HOOFDSTUK II.

DE GEOLOGIE VAN NEDERLANDSCH WEST-INDIË.

22. CURAÇAO

BY

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I. STRATIGRAPHY.

The oldest sediments on Curaçao are jasper [1]), diabasetuff, siliceous slates [2]), radiolarian chert [3]), quartzporphyrite-crystal tuffs, porphyrite-crystal tuffs, lithic porphyrite tuffs, tuffites, tuffite breccias, aphanitic crystal tuffs, tuffite-shales, graywacke-shales and graywackes [4]). This group of rocks — the Knip-series — is named after the plantation Knip.

[1]) K. MARTIN, Bericht über eine Reise nach Niederländisch West-Indien, zweiter Theil: Geologie, 1888, p. 28.

[2]) K. MARTIN, cf., page 27—29.

[3]) J. H. KLOOS was the first to recognise the existence of radiolarian cherts on Curaçao. K. MARTIN, cf., page 28.

[4]) The names tuff, tuffite and tuffite-breccia have the following meanings:

The erupted material (ejectamenta) may either fall on the land, in fresh water or in the sea.

If the size of these products does not exceed that of lapilli, they are named land, fresh water or marine tuffs after the lithification.

If the tuff contains larger particles the rock is named agglomerate tuff.

The tuffs contain four constituents: crystals, glass, rock fragments (these may be of volcanic, sedimentary or metamorphic origin) and cement. The latter is generally silica.

When the crystals predominate the term crystal tuff is used, in the case of glass, glass tuff and in the case of rock fragments lithic tuff.

If the ejectamenta fall into the sea close to the land, clastic material can be admixed. This type of composite rock is named tuffite.

If the groundmass of a marine tuff is formed by organic lime the composite rock is termed lime tuffite. In this manner the terms clay tuff and sand tuff may also be used.

There are of course transitions between marine tuff, tuffite (or lime tuffite) and clastic sediments containing tuff material (or limestone containing tuff material).

A tuffite may contain larger ejectamenta or clastic material, in which case the term tuffite breccia (or tuffite conglomerate as the case may be) is used.

The stratigraphic sequence of the Knip-series is difficult to ascertain. They are intensively folded [1]). I believe it would be safe to assert, that the oldest sediments of this series are jasper and diabase tuffs. The North limb of the anticlinorium in North-West Curaçao is very intensively folded, the South limb, however, in lesser degree, so that on the plantations Sint Jan, Groot St. Martha, St. Nicolaas, Spaansche Put, St. Kruis and Lagoen (Seroe Commandant), more can be seen of the sequence of the strata. Even so this is not much, as a large part of the Knip-series has been carried away by later denudation.

It is noteworthy that the Knip-series have frequently been silicified. On page 20 and 21 of my docter's thesis [2]) I showed that the siliceous slates that contain crystals, radiolaria and foraminifera, must be looked upon as silicified tuffs. From the presence of foraminifera I concluded that the sea in which these tuffs were deposited could not well have been deep sea. As the silicification was complete the character of the groundmass before the silicification could not be determined. The petrographic investigation of the siliceous slate containing radiolaria no. 27 from the collection of Dr. I. BOLDINGH [3]) showed that before the silicification the groundmass of this rock contained calcium-carbonate. The siliceous slates bearing radiolaria therefore contain silicified lime tuffites.

The siliceous slate no. 23 of the coll. BOLDINGH contains quartz and felspar splinters and is partly silicified. The groundmass is built up in part of carbonate of lime. Possibly these splinters are clastic, in which case the rock would be a silicified marl.

The light grey and dark grey crystal tuffs that contain radiolaria and foraminifera are mostly silicified lime tuffites.

The presence of carbonate of lime in the groundmass of the rocks mentioned above confirms my conclusion that the rocks from which they were formed by silicification were not deposited at abysmal depths.

As to the radiolarian cherts, it should be mentioned that on Curaçao transitions occur between radiolarian chert and silicified crystal tuffs containing radiolaria and foraminifera. My collection contains radiolarian cherts with enclosed crystals.

One may suggest that the radiolarian chert on Curaçao is tuff or lime tuffite, containing radiolaria changed to hornstone after submarine decomposition. It may be safely assumed that clastic products that have been deposited on the seabottom and have decomposed there, can be silicified. It is a well known fact that the nucleus of recent manganese nodules are often formed by these products or by tuffs. The white nuclei of these nodules are the decomposition products of this material [4]).

[1]) K. MARTIN, cf., page 29.

[2]) G. J. H. MOLENGRAAFF, Geologie en geohydrologie van het eiland Curaçao. Delft, 1929.

[3]) This collection is to be found in the Mineralogisch-Geologisch Instituut der Rijks-Universiteit te Utrecht.

[4]) J. MURRAY and A. F. RENARD, Report on deep sea deposits, 1891, p. 307, 342, 345 a. o.; J. MURRAY and G. V. LEE, The depth and marine deposits of the Pacific, Mem. of the Mus. of Comp. Zoöl. at Harvard College, Cambridge U.S.A. 1909, page 29, 143, 146, 147, 148 and 167.

MOLENGRAAFF microscopically examined the white nucleus of a manganese nodule from the Cretaceous red clay of Timor and found that it consisted of radiolarian hornstone that was almost entirely changed to amorphous silica [1]). I believe we may conclude from this that clastic products or tuffs bearing radiolaria can change to radiolarian chert after submarine decomposition.

I even consider it possible that on the silicification of lime tuffites containing radiolaria and foraminifera not only the carbonate of lime of the groundmass but even the skeletons of the foraminifera can be completely replaced [2]). Thus a radiolarian chert is formed from this kind of rock.

As we have seen, transitions between radiolarian chert and silicified crystal tuffs exist and the latter contain both radiolaria and foraminifera and are therefore certainly not of deep sea origin. This and the stratigraphic position of the radiolarian chert of Curaçao seem to me to disprove that this rock is a deep sea deposit (radiolarian-ooze).

Neither the radiolarian cherts, nor generally the siliceous slates contain clastic products; the tuffites and the graywacke-shales, on the other hand, do contain them. Probably only when exceptionally heavy rains fell, could clastic material be carried out to sea to places too far to be reached by this material in the normal course of events.

The occurrence of radiolarian chert together with deposits from near the shore has been met with repeatedly. It is curious, that geologists have tried to explain this association on quite different lines.

Some assume that such a radiolarian chert is a silicified radiolarian ooze that was deposited close to the shore. The absence of foraminifera is explained by supposing that they could not live in the water above the radiolarian deposits. It is assumed that the sea in these regions contains so much silica that the foraminifera avoid them. I cannot enter further into this hypothesis here, but I only wish to point out that up till now no radiolarian ooze has ever been found close to the shore.

In the case we are considering, some geologists believe the radiolarian chert to be a lithified silica gel flaked out near to the coast, into which only skeletons of radiolaria have fallen. The absence of foraminifera is explained in the same manner as mentioned above.

Opinions as to the formation of the silica gel differ. Some assume that the sea water is able to flake out the silica supplied by rivers. However, experiments have proved this to be impossible. Others believe that submarine geysers have supplied dissoluble alkaline silicates or that submarine „pillow-lavas'' have emanated solutions containing silica during their formation and that the sea water has flaked out the silica gel. As far as I am aware no sounding has ever brought up a silica gel from the sea bottom, nor a silica gel in which only radiolaria occur laid down near the coast.

[1]) G. A. F. MOLENGRAAFF, On manganese nodules in mesozoic deep-sea deposits of Dutch Timor, Koninkl. Akad. Wetensch. Amsterdam, Proc. Vol. XXIII, No. 7, 1920, page 1006.

[2]) The small number of skeletons of foraminifera in the siliceous slates agrees with this view.

The theories mentioned above appear to me to be far fetched. They are the interpretation of „Gedankenexperimenten'' instead of an interpretation of processes occurring in nature.

The Knip-series contain some curious tuffites and tuffite breccias. RUTTEN has ingeniously made out the genesis of these rocks. The eruptive material is formed by plagioclase crystals, the clastic material by quartz, perthitic orthoclase, fragments of granite (orthoclase together with quartz) and by fragments of hornstone and slate. The rock is therefore partly built up of detritus of granite, slate and hornstone from the sedimentary covering. It is of great importance that in this way the detritus of an old folded system of strata with granit intrusions has been found on Curaçao. Many geologists assign a paleozoic age in the West Indies to this series.

The dolomitised siliceous slates containing radiolaria and foraminifera are other interesting rocks belonging to the Knip-series.

In East Curaçao on the plantations Brievengat and Ronde Klip dark grey, fine grained rocks — the Ronde Klip-series — occur that I was not able to find in North-West Curaçao. They consist of lime tuffites or foraminiferal limestones containing tuff, in which many textularia and crystals of plagioclase, quartz, green hornblende and augite splinters occur. They belong to the North limb of the anticline in East Curaçao and are of the same age as the Knip-series. An intrusive sheet of vintlite has produced contact metamorphism in these rocks over a short distance.

From the above it follows that volcanic eruptions took place while the Knip-series was being deposited.

The Seroe Teintje limestone [1]) is younger than the rocks mentioned above. The outcrop of the Seroe-Teintje limestone, East of Seroe Djaka Komé on the plantation Savonet contains pebbles of diabase — and of siliceous slate at its base. From this it follows that after the deposition of the Knip-series a regression occurred, followed by a transgression.

From the tectonic structure it also follows that the Seroe Teintje limestone is younger than the Knip-series. The limestone occurs only on the outer sides of both limbs of the anticlinorium in North-West Curaçao: for the North limb from Piedra Grandi (on the plantation St. Hyronimus) to the West point (foot of the North slope of Seroe Belafa) and for the South limb, to the North of the road between Krakeel and Klein Fontein, North-East of point 98.6 m. and further on the West side of Sint Martha Bay, the plantation St. Nicolaas [2]). MARTIN already pointed out these facts [3]).

I consider it possible that the outcrops of limestone on the plantation Savonet are the remains of the cores of secondary isoclinal synclines.

According to MARTIN the age of the Seroe Teintje limestone is Upper Cretaceous. GERTH described some corals from this limestone. He not only affirmed the Upper Cretaceous age, but could define it even more precisely

[1]) K. MARTIN, cf., p. 35. This limestone was named after the hill Seroe Teintje on the plantation Savonet, that consists entirely of this rock.

[2]) Rocks nr. 384 and 387 in the collection of Ir. G. DUYFJES.

[3]) K. MARTIN, cf., p. 35.

and assigned a Lower Senonian age to the Seroe Teintje limestone [1]).

The number of fossils that has been found in this limestone is small. The limestone has recrystallized more or less, so that one can only collect the silicified fossils that stand out from the surface when the limestone has weathered. The fossils are a typical reef fauna and flora, that is: *corals, rudistes* and *calcarious algae* [2]). This reef was built up in shallow water and the formation indicates a tropical climate during the Lower Senonian.

From the foregoing it follows that the Knip-series is older than Lower Senonian.

The Middle Curaçao series is younger than the Seroe Teintje limestone. It consists of conglomerates, graywackes with marl concretions, arkoses and marls [3]). This series is distinguished from the Knip-series by the absence of tuffs and tuffites. The oldest rock of this series is a conglomerate the pebbles of which are diabase, siliceous slate and Upper Cretaceous limestone. The graywackes also contain fragments of older rocks, such as small pieces of diabase, siliceous slate, radiolarian chert and tuff. After the formation of the Seroe Teintje limestone there must have occurred another regression, followed by a transgression. Probably the interval during which erosion occurred was of longer duration in East Curaçao, than in North-East Curaçao. The Seroe Teintje limestone does not occur in East Curaçao and the Knip-series form a thicker series in North-West Curaçao than in East Curaçao.

The oldest sediments that are met with in the anticlines belong to the Knip-series, the core of the syncline consists of Middle Curaçao strata. It therefore also follows from the tectonic structure, that the Middle Curaçao series is younger than the Knip-series. The actual age of the Middle Curaçao series is not known. The fossils that I collected from these strata were found to be of no use for determining the age.

In Venezuela the folding of the Mesozoic rocks took place towards the close of the Upper Cretaceous. If this is also the case in Curaçao the Middle Curaçao-series can only be Upper Cretaceous. In some parts of the West Indies the chief phase of the folding of the Mesozoic rock occurred in the Lower Eocene. If this was the case on Curaçao the Middle Curaçao series can be Upper Cretaceous or Paleocene.

The Seroe di Cuba, and the adjoining Seroe Bartool, is the only locality in which I found Lower Tertiary deposits (the Seroe di Cueba series). It is formed by a brown limestone covered conformably by white foraminiferal limestone.

The impure lower limestone consists of small pieces of algae, siliceous slate, felspar, quartz and augite. Foraminifera and radiolaria are rare. This limestone contains several casts of mollusca and the echinide *Eupatagus grandiflorus* COTTEAU. The latter is also found in the Upper Eocene limestone of St. Barthélemy.

The foraminiferal limestone is built up principally by algae and

[1]) H. GERTH, Beiträge zur Kenntnis der mesozoischen Korallen-faunen von Südamerika. Leidsche Geologische Mededeelingen, Deel III, 1, 1928.

[2]) K. MARTIN, cf., p. 21—27.

[3]) K. MARTIN, cf., p. 30, 31 and 34.

foraminifera. Clastic material is not present. In this rock RUTTEN[1]) found foraminifera that are characteristic for the Upper Eocene:

Pliolepidina tobleri H. DOUV.

and *Isolepidina trinitatis* H. DOUV.

Further more, this limestone contains *Serpula clymenioides* GUPPY, of which G. D. HARRIS[2]) says that it is „the most conspicuous fossil'' in the Upper Eocene of West Trinidad. This limestone further contains some species of the echinide genus *Oligopygus*, that up till now has only been found on Trinidad[3]) and in Venezuela[3]) in the Upper Eocene.

R. KOCH[4]) believes that the highest foraminiferal limestone belongs to the Lower Oligocene. This is not in accordance with the paleontological investigation of the fossils that I found in these limestones. If KOCH's opinions are right we should expect to find that the pebbles from the basal conglomerate that lies on this limestone, consisted of Lower Oligocene limestone. This is not the case, for RUTTEN found Upper Eocene foraminifera exclusively in the pebbles.

In spite of R. KOCH's difference of opinion I believe the Seroe di Cueba series to be Upper Eocene.

The Upper Eocene of Cuba, Haiti, Santo Domingo Venezuela, Barbados and Trinidad is intensively folded. In Curaçao, however, this is not the case.

Oligocene and Neogene are absent on Curaçao.

During the Pleistocene a renewed transgression took place. The Pleistocene beds — the Seroe Domi series — are composed in the following manner from bottom to top: basal conglomerate, that changes to a fine conglomerate here and there; then weathered soft limestone resembling chalk tuff and finally reef limestone[5]).

According to whether the basal conglomerate rests on diabase, Upper Eocene foraminiferal limestone or the Knip-series the pebbles consist of diabase, foraminiferal limestone or rocks from the Knip-series.

The fine conglomerate consists of small rounded pieces of algae, organic limestone, siliceous slate and sometimes diabase. The cement is calcite, in which *Amphistegina* occurs. Mrs. Dr. A. WEBER—VAN BOSSE told me, that the genera *Amphiroa* is by far the most frequent among the calcarious algae in the fine conglomerate.

A limestone containing the same fauna and flora, but without the clastic material covers the Tafelberg, on the plantation St. Hyronimus. The Pleistocene reef limestone has been described in detail by MARTIN[6]).

The oldest Holocene deposits are horizontal beds of coral and shells — the Asiento series — about 5 m. above sea level[7]).

[1]) L. RUTTEN, Tertiaire Foraminiferen van Curaçao. Koninkl Akad. Wetensch. Amsterdam, Deel XXXVII, No. 9, 1928, p. 857—867.

[2]) G. D. HARRIS, Notes on the paleontology of the island of Trinidad. The John Hopkins University Studies in geology, No. 7, 1926, p. 176.

[3]) A. JEANNET, Sur des Echinides tertiaires du Venezuela et de la Trinité conservés au Musée d'Histoire naturelle de Bâle. Mém. de la Soc. pal. Suisse.

[4]) R. KOCH, Tertiärer Foraminiferenkalk von der Insel Curaçao. Eclogae geologicae Helvetiae, Vol. 21, 1, Juin, 1928.

[5]) K. MARTIN, cf., p. 14—18, p. 39—40, p. 79—86.

[6]) K. MARTIN, cf., p. 79—86.

[7]) K. MARTIN, cf., p. 125—130.

The most recent formations are coral reefs around the island and in some inlets, the shore conglomerate in the Westpuntbaai and in the Boca Santa Preto, the alluvial deposits and the limesinter in some of the river-beds.

Below follows a table of the stratigraphy:

Holocene	Recent reefs and alluvial deposits Conglomerate Coral- and shell-beds	Westpuntbaai and Boca Santa Preto-conglomerate Asiento formation
Pleistocene	Reef limestone Soft limestone resembling calcareous tufa Fine conglomerate Basal conglomerate	Seroe Domi-Series
Upper Eocene	White foraminiferal limestone Brown impure limestone	Seroe di Cueba Series
Paleocene or Upper Cretaceous	Graywackes with marl concretions arkosen, marl-shales Conglomerate	Middle-Curaçao Series
Lower Senonian	Compact, blue-grey reef limestone	Seroe Teintje limestone
Cretaceous ?	Knip-series siliceous slates, radiolarian chert, aphanitic crystal tuffs, quartzporphyrite tuffs, porphyrite tuffites, tuffites, graywackes, diabase tuffs and jasper.	Rondeklip-series Lime tuffites on foraminiferal limestone containing tuff.

II. IGNEOUS ROCKS.

The oldest igneous rocks are diabase [1]), diabase porphyrite [2]) and labradorite porphyrite. They are at the same time the oldest rocks exposed on Curaçao.

The texture of the aphanitic diabases points to a swift eruption and cooling. I consider it likely that the diabase magma flowed from a submarine fissure. The absence of a basal conglomerate between the Knip-series and the diabase agrees with this supposition.

The age of the diabase cannot be ascertained accurately. The diabase has been folded intensively together with the Knip-series, the Seroe Teintje limestone and the Middle Curaçao-series [3]). The diabase is the oldest rock, forming the centre of the anticlines and appears where the core has been exposed. At several points it may be seen that the Knip-strata that are the oldest sedimentary rocks of the limbs of the anticlines, rest on diabase and have protected this rock from denudation. As the diabase is older than the Seroe Teintje limestone it must be older than Lower Senonian.

No inferior limit to the possible age of the diabase can be fixed, for there are no sedimentary rocks known from Curaçao that are older. In the West Indies, however, the folded Mesozoic rocks lie unconformably on the folded Paleozoic strata. The diabase is therefore certainly Mesozoic.

During the intensive folding of the old sediments a quartz augite diorite was intruded [4]).

The rock is fine grained and of a greyish-green colour. The structure is hypidiomorphic granular. Quartz, a dark mineral and ore occur between thin slab-shaped felspars. On microscopic examination it was found that the oblong sections of the slab-shaped felspar are often warped. This felspar — an albite — is twisted according to the albite and the Carlsbad laws. Quartz has crystallized simultaneously with this felspar and later. It has partly replaced the plagioclase. The presence of quartz and albite points to the crystallization of a residual magma rich in sodium-silicates and SiO_2 [5]). An analysis of the K_2O and Na_2O contents of this rock from the collection DUYFJES (nr. 265) has shown the absence of orthoclase:

$$K_2O = 0.445\ \% \pm 0.003,\ Na_2O = 3.89\ \% \pm 0.015.$$
(the amount of SiO_2 is 68.7 %).

[1]) K. MARTIN, cf., p. 39.
[2]) K. MARTIN, cf., p. 36.
[3]) K. MARTIN, cf., p. 31.
[4]) MARTIN found this rock amongst others South-East of the St. Christoffelberg not far from Paradera. J. H. KLOOS, however, classifies this rock as a quartz diabase. In accordance with KLOOS, this rock has been termed a quartz diabase in several collections.
[5]) In this connection see: C. N. FENNER, The Katmai magmatic province, J. G. Vol. XXIV, 1926, p. 763—764 and R. J. COLONY, the final consolidation phenomena in the crystallization of igneous rocks, J. G. Vol. XXXI, 1923, page 170.

The felspar and quartz greatly predominate over the diopside. The diopside is often changed to uralite and sometimes the uralite has in turn been changed almost entirely to a chloritic substance.

Ir. C. SCHOUTEN made a minerographic investigation of the ore and found that it consists of magnetite that is partly replaced by haematite along the crystallographic planes.

The dyke rocks of the diorite magma are: quartz-hornblende-diorite porphyrite [1]), hornblende-diorite porphyrite and vintlite.

The vintlite is a holocrystalline-porphyric rock. The phenocrysts are: rounded felspar [2]) and dark green hornblende. The groundmass consists of felspar and a ferro-magnesian mineral.

The rocksample nr. 385 of the collection DUYFJES was examined microscopically. The core of the zonary plagioclase phenocrysts is an acid plagioclase and the outer zone an albite. The felspar phenocrysts are corroded and surrounded by a colourless mica.

Green zonary phenocrysts of hornblende also occur. They are partly uralitized. This starts at the outside, so that they are surrounded by a rim of uralite.

The felspar of the groundmass is an albite. This was to be expected, as these dyke rocks have crystallized from an injected residual magma. The felspars of the groundmass of the rock described above are small albite laths. The groundmass further contained an uralitized green hornblende. The groundmass is devoid of orthoclase.

Besides sodium silicates the residual magma contained SiO_2. Quartz occurs in the diorite porphyrites and part of the albite in the augite diorite is replaced by quartz. The question therefore arises, whether the quartz crystals that occur in the second type of vintlite in my collection are xenolithic. The presence of green hornblende in the groundmass, of colourless mica — a „deuteric mineral'' — around the plagioclase phenocrysts and of green hornblende around corroded quartz crystals in the vintlite of the second type, point to the crystallization under pressure of residual magma that was rich in volatile constituents.

Later, the dyke rocks of the diorite magma have often undergone alterations by hydrothermal solutions rich in Ca. In this case the felspar phenocrysts are partly epidotized and the white veins in the rock consist of prehnite, plagioclase and quartz [3]). Sometimes the whole of the dyke rock has been changed to epidote and prehnite [4]).

Probably an injection of gabbro took place during the folding of the oldest sediments. Injection occurred of augite diorite porphyrite or diabase porphyrite of the dyke rock-type and of dolorite. The latter forms amongst others a sill, sometimes together with vintlite in the lime tuffites of the Ronde Klip-series to the East of the country house of Ronde Klip.

In North-West Curaçao the quartz augite diorite only occurs where

[1]) This rock was found at Westpunt by MARTIN, cf., p. 39.

[2]) This mineral is sometimes entirely changed to prehnite (nr. 386 collection DUYFJES, nr. 54 in my own collection).

[3]) Rock samples nr. 132, 14*b* and *c*, 24*b*, 134, 40*a* and 32 in my collection.

[4]) Rock sample nr. 36 in my collection.

the core of the anticlinorium is exposed. As might have been expected, the dyke rocks of the quartz augite diorite magma do not occur in the neighbourhood of the dome of the anticlinorium. I found nearly all the dyke rocks in the diabase to the North of the North limb of the anticlinorium in North-West Curaçao. However, vintlite has also been found at Sint Martha Baai, the plantation St. Nicolaas [1]) and on the East shore of the St. Kruisbaai [2]).

The old sediments are folded in an anticline in East Curaçao also. In the exposed core of this anticline, however, intrusive quartz augite diorite is not exposed. Probably the intrusion of the quartz diorite magma reached to a lower level in the core than in North-West Curaçao. The occurrence of intrusive quartz augite diorite in the core of the anticline in East Curaçao is to be expected, for the dyke rock of the quartz augite diorite magma does occur in East Curaçao.

III. THE GEOLOGICAL HISTORY OF THE ISLAND CURAÇAO [3]).

Owing to several factors, the geological history of Curaçao is imperfectly known. For instance the age of the Knip-series and of the Middle Curaçao series are not known and the chance of guide fossils being found is small.

Another disadvantage is that the denudation has only spared small remnants of the old sediments. Amongst others the erosion interlude between the Knip-series and the Seroe Teintje limestone is difficult to ascertain.

The Upper Eocene only occurs at one place on Curaçao and the geological history after the Pliocene is difficult to unravel.

From the above it follows that only an incomplete picture of the geological history of the island can be given.

The oldest sediments: the Knip-series, the Seroe Teintje limestone in the Middle Curaçao series have been intensively folded [4]). If the Middle Curaçao series is of Upper Cretaceous age the folding may have occurred at the close of the Upper Cretaceous or later, for instance during the Lower Eocene. If on the other hand these strata are of Paleocene age the folding probably occurred during the Lower Eocene [5]).

Three major axes of folding can be distinguished: a chief anticlinal axis in the North-West part of Curaçao, a synclinal axis in Central Curaçao and an anticlinal axis in East Curaçao.

[1]) Nr. 385 and 386 in the collection DUYFJES.

[2]) Nr. 301 in the collection DUYFJES and nr. 600, 601, 609, 603 and 596 in the collection GRUTTERINK.

[3]) As far as not dealt with in chapter I.

[4]) K. MARTIN, cf., p. 31.

[5]) See p. 8.

The major anticlinal axis in the North-Western part of the island begins with a direction from East to West and then curves Northwards in a direction N. 20° W. Finally this axis curves to the North-West and then pitches below sea level in a directon N. 68° W. The axial plane grades to the North-East where the axis has a North-Westerly direction. The anticlinorium therefore is asymmetrical.

In the North-West part of Curaçao the folding has been very intensive. Secondary anticlines and synclines occur frequently.

The pitching of the axis does not only follow from the pitching of the axes of the secondary anticlines and synclines but also from the meeting of the two limbs of the anticlinorum in the neighbourhood of Westpunt.

The intensity of the folding decreases towards the south.

The axis of the syncline, the core of which consists of Middle Curaçao strata, runs East-West. The South limb of this syncline is also the North limb of the anticline in East Curaçao. Of this anticline only the North limb is found. The direction is also East—West.

The Middle Curaçao series has been preserved in the syncline in Middle Curaçao and in the North limb of the anticline of East Curaçao.

During the folding an intrusion of quartz augite diorite took place in the core of both anticlines and diorite porphyrite and dolerite were also injected.

During the Middle Eocene Curaçao stood above sea level.

As the Upper Eocene occurs only in one single locality on Curaçao we cannot be sure that the whole of Curaçao was covered by the sea. Possibly the Upper Eocene is the remains of the North limb of a slight anticlinal elevation during the Lower Oligocene. If this is the case the local occurrence should be explained by assuming, that the formation of a graben saved this deposit from total destruction.

The Oligocene and the Neogene are absent on Curaçao.

During the Pleistocene a renewed transgression occurred. Before the close of the Pleistocene the island was warped up asymmetrically. The strike of this anticlinal formation follows the axis of the island. In North-West Curaçao the anticline pitches below sea level in a direction N. 55° W. In South-East Curaçao the axis runs N. 110° E. and pitches below sea level in the direction 115° E. towards the island Klein-Curaçao. The strike of this axis therefore differs entirely from the strike of the axis of the older folding.

The Pleistocene strata dip at an angle of 20° to the South along the South coast, while these layers along the North coast only show a slight dip to the North. The Pleistocene doming is therefore asymmetrical. The axis of this folding shows two culminations and dips below sea level both at the North-Western and the South-Eastern end of the island. Between the two culminations of the axis a saddle[1]) or depression occurs.

[1]) In accordance with the custom of American geologists, who call the depression between two domes in an anticlinal axis a „saddle''.

f. i. D. HAGER, Practical oil geology, 1919, p. 52; E. R. LILLEY, The geology of petroleum and natural gas, 1928, p. 293.

In this connection see also B. G. ESCHER, De gedaanteveranderingen onzer aarde, 2e druk, 1920, p. 388.

In the depressed region (Kleine and Groote Berg) the island is still entirely covered by Pleistocene reef limestone [1]). Here, below the Pleistocene limestone, the syncline of the older period of folding lies buried of which the core consists of Middle Curaçao strata.

The areas of culmination of the axis are to be found in North-West Curaçao and in East Curaçao. Here the Pleistocene terraces of reef limestone occur at the highest altitudes. The areas of culmination coincide with the anticlinal areas of the older folding.

The abrasion of the Pleistocene transgression and former erosion had carried away the sediments from both these anticlines. Consequently the Pleistocene limestone lies on the cores of the anticlines mentioned above. On the Tafelberg in North-West Curaçao the Pleistocene limestone lies directly on diabase and in East Curaçao at the mesa Ronde Klipberg as well as at the mesas on Steenen Koraal.

It appears that during the asymmetrical Pleistocene folding the cores of the old anticline gave more resistance than the cores of the syncline that consists of Middle Curaçao strata. They were forced up to a higher level and consequently the axis of the recent Pleistocene folding shows two culminations and a saddle.

Probably it is the quartz augite porphyrite that has given the great resistance.

The thickness of the Pleistocene deposits agrees with this conception. In the depression it is no greater than on the culminations [2]).

The geological history of Curaçao during the Pleistocene was more complicated, however, than as told above.

I already mentioned that if the major anticlinal axis is followed from East to West a pitch can be observed. The intensive folding and the pitching of the axis have formed a comparatively small region in North-West Curaçao of resistent strata — the Knip-series. Before the Pleistocene transgression this region was the highest part of the island and probably the sea never covered the area now above the 250 m. line [3]).

The existence of terraces [4]) shows that the young Pleistocene elevation was intermittent. At present the terraces are found at the following altitudes: ± 230 m. (Tafelberg, St. Hyronimus); 150 m. (Tafelberg, Santa Barbara); 140 m.—?; 115—135 m.?; 90—110 m.; 50—85 m.; 20—45 m.).

MARTIN does not consider the dip of the Pleistocene coralbeds towards the South along the South coast of the island to be the consequence of folding. He believes that the strata had a primary dip [6]). I must admit that the section to the West of St. Anna-baai, behind the coaldump of the firm S. E. L. Maduro & Sons, is more simply explained by MARTIN's hypothesis.

[1]) K. MARTIN, cf., p. 86.
[2]) K. MARTIN, cf., p. 84.
[3]) K. MARTIN, cf., p. 119.
[4]) K. MARTIN, cf., p. 106—112.
[5]) The second number shows the height of the foot of the cliff at the edge of the terraces.
[6]) K. MARTIN, cf., p. 83.

The Pleistocene folding elevated Curaçao above the sea. During the Pleistocene glaciation the sea level was lower.

The shape of the Submarine base of the island is unknown, for no soundings have been taken around the island. The amount of the lowering of the sea level can thus only be deduced from the depths of inner waters and their mouths. Probably the sea level lay at about 30 m. below the present coastline.

During the ice age an intensive erosion took place. The drainage was chiefly obtained by consequent rivers, flowing North or South. The remains of the consequent vallies is still extant, for instance in the plantation Fuik. Fine examples are the gorges on Souax and on the boundary between Gato and Papaja.

After the Pleistocene reef limestone had been cut through in places the stream could enlarge its drainage area by undermining this limestone. East Curaçao thus obtained a curious aspect. As soon as the erosion had reached the diabase a rock that offers less resistance than the reef limestone the interior regions could be denuded to a lower altitude than the coastal regions, where the diabase was still protected by the reef limestone. The amount to which the stream could cut down into the reef limestone in its lower course depended on the size of its drainage area.

After the ice age the sea level rose again. As wave-cut notches occur in the reef limestone and in the Upper Eocene limestone at an altitude of 70 m., the sea level must have risen $30 + 70 = 100$ m.

Afterwards, during the Holocene, the island has risen $\pm$ 65 m. Traces of this elevation are still present. At several points an abrasion platform can be found that has been partly destroyed subsequently by erosion. Examples occur in the planes to the East and North-East of the country house Savonet, to the North-East of the country house St. Hyronimus, to the North-East of Salinja of St. Michiel and to the South of Seroe Manuel Kuiper, on Groot-Piscadera and Mahoema, on Rio Canario, Suffisant, Muizenberg and Sint-Jacob, on Corrie, Cas Koraal and Jongbloed, on Fuik, to the South and South-East of the country house Fuik, on Santa Catharina.

Without doubt the short lived transgression to the present 70 m. line has accentuated the differences in the relief. The resistant strata, such as the Knip-series, have been prepared out more as compared to the less resistant strata like the diabase. This is clearly demonstrated between Savonet and Westpunt.

The question arises what effect this transgression had on the above mentioned Pleistocene terraces of reef limestone.

On the West coast of North-Western Curaçao only remnants of terraces of reef limestone dipping towards the sea occur. Moreover, a distinct new terrace may be seen, especially East of Plaja Djerimi on Lagoen. This terrace reaches from about 6 to about 20 m. above sea level. I propose, to call it the new, young or lower terrace.

Along the North coast and the East coast of North-Western Curaçao little remains of the Pleistocene terraces of reef limestone. The new terrace may be clearly seen along the North coast, North of Seroe Cabajé.

On the East coast, East of Boca Grandi, this terrace is well developed.

Remnants of the middle terrace and the higher terrace, consisting of Pleistocene reef limestone also occur here.

Along the North coast of Middle and East Curaçao the new, lower terrace is also very distinct. Here too it reaches from about 6 to about 15 m. above sea level.

At one spot on the plantation Hato the middle terrace has disappeared in consequence of abrasion during the transgression. Here the underlying marl shales are exposed. The valleys of the old consequent water courses in the Pleistocene reef limestone were then widened in their lower parts. Fine wave cut notches occur in these valleys.

The new terrace also occurs on the East coast of East Curaçao and here and there along the South coast of Middle and East Curaçao.

Above I already pointed out that the transgression was the consequence of a rise of sea level of 100 m. and that since the transgression the island rose about 65 m. The elevation of the island was therefore less than the previous rise of the sea level.

The fact that the elevation was less became later of great importance for the economic development of the island. Part of the rim of Pleistocene reef limestone thus remained covered by the sea, and the gorges of the streams, that had been cut down deep enough into this limestone remained filled with sea water. In some cases the streams with their tributaries had eroded away the reef limestone higher up and cut down into the less resistant rocks underneath. Not only the major valley but the lower courses of the tributaries were submerged too. In this manner the inner waters connected with the sea were formed. One of these, the Schottegat with the St. Annabaai, forms the beautiful natural harbour of Curaçao. Fine examples are: St. Jorisbaai, Spaansche water with mouths into the sea between Kabrietenberg en Seroe di Boca, Lagoen, Jan Tiel, Schottegat with St. Annabaai, Piscaderabaai, Salinja of St. Michiel, Salinja St. Marie, St. Janbaai, St. Marthabaai, St. Kruisbaai, Plaja Grandi.

The course of the submerged tributaries may be deduced from the soundings in the inland waters (One should consult map 213, Baaien op de Zuidwestkust van Curaçao, published bij de Afdeeling Hydrographie). Generally speaking the inner waters of great extent have deeply drowned valleys. An inner water of great extent points to a large drainage area of the valley system before the transgression took place. A valley with a large drainage area could cut itself deeper into the reef limestone and the underlying rocks. The consequence was that the valley system lay at a lower level. As the elevation of the island was less than the rising of sea level before a large part of this system remained drowned.

The formation of these inner waters has had an important consequence. The material that was brought down by the streams was no longer carried to the sea but deposited in the inner waters. Around the mouth the water remained clear and coral reefs could establish themselves. Thus a sill could be built up of coral reefs in the mouth of the drowned major valley [1]).

[1]) In the inner waters of great extent coral reefs could here and there grow up. The arid climate of Curaçao renders this possible.

The amount of salt in the ground water proves that the island did actually rise after the transgression. This also follows from the fact that the supergene copper sulfides in the quartz augite diorite have been brought into the zone of oxydation.

DALY has postulated a recent sinking of ocean level of 6 meters or 20 feet (perhaps not more than 16 feet). This sinking may be seen on Curaçao also. This follows from the existence of horizontal coral reefs and shell limestone benches — the Asiento-formation — 5 to 6 m. above sea level on many islands in the inner waters. These benches occur at the same level at some places along the banks of the inner waters.

The lowering of sea level is confirmed by the existance of wave cut notches in the „Boca's''. Instructive examples are shown by the „Boca's'' on the „domein'' between the plantation Savonet and Westpunt.

The inner waters have shrunk in consequence of the lowering of sea level and some have been changed to land. Examples of inner waters converted into land are met with on: Fuik, Blauw, Mount Pleasant, Salinja Abau near Daaibooibaai, Cas Abau, Knip (Plaja Abau), Savonet (Boca Grandi), St. Hyronimus (Bartoolbaai). As a rule the smaller drainage areas contain inner waters converted to land.

The sinking of ocean level has exposed young reefs around the island. The recent reefs that grew up on the drowned divides are now above sea level. For instance the reef between Waaigat and the sea, the reef between Spaansche water and the Caracasbaai, and the reef between Fuikbaai and the sea.

The same has sometimes occurred with the sill reef in the drowned major valley. Small drainage areas have sills above sea level with a narrow V-shaped exit.

The recent sinking of sea level has rejuvenated the erosion. The streams have again entrenched themselves.

The geomorphology of Curaçao is controlled by the climate in conjunction with the tectonic structure of the island and the resistance that the various rocks afforded against weathering, abrasion and erosion.

Where the core of the two old anticlines has been exposed the landscape consists of quartz augite diorite and diabase, or of diabase only. The diabase offered less resistance to abrasion and erosion than the reef limestone and the Knip-series. It now forms a low lying country with typical, rounded hills [1]). Only in places where the diabase has lost the covering of reef limestone a short while ago it forms a higher, hilly country.

There is a difference between the North coast and the South coast. The South coast is characterized by reef limestone dipping towards the South that protects the diabase from denudation in East Curaçao.

The North coast consists of terraces dipping slightly to the North. In East Curaçao they protect the Middle Curaçao series.

Since the most recent elevation of the island above the sea the streams than run South or East in the East parts of Curaçao have gained on the streams that drain off to the North. This is probably a consequence

[1]) K. MARTIN, cf., p. 8.

of the position of the abrasion plane. The streams that now run North on the plantations Ronde Klip, Brievengat, Hato have breaches through the reef limestone at the coast that were cut out by streams with a much larger drainage area.

Middle Curaçao is characterized by the presence of reef limestone that covers the entire breadth of the island at two points (Groote and Kleine Berg). In a structural sense Middle Curaçao is the saddle in the young Pleistocene anticlinal axis. Orographically Groote and Kleine Berg are now the highest points of the surroundings.

In North-West Curaçao the character of the landscape changes where the Knip-strata are still present, as these offer more resistance to abrasion and erosion [1]). This region is characterized by deep, narrow V-shaped valleys and hills with distinct ridges [2]). The summits of these hills are the highest points of the island and the arrangement of the hills roughly indicates the structure of the old folding.

The Tafelberg in St. Hyronimus in North-West Curaçao is covered by horizontal Pleistocene limestone. In a structural sense this is the greatest altitude to which Pleistocene deposits have been folded in North-West Curaçao. Here too the limestone has protected the underlying diabase from denudation. Thus the Tafelberg has become the highest hill in the diabase landscape.

The following remarks can be made concerning the relative positions of the Dutch Benedenwindsche eilanden.

Probably Paleozoic rocks occur on Aruba, La Blanquilla and Los Hermanos. It is possible that the Curaçao deep was formed during the folding of these rocks (during the Permian). Renewed folding took place at the end of the Upper Cretaceous or during the Lower Eocene, and this may have caused a further deepening of the Curaçao deep. During the Pleistocene the islands were raised and the deeps between them formed by a folding „en échelon''.

The axial direction of this folding diverges from that of the older period.

While writing this synopsis of the geology of Curaçao I have often had recourse to MARTIN's volume on the geology of the Dutch Benedenwindsche eilanden, and have referred the reader to the original publication.

During my stay on Curaçao I was now and then able to do geological explorations. I acquired a great admiration for the geological fieldwork of MARTIN on Curaçao. He was only able to spend eighteen days on the island and a topographical map and means of transport were almost entirely absent in the years 1884—1885.

Thirty seven years elapsed between our investigations. In those thirty seven years geology has advanced by leaps and bounds. In 1884 structural geology was still in its infancy. DALY's „theory of the glacial control

[1]) The same is the case for that part of East Curaçao where the Knip strata appear, as for instance South-East of the country house Steenen Koraal.

[2]) K. MARTIN, cf., p. 38.

of coral reefs'' dates from 1910 and he postulated a „recent worldwide sinking of ocean level'' in 1920.

MARTIN's volume still remains an indispensable guide to every geologist who visits the Dutch Benedenwindsche eilanden.

The committee has proposed to celebrate MARTIN's eightieth birthday by offering him a symposium which will show his great influence on the evolution of our geological knowledge of the Dutch East and West Indies. I hope this contribution shows that MARTIN may be called the founder of our geological knowledge of the island Curaçao.

The Hague, December 1929.