CONTRIBUTION TO THE GEOLOGY OF THE CENTRAL AND WESTERN CORDILLERA OF COLOMBIA IN THE SECTOR BETWEEN IBAGUÉ AND CALI

BY

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CONTENTS

PREFACE

The present paper is the result of a series of field and laboratory studies carried out in the course of the years 1952—1956 in Colombia (South America), during which time the author was employed as a petrologist with the Instituto Geológico Nacional de Colombia at Bogotá.

Concluding this publication I want to express my sincere gratitude to my former colleagues of the Instituto Geológico Nacional who cooperated in many respects in the solution of the geological problems. In the first place I want to acknowledge the intimate collaboration of my friend and colleague Mr Jan Keizer. The maps bordering either side of the Cauca valley are the result of a joint field and laboratory research. Without his experienced photo-geological interpretation the surveyed area would be of a much smaller extent. Further, I am very much indebted to my friend Dr T. v. d. Hammen, palynologist of the Instituto Geológico Nacional, for the determinations carried out by him and for the interesting discussions I had with him regarding the correlation of Cretaceous and Tertiary formations. Dr H. Bürgl determined the collected fossils. Dr H. C. Raasveldt furnished a general photo-geological map of Tolima which served as a basis for the mapped area of Payandé. The great knowledge of the Colombian territory of Dr E. Hubach, Director of the Instituto Geológico Nacional, oriented in problems arising in adjacent areas. Mr Humberto Villegas was an efficient assistant in the field as well as in the laboratory.

The compilation of the various individual studies was done after my return to Holland in the Geological Institute of Leyden. I want to express my sincere gratitude to Prof. Dr L. U. de Sitter and Prof. Dr W. P. de Roever for the interest they have shown in my work and for their valuable advice. My former fellow-student Dr H. J. Zwart was a great help in preparing the manuscript and he discussed several problems with me.

The drawings were partly made in Bogotá and partly prepared for publication by Miss Cor Roest in Leyden. Mr J. Hoogendoorn took care of the photographs.

The maps were prepared by Mouton in The Hague, and the text was printed by E. IJdo, Leyden.

INTRODUCTION

The different character of the three main Cordilleras of Colombia has drawn the attention for a long time. Within the framework of the systematical regional survey of the Geological Institute of Bogotá, three areas distributed over the Western and Central Cordilleras and with a total area of 9000 km² have been mapped, in close collaboration with the Department of Photogeology of the same Institute. Special attention was paid to the metamorphic basement rocks, in order to obtain additional information about their composition and origin. The areal survey was extended with complementary cross-sections through all three Cordilleras, leading to a broader concept of their structural relation and constitution.

Geological investigation of the Andean mountain ranges by means of terrestrial survey as well as by means of aerial photographs is made difficult by various circumstances. In the first place younger volcanism has covered vast areas with its products. Especially the volcanoes that lie on top of the Central Cordillera have produced large amounts of pyroclastic materials which filled up the steep valleys on both sides of the Cordillera. The tuffs have only partly been removed by the rivers and the remnants form conspicuous high terraces in the valleys. In the second place climatologic agents caused a rather intensive alteration. These effects are very pronounced in the Western Cordillera and resulted in a profound lateritization of the Mesozoic volcanic rocks Apart from these natural factors terrestrial observation is restricted to a certain degree by the activity of political and criminal groups that have taken refuge in isolated parts of the Cordilleras and make penetration into this area rather hazardous.

Although several important studies have been published by various authors, the systematical regional survey is still in an initial stage. Under these circumstances it was necessary to map on a small scale. We are aware of the fact, that corrections and completions are needed in various parts. They can be made by means of a series of check-ups in the field.

1. Outline of the Physiography of Colombia

Before we start the discussion of the investigated areas, we first give for those readers not familiar with the physiography of Colombia a short exposure of the topographic conditions.

Physically the Colombian territory is built up of two different parts: a mountainous region occupying the western part and a vast plain extending towards the East. The mountains belong to the Andean system and enter from Ecuador as two parallel mountain ranges separated by an interandean high plateau. The western range follows at a short distance the Pacific coast. Between Pasto and Popayán the eastern range splits up into two ramifications, which continue their course in a northern and a north-eastern direction. In this way three ranges originate, indicated as the Western Cordillera, the Central

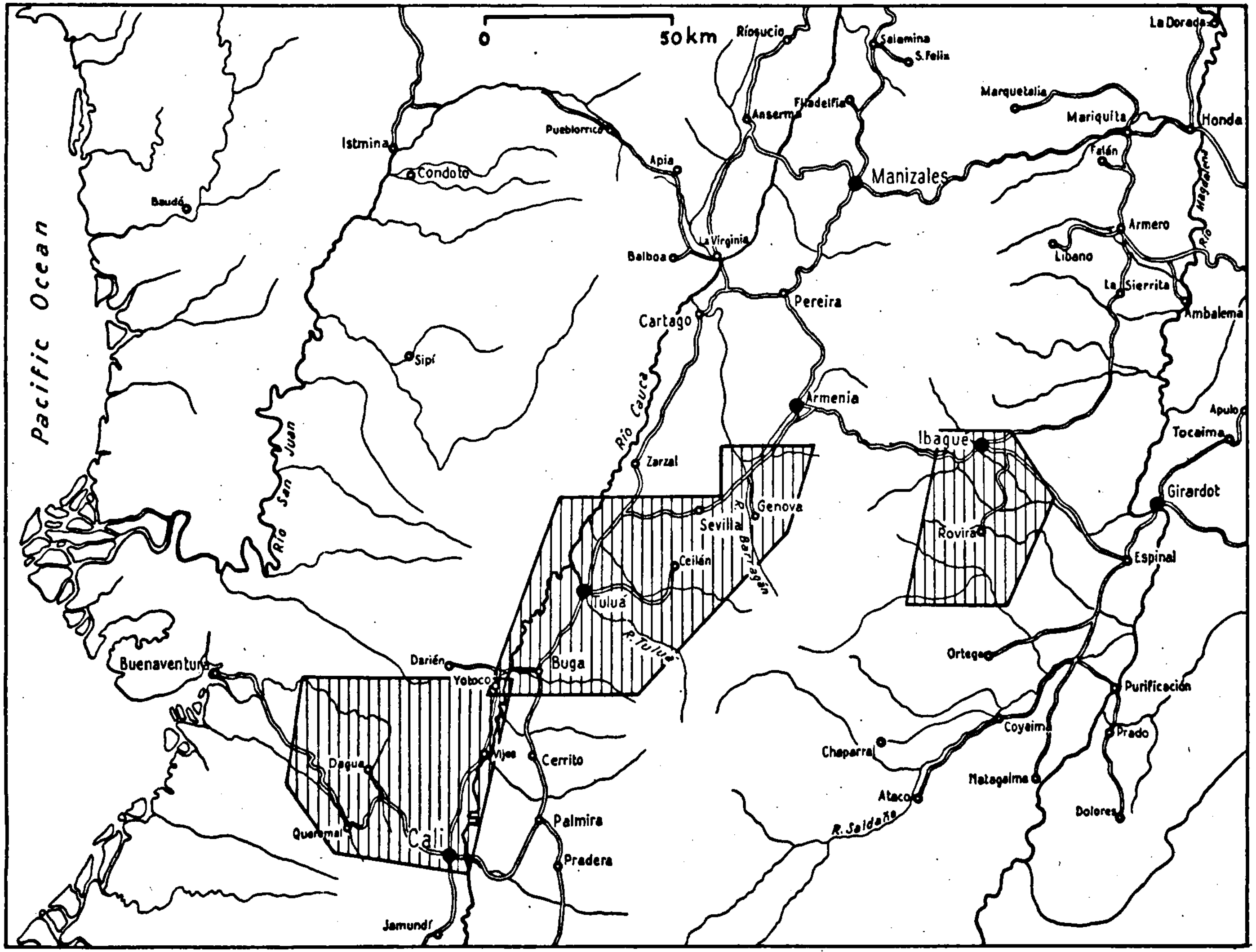


Fig. 1. Index map showing the location of the areas studied.

Cordillera and the Eastern Cordillera *). The highest elevations are formed by volcanoes, now extinguished and changed into snow-clad peaks (nevados). In the Central Cordillera the most famous are the Nevados del Quindío (5.150 m), Tolima (5.620 m), Santa Isabel (5.100 m), Ruiz (5.400 m) and Huila (5.750 m). In the Eastern Cordillera the highest elevation is the Sierra Nevado del Cocuy (5.493 m). Still active volcanoes are in the departments of Cauca and Nariño.

Apart from these three Cordilleras a lower mountain chain borders the Pacific coast in the department of Chocó. This Coastal Cordillera — according to GANSSER (1950) — trends in Cabo Corrientes into the sea, but reappears in the Gorgona Islands, then probably passes off Tumaco and is observed again in the Esmeralda Province of Ecuador (see fig. 3).

A conspicuous isolated mountain-stock is the Sierra Nevada de Santa Marta, whose peaks reach up to 5.800 m. Based on geological reasons, it is supposed to be the continuation of the Central Cordillera.

The tropical lowlands that extend east of the Eastern Cordillera occupy more than one half of the total area of Colombia. Yet this vast area (about 600.000 km^2) contains less then one-tenth of the Colombian population. The lowlands can be divided into two different parts by a line that follows more or less the Río Guaviare. The northern part is a nearly treeless plain (llanos), whereas the southern part is covered by jungle (selva).

Although Colombia borders on two Oceans, the drainage is oriented mainly towards the Caribbean Sea or the Atlantic Ocean. The continental water divide is formed by the Western Cordillera and passes in Chocó by the so-called Isthmus of San Pablo to the Coastal Cordillera. The interandean depressions are drained by the Río Magdalena, Río Cauca and Río Atrato. The llanos belong to the Orinoco basin and the jungle area to the Amazonas basin.

The climate is dominated by the altitude more than by annual seasons. In rough outlines three climatologic zones are distinguished: the torrid zone (tierra caliente), to which belong the lowlands and the large interandean river-valleys; the temperate zone (tierra templada), to which belong the lower parts of the Cordilleras up to a height of about 2000 m; the cold zone (tierra fría) to which belong the higher parts of the Cordilleras. The capital Bogotá lies on a high plateau or sabana (2600 m) in the cold zone, with a average yeartemperature of 13° C and an atmospheric pressure of 560 mm. The extensive gently undulating plateaus near the ridges of the Cordilleras on a level between 3000—4000 m are covered with grass-lands and form the chilly and foggy paramos. Perpetual snow covers the elevations over 4800 m.

2. Geological setting of the investigated areas

In fig. 3 we reproduce the outline map published by A. GANSSER (1950) in connection with his paper on the Gorgona islands. As can be derived from this excellent map, the Central Cordillera consists of pre-Mesozoic metamorphic rocks intruded by granodiorites. On the eastern flank this basement is covered by Mesozoic formations. In the investigated area SE of Ibagué

*) Geologically, however, the East Cordillera seems to develop from a lower mountain-range in northern Ecuador.

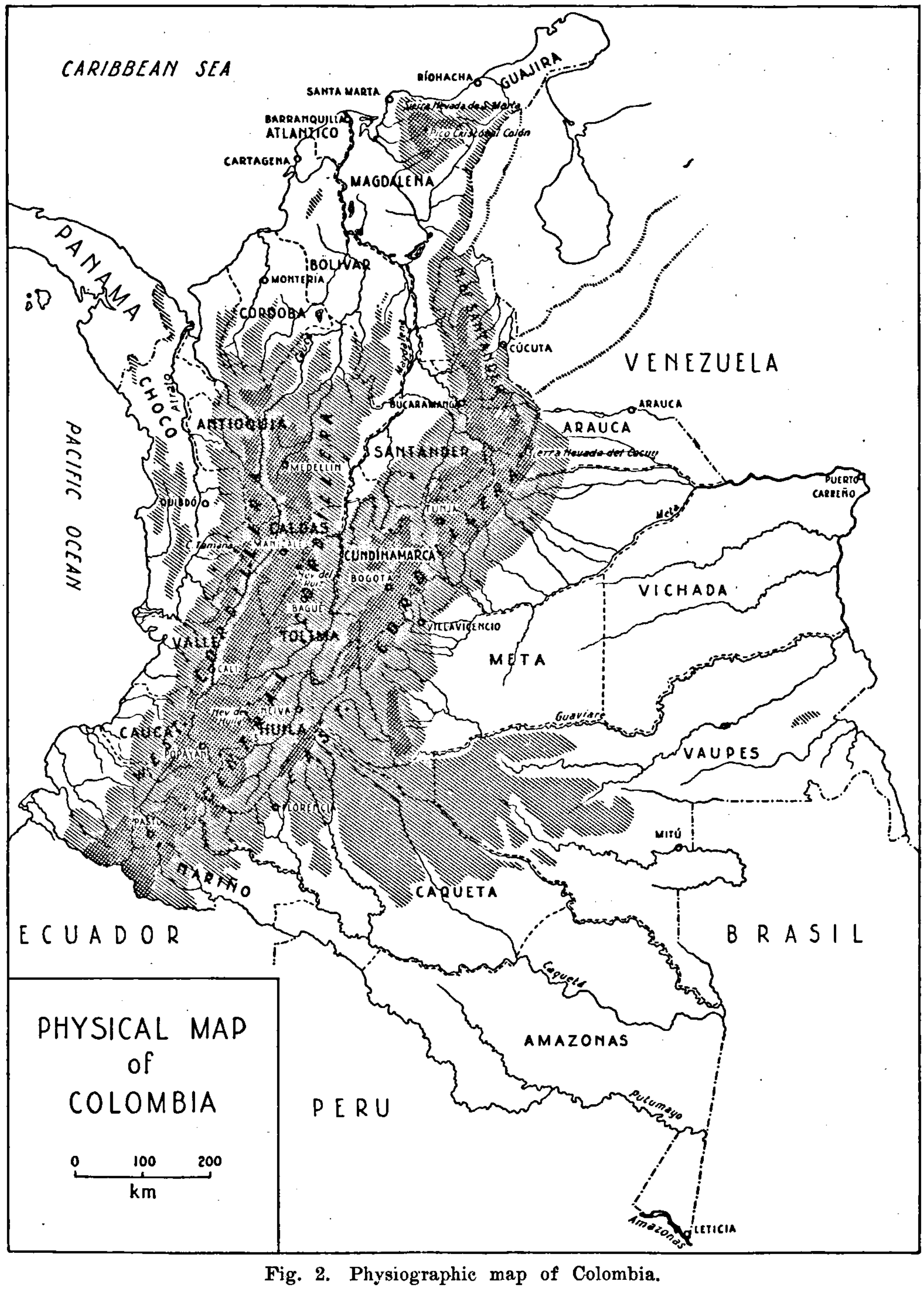


Fig. 2. Physiographic map of Colombia.

one can observe that the denudated granodiorite pluton is covered by acid extrusives, probably of Permo-Triassic age. The extrusives are overlain by the Payandé formations which show the following succession, first terrestrial red beds containing conglomerates, etc. (pre-Payandé formation), then fossiliferous limestone of Upper Triassic age (Payandé-formation) and finally volcanic strata (post-Payandé formation). The Payandé formations are intruded by granodiorites. Marine Lower Cretaceous overlaps both the Payandé formations and the intruded stocks. Finally, fluviatile Lower Tertiary (Gualanday-formation) covers part of the older formations.

On the western slope of the Central Cordillera the basement rocks are in contact with different formations. In the mapped area the lower part of this slope is formed by submarine volcanic rocks of basic composition. They are overlain by Paleocene and younger Tertiary deposits.

The same volcanic rocks constitute the main part of the Western Cordillera. Interbedded cherts yielded a Middle to Upper Cretaceous fauna. The volcanic rocks are conformably underlain by slightly metamorphosed sedimentary rocks which must be of Mesozoic age, the upper part being probably Lower Cretaceous. The sedimentary as well as the volcanic rocks are intruded by tonalites. In the mapped area of the West Cordillera Lower Tertiary outcrops on the lower part of the E slope. On the W side of the Cordillera the Mesozoic formations disappear below the Upper Tertiary of the Pacific coastal plain.

3. Previous studies

The geological information about the Colombian mountain ranges is rather extensive and here we will consider only those publications that have contributed in some way to our own investigations.

Disregarding the older and more occasional literature we have to mention O. STUTZER (1934). This author traversed the Central Cordillera in the year 1925, taking the old trail from Ibagué to Armenia wich has been followed more or less by the present highway, and returned to the Magdalena-valley by the trail from Manizales to Mariquitá. He describes briefly the rock sequences encountered along both trails and states that in this part the Cordillera consists only of metamorphic schists into which granodiorites intruded. He remarks the complete absence of Cretaceous rocks, which are so important in the Eastern Cordillera.

In the same year STUTZER crossed the Western Cordillera along the railway track from Cali to Buenaventura. In his quick reconnaissance he observes that this sector of the Western Cordillera is built up of two formations, viz. a sedimentary formation composed of shales and siliceous shales intruded by basic eruptives. He arrives at the conclusion that Cretaceous rocks are absent and presumes that during Cretaceous time both the Western and Central Cordillera formed one mainland, in which the Caucarift was formed afterwards by tectonic subsidence of a central part.

In a third publication STUTZER deals with the evolution of the Caucarift and its southern prolongation, the Patía-rift. He gives a description of the main morphological units, being from north to south: the interandean plain of Cartago-Cali (1000 m) on the middle Cauca and extending over a distance of approximately 200 km with a maximum width of 30 km; the cross-ridge of Suárez-Santander (elevations up to 2200 m) formed mainly by Middle Tertiary

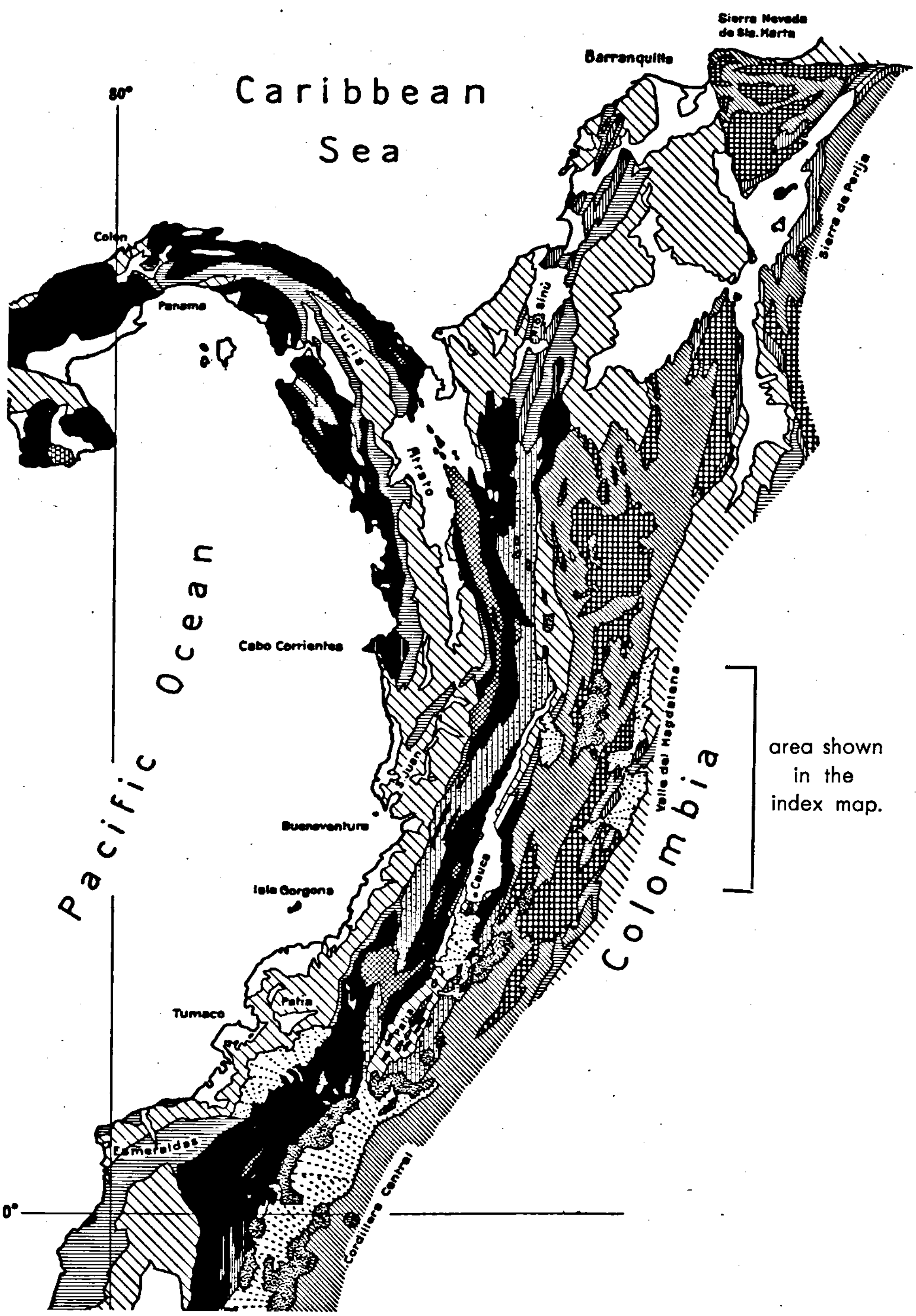


Fig. 3. Geological map of NW South-America by A. GANSSER, scale 1: 7.500.000.

extrusive stocks; the undulating high plateau of Popayán (± 1700 m) and the Patía-valley which quickly deepens towards the south.

Very important are the contributions of E. GROSSE (1926). This author made a detailed study in Antioquia in the years 1920—1923, where he mapped a region west of Medellin on the western slope of the Central Cordillera. He distinguishes the "porphyrite-formation" consisting of basic extrusives and pyroclastics and assigns a Lower Cretaceous age to part of this formation, in view of the fossils found in interbedded sediments. These intercalations moreover demonstrate the submarine nature of the volcanic eruptions. Apart from the porphyrite-formation GROSSE distinguishes older basement rocks. He makes a stratigraphic subdivision of the latter, based on the degree of metamorphism as he attributes it to the different rock types. Amphibolites are placed in the Archaic; phyllites, micaschists, actinoliteschists, etc. in the Lower Algonkian; phyllitic shales in the Middle Algonkian and finally slates and shales in the Upper Algonkian. Undoubtedly, part of these rocks are of Mesozoic age and equivalents of the Dagua Group, which — together with the overlying "porphyrite formation" (Diabase Group) — is well exposed in the Western Cordillera. In this area the Western Cordillera is linked geologically to the western slope of the Central Cordillera and only separated in a morphological sense by the narrow Cauca-valley. The Mesozoic age of the supposed Algonkian rocks was already suggested by R. SCHEIBE, who prior to GROSSE visited the same area and to whose observations the latter refers. As we will see in the discussion of the area in the Western Cordillera investigated by us, the strong thrusting caused transformation of slates to phyllites, whereas sheared diabases may give the impression of greenschists. The Mesozoic and older formations are unconformably covered — according to GROSSE — by Lower Tertiary fluviatile to limnic sediments which in its

LEGEND:

- Alluvium
- Recent to Subrecent pyroclastic sediments
- Young Tertiary to Recent volcanic rocks (volcanoes)
- Young Tertiary
- Old Tertiary (Pre-Miocene)
- Mesozoic (mainly Cretaceous)
- Mesozoic somewhat metam.
- Basic intrusiva-extrusiva, mainly U. Cret.-Early Tert.
- Acid intrusiva U. Cretaceous-Early Tertiary
- Metamorphics (Pre-Mesozoic)
- Acid intrusiva (Pre-Mesozoic)

middle part contain exploitable coal beds. These, in turn, are unconformably overlain by Upper Tertiary (Miocene) sediments, beginning with reworked tuff-deposits. These deposits, less folded than the underlying Lower Tertiary, demonstrate the beginning of the Neotertiary volcanic activity.

A second important study was made by GROSSE (1935) in the Patía-valley. The observations made above referring to Antioquia can to a certain degree also be applied to this area and we will not go into the sub-

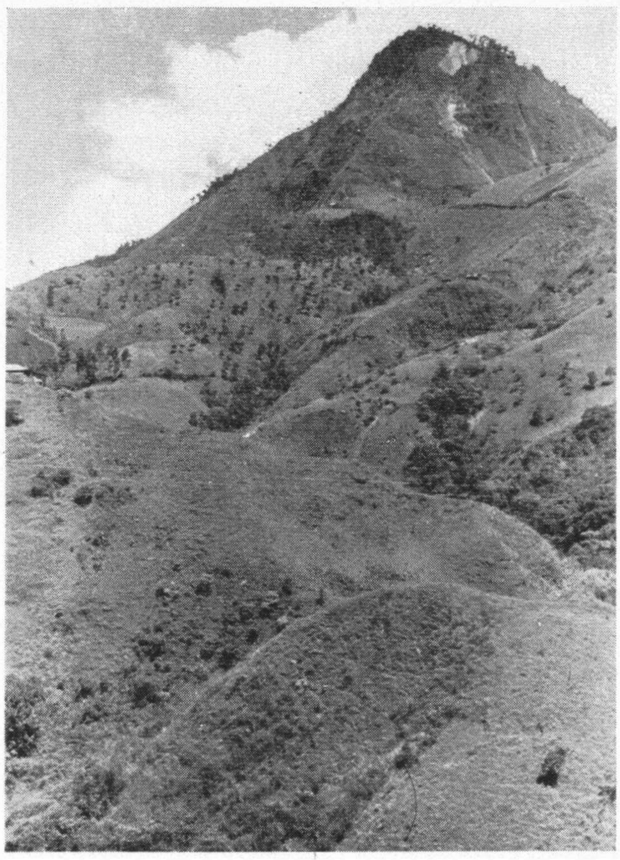


Fig. 4. Superimposed tuff-morphology, upstream from Cajamarca (Central Cordillera).

ject here. GROSSE (1935) also crossed the southern part of the Central Cordillera and illustrated his observations with two cross-sections. Although the older rocks are covered over wide areas with neovolcanic tuffs, in one of these sections the "porphyrite-formation" outcrops on the western slope of the Cordillera. Silicified tuffaceous intercalations contain badly preserved foraminifera; in chert beds ammonites were found. GROSSE ascribes a Cretaceous age to the porphyrite-formation. On the eastern flank Lower Cretaceous transgresses with a basal conglomerate over the metamorphic basement rocks. Further downwards, towards the Magdalena valley, volcanic strata outcrop again. GROSSE correlated these rocks with the "porphyrite formation" of the Cauca-Patía rift, but they belong undoubtedly to the Jura-Triassic volcanics, as GERTH also suggests.

E. HUBACH has visited many interesting regions in Colombia. Unfortunately, only part of his observations have been published up till now. As far as our area is concerned, HUBACH (1934) made an exploration in the Cauca

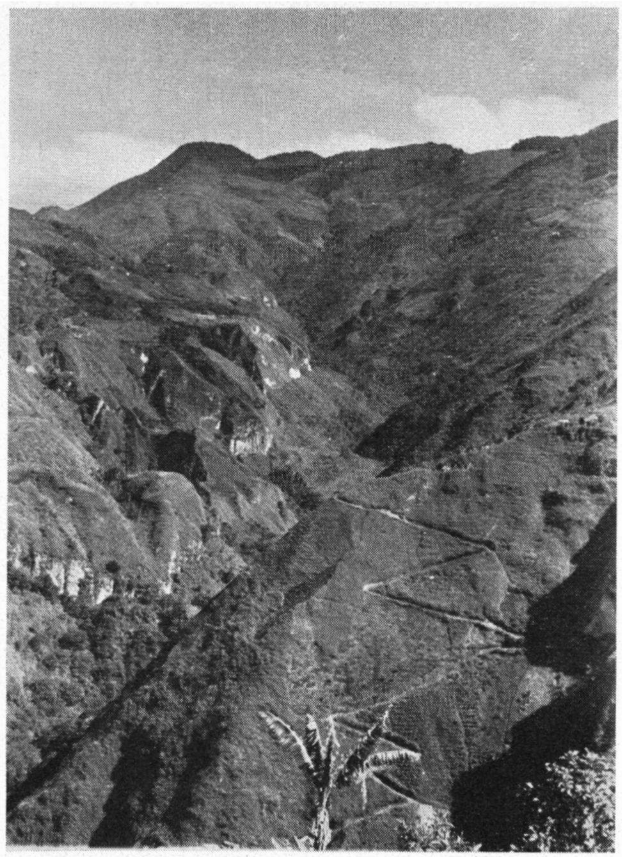


Fig. 5. Remnants of tuffs which form high terraces in the river valleys. Río Toche.

valley, during which he examined the coalcontaining Lower Tertiary. The investigations were extended to Dagua, where he defined the Dagua and Espinal formations. He made also valuable observations along the Río Cucuana and the Río Bugalagrande, crossing the Central Cordillera. He distinguishes clearly between the different facies of the Mesozoic Andean geosyncline on either side of the Central Cordillera.

Finally, we have to mention the publication of D. TRUMPY (1943), dealing with the localities which have yielded a pre-Cretaceous fauna in Colombia. The Payandé area is one of these localities.

PART A

STRATIGRAPHY OF THE CENTRAL CORDILLERA

CHAPTER I

THE CRYSTALLINE BASEMENT ROCKS

1. The Cajamarca Group

The oldest formation of the Central Cordillera in the sector considered here consists of low to medium-grade crystalline schists. They form the upper part of the western slope and extend to the base of the Cordillera near Armenia, where they disappear under the fluvioglacial fan deposits. They constitute also the main part of the eastern side, but further downwards are intruded by granodiorites. The higher parts of the mountain chain are covered over large stretches by pyroclastics, produced by younger volcanism, now extinguished in this sector of the Cordillera.

The schists in question show local intercalations of slightly metamorphic volcanic rocks of diabase composition, apparently in normal interstratification. These individual flows outcrop on the western slope and moreover constitute a morphological feature near La Línea, the highest pass (3400 m) of the road that connects Ibagué with Armenia. Here the diabase rocks with a marked eastward inclination form the proper ridge of the Cordillera.

Because of their similar character we combined all these rocks into one geological formation, designated henceforth as the Cajamarca Group, named after a small village situated on this formation.

At first sight there seems to be only little variation in the metamorphic rocks of the Cajamarca Group. This apparent uniformity is partly due to the effects of weathering, obliterating original differences in rock type. The total impression obviously is so monotonous that prior to the present study even the diabase intercalations remained unobserved. However, careful field observation combined with microscopic examination can considerably broaden our concepts of the petrological conditions of this Cordillera and — to a certain degree — also of its structural constitution.

As to the age of this Group there are very different opinions, ranging from Archaic to Mesozoic. We consider a Paleozoic age as the most probable in view of its stratigraphic position below not-metamorphic fossiliferous limestone of Triassic age and in view of the findings of graptolites in a zone of lower metamorphism, north of the area considered here. In a later chapter we will return to this subject.

In the following paragraphs a description will be given of the main rock types of the Cajamarca Group, principally based on the Ibagué—Armenia section.

a. *Greenschists* (prasinites)

The rocks classified in this group constitute the main rock type of the Central Cordillera in the sector studied here. They may occur as rather compact rocks, but generally show a fine schistosity with a dull phyllitic lustre on the schistosity planes. The rocks are characterized by a definite mineralogical composition that varies within minor limits. Under de microscope the mineral assemblage of actinolite-epidote-chlorite-albite is very

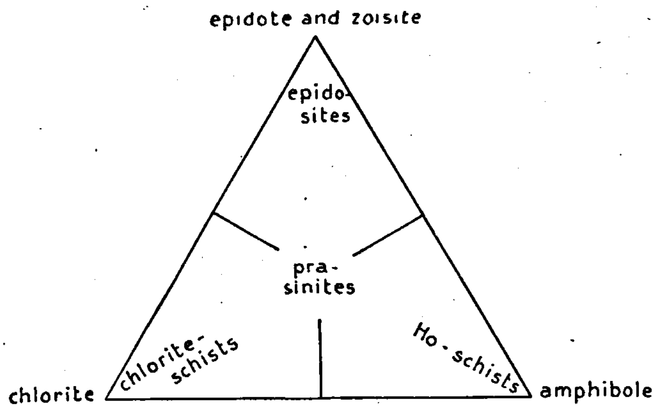


Fig. 6. Diagram indicating the composition of the prasinites and their relation to other greenschists (after DIEHL, somewhat simplified).

TABLE I

Locality	sample	Act	Ep	Cl	Ab	Accessory minerals
Between Q. Perico and Cajamarca:						
	166	xx	xx	xx	xx	biotite
	167	xx	xx	xx	xx	calcite (15 %), biotite
	169	xx	xx	xx	xx	calcite, quartz
	170	xx	xx	xx	x	
	328	xx	xx	xx	*	
Between Cajamarca and La Línea:						
	182	xx	xx	xx	x	
	183	*	xx	xx	x	
	195		xx	xx		quartz
Between La Línea and Calarcá:						
	203	x	xx	xx	xx	
	199	xx	xx	xx	xx	quartz
	197	xx	xx	x	*	quartz

xx = main constituent
x = subordinate constituent
* = in small quantity

typical and indicates an epi-zonal regional metamorphism. These rocks correspond to DIEHLS prasinites according to the diagram given below (LEITMEIER, 1950).

The amphibole of the greenschists is in general of a fibrous actinolitic variety. Epidote or sometimes clinozoisite occurs in small grains between the other minerals. Smaller quantities of quartz, calcite, biotite, sphene and ore minerals may enter as accessory components.

Table I shows the very constant composition of a number of samples collected along the Ibagué—Armenia road.

Calcareous greenschists were observed in the western slope of the Cordillera near Quebreda Plancha. The calcite content may be as much as approximately 30 % and is usually concentrated in small layers which alternate on microscopic scale with layers mainly composed of albite, sericite and minor quantities of chlorite, with fine cubes of pyrite. These calcareous greenschists may pass into rocks of the normal type. Elsewhere the greenschists grade into graphite schists or into quarzitic graphite schists. In this case we observe, besides the graphitic element, an increase of quartz and sericite or muscovite and a simultaneous decrease of albite and of actinolite or chlorite. The content of epidote may decrease to complete absence. The alternations of greenschists, graphite schists, etc., at least those on a megascopic scale, can be contributed to particular variations in the original sedimentary sequence.

b. *Amphibolites near the batholith of Ibagué*

Approaching the batholith of Ibagué there is a zone of about 1—2 km width of amphibolites instead of greenschists. The amphibolites are in abnormal contact with the batholith by means of an important fault, passing along the Quebrada Perico. As the amphibolites represent a higher metamorphic facies than the greenschists, the conclusion seems attractive that this transformation is due to thermal effects resulting from the intrusion of the granodiorites. A fact, however, is that the outer zone of the granodiorite shows a marked schistosity towards the contact. The increasing schistosity finally results in a very remarkable gneiss with oriented hornblende crystals and with distinct vertical schistosity planes, more or less parallel to the direction of the fault and traversed perpendicularly by joints. Possibly the oriented structure was already attained through syntectonic intrusion during the hercynian (?) orogeny. Dislocation effects of the same orogeny might also have produced the amphibolites in question. Andean dislocation effects are also apparent and caused mylonitization of the granodiorite in the fault zone.

Amphibolites also occur as inclusions of different size in the batholith. Other inclusions are transformed into genuine hornfelses with crystalloblastic development of diopside and hypersthene. They will be described in the chapter on the granodiorite intrusion.

The normal contact with the intrusion is exposed on the road between La Sierrita and Junín. Here amphibolites are cut by aplitic and porphyritic dikes. Occasionally the amphibolite rock is so intensely veined that it becomes a real injection-gneiss; furthermore hornblende schists with about 80 % amphibole content may be observed.

In the field the amphibolites appear as dark green and rather massive rocks which may show a fine banding and parallel orientation of the hornblende crystals. The rocks are frequently traversed by joints. In this section the main constituents are dark green hornblende and plagioclase of andesine composition. Both minerals occur in approximately equal quantities, with occasionally a slight predominance of the dark component. The hornblende is in general fresh whereas the plagioclase is frequently turbid and partly altered into saussurite, epidote, prehnite and calcite. These products may even substitute the whole plagioclase, thus producing saussurite amphibolite, zoisite amphibolite, etc. Sphene is always present in fine grains as an accessory component, sometimes accompanied by ilmenite with typical leucoxene borders. Quartz is seldom seen. The disposition of the main constituents may be in alternating layers causing a notable banding. A parallel arrangement only of the prismatic amphibole gives more massive rock types. Allotriomorphic structure also occurs.

c. *Graphite schists*

Graphite schists form next to the greenschists the main element of the Central Cordillera. During a quick reconnaissance they are likely to be underestimated owing to their soft character, their outcrops being less striking than those of the harder rocks. Seen under the microscope the graphite schists consist of a more or less granoblastic mass of fine grained quartz with some albite, containing numerous flakes of muscovite, chlorite and graphite, giving a parallel or undulating schistosity. They may contain pyrite crystals up to 3 or 4 mm in size.

An increase of the chlorite component is frequently observed and with a simultaneous diminution of the graphite element the rocks lose their black colour and pass into greenschists. Constant alternations of both types are very common. Other transitions are towards quartzphyllites, in which the quartz grains are arranged in fine laminae, separated by chlorite and sericite flakes.

Due to their high plasticity the graphite schists are sometimes steeply subfolded and also acted as shear zones on a major scale.

d. *Quartzphyllites*

The phyllites in question form important outcrops on both sides of the Cordillera in the Ibagué—Armenia sector. Moreover, similar rocks have been observed in the Bugalagrande sector, upstream from Alegrías. The fine lamellar banding and the bluish-gray colour are very distinctive. In altered state it may be difficult to identify these rocks because of a fine film of ferruginous material, giving a brownish hue.

A typical even grained quartz is its main constituent, arranged in almost lamellar development, thus denouncing a fine schistosity, which is generally accentuated by a parallel arrangement of sericite and chlorite flakes. Graphitic substance may also participate, darkening the colour of the rock proportional to its content, or finally bringing about a normal graphite schist. The origin of the rock is difficult to determine. It may have been a pure sandy sediment, or rather a cherty rock that suffered recrystallization owing to the dynamometamorphism.

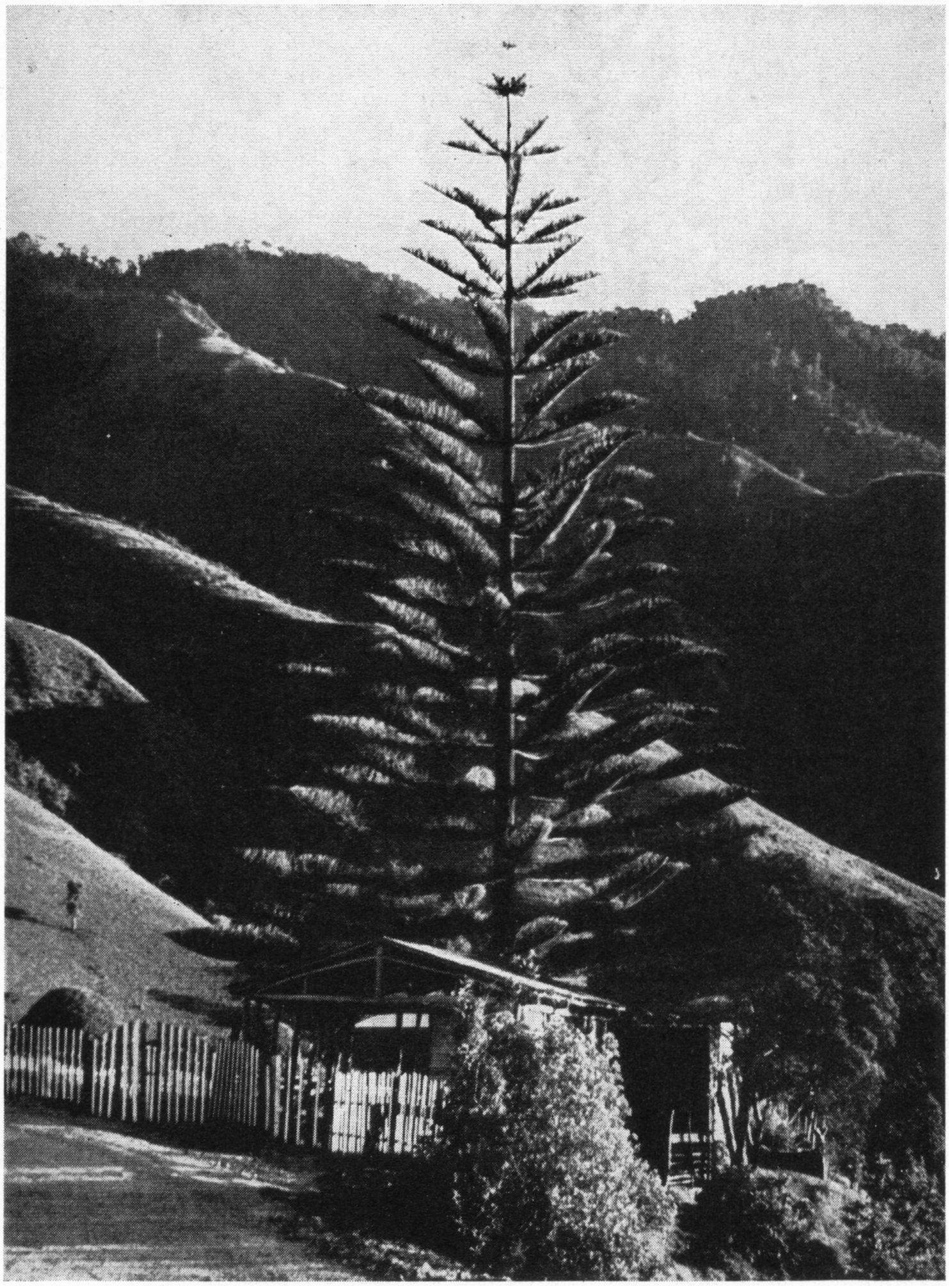


Fig. 7. General view of the Central Cordillera near La Luisa, on the road from Ibagué to Armenia.

e. *Gneissic quartzschists*

The gneissic quartzschists seem to a certain extent to be related to the quartzphyllites. They differ from the latter by a more or less gneissic appearance produced by the presence of lenticular bodies. These lenses may have been originated by shearing. Besides these structural differences there may be variations in the mineral content and some albite and graphite are common associates. These rocks attract attention in the field by their greater resistance to erosion. Their scarps cause various cascades, as can be observed especially in the upper course of the Quebrada Los Chorros.

In connection with the supposition, that these quartzschists suffered stronger dislocation effects than the normal quartzphyllites, their position near the rigid diabase flow is perhaps significant. The latter may have acted as a buffer for tectonical forces.

f. *Metamorphic diabases*

The metamorphic diabases form an interesting element in the Cajamarca Group, in a morphological as well as geological way. Morphologically, a rather thick layer of this rock dominates the actual ridge of the Central Cordillera in the sector of the Depresión del Quindío, only covered by recent volcanic tuffs. In a petrological way they are interesting with regard to the origin of the sedimentary material that has constituted the Cajamarca Group.

In the exposures the diabases occur as dense, greenish and rather altered igneous rocks of basic composition. Sometimes a spherical alteration may be observed. The true nature can only be established in thin sections. The original components of a common diabase are still clearly recognizable, more or less crushed by tectonical forces and rather altered to secondary products. Relics of the ophitic structure are also distinct. The prismatic plagioclase is completely altered into albite; furthermore saussurite, chlorite and quartz occur as secondary products. The diopside augite was better preserved, but especially at the borders there is a development of uralitic actinolite, whose fibres may penetrate the adjacent plagioclase crystals. Ilmenite, partly altered to leucoxene, is the only important accessory mineral; some apatite is also found.

Study of aerial photographs revealed the continuation of the diabase intercalation of the Quindío Depression in the neighbouring area, as shown in fig. 8, elaborated by J. KEIZER. The approximately 100 m thick layer inclines about 25° to the SE, in apparent conformity with the surrounding schists. The escarpment of the diabase forms the highest ridge and the actual water divide in this sector. The place of the transversal displacement (see fig. 8) is the lowest depression (3200 m) of the central ridge, through which passes the road from Cajamarca to Armenia.

The thick cover of neovolcanic tuffs and the advanced alteration of the older outcrops make field observations very difficult and the evidence of the presence of diabase outcrops is mainly based on microscopic examination. Moreover the outcrops have as yet not been traced in adjacent areas. Under these circumstances it is hard to determine the exact nature of these diabases. Fundamentally, it may concern either normal interstratified flows of Paleozoic age or interposed sills of later date, perhaps related to the diabase activity

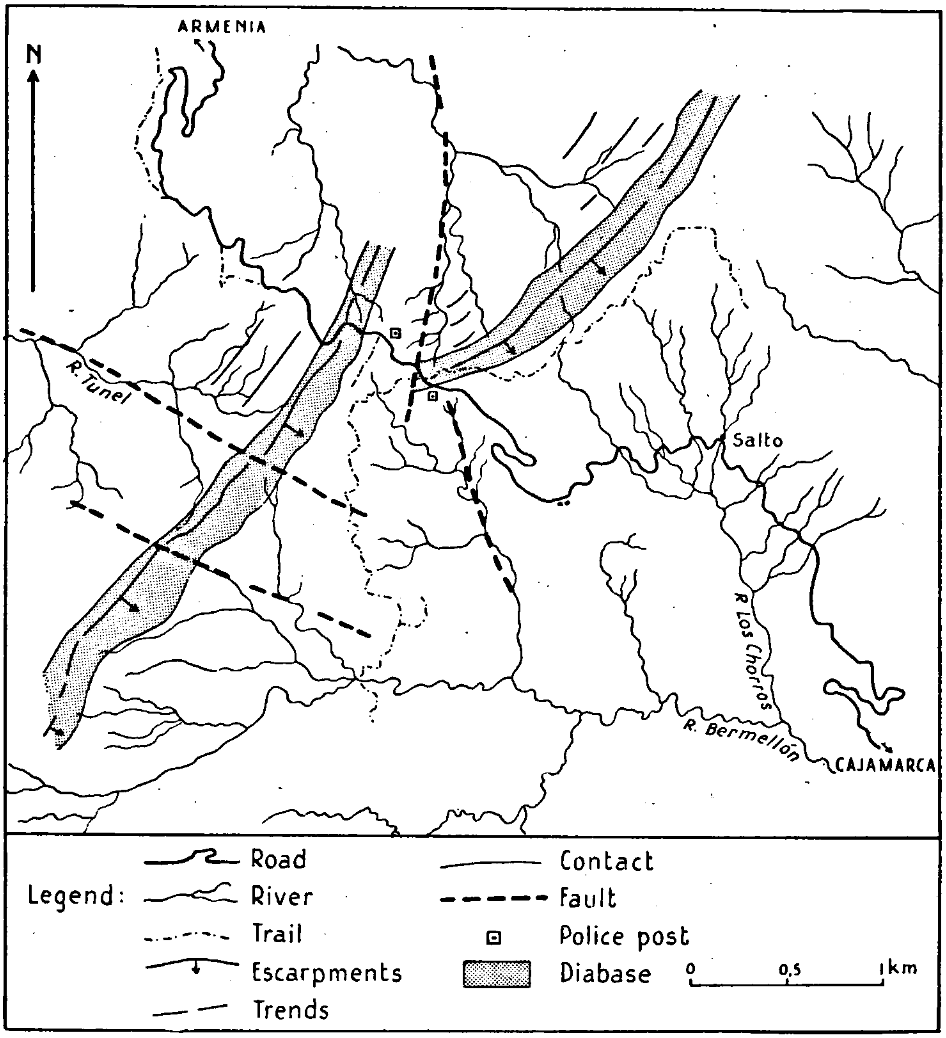


Fig. 8. Situation of the diabase intercalation in the Quindío Depression (Central Cordillera). Interpreted from aerial photographs by J. Keizer.

in the western Andean geosyncline during the Middle and Upper Cretaceous. A third possibility is that the diabase flows produced during this Cretaceous volcanism are themselves in abnormal contact with the Paleozoic basement rocks due to strong dislocation effects. We will return to this subject in a later chapter, after having discussed the volcanic facies of the Paleozoic greenschists and the shearing effects on Cretaceous diabases in the Western Cordillera.

g. *Interbedded crystalline limestones*

Along the eastern border of the Cajamarca Group near the contact with the batholith of Ibagué crystalline limestones are interbedded in the metamorphic schists. They do not constitute continuous horizons, but rather isolated wedge-shaped intercalations of different sizes, which occur in a limited zone extending in NNE direction between Ibagué and Armero. Lenticular bodies of only a few tens of metres are exposed W of Armero and W of La Sierrita. On the other hand, the beds exposed on the road from Ibagué to Cajamarca may attain a length of a few kilometres.

In view of their proximity to the dislocation, which separates the Cajamarca Group from the Ibagué batholith, E. Hubach considers the limestones to be tectonic intercalations. They should be derived from the Upper Triassic Payandé formation. Our observations, however, do not support this point of view. Apart from the fact that only limestones have been observed and never

Fig. 9. Spherical alteration of the diabases forming the ridge of the Cordillera in the Quindío Depression.

intercalations corresponding to the clastic pre-Payandé or volcanic post-Payandé, it is difficult to explain in this way the succession of various small limestone beds within the schists, as exposed near Quebrada Perico, on the road from Ibagué to Cajamarca. Furthermore the dense marble is sometimes slightly graphitic, which is not known from the Payandé limestone. Also the presence of calcareous amphibolites in the immediate vicinity, in our opinion indicates a transition into a more calcareous facies.

Further, the lenslike bodies more northward give sufficient evidence that they constitute normal intercalations in the Cajamarca schists. For instance, W of Armero a bigger lens of marble contains up to 20 % of impurities, which recrystallized to quartz, muscovite, tremolite, sphene and small pyrite cubes, in accordance with the metamorphic grade of the adjacent amphibolites.

West of La Sierrita there are two lenses of marble. The surrounding amphibolites as well as one of the lenses are cut by dikes that undoubtedly belong to the granodiorite intrusion of Paleozoic age.

Marble intercalations are also known from the lower part of the western slope, viz. north of La Enea near Manizales, where beds up to 6 m occur in massive greenschists.

h. *Quartzites and amphibolites of the Bugalagrande section*

Along the Río Bugalagrande, downstream from the hamlet of Alegrías, quartzitic rocks with intercalated graphite schists are exposed on a stretch of about two kilometres. These rocks probably form the lowest part of the Cajamarca Group known in this sector of the Cordillera. The same quartzites can be observed on the road from Puerto Frazadas to Barragán, near the Depresión del Alto Italia pass (3350 m), but the "paramos" of this high area only offer bad exposures. Whereas pebbles of quartzite are still abundant in the Quebrada Bomboná near Cumbarco, more northward the quartzite horizon seems to disappear against the important dislocation, which brings the Cajamarca Group in abnormal contact with the Diabase Group, and no outcrops have been found along the Río Barragán, nor along the Quindío section (Ibagué—Armenia).

The quartzites in question are bluish-gray rocks of a rather dense structure. In thin section they consist essentially of quartz with some albite, aggregated in a mosaic or suture structure. The original cement is recrystallized to quartz and sericite and may be wholly incorporated in the granoblastic mass. Occasionally the original grains are still recognizable, producing a blastopsammitic structure.

Upstream from Alegrías amphibolites dominate the terrain, in alternation with graphite schists. The amphibolites may contain small crystals of almandine garnet. Other schists show conspicuous porphyroblasts of albite up to 3 or 4 mm in size. Thin sections show that these porphyroblasts enclose small crystals of epidote, hornblende and garnet.

The dip is invariably to the East. In view of the general situation the conclusion seems justified that the quartzites form the lower part of the Cajamarca Group.

E. HUBACH considers the quartzites as a sandy and low metamorphic equivalent of the Mesozoic Dagua Group, which in the Western Cordillera underlies the Diabase Group. He indicates this sandy facies as Barragán formation. But apart from the geological situation there are also petrological arguments against this supposition. In their metamorphic grade the quartzites agree perfectly with the amphibolites, albite schists, etc. of the Cajamarca Group, but they are in strong contrast to the Diabase Group west of the dislocation, which does not show any signs of metamorphism. Moreover, graphite schists of the same metamorphic grade alternate with the quartzites as well as with the amphibolites. The quartzitic horizon has also been observed much further to the South and is locally interbedded with marbles. J. KEIZER visited the outcrops along the Río Palacé (N. of Popayán) and along the Río Güengüe (S. of Miranda) and came to the same conclusion.

i. *The facies of the Cajamarca Group*

The foregoing petrographical study suggests a certain relationship between the facies of the different rock types that compose the Cajamarca Group.

For a number of rocks, such as the graphite schists, quartzphyllites, quartzites, a. o., the original environment is obvious: they were deposited as an argillaceous or fine sandy facies in a marine basin under geosynclinal circumstances. Fossils have not been found, nor can they be expected to be found owing to the metamorphic state of these sediments. The variable graphite content is perhaps the only organic relic.

Less unequivocal is the origin of the greenschists and amphibolites. Their mineralogical composition cannot result from the metamorphism of argillaceous or fine sandy sediments, in view of their low content of silica and their high content of calcium and magnesia. Within the domain of sedimentary rocks only a dolomitic marl would correspond to the composition of the major part of the greenschists. It is not very probable that this rather scarce class of sediment should have formed so mighty layers with such constant repetition as to correspond with the actual successive layers of the greenschists in question.

Chemical analyses show the remarkable similarity in composition between the greenschists and amphibolites on the one hand and the diabases on the other hand. Table No. II gives the results of two analyses of each rock type, all from the Cajamarca Group. The corresponding molecular values are given in table III. Minor differences exist only in a somewhat higher *si*

TABLE II

	Prasinites		Amphibolites		Diabases	
	Ne 328	Ne 182	Ne 297	Ne 314	Ne 339	Ne 216
SiO_2	48.33	46.05	49.85	49.07	48.40	50.38
Al_2O_3	14.30	16.28	15.48	17.33	15.50	15.37
Fe_2O_3	5.85	7.73	4.72	4.25	5.11	4.00
FeO	5.30	3.59	5.99	5.23	7.22	7.15
MnO	0.21	0.20	0.22	0.22	0.22	0.17
MgO	8.56	6.98	5.70	7.40	6.28	7.35
CaO	8.86	12.38	11.95	11.50	6.76	6.06
Na_2O	3.42	2.77	2.96	2.25	3.77	3.71
K_2O	0.38	0.07	0.13	0.20	0.18	0.42
H_2O+	1.40	2.14	0.48	0.44	3.00	2.91
H_2O-	0.10	0.06	0.12	0.08	0.15	0.19
TiO_2	1.80	1.85	1.76	1.30	2.50	1.70
P_2O_5	0.38	0.28	0.24	0.27	0.42	0.34
[1])	0.37	0.11	0.06	0.14	0.02	0.34
Total	99.26	100.49	99.66	99.78	99.53	100.09

Analysed by: Laboratorio Químico, Bogotá.

[1]) Loss on ignition except water.

The locality of the six analysed samples is:

Ne 328 1 km east of Cajamarca
Ne 182 2 km west of Cajamarca
Ne 297 half way between La Sierrita and Junín
Ne 314 NW of Armero (Estación Agropecuaria)
Ne 339 La Línea, highest pass between Ibagué and Armenia
Ne 216 do

TABLE III

Molecular values of six samples (Locality see Table II)

	Prasinites		Amphibolites		Diabases	
	Ne 328	Ne 182	Ne 297	Ne 314	Ne 339	Ne 216
si	112	102	118	112	122	127
al	19.5	21.5	22	24	23	23
fm	50.5	43	41	43	49	51
c	22	29.5	30	28	18.5	16.5
alk	8	6	7	5	9.5	9.5
k	0.1	0.1	0.1	0.1	0.1	0.1
mg	0.6	0.5	0.5	0.6	0.5	0.5
qz	—20	—22	—10	—8	—16	—11

and *alk* (soda) and a lower *c* in the diabases. Possibly these minor differences are due to the complete albitization of the plagioclase in the diabase, as shown in the thin sections.

This chemical similarity makes an igneous origin of the greenschists and amphibolites very probable. But we need not necessarily think only of volcanic flows of basic composition in order to explain the origin of these rocks. Volcanic tuffs produced during eruptions would answer the observed composition as well. They would account much better for certain observations. In the first place the transitions between greenschists and other rocks of sedimentary origin described in previous paragraphs are explained easily in this way. During an eruptive phase the pyroclastic products dominated strongly over the normal sedimentation products in wide areas. When volcanic activity decreased the normal sedimentation products again became dominant. It is obvious that according to the prevailing facies at the moment of eruption all kinds of mixed sediments may be formed. Continuous and swift alternations like those observed at various places do not depend on alternations of the existing marine facies, but in the first place are due to the variable supply of volcanic pyroclastics. Volcanic flows would not produce mixed rock types and are not likely to produce such differences in the thickness of the layers.

There are still other indications that point towards a tuffaceous origin. It seems doubtful whether metamorphism of a rather low grade as expressed by the mineral combination epidote-actinolite-chlorite-albite would have been able to destroy so completely every vestige of the igneous fabric and mineral composition of real diabase flows. In this connection we should recall the presence of real diabases in the Depresión del Quindío and at a few other places. These diabases are in clear contrast to the greenschists and show a distinct relic structure and only a partial transformation of the mineral components. Although it is not impossible that the diabases in question represent post Paleozoic sills and in that case escaped the hercynian metamorphism, the general geological situation points rather to their being normally interbedded flows. This concept is in perfect harmony with the volcanic nature of the greenschists but at the same time difference in the effects of metamorphism indicates a difference in original character.

From the marine facies of the Cajamarca Group we may conclude that interbedded flows must have been of a subaquatic kind. In submarine flows spilitization is regarded to be a normal phenomenon. So the albitization of the diabase feldspars may have been a pre-metamorphic phenomenon.

2. The batholith of Ibagué

The metamorphic schists of the Cajamarca Group are limited towards the East by a batholith of granodiorite. This pluton can be followed from near Armero towards the South, first as a small border zone until near Ibagué, then broadening quickly along the fault line of the Río Cocora inwards into the Cordillera. East of the line Armero-Ibagué the intrusive rocks are covered by younger sediments, especially by the extensive fanlike fluvioglacial deposits derived from the Cordillera. On a few places, a. o. West of Piedras, the igneous rocks emerge from under these deposits and form small isolated hills that attract attention in the vast, flat plain. A similar, but more extensive igneous outcrop forming the Lomas de los Potreritos, north of the Río Coello, draws the attention already from a great distance. More southward the batholith is covered by Mesozoic and early Tertiary formations, thus demonstrating its pre-Mesozoic and probably hercynian age. Furthermore, its intrusive character into the Cajamarca schists is proven by direct contacts and a wide zone of injection-gneisses near La Sierrita.

Seen as a whole the batholith has a rather uniform composition and consists of biotite-hornblende granodiorite, in which the dark components occur in approximately equal quantities. In some areas, as in the borderzone north of Ibagué, potash feldspar may be rare or absent so that the rock passes into a quartzdiorite. The fabric is generally granitic, with a medium grain size.

Although a detailed study could not be made, we wish to mention some interesting observations made during an exploration along the Quebrada La Chumba, near the hamlet of La Flor, a few kilometres NW of the village of El Salado, where the riverbed offers fine exposures, in which two different types of rocks can be clearly distinguished. The first type has a "granitic" aspect and is of a light colour and rather coarse grained. It consists of white plagioclase and prismatic hornblende crystals up to 8 mm in size besides biotite and quartz. The second type has a more "dioritic" aspect, with a much darker colour and a finer grain, but with the same mineralogical constituents. Both types occur side by side, mutually enclosing each other in irregular masses, which measure from a few decimeters to several meters. They give the impression of forming a more or less coherent system in a three dimensional sense. The mutual limit is generally well defined, without a distinct transitional zone, even in thin section.

The average mineral composition of both types, obtained by means of a rough estimate from thin sections, is given in table IV. The chemical composition of two representative samples is reproduced in the next table.

The mineralogical differences are mainly limited to a lower quartz percentage and a higher feldspar content in the dark rock type. The quantity of the dark elements is only slightly higher, with predominance of hornblende instead of biotite. Consequently, the darker colour must be mainly ascribed to the finer grain. The chemical analyses confirm the small mineralogical differences. Besides these, there are structural differences. The dark "dioritic" rock type shows an allotriomorphic development of both coloured

TABLE IV

Average mineral percentages of two types of quartzdioritic rocks:
Locality: Quebrada La Chumba, NE of Ibagué

	light type	dark type
quartz	25 %	13 %
plagioclase	55	63
hornblende	8	14
biotite	12	10

TABLE V

Weight-percentages and molecular values of two types of quartzdiorites
Ne 262 coarse grained, light coloured type
Ne 263 fine grained, dark type.
Locality: Quebrada La Chumba, NE of Ibagué

weight %	Ne 262	Ne 263	molecular values	Ne 262	Ne 263
SiO_2	63.02	61.02	si	229	207
Al_2O_3	15.40	17.10	al	33	33
Fe_2O_3	3.30	3.20	fm	30	29
FeO	2.94	2.64	c	22	26
MnO	0.19	0.16	alk	15	12
MgO	2.21	2.48	k	0.3	0.15
CaO	5.60	7.10	mg	0.4	0.45
Na_2O	2.95	3.15	qz	69	59
K_2O	1.93	0.72	T	—4	—5
H_2O+	0.90	0.57			
H_2O-	0.16	0.07			
TiO_2	0.85	0.86			
P_2O_5	0.36	0.38			
[1])	0.22	0.11			
Total	100.03	99.56			

Analysed: Laboratorio Químico, Bogotá.

[1]) Loss on ignition except water.

constituents; in other words the biotite and hornblende occur as irregularly bounded flakes and crystals, often in mutual intergrowths. They may enclose small and well-shaped plagioclase crystals, creating a noteworthy poikilitic structure, but giving the impression as if the feldspar has grown at the expense of the dark minerals. As a rule the plagioclase constituents have a zonal structure; the centre is often sericitized and may be corroded. On the other hand, the thin sections of the coarse grained, light coloured type show the common "granitic" structure, with hypidiomorphic development of the dark components and poikilitic intergrowth is only rarely observed. The plagioclase is zoned, but generally without sericitization of the centre. We do not intend to draw conclusions from these incidental observations, but we cannot escape the impression that the darker parts correspond to schists, in which the assimilation has not been entirely completed.

Xenoliths have been observed in various parts, especially in the exposures along the road from Ibagué to Cajamarca. They vary in size from a few inches to various metres. The smaller ones often have an oblong or lenticular form. Under the microscope part of the inclusions appear to be hornfels-amphibolites, composed of dark green hornblende and plagioclase; seldom diopside is associated; the structure is a granoblastic mosaic, but sometimes parallel orientation of the components is seen. Other inclusions appear to be hornfelses composed of a mosaic of basic plagioclase (andesine/labradorite), diopside, hypersthene and some biotite. Sometimes they have a marked poikiloblastic structure, that probably forms a threedimensional reticule within the rock, as shown by the simultaneous extinction of various patches of pyroxene.

CHAPTER II

THE MESOZOIC AND LOWER TERTIARY OF THE EASTERN BORDER

1. Rhyodacitic extrusions

South of Ibagué the granodiorite batholith is covered over a great extension by acid extrusions. They form the hills between this town and the canyon of the Río Coello. The morphology of this part has much resemblance to a tilted plateau limited towards the NW by a steep slope and gently inclining towards the SE. The general drainage well illustrates this morphology. Towards the East the extrusives disappear under the wedge-shaped rift, traversed by the Río Combeima, but they reappear on the opposite side. Here they form the steep V-slope, up to the marked mountain-ridge on which San Antonio is situated, whereas the less inclined dip slope is formed by the Payandé-formations of Triassic age. It has not been possible to establish, whether the extrusions also lie on the higher parts of the hills between the canyon of the Río Coello and the Río Luisa. Boulders found in a northern tributary of the Río Guadual point into this direction, but might as well be derived from quartzporphyry dikes. Further, outcrops have been found along the Río Luisa, downstream from Rovira and along the Río Cucuana. The areal distribution gives the impression, that acid flows extruded over a denudation-surface of the hercynian batholith. The Payandé-formations overlie them with a small unconformity. Later, the Andean orogeny caused block-faulting and tilting with inclinations towards the East. The stratigraphic position suggests a Permo-Triassic age for the extrusives. Tuffs or other pyroclastic products have not been formed during this period of volcanism.

The flows show certain variations as to their composition, but they are always of an acid type. In accordance with their chemistry they have more or less light colours, varying generally from reddish to gray tints. The most acid types are rhyolites, composed of phenocrysts of quartz, orthoclase and sodic plagioclase, together with the usual small percentages of biotite and/or hornblende. The quartz often shows magmatic corrosion. Sometimes quartz and feldspar occur intergrown, forming compound phenocrysts, called micropegmatite-phenocrysts. The groundmass is generally crystalline and may have a fine granular or granophyric texture; also microfelsitic texture is seen. As an accessory mineral some orthite is found, intergrown with clinozoisite. The more basic types may be classified as dacites. Among these rocks a buff coloured type calls attention. It is so crowded with phenocrysts that at first sight it has the appearance of an intrusive rock. In thin section the porphyritic nature is easily recognized. It consists of phenocrysts of plagioclase and hornblende with a little biotite and rarely quartz, embedded in a microcrystalline groundmass, often with micrographic texture.

Along the important dislocation zone limiting the Permo-Triassic plateau the extrusive rocks suffered deformation and appear to have been changed into porphyroid gneisses. Especially the outcrops along the road from Ibagué to Rovira offer a fine example of this kind of rock. The porphyroid gneisses have a blastoporphyric structure owing to the presence of original phenocrysts, especially of feldspar. The latter may be partially replaced by the granoblastic mass, containing quartz, microcline, sodic plagioclase and muscovite flakes; also garnet has occasionally been observed.

On the eastern side of the small rift, especially at the base of the steep slope towards the Río Coello, the extrusive rocks are strongly crushed. The cracks have been filled up with gypsum, that can be even concentrated in such quantities as to form deposits of economic value.

The total thickness of the extrusive flows can be estimated at approximately 500 m.

In table VI we reproduce the results of chemical analyses, made from a rhyolitic and a dacitic type. The somewhat high T-value might be due to a slight kaolinization of the feldspar.

TABLE VI

Weight-percentages and molecular values of a rhyolite (Ne 228) and a dacite (Ne 222)

weight %	Ne 228	Ne 222	molecular values	Ne 228	Ne 222
SiO_2	71.30	66.02	si	385	268
Al_2O_3	15.12	15.82	al	48	40
Fe_2O_3	1.61	2.24	fm	13	28
FeO	1.18	2.14	c	6.5	16
MnO	0.07	0.07	alk	32.5	16
MgO	0.07	1.97	k	0.4	0.2
CaO	1.14	3.41	mg	0.1	0.5
Na_2O	3.97	2.91	qz	155	104
K_2O	3.42	1.38	T	+9	+8
H_2O+	0.96	0.75			
H_2O-	0.30	0.21			
TiO_2	0.36	1.28			
P_2O_5	0.15	0.05			
[1])	0.17	1.81			
Total	99.82	100.06			

Analyses: Laboratorio Químico, Bogotá.

[1]) Loss on ignition except water.

2. The Payandé-formations

The Payandé-formations were first described by D. TRUMPY (1943) and named after the small village of Payandé, on the southern border of the Río Coello. Fossils collected by RENZ in limestone outcrops near this locality indicate an Upper-Triassic age. These fossiliferous limestones are underlain by a series of consolidated conglomerates, arkosic sandstones, etc., which has been designated by TRUMPY as the pre-Payandé formation. The Payandé limestones are overlain by volcanic red beds composed of dacites and andesites, together with tuffs. These strata are distinguished as the post-Payandé formation. Towards the end of this period of volcanism granodioritic and monzonitic stocks are intruded, forming typical limesilicates in the contactzone with the Payandé formation.

Lower Cretaceous sediments overlie unconformably the Payandé formations and the above mentioned intrusive stocks. Some 50 km south of the investigated area, the volcanic post-Payandé is covered by a series of little coherent conglomerates and arkosic sandstones, which pass with a scarcely perceptible disconformity into white quartzitic sandstones of Aptian age.

The strata of the Payandé-formations dip with moderate angles to the E and constitute the eastern slope of a marked asymmetric mountain ridge between the rivers Coello and Cucuana. The highest outcrops of this mountain ridge are formed by the resistant pre-Payandé formation, overlying the rhyodacitic extrusives, discussed in the previous paragraph, which outcrop on the steep western slope. The Payandé formations are cut by dikes of quartz-porphyry and of dark augite-hornblende-porphyrite, probably related to the monzonitic and quartzdioritic intrusions of Jurassic age.

In the following paragraphs we will discuss the particularities of each formation.

a. *The pre-Payandé formation*

The pre-Payandé formation consists of a series of red beds composed of conglomerates, greywackes and ferruginous shales. The coarser components predominate in the lower part of the series. These deposits, especially the coarse grained ones, are consolidated to such an extent that they attain the hardness of gritstones. The small rapids that come down from the steep mountain slope NW of San Antonio, carry big blocks of conglomerate, which owing to their variegated components are very conspicuous. The blocks show parting along nearly flat planes, that cut through the individual boulders, thus demonstrating the high consolidation of the rock. Sometimes the poorly sorted components may be so angular, that the rock is a breccia rather than a conglomerate. The débris consists of fragments of granodiorites, dacites, rhyolites, porphyrites, etc. and consequently has been derived from the erosion of the Ibagué batholith and of the Permo-Triassic extrusives.

Under the microscope the same igneous components, together with abundant fragments of feldspar and quartz, are observed in the greywackes. Again, the same minerals, but in finer grain size, constitute the ferruginous quartzitic sandstones and finally the ferruginous shales. It is recommanded to avoid classifications as "tuffaceous sandstones" or "tuffaceous shales" for these rock types, which are in no way related to contemporaneous volcanism, but are derived from the erosion of older eruptive rocks.

Evidently it was the rapid uplift of the Central Cordillera that has provided the coarse clastics for this formation. The débris were deposited in terrestrial facies along the border zone of the Cordillera. The thickness of the sediments is about 300—400 m, but seems to increase towards the Río Cucuana. In the opposite direction the formation decreases in thickness, and finally wedges out, completely north of San Antonio. This reduction in thickness may be partly a tectonical reduction, caused by a small overthrust of the limestone in this sector.

b. *The Payandé-formation*

The Payandé-formation is developed mainly in calcareous facies and reflects a marine ingression during the Upper-Triassic time. The contact with

Fig. 10. Pre-Payandé conglomerate. The rock is highly consolidated and consists mainly of little rounded igneous pebbles.

Fig. 11. Payandé limestone, interbedded with cherts, outcropping on the southern border of the Río Coello.

the underlying terrestrial sediments of the pre-Payandé is only badly exposed. Our observations, however, have not established in any area an appreciable unconformity. In the Quebrada Aguirre both formations outcrop in short distance from each other, both inclining with moderate angles to the SE. Along the trail from San Antonio to El Salitre and along the Río Luisa the same observations can be made.

Locally, the formation is fossiliferous. RENZ collected in the lower part *Myophoria jaworski* STEINMANN, besides gastropods, crinoids (*Pentacrinus*) and echinoids. *M. jaworski* has been described from limestone of Karnian age in Perú. The middle part of the formation furnished several ammonites identified as:

Nevadites sutanensis JAWORSKI
N. cf. *lissoni* JAWORSKI
Anolcites dieneri JAWORSKI.

The upper part contains *Pseudomonotis ochotica* KEYSERLING, which fossil is characteristic of the Norian. Corals have been found in some beds throughout the formation, but have not been determined.

Lithologically, the formation consists of a series of about 600 m of greyish-blue to dark limestones. In a few horizons the limestone is interbedded with slaty shales and black cherts; also beds of calcareous breccia occur. Occasionally the limestone contains nodules of black chert. The limestone is frequently arenaceous and the admixture with terrigenous sediments may be so high, that the rock is rather a calcareous sandstone; even pure sandstone intercalations occur. Thin sections show that in the arenaceous rocks grains of feldspar are always abundant. Undoubtedly the terrigenous components come from the same source as the clastics that compose the underlying pre-Payandé formation; that is to say, they are derived from the erosion of the Central Cordillera. Consequently, we may conclude that the deposition of the Payandé formation took place in a rather shallow sea, with frequent influx of clastic sediments, derived from the progressing denudation of the Central Cordillera, which must have been an emergent landmass.

The Payandé formation has been intruded by granodioritic rocks of Jurassic age, which produced extensive thermal contact zones. The limestones were metamorphosed to white marbles, whereas the sandstone intercalations were transformed to hornfelses of a greenish colour. In the field the latter may resemble dense volcanic or tuffaceous rocks, but in thin section the true nature is easily revealed. They consist of fine grained quartz and feldspar; the feldspar may be partially altered to sericite; in the recrystallized cement small biotite flakes developed and occasionally xenomorphic hornblende crystals. Arenaceous limestones altered to interesting hornfelses, composed of diopside, wollastonite, tremolite, epidote, albite and sphene. A reddish-brown hornfels, exclusively composed of grossularite-andradite-garnet ($n = 1{,}83$) outcrops over a distance of about 50 m on the trail to the Minavieja, south of the Quebrada Ríofrío, near an abandoned coppermine in this locality. A tough wollastonitefels outcrops in the Quebrada Trujillo, where huge blocks obstruct the course of the small river.

This intrusive phase was followed by hypogene solutions, which caused mineralizations in the limestone beds. In former times they have been worked for their copper content.

The outcrops of the Jurassic igneous rocks west of the village of Payandé can be followed for several kilometers in the steeply eroded valleys of the small rivers. At first sight, it may give the impression, as if the limestone beds unconformably overlie the igneous rocks and that the latter be older than the former. In particular the study of aerial photographs may easily lead to misinterpretations when one is not aware of the thermal contacts, especially because of the confusing vicinity of the Paleozoic basement rocks, outcropping in the Lomas de los Potreritos.

c. *The post-Payandé formation*

This period begins with the revival of volcanic activity, whose products overlie the Payandé strata. A small transitional zone, formed by tuffaceous shales and chert beds, may be present, but has not been observed clearly due to advanced alteration in the exposures. During this transition the facies changed from marine to terrestrial, and no marine intercalations are found on higher levels.

The formation outcrops east of the hamlet of El Salitre, where the Que-

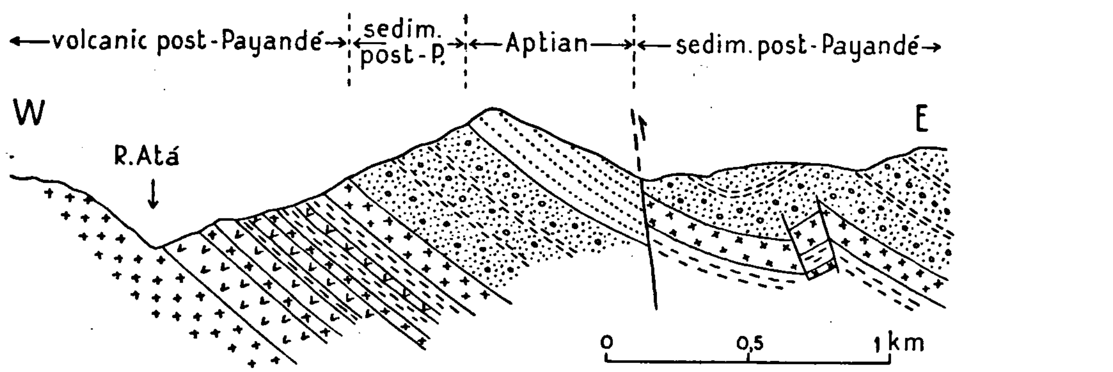


Fig. 12. Section showing the stratigraphic position of the sedimentary post-Payandé overlying the volcanic red beds. Road from Prado to Dolores.

brada la Hondura provides fine exposures. The same formation may be seen south of the Río Luisa, where it forms the western slope of a conspicuous ridge called the Cuchilla del Pital.

The formation consists of a series of volcanic rocks of reddish and greenish colours, formed by flows, tuffs and agglomerates. The rocks are very massive and often the pyroclastic strata can only be distinguished by means of thin sections. It seems that rhyolite and dacite flows and tuffs prevail in the lower part, whereas in the upper part andesitic products predominate. The total thickness in the exposed area is about 500—600 metres.

In the sector between the Río Coello and Río Cucuana the volcanic strata as well as the older Payandé formations are overlain unconformably by Lower Cretaceous (Aptian). A section made some 50 km further to the South, along the road from Prado to Dolores, shows a different and more complete development of the post-Payandé formation. Here the volcanic strata are conformably overlain by a 400 m thick series of red beds composed of loose conglomerates, greywackes and arkosic sandstones. The pebbles of the conglomerate consist of intrusive and volcanic rocks. Some beds contain abundant opalized wood, which according to v. d. Hammen originates from Conifera. On higher levels the deposits become finer grained and less arkosic, and finally they pass without a clearly perceptible limit into white quartzitic sandstone of Aptian age.

The same red beds of terrestrial conglomerates, greywackes, etc., outcrop on the road from Coyaima to Ataco. They also yielded silicified wood of Conifera. In this locality the red beds are intercalated with a few thin limestone beds and calcareous breccias, indicating marine ingressions. Unfortunately, fossils have not been found during our quick reconnaissance.

Obviously, tectonic movements towards the end of the volcanic activity which characterizes the post-Payandé period, caused erosion in certain areas, resulting in an angular overlap of the marine Lower Cretaceous, whereas in other areas the débris accumulated on the volcanic post-Payandé strata and pass without a marked disconformity into the Lower Cretaceous. These movements seem to be related to the intrusion of monzonitic and granodioritic stocks, which will be discussed in the next paragraph.

3. Jurassic Intrusions

West of Payandé the Upper Triassic limestones are intruded by acid igneous rocks, which have produced the thermal contacts described in a previous paragraph. More to the South, the same plutonic rocks are exposed along the foot of the Cuchilla del Pital, where they were intruded exactly along the limit between the above mentioned limestone and the volcanic strata of post-Payandé age. From this position we may deduce a post-Triassic age for the intrusives in question. On the other hand, no thermal metamorphism is observed in the Lower Cretaceous (Aptian) of the mapped area, nor in the underlying red beds described from the Prado-Dolores and the Coyaima-Ataco sections. Consequently, the plutonism must be of Jurassic age.

At first sight the outcrops give the impression that each constitutes a small individual stock. But the extension of the contact-metamorphic area suggests rather the presence of more extensive bodies, which underlie at relatively low depth the Mesozoic and Cenozoic formations. Likewise, the individual outcrops near Natagaima can be followed to north of Coyaima, where they emerge in several places through the Miocene Honda formation.

In the sector between the Río Coello and Río Cucuna the Jurassic intrusives are classified as hornblende-biotite-granodiorites. In the immediate vicinity of the contacts the rock may attain a porphyritic structure. Petrographically, the Jurassic intrusives can hardly be distinguished from the Paleozoic intrusives of the Ibagué batholith and the stratigraphic position must be ascertained by field observations rather than by means of thin sections. The Jurassic intrusions that outcrop in the area of Coyaima-Natagaima-Dolores have a different composition and are classified mainly as augite-quartz-monzonites. Quartz rarely exceeds 10 % and occurs interstitially or as perthitic intergrowths. The pyroxene may have a "Schiller"-structure and is partly altered to uralite. Occasionally some biotite is present. As accessory minerals occur zircon, sphene and pyrite. The structure is typically monzonitic; that is to say, orthoclase occurs in tabular xenomorphic crystals, which may enclose small idiomorphic plagioclase crystals. The mineral composition of some samples is given in table No. VII. The chemical analyses and molecular values of two samples are reproduced in table No. VIII.

TABLE VII

Mineral composition of some monzonites.
Locality: Ne 87 and Ne 88 between Natagaima and Dolores.
Ne 387 and Ne 392 Río Anchique, W of Natagaima

	Ne 87	Ne 88	Ne 387	Ne 392
quartz	10 %	6 %	12 %	10 %
orthoclase	25	40	35	30
plagioclase	40	32	40	38
pyroxene	23	20	12	20
accessory min.	2	2	1	2

TABLE VIII

Weight-percentages and molecular values of two monzonites.
Locality: between Natagaima and Dolores.

weight %	Ne 87	Ne 88	molecular values	Ne 87	Ne 88
SiO_2	55.10	55.02	si	160	167
Al_2O_3	17.55	18.35	al	30	33
Fe_2O_3	4.49	5.01	fm	35	32
FeO	2.97	2.02	c	19.5	20.5
MnO	0.14	0.14	alk	15.5	14.5
MgO	4.05	3.35	k	0.20	0.40
CaO	6.26	6.40	mg	0.50	0.45
Na_2O	4.40	2.95	qz	—2	+9
K_2O	1.67	3.02	T	—5	—2
H_2O+	1.71	1.35			
H_2O-	0.26	0.20			
TiO_2	0.67	0.73			
P_2O_5	0.36	0.22			
[1])	0.23	1.24			
Total	99.86	100.00			

Analyses: Laboratorio Químico, Bogotá.

[1]) Loss on ignition except water.

The relation of the monzonitic intrusions near Natagaima with the granodioritic intrusions near Payandé is difficult to establish due to the great distance between both localities and the lacking of intermediate outcrops. The Jurassic intrusives near Payandé are perhaps derived from the same monzonitic magma, modified to a granodioritic magmatype by assimilation at the contacts with the arenaceous limestones.

4. Cretaceous

The Cretaceous and Cenozoic formations are beyond the scope of the present study, as the stratigraphical problems of these formations lie mainly in the domain of paleontologic and palynologic investigation. Nevertheless, it may be useful to record in this place some incidental observations about the development in the mapped area.

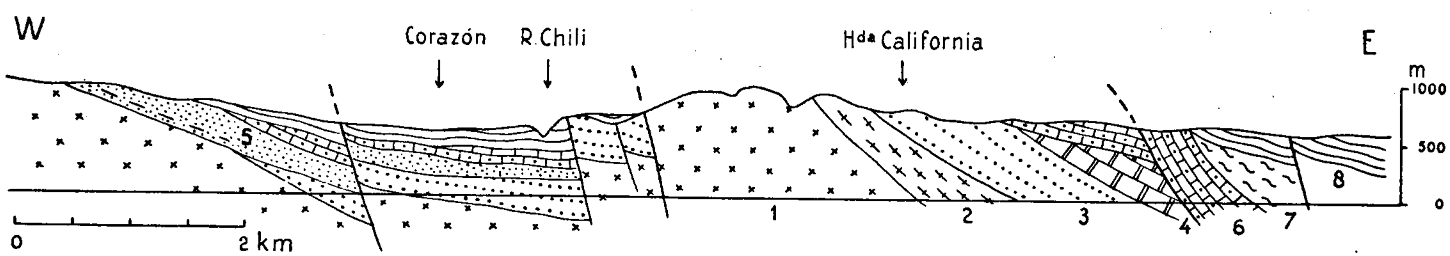


Fig. 13. Section along the Río Cucuana near Corazón.
1. pre-Mesozoic granodiorite; 2. Permo-Triassic rhyodacites; 3. pre-Payamé conglom., etc.; 4. Payandé limestone (Upper Triassic); 5. Aptian (sandy facies with lignite seams); 6. Aptian (calcareous facies); 7. Albian/Cenom./Turon.; 8. Gualanday sandstone (Olig.).

As stated before, Lower Cretaceous transgresses unconformably over the Payandé formations. Interesting is the variation of its facies from W to E. About 2 km upstream the Río Cucuna from the hamlet of Corazón, greyish compact sandstones lie directly on the Paleozoic granodioritic basement rocks. The sandstones contain small shaly beds with plant remains and a few lignite seams. The latter yielded pollen, which — according to T. v. d. Hammen — indicate a Lower Cretaceous age for the deposits. Although at this moment the age cannot be defined more precisely, these sediments possibly border the Aptian transgression towards the Central Cordillera.

Some 6 km downstream from Corazón, Lower Cretaceous is again exposed, overlying disconformably breccias and ferruginous shales of the pre-Payandé formation. The lower levels of the exposed Cretaceous are formed

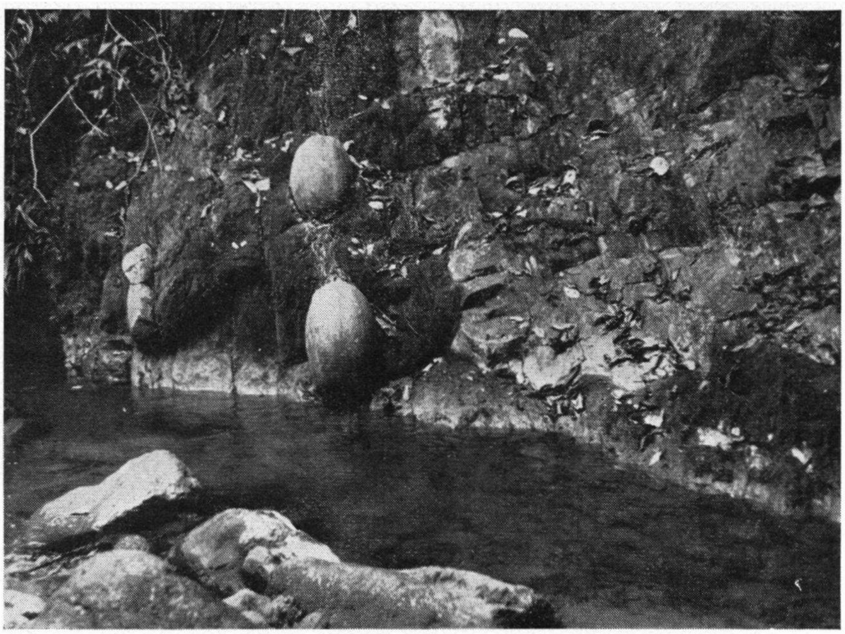


Fig. 14. Dark blue shale with "waggon-wheels". Zanja Seca.

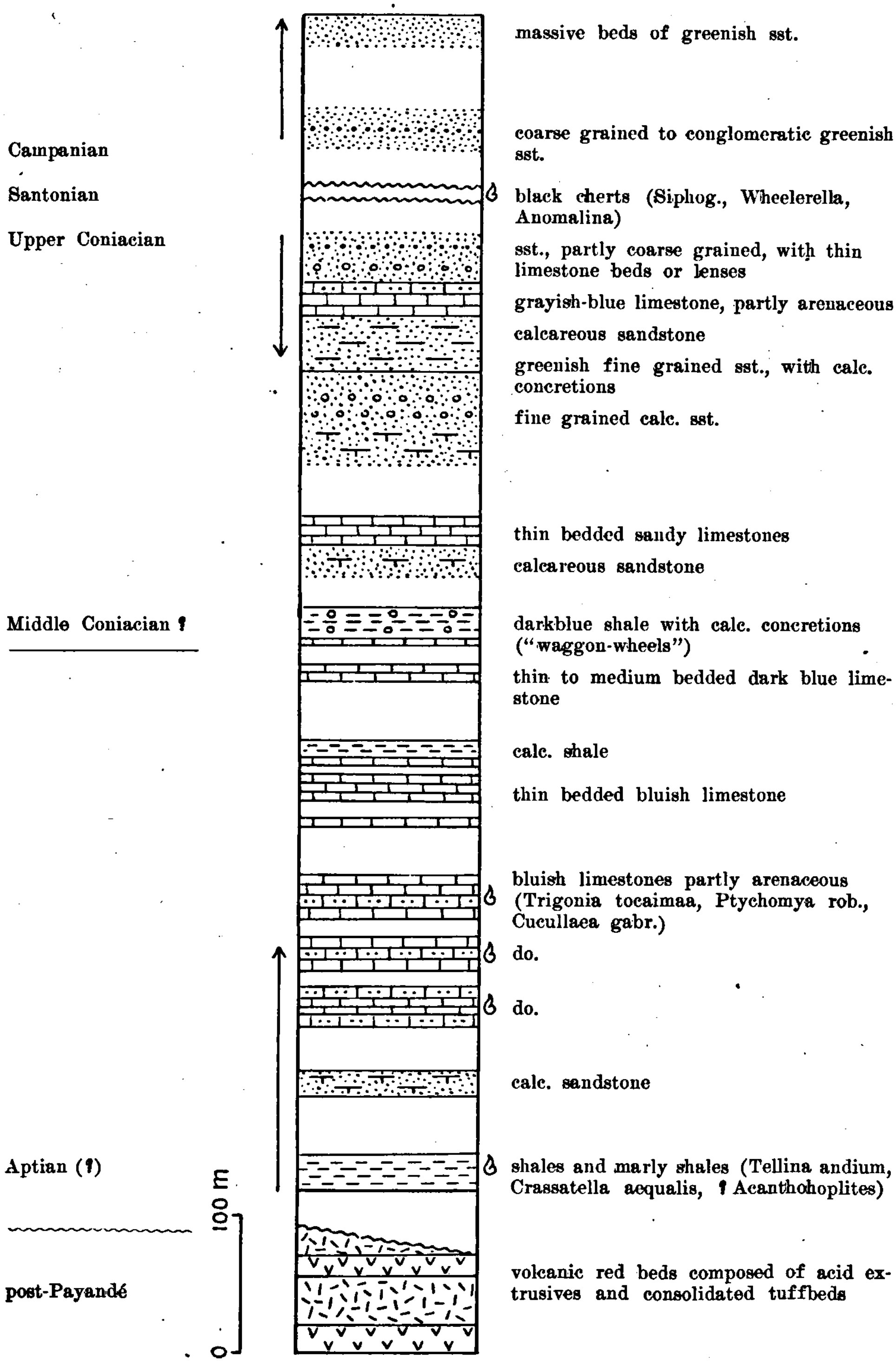
by calcareous sandy shales of black colour due to carbonaceous substance in the calcareous cement. These rocks pass to less carbonaceous calcareous sandstones, which in thin section show remnants of foraminifera. Their fauna has not yet been examined. The highest levels are formed by a finely arenaceous yellowish gray limestone, in which shells of *Cardita* are so abundant that the rock represents a real lumachel. H. Burgl determined the following fauna:

Cardita (Venericardia) cf. *neocomensis* d'Orbigny
Cheloniceras (?) spec. indet. juv.
Exogyra spec. off. couloni Defrance
Lamellibranchs indet.

According to H. Burgl the same species of *Cardita* has been described by W. O. Dietrich (1938) from the Aptian near Ubaque, SE of Bogotá, and

TABLE IX

Section through the Cretaceous exposed in the Zanja Seca
(Cuchilla del Pital, Tolima)



a similar form by A. GERHARDT (1897) from the Gault of Pariatambo in Perú, under the name of *C. (Venericardia) subparallela.* The specimen of *Cheloniceras* has a diameter of 12 mm. In this juvenile stage the characteristics of the species cannot be recognized; even the determination of the genus is uncertain. The lamellibranchs seem to be identical to those commonly found in the Aptian and Albian of adjacent areas. We may conclude that the sediments in question are probably of Aptian age.

Interesting is the geological constitution of the Cuchilla del Pital, north of the sharp bend of the Río Cucuana, near the eastern limit of the mapped area. The Zanja Seca traverses this marked ridge in its southernmost part and forms a "Kluse" with good exposures. Going downstream one first observes granodiorites, intruded as an oblong mass into Payandé limestones and separating the latter from volcanic red beds of post-Payandé age. These red beds are exposed for about 500 m. Though somewhat disturbed, they still dip with approximately 35° to the SE, in harmony with the limestones upstream. Then, after a steep fault, Lower Cretaceous follows in nearly vertically erected strata. The lithologic succession is reproduced in table No. IX. The first outcrops are fossiliferous shales and marly shales with abundant impressions of small lamellibranchs. H. BURGL determined:

Tellina (Linearia) andium GERHARDT
Crassatella (Plionema) aequalis G.

A collected ammonite was too compressed to allow correct determination; it resembles *Acanthohoplites karsteni* MARCOU, a species encountered in the Lower Albian near Apulo-Tocaima. Then follow in major extension grayish-blue, arenaceous limestones, with abundant Trigonia shells.

H. BURGL determined the following fauna:

Trigonia (Notoscabrotrigonia) tocaimaa LEA
Trigonia spec. indet.
Ptychomya robinaldina buchiana KARSTEN
Cucullaea gabrielis DE LEYMERIE.

This fauna characterizes a horizon of arenaceous limestones, which in the area of Tocaima—Villeta is of Lower Aptian age, but which north of this area moves gradually to younger strata and in the area of Leiva-Vélez-Tablazo this fauna is encountered in the Lower Albian. The findings from the Zanja Seca might — in view of its geographic position — characterize the Lower Aptian. Further downstream the limestones are followed by a series of greenish sandstones, with calcareous intercalations. Near the base of this series we find a conspicuous bed of about 10 m thickness of dark blue shales with big calcareous concretions ("waggon-wheels") reaching a diameter of 50 cm. This horizon probably represents the Middle Coniacian. Near the top of the sandy series a bed of black chert is intercalated. Thin sections show a microfauna, from which H. BURGL determined:

Siphogenerinoides cf. *bermudazi* STONE
Wheelerella cf. *magdalenaensis* PETTERS
Anomalina cf. *redmondi* PETTERS
Globigerina
Bulimina.

The *Siphogenerinoides* is characteristic of the Campanian and Maestrichtian, while the *Anomalina* is known from the uppermost Coniacian. Consequently, a Santonian age for the chert bed in question is very likely. H. Burgl wishes to ascribe this age to the lower part of the so-called "first chert horizon", which is the upper one of three chert intercalations known from the Senonian of adjacent areas. *Wheelerella* is characteristic of the lower part of this "first chert horizon". The "second chert horizon" and "third chert horizon" are absent in this section due to faulting.

5. Lower Tertiary

Of the Tertiary formations only the Middle Gualanday has been encountered during the fieldstudies. The formation consists of a succession of thick-bedded sandy shales to coarse sandstones of greenish or reddish colour. The coarser sediments are composed mainly of quartz; tuffaceous components are not found. The formation was deposited under fluviatile conditions.

The type locality is Gualanday, where the formation reaches a considerable thickness. It begins with a basal conglomerate, which contains numerous more or less angular chert pebbles (Lower Gualanday). The upper horizon is also formed by a conglomerate (Upper Gualanday), containing chert and jasper, but the pebbles are less angular and the deposits have more the character of coarse fluviatile deposits in which conglomerates alternate with sandstone beds. According to a palynological investigation of T. v. d. Hammen the Lower Gualanday corresponds to the Middle Eocene and the Upper Gualanday to the lower part of the Upper Oligocene.

CHAPTER III

CRETACEOUS AND TERTIARY OF THE WESTERN BORDER

The constitution of the western side of the Central Cordillera is entirely different from that of the eastern side, described in the previous chapter. This fact clearly demonstrates an independent geologic development during the Mesozoic and Lower Tertiary of two individual sedimentation basins on either side of the hercynian Central Cordillera massif. However, the development during early Mesozoic time in the western Andean basin is unknown, at least in the epicontinental zone of the Central Cordillera. This may be partly explained by the presence of an important dislocation, which brings the Diabase Group of Middle to Upper Cretaceous age into abnormal contact with the Paleozoic basement rocks of the Cajamarca Group. This tectonic dislocation has been traced over a distance of more than 150 km. Towards the North it disappears under the younger fan deposits of Armenia. Towards the South, the fault has been proved to cross the Río Palo, where it follows the course of the left tributary, the Río Jambaló.

The western Andean basin must have extended also over the area of the present Western Cordillera, as is clearly shown by the submarine diabase flows of Middle and Upper Cretaceous age that outcrop on the lower flank of the Central Cordillera as well as in the Western Cordillera. In the latter they form the proper "basement-rocks", together with the subjacent sedimentary Dagua Group. Older formations are not known in the Western Cordillera.

In the following paragraph we will describe the particulars of the formations outcropping within the mapped area of the western slope of the Central Cordillera.

1. Diabase Group

In a morphological way the diabase outcrops form part of the proper mountain range of the Central Cordillera. They arise rather abruptly from the undulating Tertiary foreland and in the 25 km of their maximum extension they reach heights of over 3000 m. Towards the East the diabases are limited by a fault from the Paleozoic basement rocks. Near Barragán a small strip of crushed intrusives is tectonically intercalated between both formations. These intrusives possibly belong to the same batholith, which east of Buga takes the place of the diabases and has intrusive contacts with the latter.

Small intercalated chert beds prove the submarine and extrusive character of the diabases. Similar intercalations yielded in the Western Cordillera a micro- and macrofauna, which places the Diabase Group in the Middle and Upper Cretaceous. Along the Río Nogales, within the mapped area, cherty and arenaceous sediments have been found to overlie the diabases. These sediments are probably of Paleocene age and were deposited in a limnic environment. They clearly show the conclusion of the submarine diabase activity by that time.

Except by the aid of the intercalated chert beds, the strike and dip can occasionally be measured on the proper diabase flows. Especially between Ceilán and Puerto Frazadas, where individual flows of only a few metres thickness can be distinguished, dip measurements are successful. A moderate

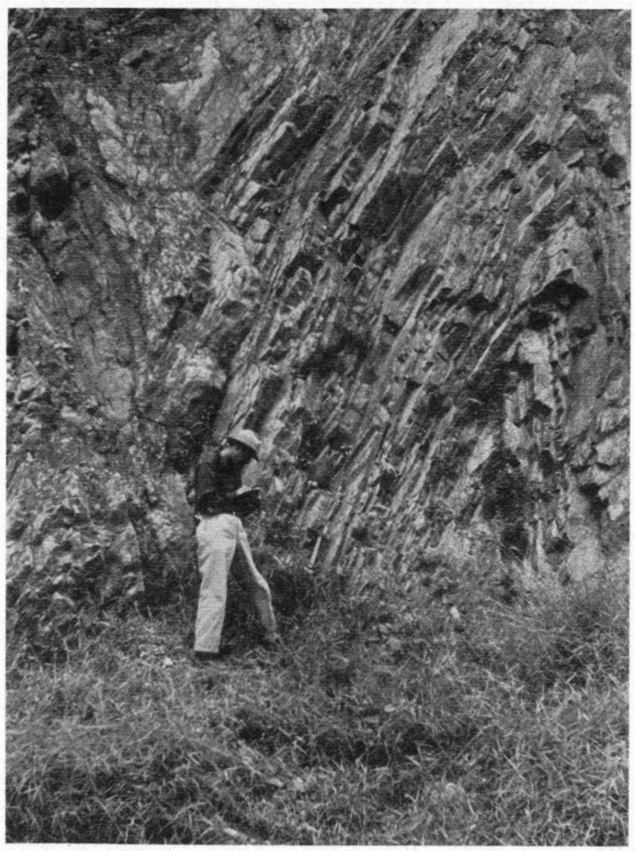


Fig. 15. Crumpled chert beds of Paleocene age, exposed on the road along the Río Bugalagrande, downstream from Ceilán.

to rather strong western inclination, interrupted by several faultzones, predominates. Near the declivity towards the Tertiary, the diabases are so intensely faulted, that they have become schistose and resemble greenschists. The latter are well exposed near the Boquerón of the Río Bugalagrande.

Most of the extrusives of the Diabase Group are real diabases, in which the two main components, plagioclase and augite, are arranged in ophitic structure. We will deal more extensively with these rocks in the chapter on the Western Cordillera.

2. Nogales formation (Paleocene)

During an exploration upstream the Río Tuluá a series of black cherts and dirty greenish sandstones was encountered near the mouth of its affluent, the Río San Marcos. These rocks form a folded structure, moulded into the subjacent diabase flows. It extends along the Río Nogales and Río Tuluá and can be traced towards the North to near La Moralia. The structure is limited towards the West by a fault which cuts the structural axes under a small angle and brings the formation in question over a considerable distance in contact with a tonalite body, which is intrusive into the Diabase Group.

The thickness of the formation can be estimated to be about 500—600 m. The base is formed by compact dark greywackes, composed of grains of quartz, feldspar, altered biotite flakes, occasional grains of augite and fragments of igneous rocks, especially volcanic types. The rest of the formation is composed of a succession of greywackes and thin-bedded cherty rocks. The latter differ from the cherts intercalated in the Diabase Group by their often fine-sandy character; seen in thin section they rather constitute fine-grained dark sandstones. Other types are distinctly calcareous and contain a fine opaque substance, which — according to an X-ray diagram — appears to be disseminated pyrite and carbonaceous material. These black calcareous cherts yielded a small amount of pollen, which were examined by T. v. d. Hammen with the following result:

Monocolpites operculatus
Monocolpites medius
Monocolpites minutus
Triporites sp.
cf. *Tetradites magnus*
Monoporites sp.
Triletes sp.

According to v. d. Hammen, this association makes a Paleocene age of the sample very probable. The formation was deposited in a limnic environment.

The same sediments, but badly thrusted and hardly recognizable, were noticed near the declivity of the Diabase Group toward the Tertiary foreland, in association with sheared diabases (greenschists).

Especially in the so-called "Boquerón" of the Río Bugalagrande and in the small brooks that come down the declivity north of this locality, interesting exposures may be found. Fig. 16 shows an example of a crushed black chert, whose cracks are filled with secondary white quartz. In other cases the rock is so intensely crushed that it resembles a pseudo-tachylite, composed of a nearly isotropic mass.

J. Keizer observed similar rocks, but in a less sandy and more shaly facies, on the opopsite side of the Cauca valley. They outcrop along the foot of the Western Cordillera over a distance of more than 50 km, extending from the Río Marilópez (West of Timba) to near the place where the course of the Río Cauca leaves the foothills of the Western Cordillera and bends toward Popayán. The formation seems to lie conformably over the Diabase Group.

Marine Paleocene has been proved to exist in the Department of Nariño, where J. A. Bueno collected dark cherty rocks in the intersection of the road from Ancuyá to Guaitarilla with the Quebrada Bocanegra, on the eastern slope of the Western Cordillera. H. BURGL encountered in these samples *Rzchakina epigona paleocena*. The outcrop forms part of the Chita-formation, distinguished by GROSSE, who considered this formation to be of Paleozoic age on account of its slightly metamorphic appearance.

Fig. 16. Crushed black chert. The cracks have been filled up with white quartz. Near the Boquerón of the Río Bugalagrande.

3. Tonalite intrusions

In the area of Buga and San Pedro the Diabase Group has been intruded by a large body of acid igneous rocks. In the morphology of this terrain the intrusive body does not show up as a separate unit but merges with the Diabase Group, both rising abruptly from the gently undulating Tertiary foreland.

The rock is rather varying in its composition, possibly due to assimilation of the diabase host rock. The western and purest part consists of leucocratic quartzdiorites with only a small quantity of dark minerals; the plagioclase is generally as acid as oligoclase. Towards the East the composition becomes distinctly more basic and nearly dioritic. The assimilation may be predominant over large areas. In other places sharper contacts can be seen, sometimes with the development of large hornblende crystals. We classified the rock as tonalite, in accordance with previous investigations by other authors.

Similar intrusions are found throughout the western Andean geosynclinal unit. On the western slope of the Central Cordillera, for instance, they outcrop near Pijao (situated within our mapped area), Pradera (Río Fraile) and Tacueyó (between Río Palo y Quebrada Frisoles). In the Western Cordillera its most striking outcrops are the Farallones de Cali, which attain a height of about 4000 m; further, near the hamlet of Danubio on the Río

Anchicayá, a. o. These igneous bodies are intrusive into the Paleozoic Cajamarca Group, the Mesozoic Dagua Group or the Diabase Group. On the other hand, at some places they outcrop from below the Lower Tertiary, as stated by E. GROSSE (1934) in his publication on the Patía-rift. According to J. KEIZER, a small tonalite body named the Maraveli-Massif, a few kilometres SW of Suárez, is covered even by Paleocene, which in its turn underlies as a thin zone the Lower Cauca formation of Eocene age. Consequently, an Upper Cretaceous to Lowermost Tertiary age must be assigned to these tonalite intrusions.

4. Upper Cauca formation

SW of Sevilla a syncline containing clastic sediments is moulded into the underlying Diabase Group. The exposed rocks are of a uniform character and can be classified as greywackes. They are rather compact and of a dark greenish colour. Cross-bedding is frequently observed and the formation in question is a typical fluviatile deposit.

The greywacke is medium to coarse grained and may even grade into a fine conglomerate, in which numerous small pebbles of black chert varying in size from ½—2 cm are conspicuous. Under the microscope the finer varieties consist of sub-angular grains of quartz, plagioclase, augite, some hornblende and fragments of chert and volcanic rocks. Obviously the debris was derived partly from the erosion of the Diabase Group and its intercalated chert beds.

Unfortunately, lignite seams have not been found, so that a palynological age determination could not be made. Lithologically, the greywackes are very similar to those encountered along the Río Nogales, which are known to have a Paleocene age. However, intercalations of cherty horizons such as along the Nogales river are absent in the Sevilla syncline.

The formation extends towards the North, first as a small strip and then it broadens quickly and forms conspicuous escarpments. Probably the same formation outcrops in Antioquia and there corresponds to the upper part of the Lower Tertiary, as described by GROSSE (1926). According to this author the upper part consist of curious sandstones of a bluish gray colour, in contrast with the light coloured sandstones of the middle and lower parts. In Antioquia the sandstones in question contain small coal seams. Palynological investigation of the latter, carried out by T. V. D. HAMMEN, places these sandstones in the upper part of the Oligocene. In Antioquia the Lower Tertiary is unconformably overlain by reworked tuffs, which form a characteristic horizon at the base of the Upper Tertiary, indicating the beginning of the Neotertiary volcanic activity. This tuff-horizon can be found throughout the Cauca-Patía valley and is also present in the area investigated by us, where we designated it as Lower la Paila formation. This formation will be dealt with in the next chapter.

There is no direct relation of the Upper Cauca formation with the Middle and Lower Cauca formations outcropping near Cali.

5. La Paila formation

The foreland of the Central Cordillera towards the Cauca valley is formed by an undulating landscape consisting of Upper Tertiary deposits. Lithologically, the following subdivision can be made:

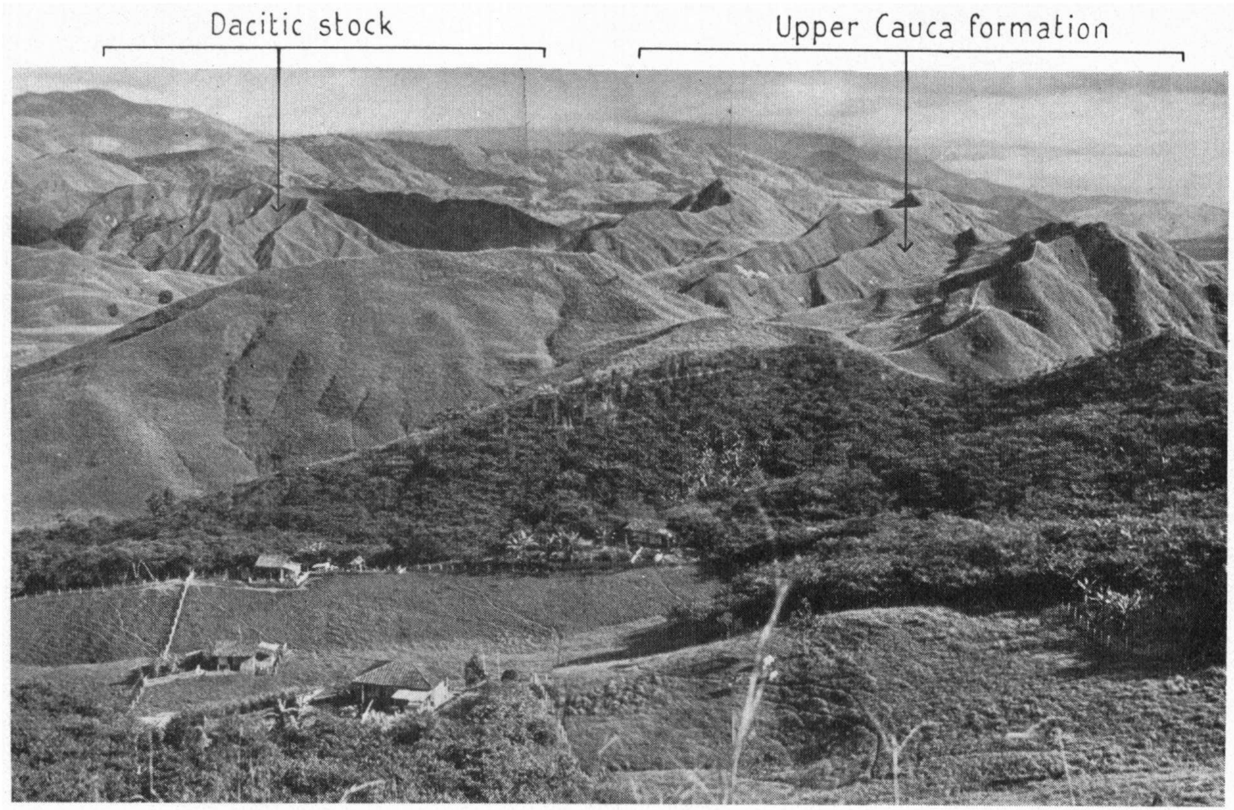


Fig. 17. Dacite stock cutting through Upper Cauca sediments SW of Sevilla.

The *Lower La Paila* consists of approximately 200 m of reworked dacitic tuffs of light grayish colour. The pyroclastics are derived from eruptions in the Central Cordillera and indicate the beginning of the neovolcanism. This eruptive phase can be observed throughout the Cauca-Patía valley and probably also in the Magdalena valley, where the Honda formation seems to be the equivalent of the La Paila formation. In our area the exact stratigraphic position cannot be determined due to abnormal contacts. But the young character of the sediments, the folding they have undergone and the fact that GROSSE (1926) in Antioquia clearly observed the unconformable position on the Lower Tertiary (Upper Oligocene) puts these deposits in the Miocene, probably in the Lower Miocene. The equivalents in Antioquia were designated by GROSSE as Combia formation.

The *Upper La Paila* consists of fluviatile deposits of conglomerates, soft sandstones and sandy claystones, which show a marked cross-bedding. At the top of the formation the coarser components are lacking and lignite seams are intercalated. The total thickness is about 400 m. The pebbles of the coarser deposits are mainly of diabase, black chert, metamorphic rocks, andesite and quartz.

The fluviatile sediments are in apparent conformity with the underlying tuffaceous deposits. A detailed palynological study of the lignite seams has not yet been made, but probably the Upper La Paila sediments are of Middle Miocene age and constitute a syntectonic deposition.

6. Zarzal formation

Near Zarzal occur deposits of diatomites in association with clays and tuffaceous sands. This lacustrine formation suffered only small dislocation-effects and overlies unconformably the Upper La Paila sediments. The deposits have been assigned to the Pliocene. The outcrops have not been visited by us.

7. Rhyolitic and dacitic stocks

SW of Sevilla a swarm of smaller igneous stocks has traversed the Upper Cauca formation and the adjacent diabases. The stocks with their higher relief contrast distinctly with the surroundings. The igneous rock is so altered that a correct classification is not possible. However, large kaolinized feldspar phenocrysts and hexagonal quartz-phenocrysts point to rhyolites and dacites.

The exact stratigraphic position cannot be defined in our area, except that the stocks are younger than the Upper Cauca formation and hence are of post-Oligocene age. Probably they are related to the volcanic phase that produced the tuffs of the Lower La Paila formation.

Similar stocks also occur elsewhere in the Cauca valley. They always appear to be younger than the Lower Tertiary, but some of them — according to observations made by GROSSE in Antioquia — may even be younger than the Combia formation (Lower La Paila).

CHAPTER IV

NEOTERTIARY AND QUARTERNARY FORMATIONS

1. Neovolcanic deposits

Younger volcanism was active from Neotertiary to Recent time and has produced large amounts of tuffs that cover wide areas on both flanks of the Cordilleras. The thickness of this cover is variable but generally very considerable and the tuffs have imposed a smooth morphology over the original and more rugged relief of the older rocks. The major part of the

Fig. 18. Neovolcanic hornblende-andesite outcropping between la Línea and Calarcá. Note the spherical alteration.

pyroclastics that filled up the steep valleys has been removed again by erosive action of the rivers, but the remainders form conspicuous high terraces. Part of the removed tuffs and volcanic rocks accumulated in the extensive fan-deposits on either side of the Cordillera.

The flows that have been produced by neovolcanism are of different composition. We observed the following types:

a. *hornblende-dacite.* The porphyritic rock outcrops along the road between Cajamarca and La Línea over a distance of about 2 km. The layers are broken by faults of minor importance.

b. *hornblende-andesite.* Forms a small circular outcrop of only 300 m in diameter, about halfway La Línea and Calarcá. Possibly it represents only a craterpipe. In the sample only very fine black needles of hornblende can be distinguished. In thin section they are identified as basaltic hornblende, flowing in a vitreous groundmass with microlites of andesine. Some pyroxene is also present.

c. *hypersthene-andesite.* Though in the investigated area hypersthene andesites were encountered only in one locality, they probably represent the most characteristic products of neotertiary volcanism. They were observed between Armero and Convenio, where small isolated hills are composed entirely of blocks of hypersthene andesite. In thin section the rock consists of small phenocrystals of plagioclase (basic andesine), hypersthene, some clinopyroxene and occasionally basaltic hornblende. The groundmass is vitreous and contains numerous microlites of plagioclase and pyroxene.

In samples from Nariño the author also observed hypersthene andesites of neovolcanic age and they are easily distinguished from the Cretaceous augite andesites of the "porphyrite formation" (Diabase Group), in which hypersthene has not been found. GROSSE (1926) mentions the same rocks from Antioquia. It is interesting that obviously these volcanic rocks also occur in the Magdalena valley. An examination of the fluvioglacial deposits of the Ibagué-fan showed that hypersthene andesites form a considerable percentage of the boulders of this formation, and must have been produced in great quantities. About the relative age of the different extrusive types no conclusions can be drawn. But probably the hypersthene andesites belong to the older (perhaps Upper Tertiary) extrusives, in view of the fact that they are now mainly accumulated in the fan deposits. The dacites might be of a younger age.

2. The fans of Ibagué and Armenia

From various points more or less fanshaped flat plains extend along the foot of the Cordillera, which are built up of the débris of the Cordillera. One of the most extensive of these plains is the one which radiates from Ibagué. It has a width of about 30 km and its surface inclines with about 2° in easterly direction, so that the eastern limit of the fan, near Gualanday, has an altitude of about 600 m, as against 1250 m in Ibagué. The fan is composed of thick strata of unsorted boulders, gravels and soft sandstones, with intercalated beds of tuffaceous sediments. Cross-bedding is sometimes observed. The coarser components are mainly greenschists and graphite schists, derived from the Cajamarca Group, besides neovolcanic rocks. Among the latter dark hypersthene andesites dominate.

These enormous accumulations of coarse clastics require special conditions for their deposition. These conditions were realized during the Pleistocene and the deposits will be of a fluvioglacial nature.

At the opposite side of the Cordillera a similar fan exists on which Armenia is located. These deposits, however, are of a finer grain and tuffaceous sediments are more numerous.

PART B

STRATIGRAPHY OF THE WESTERN CORDILLERA

CHAPTER V

THE MESOZOIC BASEMENT

1. Dagua Group

The name Dagua formation was given by E. HUBACH (1934) to a series of slightly phyllitic shales and slates, outcropping in the canyon of the Río Dagua, west of the hamlet of Lobo Guerrero (formerly called Espinal) and which rocks conformably underlie black cherts and siliceous slates, defined by the same author as Espinal formation. The latter formation, in its turn, outcrops under the Diabase Group, in apparent conformity.

On account of the arbitrary limit between the Dagua and Espinal formations, due to a gradual transition and the fact that chert beds are not restricted to the Espinal formation, we combined both formations into a single one, called Dagua Group. In this Group we also include other rock types, which we found to belong to the same series when we carried our mapping along the Río Dagua and Río Anchicayá down to the Pacific coastal plain.

The Group in question has an important share in the constitution of the Western Cordillera, especially on the slope towards the Pacific plain. A striking feature are the long striplike outcrops near Dagua and Queremal. These were found to be due to a markedly imbricated structure, causing the upper part of the Dagua Group to outcrop repeatedly from below the Diabase Group. Between La Elsa and La Cascada thrusting is particularly strong. Owing to this feature, it is rather hazardous to reconstruct the stratigraphic succession of the Dagua Group. But in a broad outline the following subdivision, based on the section along the Cali-Buenaventura road, seems justified:

a. *The Lower Part*

The Lower part is formed by the westernmost outcrops along the Cali-Buenaventura road, from about the confluence of the Río Digua with the Río Anchicayá down to the coastal plain. The basis of the formation is not exposed. The position is rather undisturbed, the strata inclining with moderate angles in easterly and northeasterly directions.

This part consists of a rather monotonous series of phyllitic slates, which may be more or less graphitic. In thin section the slight degree of dynamometamorphism is expressed by the development of oriented sericite and chlorite flakes, while the opaque substance is concentrated into thin layers.

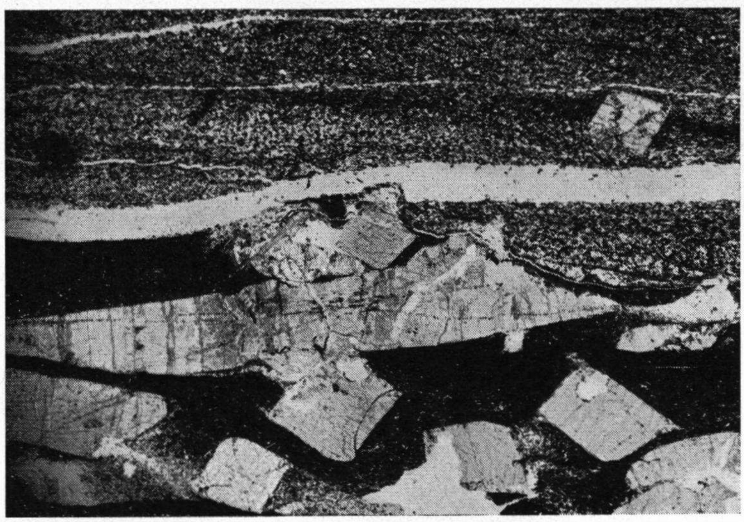


Fig. 19. Chiastolite schist. Río Anchicayá (12 ×.)

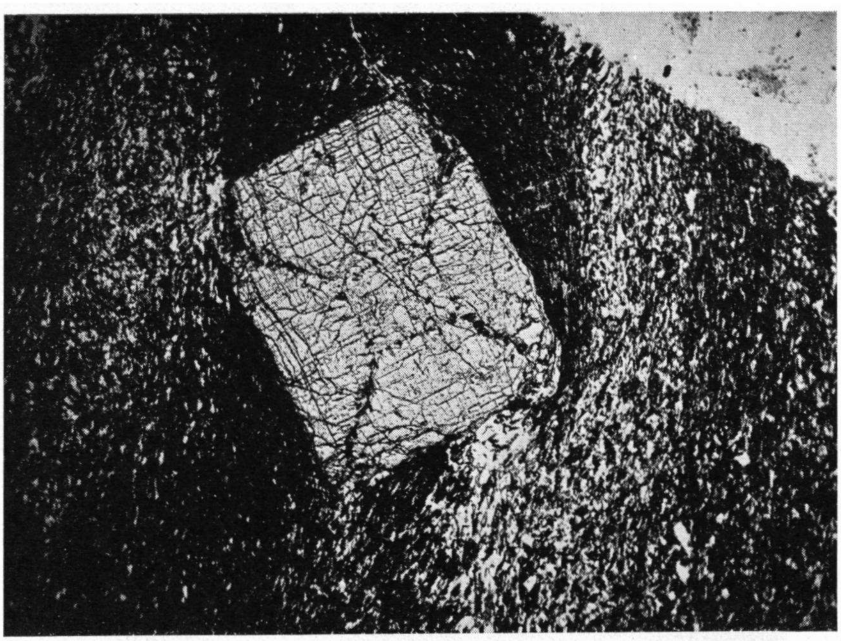


Fig. 20. Chiastolite schist. Río Anchicayá (50 ×).

In the contact zone with a big tonalite body, the slaty rocks are transformed to rather dense micaschists, with a characteristic purplish lustre on the schistosity planes, caused by numerous small biotite flakes. Some layers contain abundant porphyroblasts of chiastolite, in prismatic crystals up to 4 cm in size; also staurolite was found. It seems that finely arenaceous slates have the tendency to alter into ordinary micaschists, whereas with an increasing carbon content andalusite is produced and with a higher content in iron staurolite begins to appear.

The thickness of the lower part attains several thousand metres.

b. *The Middle Part*

To the middle part we attribute the strongly thrusted area west of La Elsa. But it should be kept in mind that the stratigraphic succession is not indicated by the sequence of the outcrops and that tectonic intercalations of other rock series or formations occur. This is clearly shown by the intercalations of diabases, varying from small wedges to thick strata, belonging to the overlying Diabase Group.

The middle part of the Dagua Group consists mainly of limestones and

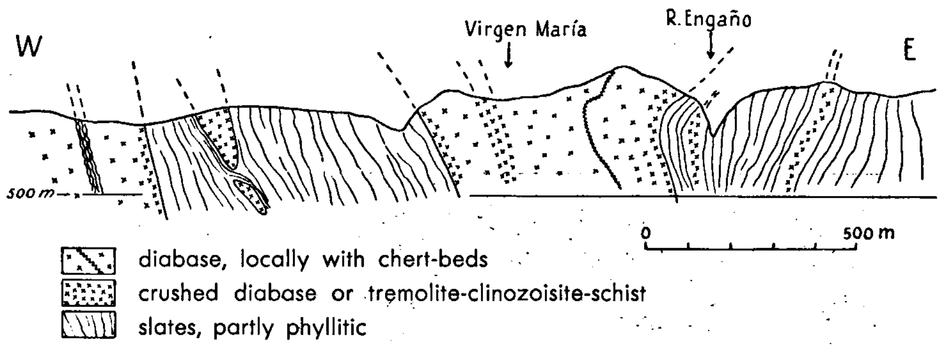


Fig. 21. Situation of the strongly thrusted zone near Río Engaño.

arenaceous rocks. A limestone horizon of about 350 m thickness outcrops 2 km west of La Cascada and forms small escarpments in the field. This rock is rather arenaceous; under the microscope it consists of a granoblastic mass of about 75 % calcite and 25 % quartz, with some biotite flakes as accessory mineral. Outcrops of schistose sandy rocks are rather frequent, but are not found east of the Río Blanco. These rocks are composed of subangular grains of quartz and some feldspar; the cement is partly or wholly recrystallized; they alternate with siliceous slates, slightly graphitic slates and calcareous shales. Between the Río Blanco and La Elsa black slaty shales dominate which are sometimes siliceous.

In shear zones the rocks are distinctly altered. Slates have been transformed into phyllites. More difficult to interpret are rather massive, dark greenish and violet schists. These rocks are very deceptive and at first sight have the appearance of belonging to a higher metamorphic stage than would harmonize with the adjacent rock types. Tested with HCl they frequently effervesce. Typical outcrops are found between the Río Engaño and the Río Blanco, near the statue of the Virgen María. However, detailed field observations show that these rocks are always related to diabases and preferably constitute the marginal zones of the tectonical intercalations; in other words they are mylonitized diabases. In thin section the diabase nature is generally easily recognized, except in those cases where shearing has produced tremolite-clinozoisite-schists in which no mineral relics of the original rock are found.

The thickness of the middle part cannot be established, but at all events exceeds 2000 metres.

c. *The Upper Part*

The upper part is mainly formed by black cherts and siliceous slates. They outcrop normally from below the Diabase Group. This part corresponds

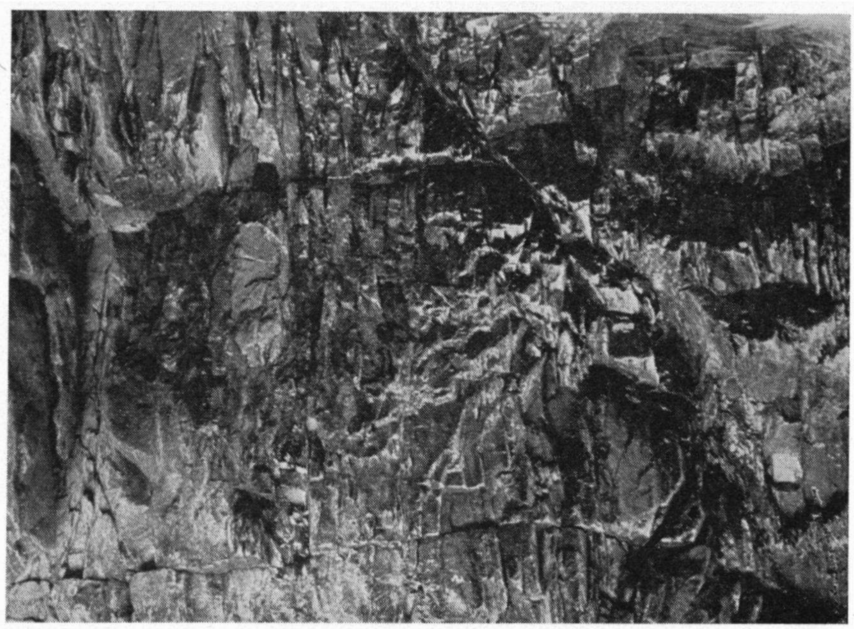


Fig. 22. Outcrop of sheared diabase, near Río Engaño. (1.60 m × 2.20 m).

to the Espinal formation of HUBACH and is well exposed along the Río Dagua. On lower levels the rocks lose their cherty character and pass into normal slates which may be somewhat graphitic. Due to the imbricate structure in this area, the cherty rocks reappear along the fault of Queremal, again overlain by diabases.

In thin section no microfossils were found. Only small globules were observed, which may have originated from radiolaria or diatomea. These organisms probably caused the silicification of the rather argillaceous cherty rocks.

The thickness of the upper part, although somewhat arbitrary, is about 200 to 300 m.

Summarizing, we may conclude that the Dagua Group consists of marine sediments of considerable thickness. Deposition started with argillaceous sediments, whereas later on calcareous and sandy facies prevailed. This, in turn, was followed by an argillaceous-siliceous facies. Fossils have not been found and the age of the Dagua Group can only be established by its stratigraphic position below the Diabase Group. This position gives a Lower Cretaceous age for the higher part of the formation.

Along the railroad-section the situation is much more complicated, due to stronger disturbances. Large slices with a normal stratigraphic succession such as near Dagua or Queremal are absent. The black cherts near the type locality of Lobo Guerrero (Espinal) appear to be very thin and incomplete. The canyon proper of the Río Dagua, which over a distance of about 3 km forms a steeply eroded narrow passage for the river, consists entirely of diabases. Towards the coastal plain the Miocene Naya formation transgresses over the Diabase Group, while along the road it is transgressive over the lower part of the Dagua Group. The lack of aerial photographs in the strip between the road and the railway-track prevents as yet the connection of the zonal sequences of both sections. Moreover, a good deal of field reconnaissance will be necessary to unravel the geology of this mountain range with its strongly thrusted structures.

2. The Diabase Group

Submarine basic volcanism on a large scale undoubtedly forms the most striking feature of the western Andean geosynclinal basin. In Colombia its products form the main element in the constitution of the Western Cordillera and, moreover, outcrop on the western flank of the Central Cordillera. As far as the mapped area is concerned, i. e. from about Armenia to Cali, volcanism produced only rather uniform diabase flows. GROSSE reports intercalations of tuffs and volcanic agglomerates from Antioquia. According to the same author pyroclastic intercalations also occur in Nariño. Samples collected by J. KEIZER show that dense tuffs appear already near the boundary of the Cauca with the Patía basin. Besides by the participation of pyroclastics, the difference in development is also indicated by the flows themselves; apart from normal diabases porphyritic augite-andesites, labrador-andesites and dark aphanitic extrusives occur (classified by GROSSE as augite and labrador porphyrites, resp. spilites).

Ultrabasic rocks have only been observed occasionally. Picrites have been found near San Marcos, south of Vijes; these are probably of an extrusive kind. Serpentinized peridotite was found near Lobo Guerrero and blocks of fresh pyroxene peridotite were encountered in a small brook near Sevilla. HUBACH places the ultabasic rocks at the top of the Diabase Group as a separate stratigraphic horizon. This opinion, however, could not be confirmed during our investigations. At all events the quantity of ultrabasic rocks has been considerably overestimated and many samples taken from outcrops of supposed ultramafites appeared in thin section to be normal diabases.

a. *Sedimentary fossiliferous intercalations*

During the periods of volcanic inactivity sedimentary intercalations, mainly consisting of black cherts and siliceous shales, were formed. They vary in thickness from a few inches to several meters, but occasionally may

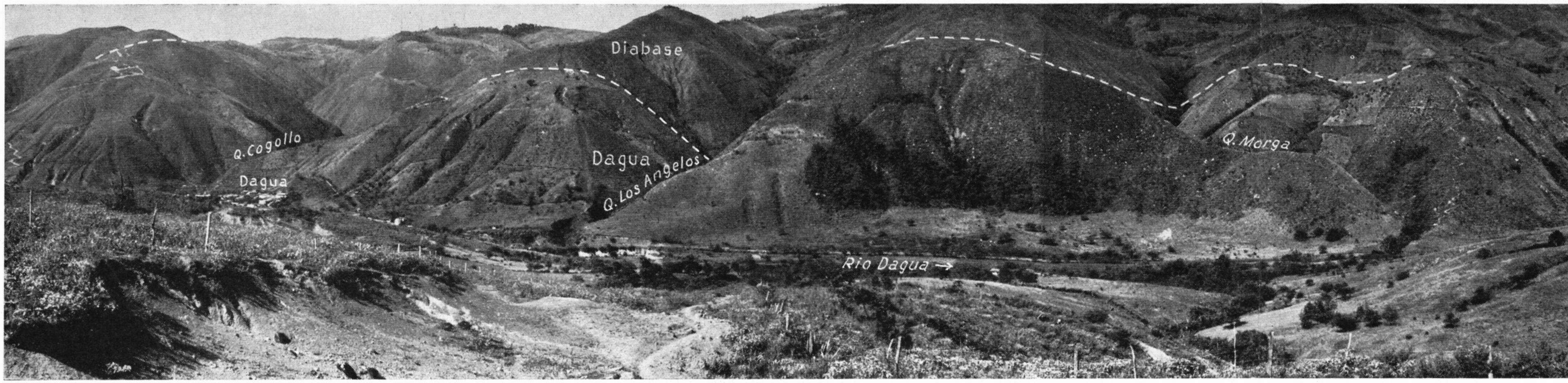


Fig. 23. Geological situation near Dagua.
The sedimentary Dagua Group is conformably overlain by the volcanic Diabase Group. The latter reappears on the right (eastern) border of the Río Dagua, separated from the Dagua Group (left border) by a fault following the course of the river.

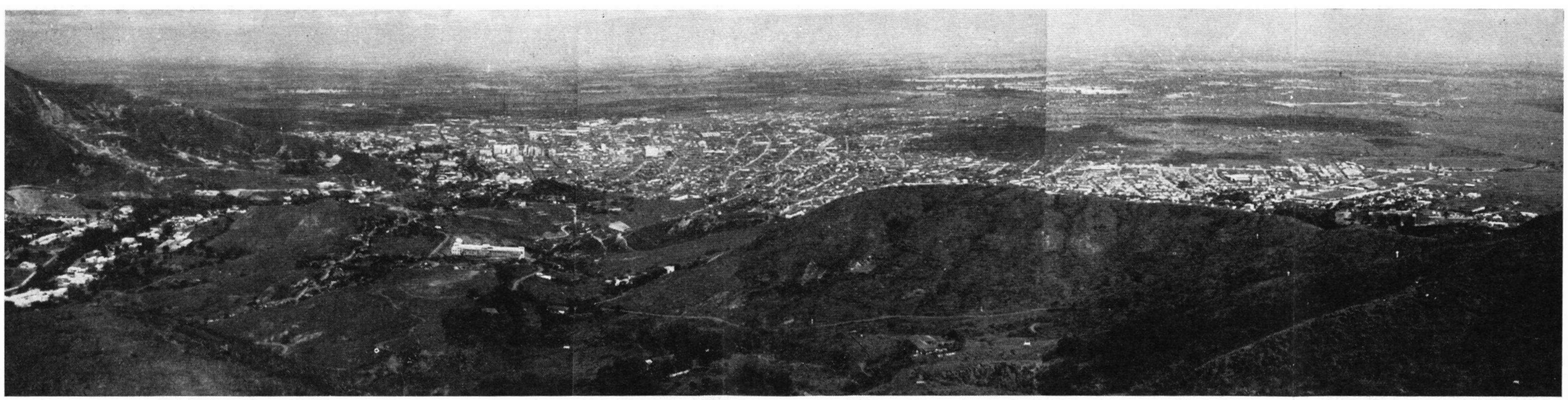


Fig. 24. Panorama of Cali, situated in the Cauca valley, on the foot of the Western Cordillera. In the hills the Lower Tertiary coalcontaining sediments are exposed.

attain a thickness of over 100 m. Occasionally intercalations yielded a determinable fauna. Siliceous shales that outcrop in the Quebrada San Marcos, south of Vijes, contain *Inoceramus* cf. *peruanus* BRÜGGEN, which fossil — according to H. BURGL — is characteristic of the Lower Coniacian. Marly shales, overlying an outcrop of picrite near the same locality, yielded besides this bivalve also *Gümbelina* spec., a foraminifera characteristic of the same period.

Near San Antonio, a hamlet 30 km SSW of Cali, J. KEIZER encountered two fossiliferous horizons of different age. The lower horizon, of about 80 m thickness, is characterized by *Inoceramus peruanus* and consequently is of Lower Coniacian age. The upper horizon contains a microfauna, studied by H. BURGL with the following result:

Haplophragmoides excavata CUSHMAN & WATERS
Haplophragmoides cf. *glabra* CUSHMAN & WATERS
Glomospira gordialis (JONES & PARKER)
Ammodiscus glabratus CUSHMAN & JARVIS
Bathysiphon taurinensis SACCO
Bathysiphon alexanderi CUSHMAN
Ammobaculites coprolithiformis (SCHWAGER)
Pelosina complanata FRANKE

H. BURGL concludes: "This fauna consists exclusively of arenaceous foraminifera. The major part of the species occur troughout the Upper Cretaceous of the Caribbean region. *Ammodiscus glabratus, Haplophragmoides glabra* and *H. excavata* seem to be more characteristic of the Upper Santonian, whereas *Glomospira gordialis, Bathysiphon alexandri* and *B. taurinensis* would rather indicate a Lower Senonian age. In the area of Girardot a similar fauna was found in the Upper Santonian, for which reason a Santonian age is very probable for the fauna in question."

The enormous thickness of the Diabase Group is demonstrated by the fact that the above mentioned sedimentary horizons are separated by about 5.000 m of volcanic flows. Moreover, the lower sedimentary horizon is underlain by some thousands of metres of diabases.

During a quick reconnaissance in Caldas the author found between La Virginia and Balboa an outcrop of thick-bedded black cherts of more than 100 m thickness. Thin sections of the cherty rocks showed *Gümbelina* and *Globigerina,* which association — according to H. BURGL and based on his experiences in the Eastern Cordillera — is typical of the Lower Coniacian. The same microfauna was found on the western slope of the Central Cordillera in crumpled beds of siliceous slates some 5 km west of San Felix. In this section diabase flows seem to occur only very subordinately between black shales and slates. However, it seems to us, that the association *Gümbelina* and *Globigerina* might be characteristic of a larger period than only the Lower Coniacian.

Summarizing, an Upper Cretaceous age can be concluded for the Diabase Group, perhaps extending into the Middle Cretaceous.

A somewhat older fauna has been reported by GROSSE (1926) from Antioquia. Here, intercalations of ferruginous sandstones yielded lamellibranchs of Aptian age. We have already referred to the different composition of the volcanic products in this area, consisting mainly of porphyritic andesites and pyroclastics. This composition, in combination with its older age, forms a remarkable harmony with observations made in Ecuador (Piñon series,

H. GERTH (1955), p. 135). From a stratigraphical point of view it is recommended that during future investigations — e. g. in Nariño — special attention be paid to this coincidence in geological age and petrographic constitution of the volcanic rocks.

b. *Petrographical characteristics*

The rather uniform character of the extrusives has already been pointed out in former paragraphs. Studied under the microscope the main part of the samples appeared to be genuine diabases. That is to say, the rocks show a typical ophitic structure, in which at random oriented plagioclase laths penetrate larger pyroxene crystals. When the latter become smaller, several pyroxene grains are likely to fill up the interstitial spaces between the plagioclase laths, giving a type of "granular-ophitic" texture. The plagioclase may have the composition of basic andesine, but more frequently it is found to be replaced by albite. The pyroxene has a rather small optic angle varying from about 20° to 50° and probably is a pigeonitic variety. As accessory minerals occur magnetite or ilmenite bordered by sphene. Olivine is absent.

Other varieties are rare. Occasionally glassy rocks were observed, in which the pyroxene is developed as very fine sheaf-like crystals, recalling an arborescent structure. In other types small pyroxene phenocrysts are embedded in a glassy groundmass crowded with microlites. Also amygdules filled up with chlorite, chalcedony and calcite may occur. Probably these vitreous rocks form the marginal parts of the flows. They were observed on various places,

TABLE X

	diabase	red clay	picrite
weight %	Ne 602	K 105	Ne 977
SiO_2	48.09	29.02	33.49
Al_2O_3	14.90	30.24	17.53
Fe_2O_3	3.34	23.76	6.44
FeO	8.44	0.20	0.07
MnO	0.35	0.06	0.10
MgO	8.44	0.38	26.75
CaO	10.55	0.20	6.72
Na_2O	2.32	0.41	1.34
K_2O	0.17	0.08	0.03
H_2O+	0.58	12.06	2.66
H_2O-	0.22	1.86	0.34
TiO_2	0.80	0.60	0.12
P_2O_5	0.52	0.45	0.03
[1])	1.26	0.87	4.42
Total	99.98	100.19	100.04

[1]) Loss on the ignition other than water.

Analyses: Laboratorio Quimico, Bogotá.

Locality: Ne 602 West of Cali.
K 105 Jamundí.
Ne 977 San Marcos.

but are exceptionally well exposed in thin bedded flows, of about 2 to 3 m thickness, near Puerto Frazadas.

The picrite encountered near San Marcos has the following composition:

olivine, partially altered to antigorite	40 %
hypersthene	35 %
plagioclase	25 %

The chemical composition of the rock is given in table X, and the molecular values in table XI.

TABLE XI

	diabase	red clay	picrite
molecular values	Ne 602	K 105	Ne 977
si	107	81	52.5
al	20	48	16
fm	50	50	70.5
c	25	0.5	11.5
alk	5	1.5	2
k	0.05	0.10	0.02
mg	0.56	0.03	0.88
T	—10	+46	+2.5

Locality: see table X.

Fig. 25. Fresh outcrops of diabase are only found in the river beds, due to the rapid weathering of the rock. Quebrada El Cabuyal, West of Cali.

c. *Alteration to red clayey soils*

A large part of the area occupied by the Diabase Group is covered by a layer of tough reddish clay, sometimes referred to as laterite. The clayey soil is obviously the product of weathering of the underlying basic eruptives and roundish boulders of fresh diabase rock are still preserved in the clay. If we compare the analysis of a fresh diabase with that of its alteration product, we note a nearly complete lixiviation of the magnesium (0,38 % vs. 8,44 %) and of lime (0,20 % vs. 10,55 %), and a partial removal of silica (29,02 % vs. 48,09 %), whereas alumina and iron are concentrated in the residue. The proportion of silica, however, is much too high to classify the soil as a laterite.

The actual cover of red clay must, of course, have been formed subsequently to the Andean orogeny. But also in former periods the diabases were covered with similar decomposition products. This is demonstrated by observations made by J. KEIZER near Jamundí. The lowermost part of the transgressive sediments of the Cauca formation (Lower Tertiary) consists locally of more or less plastic red shales, obviously derived from the weathered surface of the underlying Diabase Group.

CHAPTER VI

TONALITE INTRUSIONS

A rather big tonalite body is exposed near the hamlet of El Danubio. The intrusion has caused a rather extensive thermal metamorphism around its margin, producing micaschists, chiastolite and staurolite schists. These rocks have already been discussed in the paragraph on the lower part of the Dagua Group.

The igneous rock has a rather uniform development, the average composition being:

quartz	20 %
plagioclase (sodic andesine)	45 %
orthoclase	10 %
biotite	15 %
hornblende	10 %

Near the marginal zone the rock becomes porphyritic, and contains small dark hornfels inclusions.

Possibly a tonalite body also occurs at little depth under the mountain range of the continental water divide in the Western Cordillera, suggested by metamorphosed diabase rocks near Mares and pebbles of tonalite, observed by O. STUTZER (1934) in the Quebrada Cordovita near the village La Cumbre. This zone lies in the direct prolongation of the Farallones de Cali, a high mountain range consisting of tonalite.

The geological position has already been dealt with in a previous chapter. As we explained there, we should like to ascribe a Late Cretaceous to Early Tertiary age to the tonalite intrusions.

CHAPTER VII

CENOZOIC FORMATIONS

The Cenozoic deposits of the Western Cordillera did not form part of our investigations and were only occasionally visited. For the sake of completeness we give a short exposure, mainly based on investigations made by J. KEIZER and T. V. D. HAMMEN.

1. **Lower Tertiary** (Cauca formation)

Near the foot of the Western Cordillera towards the Cauca depression small strips of Lower Tertiary sediments with intercalated coal beds outcrop. The sediments have been preserved due to a complicated imbricate structure and are moulded into the underlying diabases. Undoubtedly they underlie also the younger deposits of the Cauca valley, but probably wedge out in eastern direction as no outcrops of the sediments in question have been found along the borderzone of the Central Cordillera.

In fig. 26 we reproduce the stratigraphical correlation column of a number of sections, elaborated on palynological basis by T. V. D. HAMMEN. From this table we derive that the Lower Tertiary deposits decrease considerably in thickness from South to North. The basis of the Cauca formation is generally formed by a transgressive conglomerate, which may locally be developed as a coarse sandstone. Near Timba it overlies the limnic Paleocene deposits, whereas near Cali (Golondrinas) there is an important hiatus and the conglomerate overlies unconformably the Upper Cretaceous diabases. The basal conglomerate is followed by a series of argillaceous sandstones which occasionally contain a few coal beds. The top of the Lower Cauca formation is formed by a characteristic horizon of sandstones (La Cima horizon). The lower part of the Middle Cauca is the main coal productive zone. It consists of blue shales with various intercalations of coal beds. The upper part is composed of ferruginous sandy shales; near Cali this part is lacking. The Upper Cauca, only developed near Timba, is again productive; it begins with a quartz conglomerate, followed by shales with coal beds. There is no direct relation with the Upper Cauca greywackes distinguished SW of Sevilla. These greywackes have been correlated with a similar horizon in Antioquia, and probably represent a higher stratigraphic level than the Upper Cauca sediments near Timba.

The paralic coal facies disappears north of Yumbo. Instead, marine limestones outcrop. O. STUTZER (1934) reports these limestones and assigns them to the Oligocene. Recently, J. KEIZER mapped the small and isolated outcrops in detail. He found that the marine deposits are underlain by a layer of biotite rhyolite, weathered to reddish colours. The bottom of the marine deposit is formed by a breccia; then follow the Vijes limestone beds and the top is formed by a bed of ferrugineous sandy shale. The

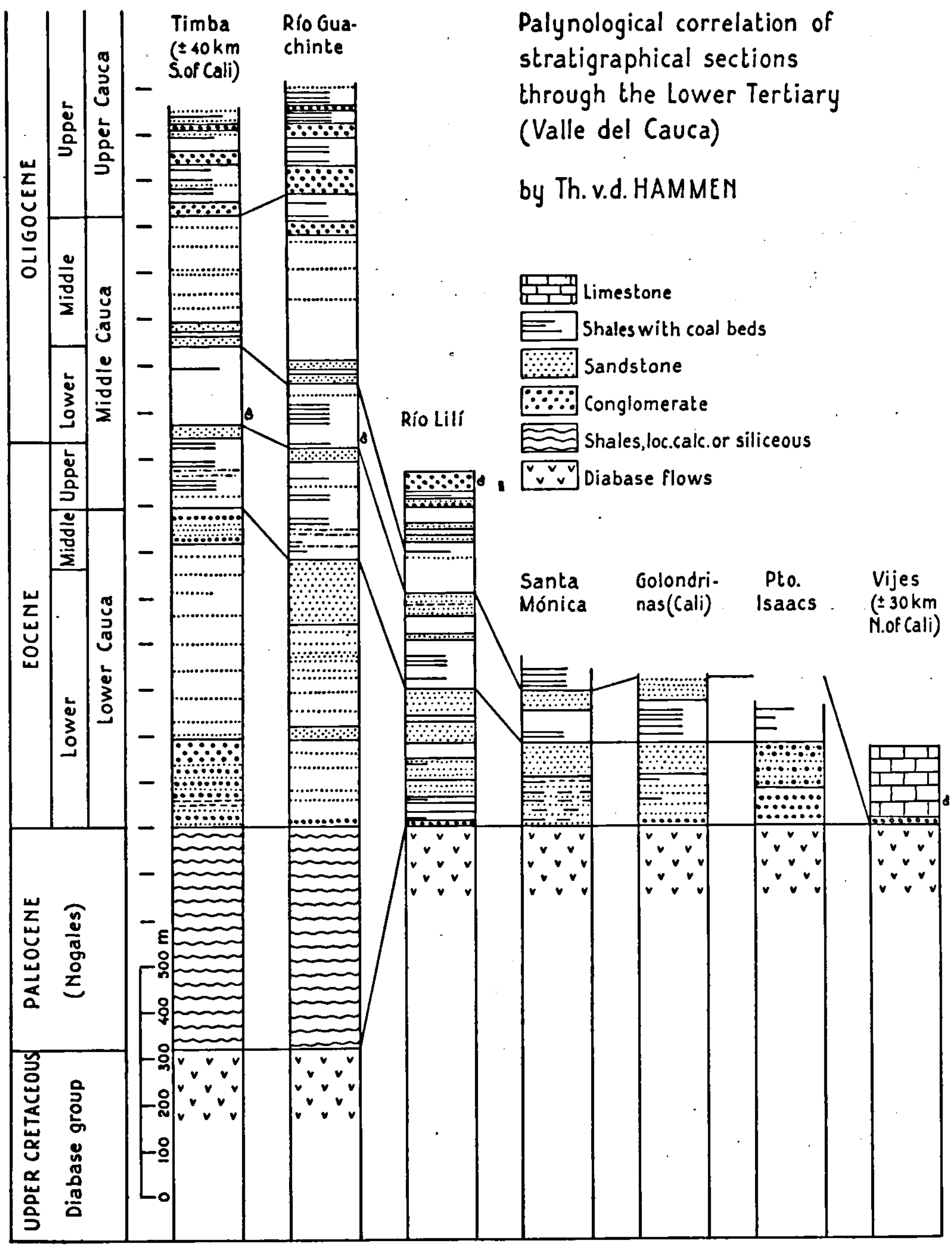

Palynological correlation of stratigraphical sections through the Lower Tertiary (Valle del Cauca)
by Th. v.d. HAMMEN
Limestone
Shales with coal beds
Sandstone
Conglomerate
Shales, loc. calc. or siliceous
Diabase flows
Timba (± 40 km S. of Cali)
Río Guachinte
Río Lilí
Santa Mónica
Golondrinas (Cali)
Pto. Isaacs
Vijes (± 30 km N. of Cali)
OLIGOCENE
EOCENE
PALEOCENE
UPPER CRETACEOUS
Upper
Middle
Lower
Upper Cauca
Middle Cauca
Lower Cauca
(Nogales)
Diabase group
0
100
200
300
400
500 m

Fig. 26

collected macro- and microfauna, determined by H. BÜRGL, indicates a Middle Oligocene age. The facies is littoral. The marine deposits and the underlying rhyolite were moulded together into the Diabase Group.

Since in Antioquia the Middle Oligocene is again represented in a paralic facies comparable to that near Cali and Timba, it seems probable that the shallow sea in which the Vijes limestones were deposited, was in open connection with the Pacific Ocean.

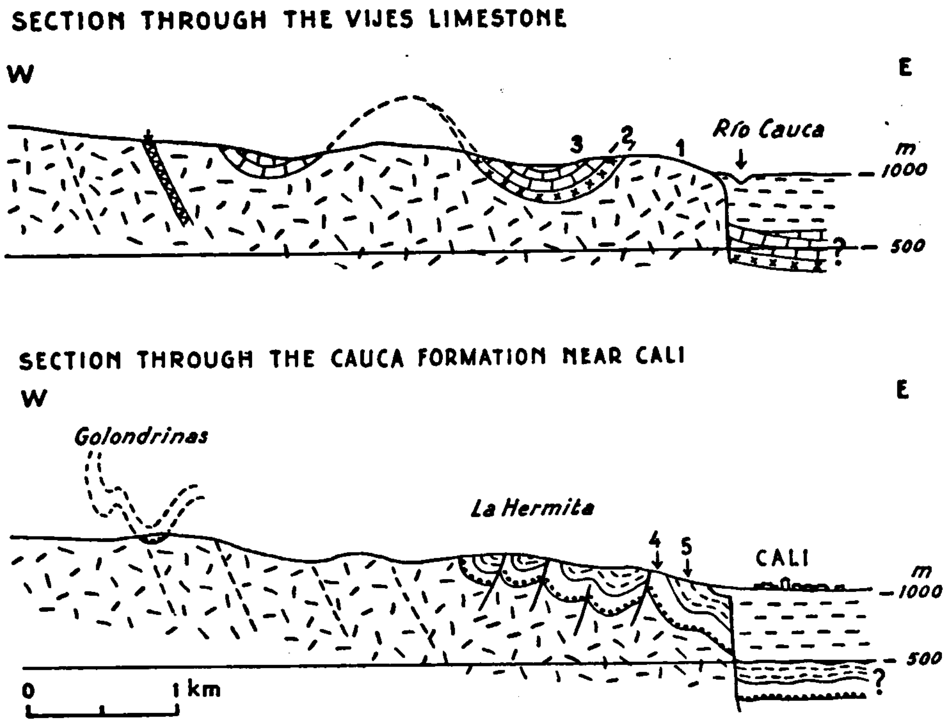


Fig. 27. Section through the Lower Tertiary.
1. Diabase Group (with chert bed), 2. Rhyolite, 3. Vijes limestone, 4. Lower Cauca formation, 5. Middle Cauca formation.

2. Naya formation

The coastal plain extending along the foot of the Western Cordillera towards the Pacific Ocean has a width of about 25 km near Buenaventura. The plain is not perfectly flat but is gently undulating, the low ridges trending in NNE or Andean direction. The few outcrops that were visited consist of bluish claystone, soft shales and some conglomerate beds, which were deposited in a limnic-fluviatile environment. The formation should probably be assigned to the Miocene.

3. Popayán formation

West of Cali a high terrace, gently inclined towards the Cauca valley, draws the attention. The road to Buenaventura offers good exposures and the formation recalls the fans of Ibagué and Armenia.

A few kilometers south of Cali similar deposits occur again. From here they can be followed as a continuous formation in a southern direction, bordering the eastern slope of the Western Cordillera, then extending over the cross-ridge ("Dintel") of Suárez-Santander and finally the deposits cover the high plateau on which is situated Popayán, the type locality of the formation. Here the deposits, consisting of tuffs with interbedded andesite flows, sands and gravelbeds, reach a thickness of 300—400 m and overlie the Tertiary formations. The fluviovolcanic deposits are of Pleistocene age, the lower part possibly including the Upper Pliocene.

PART C

STRUCTURE AND GEOLOGIC HISTORY

CHAPTER VIII

STRUCTURAL GEOLOGY

1. Central Cordillera

The oldest rocks outcropping in the areas under consideration are metamorphic basement rocks of the Central Cordillera. The stratigraphic position below the non-metamorphic Lower Cretaceous sediments as seen on the eastern flank of this Cordillera, evidences that the basement rocks have participated in at least two orogenic periods, viz. the Andean orogeny and a pre-Mesozoic orogeny. The tectonic condition of this basement cannot be reconstructed in detail and the section of the Central Cordillera given in the annex and showing the main rock types and their position, should be considered only as a base for further investigations.

However, certain features can be derived from this preliminary study. In the first place it is striking that the strata outcropping on the western flank nearly invariably dip in eastern directions. Indications of intense folding have not been found, although it remains possible that isoclinal folds have escaped observation. Faults, on the other hand, do occur. Various outcrops of metamorphosed diabases have been found; one of these forms the mountain ridge in the Depresión del Quindío. Several reasons can be advanced for assigning these metamorphosed diabases to the Cajamarca Group and considering them as interstratified flows. Thus they would be related to the greenschists, which are of volcanic origin, and — in our opinion — derived from tuffaceous sediments. On the other hand, it is attractive to consider the diabases in question as tectonic intercalations of the Diabase Group, which outcrops more southwards (see geological map of the Sevilla-Buga area). Unfortunately, the large fault which in this area separates the Diabase Group from the Cajamarca Group disappears towards Armenia below the fan deposits, but its trend passes west of Armenia. Moreover, the Cretaceous diabases in the down-faulted block west of this dislocation, show no signs of metamorphism and thus contrast with the metamorphosed diabase intercalations in the Cajamarca Group. However, in view of the observations made during later investigations on sheared Cretaceous diabases of the Western Cordillera, we want to point out that future study may demonstrate that in the western slope of the Central Cordillera near Armenia an imbricated structure prevails, similar to that of the Western Cordillera. In that case one could suppose that the diabases of the Cajamarca Group in reality are tectonically imbricated Cretaceous diabases.

On the eastern flank of the Quindío Depresion we observe first a conspicuous horizon of thick bedded gneissic quartzschists; they dip with low to moderate angles in eastern direction. The middle part of this flank is strongly thrusted and strike and dip vary widely; in some parts the presence of folds is suggested. Finally, near the contact with the batholith of Ibagué, the layers are strongly erected. In the present stage of investigation it is impossible to determine the share of each of the orogenic periods that have affected the basement rocks.

A more satisfying analysis can be given of the lower slope of the Cordillera. Here a marked block-faulting is evident. First we observe a triangular shaped block of granodiorite, on which Ibagué is situated. The raised block is in contact with the Cajamarca Group. The fault producing this abnormal contact fades away in NE direction, where intrusive contacts have been observed. The other fault, running along the Río Cocora, strikes in ENE direction below the fan of Ibagué. A vertical displacement of about 2 m in the fan deposits shows that it has still been active in Quaternary time. The Cocora fault is in contact with a large block that is probably tilted and dips in E to SE direction, judging from the area occupied by the overlying extrusives on the dipslope and from the abrupt V slope towards the Río Coello. The triangular depression filled up with Quaternary fan deposits is a down-faulted block. This rift emerges towards the South, but after passing a strongly thrusted zone, a new tectonic depression is observed in which Rovira is situated. Both blocks seem to be tilted and to dip in eastern direction. Interesting are the remainders of the Middle Gualanday (Oligocene) along the fault zones of the northern down faulted block. Undoubtedly this formation underlies the Quaternary deposits of the depression. Finally, a large tilted block is formed by the Payandé formations. The post-Payandé formation outcrops only in a relatively small area and is broken along transverse faults. The part South of the Quebrada la Hondura has been thrusted towards the West, and this displacement caused the complicate thrusting west of the hamlet of San Antonio. There is probably a tectonic repetition of the limestones west of Payandé, as is suggested by a small strip of the pre-Payandé formation crossing the Quebrada Aguirre, but the dislocation is obliterated by the shoe-shaped Jurassic intrusion. The Cretaceous and Lower Tertiary outcropping near the eastern border of the area in discussion show folding. An important dislocation runs from South of Payandé in SSW direction and can betraced to beyond the Río Cucuna. The nearly vertical fault plane exposed in the Zanja Seca seems to diminish its dip towards the North, and in the Cretaceous sediments this fault is rather a small overthrust. Summarizing, we may conclude that the area under consideration is characterized by a marked block-faulting. The strike of the faults does not coincide rigorously with the general Andean trend. It seems probable that the block-faulting was originated by a strong compressive stress, coming from eastern direction. The fault pattern gives the impression that the blocks are bounded by wrench-faults. In our opinion the Cocora fault is one of the most important wrench-faults, although its importance does not find expression in our map. But it can be traced over a distance of about 40 km in ENE direction to Piedras in the Magdalena valley. The geological conditions near this locality do assume that the part South of this fault has been pushed considerably to the West.

The geological age of the block-faulting cannot be defined exactly, except that the faults originated in Upper Tertiary time, since they cut the Gualanday formation (Oligocene).

The western part of the Central Cordillera, in the area of Buga-Sevilla (see map), is also characterized by block-faulting. The metamorphic basement is separated by an important fault from the Diabase Group. This fault has been traced for more than 150 km and must have a considerable vertical throw. West of Barragán mylonitized tonalite, probably belonging to the Buga massif, is tectonically intercalated in the fault zone. Interesting is a synclinal structure, outcropping SW of Sevilla in the middle of the Diabase Group. It is composed mainly of Upper Cauca sediments that were moulded into the diabases and thus escaped erosion. The layers are strongly folded and even overturned. The folding axes are cut obliquely by a large fault. More southwards a similar truncated syncline, composed of Paleocene sediments, can be observed. It is in abnormal contact with a raised block composed partly of tonalite. Towards the foreland of the Central Cordillera the tonalite is in abnormal contact with the Upper La Paila formation. The truncated folding axes of this Upper to Middle Miocene formation show that the block-faulting occurred in a late stage of the Andean orogeny, probably during the general uplift of the Cordillera. The main dislocations follow more or less the Andean trend and probably represent normal faults. The folded structures are asymmetric; typical are relatively broad and shallow synclines, and sharply bent anticlines which often show small upthusts (see section A-A').

2. Western Cordillera

When we now turn to the Western Cordillera, we are confronted with a complicate fault-structure of a different nature. Although in this stage of the examination it is impossible to reach to a clear concept about its tectonic structure, it may be interesting to point out a few observations made along the Cali-Buenaventura road (see section).

Most striking is a typical imbricate structure of the middle part. This is well demonstrated in the fault running along the Río Dagua and Río Jordán, and in the fault near Queremal. The slices dip westwards and the underlying Dagua Group outcrops each time in a small zone on the eastern side of the slices. Another starting point for a tectonical analysis may be provided by the lower part of the Dagua Group, which dips rather undisturbed with moderate angles to the East. The intermediate part, however, is strongly thrusted and the two main formations occur side by side in numerous shearing zones. East of the Río Dagua the Diabase Group outcrops without interruption as far as the Cauca depression. Only near the foot of the Cordillera towards the Cauca depression small strips of Lower Tertiary sediments are found, folded into the underlying diabases and thus preserved against erosion. They undoubtedly have their prolongation below the younger Cauca deposits. In San Antonio, South of Cali, intercalated fossiliferous chert beds demonstrate that the diabase strata become younger in direction of the Cauca. This fact, in connection with the dip of the slices near Dagua and Queremal, suggests that the Diabase Group in this part of the Cordillera is tectonically developed in an anticlinal structure. The anticline must be deepseated, since no Dagua sediments outcrop in this part. Hence, the conspicuous fault along the Río Dagua and Río Jordán caused a considerable vertical throw. When we also consider the tectonical position of the lower Dagua Group, we possibly have to interpret the whole section as in principle an eastward dipping monocline, interrupted by a broad anticlinal fold, to whose western limb belong the imbricate structures near Dagua and Queremal, and whose central part was down-faulted.

The Western Cordillera is bounded towards the Cauca valley by a large fault which finds its physiographic expression in a steep inclination of the Cordillera towards the Cauca valley and further by the conspicuous straight course of the Cauca river along the foot of the Cordillera. On the opposite side of the flat interandean plain no such a characteristic fault exists (see also map of Buga—Sevilla; the locality of Yotoco is a reference point in connecting both sheets). Here the foreland of the Cordillera has an irregular boundary with the Cauca valley and the folded Upper Tertiary sediments dip gradually below the younger fluviatile deposits, where they probably wedge out. In our opinion the Cauca valley does not represent a normal rift, but rather a tilted block, with a much greater vertical throw at the foot of the Western Cordillera than along the Central Cordillera. This kind of structure could be compared to that of the Basin and Range province in Nevada. Towards the Central Cordillera the Cauca depression seems to be bounded locally by the fault along the tonalite body and the Diabase Group, which is also a marked morphological line, but nevertheless small outcrops of diabases appear west of this line, e. g. near Andalucía. These incidental outcrops support our opinion about the asymmetric tectonic condition of the Cauca depression.

CHAPTER IX

GEOLOGIC HISTORY

The stratigraphic successions in the Western and Central Cordillera are summarized in table XII. In addition, the following remarks may be useful.

The age of the Cajamarca Group has not been established by means of direct paleontological evidence. This Group was assigned to the Paleozoic on account of its stratigraphic position below the fossiliferous Payandé limestone of Upper Triassic age. Furthermore, graptolites have been found near Puerto Berrío and they indicate the presence of Ordovician in the Central Cordillera. It is also interesting to compare the Cajamarca Group with the Paleozoic outcrops in the Eastern Cordillera. Along the section from Quetame to Villavicencio two Paleozoic formations of different age can be distinguished. The older formation, called Monterredondo formation, consists mainly of more or less sandy phyllitic schists of greenish or occasionally violet colour. The thickness of this monotonous series attains several thousand meters. Under the microscope the association chlorite-sericite, frequently as compound crystals of alternating flakes of both minerals, is very characteristic. Small intercalated beds of quartzitic sandstone consist of subangular poorly sorted quartz grains, together with some feldspar, embedded in a recrystallized cement of quartz, chlorite and sericite. From this mineral assemblage and texture we may deduce an epizonal metamorphism for the Monterredondo formation. As shown in the section, the same fomation outcrops near Buenavista in the steep flank of the Eastern Cordillera facing the Llanos. Although in this locality the rocks suffered strong dislocation, they can be recognized under the microscope thanks to the typical compound crystals of the flaky minerals. The Monterredondo formation is overlain by the Pipiral formation, which starts with quartz conglomerates, interbedded with sandstones, well exposed in the Quebrada Choapal. On higher levels the formation is interbedded with fossiliferous shales, calcareous shales and a few limestone beds. The fauna indicates a Carboniferous age (Royo y Gomez, 1945). The formation shows only a slight degree of metamorphism. The underlying Monterredondo formation (also called "Quetame formation") is characterized by a higher degree of metamorphism and probably is of Lower Paleozoic age.

Apart from the sandy admixture and the somewhat lower degree of metamorphism, the chlorite-sericite-schists of the Monterredondo formation have a certain resemblance to the greenschists of the Cajamarca Group. In this relation the observations of Marshall Kay (1951) on geosynclines are interesting. According to this author the large continental shields are generally bordered by two types of geosynclines, viz. miogeosynclines, situated next to the craton, and eugeosynclines, forming the outer zone. The latter may merge into the former or be separated from it by tectonic welts. The eugeosynclines have subsided deeply in a belt of active volcanism and their deposits consist mainly of volcanic rock-sequences, such as flows, agglomerates and tuffaceous

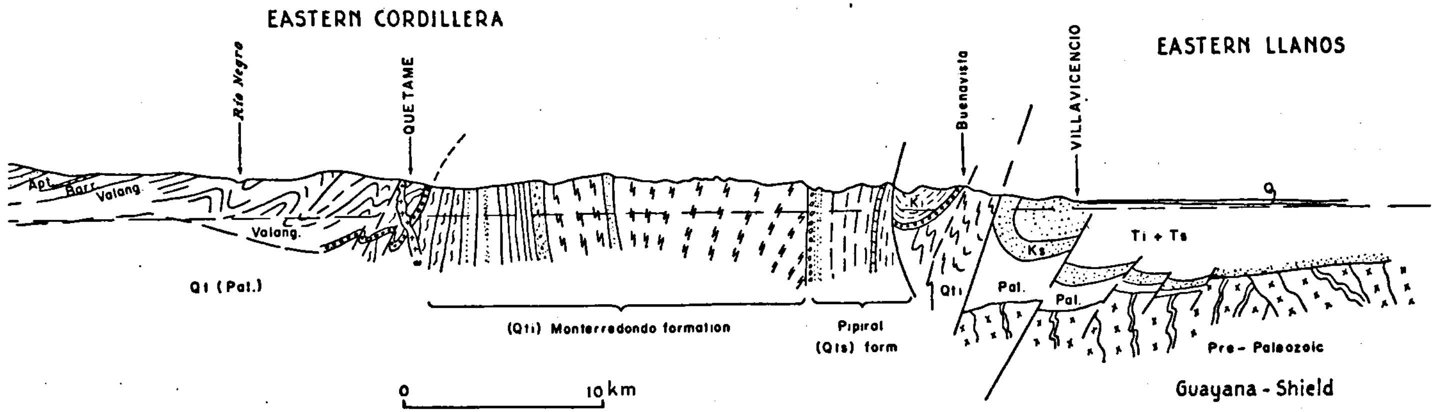


Fig. 28. Section through the Paleozoic rocks of the Eastern Cordillera, according to H. W. NELSON and J. KEIZER.

greywackes, besides argillites, cherts and cherty argillites. The generally less subsided miogeosynclines are situated in a belt lacking volcanism and their sediments are characterized by arenites, calcareous rocks, a. o. The theory seems to account very well for the volcanic facies of the Cajamarca Group and for the modifications to a more sandy facies approaching the Guyana shield.

Correlating the Cajamarca Group with the Monterredondo formation of the Eastern Cordillera, the folding would be due to the Caledonic orogeny, but additional proof is not available.

The intrusion forming the Ibagué batholith, is probably syntectonic and in the case of a Lower Paleozoic age of the Cajamarca Group, the granodiorites would be of Caledonian age. On the other hand, the possible relation between the intrusive cycle and the subsequent extrusive volcanism, might speak for a Hercynian age, because we have placed — in view of its position below the Triassic Payandé formation — these volcanics in the Permo-Triassic.

According to the theory of MARSHALL KAY (1951) the eugeosynclines are not only the belts of deepest subsidence but also the most active during the subsequent orogenic phase. A fact is that the Central Cordillera has remained a positive area throughout the Mesozoic. At the beginning of this era a geosyncline develops on either side of this mainland. Each of these geosynclines has its individual evolution, characterized by a different sedimentary facies and different magmatic cycles, in time as well as in type. Again, the western trough is the deepest and during the Cretaceous period there is intensive submarine volcanic activity. The beginning of the geosynclinal development is unknown, since the base of the Dagua Group is not exposed. Remarkable is the phyllitic stage of metamorphism of the lower part of the Dagua Group, in contrast to its non-metamorphic upper part. The metamorphism of the lower part is probably a consequence of deep subsidence during the volcanic stage of the geosyncline.

Towards the end of the Cretaceous the submarine volcanism decreases and the geosynclinal deposits are intruded by tonalites. By that time, and perhaps related to the intrusive tonalitic cycle, tectonic paroxisms caused the upheaval of the geosyncline above sealevel.

There is a remarkable range in the hiatus between the Diabase Group and the Lower Tertiary sediments, even between adjacent zones. No visible disconformity is observed between the Diabase Group and the limnic or fluviatile Paleocene. The Paleocene, however, is only locally developed. The Lower Eocene transgresses with a basal conglomerate, or sometimes with a coarse sandstone. A distinct disconformity can be observed especially where the Lower Tertiary transgresses directly over the Diabase Group. Evidently, during the Paleocene certain areas were submitted to erosion, furnishing the erosion products which were deposited in adjacent depressions, in which reigned a limnic facies.

Epeirogenic movements during the Lower Tertiary caused paralic conditions, during which coal beds were formed.

The main orogenic phase is of Miocene age and starts with volcanic eruptions in the Central Cordillera. The tuffs were washed down and deposited in the foreland of the Cordillera, where they overlie disconformably the older Tertiary sediments. Continued uplift caused fluviatile deposition of coarse sediments in the same area.

The first indications of the future Cauca depression can already be

TABLE XII

STRATIGRAPHIC COLUMN OF THE WESTERN AND CENTRAL CORDILLERA

WESTERN CORDILLERA AND WESTERN BORDER CENTRAL CORDILLERA

Geologic age		Local names	Lithology	Facies	Magmatic phases
HOLOCENE		Valle	Alluvial deposits	fluviat.	Andesite tuffs and flows
PLEISTOCENE		Popayán	Fluvioglacial deposits with tuff. intercalations	fluviat.-volcanic	
PLIOCENE		Zarzal	Diatomites, clays and tuff. sands	lacustrine	
MIOCENE		Upper La Paila	Coarsegrained to argillaceous sandstones and conglomerates; lignite seams at the top	fluviat.	Dacitic stocks and tuffs
		Lower La Paila	Reworked sandy tuffs	fluviat.	
OLIGOCENE	U.	Upper Cauca	Greenish greywackes (Sevilla); Shales with coal beds, quartzconglom. (Timba)	fluviat. paralic	
	M.	Middle Cauca	Sandy shales (upper part); Shales with coal seams (lower part). Loc. developed in marine limestone facies, underlain by rhyolite flows (Vijes)	paralic (marine)	Rhyolite (Vijes)
	L.				
EOCENE	U.				
	M.	Lower Cauca	Sandstones (upper part); Shales with sandstone beds and coal beds; Basal conglomerate	paralic	
	L.				
PALEOCENE		Nogales	Black calcareous cherts with carbonaceous material, intercalations of greywackes	limnic-fluviat.	Tonalite
CRETACEOUS	U.	Diabase	Diabase flows with some intercalations of chert beds and siliceous shales; loc. ultrabasic eruptives	marine-volcanic	Basic volcanism
	M.				
	L.	Dagua	Black chert and siliceous slates (upper part); Slates, siliceous sandy rocks and a few limestone horizons (middle part); Phyllitic slates, more or less graphitic; in contactzone chiastolite schist (base not exposed)	marine	
JURA-TRIASSIC					

CENTRAL CORDILLERA

Volcanism
Volcanism
EMERGED CONTINENTAL RIDGE

EASTERN BORDER CENTRAL CORDILLERA

Geologic age		Local names	Lithology	Facies	Magmatic phases
HOLOCENE			Alluvial deposits	fluviat.	Andesite tuffs and flows
PLEISTOCENE			Fluvioglacial deposits (fans)	fluviat.	
PLIOCENE			(not developed in the area mapped)		
MIOCENE					
OLIGOCENE	U.	Gualanday	Conglomerates (Upper Gualanday)	fluviat.	
	M.		Variegated sandy shales to coarse sandstones		
	L.		Conglomerates (Lower Gualanday)		
EOCENE					
PALEOCENE		Guaduas	Red mottled shales and sandy shales	fluviat.	
CRETACEOUS		Camp./Maestr.	Greenish sandstones	littoral	
		Santonian	Bed of black chert		
		Coniacian	Shales with "waggon-wheels"	marine	
		Alb./Turon.	Sandy limestone		
		Aptian	Sandy limestone; in the lower part standstones with lignite seams (R. Cucuana)	littoral	
JURA-TRIASSIC		post-Payandé	Andesitic to dacitic flows and pyroclastics	volcanic-terrestr.	Monzonite Andesitic volc.
		Payandé	Limestone, partly sandy; in contactzones hornfels	marine	
PERMO-TRIASSIC		pre-Payandé	Consolidated breccias, greywackes and ferruginous shales	fluviat.	
			Rhyodacitic flows	volcanic-terrestr.	Rhyodacitic extr.

		Intrusion of granodiorites	
PALEOZOIC	Cajamarca	Mainly greenschists with intercalations of graphite schists; Quartzphyllites and gneissic schists; Some diabase flows in the lower part; Quartzites with graphite schists	marine-volcanic

dated in an early Tertiary stage and the zone of greatest subsidence obviously bordered the actual Western Cordillera. This can be concluded from the fact that the paralic Lower Tertiary outcrops only along the western margin of the depression.

The later stage of the Andean orogeny and the subsequent uplift was accompanied by block-faulting in the Central Cordillera.

Very different is the development of the eastern Andean basin during the Mesozoic era; a fact already observed by E. HUBACH (1934). Terrestrial sedimentation prevails throughout the Triassic and Jurassic periods, except for the shallow marine ingression during which the Payandé limestones were formed. Volcanism produced lavas and tuffs of intermediate composition at the end of the Triassic or beginnig of the Jurassic period. The deposits were intruded by monzonitic magmas.

In the Lower Cretaceous the sea invades the eastern geosyncline, but in the borderzone of the Central Cordillera the deposition remains calcareous and sandy. The lack of any vestige of volcanism in this period seems to indicate that there was no connection with the volcanic western Andean geosyncline. This assumption certainly applies to our area. In other areas, however, circumstances may have been different. In this relation the author wants to mention the findings of plant remains about 10 km east of San Felix, on the paramos of the broad mountain ridge of the Central Cordillera in that region. The fossil plants occur in fine sandy shales, forming small intercalations between thick beds of quartz conglomerate, outcropping from under neovolcanic tuffs. The plant remains were identified by T. V. D. HAMMEN as *Otozomites*, a genus of *Cycadea*, and are characteristic of the Wealden facies. These deposits indicate a Lower Cretaceous transgression in this region.

Unfortunately, it was not possible to ascertain whether these Wealden deposits pass on higher stratigraphic levels into the siliceous slates encountered about 5 km west of San Felix, which yielded a microfauna of Lower Coniacian age (see chapter V). In that case the major part of the Central Cordillera in this section would be formed by Cretaceous sediments. The stratigraphical position of the Wealden deposits, however, suggests also a relation to the marine Cretaceous of the eastern Andean sedimentation basin. Consequently, in this part of the Central Cordillera there would have existed a connection between both Andean geosynclines during Cretaceous time.

SAMENVATTING

Het Westelijk gedeelte van de Republiek Columbia (Zuid Amerika) wordt ingenomen door de Cordilleras de los Andes, welke in genoemde republiek uit drie hoofdketens bestaat, t. w. de West Cordillera, de Centrale Cordillera en de Oost Cordillera. Een studie werd gemaakt van een centraal gelegen strook door de Westelijke en Centrale Cordillera, waartoe drie gebieden geologisch gekaarteerd werden en de structurele concepties in profielen werd weergegeven.

De oudste gesteenten, die in de Centrale Cordillera aan de dag komen, bestaan uit een epimetamorfe serie van prasinieten, afgewisseld met grafietschisten; ondergeschikt komen kwartsphyllieten en gneisachtige kwartsschisten voor; voorts werd een aantal inschakelingen van metamorfe diabazen waargenomen. Een tuf-oorsprong voor de prasinieten wordt verondersteld; de metamorfe diabazen zijn waarschijnlijk geïnterstratifieerde lavas geëxtrudeerd tijdens dit vulkanisme. Het grondgebergte van de Centrale Cordillera wordt bij wijze van proef vergeleken met de metamorfe gesteenten van Oud-Palaeozoische ouderdom, welke in de Oost Cordillera aan de dag komen.

Een beschrijving wordt gegeven van de Jura-Triassische formaties, welke de Oostelijke helling van de Centrale Cordillera bedekken en gelegen zijn tussen de Río Coello en Río Cucuana. Monzonieten en granodiorieten werden tijdens de Jura geïntrudeerd. Een sectie werd gemaakt door het marine Krijt, dat een micro- en macrofauna bevat.

Op de Westflank is het grondgebergte van de Centrale Cordillera in abnormaal contact met de Diabaas Groep („porfyriet formatie"-GROSSE) van Midden tot Boven Cretaceische ouderdom. Deze Diabaas Groep bestaat uit submarine lavas, geïnterstratifieerd met kiezelleien en cherts. Ingeplooide limnische afzettingen van Paleocene ouderdom liggen discordant op de Diabaas Groep. Een schollenbouw is karakteristiek voor beide flanken van de Centrale Cordillera.

Het grondgebergte van de West Cordillera wordt hoofdzakelijk gevormd door twee formaties, t. w. de Dagua Groep en de reeds genoemde Diabaas Groep. Eerstgenoemde kan op de volgende wijze in drie series onderverdeeld worden: de onderste serie, bestaande uit phyllitische leien; de middelste serie, bestaande uit fijnzandige gesteenten, afgewisselde door enige kalkhorizonten, voorts leien, die phyllitisch kunnen zijn tengevolge van dislocatie-effecten; de bovenste serie, bestaande uit kiezelleien en zwarte chert. De Dagua Groep wordt concordant bedekt door de Diabaas Groep. Deze bezit dunne inschakelingen van schalies en kiezelleien, waarin een Boven Krijt fauna gevonden werd. Het Cauca bekken is geïntrudeerd door tonalieten van Boven Krijt tot Onder Tertiaire ouderdom, welke duidelijke thermale contacten teweeg gebracht hebben. Het middengedeelte van de West Cordillera heeft een typische schubstructuur. De Cauca vallei moet niet gezien worden als een tectonische slenk in de gebruikelijke zin van het woord, doch als een neergedrukt, gekanteld blok.

In het laatste hoofdstuk worden enige opmerkingen gemaakt over de ontwikkeling van de Andine geosynclinalen.

SUMMARY

The present article deals with the geological survey of three areas, two of which being situated on either side of the Central Cordillera and one covering a sector of the Western Cordillera. Special attention has been paid to the composition of the basement rocks and an attempt has been made to arrive at a concept of the tectonical structure of these Cordilleras.

The oldest rocks outcropping in the Central Cordillera consist of an epimetamorphic sequence of greenschists and graphite schists, with subordinate quartzphyllites and gneissic quartzschists; besides these, a few intercalations of metamorphosed diabases have been observed. A tuffaceous origin for the greenschists is assumed, whilst the metamorphic diabases probably represent interstratified flows produced by the same volcanism. The basement rocks of the Central Cordillera are tentatively compared with metamorphic rocks of Lower Paleozoic age outcropping in the Eastern Cordillera.

A description has been given of the Jura-Triassic formations, bordering the eastern slope of the Central Cordillera between the rivers Coello and Cucuana. Plutonism produced monzonitic and granodioritic intrusions during the Jurassic period. A section is given through the marine Cretaceous containing a micro- and macrofauna.

On the western flank the basement rocks of the Central Cordillera are in abnormal contact with the Middle to Upper Cretaceous Diabase Group ("porphyrite formation"-GROSSE), consisting of submarine volcanic flows, interbedded with cherts. They are unconformably overlain by limnic deposits of Paleocene age, folded into the Diabase Group. Block-faulting is characteristic of both flanks of the Cordillera.

The basement of the Western Cordillera is formed mainly by two formations, viz. the Dagua Group and the Diabase Group. The former we subdivided into three parts: the lower part consisting of phyllitic slates; the middle part consisting of arenaceous rocks intercalated by a few limestone horizons, and of slates partly phyllitic due to strong thrusting; the upper part consisting of siliceous slates and black cherts. The Dagua Group is conformably overlain by the Diabase Group. Shaly and cherty intercalations yielded an Upper Cretaceous fauna. Tonalite intrusions of Upper Cretaceous to Lower Tertiary age produced distinct contact zones. The Western Cordillera shows in its middle part a typical imbricated structure. The Cauca valley is shown not to be a normal tectonical rift, but rather a downfaulted and tilted block.

In the last chapter remarks are made regarding the development of the Andean geosynclines.

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