. Prado east of Santa Lucía there is a surface which truncates tilted beds of the Tacaza Formation at an altitude of 4327 meters.

Southwest of Puno, at Hda. San Miguel, this surface levels flows and nonwelded tuffs of the Tacaza Formation, it is a little above 4000 meters.

This erosion surface is tentatively correlated with the surface that Walker (1949, p. 651) described along the divide between the Amazon and the Altiplano basins (Bolivia), which he considered equivalent to the Puna surface of McLaughlin (1924) near Cerro de Pasco and also to the mature erosion surface that Bowman (1916) described on the border between Bolivia and Chile. Puna is the Quetchua word for the high and cool uplands of the Andes. Walker (1949, p. 659) assigned a Pliocene age for the Puna surface.

Newell (1949, p. 13) considers this surface to be a peneplain elevated from near sea level to its present altitude.

CHAPTER VI

GEOLOGIC HISTORY

Devonian rocks are the oldest sediments thus far recognized in the Titicaca Basin. A marine transgression deposited a thick sequence of shales and sandstones bearing brachiopods, conularids and trilobites of Early to Middle Devonian age. The structural history of the Devonian and in general of the Paleozoic still remains obscure, since the scattered Paleozoic outcrops have not been studied in detail. Permian and Devonian rocks are nearly parallel throughout southern Peru (Newell, 1949). Ahlfeld (1960) mentions a disconformity between the Devonian and Upper Paleozoic in Bolivia. Pennsylvanian rocks have been described at Muñani about 50 kilometers north of Lago Titicaca by Newell et. al., (1953, p. 14).

Triassic rocks are not known in this area or in northern Bolivia.

The Lower Jurassic Chocolate Formation of the Arequipa region (Jenks, 1948) has not been identified in the Puno-Santa Lucía area.

Marine sedimentation was continuous from Sinemurian to Callovian time, depositing bituminous limestone and black shales bearing ammonites. The volcanic facies in Callovian strata described on the coast of northern Chile (Douglas, 1914) and by Ruegg in Nazca (1956a), has not been recognized in the Lagunillas Group in the area studied in this report. Folding marked the end of the Jurassic; this orogeny is related to the Nevadian orogeny of western North America. The structures made up of Jurassic rocks are evidently the product of an independent stage of crustal deformation, with low plunge folds. Their axial planes are parallel to a weak slaty cleavage in black shales and limestones. No igneous intrusions of this age have been recognized.

A new marine transgression deposited conglomerates, limestones, shales and sandstone of the Huancané and Moho groups, on a surface of moderate relief. The age of this new incursion of the seas is uncertain. Cenomanian fossils have been found in the Ayavacas Limestone uppermost unit of this sequence. A Neocomian age for this transgression at the present time is suggested by the writer. By the end of Cenomanian time an uplifting and warping occurred in this region producing the sliding of the Ayavacas Limestone by the effects of the gravity. This sliding is considered here as a nonorogenic process.

During the Upper Cretaceous local volcanic outbreaks of trachytic composition took place within the Titicaca region. The Andean ranges started to individualize and the seas were excluded from this region forever. A thick sequence of red sandstones, shales and conglomerates (Cotacucho, Vilquechico and Muñani formations) was deposited in an internal basin bounded by uplifted areas which are now the Cordilleras Occidental and Oriental. The Late Cretaceous orogeny was definitely expressed in this basin producing broad and more open folds in the Cotacucho, Vilquechico and Muñani formations. The disturbance was especially strong along the southwest portion of the area where two major thrusts have been mapped. These structures which may have been initiated during the Jurassic were probably reactivated during this Late Cretaceous orogeny. This folding is related to Steinmann's Peruvian folding.

The Tertiary began with tectonic depressions along the axis of today's Cordillera Occidental, which explains the presence of the limestone and andesite conglomerates of the Saracocha Formation. It was followed by a large scale volcanism, originating from planes of shear fractures striking northwest and outlining the present Cordillera Occidental. The volcanic sequence thins towards the east and the thickest sections are along the western range. This volcanic process, intermittent but cumulative, took place during the Tertiary. Small stocks intrude the lower part of the Tacaza Formation.

It has been inferred by the writer, that the stocks acting diapirically on the Ayavacas Limestone and enclosing red beds forced the incompetent formation out, so that it glided over flows of the Tacaza Formation. This intrusion and thrusting are evidence of a third major orogeny. Plutons were relatively late in the tectonic sequence. There is not enough available information for warranting the exact dating of this orogeny which correlates with Steinmann's Incaic folding.

The end of the Tertiary time is marked by faulting, mylonitization and local crushed zones in the volcanics and plutonic rocks, this movement is related to the third orogeny of Steinmann (1929), the Quechuan folding, for which a probable Early Pliocene age is postulated. The rhyolite bodies mapped in this area may also be related to the Quechuan orogeny. The final structural history of the Puno Group is shown by the tilting, and warping of this sequence towards the southwest along the western range, and normal faulting within the Titicaca area, and development of the "Puna" erosion surface.

The deposition of the basaltic flows of the Sillapaca Formation on the fairly level Puna surface, probably took place in Pliocene-Pleistocene time. The area was subjected to an uplifting of epeirogenic nature, producing strong normal faulting affecting the Sillapaca Formation. This faulting produced tectonic depressions, one of which is occupied by Lago Titicaca.

In Late Pleistocene to Recent time, a widespread glaciation covered parts of this area. Along the Cabanillas River there are two well defined terraces which might be ascribed to variation in climatic conditions. Recent running waters are cutting these terraces and some other alluvium deposits.

APPENDIX I

Measured sections of the Huancané Group in the Puno-Santa Lucía area. The sections are shown graphically on the fence diagram of Plate 3.

Partial section of the Huancané Group at Co. Cruzocollo, Peninsula de Chucuito.

Unit		Meters
	Moho Group Sandstone, brick-red	
	Huancané Group	
4	Sandstone, reddish-white, medium to very coarse-grained, rounded, x-bedded, with minor beds of vein quartz pebble conglomerate	70
3	Conglomerate, white, rounded vein quartz and quartzite pebbles	1
2	Sandstone, white, rounded, sugary, friable, interbedded with thin and lenticular conglomerates, made up of quartz and quartzite pebbles, x-bedded, iron oxide-spotted	80
1	Sandstone, reddish-white, fine to coarse-grained, grains are rounded and frosted, x-bedded, lower part is clayey	50
	Base not seen (faulted)	
	Partial measurement	201

Partial measurement of the Huancané Group at Co. Chuncallama, north of Puno.

Unit		Meters
	Moho Group Sandstone, reddish-brown	
	Huancané Group	
6	Sandstone, red, medium-grained, sub-rounded, interbedded with very thin red siltstone at the top, thin-bedded	15
5	Conglomerate, reddish-white, sub-rounded to rounded, pebbles up to 1 cm. diameter, x-bedded in places, thick-bedded; interbedded with sandstone, medium to coarse-grained, sugary	41
4	Orthoquartzite, white, sugary, medium-grained, grains well rounded and frosted, conglomeratic, thin-bedded, cross-laminations in some beds	125
3	Shale, brownish-red, silty, some quartz grains	8
2	Sandstone, brownish-white, sugary in texture, iron spotted with bands of white pebbles of vein quartz	50
1	Shale, red	6
	Base not seen (covered)	
	Partial measurement	245

Section of the Huancané Group at Co. Infiernillo, southwest of Cabana.

Unit		Meters
	Moho Group Limestone, brownish-gray, sandy, silty, thin-bedded	
	Huancané Group	
6	Sandstone, reddish-white, medium to very coarse-grained, rounded and frosted grains of quartz, conglomeratic in places, x-bedded, beds from a few cm. up to 30 cm. thick	65
5	Conglomerate, white to buff, rounded and frosted quartz and quartzite pebbles up to 2 cm. diameter, cross-bedded; interbedded with sandstone, white, sugary, medium-grained, thin-bedded, x-laminated	40
4	Sandstone, reddish-white, sugary in texture, medium to very coarse-grained, frosted; interbedded with irregular bands of white pebbles of quartz up to 1 cm. diameter, x-bedded	25
3	Sandstone, reddish-brown, coarse, rounded and some frosted quartz grains, massive	10
2	Limestone, reddish-brown, to brownish-gray color, well bedded, beds up to 20 cm. thick, interbedded with a few thin conglomerate beds	55
1	Conglomerate, yellowish-gray, sub-angular, thick bedded, made up of quartzite 80%; sandstone 10%; siltstone 8%; granite 2%	15
	Total	210
	Unconformity Devonian quartzites	

Section of the Huancané Group at Co. Chicurmaco, northeast of Maravillas.

Unit		Meters
	Moho Group Sandstone, reddish-white, feldspathic	
	Huancané Group	
5	Sandstone, yellowish-white, medium to very coarse-grained, sub-rounded to rounded, conglomeratic in places, thin-bedded, cross-laminated, silica cement	46
4	Conglomerate, white to buff, quartz pebbles up to 1 cm. diameter; interbedded with sandstone, sugary, thin-bedded	33
3	Orthoquartzite, white, medium-grained, iron spotted, sugary, rounded and frosted quartz grains, x-bedded scattered pebbles of quartz, thin-bedded	44
2	Sandstone, brownish-gray, clayey, feldspathic	1
1	Conglomerate, reddish-gray, sub-angular, made up of quartzite and shale fragments up to 10 cm. diameter, sandy and clayey matrix	1
	Total	125

Unconformity
Devonian quartzites

APPENDIX II

Measure sections of the Cotacucho Formation in the Puno-Santa Lucía area. The sections are shown graphically on the fence-diagram of Plate 4.

Partial measurement of the Cotacucho Formation at the Peninsula de Capachica, east of Capachica village.

Unit		Meters
	Vilquechico Formation Shale, brick-red, fissile	
	Cotacucho Formation	
5	Sandstone, brownish-white, medium to coarse-grained, sub-rounded to rounded and frosted quartz grains, conglomeratic, a few mica flakes, feldspathic, beds up to 1.20 m. thick	300
4	Sandstone, brick-red, fine-grained and thin-bedded, highly feldspathic	40
3	Sandstone, light-gray, medium to very coarse-grained, tuffaceous; interbedded with conglomerates, brownish-gray, made up of quartz, quartzite and sandstone, beds up to 50 cm. thick	150
2	Sandstone, grayish-buff, medium-grained, massive; x-bedded, feldspathic, iron stained	50

Unit		Meters
1	Sandstone, brownish-white, sub-rounded to rounded, arkosic, silty, iron-stained, a few mica flakes, friable, beds from a few mm. up to 1.50 m. thick, x-bedded; interbedded with some lenticular conglomerates	200
	Partial measurement	740

Lower contact faulted

Partial measurement of the Cotacucho Formation on east slope of Co. Chullumpe (Peninsula de Chucuito).

Unit		Meters
	Vilquechico Formation	
	Shale, brick-red	
	Cotacucho Formation	
1	Sandstone, reddish-white to reddish-brown, fine to coarse-grained, angular to rounded, some frosted quartz grains coated with iron oxide, feldspathic, conglomeratic; x-bedded, beds up to 50 cm. thick; interbedded with siltstone, brick-red, thin-bedded	260

Lower contact faulted

Partial measurement of the Cotacucho Formation at Co. Queraya.

Unit		Meters
	Vilquechico Formation	
	Shale, brownish-red	
	Cotacucho Formation	
5	Sandstone, purple to brownish-red, fine to medium-grained, sub-angular to sub-rounded, iron-stained, some beds are tuffaceous, feldspathic; beds up to 1 m.thick	55

Unit		Meters
4	Shale, brick-red, flaggy, thin-bedded; interbedded with some fine-grained sandstone	35
3	Sandstone, brownish-gray, medium to coarse-grained, iron-stained, some frosted quartz grains, feldspathic, beds up to 80 cm. thick	285
2	Shale, brownish-red, silty; interbedded with sandstone, cross-bedded, rounded and frosted quartz grains, friable	55
1	Sandstone, brownish-gray, medium to coarse-grained, feldspathic, thin-bedded	180
	Partial measurement	610

Lower contact faulted

Partial measurement of the Cotacucho Formation at Co. Ticalacaya, 2 kilometers northwest of Laguna Lagunillas.

Unit		Meters
	Vilquechico Formation Shale, brick-red, silty	
	Cotacucho Formation	
6	Sandstone, reddish-gray, sub-angular to rounded, tuffaceous, feldspathic; interbedded with red siltstone, thin-bedded	48
5	Sandstone, light-gray to brownish-gray, sub-angular to rounded, some frosted quartz grains, feldspathic, tuffaceous, beds up to 60 cm. thick; interbedded with some thin lenticular conglomerates	50

Unit		Meters
4	Conglomerate, purple-gray, rounded, massive, feldspathic sandy matrix; andesite, basalt, diorite, granodiorite, and sandstone fragments; interbedded with sandstone, medium to coarse-grained, reddish-gray, highly feldspathic, tuffaceous, x-bedded	180
3	Sandstone, brick-red, angular to rounded, feldspathic, tuffaceous, some frosted quartz grains coated with iron oxide, thin-bedded, x-laminated	120
2	Shale, brick-red, sandy, thin-bedded	2
1	Conglomerate, reddish-gray, massive, hard, x-bedded in places; made up of quartzite, quartz diorite, quartz monzonite, trachyte, trachyandesite, and limestone fragments; interbedded with a thin lenticular sandstone, brownish-red, feldspathic. Towards the top the conglomerate becomes finer and the amount of sandstone increases	540
	Total	940

Unconformity

Moho Group

APPENDIX III

Measured sections of the Muñani Formation in the Puno-Santa Lucía area. The sections are shown graphically on the fence-diagram of Plate 4.

Partial measurement of the Muñani Formation at the Peninsula de Ccotos.

Unit		Meters
	Covered	
	Muñani Formation	
8	Sandstone, brownish-red, medium to coarse-grained, sub-angular, highly tuffaceous, beds from a few cm. up to 1.20 m.	30
7	Conglomerate, greenish-gray, sub-angular to sub-rounded, made up of sandstone, quartz, chert, quartzites and a few andesite fragments, sandy matrix; interbedded with sandstone, reddish-brown, thin-bedded	40
6	Arkose, dark-brownish-red, very fine to very coarse-grained, calcareous, beds from a few cm. up to 10 cm.; with a few thin-beds of conglomerate	45
5	Sandstone, reddish-brown, medium to coarse-grained, conglomeratic in places, angular to sub-angular, tuffaceous, feldspathic, iron-stained, with a few beds of conglomerates made up of sandstone, quartz, quartzite and andesites, thin-bedded	35

Unit		Meters
4	Conglomerate, brownish-gray, sub-rounded, made up of sandstone, chert, quartzite and andesite fragments up to 10 cm. diameter; beds from a few cm. up to 1 m. thick; interbedded with sandstone, brick-red, tuffaceous	50
3	Arkose, brownish-red, fine to coarse-grained, angular to sub-angular, tuffaceous, some rounded and frosted quartz grains; with a few conglomerate beds	65
2	Conglomerate, brownish-gray, sub-rounded, made up of andesite, limestone, sandstone and quartzite, thick-bedded; with some sandstone, reddish-brown, feldspathic, highly tuffaceous	85
1	Sandstone, brownish-red, fine to coarse-grained, angular to sub-angular, silty, feldspathic, some rounded and frosted quartz grains, a few ferromagnesic minerals, beds from a few cm. up to 2 m., hard lithification, ridge forming	195
	Partial measurement	545

Vilquechico Formation
Shale, brick-red

Partial measurement of the Muñani Formation at Co. Chullumpe, Peninsula de Chucuito.

Unit | Meters

Covered

Muñani Formation

Unit		Meters
2	Conglomerate, reddish-gray, sub-rounded, made up of limestone, sandstone, monzonite, diorite and trachyte cobbles up to 12 cm. diameter, the amount of its components varies vertically and horizontally; with numerous beds of arkosic sandstone, greenish-gray, tuffaceous, fine to very coarse-grained, thick-bedded	500
1	Sandstone, brick-red, fine to very coarse-grained, conglomeratic in places, sub-angular to sub-rounded, some rounded and frosted quartz grains, feldspathic, tuffaceous, x-bedded, beds up to 1 m. thick; with minor beds of conglomerate	1125
	Partial measurement	1625

Vilquechico Formation
Shale, brick-red

Partial measurement of the Muñani Formation at Co. Queraya, southwest of Vilque.

Unit		Meters
	Covered	
	Muñani Formation	
6	Conglomerate, purple-gray, sub-angular to sub-rounded, made up of limestone 80%, quartzite, andesites and shale in minor amounts, cobbles up to 10 cm. diameter, sandy and tuffaceous matrix; beds up to 50 cm. thick; with numerous beds of sandstone, brownish-gray, feldspathic, tuffaceous, thin-bedded	200

Unit		Meters
5	Sandstone, reddish-brown, very coarse-grained, sub-angular, iron-stained, thin-bedded, feldspathic, tuffaceous; with minor beds of conglomerate, lilac-gray, made up of limestone, quartzite, granite, andesite, sandstone and shale fragments, thin-bedded	125
4	Conglomerate, light-gray, massive, hard lithification, ridge-forming, same composition as unit 6, with minor beds of brownish-red sandstone	130
3	Arkose, reddish-brown, medium to very coarse-grained, sub-angular, iron-stained, tuffaceous; with numerous beds of conglomerate, thin-bedded	55
2	Siltstone, brick-red, feldspathic, interbedded with sandstone, brownish-red, fine to medium-grained; and with minor beds of shale, brick-red	150
1	Sandstone, brick-red, fine-grained, conglomeratic, arkosic, x-bedded, iron-stained, beds up to 20 cm, thick	160
	Partial measurement	830

Vilquechico Formation
Shale, brick-red

Partial measurement of the Muñani Formation at Co. Yaurichampe, south of Jornoni mine.

Unit		Meters
	Covered	
	Muñani Formation	

Unit		Meters
5	Sandstone, reddish-white, medium to very coarse-grained, angular to sub-rounded, feldspathic, tuffaceous; with minor beds of conglomerate	200
4	Sandstone, light-gray to brownish-gray, medium to very coarse-grained, angular to sub-rounded, feldspathic, tuffaceous; with numerous beds of conglomerate made up of trachyte, andesite, basalt, limestone, sandstone and syenite-diorite fragments, sandy matrix	400
3	Conglomerate, dark-gray, sub-angular to sub-rounded; boulders up to 30 cm. diameter. Its composition is as follows: Limestone, basalt-trachyte, syenite-diorite and sandstone fragments; with numerous beds of sandstone, reddish-gray, medium to very coarse-grained, angular to sub-rounded, conglomeratic, tuffaceous, highly feldspathic	1200
2	Sandstone, brick-red, fine to coarse-grained, sub-angular, some rounded and frosted quartz grains coated with iron oxide, feldspathic, beds from a few cm. up to 1 m. thick	380
1	Orthoquartzite, yellowish-gray, fine to medium-grained, rounded, iron spots, thin-bedded	120
	Partial measurement	2300

Vilquechico Formation
Shale, brick-red

Partial measurement of the Muñani Formation at Co. Ticalacaya, northwest of Laguna Lagunillas.

Unit		Meters
	Puno Group	
	Andesite Flows	
	Unconformity	
	Muñani Formation	
3	Sandstone, reddish-brown, fine to very coarse-grained, angular to sub-rounded, some rounded and frosted quartz grains, iron-stained, arkosic, tuffaceous; beds up to 15 cm. thick; with minor beds of conglomerate	320
2	Conglomerate, reddish-gray, sub-rounded, tuffaceous matrix, made up of andesite, basalt, limestone and sandstone; with numerous beds of light-brown sandstone	170
1	Sandstone, reddish-brown, same as unit 3, highly tuffaceous	230
	Partial measurement	720
	Vilquechico Formation	
	Shale, brick-red	

APPENDIX IV

Measured sections of the Puno Group in the Puno-Santa Lucía area. The sections are shown graphically on the fence-diagram of Plate 5.

Section of the Puno Group at Co. Putina, 6 kilometers southeast of Puno.

Unit		Meters
	Sillapaca Formation Basalt flow	
	Unconformity	
	Puno Group Tacaza Formation	
11	Breccia, light-gray, made up of trachyte, andesite, basalt, sandstone and limestone in an andesitic matrix, massive	25
10	Basalt, dark-gray, pyroxene phenocrysts, vesicular at the top, massive, highly weathered, green chlorite patches	18
9	Conglomerate, dull-red to reddish-gray, andesite and basalt fragments up to 15 cm. diameter, in a tuffaceous matrix, massive	20
8	Breccia, greenish-gray, made up of andesite, basalt, sandstone and limestone, fragments up to 10 cm. diameter, copper mineralization, massive, green chlorite patches, with numerous intercalations of andesite flows, tuffs and brownish-red conglomerates of volcanic origin	347
	Total Tacaza Formation	410

Unit		Meters
	Saracocha Formation	
7	Sandstone, reddish-gray, coarse to very coarse-grained, angular to sub-angular, with some rounded quartz grains coated with iron oxide, feldspathic, tuffaceous, conglomeratic, a few dark-minerals, beds up to 1.2 m. thick, scattered andesite pebbles throughout the sandstone, with minor beds of arkose and conglomerate	150
6	Conglomerate, light-gray, sub-rounded, made up of andesite, syenite, trachyte and basalt pebbles up to 10 cm. diameter, beds from a few cm. up to 1.5 m. thick, feldspathic sandy matrix; with minor beds of sandstone	100
5	Sandstone, reddish-gray, same as unit 7 with numerous thin beds of conglomerate	150
4	Arkose, brownish-red, great amount of andesite particles, massive	20
3	Conglomerate, reddish-gray, sub-angular to sub-rounded, made up of quartzite, sandstone, limestone, andesite-basalt, trachyte, monzonite-diorite and vein quartz fragments up to 1 m. diameter, locally shows x-bedding, tuffaceous sandy matrix, with numerous beds of sandstone	180
2	Sandstone, reddish-gray, angular, medium to very coarse-grained, tuffaceous, feldspathic, iron-stained, x-bedded, massive, scattered volcanic pebbles	30

Unit		Meters
1	Conglomerate, light gray, same as unit 3	280
	Total Saracocha Formation	410
	Total Puno Group	1330
	Unconformity	
	Muñani Formation	

Section of the Puno Group at Co. Tacahuapata, 16 kilometers southwest of Vilque.

Unit		Meters
	Covered	
	Puno Group Tacaza Formation	
7	Breccia, greenish-gray, made up of andesite fragments in an andesitic matrix, fragments up to 15 cm. diameter, green chlorite patches; interbedded with andesite flows and lenticular tuffs and conglomerates	285
6	Tuff, white rhyolitic	80
5	Andesite, greenish-gray, porphyritic, highly altered with intercalations of low-breccias and agglomerates	500
4	Rhyolite	50
3	Basalt, dark-gray, phenocrysts of augite thin intercalations of lenticular red conglomerate, massive, and flow-breccia	75
2	Breccia, greenish-gray, made up of andesite, limestone, quartzite and sandstone fragments, in an andesitic matrix.	

Unit		Meters
	Largest diameter about 10 cm. with intercalations of andesite flows, tuffs and agglomerates	100
	Partial Measurement of Tacaza Formation	1090
	Saracocha Formation	
1	Conglomerate, yellowish-gray, sub-angular to sub-rounded, made up of quartzite, limestone and sandstone fragments, up to 1 m. diameter, in a highly feldspathic sandy matrix, the conglomerate gets finer towards the top	120
	Total Saracocha Formation	120
	Partial Measurement of the Puno Group	1210
	Unconformity	
	Lagunillas Group	

Section of the Puno Group at Co. Saihuani, 30 kilometers southeast of Santa Lucía.

Unit		Meters
	Covered	
	Puno Group	
	Tacaza Formation	
9	Andesite and basalt flows, dark-gray, massive. The top of some flows have spheroidal vesicles filled with quartz and calcite, most of the flows are separated by a reddish-coloration and lenticular conglomerates	300

Unit		Meters
8	Tuff, reddish-white, angular to sub-angular coarse-grained, agglomerate in places; feldspar grains altering to iron oxide, well-bedded, beds up to 40 cm. thick	200
7	Basalt flows, flow-breccias and agglomerates with intercalations of reddish-gray, thin conglomerates of volcanic origin	850
6	Marl replaced by silica, and calcerous sandstones, reddish-yellow, lenticular, thin-bedded, bearing gastropods	50
5	Basalt, dark-gray, with spheroidal vesicles filled up with quartz and calcite, amygdules up to 1 cm. diameter	110
4	Andesite, greenish-gray with intercalations of flow-breccias and agglomerates	325
3	Arkose, reddish-brown, coarse-grained, angular to sub-angular, with andesite fragments; beds from a few cm. up to 80 cm., with minor beds of red siltstone	110
2	Andesite, dark-gray, porphyritic, highly weathered, friable	80
	Partial Measurement of Tacaza Formation	2025
	Saracocha Formation	
1	Conglomerate, reddish-white, sub-angular to rounded, made up of limestone, quartzite, andesite, sandstone, shale and very few granite pebbles; fragments range in size from a few mm. up to 80 cms.; beds up to	

Unit		Meters
	1 m. thick; sandy matrix, arkosic with minor beds of thin sandstone	380
	Total Measurement of Saracocha Formation	380
	Partial Measurement of the Puno Group	2405

Unconformity

Lagunillas Group

Section of the Puno Group at Co. Auquirane, northeast of Laguna Lagunillas.

Unit		Meters
	Puno Group	
	Tacaza Formation	
6	Tuff, yellowish-white to white, strong vertical jointing, containing sub-angular fragments of andesite up to 4 cm. diameter, fragments of pumice with vesicles are very common	85
5	Basalt, dark-gray, highly weathered, friable with intercalations of flow-breccias, agglomerates and tuffs	225
4	Conglomerate, reddish-brown, made up of andesite and basalt fragments in a tuffaceous matrix, with intercalations of tuffs	20
3	Andesite, greenish-gray, porphyrytic with intercalations of flow-breccias, agglomerates and tuffaceous sandstones	350
2	Tuff, pale orange, poorly consolidated, thick-bedded	15

Unit		Meters
1	Conglomerate, reddish-brown, made up of andesite and basalt fragments in a tuffaceous matrix, at the contact with the granite shows a slight bleaching	65
	Partial Measurement of the Puno Group	860
	Granite (intrusive contact)	

Section of the Puno Group at Co. Coachico, 22 kilometers northeast of Cabanilla.

Unit		Meters
	Puno Group	
5	Basalt, dark-gray, augite phenocrysts, massive with minor beds of agglomerate	90
4	Tuff, reddish-white, andesite fragments, massive, dacitic composition	180
3	Andesite, greenish-gray, weathered, friable with intercalations of flow-breccias and conglomerates	145
2	Conglomerate, dull-red, andesite and basalt fragments up to 20 cm. diameter in a tuffaceous matrix, massive	15
1	Andesite, dark-gray, with intercalations of flow-breccias, made up of quartzite, andesite, basalt and limestone; largest diameter about 10 cm., and massive tuffs	95
	Total	625
	Unconformity	
	Devonian Cabanillas Group	

Section of the Saracocha Formation at Laguna Saracocha, 6 kilometers southwest of Santa Lucía.

Unit		Meters
	Tacaza Formation	
	Andesite flows, dark-gray	
	Saracocha Formation	
2	Sandstone, brownish-gray, medium to very coarse-grained, conglomeratic in places, feldspathic, some rounded and frosted quartz grains, x-bedded in places, beds up to 20 cm. thick	30
1	Conglomerate, light-brown, sub-angular to sub-rounded, massive, x-bedded in places, some lenticular sandstone; the conglomerate is made up of quartzite, sandstone, diorite, andesite, limestone and trachyte fragments up to 1 m. diameter; feldspathic sandy matrix	480
	Total	510
	Unconformity	
	Jurassic Lagunillas Group	

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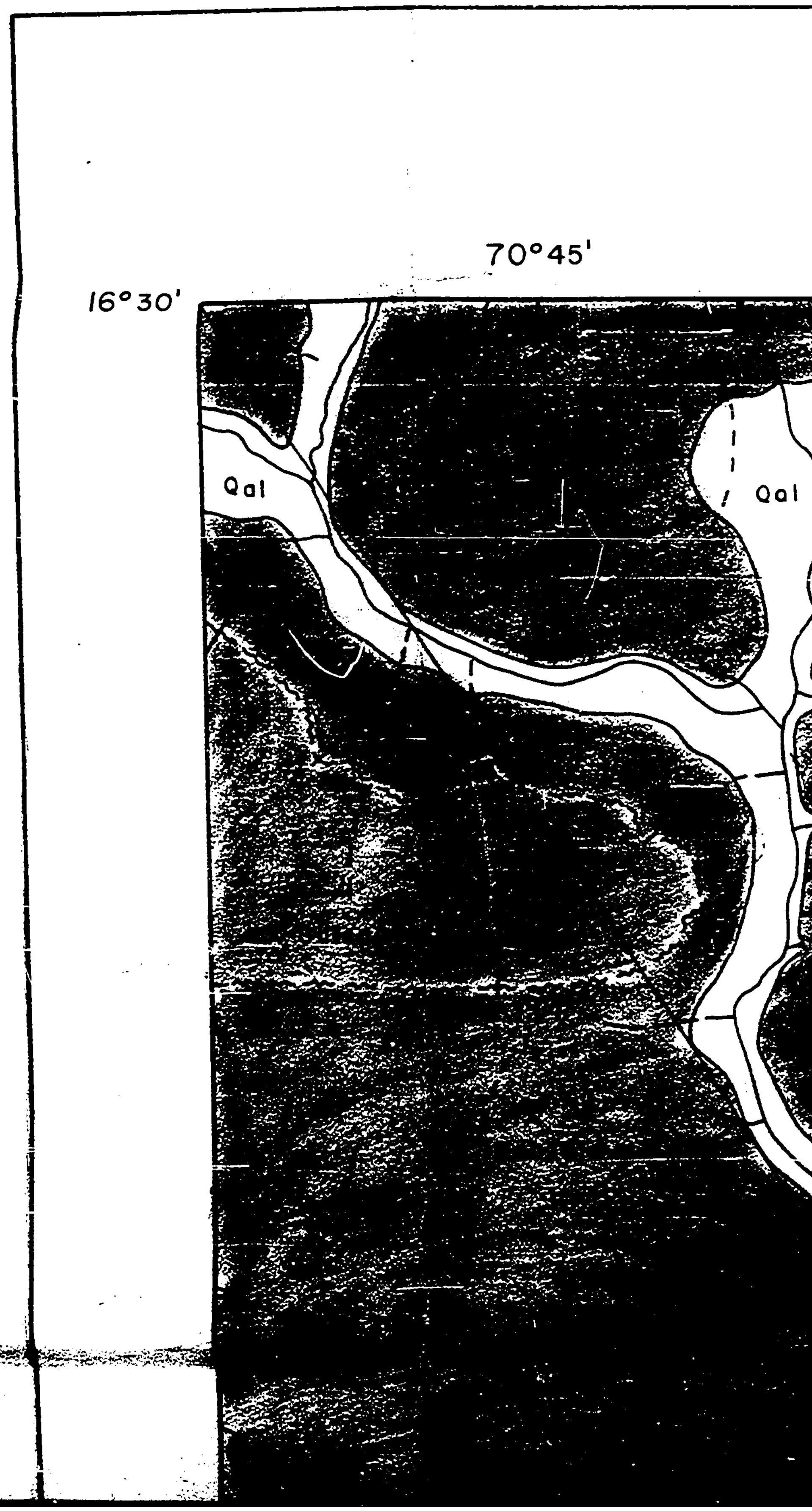
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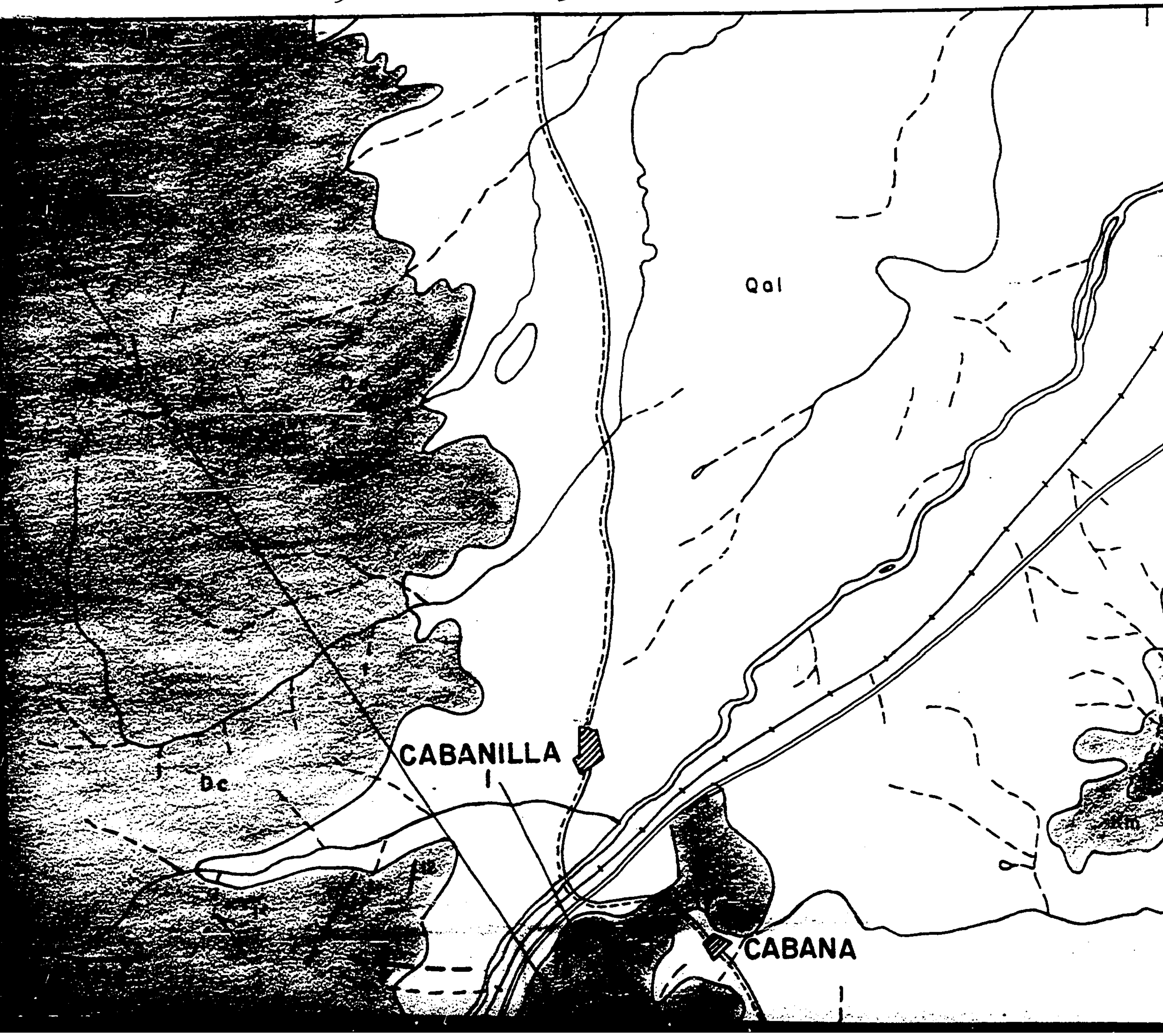

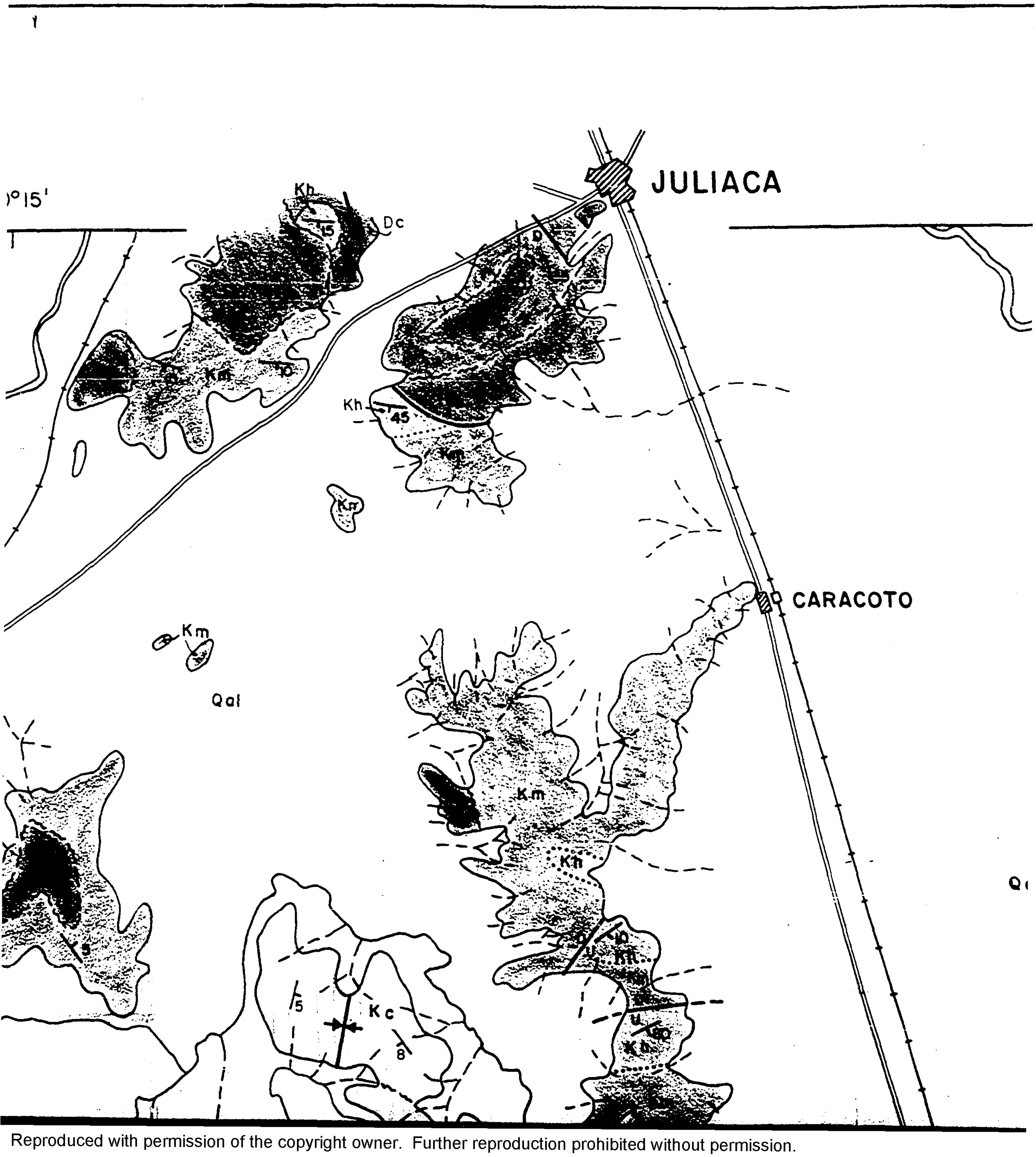
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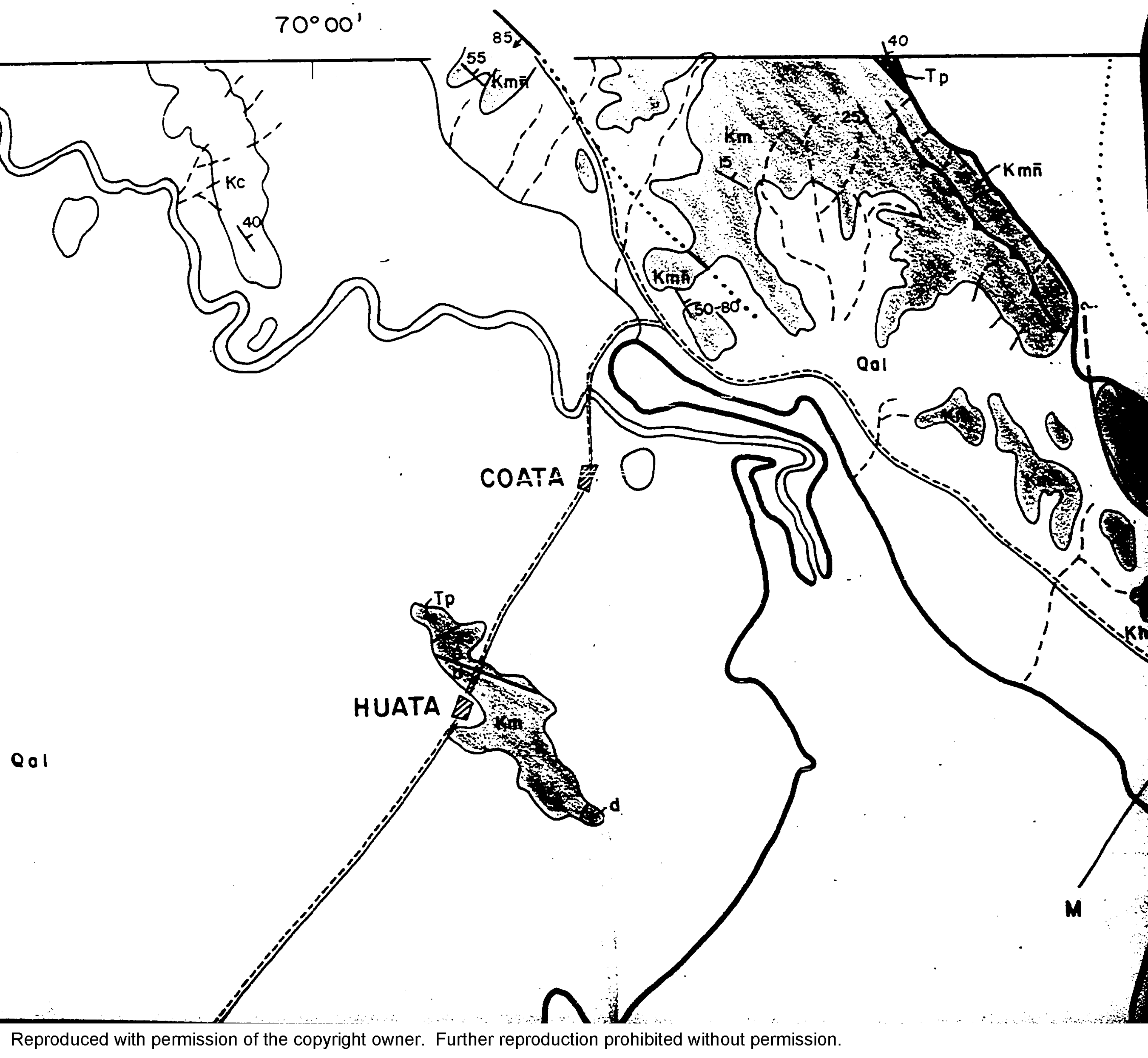
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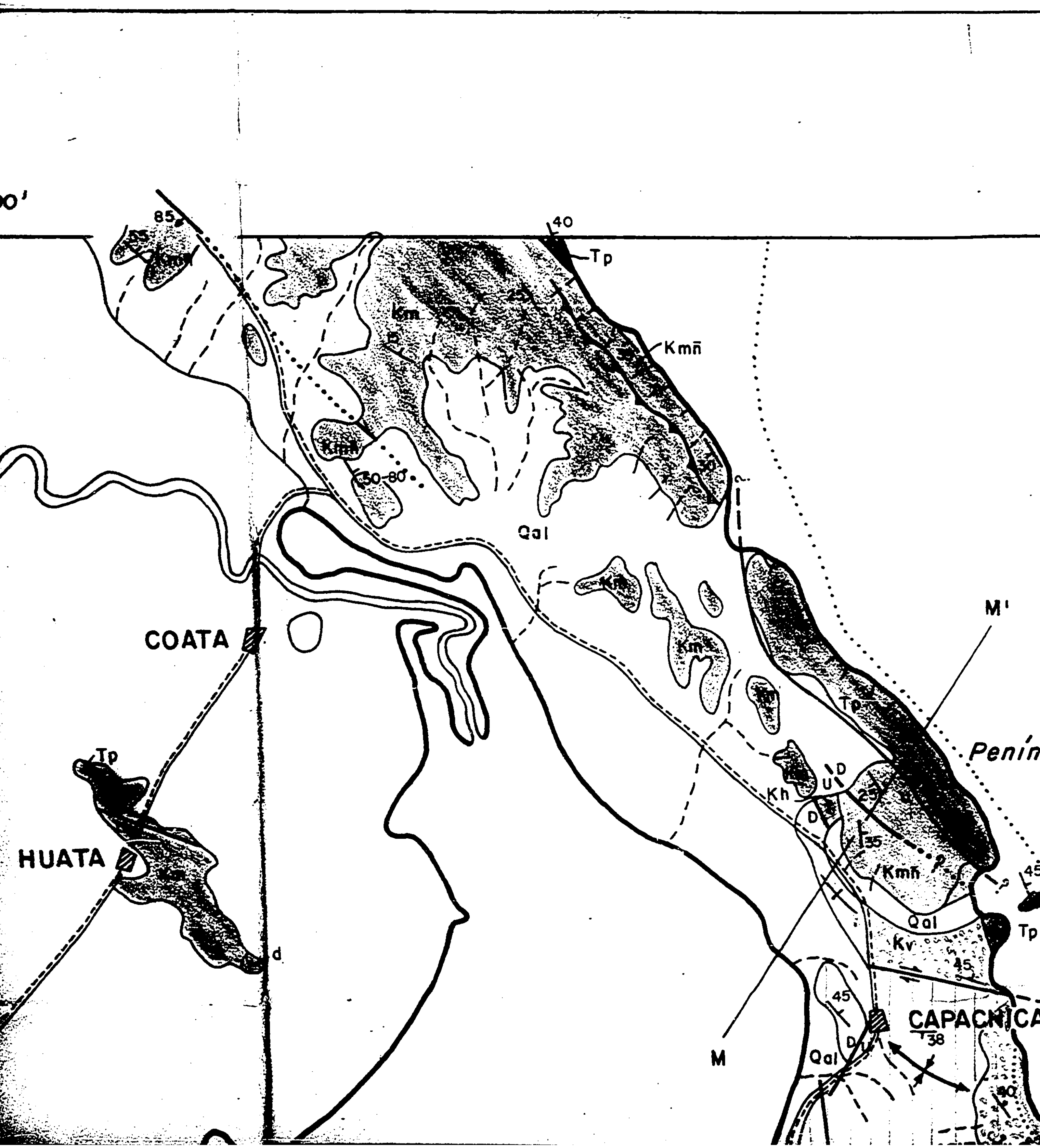

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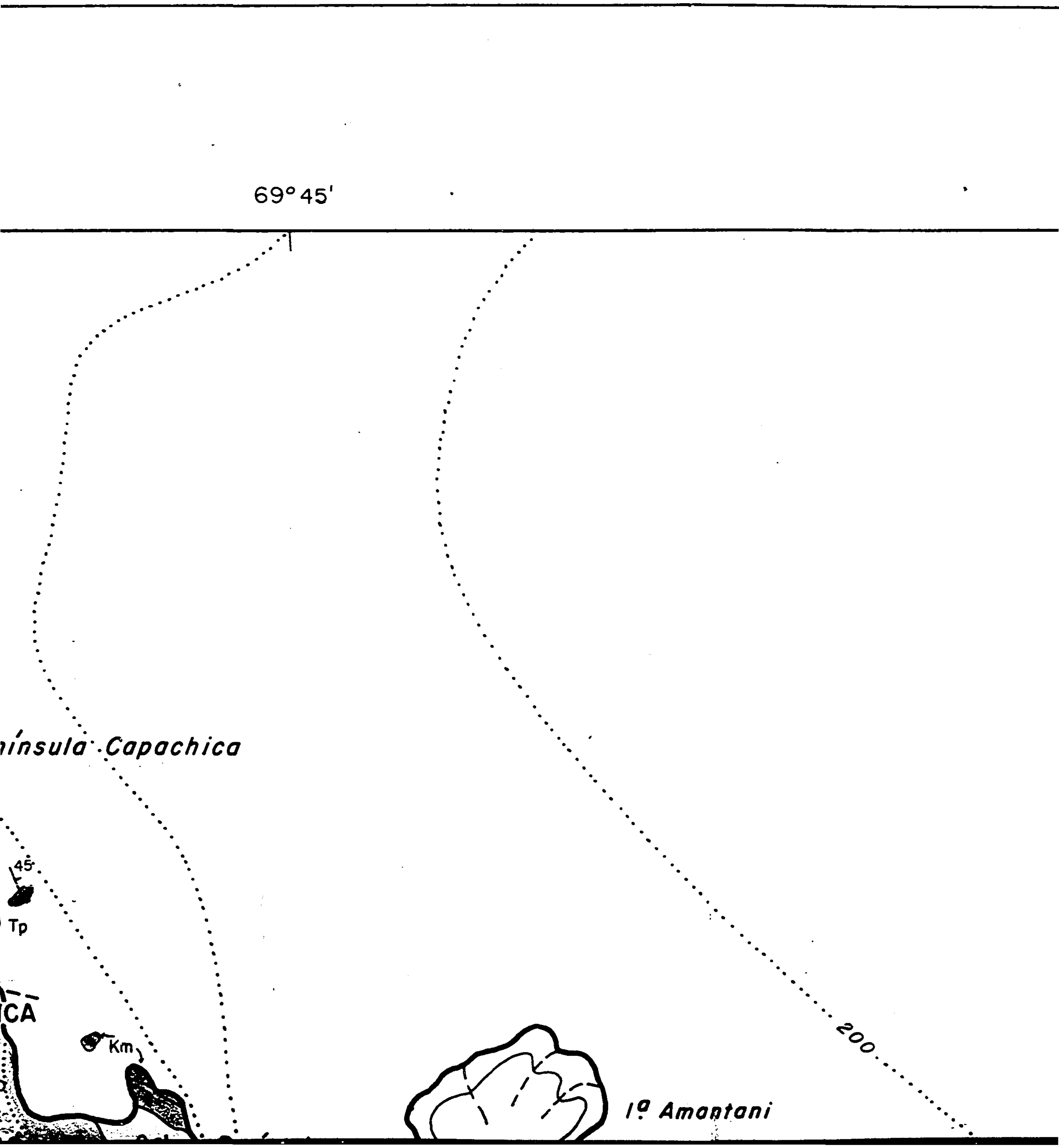
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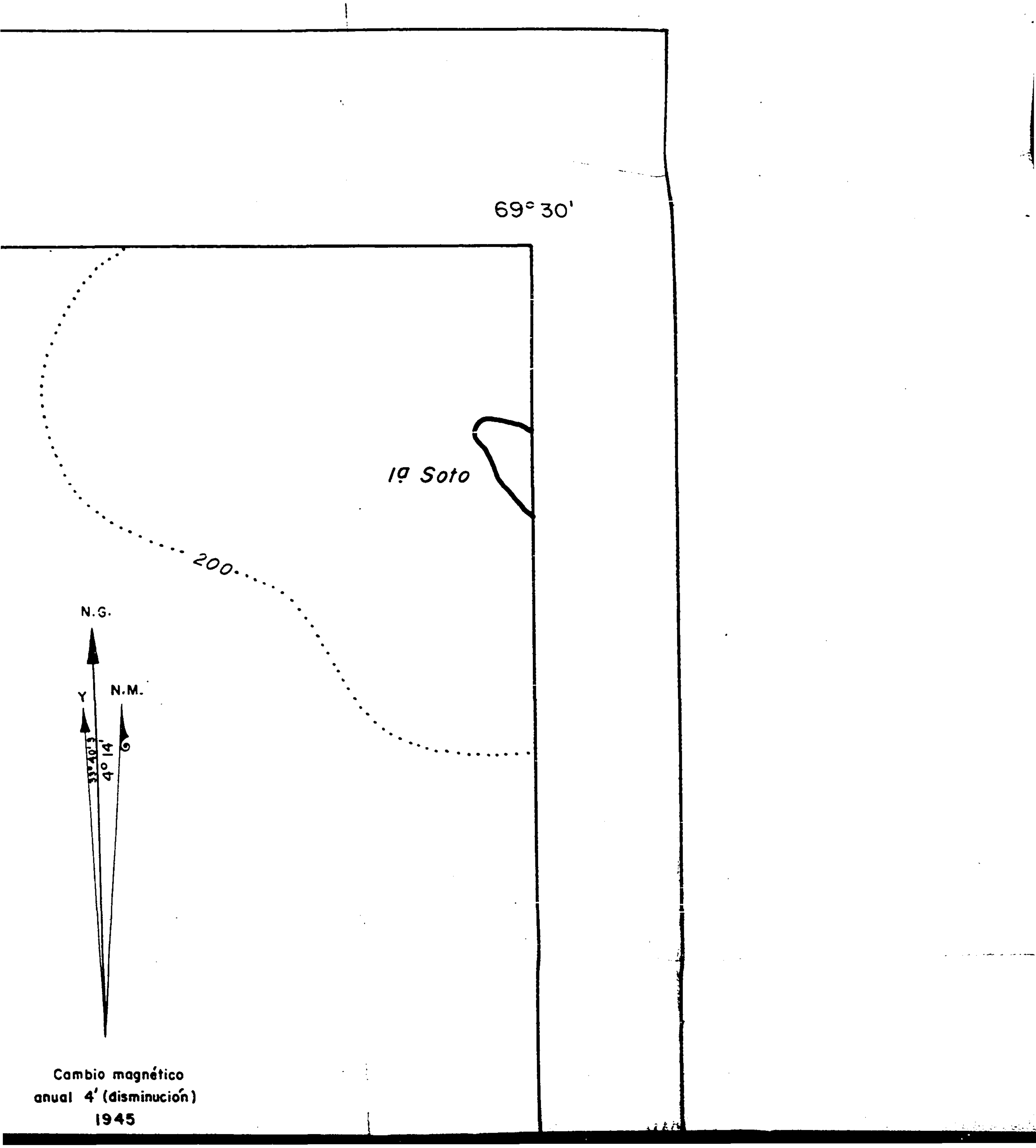
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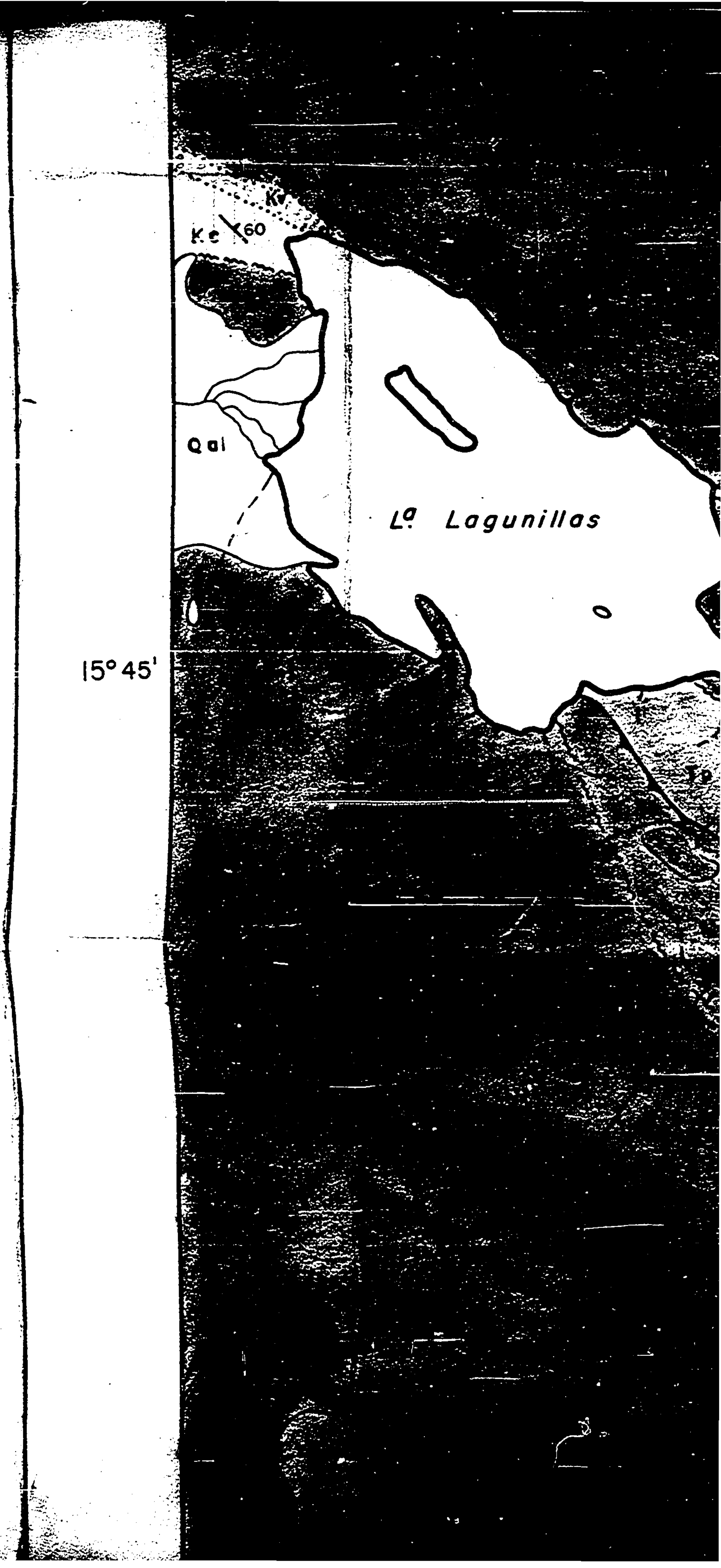
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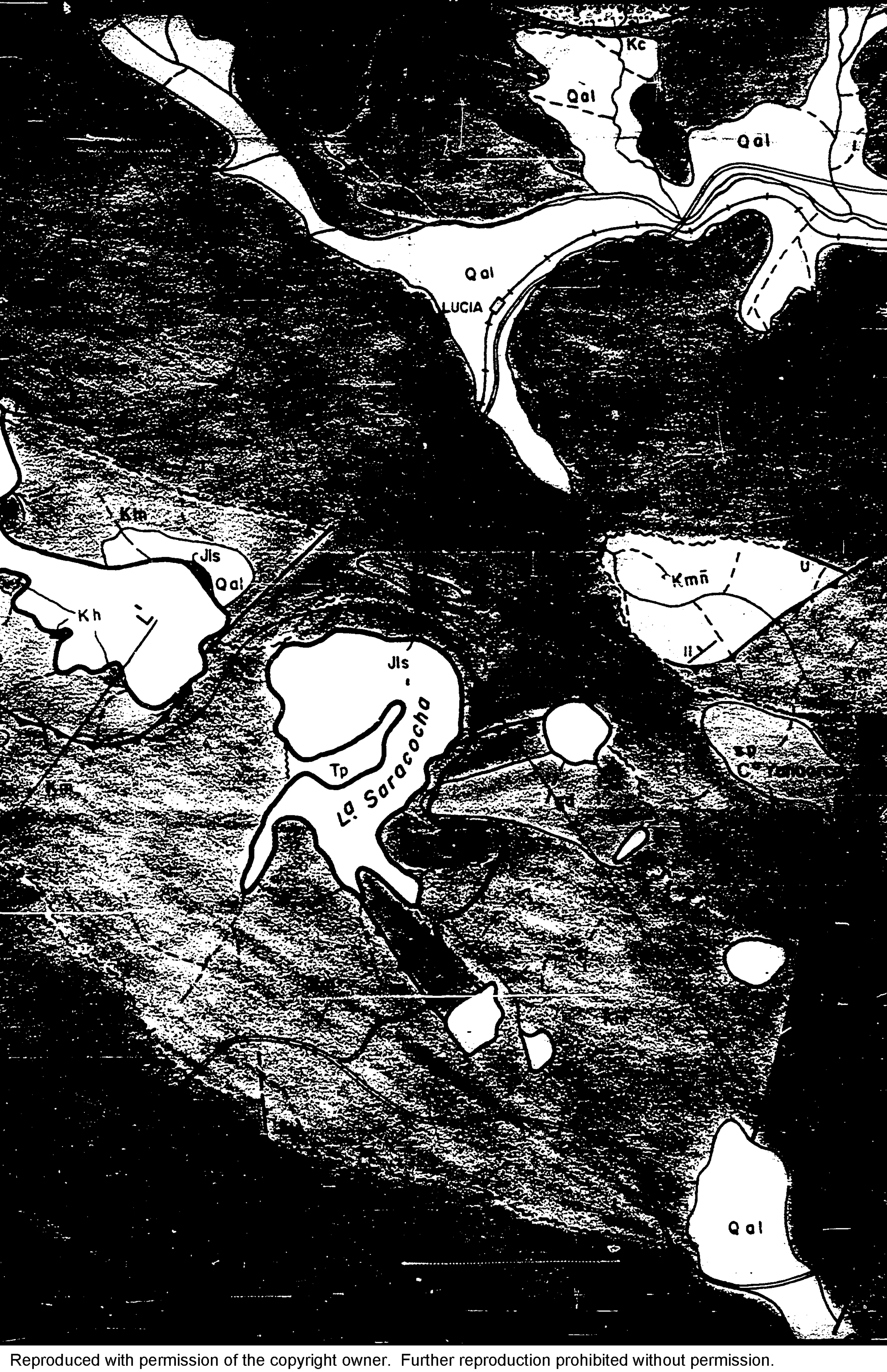
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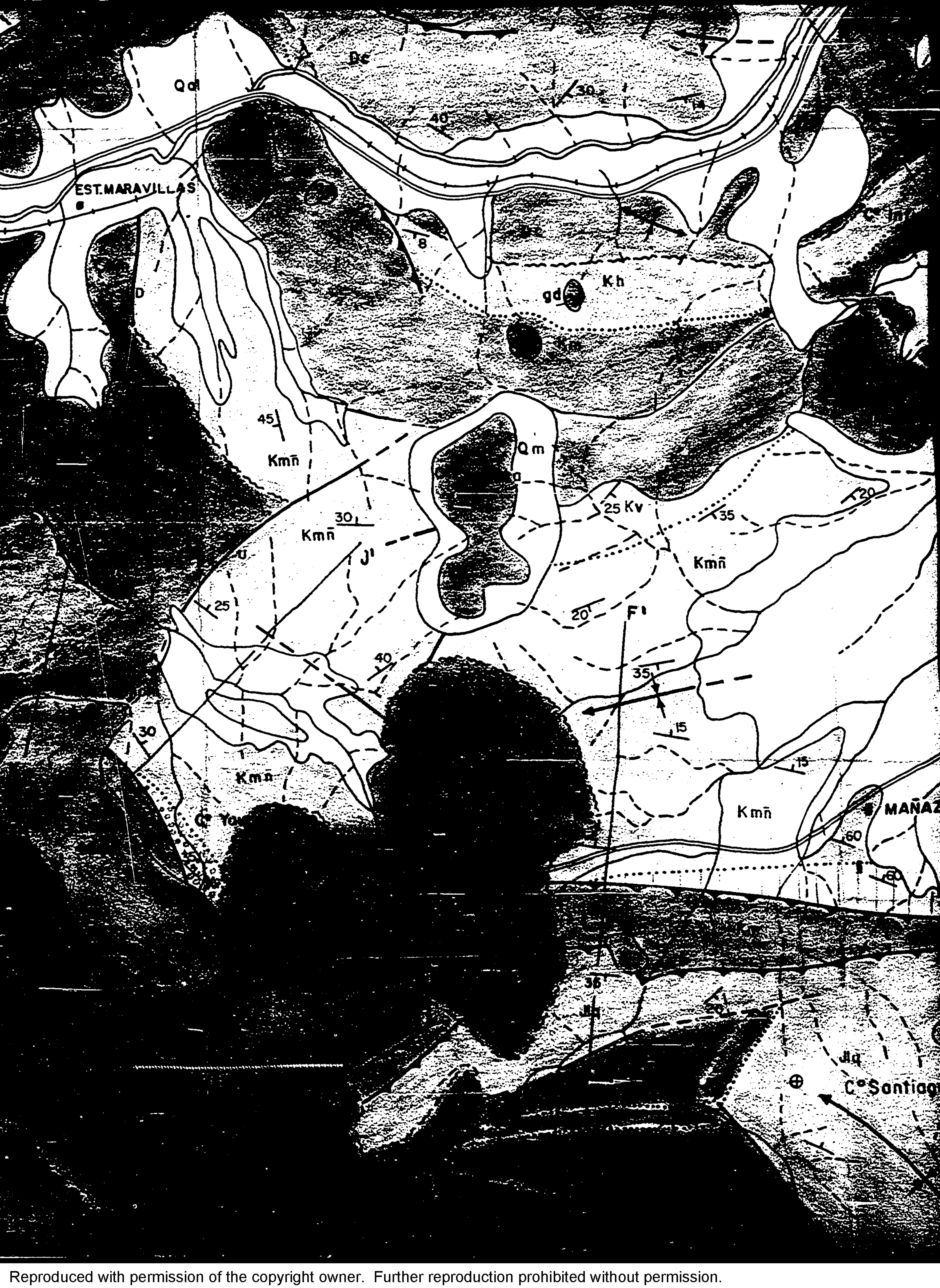

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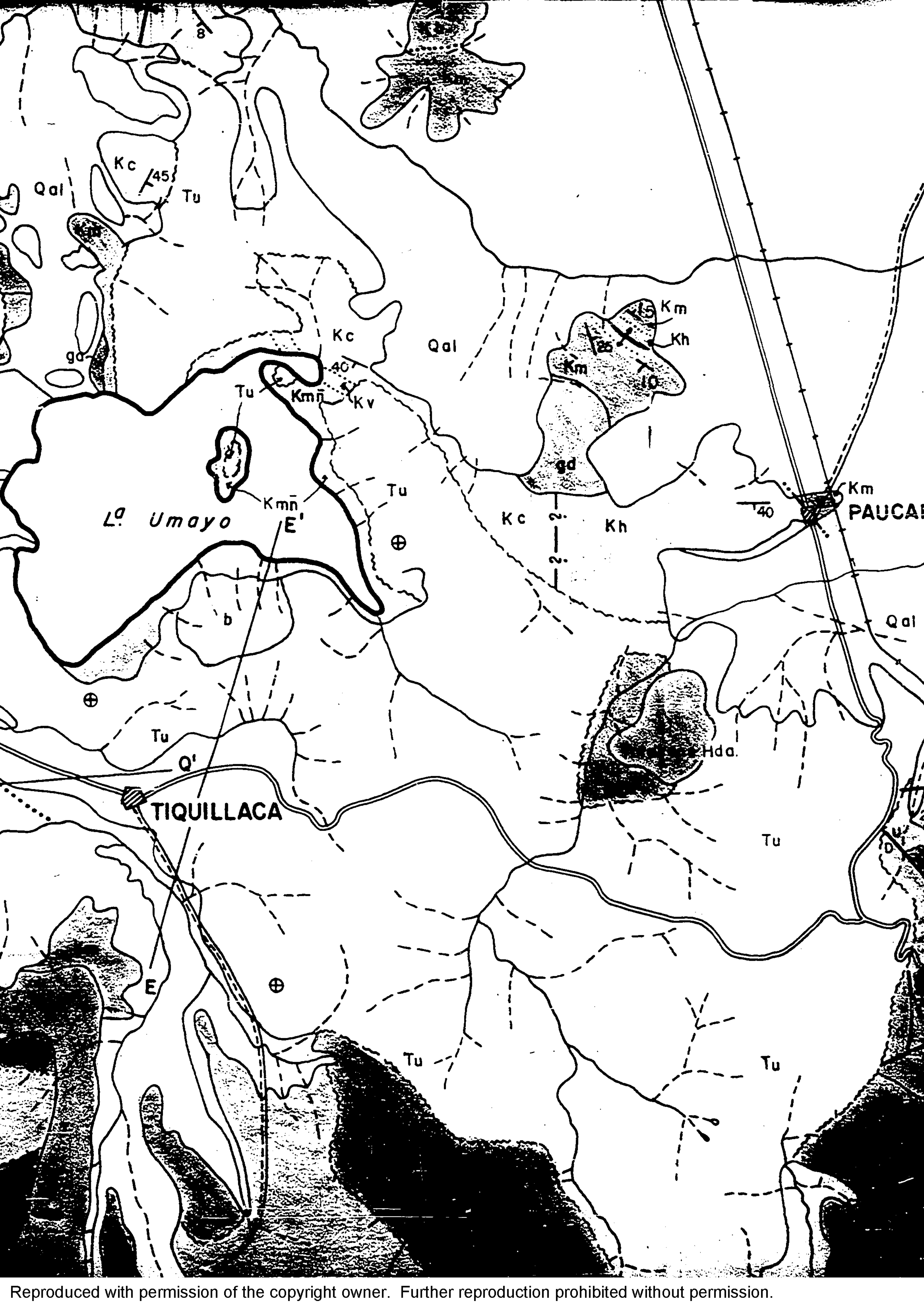
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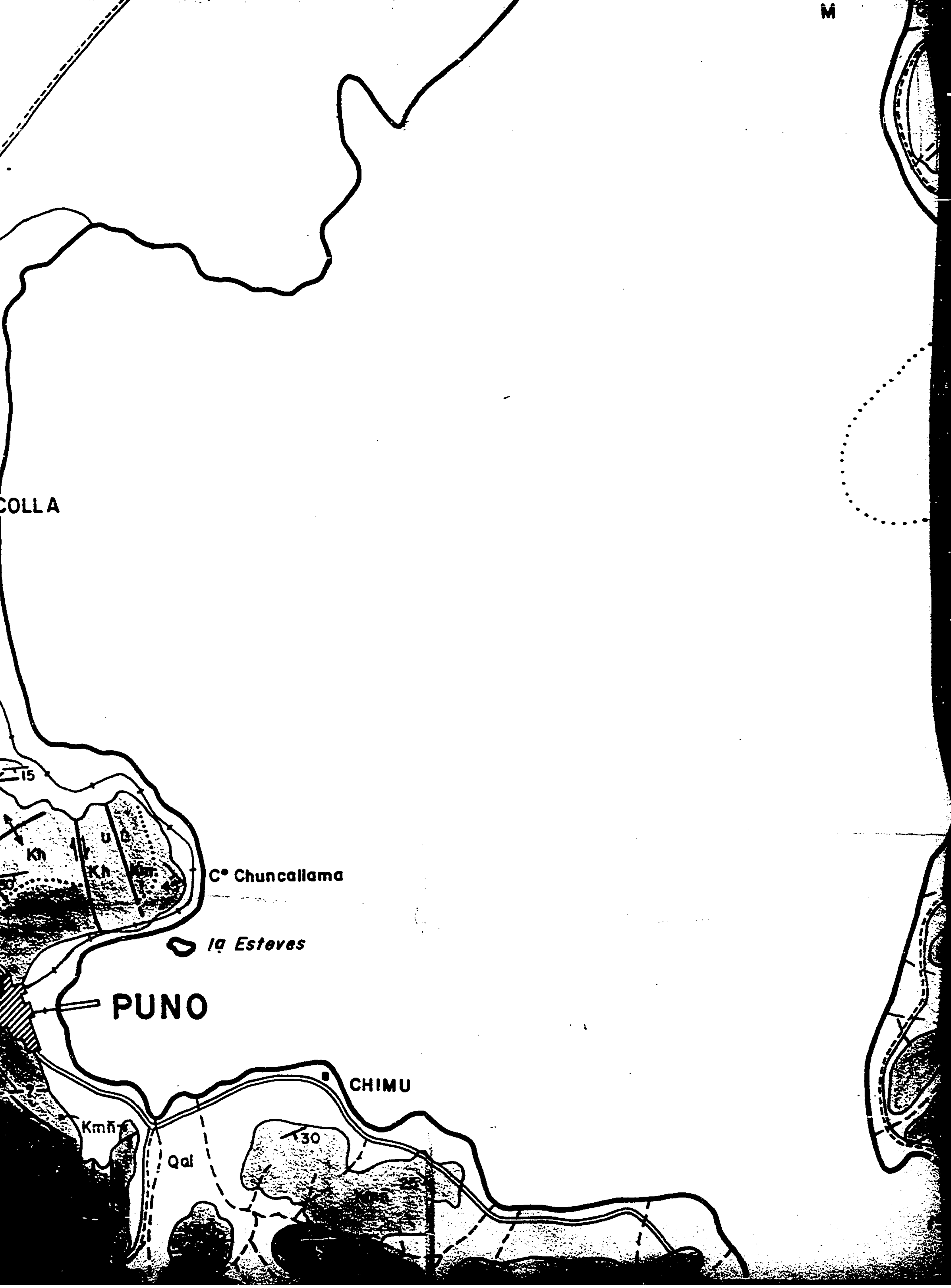
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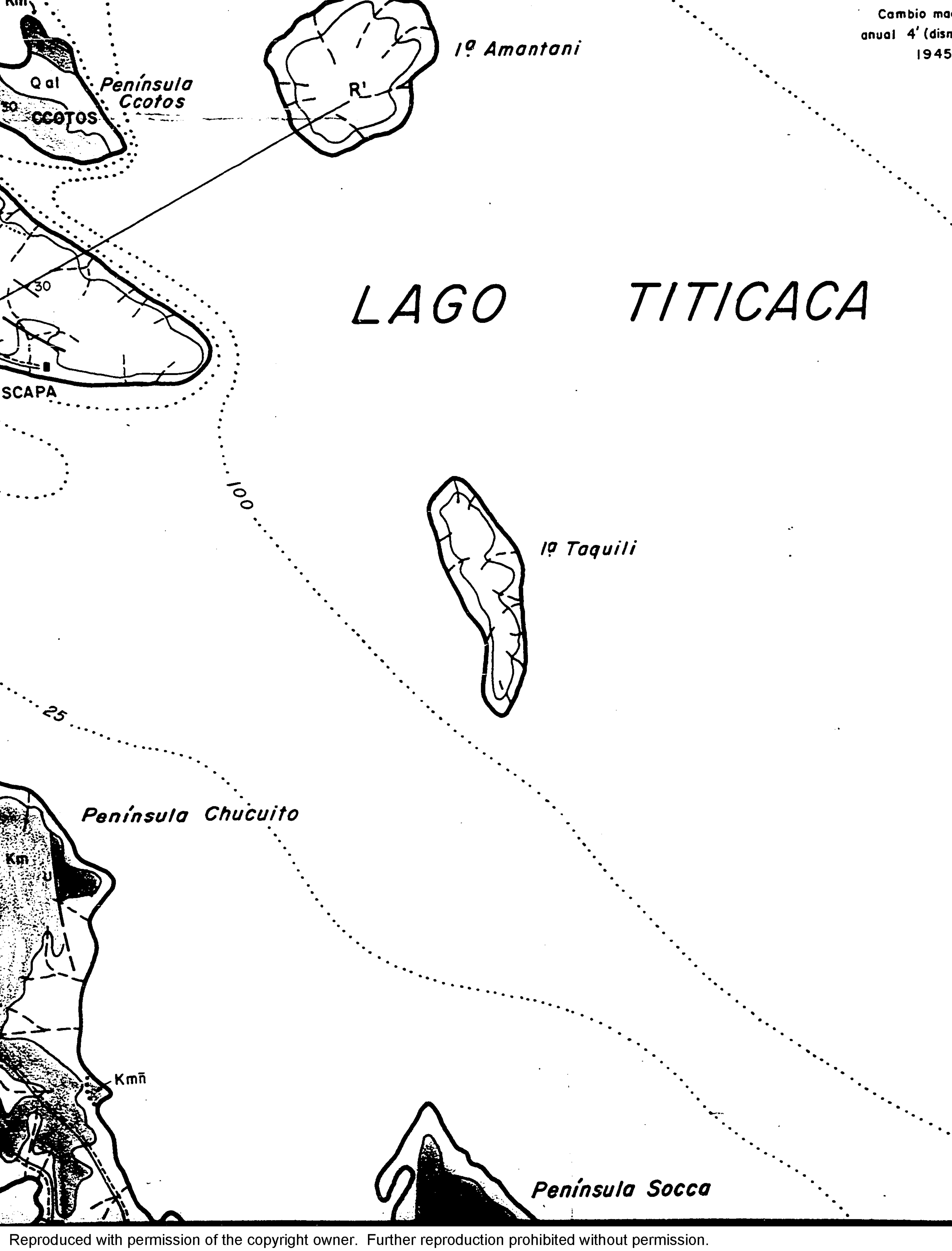
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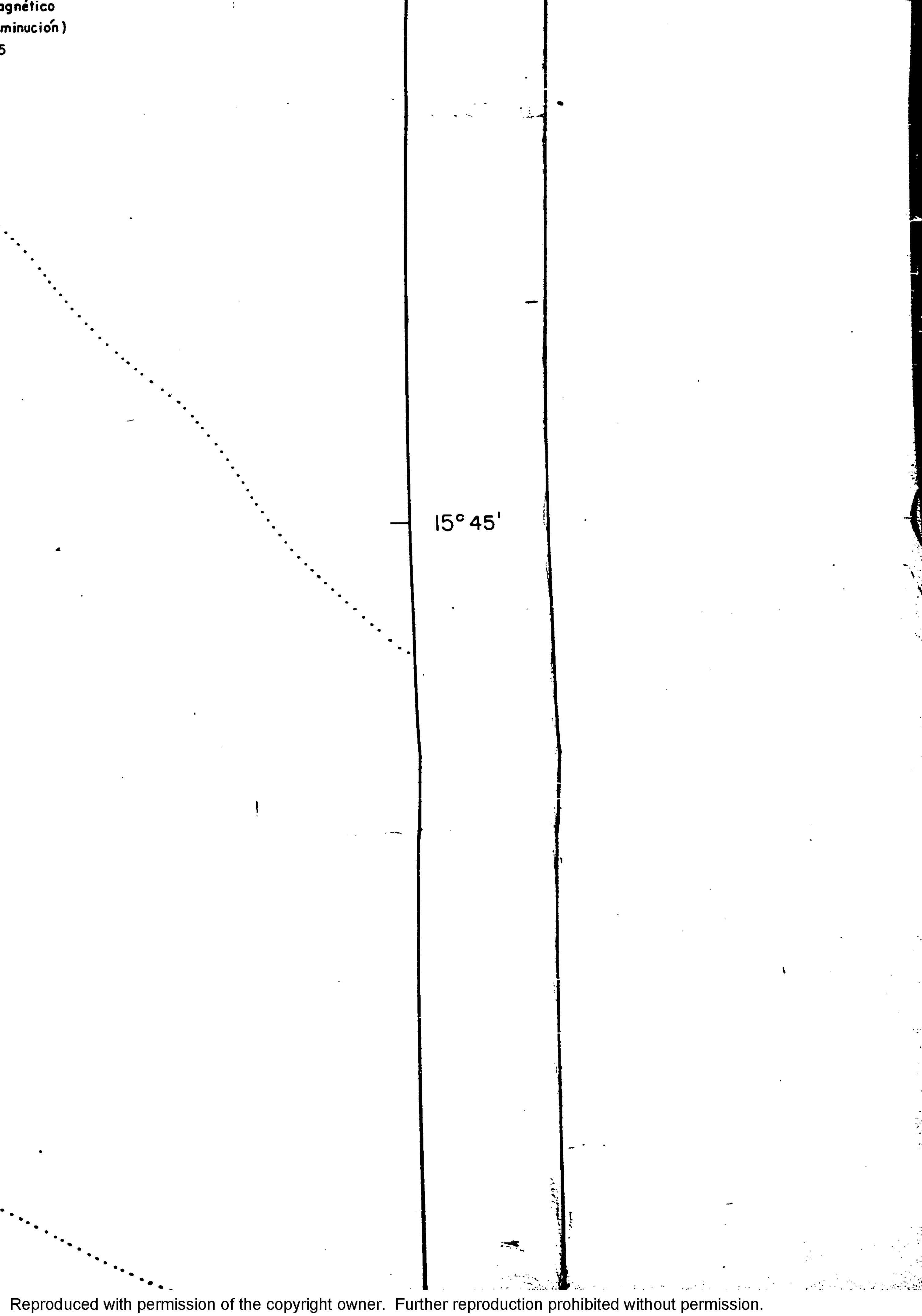
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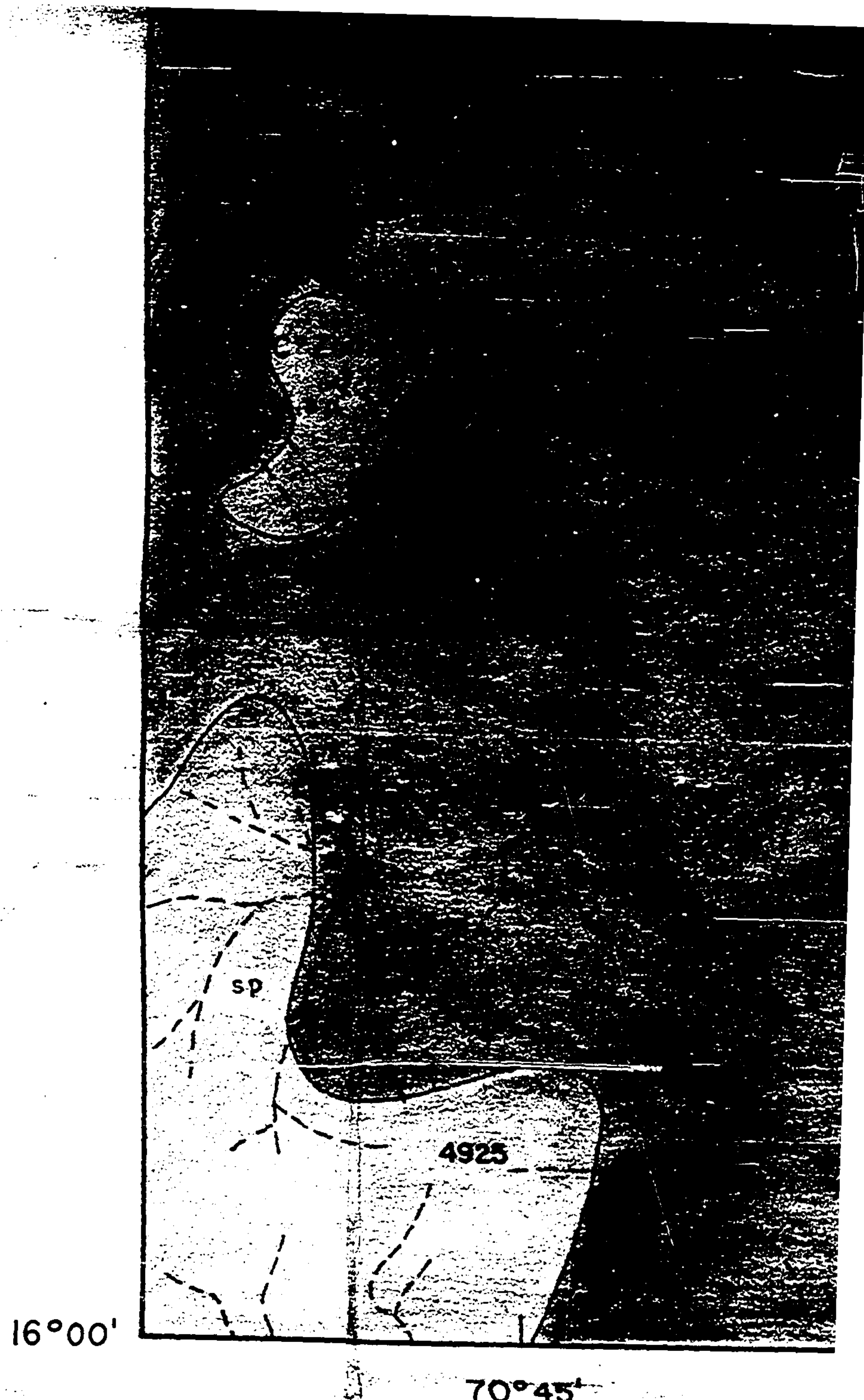
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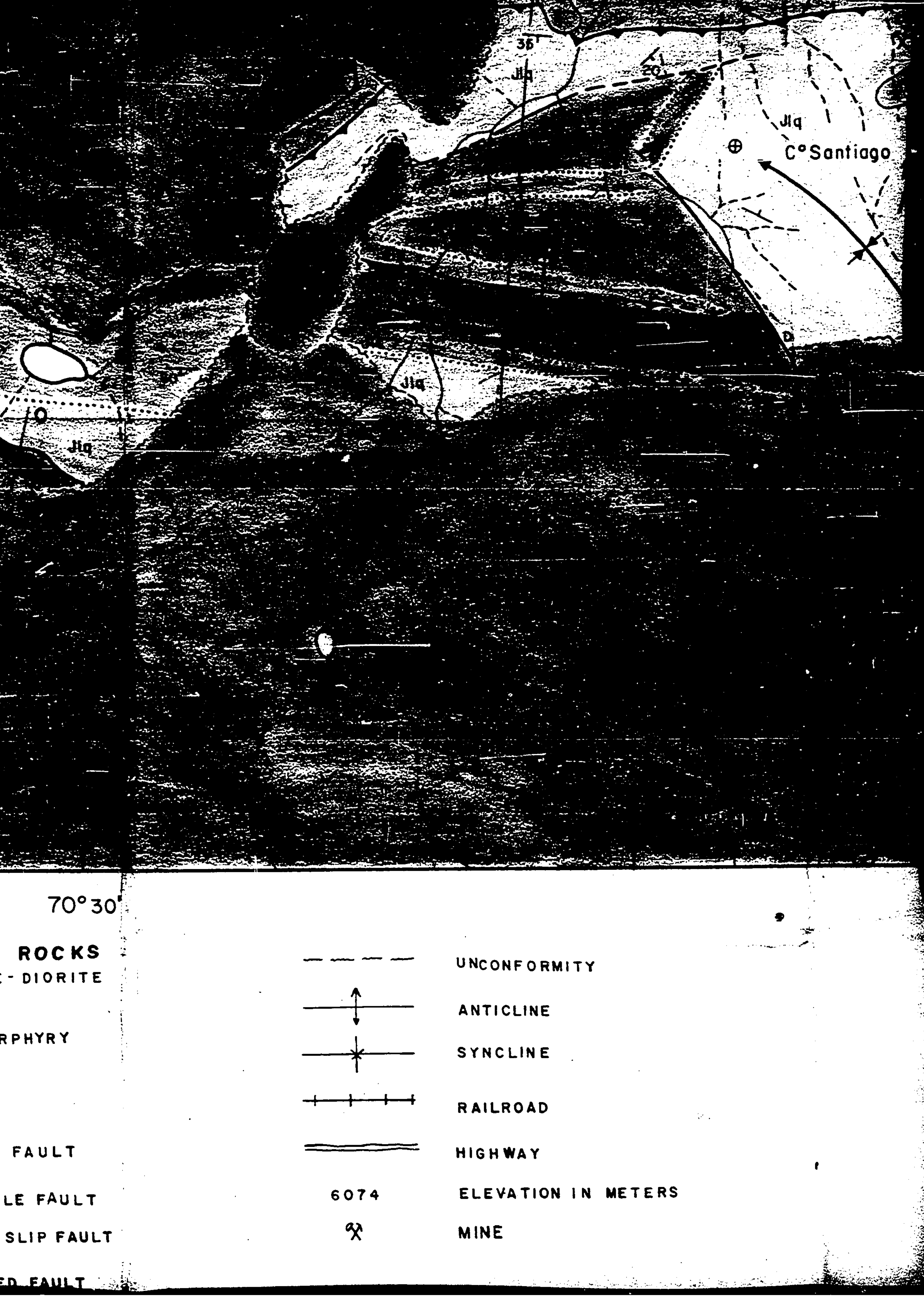

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6074 ELEVATION IN METERS
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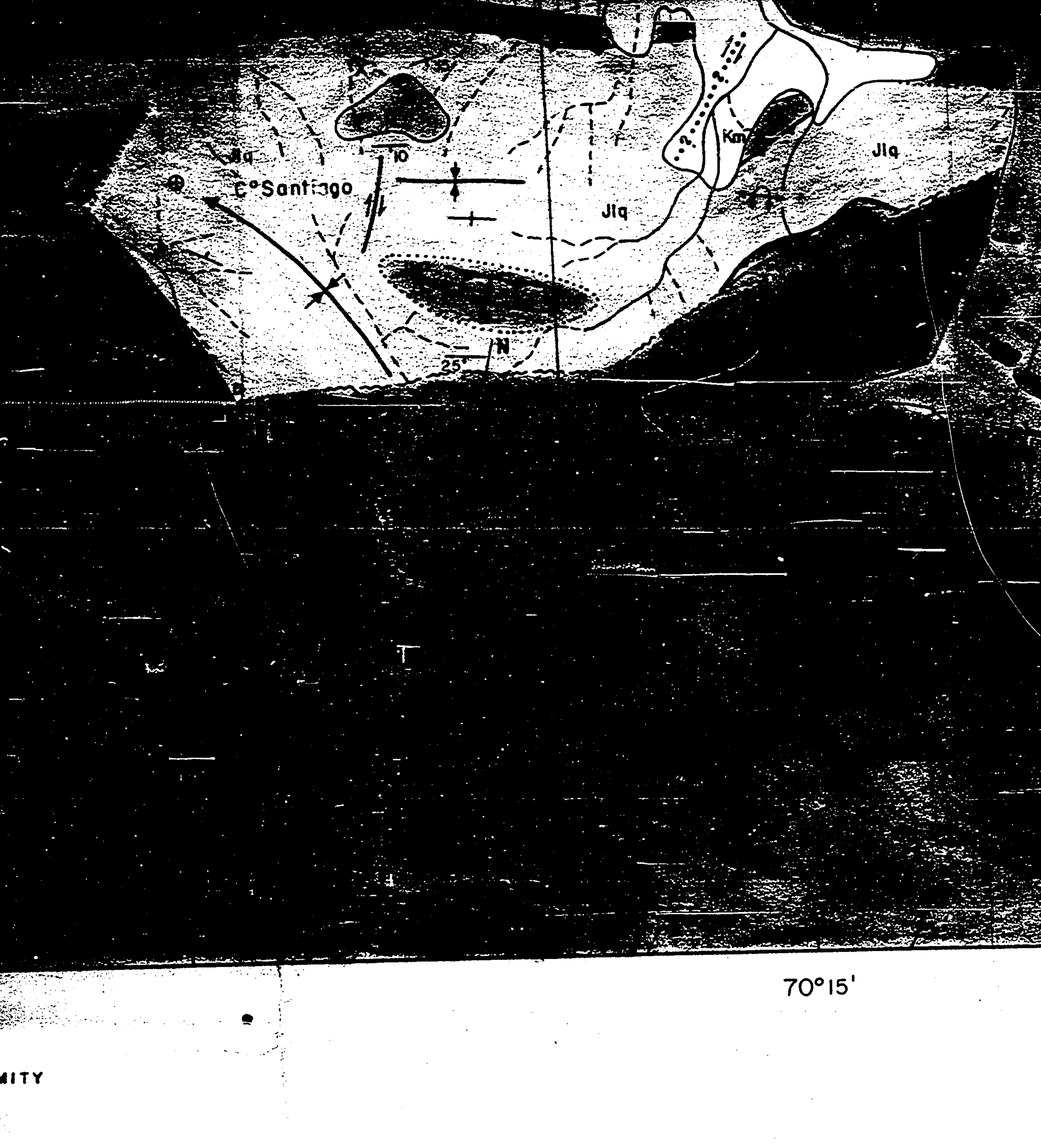
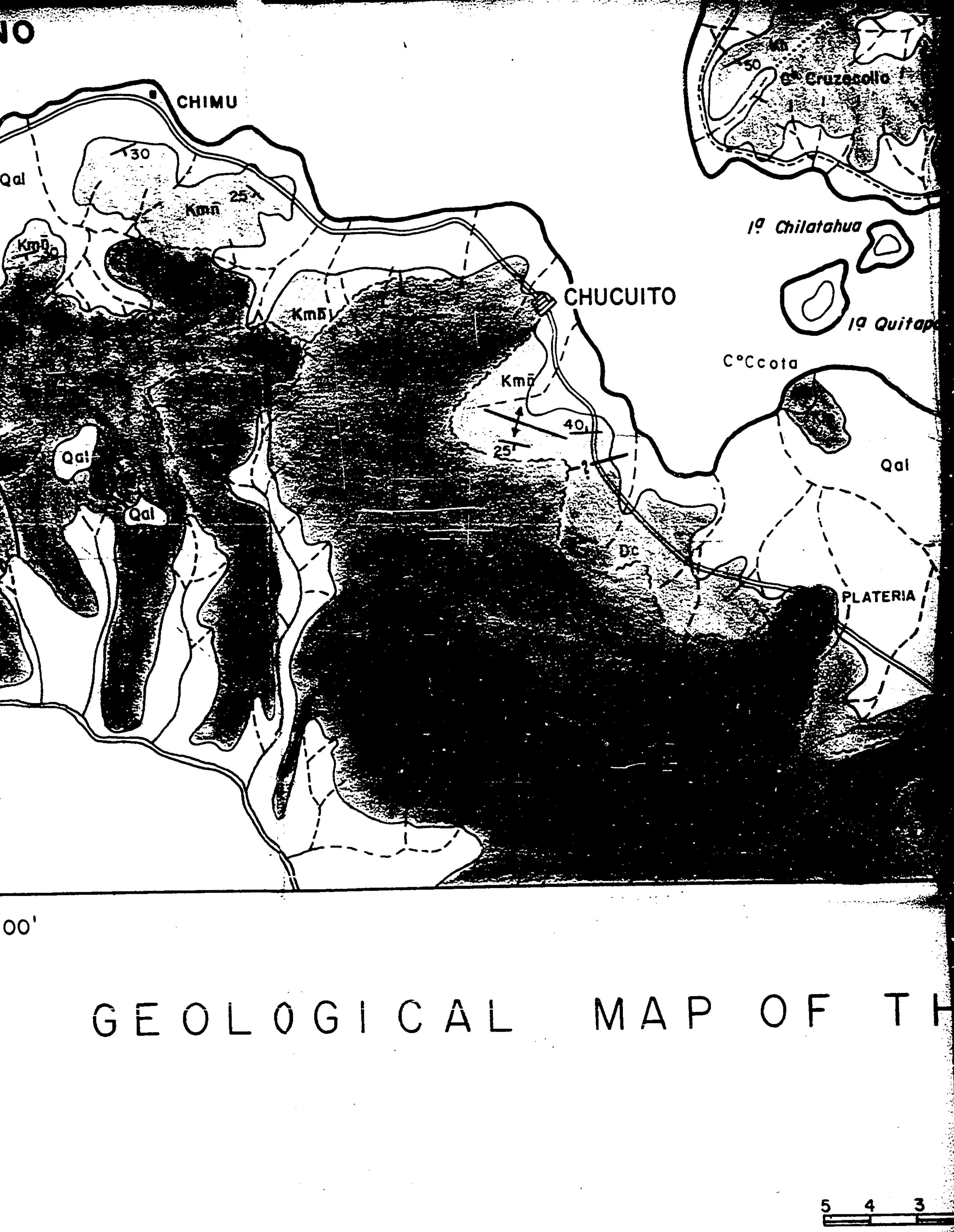


70°15'

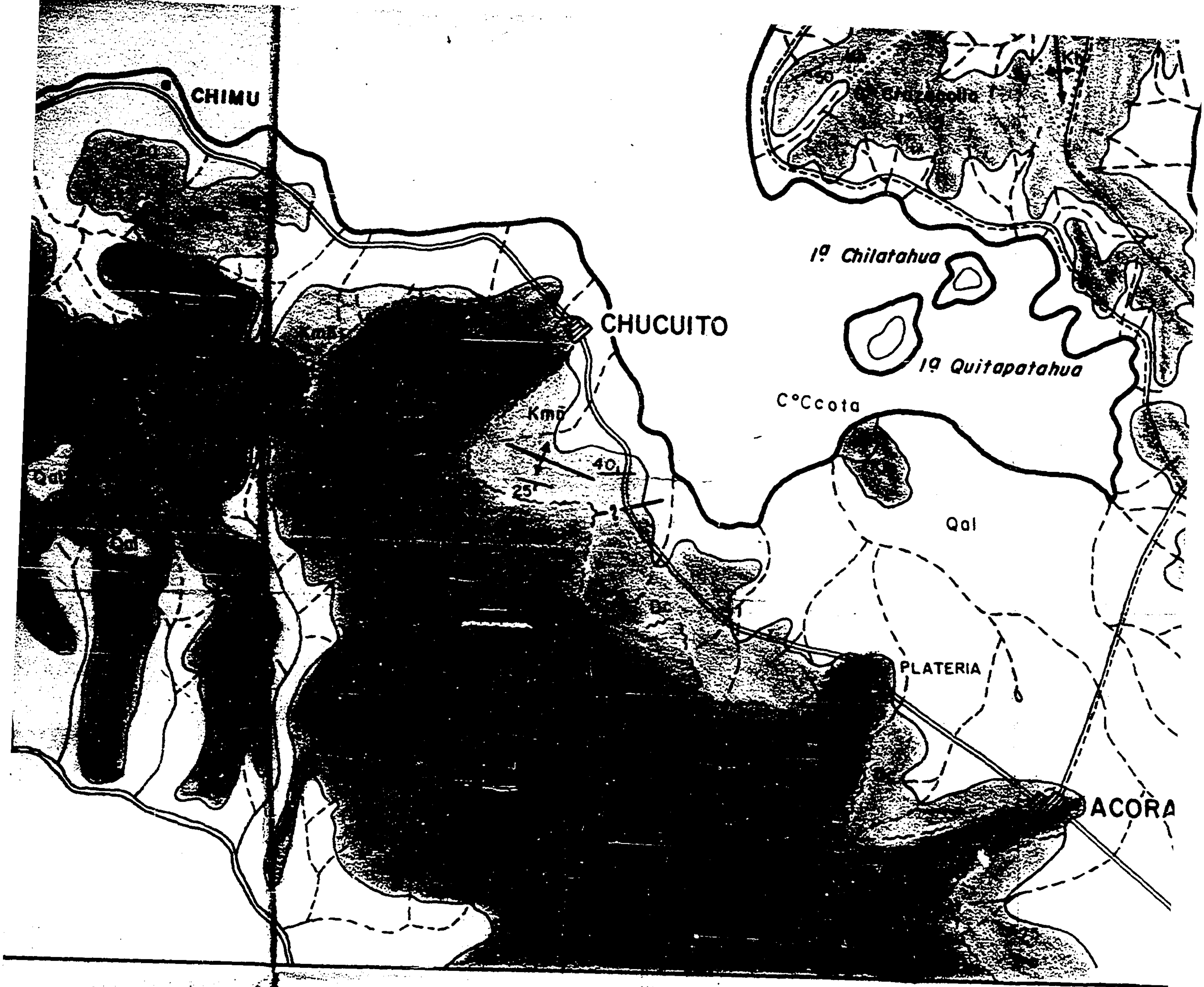
MITY

N IN METERS


PUN
Tu
Tu
Kmñ
Km
Qal
Tu
Qal
70°



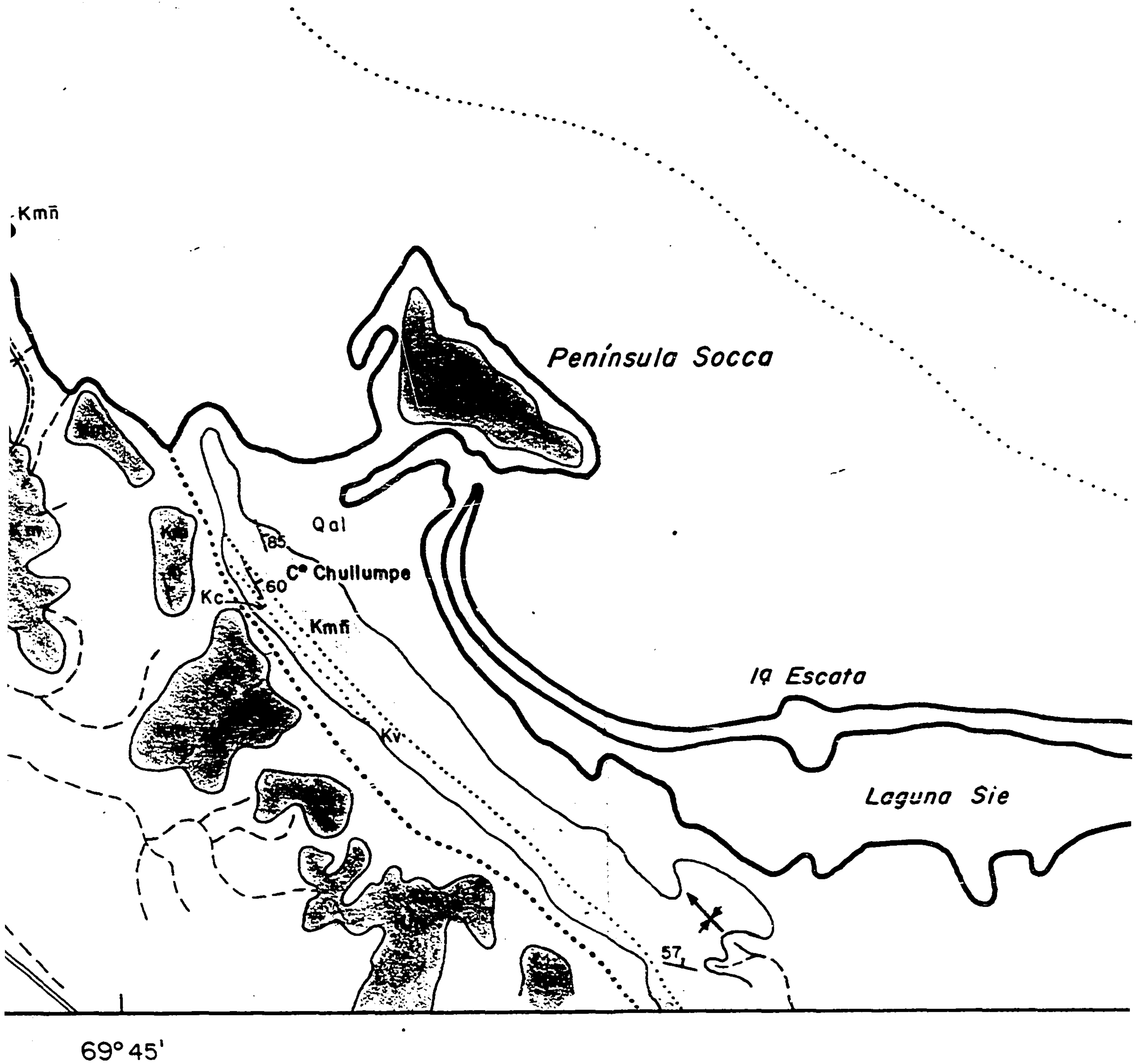
GEOLOGICAL MAP OF TH



GEOLOGICAL MAP OF THE P

5 4 3 2 1 0

1:10

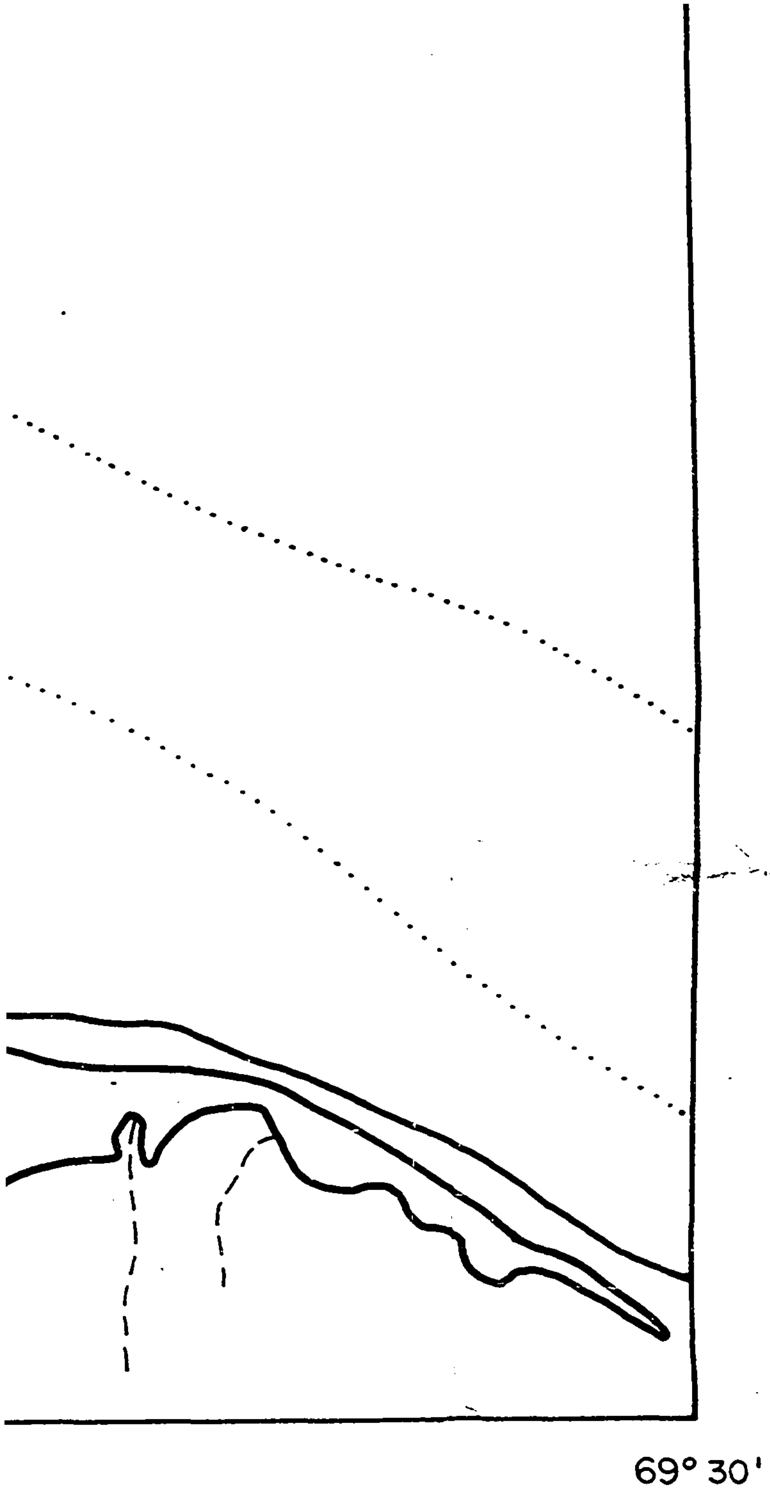


NO- SANTA LUCIA AREA, SOUTH

ALE

5 10 km.

)00



THERN PERU

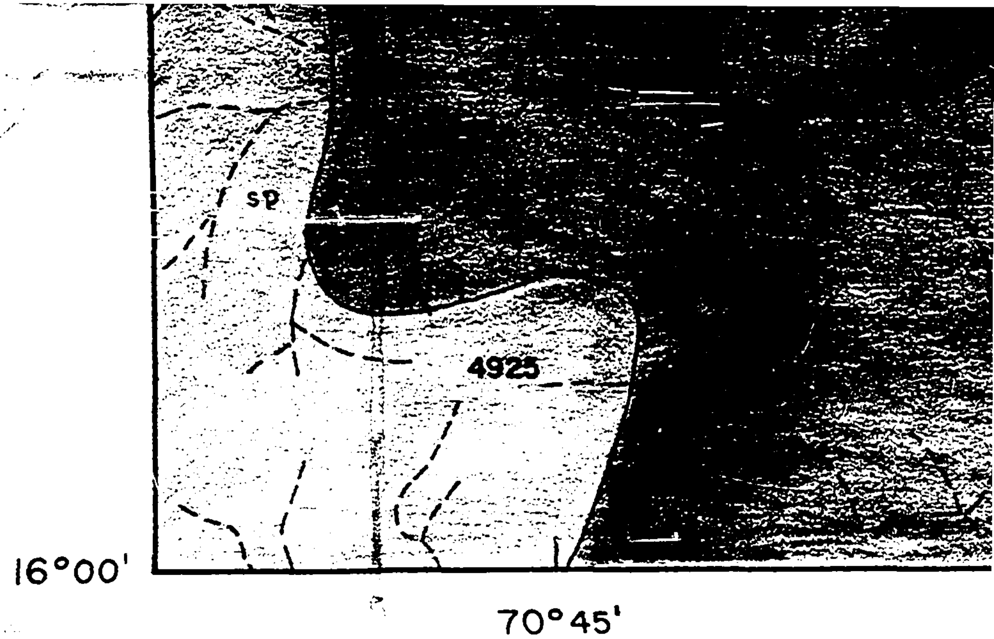
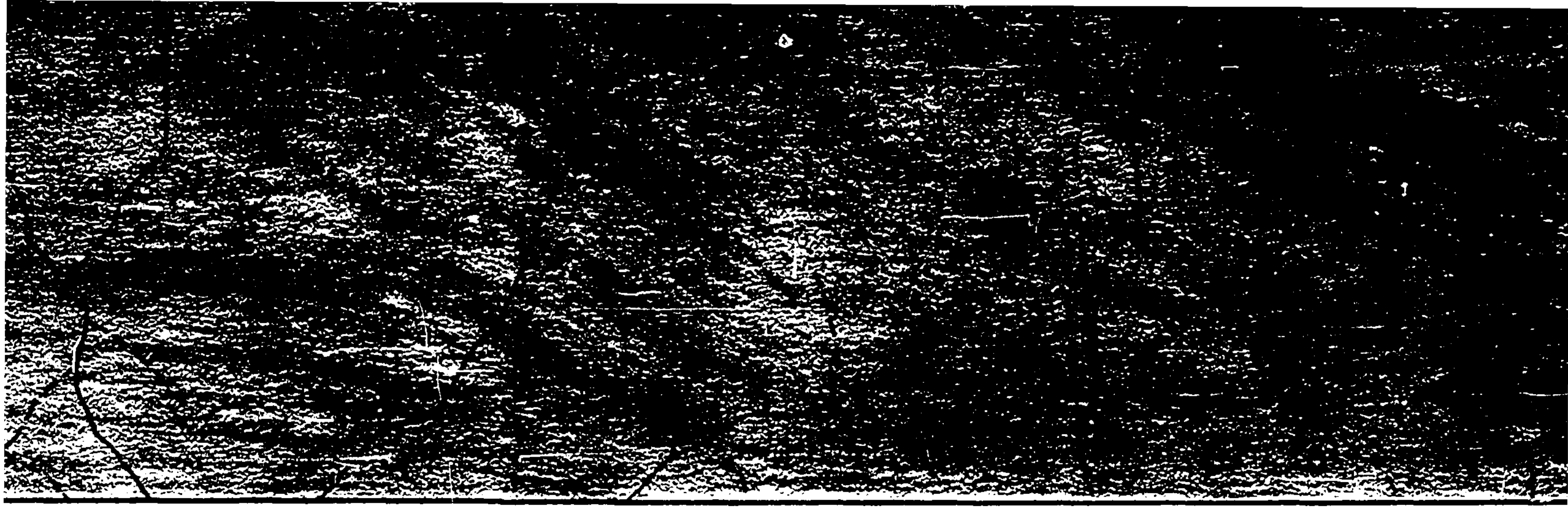


Plate I



LEGEND

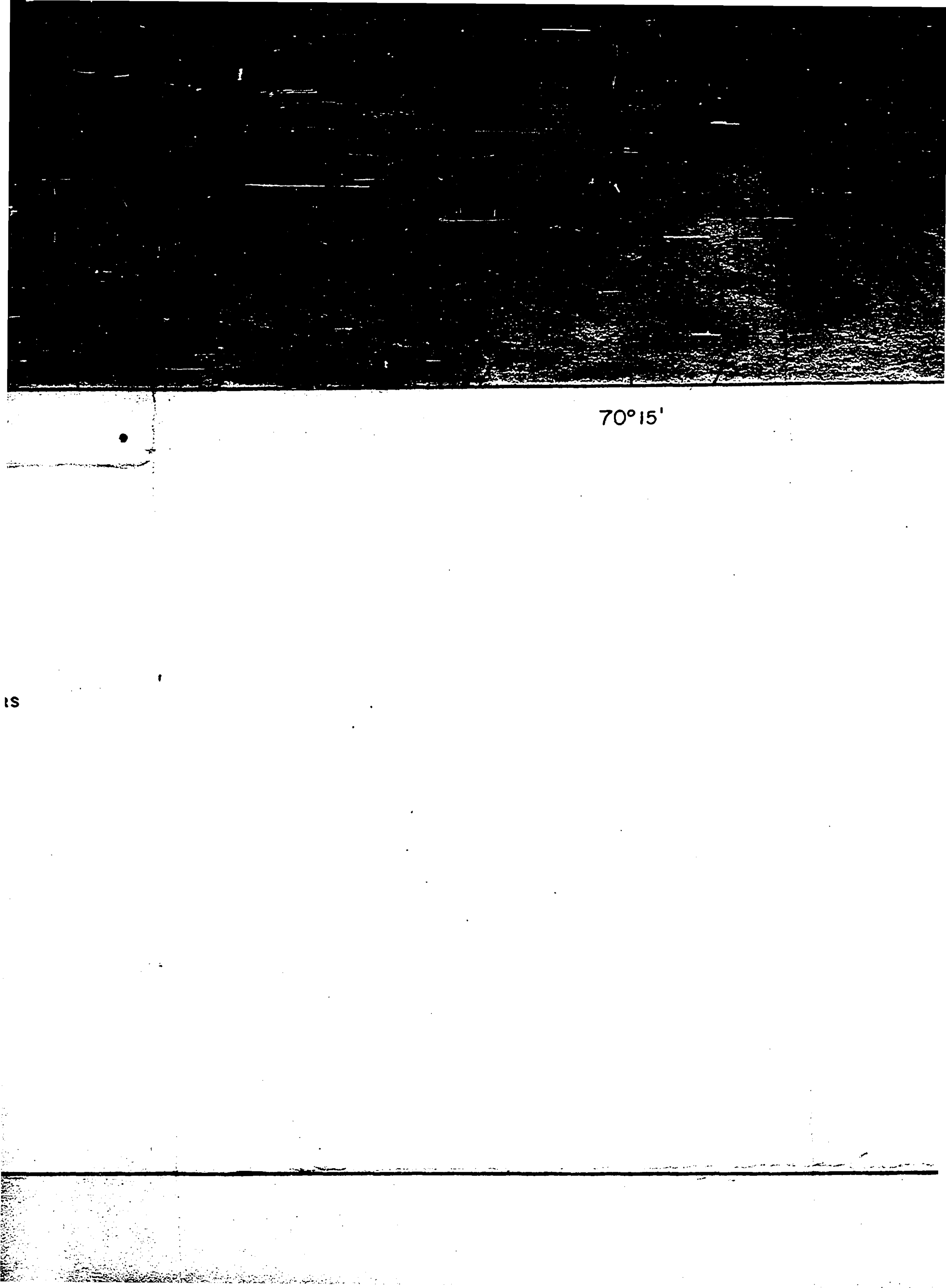
70° 3

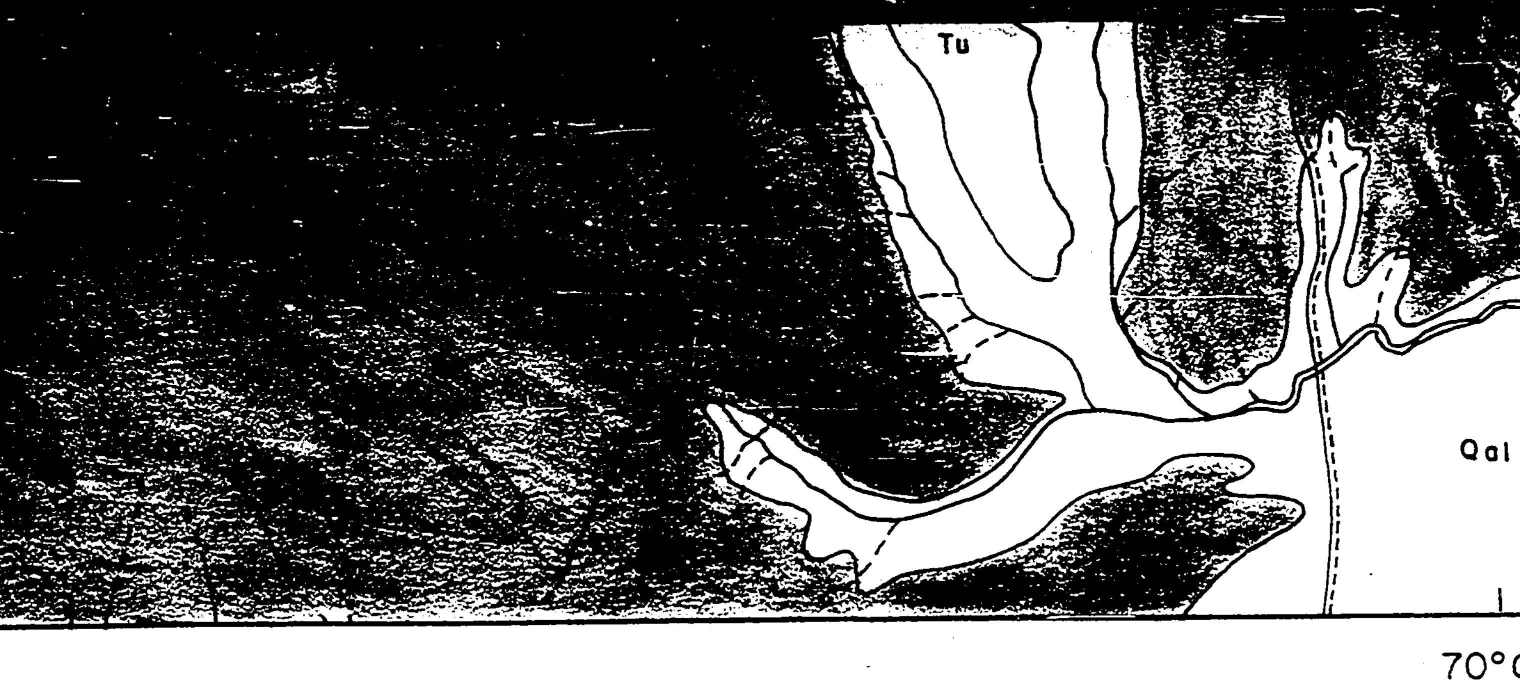
	QUATERNARY		**PLUTONIC ROCKS**
Qm	MORAINES		GRANODIORITE - DIORITE
Qal	ALLUVIAL		RHYOLITE
	TERTIARY	sp	SANIDINE PORPHYRY
	SILLAPACA FM.		
Tu	UMAYO BASALTS		THRUST
	PUNO GP.	U / D	NORMAL FAULT
	MESOZOIC		
Kmñ	CRETACEOUS, MUÑANI FM.	—?—?—?-	PROBABLE FAULT
Kv	,, VILQUECHICO FM.		STRIKE SLIP FAUL
Kc	,, COTACUCHO FM.		
	,, TRACHYTE VOLCS.		COVERED FAULT
	,, MOHO GP.		Q. ALLUVIAL
Kh	,, HUANCANE GP.		CONTACT
	JURASSIC, LAGUNILLAS GP.		
Jlq	QUARTZITE		FOLIATION
	SHALE	5	BEDDING
	LIMESTONE		
	PALEOZOIC		
	DEVONIAN, CABANILLAS GP.		VERTICAL BEDDIN

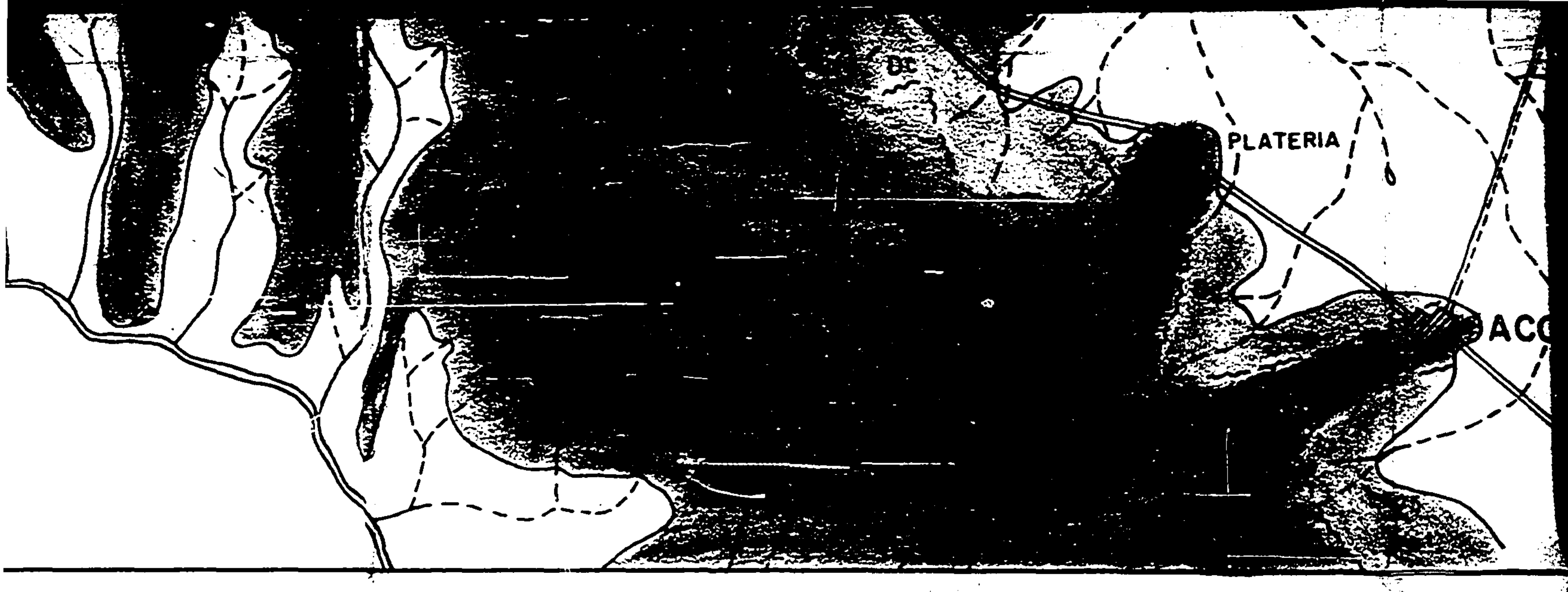
70° 30'

ONIC ROCKS
IORITE - DIORITE
ITE
NE PORPHYRY
IRUST
ORMAL FAULT
ROBABLE FAULT
TRIKE SLIP FAULT
OVERED FAULT
. ALLUVIAL
ONTACT
OLIATION
EDDING
ERTICAL BEDDING

UNCONFORMITY
ANTICLINE
SYNCLINE
RAILROAD
HIGHWAY
6074 ELEVATION IN METERS
MINE


70°15'

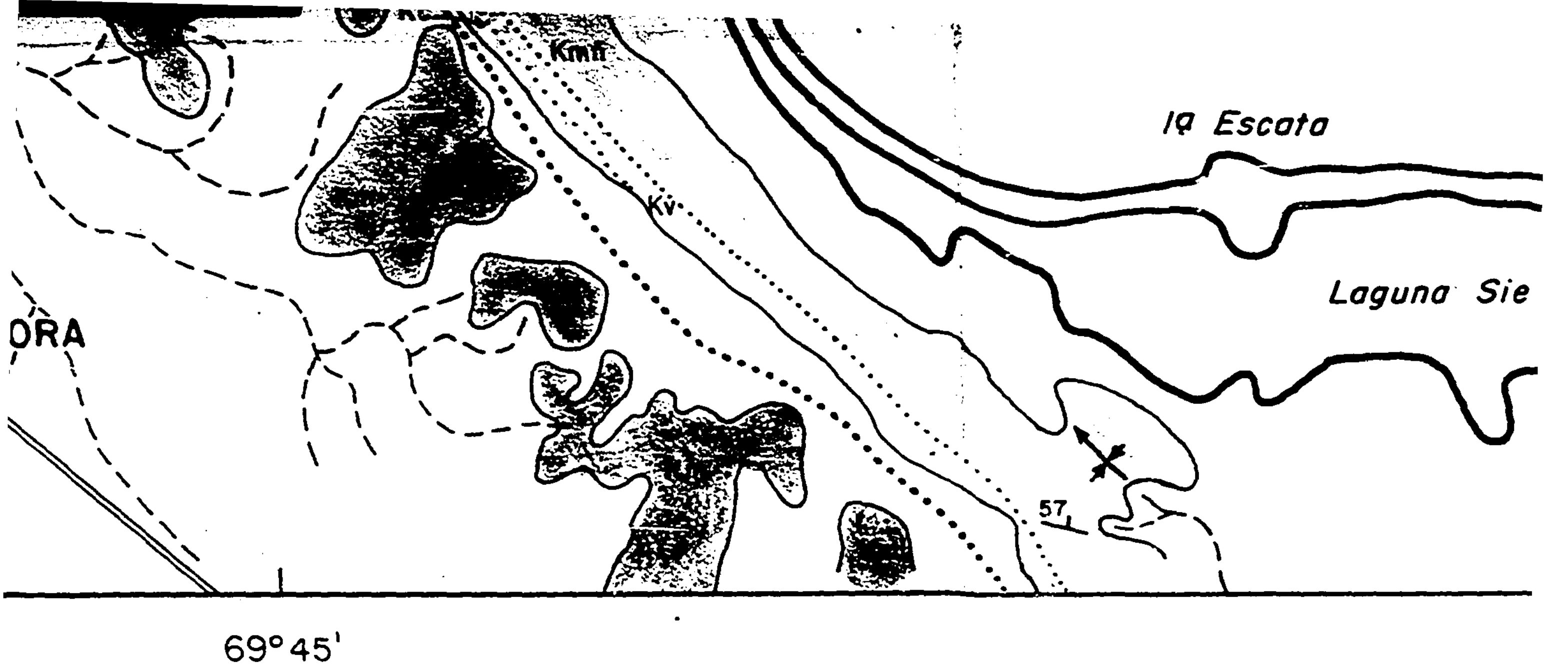

Tu
Qal



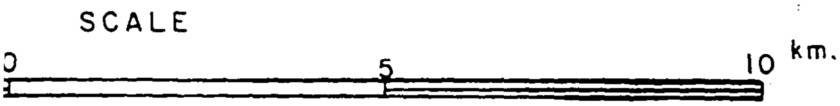
GEOLOGICAL MAP OF THE F

5 4 3 2 1 0

1:



PUNO-SANTA LUCIA AREA, SO



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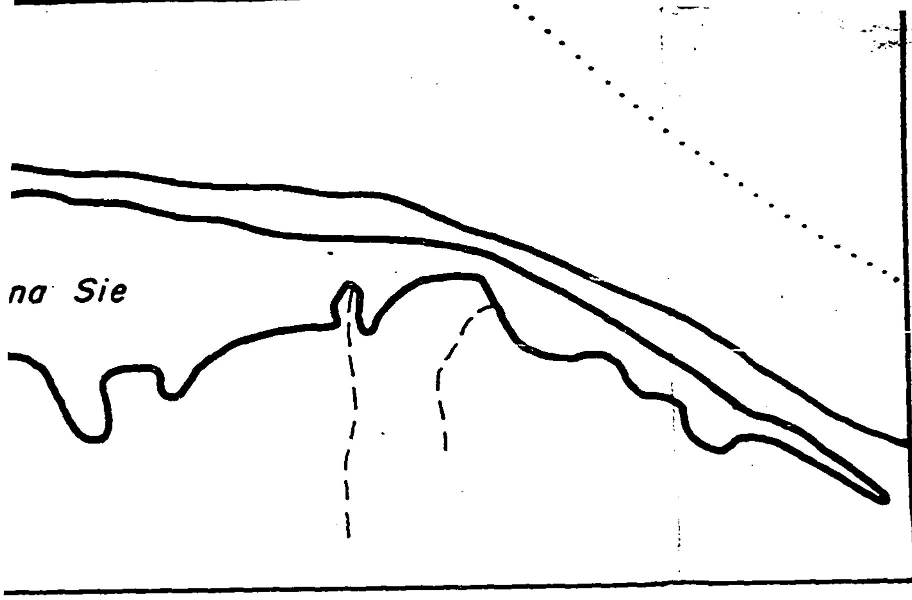
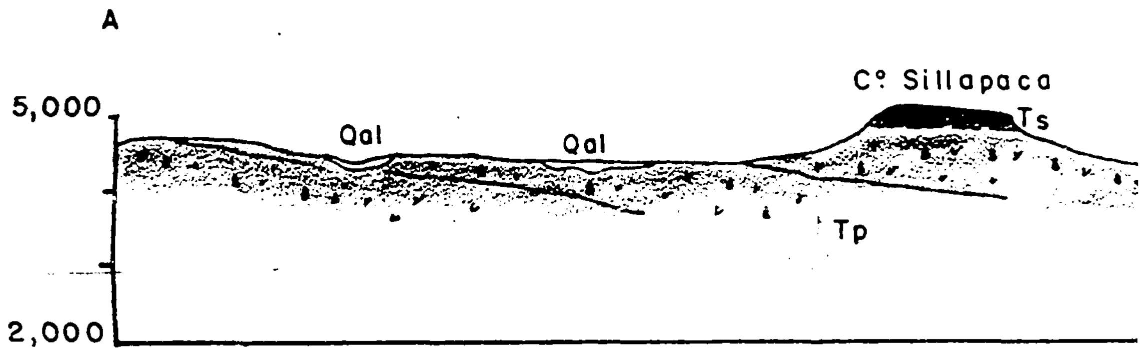


69° 30'

SOUTHERN PERU

J. PORTUGAL



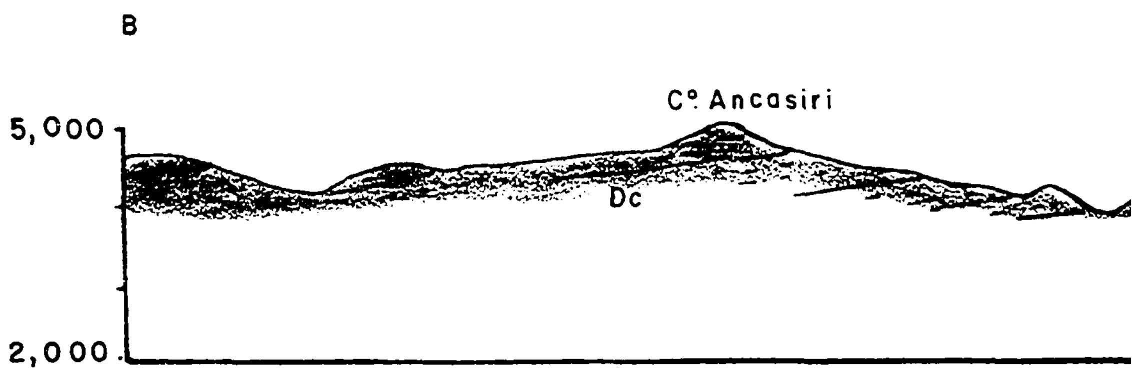
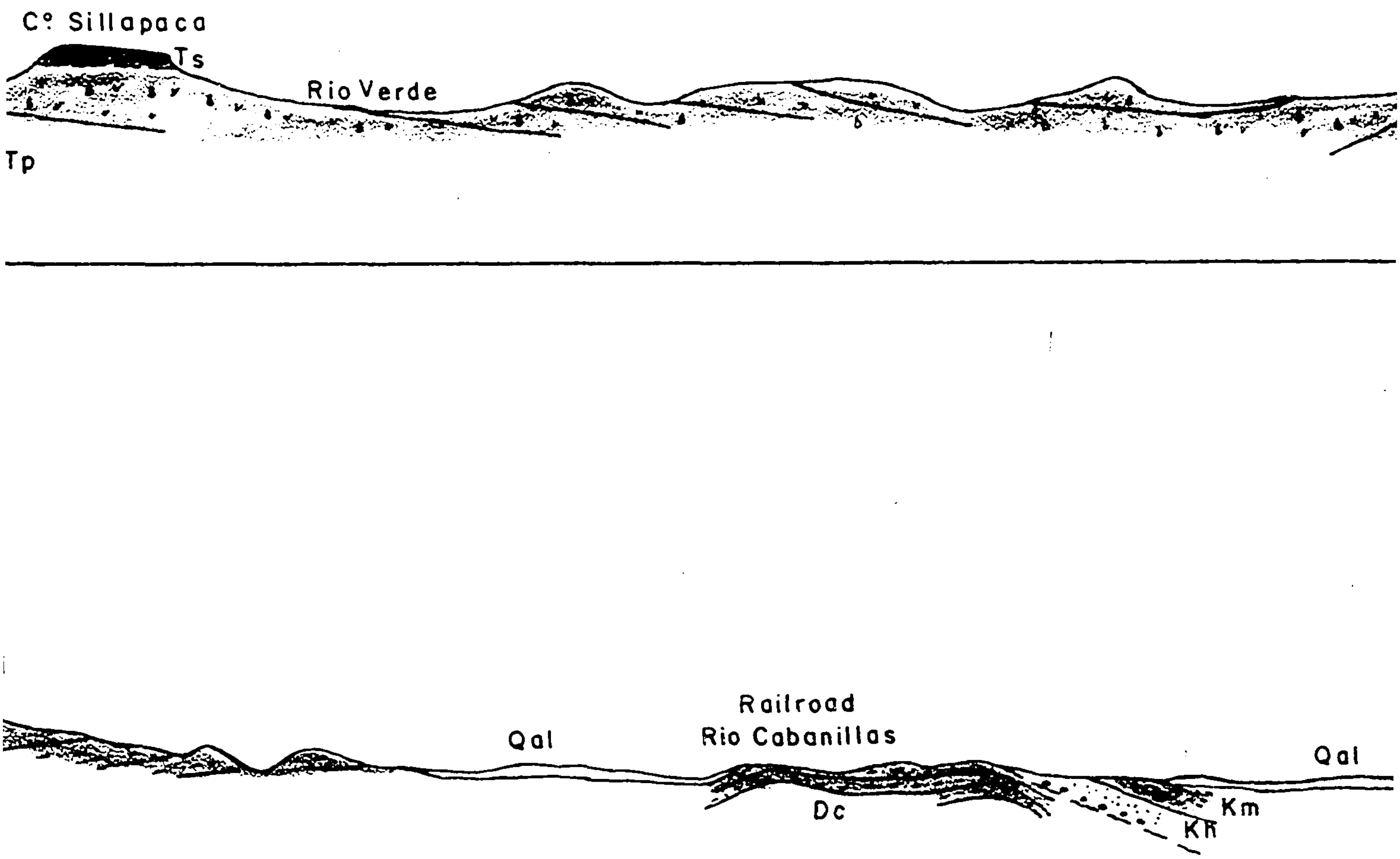
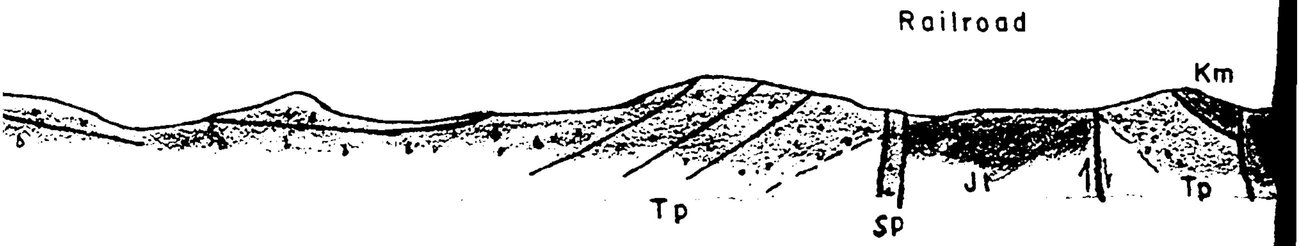


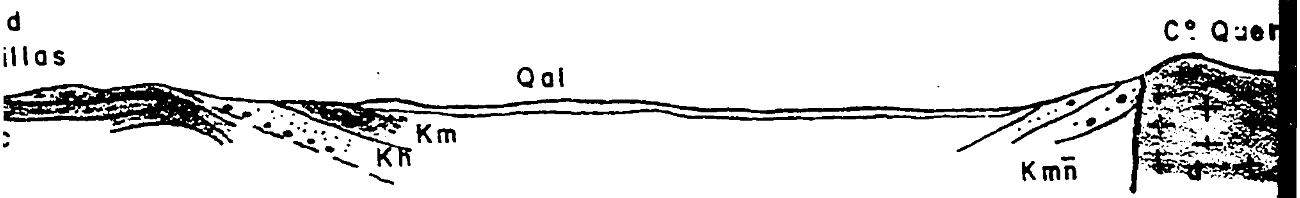
plate 2 CROSS-SECTIONS ALONG THE LIN



G THE LINES AA'- BCD, OF THE GEOLOGICAL M/

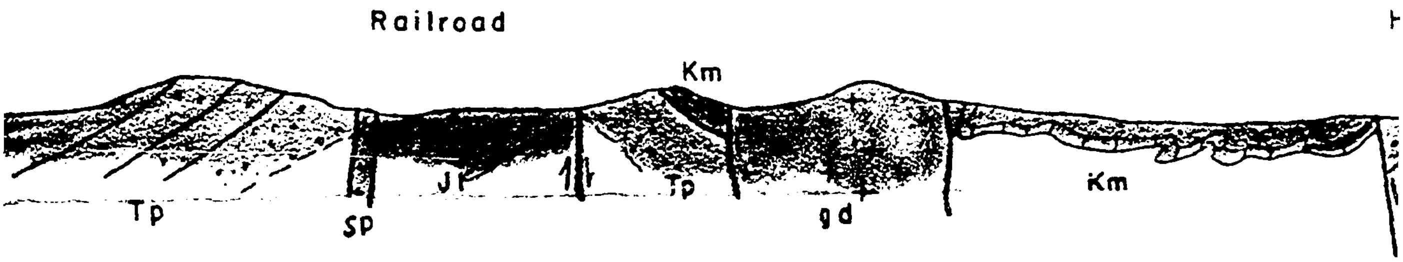


C

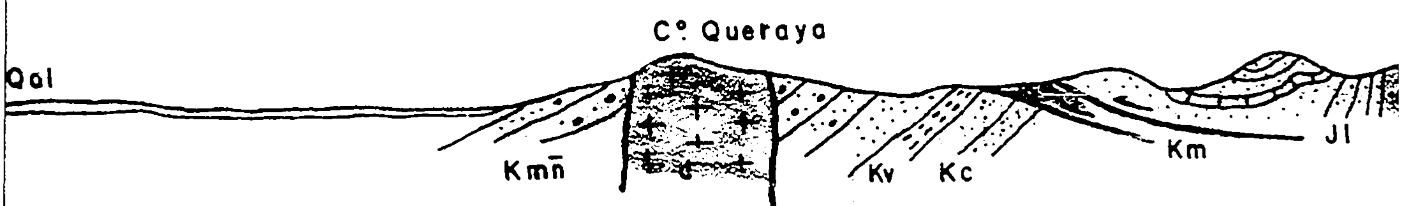


Scale 1:100,000

HE GEOLOGICAL MAP, SYMBOLS AS IN TH

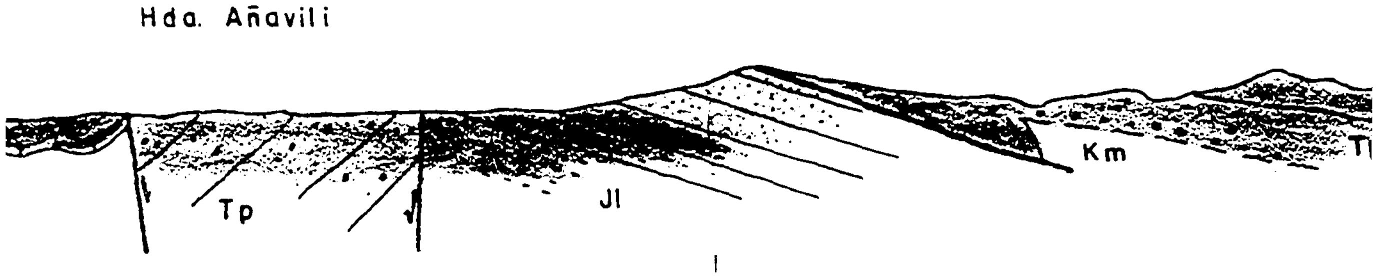


C

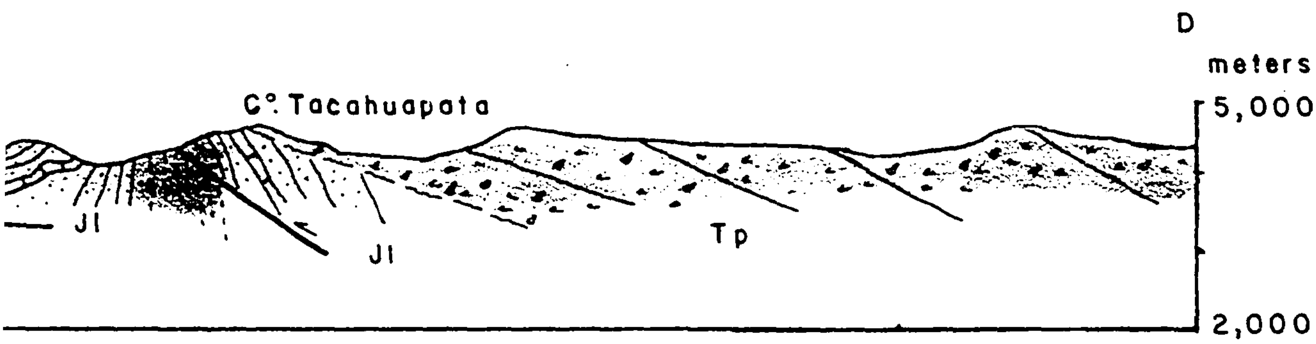


Scale 1:100,000

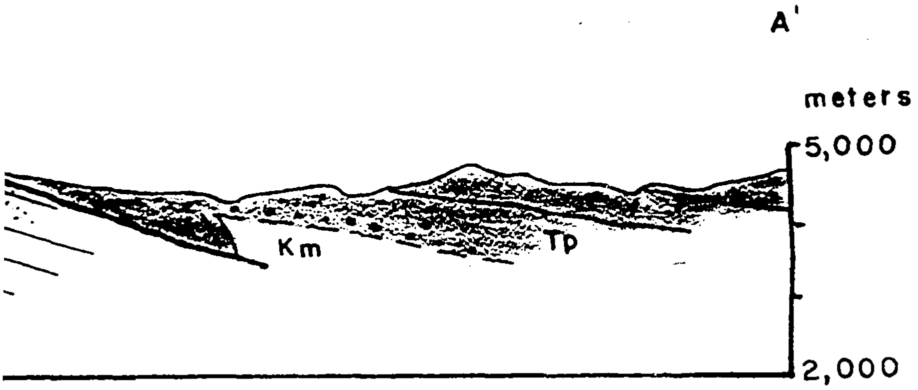
MAP, SYMBOLS AS IN THE MAP

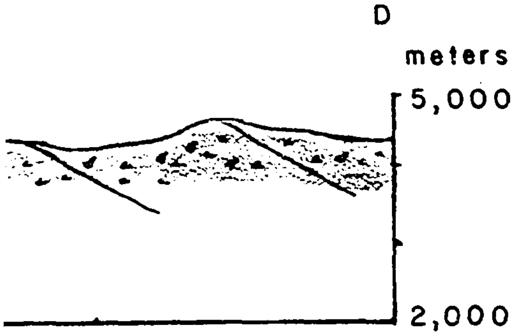


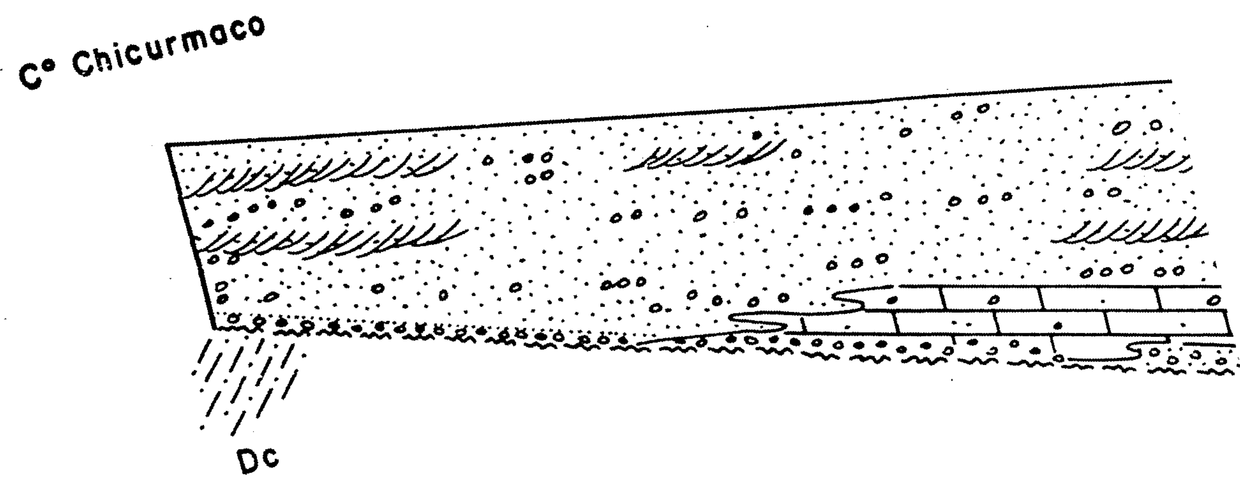
Hda. Añavili
Tp
Jl
Km
Tl

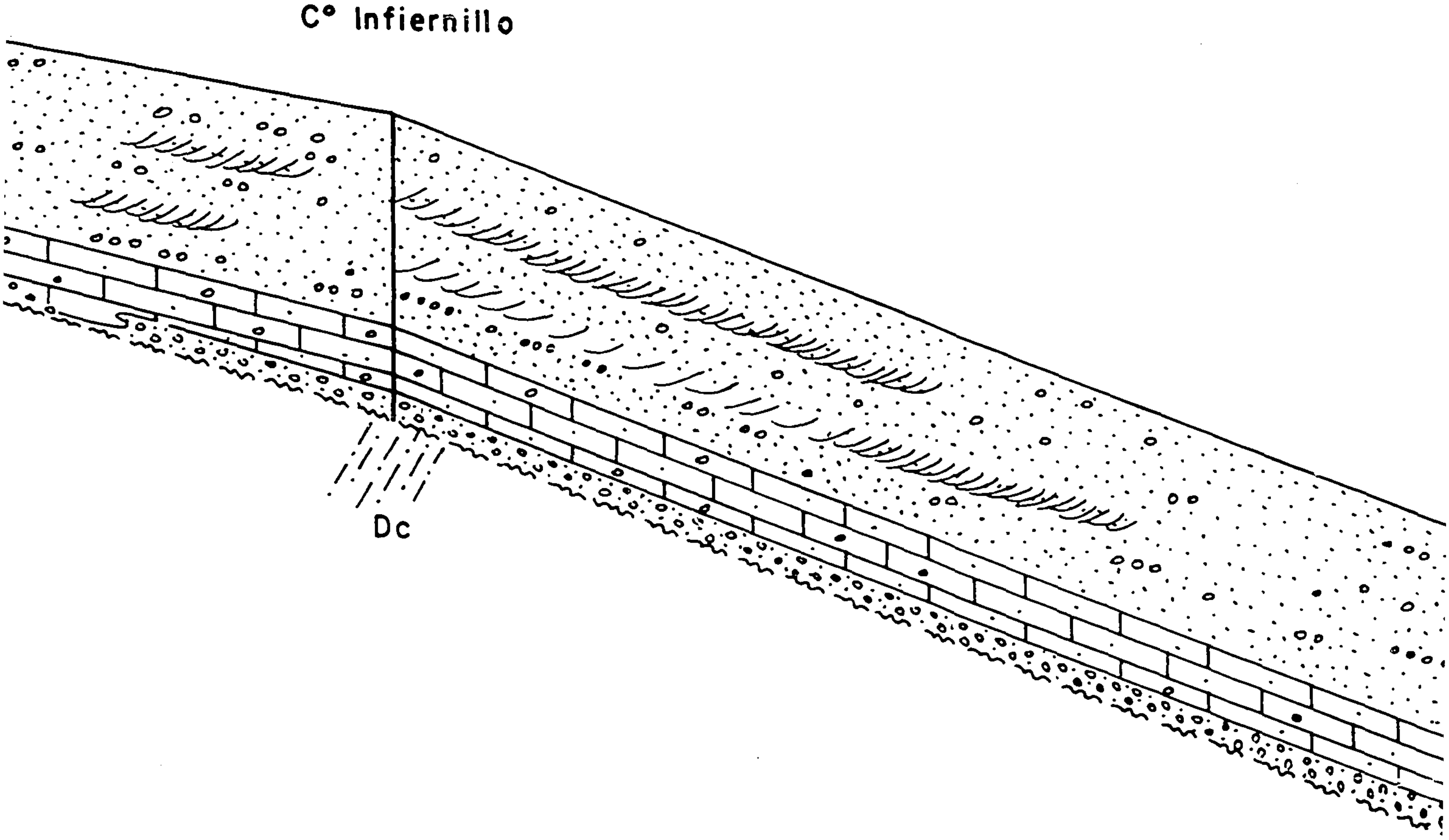


D
meters
C°. Tacahuapata
5,000
Jl
Jl
Tp
2,000

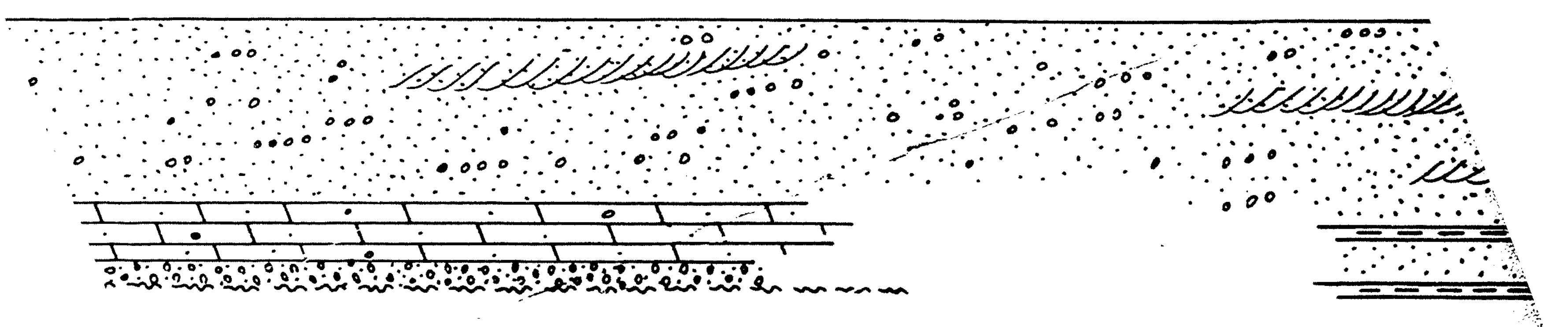

A'
meters
5,000
Km
Tp
2,000

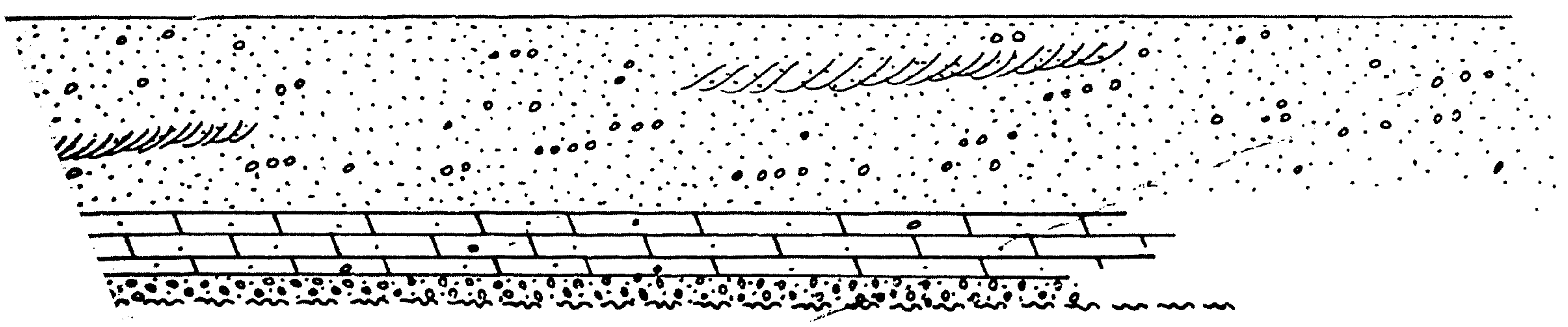

D
meters
5,000
2,000

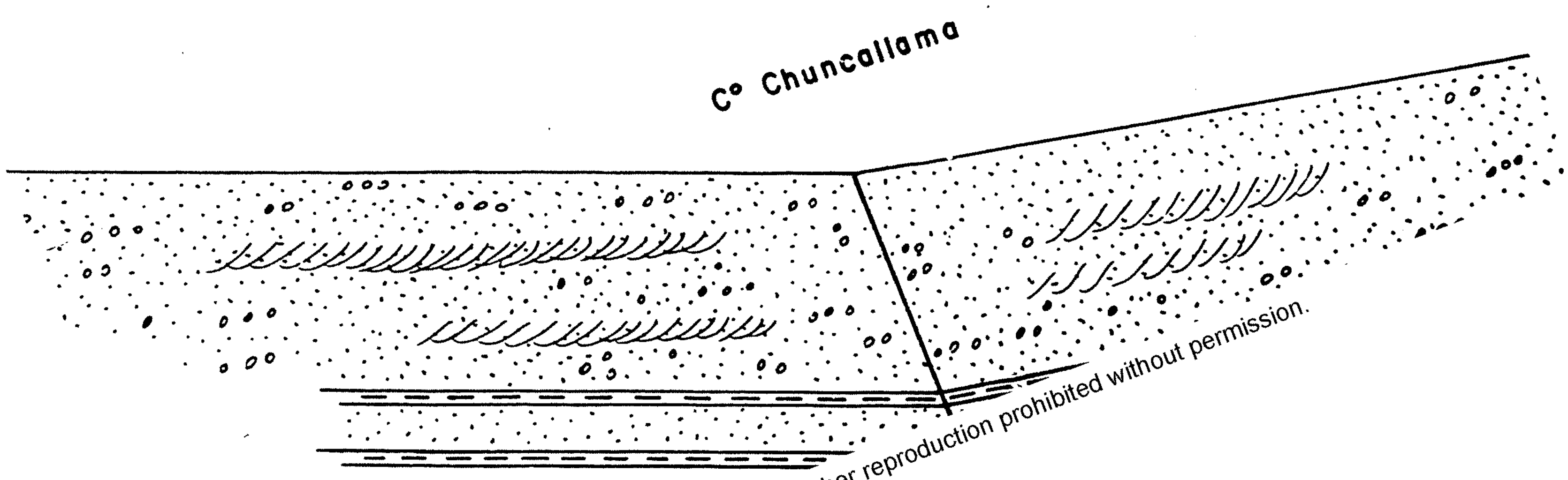

C° Chicurmaco
Dc

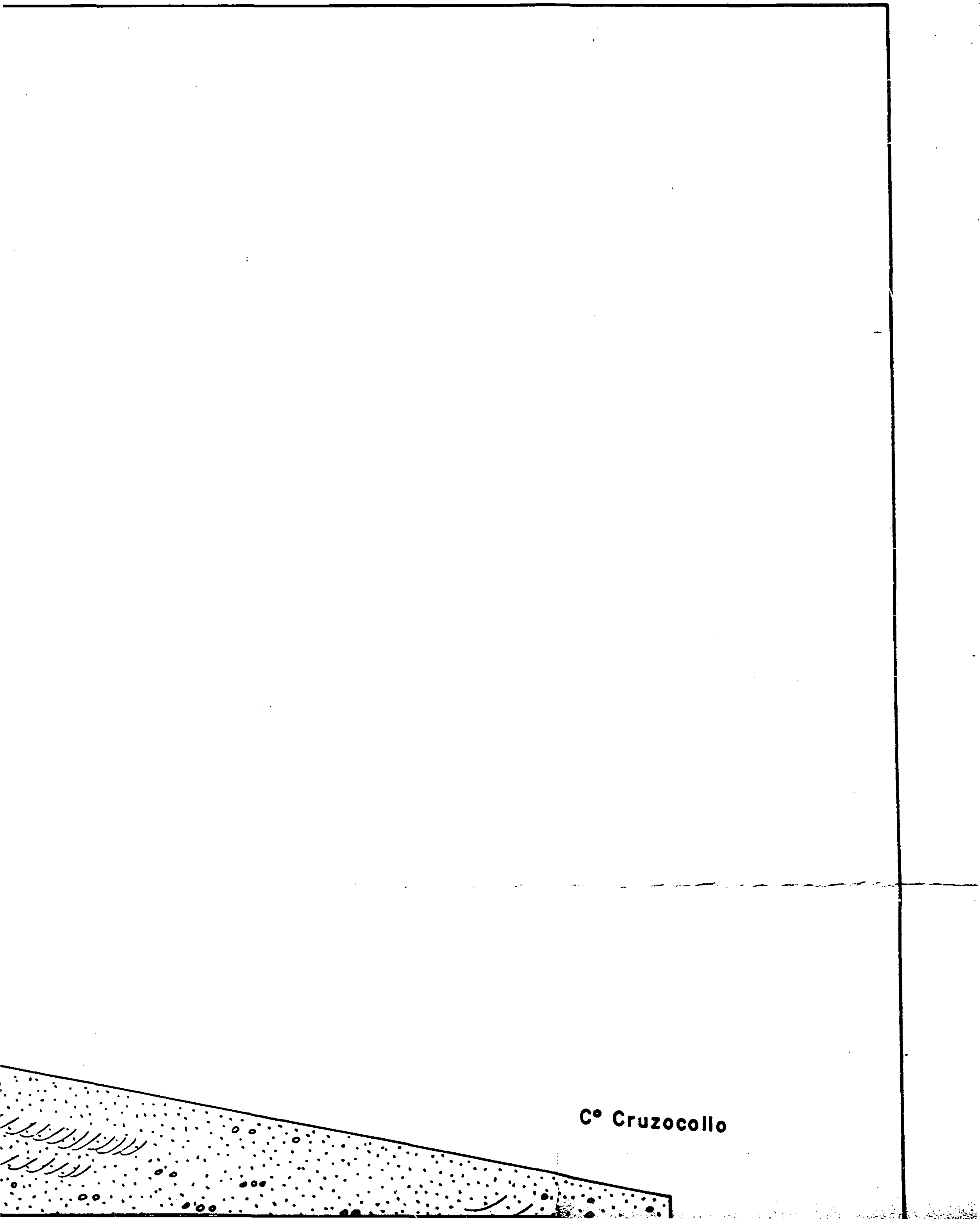


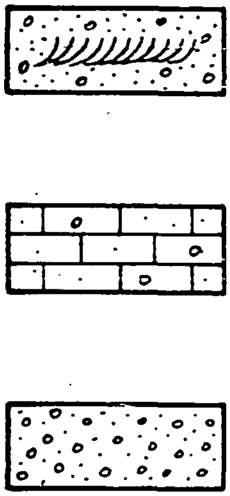
C° Infiernillo
Dc






Cº Chuncallama


C° Cruzocollo



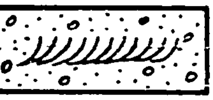
X – bed

Limest

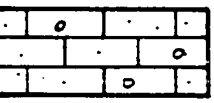
Conglo

Dc — Devonian : (

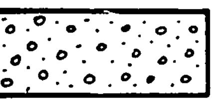
plate 3 FENCE DIAGRAM SHOWING THE DISTRIBU



X - bedded Ss.

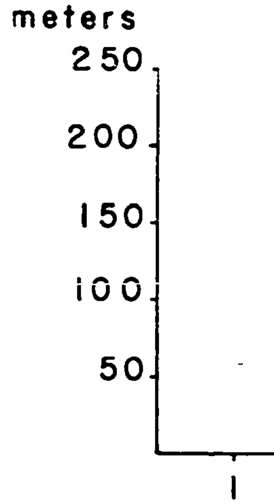


Limestone with pebbles of quartzite

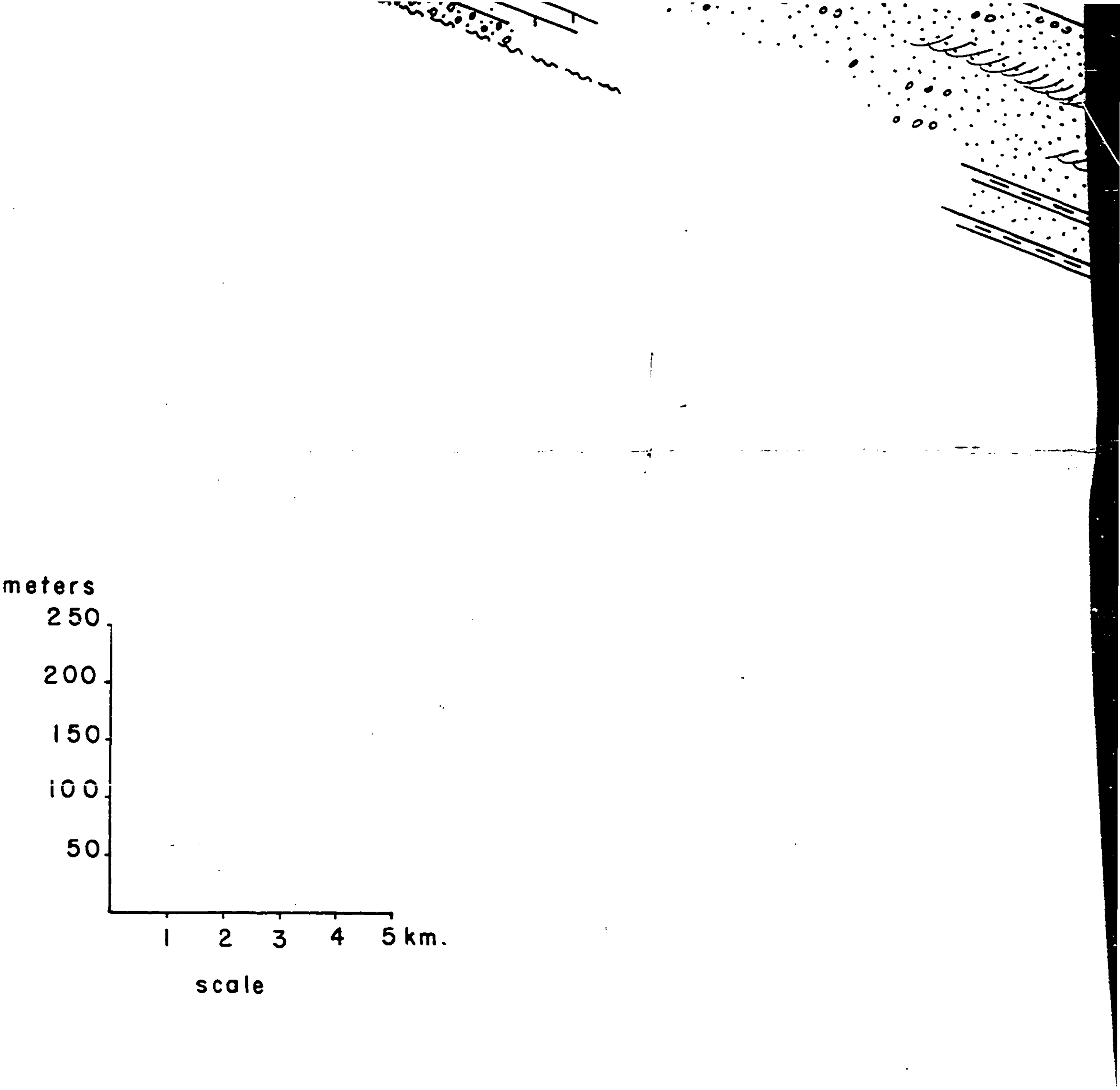


Conglomerate

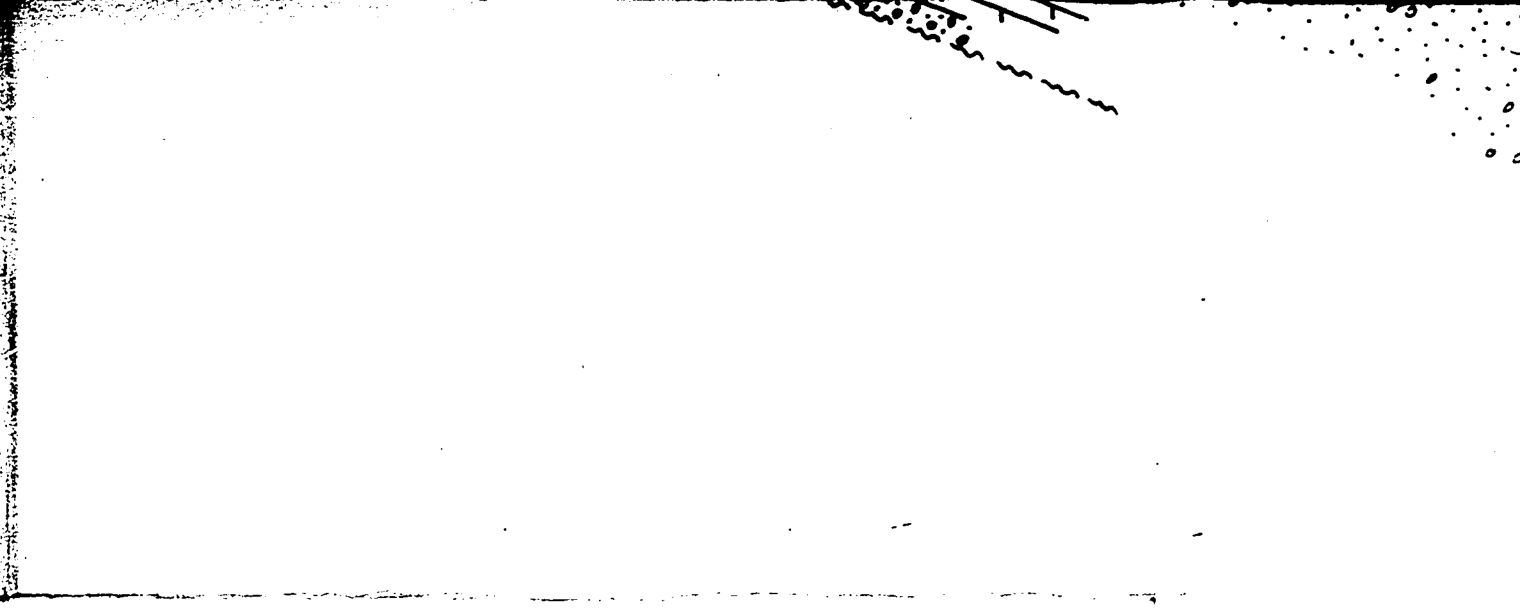
Dc — Devonian : Cabanillas Gp.

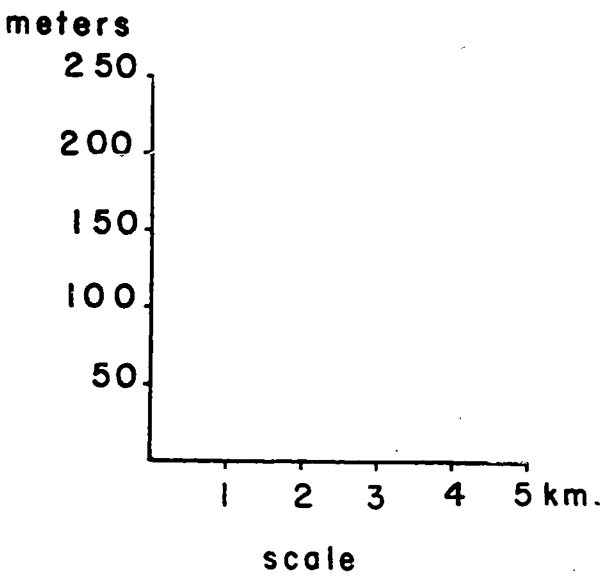


THE DISTRIBUTION OF THE HUANCANE GROUP, ITS U

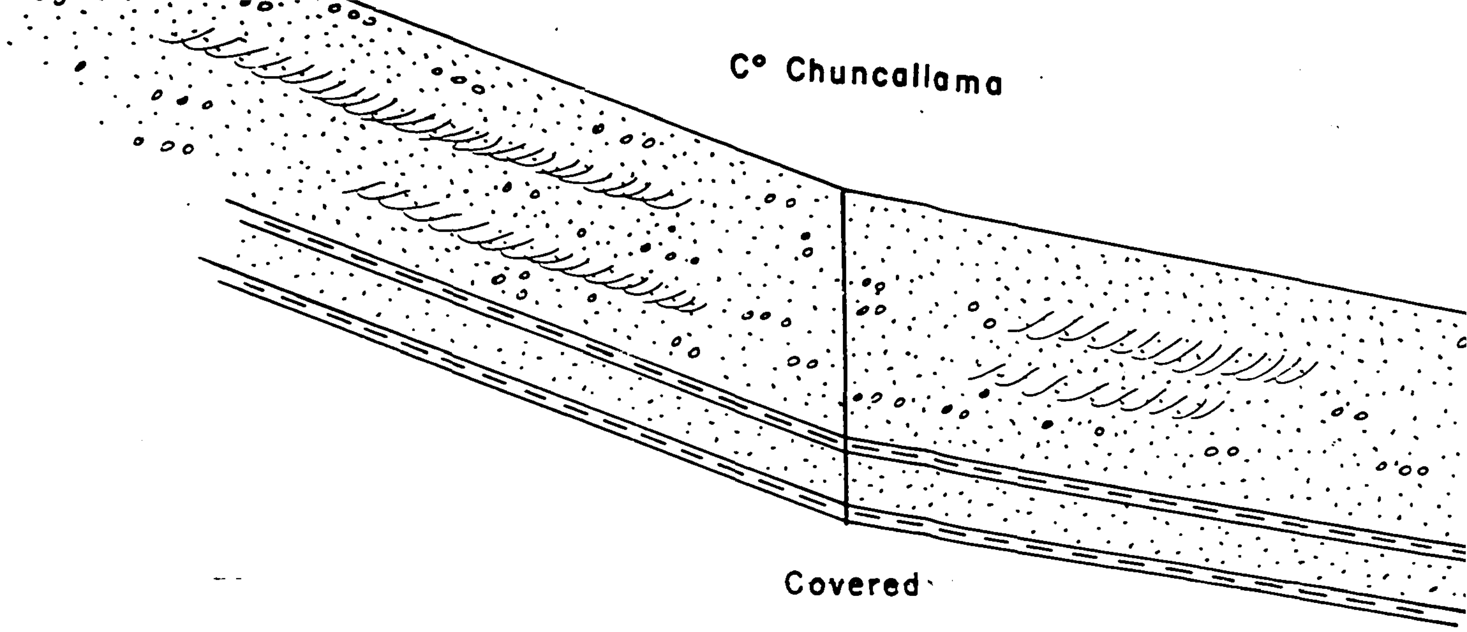


GROUP, ITS UPPER CONTACT TOWARDS THE MOHO

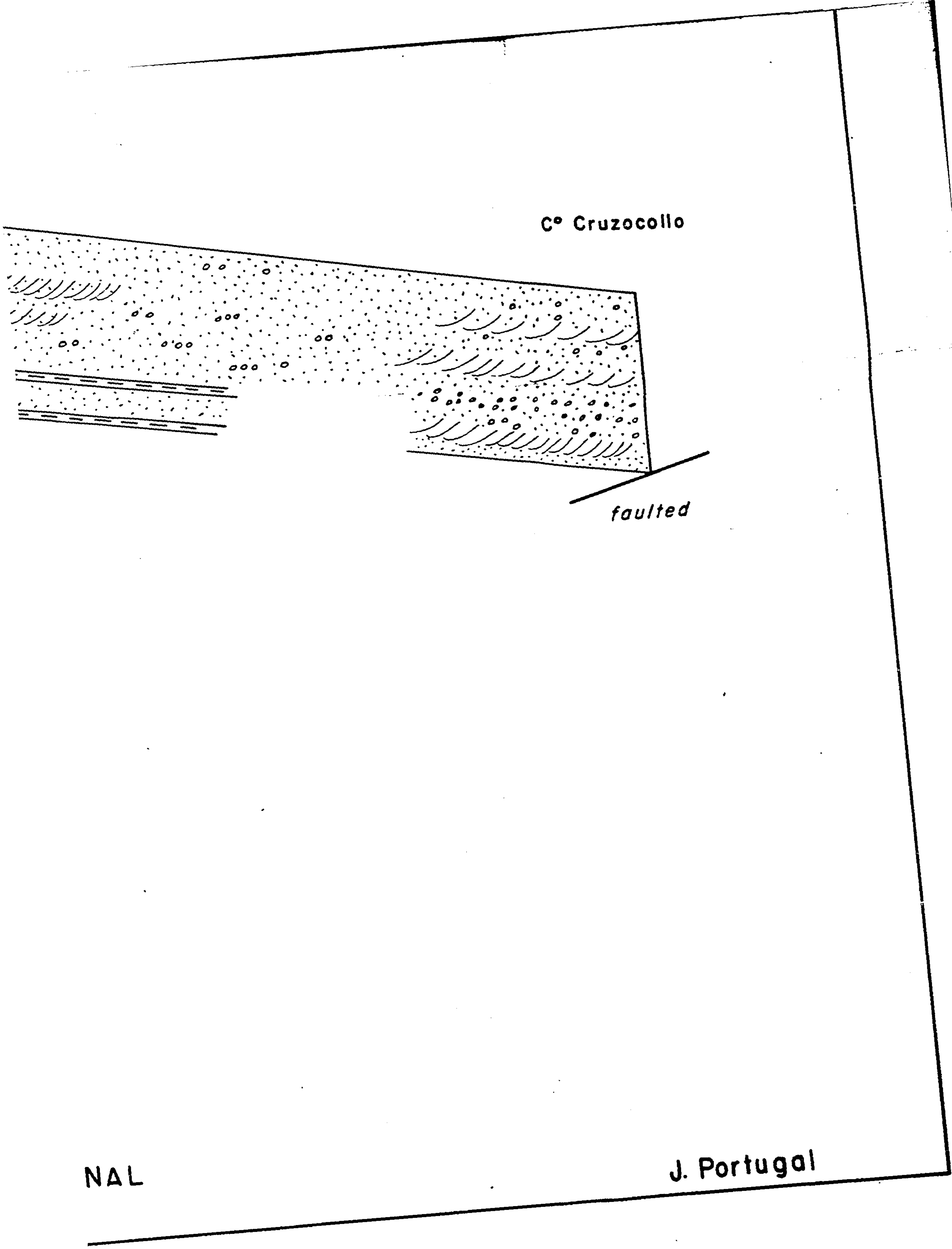




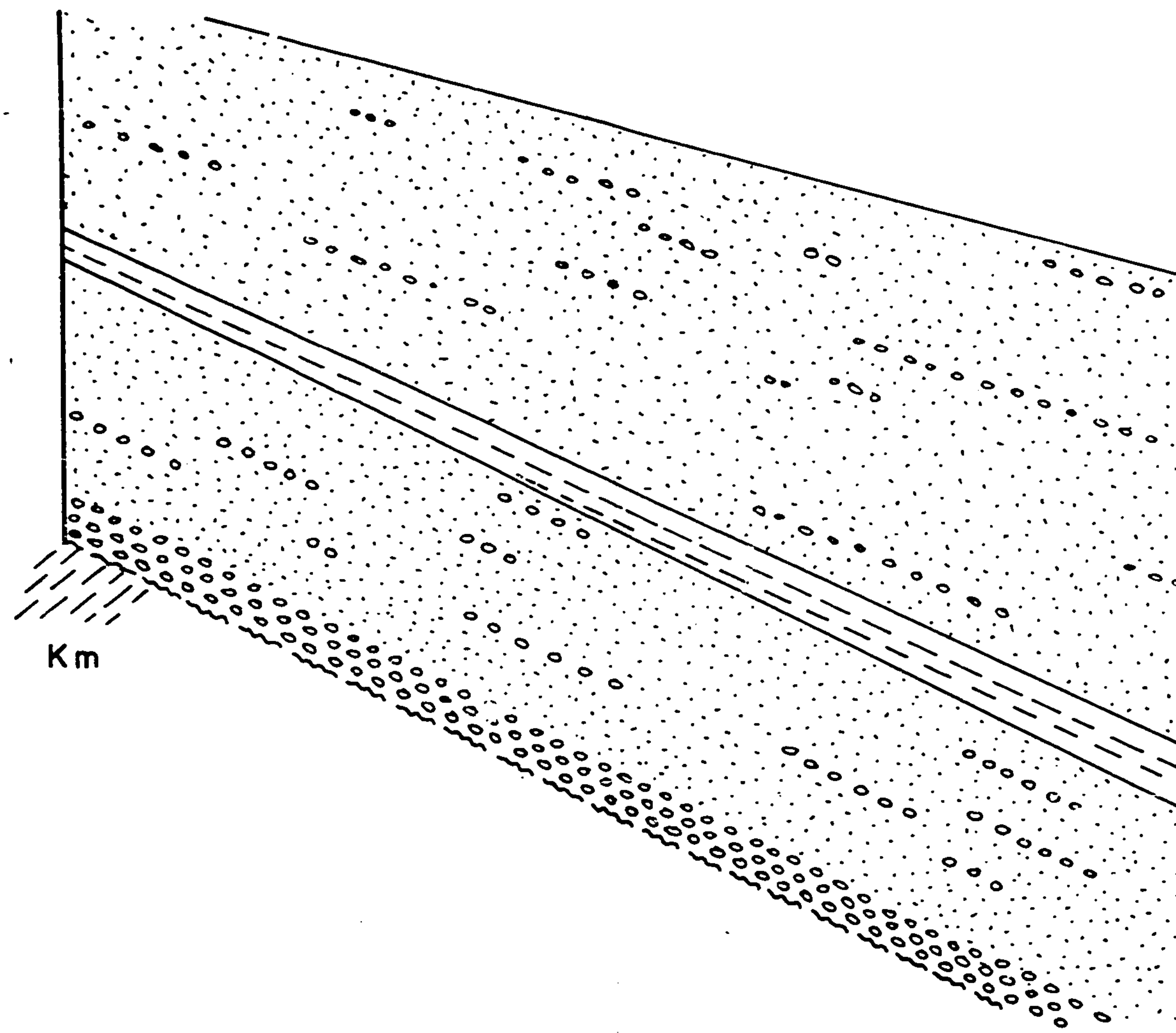
ANE GROUP, ITS UPPER CONTACT TOWARDS THE

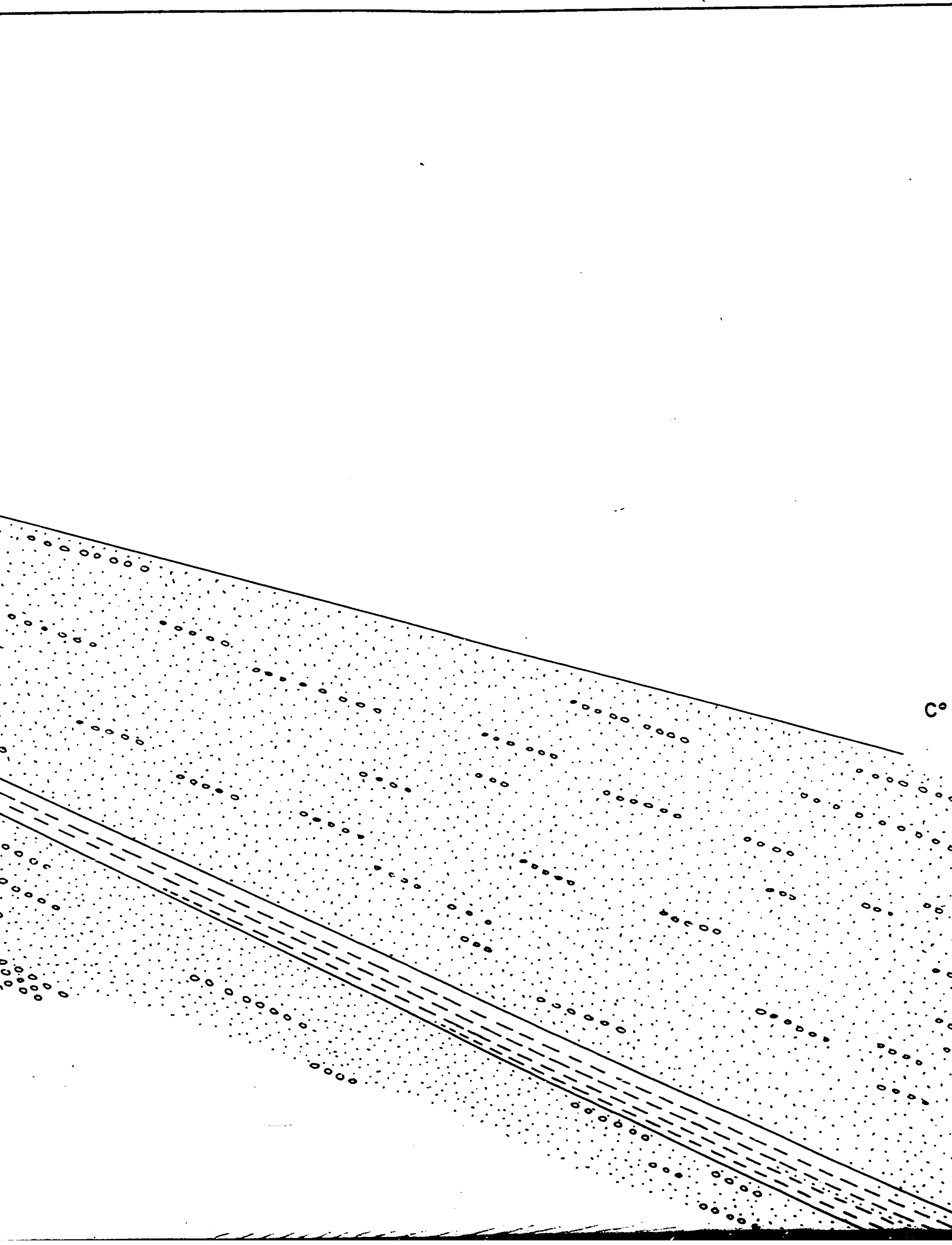


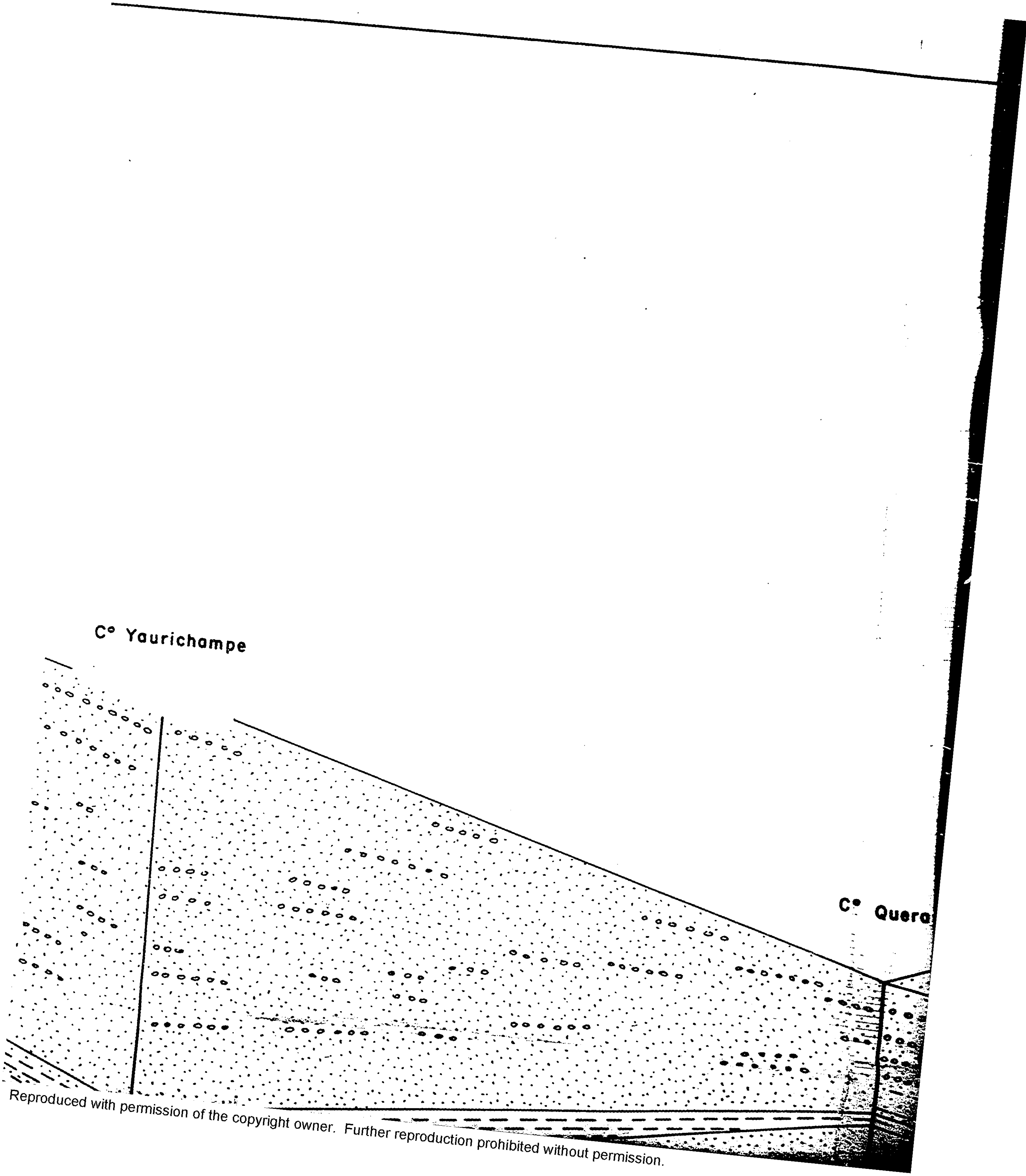
S THE MOHO GROUP IS TRANSITIONAL

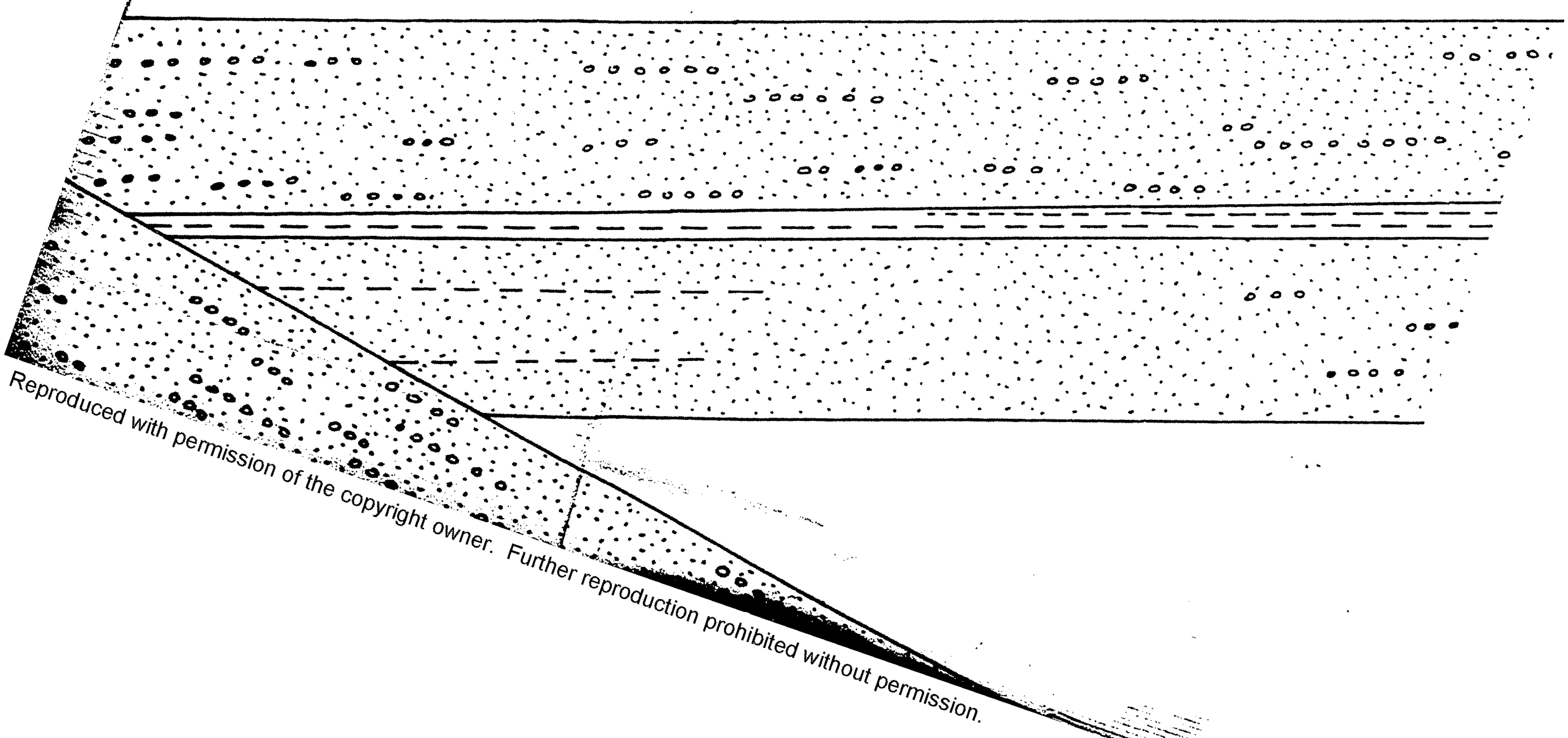

Cº Cruzocollo
faulted
NAL
J. Portugal

C° Ticalacaya

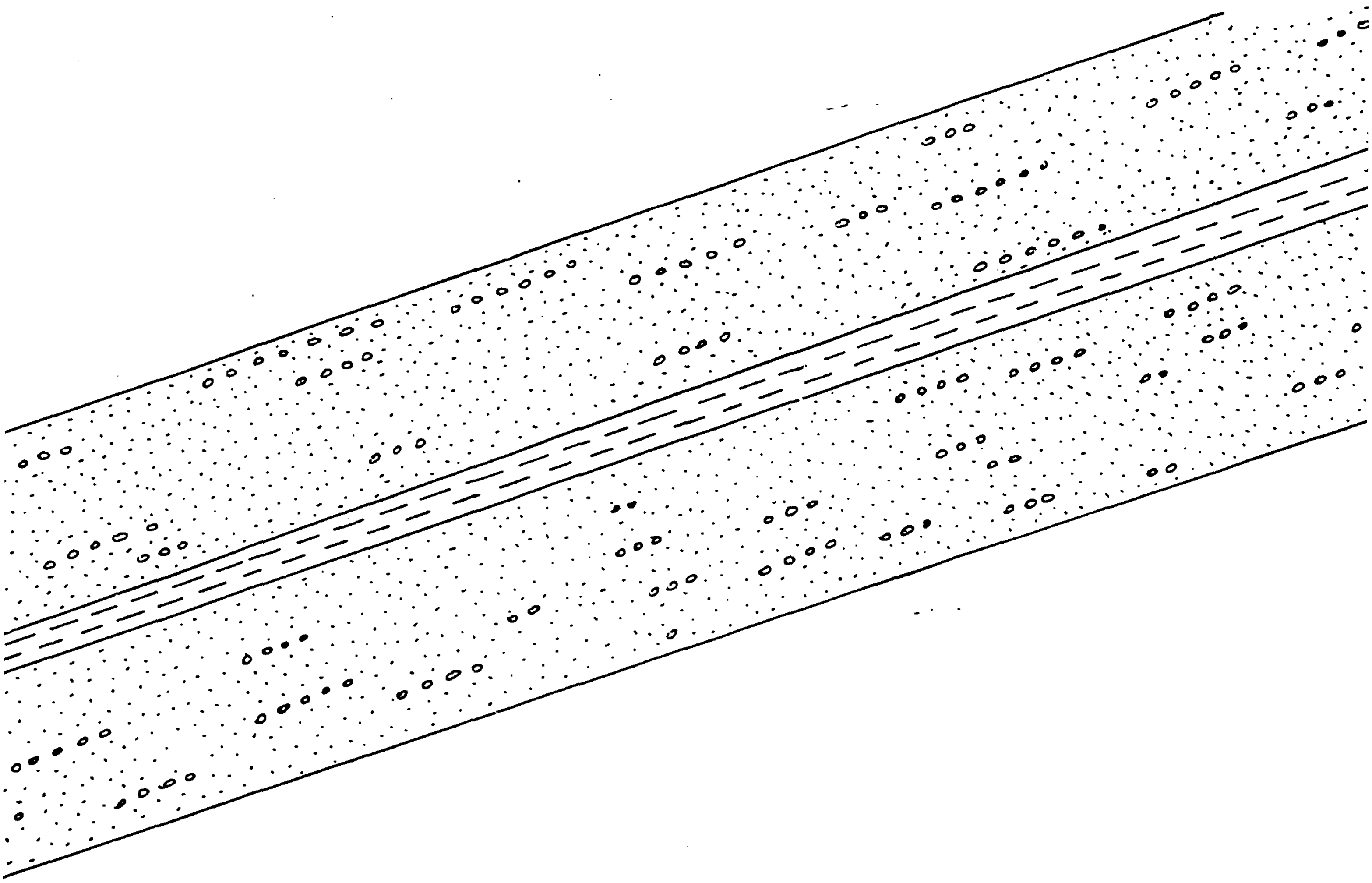


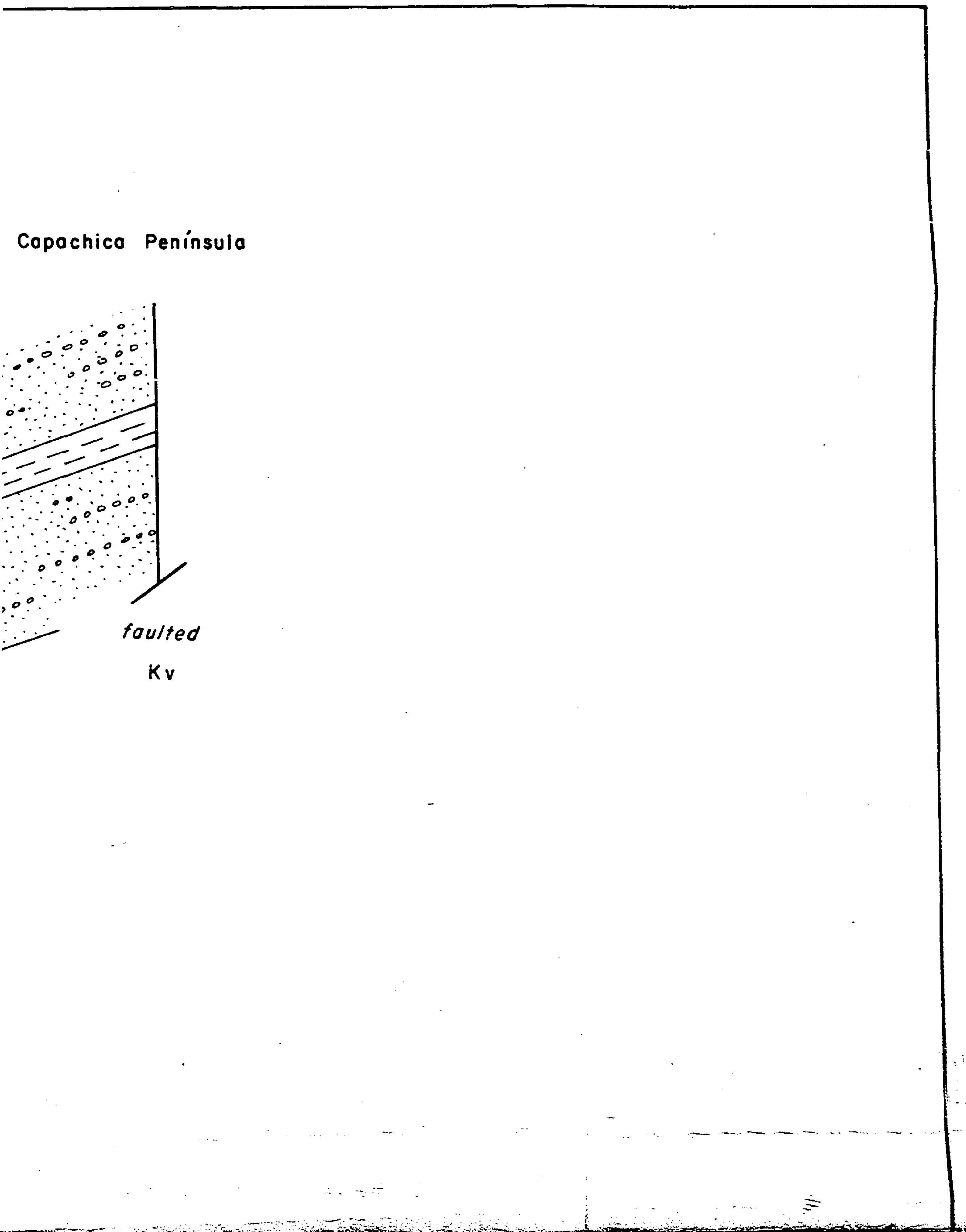

C°

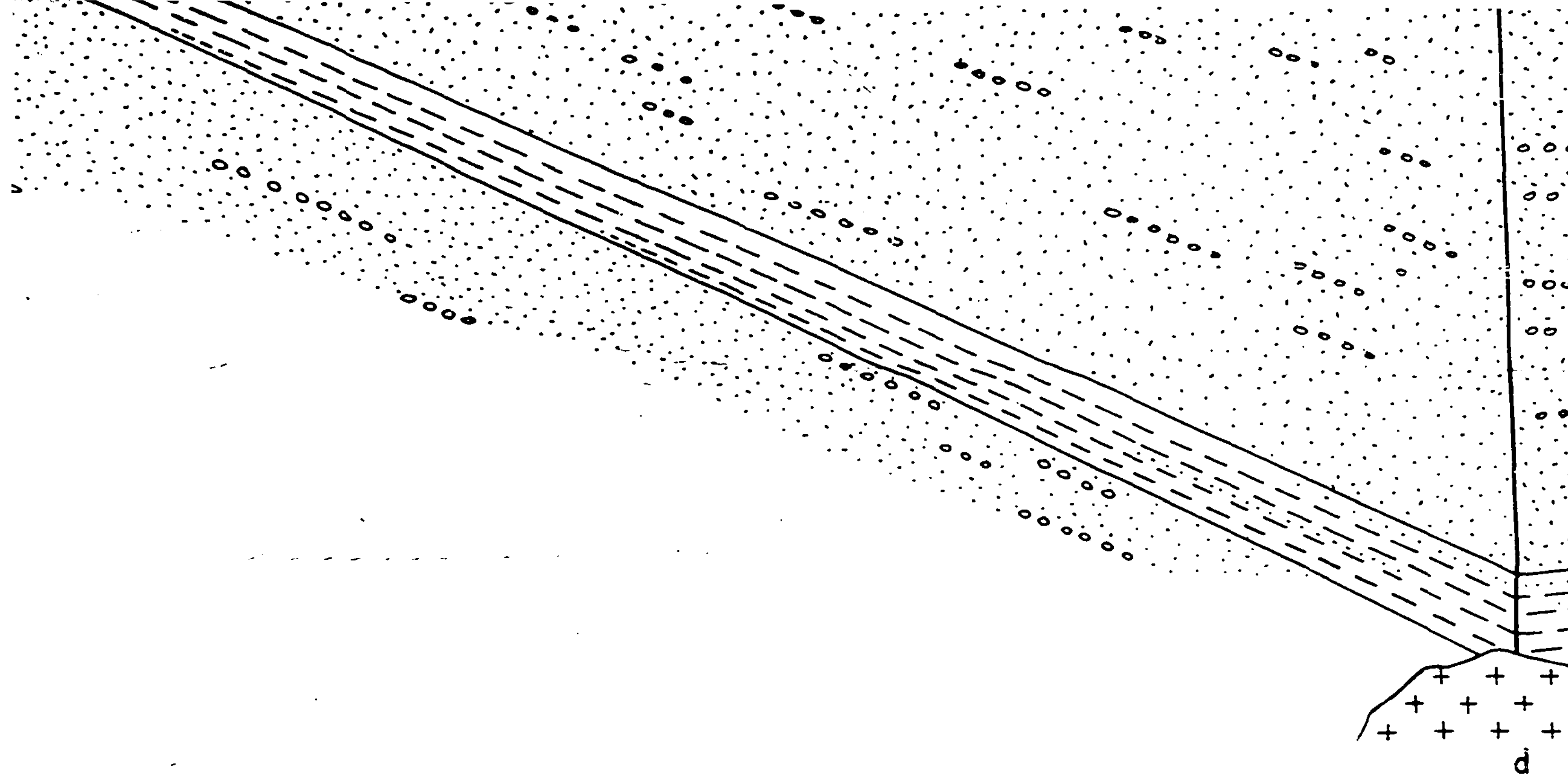

C° Yaurichampe
C° Quera



Cap




Capachica Península
faulted
Kv



Sandstone

Shale

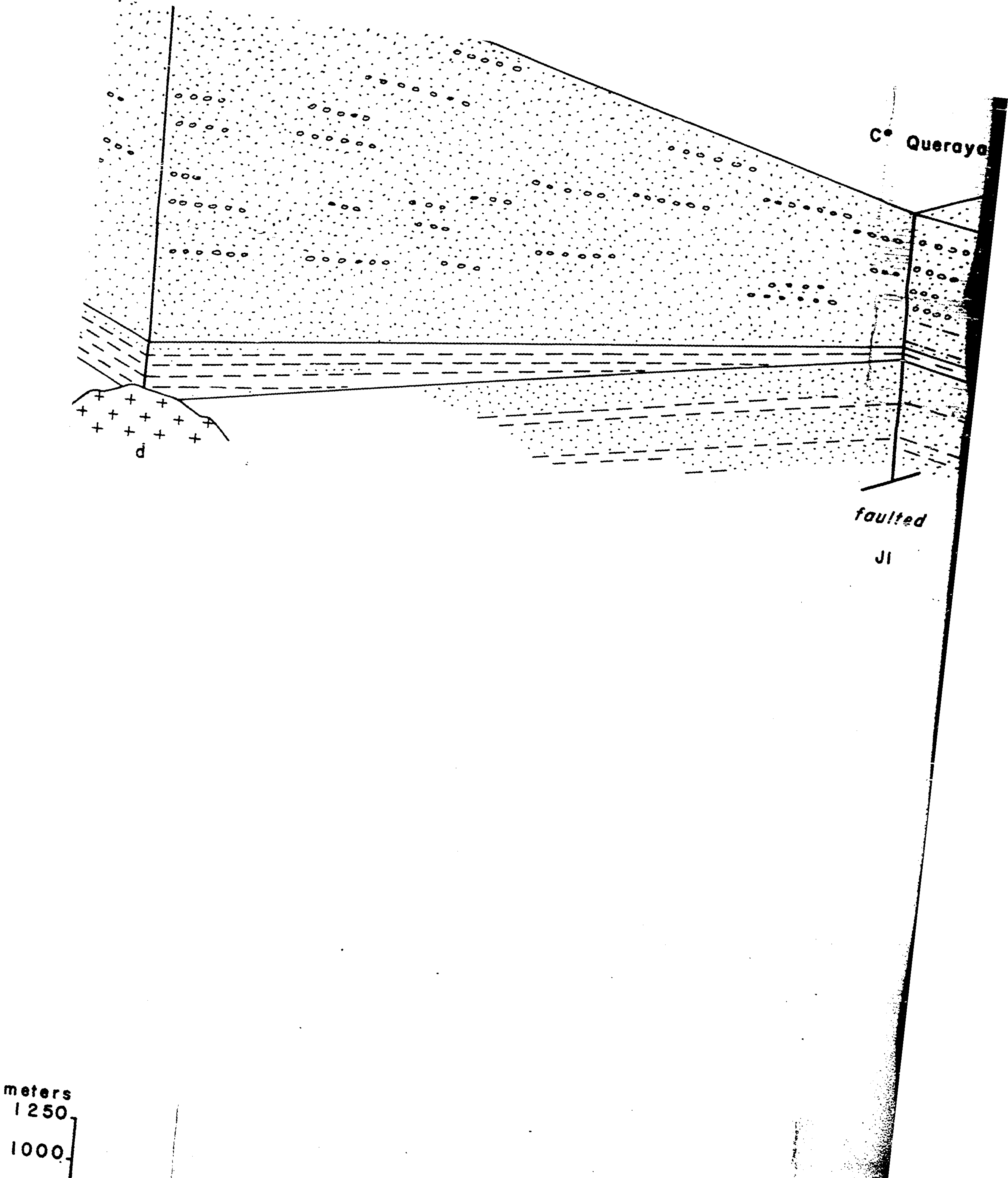
Ss. and conglomerates

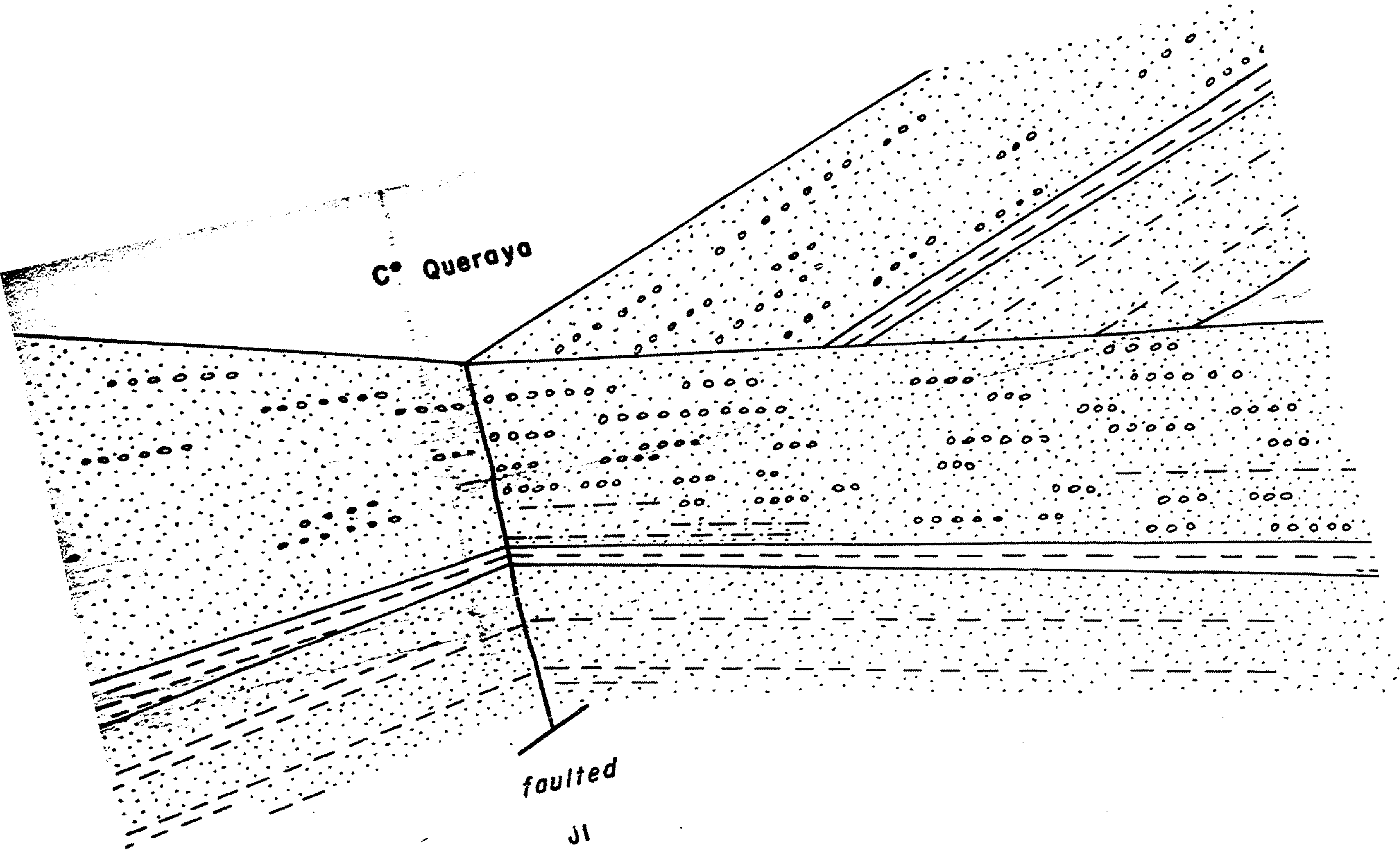
Kmñ — Cretaceous : Muñani Fm.

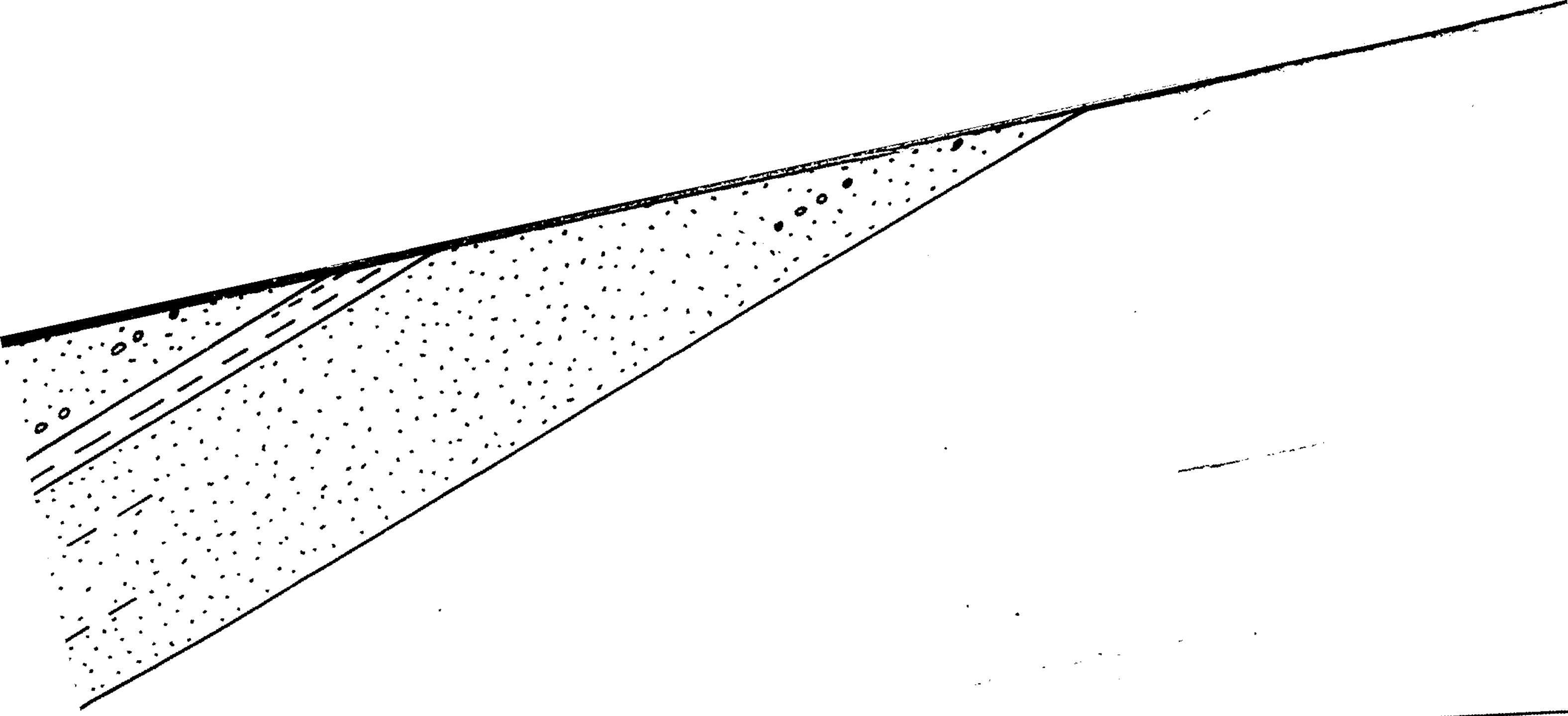
Kv — " Viiquechico Fm.

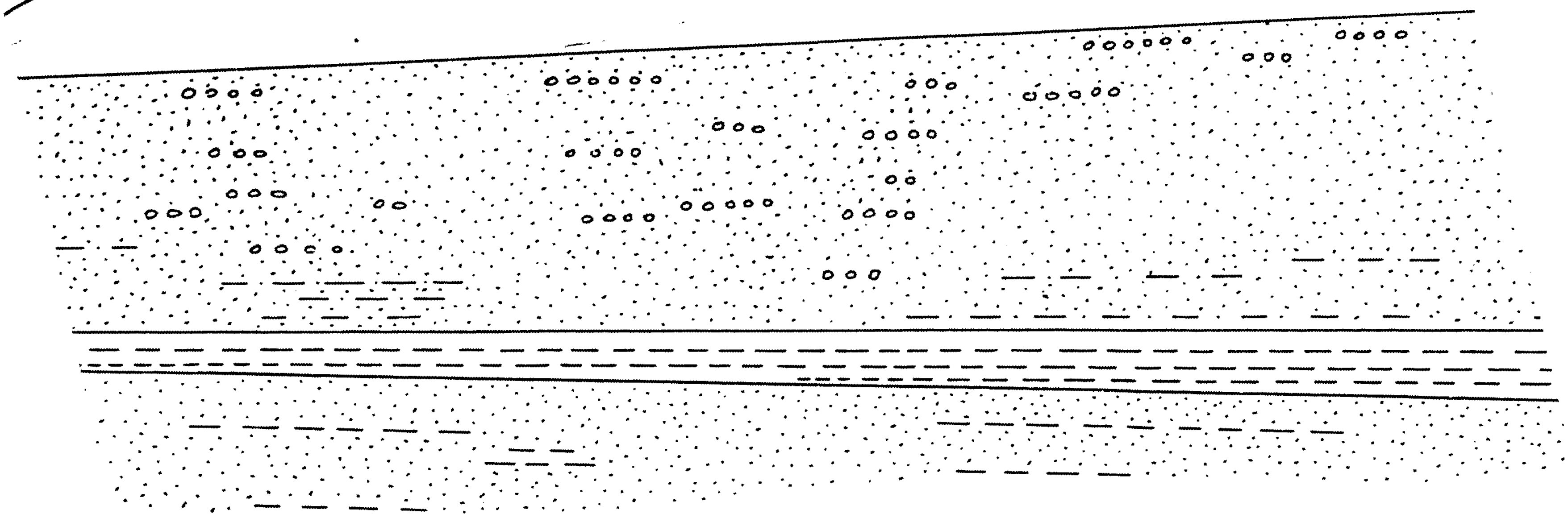
Kc — " Cotacucho Fm.

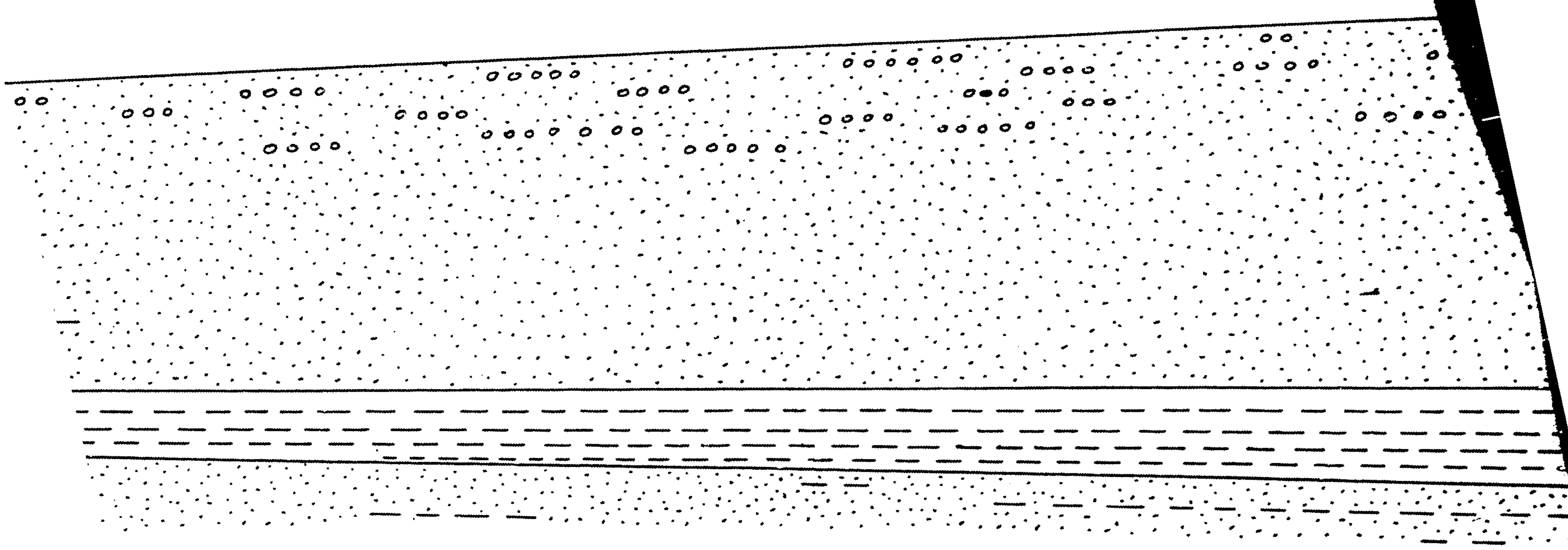
meters
1250
1000

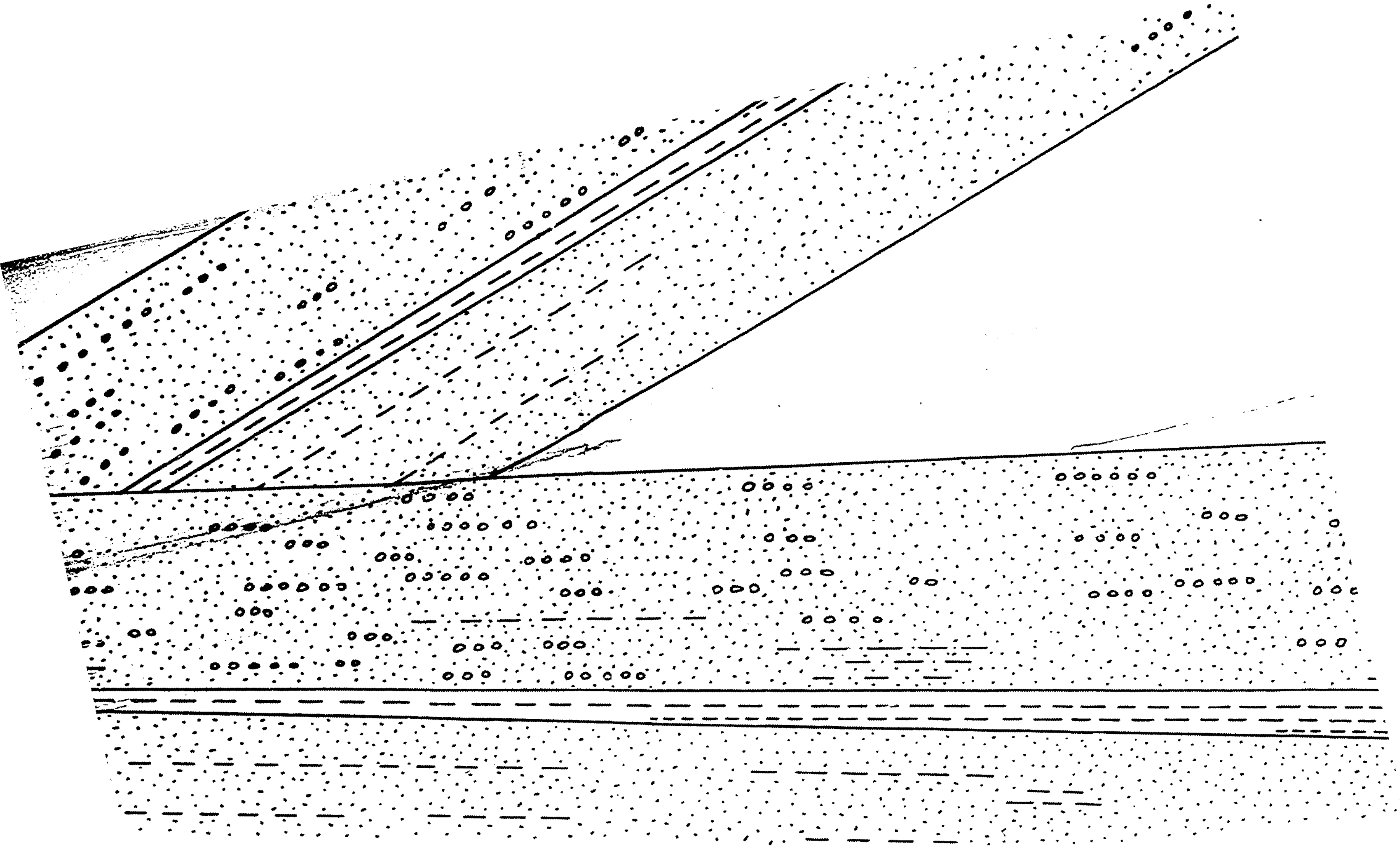

C° Queraya
d
faulted
Jl
meters
1250
1000

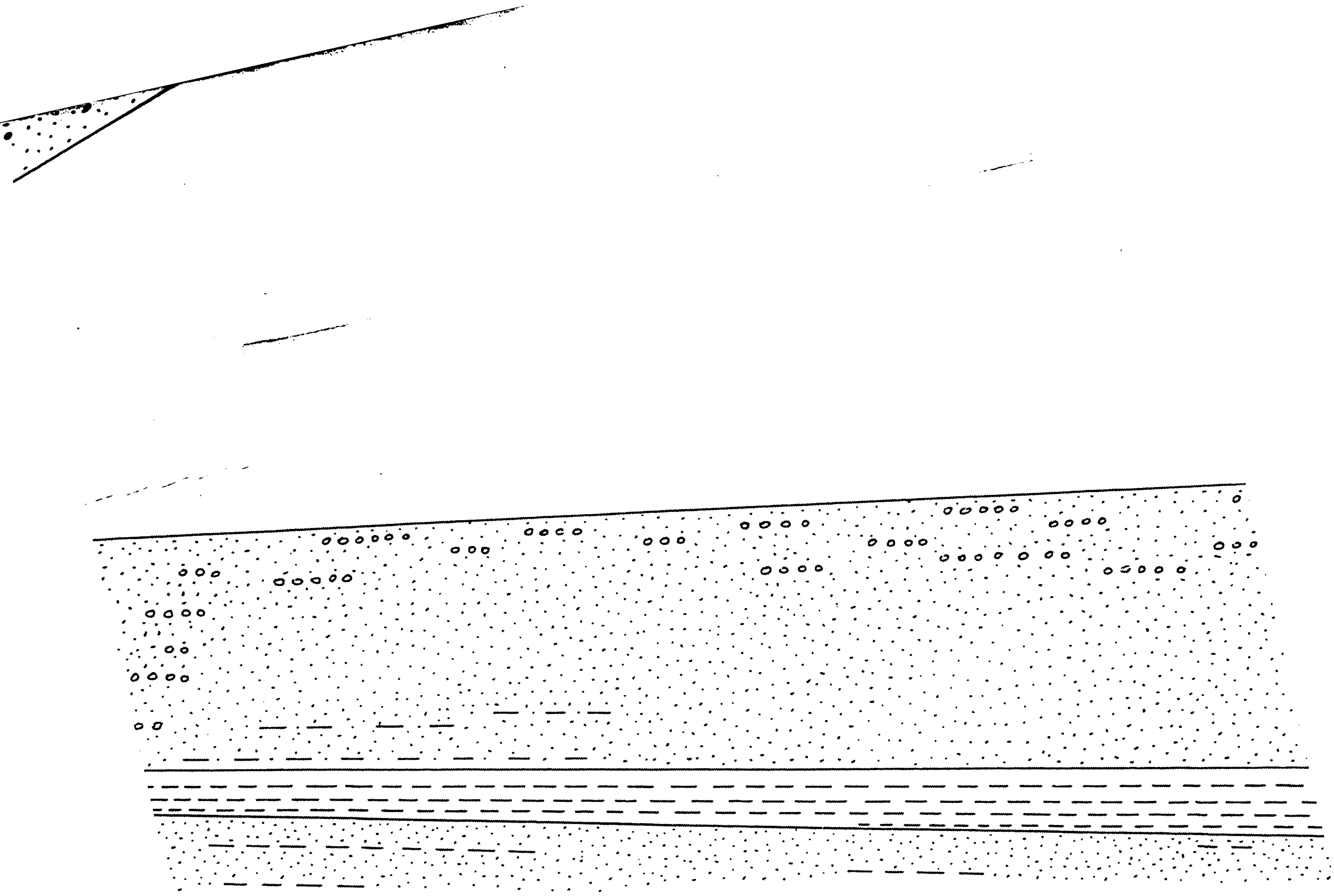

C° Queraya
faulted
Jl











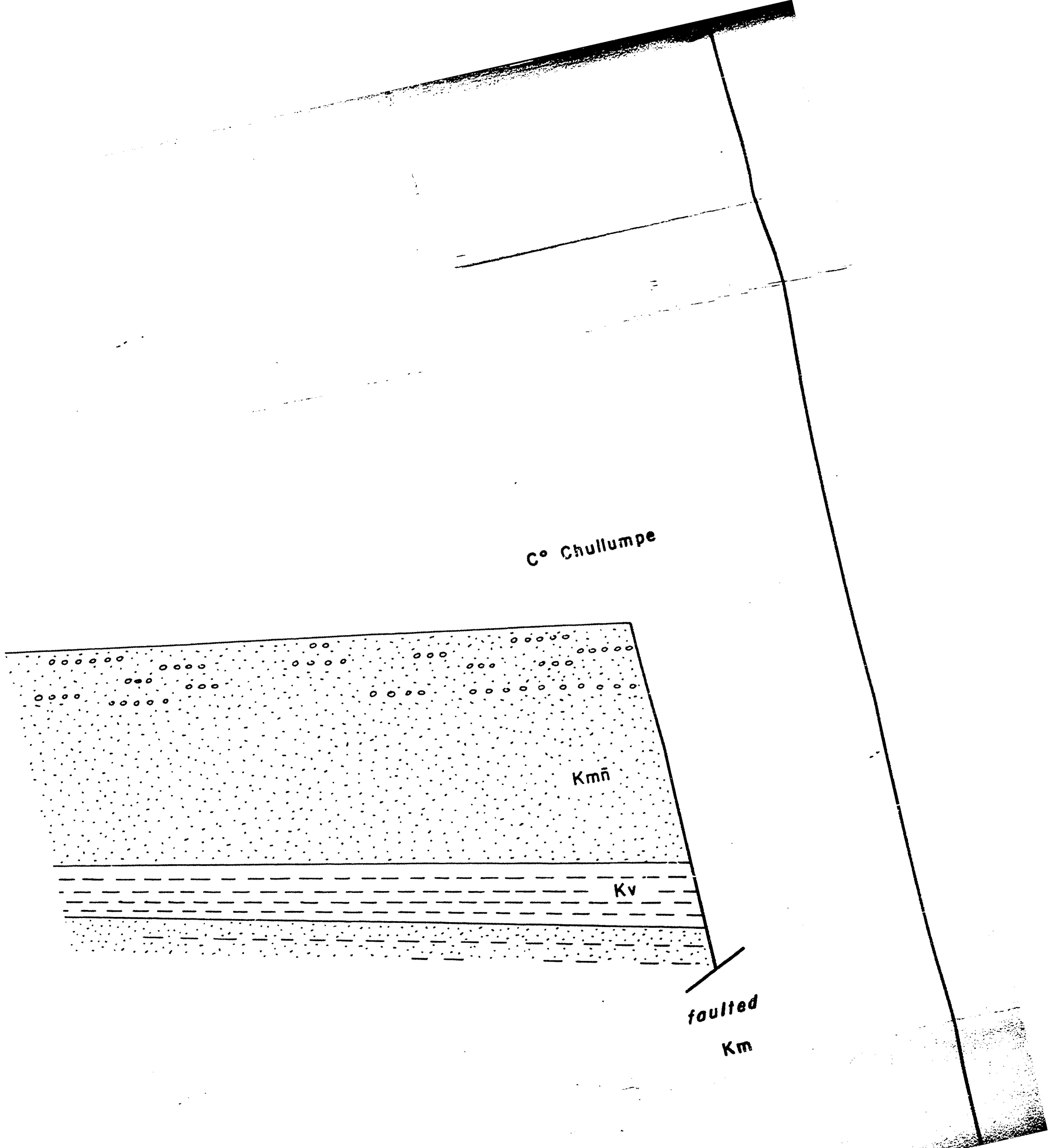
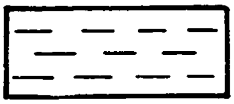
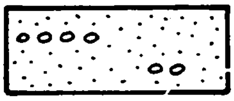

C° Chullumpe
Kmñ
Kv
faulted
Km

plate 4 FENCE DIAGRAM SHOWIN(


Sandstone


Shale


Ss. and conglomerates

Kmñ — Cretaceous : Muñani Fm.

Kv — " Vilquechico Fm.

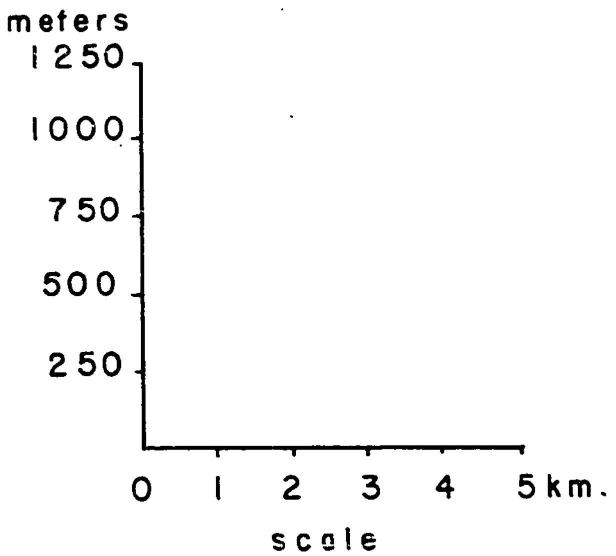
Kc — " Cotacucho Fm.

Km — " Moho Gp.

Jl — Jurassic : Lagunillas Gp.

d — diorite

G THE DISTRIBUTION OF THE UPPER

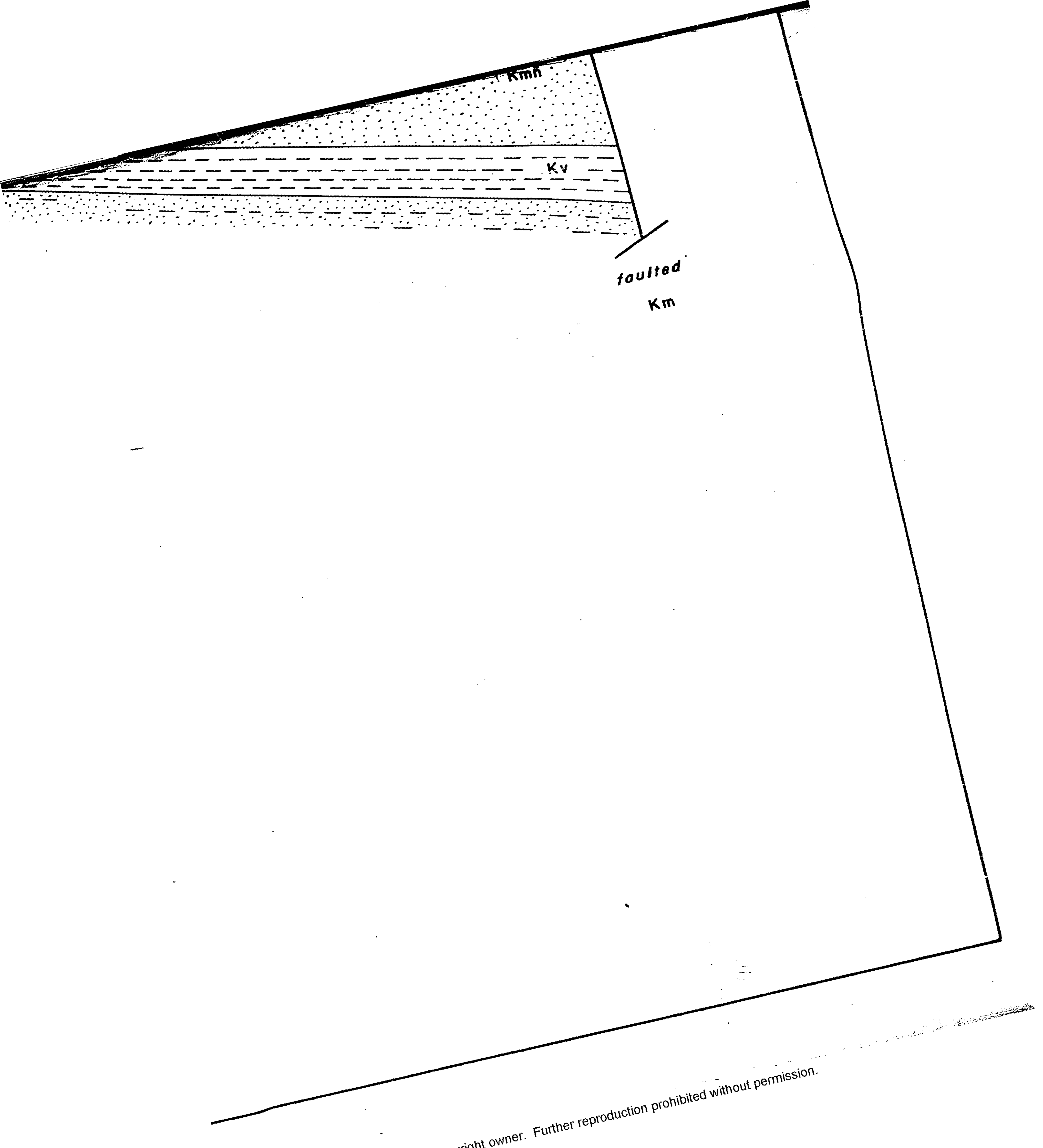


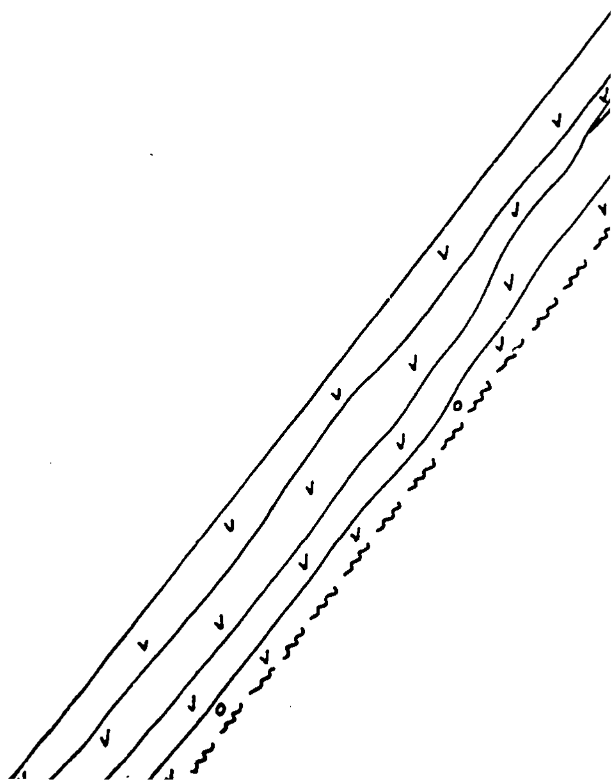
ER CRETACEOUS FORMATIONS (COTAC

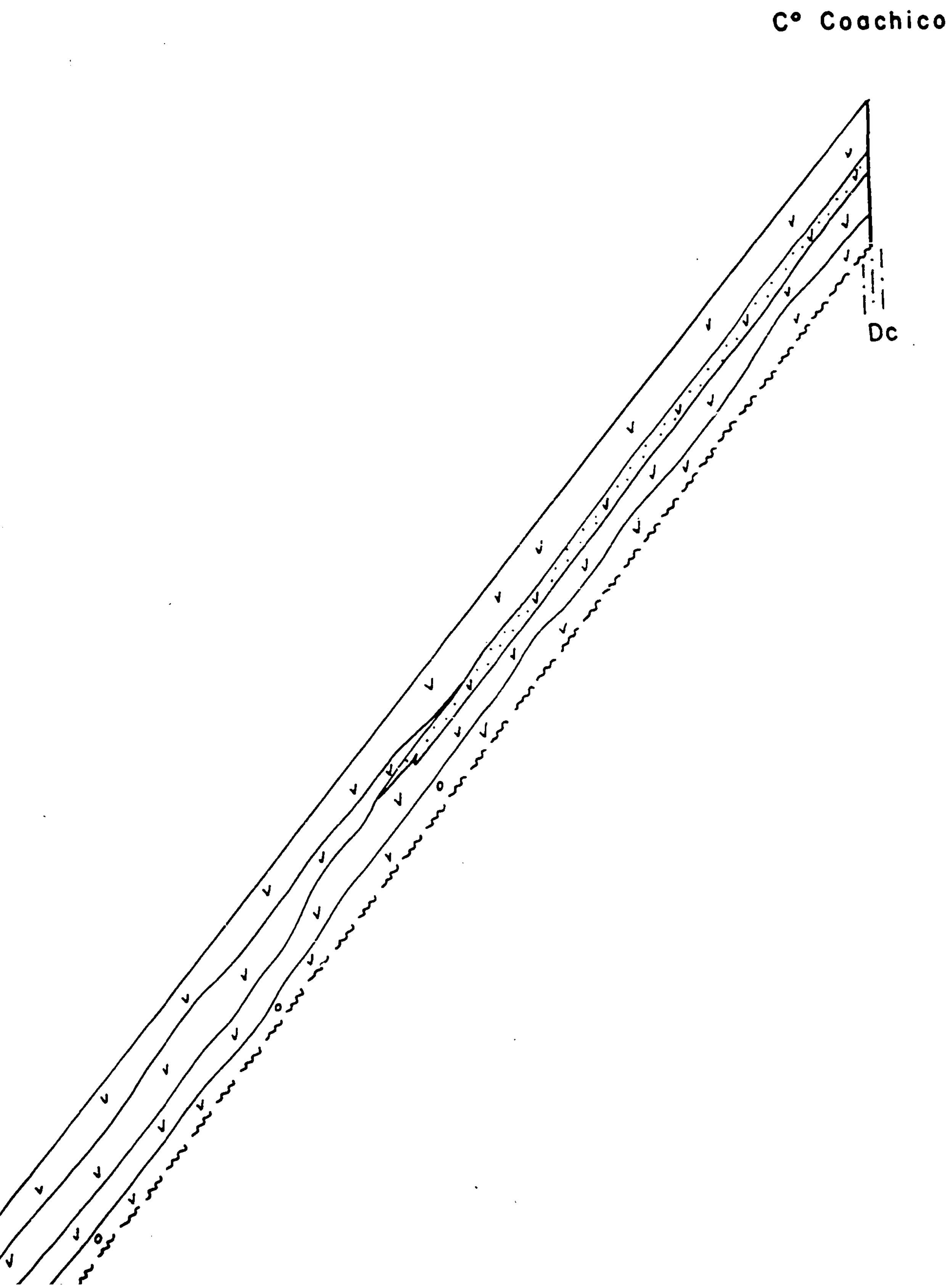
ORMATIONS (COTACUCHO, VILQUECHICO AN

AND MUÑANI)

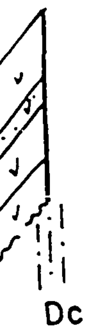
VILQUECHICO AND MUÑANI)

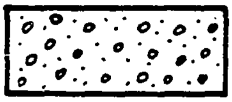

Kmn
Kv
faulted
Km




C° Coachico
Dc

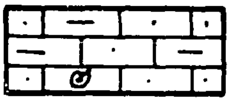
oachico



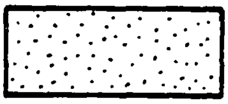


Conglomerate

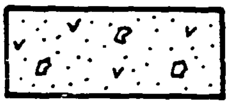
Tuff



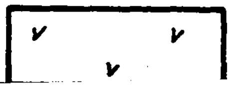
Marl



Sandstone



Tuffaceous Ss.



Volcanic breccia, bas

j

Conglomerate

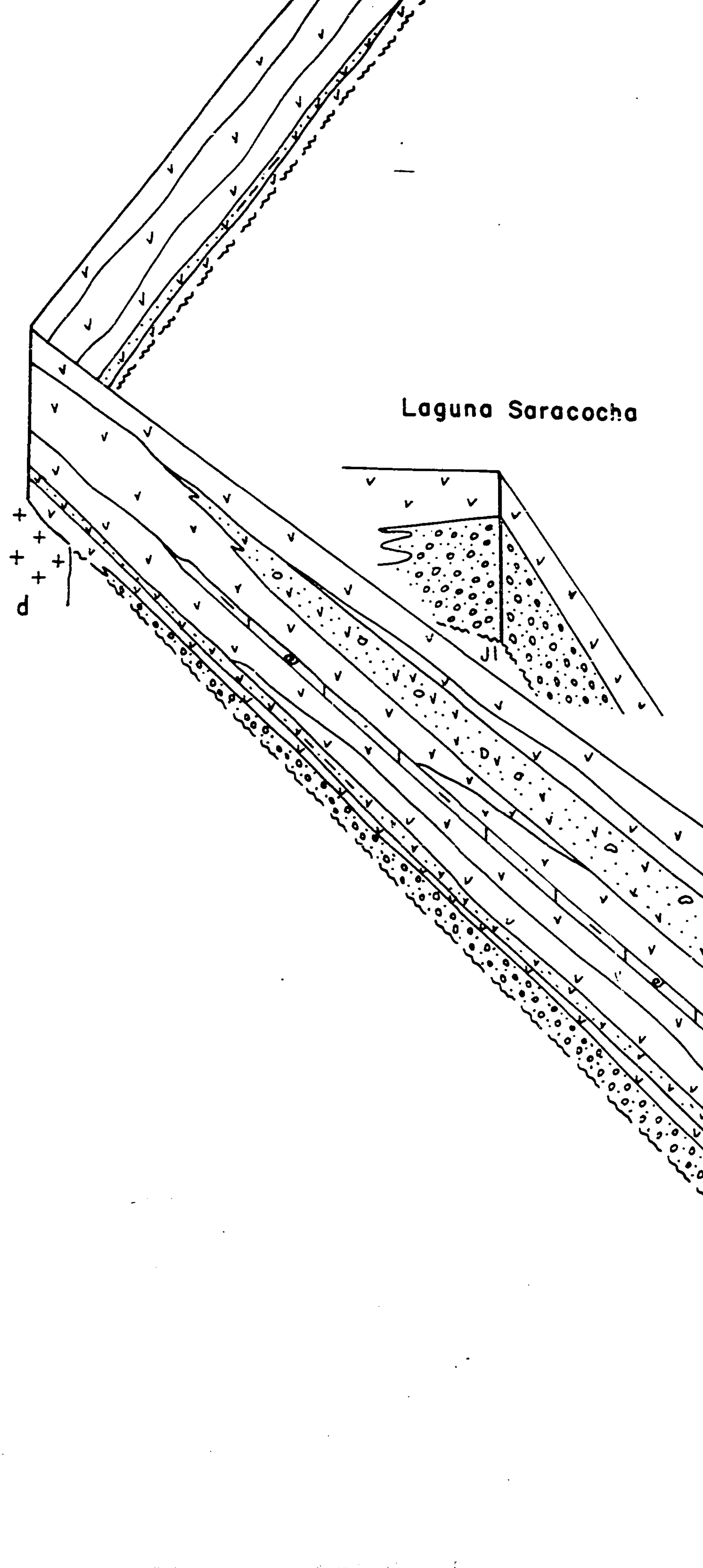
Tuff

Marl

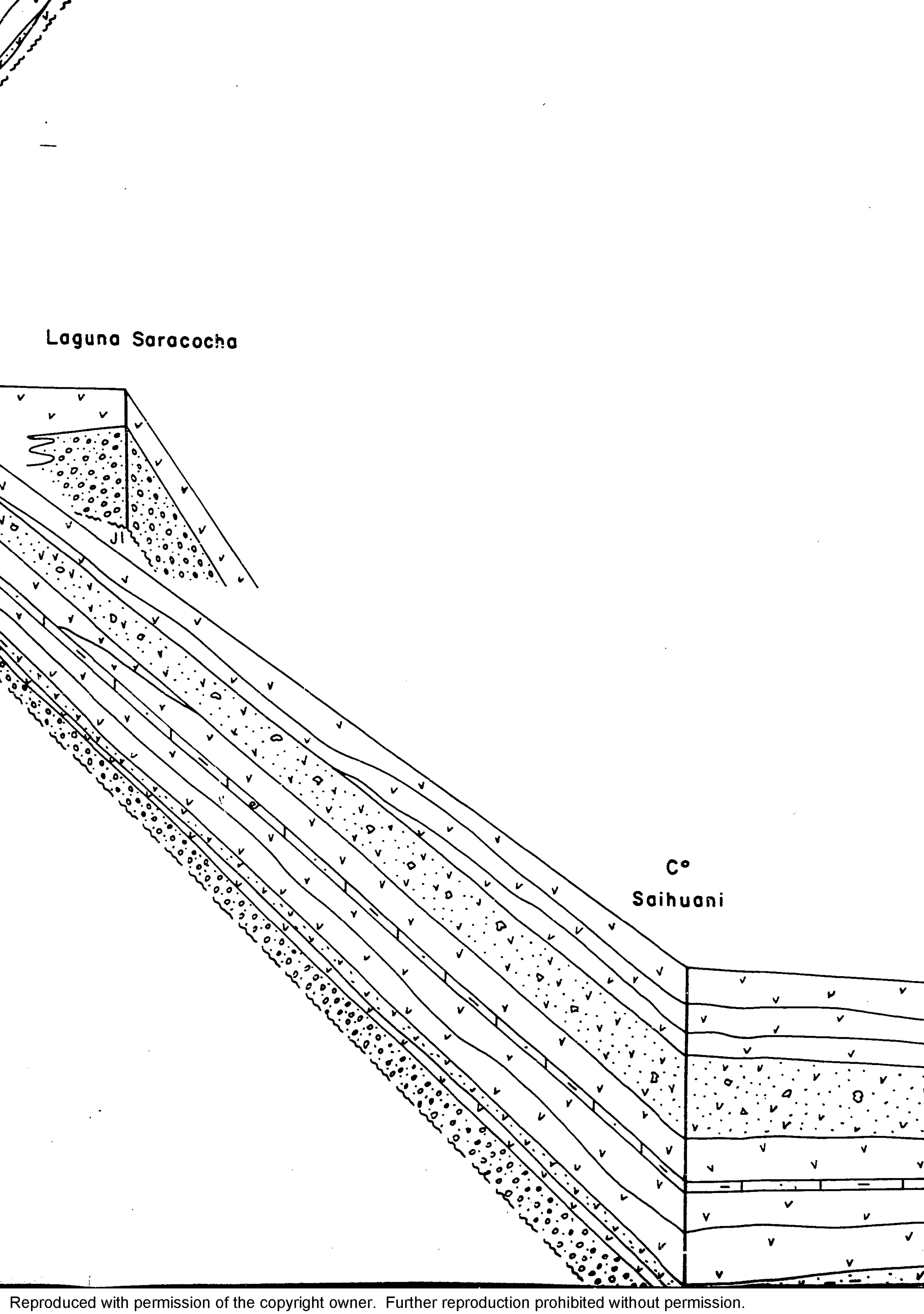
Sandstone

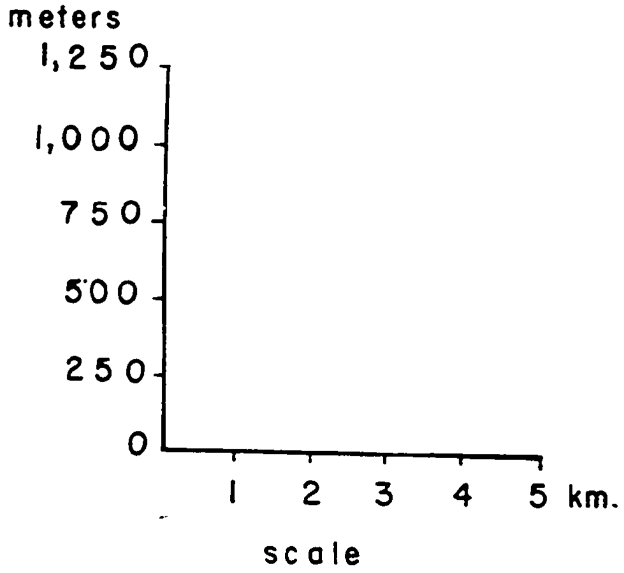
Tuffaceous Ss.

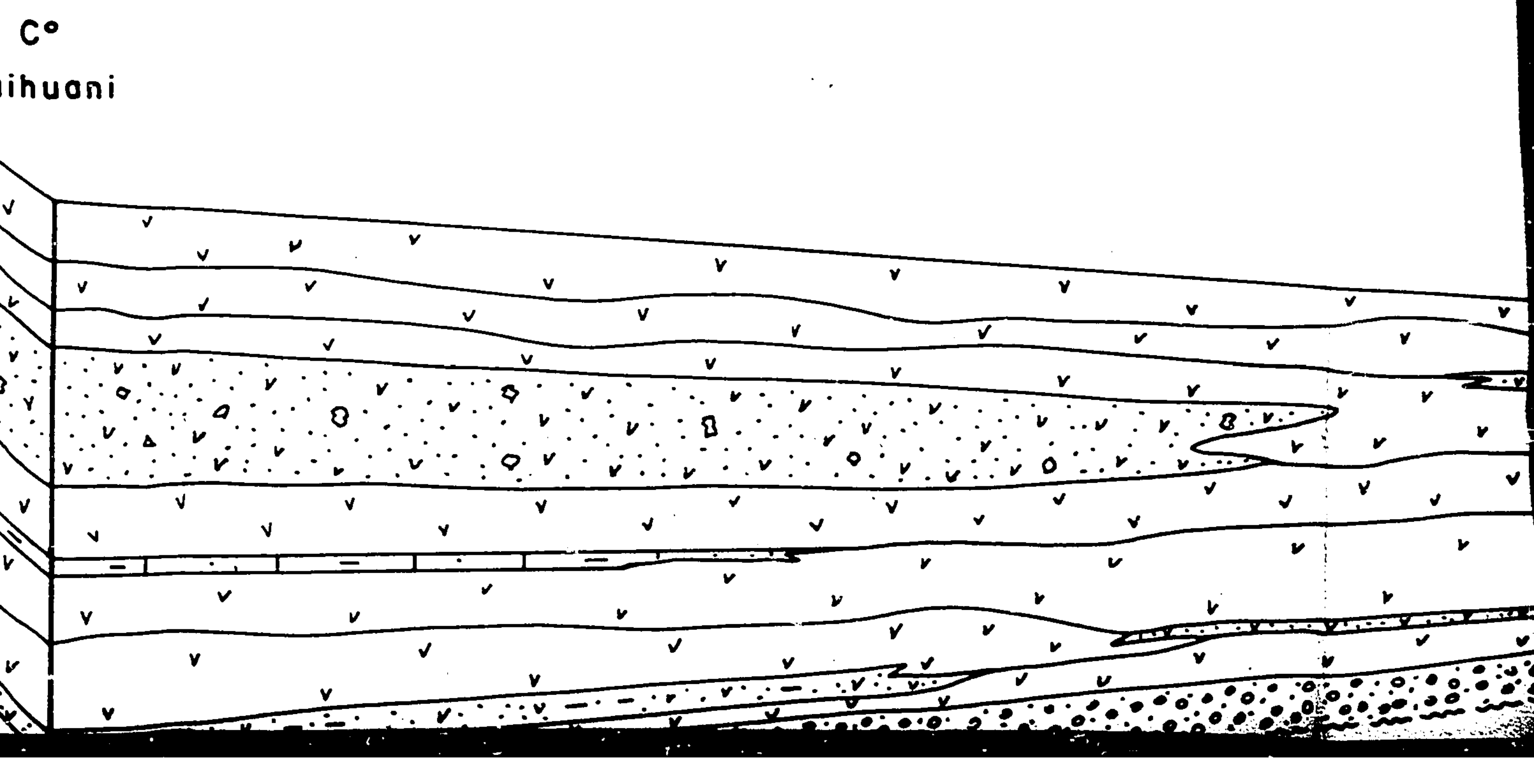
Volcanic breccia, basalt and andesite flows.

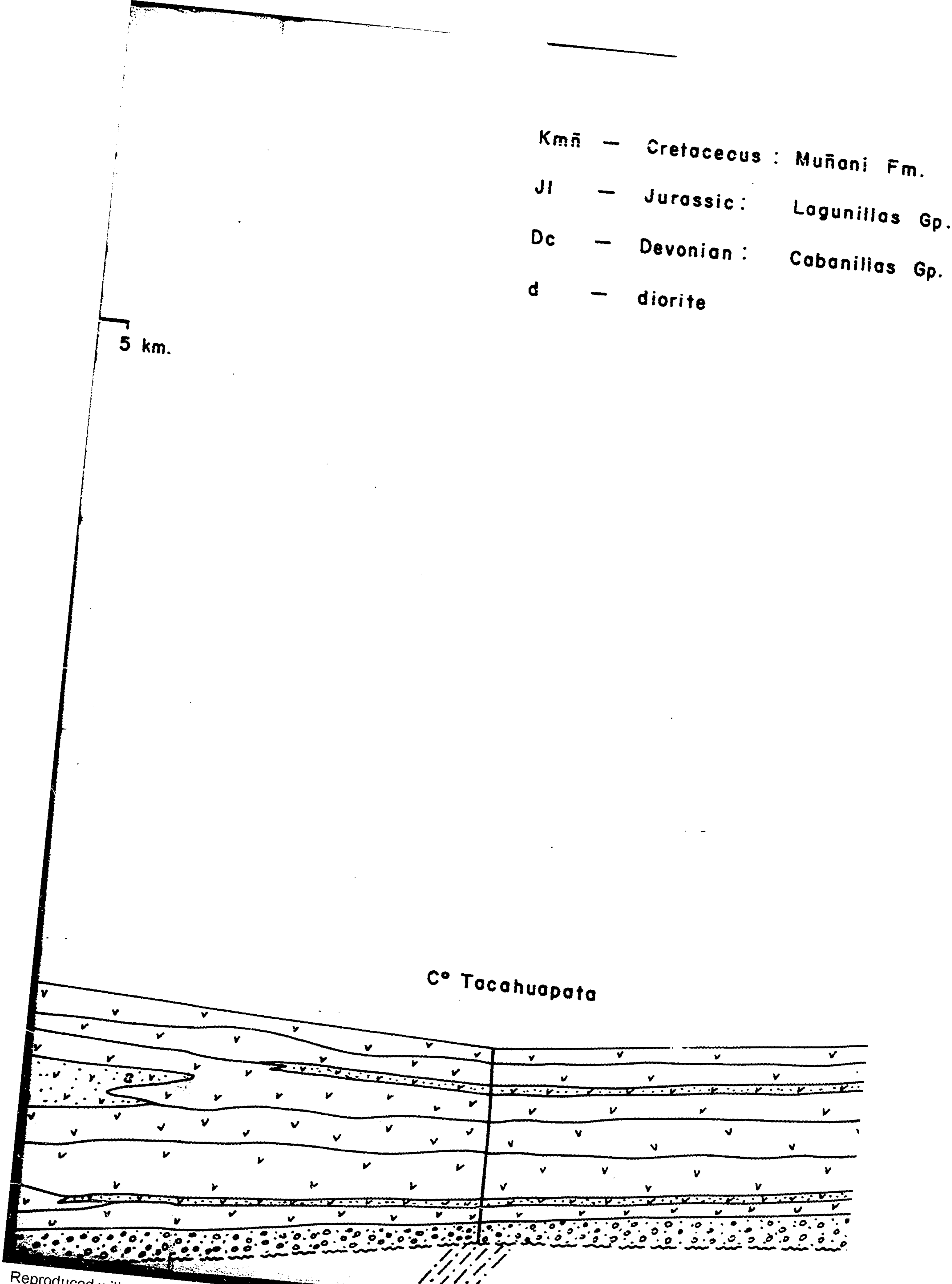


C° Auquirane
Laguna Saracocha
d
Jl


Laguna Saracocha
Jl
C°
Saihuani


meters
1,250
1,000
750
500
250
0
1
2
3
4
5 km.
scale

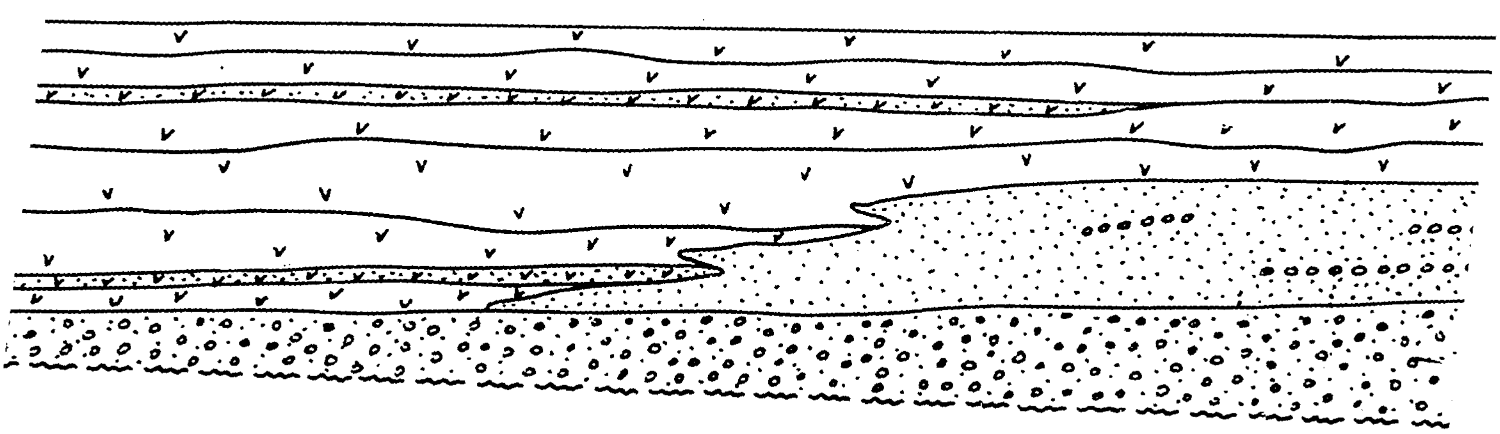

C°
ihuani


Kmñ — Cretacecus : Muñani Fm.
Jl — Jurassic : Lagunillas Gp.
Dc — Devonian : Cabanillas Gp.
d — diorite
5 km.
C° Tacahuapata

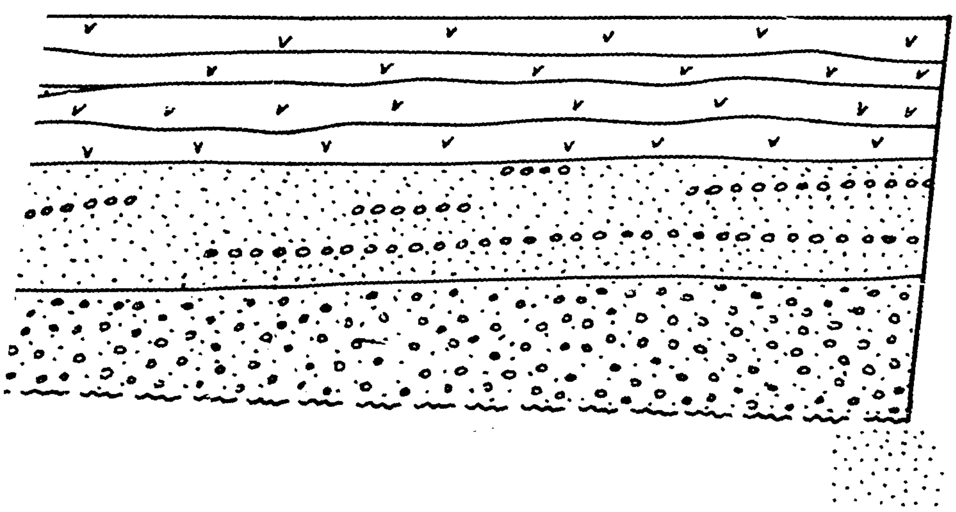
ıni Fm.

ınillos Gp.

ınilios Gp.



C° Putina



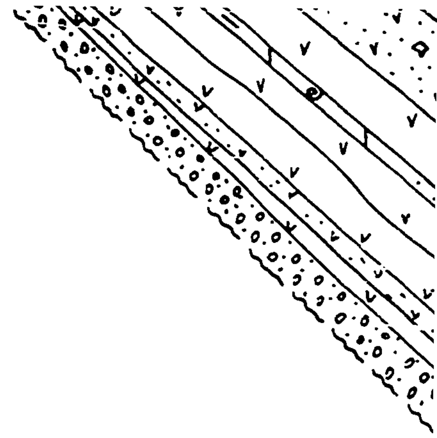
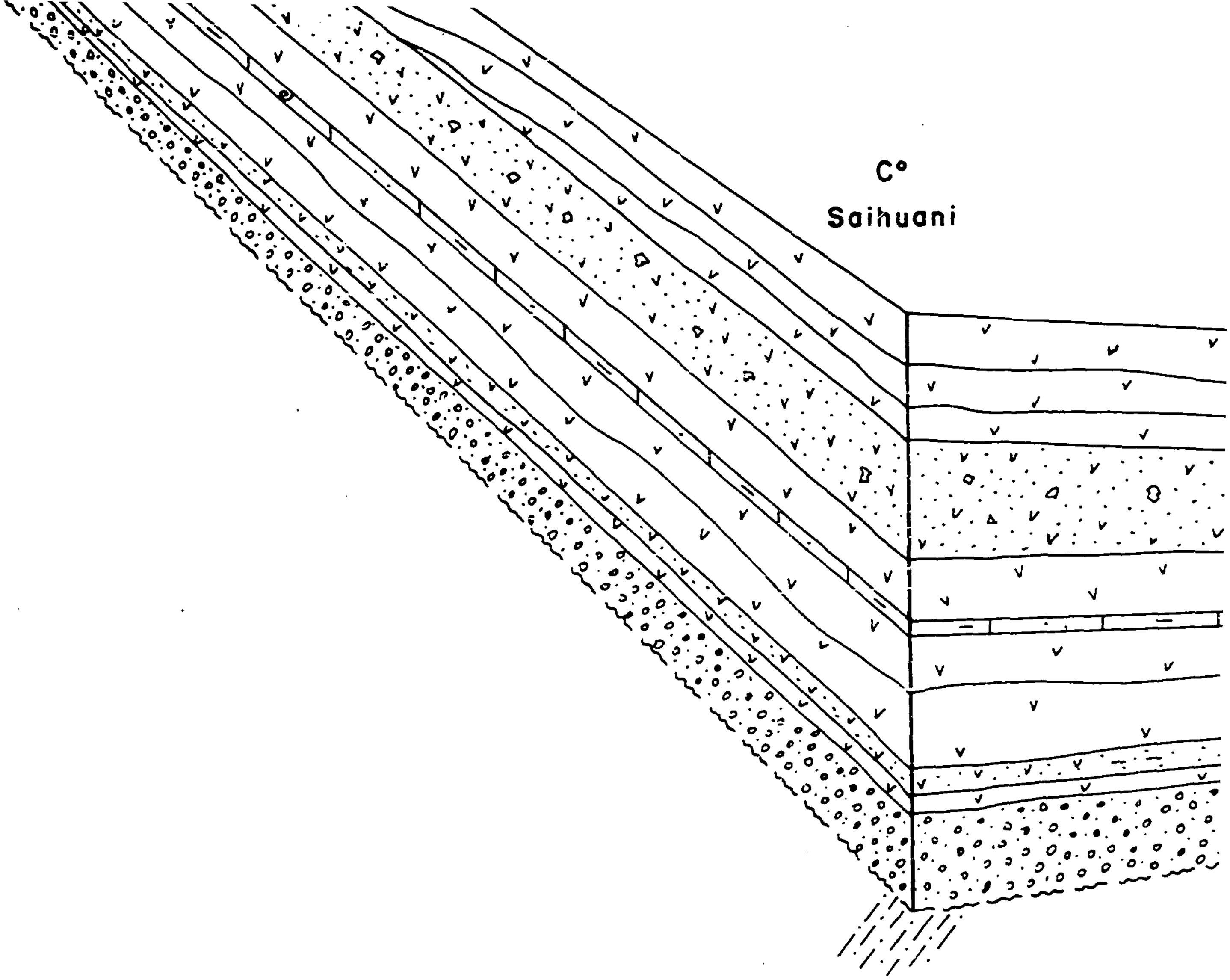
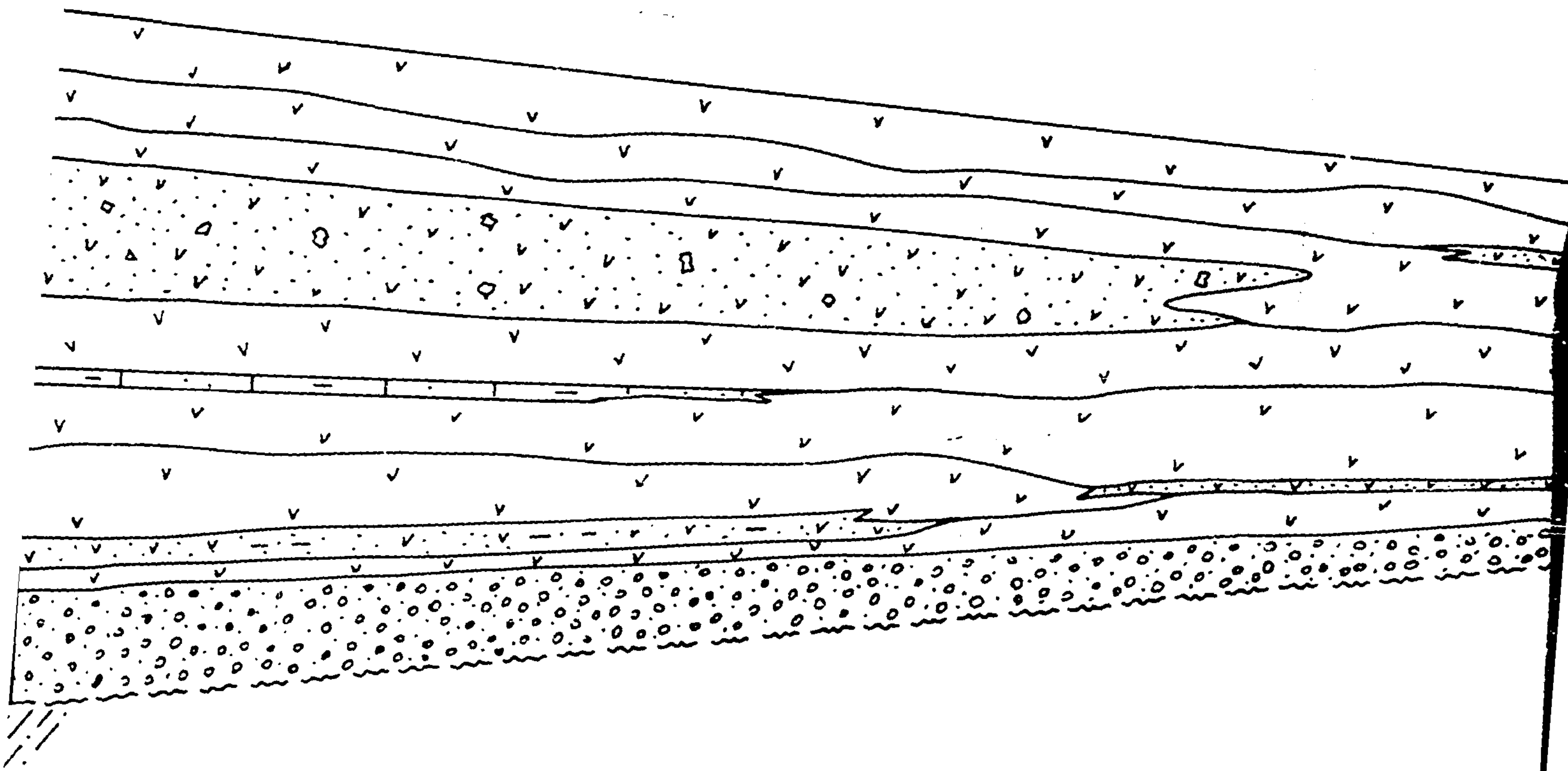


plate 5 FENCE DIAGRAM SHOW

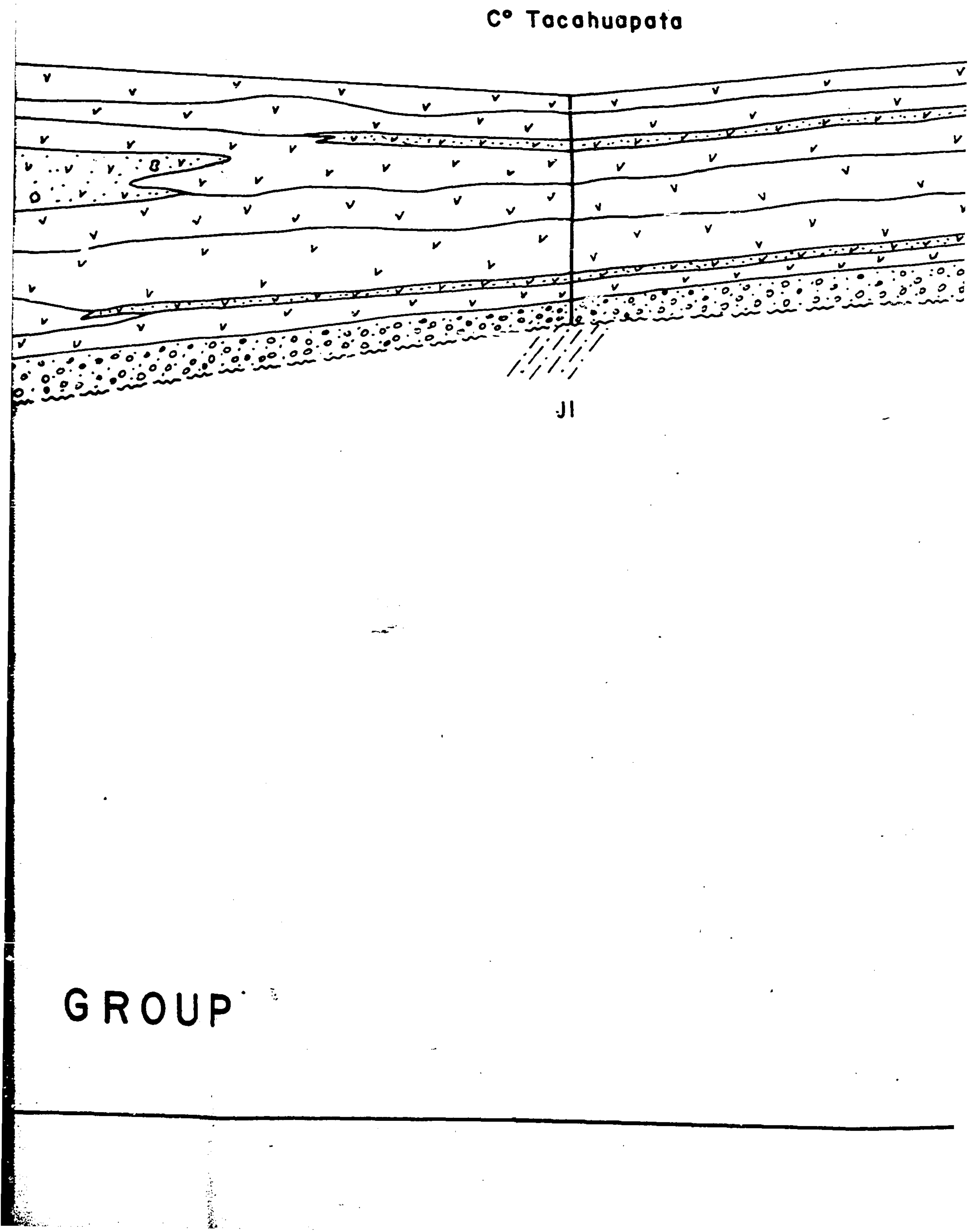


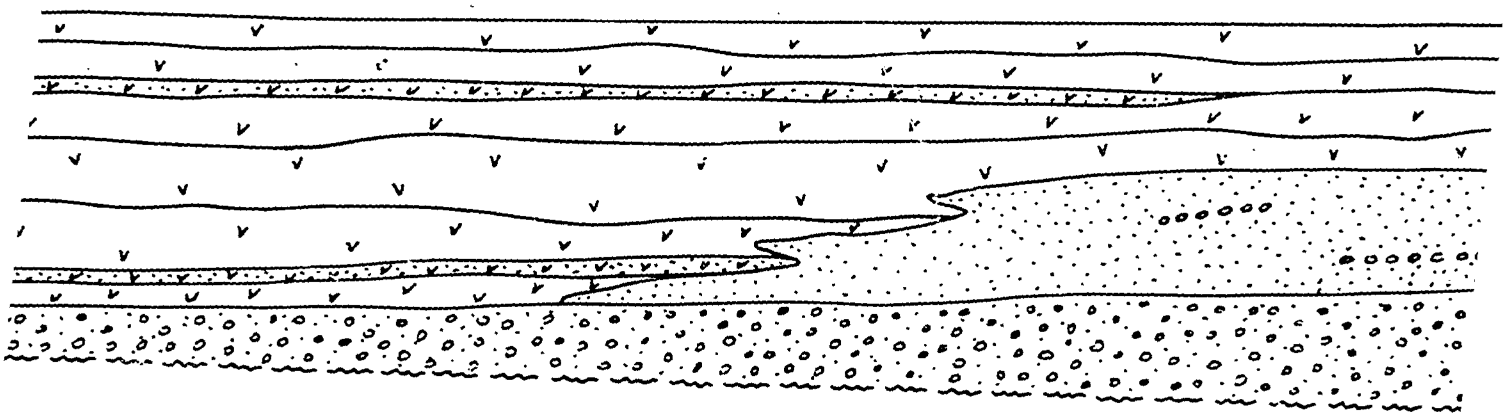
AGRAM SHOWING THE DISTRIBUTION

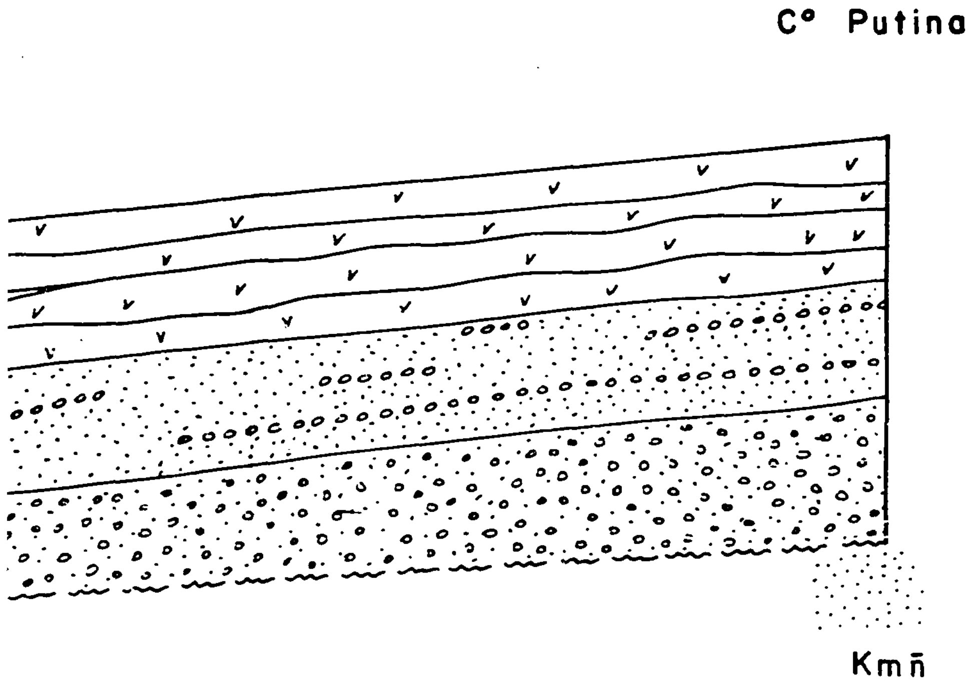
ini



IBUTION OF THE PUNO GROUP


C° Tacahuapata
JI
GROUP




C° Putina
Kmñ