BAUXITE DEPOSITS IN SURINAME AND DEMERARA (BRITISH GUIANA)

BY

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CHAPTER IV

PREFACE

The basis for this thesis is my fieldinvestigation in Suriname for the Welvaartsfonds, Paramaribo, in the years 1951 and 1953.

I should like to express my gratitude for the co-oporation shown me by the Geological and Mining Survey of Paramaribo, and in particular to the chief of the Survey Ir. H. SCHOLS to whom I extend my utmost thanks for his consistent aid during the investigation.

My gratitude to the Surinaamsche Bauxite Maatschappij, the N.V. Billiton Maatschappij and the Demerara Bauxite Company not only for their assistance during the investigation but also for permission to publish data obtained within their area of jurisdiction.

My exceptional thanks to Dr. D. R. DE VLETTER, presently chief geologist for the Nickel Processing Corporation, whos kindly assistance, before his departure to Cuba, was of great aid to me.

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CHAPTER I

INTRODUCTION

A. HISTORY

The occurrence of bauxite in Suriname is known since 1903, in which year DUBOIS published data on the bauxite from Ric a Rac.

Several years passed before plans were made for the exploitation of the bauxite.

The first company that worked the bauxite was the American Norton Co. The ore was mined during a few years, only for chemical uses.

December 19th, 1916, the Surinaamsche Bauxite Maatschappij was chartered as a subcompany of the Alcoa [1]). For several reasons, such as difficulties with concessions, the lack of jurisdiction about bauxite and scarcity of laborers, it was not until 1927 that the necessary ore-dressing plants were placed in operation at Moengo. In 1941 a second plant was finished at Paranam.

The second company which mines bauxite in Suriname is the N.V. Billiton Maatschappij. The mines are at Onverdacht. The exploration for bauxite began in 1939, the first shipments were made in 1942.

From 1929 up to and including 1954 the total export of bauxite (BOTZEN, 1954) amounted to the following:

	× 1000 ton (metr.)		× 1000 ton (metr.)
1929	183.9	1942	1227.5
1930	263.0	1943	1662.7
1931	190.6	1944	664.1
1932	126.5	1945	689.9
1933	106.4	1946	852.6
1934	101.0	1947	1797.8
1935	115.2	1948	2165.5
1936	233.9	1949	2126.7
1937	392.3	1950	2083.6
1938	377.6	1951	2674.6
1939	504.1	1952	3154.7
1940	615.4	1953*	3277.0
1941	1093.8	1954*	3421.2

* Commissariaat voor Surinaamse Zaken, 's-Gravenhage, The Netherlands.

B. GEOLOGY

A certain number of publications on the geology of Suriname has been published, along with a large number of reports on expeditions.

[1]) Aluminum Company of America.

Publications on the occurrence of bauxite are scarce, but of the more recent ones those of TER MEULEN (1949) and BAKKER, KIEL and MÜLLER (1953) should be mentioned.

IJZERMAN published in 1931 his "Outline of Geology and Petrology of Surinam (Dutch Guiana)" in which the papers on the geology of Suriname published up to 1931 are reviewed, and in which IJZERMAN gave many data from his own observations. With the publication of this work the geologists of Suriname obtained a great number of data which form a valuable basis for the investigation of the geology of Suriname.

In 1943 the Geological and Mining Survey was founded and systematic surveying began.

The regional geologic map (fig. 1) was compiled on the basis of the Geological Map in the three Guianas (1952), with additions from the data of SCHOLS and COHEN (1953) and the Annual Report of the Geological Survey at Paramaribo (1953).

The following young formations are distinguished (when not indicated to the contrary, the data are from SCHOLS and COHEN, 1953).

Demerara formation, to which belong the young marine and estuary sediments, mainly consisting of heavy, incompetent, strongly hydrated clays with intercalated sand lenses and beds and fan-shaped ridges of sand and shells. Also the recent river and streamlet alluvia belong to this formation.

Coropina formation. This formation consists of marine sands and heavy clays. The outcrops of this formation lie at a somewhat higher level than the Demerara formation from which it is separated by a distinct regression. The sandy facies lies generally to the north of the clay facies, repeating of this succession occurs locally.

ZONNEVELD (1951) investigated a number of samples of these clays and concluded that they were deposited in a milieu wherein the flow of current varied and was periodically zero. ZONNEVELD thought he was dealing with tidal-flats and kwelders (marshes).

Zanderij formation. This formation consists of coarse mostly white sands containing locally small quartzpebbles as well as intercalated layers of clay, which can attain an appreciable thickness. Locally there also occur lignite-layers.

ZONNEVELD (1951) investigated samples of these sands and believed that the material might have been deposited by a large number of creeks and streams. The occurrence of pebbles, foraminifera and shell fragments cast doubt on a continental character, SCHOLS and COHEN suppose a marine, perhaps a littoral character. Both the foraminifera as well as the shell fragments showed signs of transport, BAKKER (1953) assumed that instead of a marine deposit it was a coastal deposit.

Nickerie formation is partially diagenetically hardened and is only encountered in a few drillings.

As older deposits one sees:

Roraima formation is formed by sandstone and conglomerates. A well-known location for this is the Tafelberg, where these rocks occur in practically horizontally disposed beds. The Roraima formation is transected by a number of dolerite dikes.

Neither in Suriname nor Demerara where the Roraima formation is much more extensive, has it been possible to estimate the age. The Roraima

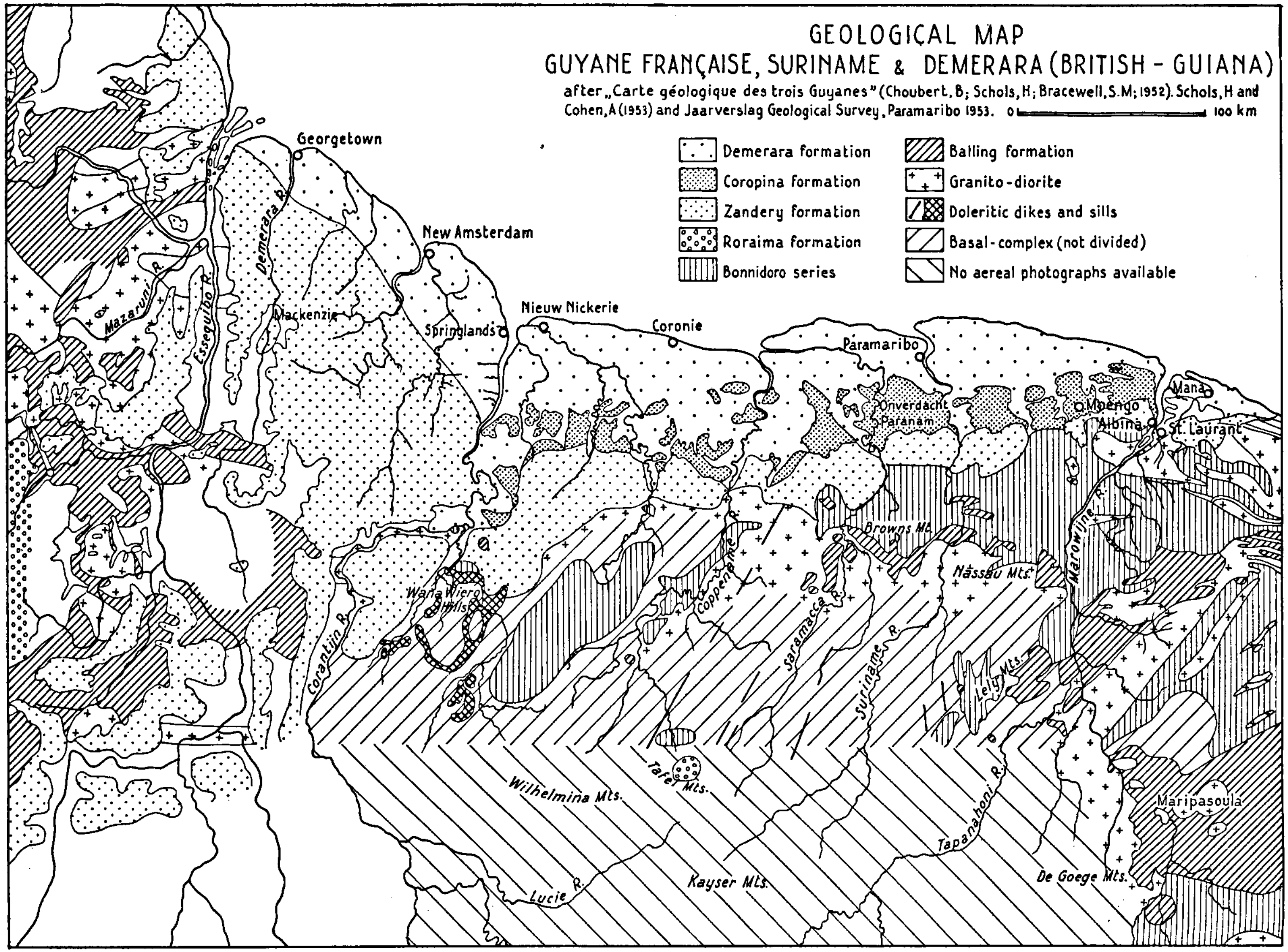

Fig. 1. Geological Map of Guyane française, Suriname and Demerara (British Guiana).

formation in Venezuela displays a great resemblance to deposits from the Lower Cretaceous and Upper Trias (LIDDLE, 1946).

The Basement, constitutes part of Guiana Shield which occurs in Guyane française, Suriname and British Guiana and Brasil.

Two formations in this basement are distinguished in Suriname i. e. the Orapu and the Balling Formation.

Of these deposits the Orapu formation and the Bonnidoro serie consist of metamorphic sediments. The Paramakka serie and the Nassau serie are formed by volcanic rocks.

Granite intrusion or granitization has occurred twice.

The following table lists the various formations and their probable age.

Recent —— -Tertiary	Demerara formation	
	Coropina formation	
	Zanderij formation	
	(Nickerie formation)	
Mesozoic?	Younger intrusive phase (Dolerite)	
	Roraima formation	
Pre-Cambrian	Granite 2	
	Orapu formation	Rosebel serie
	Granite 1	
	Balling formation	Bonnidoro serie
		Paramakka serie
		Nassau serie

C. NOMENCLATURE

The term laterite was first employed by BUCHANAN in 1807 for ferruginous earthy rock, which he found during his stay in India. Characteristic for this soft, red and yellow coloured material, full of cavities and pores, is the rapid hardening when exposed to air.

Since that time the name laterite has been used for a variety of meanings which has led to confusion.

In maintaining the use of the name laterite as a description of material that has arisen by lateritic weathering whereby leaching of alkalies and desilification are characteristic (HARRASSOWITZ, 1926), we are not evading BUCHANAN's original definition, even though it contains material resulted of lateritic weathering described by other authors. It is not proper to regard this material as a purely tropical occurrence since lateritic weathering products are also found outside the tropics.

An intensive lateritic weathering will produce material with a high iron and aluminium content, likewise such a manner of concentration of manganese is also known.

The name ferrite was introduced at the Geological Conference British Guiana — Suriname — Guyane française, Paramaribo 1950, to indicate the iron rich endproduct of lateritic weathering. In 1872 VOGELSANG [2]) remarked in relation to the name ferrite: "A general non-committal descriptive term for reddish-brown amorphous alteration products which are presumably

[2]) HOLMES, A. (1920).

ferruginous, but which can not be definitely diagnosed by ordinary optical methods" from which it appears that no objection can be raised to the decision of the Conference.

In addition to this iron rich, there also occurs an aluminium rich endproduct. HARRASSOWITZ (1926) employed the term allite for rock consisting mostly of Al-hydroxides. He divided this allites into laterite and bauxite, the laterite consisting mostly of gibbsite (Al_2O_3 $3\,H_2O$), the bauxite of boehmite and diaspore (Al_2O_3 H_2O).

Two sorts of allites are known, one kind is found in connection with silicate rocks, whereas, the other kind is found in connection with limestone. These two kinds are distinguished from each other by the mineralogical composition. The allite occurring together with silicate rocks generally consists for the most part of gibbsite, the allite found in connection with limestone for the most part of boehmite and/or diaspore.

HARRASSOWITZ formulated his terms on a mineralogical basis. Laterite and bauxite as defined by HARRASSOWITZ occur in both sorts of deposits and in various proportions. In addition, the term laterite defined by HARRASSOWITZ differs considerably from the material originally defined by BUCHANAN.

NIGGLI (1952) called allites which occur in connection with silicate rocks, laterites, and allites occurring together with limestone, bauxites. This distinction is preferable to that of HARRASSOWITZ in that the mineralogical composition now plays a less dominant rôle. However, the restriction of laterite to the allites does constitute an objection.

DE WEISSE (1948) divided the allites into a "bauxite latéritique" and a "bauxite de terra rossa", which terms were concerned respectively with allites occurring together with silicate rocks and those occurring together with limestone. These terms have no mineralogical significance, the suffixes "latéritique" and "de terra rossa" seem to suggest a difference in origin. Desilification (so characteristic for lateritic weathering) plays an important rôle in the formation of both "bauxite latéritique" and "bauxite de terra rossa".

DITTLER and KUHN (1933) used the term limestone-bauxite for allite occurring together with limestones. From this, one could postulate the diametric term silicate-bauxite.

These two terms are neither mineralogically nor strictly genetically consistent, but only the mutual connection of the allite with silicate rocks and limestone is indicated.

The name bauxite to describe rocks consisting for the most part of aluminium-hydroxides is however already so well established that it seems doubtful that a new nomenclature will attain currency.

In the following the terms ferritization and bauxitization will be employed as forms of lateritic weathering, resulting in respectively an iron rich- and an aluminium rich weathering product.

According to the Geological Conference, Paramaribo 1950, ferrite is material containing more than 45 % Fe_2O_3 and less than 15 % Al_2O_3, bauxite should have an Al_2O_3 content of more than 45 % and less than 15 % Fe_2O_3. Interpolated terms are bauxo-ferrite and ferro-bauxite.

CHAPTER II

FIELD DATA ON BAUXITE DEPOSITS IN SURINAME AND DEMERARA (BRITISH GUIANA)

A. CLASSIFICATION

IJZERMAN (1931) who first classified the bauxites on a morphological basis distinguished two types.

Plateau type. In this type IJZERMAN included the bauxite of the Brownsberg; he supposed that he could also class the bauxite of the Nassaugebergte with this type. The deposits of the Nassaugebergte as well as those of the Poeloegoedoe-, Manlobbi-, Lelygebergte and the bauxite found on the Wana Wiero Hills evidently can be included in IJZERMAN's Plateau type. These mountains are Plateau mountains varying in elevation from 300 to 700 metres.

Lowland type. IJZERMAN included the bauxite deposits at Moengo and vicinity, Rorac, Acaribo, Marechals Creek, Ongelijk, Portorico and the territory around Para Creek in this type. He noted that all these are hills with a height of from 30 to 40 metres, covered with bauxite.

IJZERMAN clearly describes the characteristics of the Plateau type. In the areas mentioned by IJZERMAN in connection with the appearance of the Lowland type, large bauxite deposits were found below the surface, which do not satisfy IJZERMAN's definition about the Lowland type.

During the fieldwork in Suriname as well as in Demerara the desirability of giving names to the various types of occurrence of bauxite became evident; names which not only have a morphological significance but which also are tied to a certain age, or with other words, the time when the genesis of the bauxite began.

In connection with this and to prevent confusion, the Lowland type by IJZERMAN is replaced by three types of deposits.

The following classification is proposed:

P l a t e a u t y p e b a u x i t e occurring as weatheringcover on plateaus of Plateau mountains with a height of from 300 to 700 metres. The age is not determined yet, but there are indications that it may be Pre-Zandery.

To this type of bauxite deposits belong the Nassaugebergte, Lelygebergte and Wana Wiero Hills, all of which will be discussed later on (see page 256).

H i g h - l e v e l b a u x i t e, the material is found as a cover on hills with a height of from 30 to 60 metres. The age is Post-Zandery and Pre-Coropina.

Examples of this type are Moengo and vicinity and Paranam and will be described later (see page 267).

M e d i u m - l e v e l b a u x i t e, found as a bed of variable thickness and is overlain by sediments of the Coropina formation. The age is also Post-Zandery and Pre-Coropina.

A number of sections measured at Onverdacht will be discussed on page 286.

Low-level bauxite. In this case the soil cover consists of material of the Zandery-formation, on top of which sediments of the Coropina-formation may be found. The age is Pre-Zandery.

Some sections measured at Mackenzie (Demerara) are discussed on page 299 as an example of this type.

Up to now Low-level bauxite has not been found in Suriname, but there are indications that this type may be found here too (see page ??).

The following would be a more lithological classification of the bauxite deposits in Suriname and Demerara. Three groups may be distinguished. The bauxite is found:

1. as a weathering residue of bedrock,
2. as a weathering residue of sedimentary clay,
3. as sedimentary or colluvial deposits.

The sedimentary and colluvial deposits only form a small part of the bauxite known at this time. Practically all important deposits belong to type 1 or 2, except the greatest part of the deposits found on the Nassau- and Lelygebergte, which belong to type 3.

It is impossible to make a sharp distinction between type 1 and 2, because bauxite formed from bedrock can continue into bauxite formed from sedimentary material. There are also deposits in which the lower part of the bauxite bed belongs to type 1 and the upper part to type 2. Part of the Plateau type bauxite belongs to type 1, and also a very minor part of the High-level bauxite and the lower part of the Low-level bauxite.

To type 2 belongs the greatest part of the bauxite of the High-level type and practically all bauxite of the Medium-level type.

Parts of all bauxite deposits form part of type 3. Sedimentary bauxite was found in all deposits; in the Nassaugebergte it was evidently a considerable portion. Colluvial bauxite was found in large quantities in the Lelygebergte.

It is apparent from the lithological classification of the bauxite deposits that the morphological classification is more appropriate.

B. PLATEAU TYPE BAUXITE

1. The bauxite deposits on the Nassaugebergte (fig. 1 and 2)

These mountains are situated in eastern Suriname about 130 kilometres from the coast on the Marowyne river. There are four plateaus which form part of the mountains; the longitudinal axes of two of the plateaus lie in an east—west direction, that of the third in a north—south direction, whereas the fourth is slightly oval. The plateaus have an elevation of about 500 metres on the eastern side and about 600 metres on the western side.

The mountains consist of basic rock (slightly to strongly epimetamorphic chloritized saussuritized basalt, which is rich in hornblende). The borders of the plateaus are locally formed by faults, the largest of which forms the western border of plateau C.

The plateaus are covered with a bauxite-ferrite material, which can reach a considerable thickness, and this is also the case at the eastern edge of plateau A and in the south—eastern part of plateau B. The bauxite-ferrite cover ends abruptly at the eastern edge of plateau A. In several places cliffs of bauxite-ferrite material with a height of from 10 to 12 metres are found.

In places where it is well-developed, the bauxite-ferrite cover shows a weathering which resembles the karst type. Here and there caves are found,

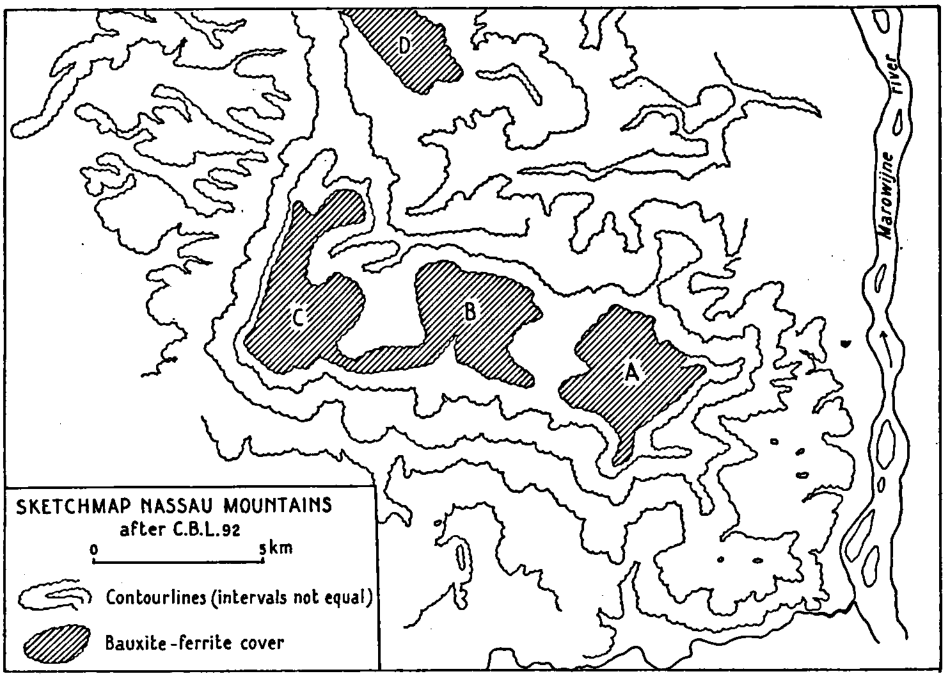

Fig. 2. Topographical sketch map of the Nassaugebergte.
(C. B. L.; Central Bureau Aerial Survey, Paramaribo.)

the roofs of which sometimes have collapsed (fig. 3); in other places the surface topography is very rough through numberless small cavings, which make it difficult and sometimes impossible to traverse.

In places where the ferrite cover attains a large thickness, the vegetation is very poorly developed (fig. 4).

The bauxite occurs disseminated on several plateaus; it is mostly found in lower parts of the terrain in contrast to the ferrite, which is found in the higher parts. In places where bauxite-ferrite is missing, light-yellow to dark brown-red clay comes to the surface.

During the rainy season, in the lower parts of the terrain where bauxite is found, on many places develop swamps (fig. 5). But bauxite deposits are also found in the higher parts of the field. When Ir. DOEVE [3]) investigated these deposits, it became apparent that these higher bauxite fields constitute old swamps, subsequently drained by several little creeks.

[3]) Ir. G. DOEVE, Personal Communication.

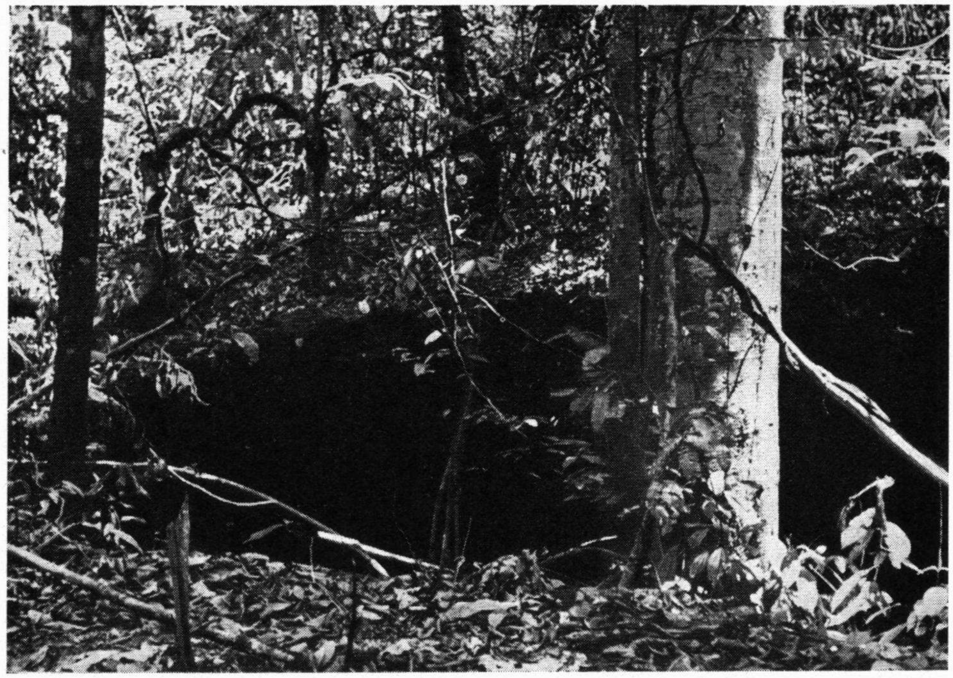

Fig. 3. Cave in the ferrite cover of the Nassaugebergte of which the roof has collapsed. The tree with which the roof has descended, has a diameter of about 80 centimetres.

Fig. 4. Very poorly developed vegetation on the ferritecap of the Nassaugebergte SE-part Plateau B.

The fact that a part of the bauxite was primary formed in situ could be established without reasonable doubt. Some quartz veins traverse from the bedrock into weathered bedrock and can be followed traversing the residuary clay, the transition zone and the bauxite-ferrite.

In the steep walls of the eastern border of Plateau A frequently weathered-out quartz veins are found.

Sedimentary bauxite is very common. The material consists of bauxite

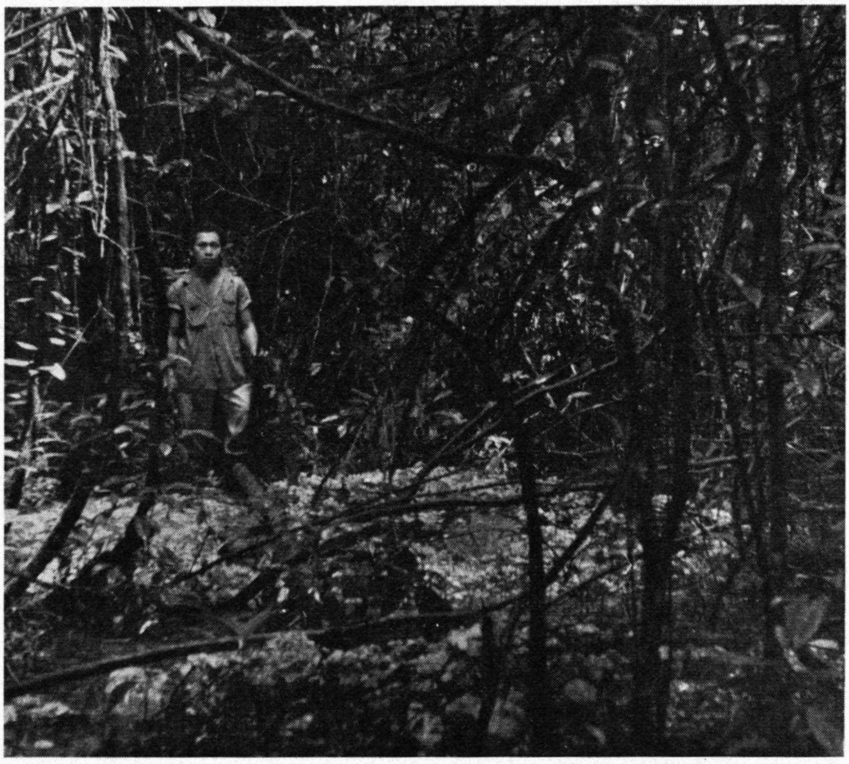

Fig. 5. **Prospection pit in white bauxite in a swamp on plateau C of the Nassaugebergte.**

gravel cemented by bauxite. Sometimes small fragments of quartz are found with a diameter of up to about two centimetres.

As the bauxite is found almost exclusively in the lower parts of the terrain, a bauxite layer which can be followed over a great distance is rarely encountered.

The weathering section (fig. 6) of the Nassaugebergte was constructed on the basis of drillingoperations, prospecting pits and surface evidence. In this section the sedimentary bauxite-ferrite is left out; bauxite- and ferrite-breccia will only be mentioned as structure types.

The lithological section from the top downward looks as follows: *soil cover, bauxite-ferrite, transition zone, residuary clay, weathering zone of bedrock (in the following mentioned as weathered bedrock) and solid rock.*

Mostly the *soil cover* is very thin, the maximum thickness being 50 centimetres. It consists of Fe-beans and small stones, black humus-rich earth and locally some clay.

The *bauxite-ferrite* here and there reaches a thickness of from 10 to 15 metres, but is missing in other places.

In general ferrite is found as the upper part of the bauxite-ferrite mantle. A number of sections of the bauxite-ferrite cover was constructed on the basis of well logs. Some of which were supplied by the Geological and Mining Survey of Paramaribo (fig. 7).

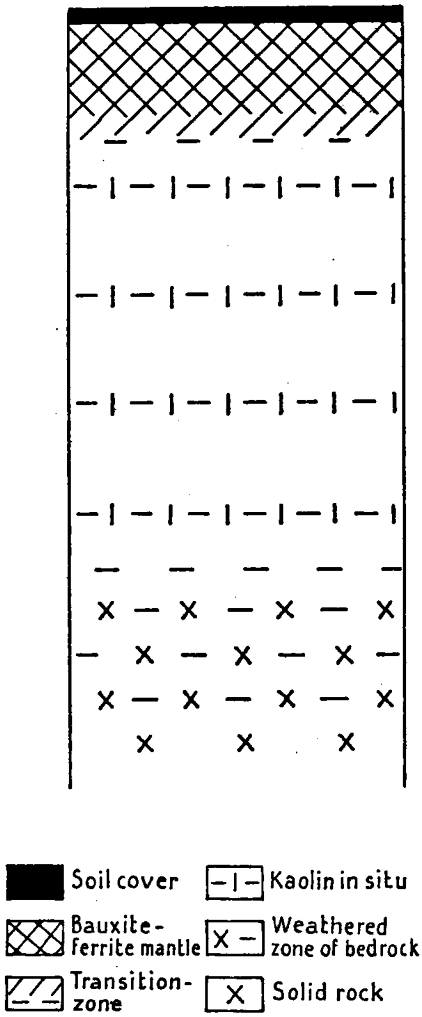

Fig. 6. Schematic weathering section of the Nassaugebergte.

The variety of bauxite and ferrite in these sections is closely connected with the type of occurrence. In the swamps practically white bauxite is found; on the borders of the swamps the bauxite changes via ferro-bauxite and bauxo-ferrite in ferrite. The morphology of the terrain is subject to continual changes; sometimes rivers cut into swamps and these are drained; in the course of time other parts of the terrain develop in such a way, that water begins to accumulate, and a new swamp is formed. In the swamps, in addition to the white bauxite, some pieces of bauxite with a pure white shell of a few centimetres thick are found, while the central part still consists of ferro-bauxite. The reverse is also found in dry run swamps, where shells of ferrite enclose a centre of white bauxite.

A number of such subsequent changes in the morphology of the terrain will produce sections as in fig. 7, as Fe-concentration and -leaching follow these changes.

Generally the following types of ferrite can be distinguished:

a. Dense, homogeneous ferrite. The material is finely granular, the colour varies between red and dark red-brown. Scattered between the ferrite are found hematite-grains, and this material is also often found on the walls of little cracks.

b. Porous ferrite, with a spongy exterior. The walls of the pores in most cases are covered with hematite. In some places in the ferrite little cavities are found, filled with very coarse, crystalline gibbsite.

c. Laminated ferrite is found only in small quantities. The layers run almost horizontal. This type of ferrite consists mostly of alternating beds of ferrite and red to red-brown clay.

d. Pisolitic ferrite. Three classes can be distinguished: 1. the pisolites consist of ferrite and are cemented by bauxite; 2. the pisolites consist of bauxite and are cemented by ferrite; 3. pisolites as well as the cement consist of ferrite. Often the exterior shells of the pisolites

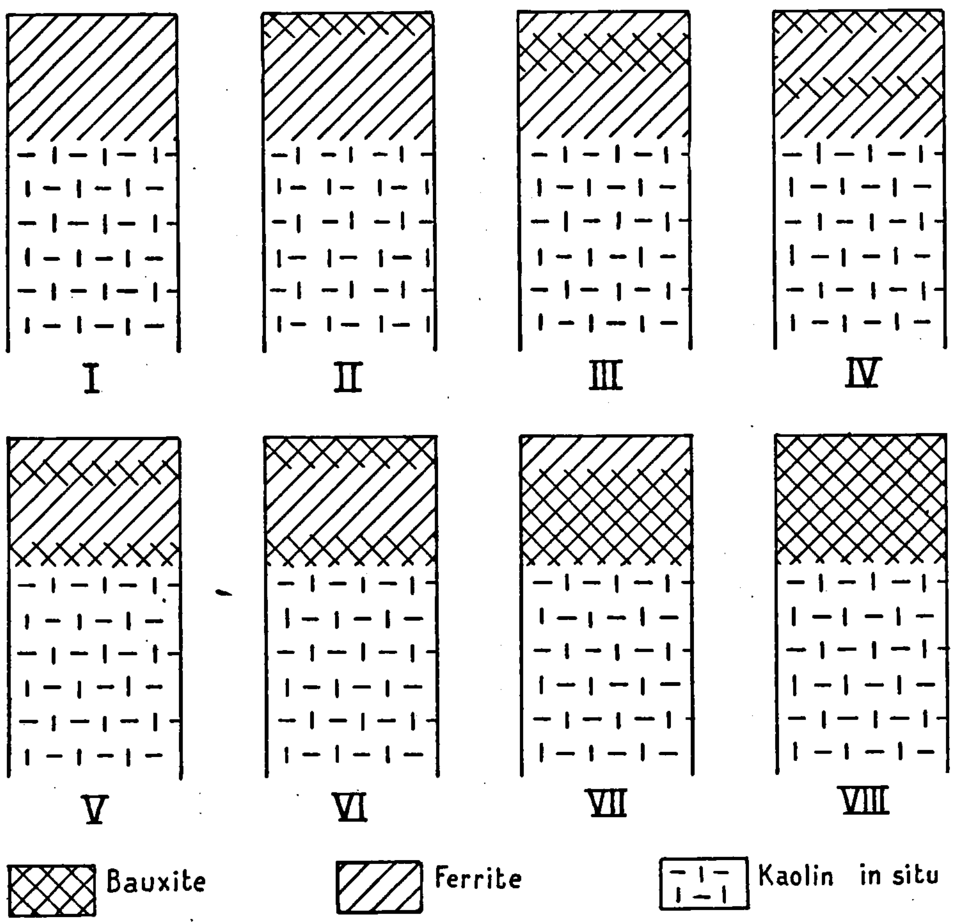

Fig. 7. Schematic bauxite-ferrite sections of the bauxite-ferrite cover on the Nassaugebergte, the variation of bauxite and ferrite is caused by the changes in the morphology of the terrain, which changes are followed by Fe-concentration and -leaching.

consist of ferrite, while the centres are built up of hematite. The pisolites have a diameter of from two to ten millimetres.

e. Ferrite breccia. This material is very dense, the size of the components varies from a few millimetres to various centimetres. The cement may consist of ferrite as well as of bauxite.

The pisolitic ferrite and the ferrite-breccia are always found at the surface. Dense, homogeneous ferrite sometimes alternates with the porous type.

These types are found when the ferrite horizontally as well as vertically continues over large distances.

In general the following lithological types of bauxite are found:

a. Dense, homogeneous bauxite. The material is of a white to light-yellow to grey colour and extremely fine-grained. Little cracks are mostly filled up with macro-crystalline gibbsite, although white clay is sometimes found also.

b. Porous bauxite, with a spongy appearance. The walls of the pores with a diameter of up to three millimetres are generally covered with a thin film of gibbsite. Some pores and cavities are filled with macro-crystalline gibbsite or white clay.

c. Laminated bauxite. The laminations consist of alternations of micro-

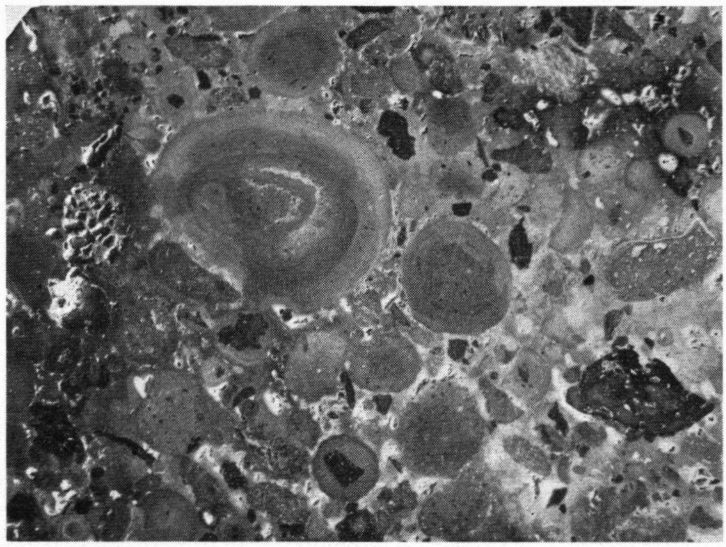

Fig. 8. Bauxite-breccia. Several pisolites show little angular centre-peaces, Nassaugebergte. × 3.

to macro-crystalline gibbsite and white clay. Locally a lamination is found caused by alternating layers of iron-rich and iron-poor material.

d. Pisolitic bauxite. This is of a white to light-yellow colour, often the centres of the pisolites are not indurated but soft argillaceous. They have a diameter of from two millimetres to ten millimetres. Occasionally two or three oölites appear as centres, and once in a while an angular fragment of bauxite forms the centre. The cement consists of bauxite.

e. Bauxite-clay. The material is white to yellow coloured and can be distinguished from the other clays by its quick disintegration in water.

f. Bauxite-breccia. The components are up to three centimetres in diameter; the cement also consists of bauxite (fig. 8).

The various types of bauxite are generally seen at the following places.

Pisolitic bauxite is found mainly at the surface of the bauxite fields. On an average, the dense, homogeneous bauxite is also found rather close to the surface and it can reach a thickness of about 1.5 metres. The beds generally pinch out rather quickly.

Porous bauxite generally occurs in the transition zone between clay and bauxite-ferrite, in which zone bauxite-clay is also frequently found. The laminated bauxite is found in layers, varying from a few centimetres to 1 metre thick, throughout the bauxite layer.

The *transition zone* between bauxite-ferrite and weathering clay varies from a few centimetres to 1 metre in thickness. In the yellow to yellow-white clay little nuclei of bauxite, about 1 millimetre in size begin to appear. Towards the top of the transition zone the nuclei begin to form horizons separated by layers of clay, partly consisting of bauxite-clay. A certain number of these nuclei grow to concretions, which are mostly irregular in shape.

Washed samples of the clay contain small, angular grains of quartz, which are still found in the lower part of the transition zone, but which practically have disappeared in the upper part of the transition zone. In the upper part of the transition zone practically all the material consists of bauxite and bauxite clay.

Some quartz veins continue from the weathering clay into the bauxite; they show symptoms of dissolving but they have not completely disappeared.

The *residuary clay* directly underlying the transition zone can reach considerable thickness. A thickness of 30 metres and more is quite common. (At the laboratory investigation the main constituent of this weathering clay turned out to be kaolinite.)

Weathered bedrock. The changing of the residuary clay into this material is gradual, generally this change takes place in a zone, which varies in thickness between 50 centimetres and about 3 metres. The colour of the rock in this zone still is preserved as well as the texture and structure. The material consists of a grey to greenish grey consistent clay, joints usually are still preserved.

The *solid rock* is very dense, fine-grained granular and has a green colour. It consists of a light to strongly epimetamorphic chloritized and saussuritized basalt. In the southern border of plateau B the quartz veins contain kyanite.

The weathering starts from the joints and tends to form spheroids.

The bauxite-ferrite cover of the Nassaugebergte partly consists of a material, which is definitely the weathering product of the bedrock. In addition to this autochthonous bauxite-ferrite there has been found a sedimentary bauxite-ferrite. The investigations showed that the sedimentary bauxite-ferrite is of more importance than autochthonous bauxite-ferrite. The sedimentary bauxite, however, consists entirely of material coming from an autochthonous weathering product of the basic rocks. The quartz components, occurring in this sedimentary bauxite are generally about as angular as the bauxite-ferrite components, so that the transport has taken place over a very short distance only.

In comparison with the bauxite-ferrite deposits which occur elsewhere in Suriname, in the shape of bauxite-ferrite covers, the covers on the plateaus of the Nassaugebergte are not thick. The cause of this probably lies in the following.

As later on will be evident (Chapter IV) the assumption may be justified, that the bauxite-ferrite of the Nassaugebergte belongs to the oldest bauxite-ferrite in Suriname. In this way the erosion has already asserted its influence for a long time, so that a large part of the bauxite-ferrite has disappeared.

That some bauxite-ferrite is left, is mainly caused by the deposition of sedimentary bauxite, which material was rapidly cemented by bauxite. Closely connected with this cementing by bauxite is the bauxitization, which

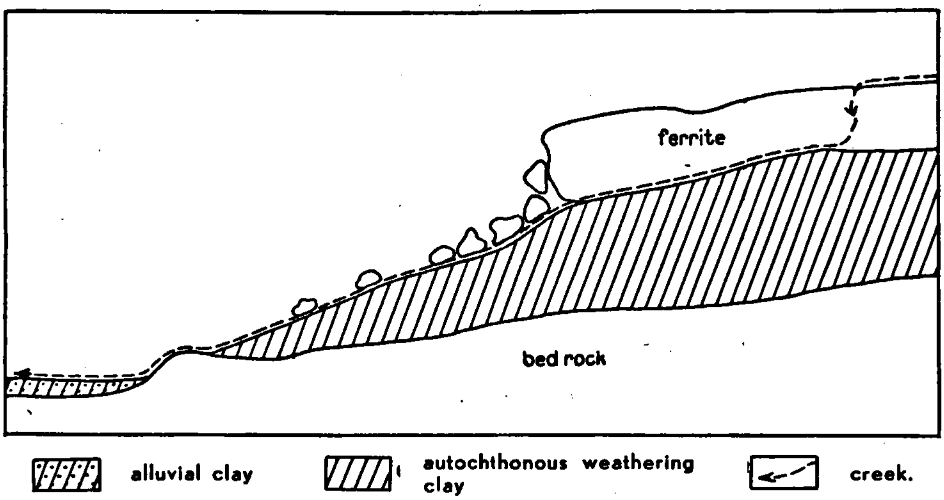

Fig. 9. Schematic section, showing the formation of steep walls at the rim of plateaus with a bauxite-ferritecap (After BLEYS, 1953).

process caused the cementing by bauxite and at the same time continually produces new bauxite. As the erosion works more rapidly than the bauxitization, the bauxite-ferrite cover will disappear eventually. Ferrite is found in much larger quantities than bauxite.

In the first place ferrite is considerably more resistant than bauxite. Pebbles of ferrite are often found, but pebbles of bauxite are much less common and then always in the close vicinity of the bauxite deposits. In the second place most of the ferrite deposits are found at the borders of the plateaus; the ferritization works very rapidly here, probably because of the greater depth of the water table. Moreover, the erosion works differently. In the centre of the plateaus the erosion only works at the surface; at the borders of the plateaus the water penetrates below the ferrite cover and carries away the underlying clay. Thus the ferrite is undermined and it caves in at the rim, where very steep inclinations come into existence in this way, as in the eastern part of plateau A. BLEYS (1953) already described this form of erosion of the bauxite-ferrite cover in the Brownsberg (fig. 9).

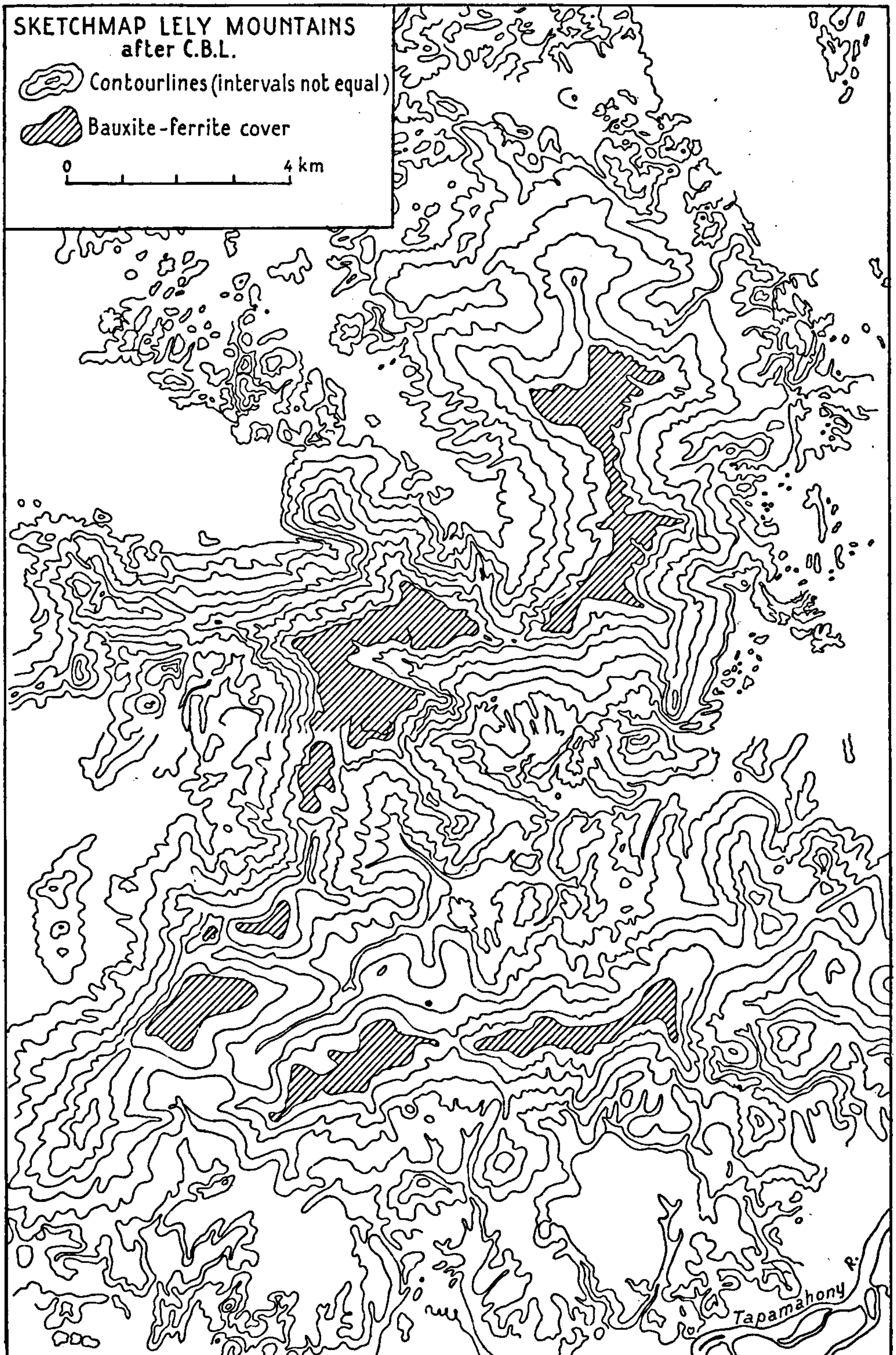

Fig. 10. Topographical sketch map of the Lelygebergte.

2. The bauxite deposits on the Lelygebergte (fig. 1, 10 and 11)

The Lelygebergte is situated in eastern Suriname, about 190 kilometres from the Atlantic coast, in the north—west corner between the Tapamahony and the Marowyne river. The plateaus which have an elevation of about 600 to 700 metres, are ranged in the shape of a horse-shoe around the Djoeka Creek, a contributary of the Marowyne river. The lowest point of the plateaus lies in the east; the elevation increases towards the west to about 700 metres.

The Lelygebergte as well as the Nassaugebergte consists of basic rock, which is again much weathered.

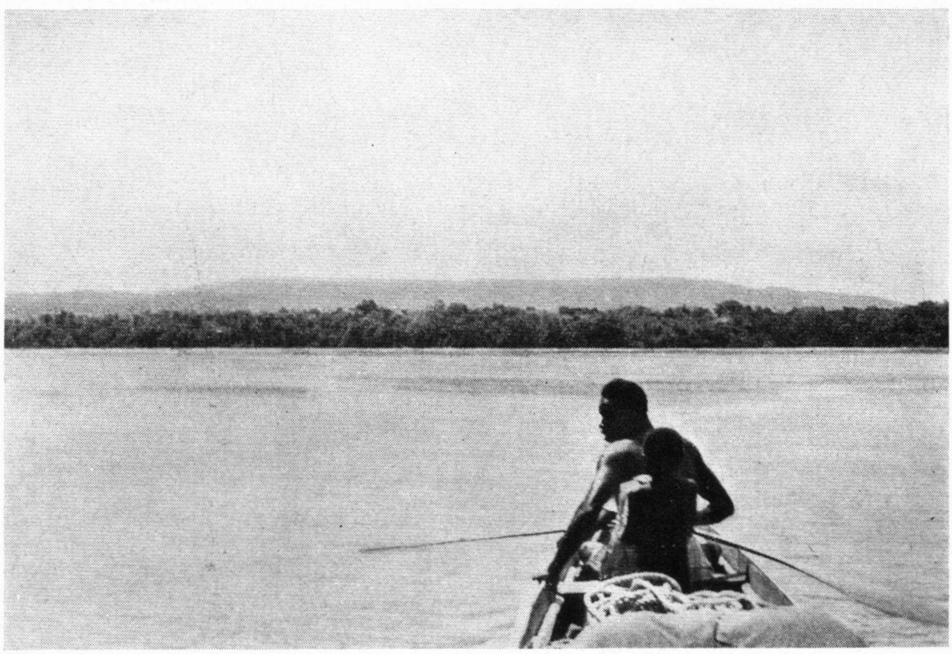

Fig. 11. View of the south-eastern plateau of the Lelygebergte, looking north-west.

The plateaus are covered with a weathering cap of variable thickness, consisting of bauxite-ferrite, partly as autochthonous weathering product of the basic solid rock, and partly as sedimentary bauxite-ferrite.

The lithological section from the top downward has the same features as that of the Nassaugebergte, namely *soil cover, bauxite-ferrite, transition zone, residuary clay, weathered bedrock* and *solid rock.*

The bauxite and the ferrite show the same texture and structure and mutual transitions as described for the Nassaugebergte.

The outside rims of the plateaus are very steep and subject to the same form of erosion as the eastern border of plateau A and the south—eastern border of plateau B of the Nassaugebergte. The inward slopes of the plateaus however, are much less steep and over large distances covered with colluvial bauxite, which may reach a thickness of more than 8 metres.

In the bauxite deposits that were visited, colluvial bauxite was found only in considerable quantities in the Lelygebergte (fig. 12).

3. The bauxite deposits on the Wana Wiero Hills (fig. 1)

The Wana Wiero Hills are situated in western Suriname, about 150 kilometres from the coast on both sides of the Kabelebo river near the Wana Wiero Falls.

The hills reach an elevation of about 300 metres; they are covered with a bauxite-ferrite cap of a thickness of from 0 to 1.5 metres. Here too the bauxite-ferrite is partly sedimentary. The weathering does not differ from the previous ones. The solid rock is a gabbro, weathering to bauxite-ferrite.

As far as is known all hills and mountains in Suriname, that consist of basic rock and its weathering products, are covered with a bauxite-ferrite mantle.

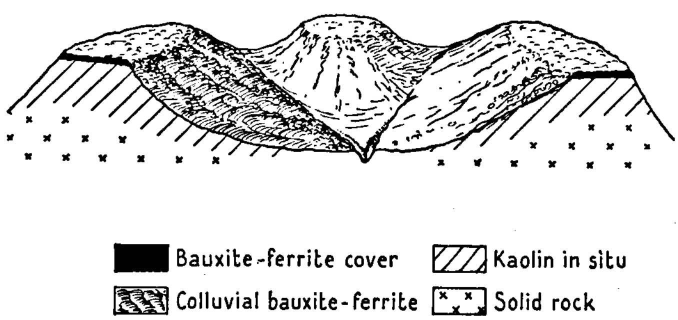

Fig. 12. Schematic section showing collovial bauxite-ferrite on the inner slopes of the Lelygebergte.

C. HIGH-LEVEL TYPE BAUXITE

1. The bauxite deposits at Moengo and vicinity

The area includes (fig. 1, 13) part of the terrain between the Cottica river and the Marowyne river; it stretches in a strip of 25 kilometres breadth over a distance of 30 kilometres, parallel with the coast.

The terrain which rises to the east as well as to the south lies at an elevation varying between 2 and 10 metres above Moengo Water Mark (the average water level of the Cottica river during 18 years). Above this level lie the summits of some hills, which reach elevations of from 30 to 60 metres, these hills can be divided into two groups:

Hills which are flat-topped and covered with bauxite-ferrite mantles, the slopes are very steep.

Hills which are round-topped and have no bauxite-ferrite cover, the slopes are much less steep.

About 30 hills in this area belong to the first type; examples are the Moengo- and the Ricanau Hill. To the second type belong the Gemerts Hill and the Sandy Hill.

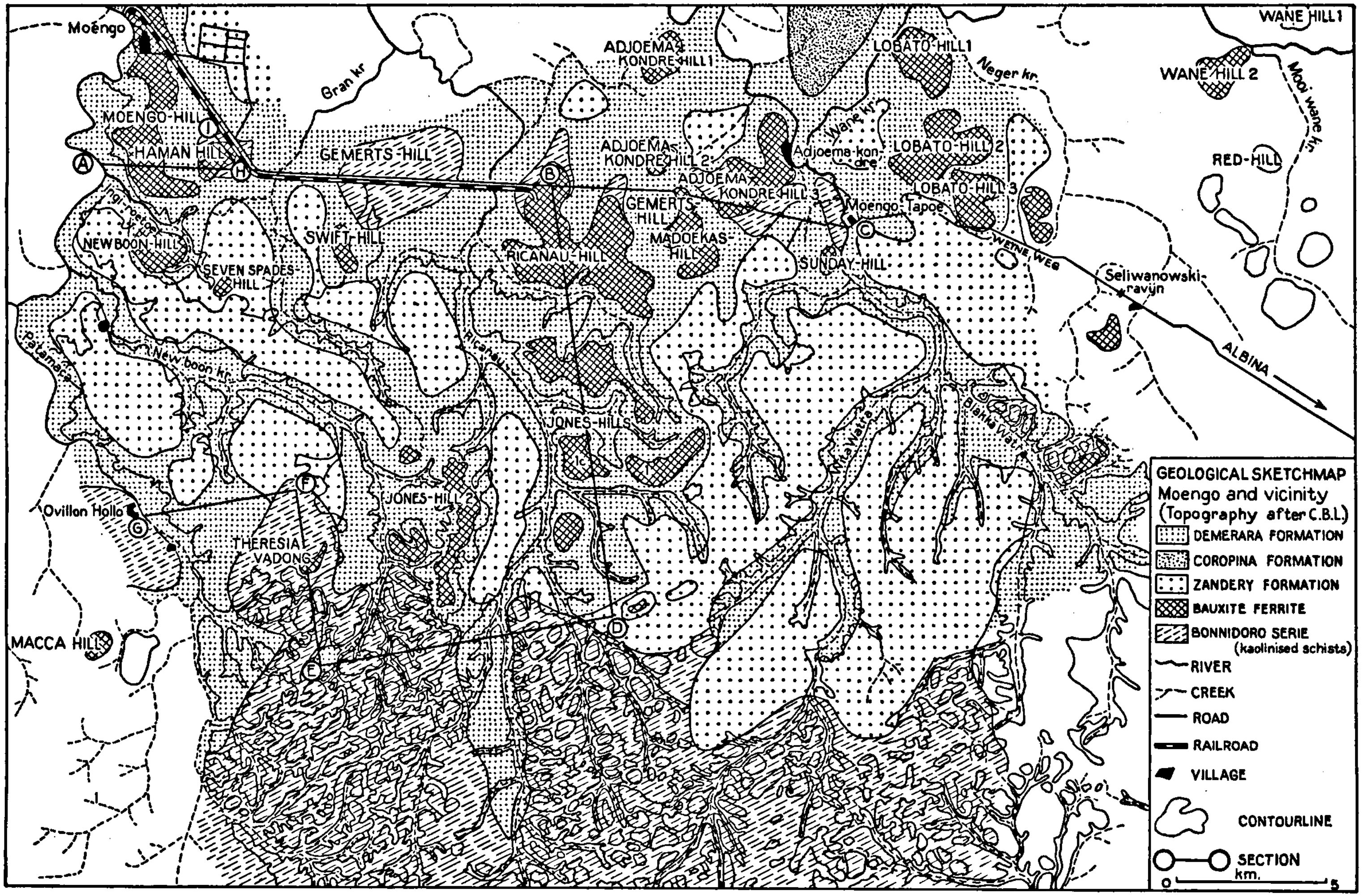

Fig. 13. Geological sketch map of Moengo and vicinity.

The region is drained by a large number of creeks which drain into the Patamaca river and the Coermotibo river, tributaries of the Cottica river.

Fig. 13 is a Geological sketch map, indicating the outcrop areas of the following deposits, listed in order of age.

d. Demerara formation,
c. Coropina formation,
b'. Bauxite-ferrite,
b. Zandery formation,
a. Orapu formation.

Although the bauxite-ferrite deposits do not constitute a separate formation because they are the weathering product of material belonging to the Zandery formation, the bauxite-ferrite has been inserted into the legend on account of its petrographic, stratigraphic and economic importance.

The various formations already have been discussed in Chapter I, but it should be emphasized that it is very difficult to distinguish the sands of the Zandery formation from the residual quartzose sands washed down from the kaolinized schists of the Orapu formation. This sand being alluvium has to be classed with the Demerara formation.

When studying the aerial photographs of the region one gains the impression that groups of hills like the Jones Hills, Adjoemakondre Hills and Lobato Hills have once formed a complex. This impression is strengthened when studying the topography of the Ricanau Hill, which almost is divided into two parts by erosion. When this division will be completed two smaller hills will be left with their longitudinal axes running north—south. This direction of the axes agrees with that of eight other hills in this area. To investigate this phenomenon a number of sections were measured through the area.

One east—west section (fig. 14, A—C) in which use was made of a part of the section which was measured by O. W and V.[4]) for a projected highway between Albina and Moengo.

One north—south section (fig. 15, B—D), which together with the following sections was measured by the Geological and Mining Survey of Suriname.

Three connected sections (fig. 15, D—E, E—F and F—G) through the southern part of the area near Moengo.

The east—west section runs from the Cottica river via the Moengo, Haman, Ricanau and Adjoemakondre 3 Hills to the Coermotibo river. The bauxite-ferrite mantles of these hills do not differ much in elevation, only the mantle of the Adjoemakondre 3 Hill has a notably higher elevation.

The north—south section starts on the Ricanau Hill, continues over the Jones Hills to 10.8 kilometres, where the section connects with section D—E, E—F and F—G. From this north—south section a clear plunge of the connection line of the bauxite-ferrite mantles to the north is apparent.

The connecting lines of the tops of the hills show respectively an inclination of 29′, 36′ and 17′ from south to north.

The section D—E, E—F and F—G cross a terrain, in which numerous small but high, steep hills are found, consisting of kaolinized schists. In the section E—F there is a hill of about 60 metres high, covered with a

[4]) Department of Public Works, Paramaribo, Suriname.

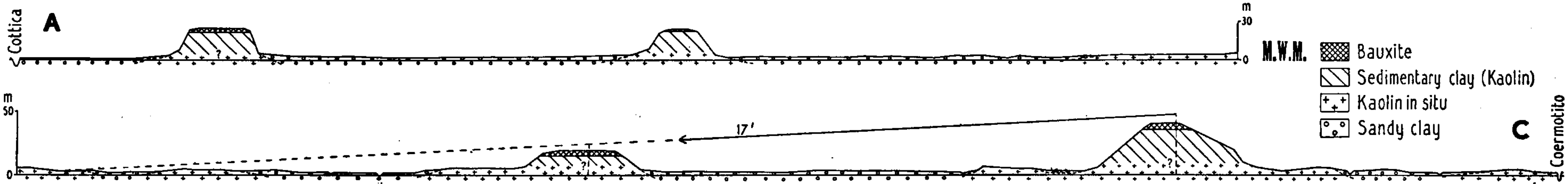

Fig. 14. East—west section (24.8 km) from the Cottica river to the Coermotibo river.

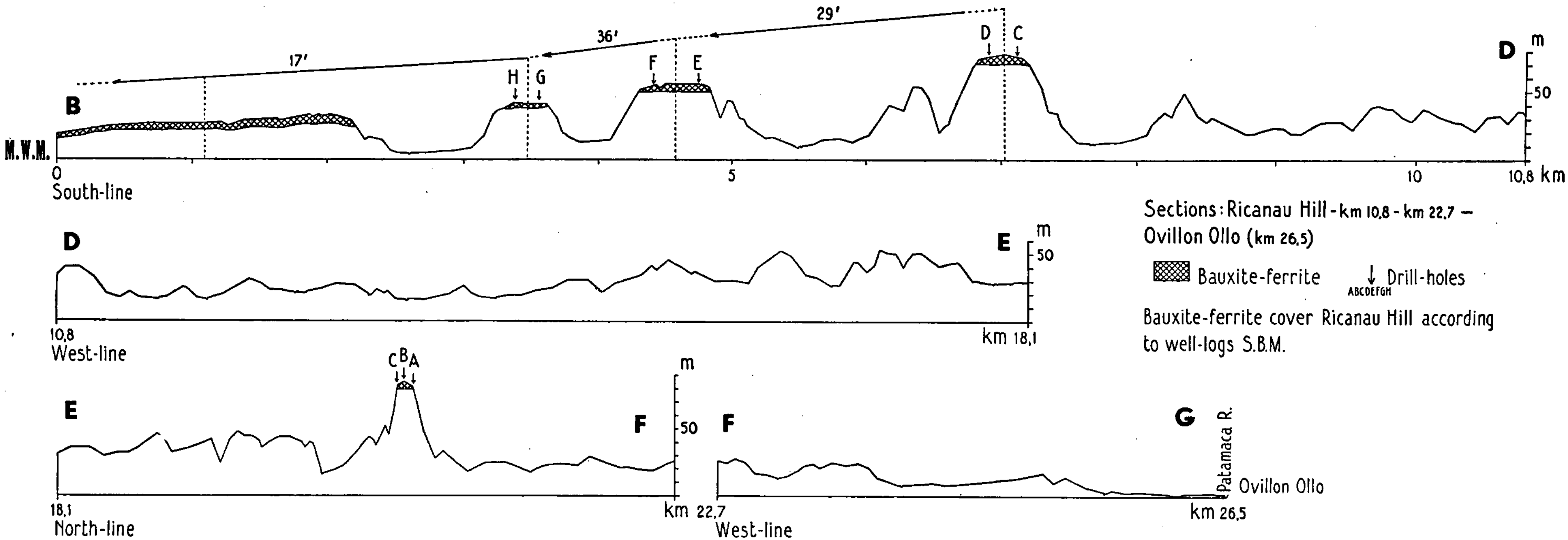

Fig. 15. North—south section from Ricanau Hill to Km 10.8 and three consecutive sections through the area south of Moengo.

bauxite-ferrite cover, rising far above the hills of kaolinized schists in the vicinity. The connecting line of the bauxite-ferrite mantle of this hill, the Theresia Vadong, with the bauxite-ferrite mantle of the Moengo Hill is inclined about 12′ to the north. For the connecting line between the Theresia Vadong and the Jones Hill 1 C an inclination of 6′ has been calculated.

The possibility that the bauxite-ferrite covers at one time formed part of one unbroken mantle will be discussed below.

The Moengo Hill as well as the Ricanau Hill are representative for the hills covered with bauxite-ferrite. Here the Haman Hill forms an exception, and therefore the section of this hill will be discussed separately.

A short description of the Gemerts Hill follows as an example of a hill which is not covered with bauxite-ferrite.

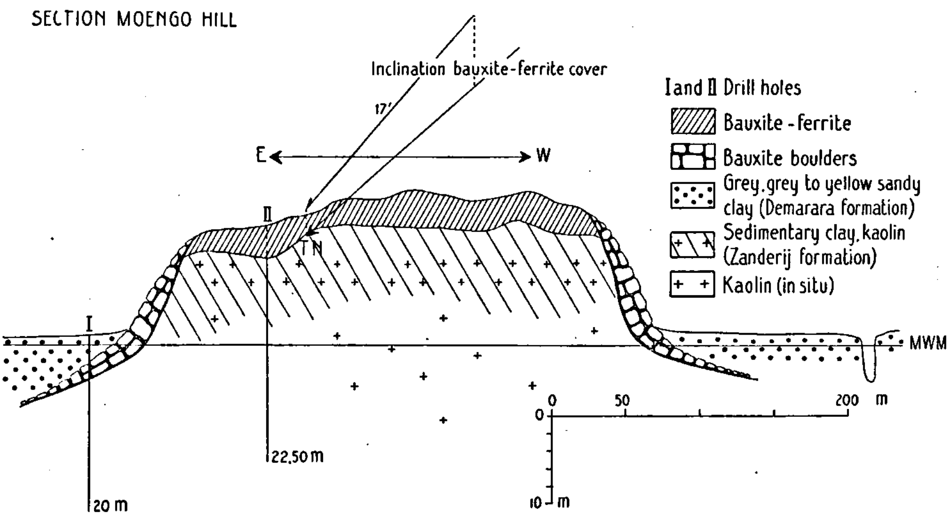

Fig. 16. East—west section through Moengo Hill.

MOENGO HILL (fig. 13 and 16)

This hill is situated in the western part of the Moengo area; the western limit is formed by the Cottica river. The material surrounding the Moengo Hill belongs to the Demerara and Zandery formations.

The longitudinal axis of this hill lies in a north—south direction. The bauxite mantle dips 18′ to the north. The lowest point is in the north at 9 metres above M. W. M., the highest in the south at 27 metres above M. W. M. A possible inclination to the east or west could not be established because the top of the hill is too narrow and the surface is too irregular.

From the top downward the section looks as follows:

	thickness
Soil cover	0 to ± 1.5 metre
Ferrite / Bauxite	± 1 to ± 8.0 metres

Transition zone ± 1.5 to ± 2 metres

Sedimentary clay. The thickness could not be measured, but from drillings it was established that this layer can reach thicknesses of more than 20 metres.

Fossil autochthonous weathering clay. Only one drilling is known to have reached solid rock [5]). In this case the weathering clay had a thickness of 39 feet.

Solid rock, consisting of staurolite schist was found in this drill hole at 99 feet.

The *soil cover* consists of beans and little stones of limonite and bauxite-ferrite boulders and sometimes some arenaceous black soil.

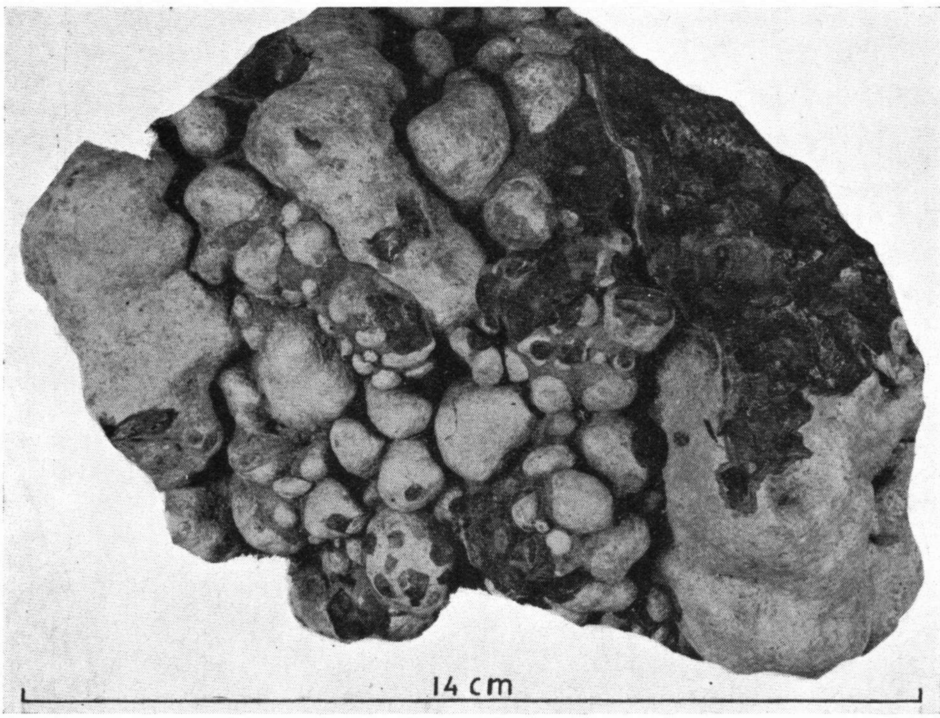

Fig. 17. Iron beans and little stones arising from the weathering of the upper part of the ferrite-cap (Moengo Hill).

The beans are mostly round with a brownish-black colour and a relativily high luster. The little stones on the other hand, have an irregular form and have a dark-brown to brown-yellow colour and no luster. These beans and little stones are formed through the weathering of the upper part of the ferrite mantle (fig. 17).

Bauxite-ferrite pebbles are found mostly in the numerous channels of ancient creeks, cutting the bauxite-ferrite mantle. On removal of the soil cover extensive creek systems appear (fig. 18). The pebbles have a

[5]) Drill hole, Surinaamsche Bauxite Maatschappij.

diameter of up to 60 centimetres; mostly consisting of ferrite; bauxite pebbles are found much more rarely.

The black earth is very rich in plant rests, occasionally a few thin lenses of quartzitic sand are found.

Ferrite is locally missing; elsewhere it may be found in beds of a thickness of various metres. The vegetation is somewhat dependent on the thickness of the bauxite; it is poorest in places where the bauxite is thickest.

Although ferrites with a high Fe_2O_3-percentage at first sight seem to occur at random, some regularity may be found. It is a fact, that ferrite often is missing in the lower levels of the terrain as in the beds of creeks

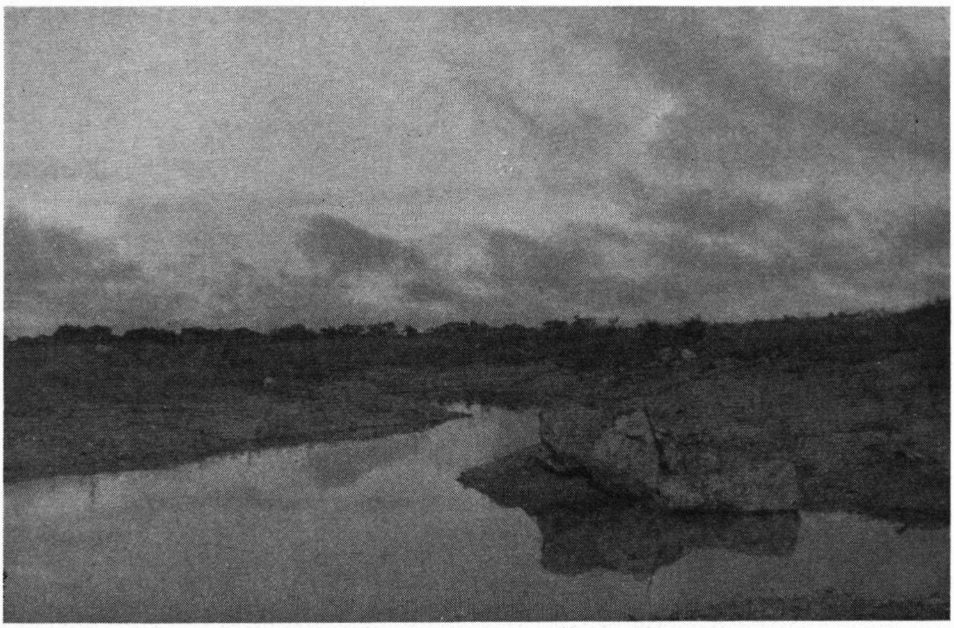

Fig. 18. An old creekbed appearing after removal of the soil cover (Ricanau Hill).

and in other depressions of the field, while especially high-grade ferrite was found in the highest parts of the terrain.

Besides, as a concentration of high-grade ferrite in the higher parts of the terrain, the ferrite is mostly found as a more or less horizontal mantle on top of the bauxite (fig. 19). The whole mantle may consist of bauxite, which is generally the case at the borders of the bauxite-ferrite mantles.

In the centre of the cover, where the ferrite bed is subject to great changes over very short distances, often the ferrite is found in the bauxite in the shape of a funnel. Downward the ferrite seems to be connected to a certain level, below which practically no more ferrite is found.

In the ferrite there are often larger and smaller, mostly capriciously formed pockets of ferrite with a poor Fe_2O_3-content, or bauxite. Several times even coarse crystalline gibbsite was found.

Macroscopically have been found in the ferrite partly dissolved quartz grains, staurolite, tourmaline, muscovite always orientated horizontally, and hematite, which covers the walls of the cellular ferrite and the walls of the pores mostly in the shape of a blue-violet dull little coat. Locally well-developed botryoidal hematite is found.

Structurally the ferrite may be divided very roughly into the following types:

a. Dense, homogeneous ferrite. The material is very fine-grained and few pores are found; the colour red to dark red-brown. Scattered grains of hematite occur which material also covers the walls of the pores.

Fig. 19. The mineface on the Ricanau Hill clearly shows the ferrite overlaying bauxite, height of the mineface is about 6 metres.

b. Fine- to coarse-grained laminated ferrite, consisting of thin beds up to 3 millimetres thick. Sometimes the lamination must be attributed to the orginal lamination of the sedimentary clay. In other cases the lamination is caused by alternating thicker and thinner beds of ferrite and ferruginous clay.

c. The cellular ferrite is found in coarse- as in finely cellular shape, the diameter of the cells varies of from 2 millimetres to 4 centimetres. The walls of the cells mostly are thin (± 0.3 to 1.0 millimetre) and they are often covered with a film of hematite. Intercellular ferruginous clay often is found, whereas, in other cases these spaces are empty. A special type of cellular ferrite is a ferrite, which is very fine cellular (a diameter of from 1 to 3 millimetres) and in which the walls of the cells consist of hematite.

d. Limonite is found as beds of dense, homogeneous material of a light-brown colour. Generally these beds are not thicker than about 50 centimetres; sometimes they show a horizontal lamination.

The dense, homogeneous ferrite principally is found in the upper layer of the bauxite-ferrite cover just below the surface. The laminated ferrite is found in several places in the section and it may continue over large distances. Porous bauxite mostly is found in the centre and at the bottom of

Fig. 20. Sharp boundary between bauxite and ferrite, which consists of cellulary hematite (Ricanau Hill).

the ferrite cover, where, together with the cellular ferrite it gradually changes into bauxite. Limonite beds are found in the entire bauxite-ferrite cover, generally they continue over large distances and occur in the ferrite as well as in the bauxite.

It must be pointed out that this classification is an approximate one and that ferrite mostly has a structure which forms the gradation between the above mentioned types. The transition to the lower bauxite may occur either gradually or very suddenly (fig. 20).

Also on the basis of the structure in the *bauxite* various classes may be distinguished:

a. In dense, homogeneous bauxite two types may be distinguished: the first is very finely-grained, and fine stromatitic structures may be observed. The colour is light pink to yellow-white. The bauxite of this type shows fracturing along the planes of the structure. The second type is coarse-grained and here crystals of gibbsite of from 1 to 4 millimetres in size occur. This material is almost colourless or yellow-pink.

In both types there are practically no pores; here and there small vugs are filled with white clay. Quartz grains are found which clearly show solution symptoms; also staurolite, tourmaline, muscovite, the last one orientated horizontally, are found. The small beds in which the heavy minerals are concentrated do not run parallel to the stromatitic structures.

b. Laminated bauxite. Here too coarsely crystalline and cryptocrystalline gibbsite occur separately and together. The lamination may be caused by a change of thin beds of bauxite and white clay up to 5 millimetres thick; another possibility is an alternation of coarse and cryptocrystalline material, lamination also may be caused by a difference in contents of Fe_2O_3. Several times lamination by alternating porous and dense, homogeneous thin beds of bauxite has been found.

c. Porous bauxite. Very porous and sligthly porous material is found in horizontal as well as in vertical directions. Often the pores still contain remnants of quartz grains; the staurolite and the tourmaline do not show solution symptoms in the handspecimen. Locally occur horizontal beds of from 20 to 60 centimetres thickness in which staurolite is found in very large quantities. Generally the quartz grains have disappeared, leaving a porous structure.

d. The very thin cell walls of the cellular bauxite consist of crystalline gibbsite. Often these walls are covered with colourless coarsely crystalline gibbsite. Often white clay and bauxitic clay is found intercellularly.

e. Bauxite clay with concretions. Here too the bauxite clay may be confused with the white clay below the bauxite, bauxite clay is locally found in small vugs and very thin beds. Here too the rapid disintegration in water forms a distinctive mark of identification. The concretions are cylindrically shaped and often they have a capricious form. The size varies between a length of a few millimetres and a few decimetres and a diameter up to $\pm$ 1.5 centimetres, their colour is white-yellow, yellow-pink to dark pink. The bauxite is very dense and fine-grained; mostly the pores and small holes in the concretions are completely or partly filled with colourless coarse macrocrystalline gibbsite.

The classification of the bauxite, as in the case of the ferrite, is very rough. The larger part of the bauxite consists of transitionmaterials and mixtures of the types mentioned.

Bauxite clay with concretions occurs in the middle as well as at the bottom of the bauxite bed. Beds of dense, homogeneous bauxite, which may attain a thickness of from 2.5 to 3 metres, traverse it. Locally the cellular bauxite is well-developed throughout the whole bed, but it does not form continuous beds over large distances. Porous bauxite is found very often at the bottom of the bauxite bed and in the transition zone to the white clay.

Here too a karst-type weathering was found, although less intense than on the Nassaugebergte. The appearance of solution in the bauxite bed is striking in places where the bauxite in the mine-face was exposed to the atmosphere for long periods (fig. 21).

• Downward increasing quantities of white clay begin to appear in the form of thin beds, vugs and pockets.

The thickness of the *transition zone* bauxite — kaoline varies of from 1.5 to 2 metres.

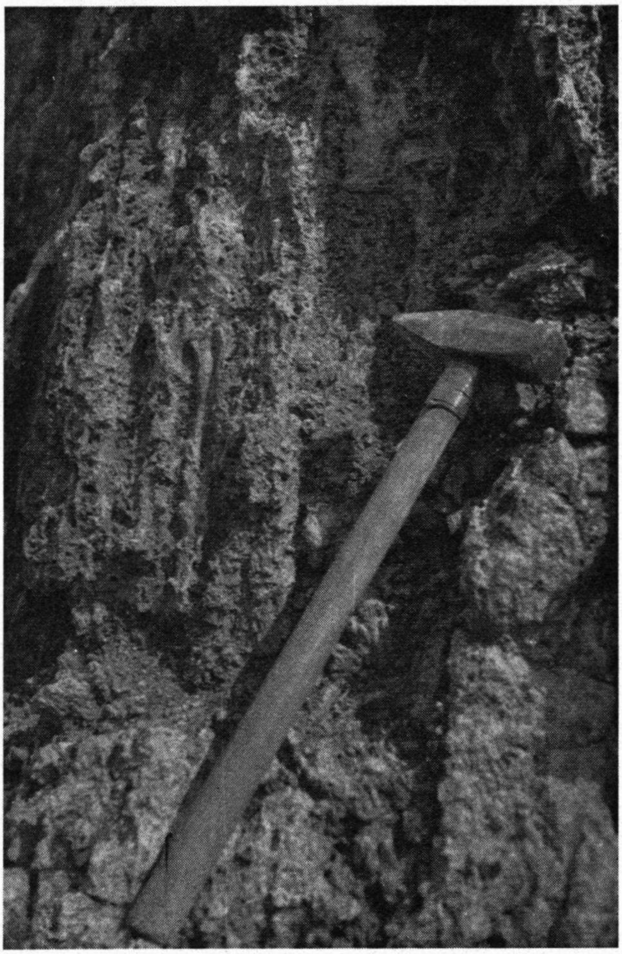

Fig. 21. Bauxite in a mineface has been exposed to atmosphere for some time, solution is apparent (Ricanau Hill).

In this zone many tubular concretions of porous bauxite are found. Here also, 10 to 20 centimetres thick banks of the same porous material appear, interfingering with the white clay (fig. 22 a and b).

The lower part of the transition zone is formed by beds consisting of partially porous bauxite up to 20 centimetres thick. Also in the lower part of the transition zone thin beds of clay are found with a material which is

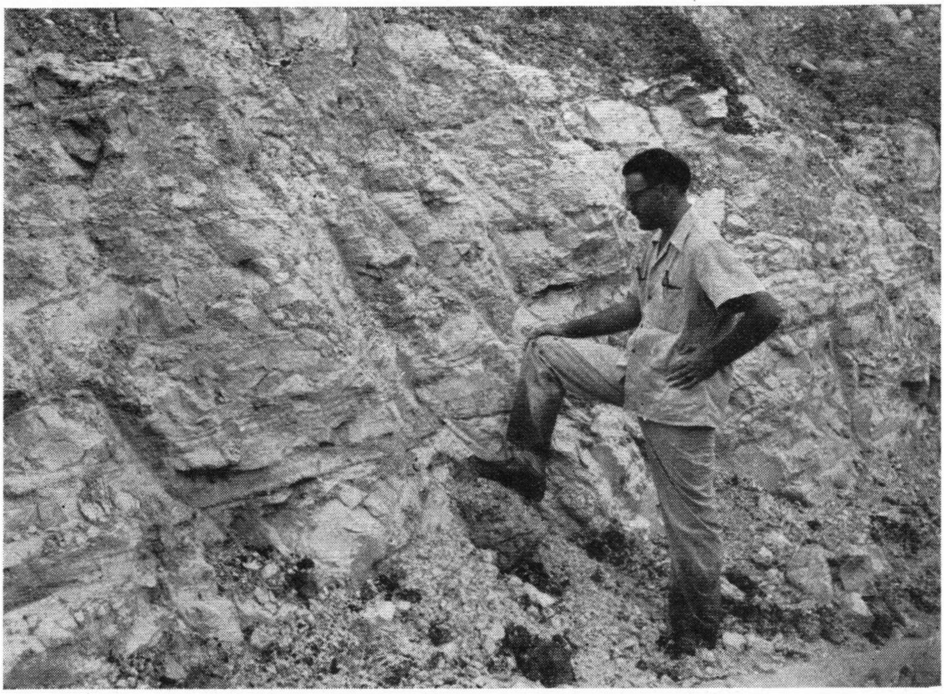

Fig. 22a. Horizontal layers of porous bauxite in which still many partly dissolved quartz grains are found (transition zone, Ricanau Hill).

Fig. 22b. Horizontal layers of porous bauxite in which still many partly dissolved quartz grains are found (transition zone, Moengo Hill).

pale pink to yellow-coloured, in contrast to the surrounding white clay. These coloured bands at the bottom of the transition zone are still soft; a little higher up they begin to become hard and then consist of bauxite and kaolin. Still higher up in the transition zone the quartz grains have disappeared more and more through solution. As a first indication of this, pores are found, which still contain remnants of quartz grains, these do not fill all the space in the pores. The grain itself is very irregular in shape and shows solution cavities. The quartz grains become increasingly smaller and finely they disappear, after which a porous material results, consisting entirely of bauxite.

Sedimentary clay; sand lenses and beds to a thickness of about 1,70 metres are found. This clay is very plastic and generally white; locally small quantities of light yellow, pink and violet varieties are seen. Laboratory examination disclosed the fact that this sedimentary clay consists mainly of kaolinite.

Much quartz, staurolite, tourmaline and muscovite has been found, concentrated in horizontal thin beds. The muscovite always is arranged parallel to the horizontal level. The grains strongly diverge in size and generally they are rather angular. The sand lenses and beds sometimes contain small grains of bauxite. Many concretions of bauxite have been found in the kaolin, most frequently in top of the kaolin bed quite near the transition zone and also often in certain other levels.

a. Bauxite eggs have a relatively smooth surface. Sometimes they are a little more cylindrical in shape, in these cases they are found with their longitudinal axes oriented vertically. The bauxite eggs occur locally and generally they are concentrated in horizontal levels. The size varies about from 3 centimetres to 20 centimetres in diameter. These eggs consist of a hard shell of bauxite and a core which often consists of kaolin. Exceptionally, bauxite eggs with a hollow core are found, sometimes containing water. In this case often small rods and tubes of coarsely crystalline gibbsite occur, which run from wall to wall through the hollow core, while in the centre they intergrow.
   A thin bed of staurolite grains was found which traversed through a bauxite egg and continued into the kaolin.
b. The compact elongated oval-shaped concretions consist of cryptocrystalline and coarsely crystalline gibbsite, while porous bauxite also may form the main constituent. In the pores often quartz grains are encountered, which hardly show any solution symptoms. The concretions give the impression that they are the first products in the transition from sedimentary clay to bauxite.
c. Cylindrical concretions are constructed principally of dense, cryptocrystalline gibbsite; in the core of the concretions often a small hole occurs, the wall of which is covered with coarsely crystalline gibbsite. Locally this type of concretions forms entire stock-works, which may spread radially from a centre that generally has a cylindrical shape and also consists of cryptocrystalline gibbsite.
d. Irregularly shaped concretions. Highly variable forms are found. Sheets with a thickness of a few millimetres, and also clews of cylindrical shaped concretions, irregular- and tubular forms are seen. Most of these concretions consist of dense, fine-grained gibbsite.

In the kaolin a large number of joints occur; on the joint planes densely crystalline gibbsite is found. On a number of these joint planes indications of movement were found in the form of striated surfaces.

Fossil autochthonous weathering clay. The laboratory examination showed this weathering clay also consists of kaolinite. Often it is difficult to fix the boundary between the sedimentary clay and the autochthonous weathering clay. Locally a bed of sand, which seldom is well-developed, is found between these two deposits. Mostly a bed of sandy kaolin rests upon the autochthonous kaolin. Pieces of quartz and muscovite nests are a sure indication in a well that this autochthonous kaolin has been reached.

In a few places this autochthonous kaolin crops out and it has been established that we have to do with a kaolin-staurolite schist.

The data on *solid rock* are very scarce. The Surinaamsche Bauxite Maatschappij disposes of a number of analyses of samples obtained of a

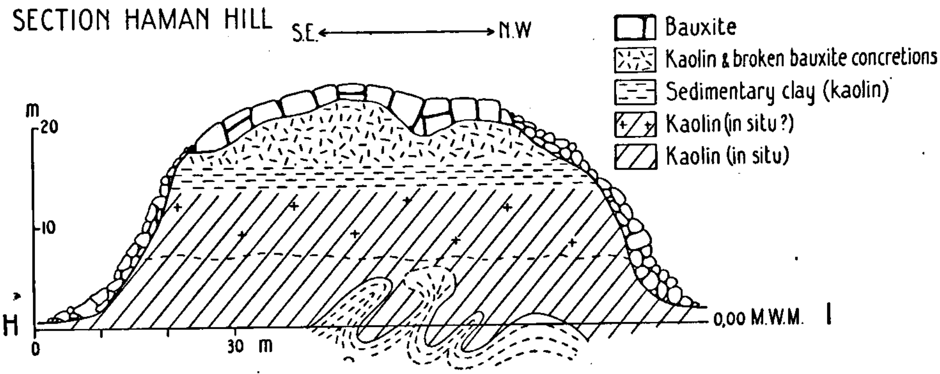

Fig. 23. S.E.—N.W. section through Haman Hill, also showing folding in the kaolinized schists (Bonnidoro serie).

drilling operation on the Moengo Hill. According to these data solid rock was reached at a depth of 99 feet.

The average of three analyzed gave:

Al_2O_3	SiO_2	Fe_2O_3
23.27 %	66.22 %	7.56 %

Though these chemical data are very limited, they do not contradict the supposition that the material that was sampled, consists of staurolite schists, a rock type frequently found in the vicinity.

HAMAN HILL (fig. 13 and 23)

This hill is situated off Kilometre 39.4 on the south side of the road from Albina to Moengo.

The section looks as follows:

Soil cover of from 0 to 1 metre.
Ferrite } up to 4 metres thick.
Bauxite }

Sedimentary clay with concretions, ± 6 metres thick.
Fossil autochthonous weathering clay.

The *soil cover* consists of iron beans and little stones together with some material rich in humus. Sometimes somewhat sandy soil is found.

Ferrite-bauxite has been found in the shape of a cover consisting of large ferrite-bauxite boulders, which are locally cemented. If no cementing took place, the cracks and joints are filled with kaolin and concretions, material from the soil cover is also found in these places.

Ferrite practically forms the upper layer of the bauxite-ferrite mantle. The bauxite predominates in the centre and the lower part of the mantle. The types occurring in the bauxite-ferrite already have been described with the Moengo Hill. Generally the bauxite here is more fine-grained than in the former deposit. In some boulders of the bauxite-ferrite mantle thin beds of heavy minerals have been found, which do not continue into the adjoining boulders.

The *sedimentary clay* with concretions contains many components of mainly laminated bauxite, which lies orientated at random. Cylindrical concretions are frequently found; they consist of small fractional pieces, which also lie orientated at random. In the upper part of this bed no relict minerals are encountered in thin beds as quartz, staurolite, tourmaline and muscovite, in contrast to the Moengo Hill and other deposits.

Downward in the section the random orientations of the minerals decrease and locally thin beds of heavy minerals with creep symptoms may be observed. Still lower the minerals are found in horizontal, undisturbed thin beds. The sedimentary character of the clay, which here also consists of kaolinite, is very evident. It is not possible to make a sharp separation between the zone which obvious has been crushed and the undisturbed sedimentary kaolin.

Fossil autochthonous weathering clay. Here kaolinized schists are found which occasionally crop out well. The folding of these schists may be observed very well (Ter Meulen 1949).

Pegmatites occur frequently, besides quartz, muscovite and large pieces of weathered tourmalines, we encounter spots of pure white kaolin. In the quartz there are often large concentrations of tiny white spots with straight sides. These white spots are probably kaolinized feldspars. Besides very much weathered pyrite also much staurolite has been found.

On the basis of these data it is suggested that the bauxite-ferrite mantle of the Haman Hill has slumped down over the transition zone and the sedimentary clay. These beds have been partially grounded, so that the beds of porous bauxite and the cylindrical concretions have been mashed.

During this partial slumping down, the bauxite-ferrite mantle has been fractured into a large number of boulders between which, kaolin with concretions and material from the soil cover, could penetrate. Later on some of these blocks have been cemented again.

GEMERTS HILL (fig. 13 and 14)

This hill is an example of the type without a bauxite-ferrite mantle and with gentle slopes.

The hill is situated off Kilometre 37, north of the road from Albina to Moengo. The bauxite-ferrite mantle and the sedimentary clay are missing here.

A cover of iron beans and stones, limonite concretions and soil rich in humic material, covers the kaolinized schists, which here are situated directly below the soil cover.

The schistose structure has faded strongly in the kaolin schists, which is caused by the concentrations of Fe-hydroxides. Throughout the schists traverse a number of pegmatites and quartz veins. As main constituent the pegmatites have muscovite, whereas further quartz, weathered tourmaline and spots of white kaolin have been found.

The bauxite-ferrite mantles are the weathering product of the sedimentary kaolin below these mantles.

This kaolin varies in thickness, and locally it is missing. Thus in these places the weathering covers are the weathering product of kaolinized schists. In some places it has been ascertained, that the sedimentary kaolin was missing, in these cases the weathering product consisted of ferrite.

On the basis of the sections (fig. 14 and 15) the inclinations between the bauxite-ferrite mantles of a number of hills were computed. The calculated amounts are relatively small and they leave open the possibility that the bauxite-ferrite mantles have earlier formed one single plain. It is possible that the alluvial plain consisted of a number of terraces. The remnants of this old bauxitized alluvial plain are too inconspicuous however to support this possibility. The extensive creek systems point out, that earlier date the bauxite-ferrite mantles have been much more widespread. The bauxitized alluvial plain has been cut into by a lowering of the erosion-basis. The hills found at present with a bauxite-ferrite cover form the last remnants of an extensive bauxitized surface. In places where the erosion has proceeded somewhat farther than on the bauxite-ferrite hills, the Gemerts Hill type is found.

2. **The bauxite deposits at Paranam** (fig. 24)

This area is situated south and south-east of Onverdacht in a part of the coastal plain occupied by the Coropina formation.

The bauxite which is found here, belongs to the High-level as well as to the Medium-level type. The Medium-level type, however, will be discussed on the basis of observations at Onverdacht, where this type of occurrence has been exposed very well in a number of mines.

High-level bauxite is found at Paranam as well as at Moengo as weathering covers over hills with an elevation of from 10 to 30 metres. At Paranam are found the Topibo-de Vrijheid, Onoribo, Osembo and St. Helena Hills. Nearly 10 kilometres east of Onverdacht the Acaribo Hill is situated. A number of hills of the same type is found on the east bank of the Suriname River at Rorac and Ric a Rac.

The bauxite-ferrite covers show a great resemblance to those at Moengo and vicinity. A large number of creek beds occur, which cut back into the bauxite-ferrite covers. In the creek beds large quantities of rounded pebbles of bauxite and ferrite were found (fig. 25).

In some places it is doubtful that all the bauxite-ferrite covers are the in situ weathering product of sedimentary clay. The sedimentary character

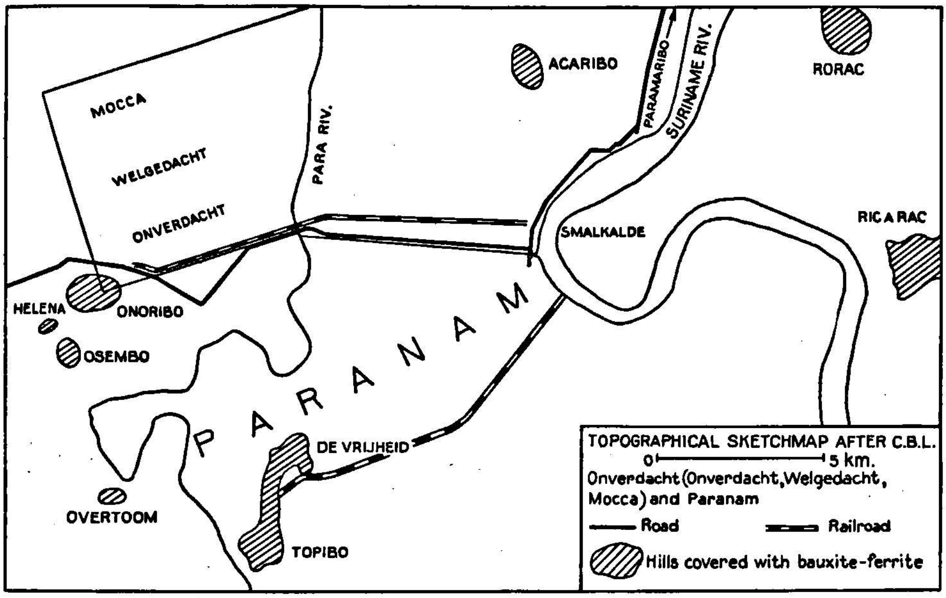

Fig. 24. Topographical sketch map of Onverdacht and Paranam.

Fig. 25. Bauxite-ferrite pebbles in an old creekbed on the bauxite-ferrite cover of Topibo-de Vrijheid.

of the kaolin clay of the Topibo-de Vrijheid, Onoribo, St. Helena and Acaribo Hills could be established.

The bauxite-ferrite mantle of the Osembo Hill has been removed so that here no more investigations could be done. The kaolin, however, which at present crops out is not sedimentary but the weathering product of schists.

Some tens of kilometres to the south, at Overtoom, kaolinized schists occur also just below the surface. It is possible that a thin bed of sedimentary clay covers these kaolinized schists, which bed was entirely bauxitized.

The kaolinized schists, which are covered with a bank of sedimentary clay in which sand lenses occur, have been found at very different depths below the surface. The drilling data give the impression that a large number of small but elevated, steep-sided hills of kaolinized schists, occur just as in the south of the Moengo area (fig. 15).

At the bottom of the transition zone from Topibo-de Vrijheid Hill a

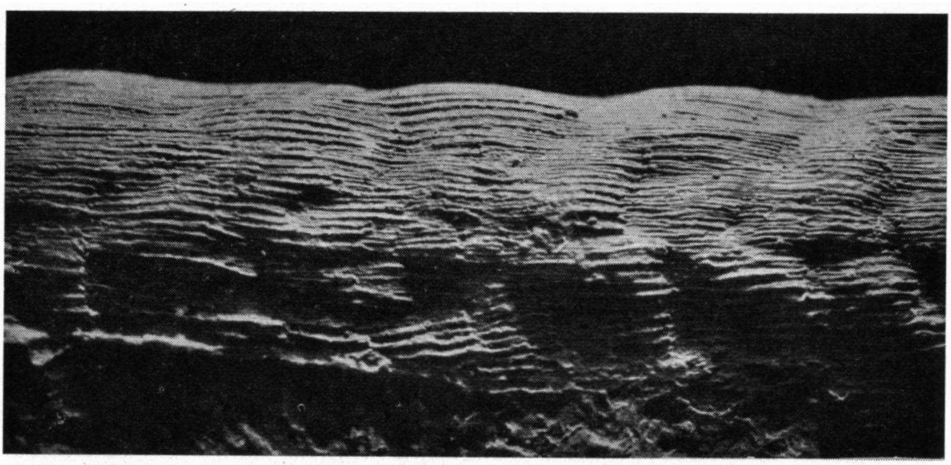

Fig. 26. Corrugated surface of a cylindrical concretion from the transition zone at Topibo-de Vrijheid. × 4.

large number of cylindrical concretions have been found in one place. By the formation of these concretions three phases may be distinguished:

a. The tubular concretions with a diameter of ± 1 to 10 millimetres, the wall of which has been built up of pure transparent gibbsite.
b. The outer wall is cryptocrystalline and is pink to pink-yellow in colour. This cryptocrystalline wall grows in thickness at the expense of the coarsely crystalline gibbsite, found inside the tubular concretions.
c. The final phase consists of a small cylinder of cryptocrystalline gibbsite, which is pink to pink-yellow in colour and has a ribbed surface (fig. 26).

The ribbed surface shows a great resemblance to the surface structure of the roots of some palm trees. Besides this fluting at the outside, nothing points to an organic structure.

In the transition zone many joints occur, the faces of which have been covered with a film of finely crystalline gibbsite (fig. 27). The solution of quartz as already mentioned in the Moengo section, is also found in the transition zones of the bauxite-ferrite covered hills at Paranam.

The bauxite-ferrite cover of the Onoribo Hill has a very disorganized appearance. Only a small part shows a homogeneous character; the largest part consists of boulders, which sometimes have been cemented, but which often are separated by ruptures and cracks. These ruptures and cracks are filled with material from the cover, such as iron beans and little stones,

Fig. 27. Gibbsite covered joint planes prepared by rain, in the transition zone of Topibo-de Vrijheid.

bauxite-ferrite pebbles, while clay with crushed concretions has been found also.

The crushing is best developed on the north and the west sides of the hill, where boulders of bauxite-ferrite lie thrown together and have been mixed with clay and great quantities of smaller pieces of bauxite of all dimensions (fig. 28).

On the basis of this appearance, DE VLETTER [6]) supposed at one time the sea reached here and broke up the deposits.

The bauxite-ferrite cover of the Onoribo Hill is inclined to the north below the Lelydorp sands and Coropina clay, which wedge out against the Onoribo Hill. This supports of course the hypothesis of DE VLETTER.

The hills at Paranam once formed part of larger units. At present only a few remnants of the earlier bauxitized-alluvial plain are found.

[6]) Dr. D. R. DE VLETTER, Personal Communication.

The bauxite-ferrite is, with few exceptions, the in situ weathering product of sedimentary clay.

Indications of recent bauxitization have been found; the details will be discussed in a later chapter.

At Paranam (Onoribo) we see that High-level and Medium-level bauxite are part of one bauxitized surface (fig. 29).

Fig. 28. Accumulated boulders of bauxite and ferrite, probably caused by action of the sea.

D. MEDIUM-LEVEL TYPE BAUXITE

The bauxite deposits at Onverdacht (fig. 1 and 24)

The terrain is situated 35 kilometres south of Paramaribo between the road to Zandery and the Suriname river, in the part of the coastal plain

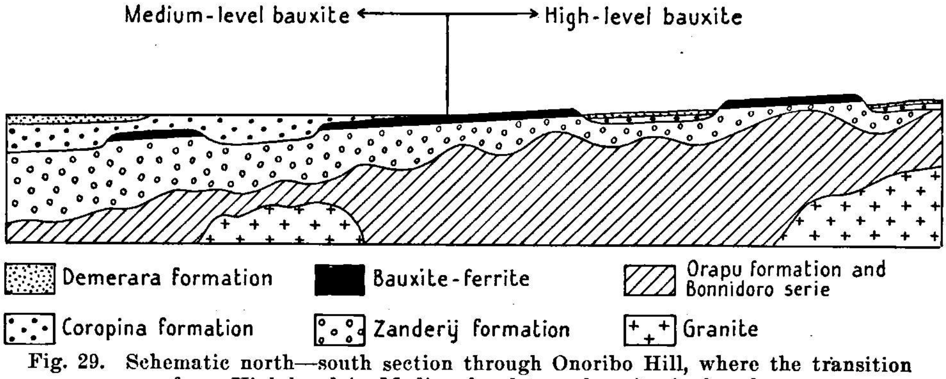

Fig. 29. Schematic north—south section through Onoribo Hill, where the transition from High-level in Medium-level type bauxite is found.

that is formed by the Coropina formation. The terrain is slightly hilly; the differences in elevation at most amount to 6.5 metres. Large swamps cover part of the terrain (fig. 30); many of these swamps do not dry out entirely during the dry season. Mostly they are grown over with grass.

Generally the higher parts of the terrain are covered with open savannah woods, while locally wild coffee and cacao form the remnants of plantations, which were operated here formerly. To these plantations belong also the drainage ditches, which are clearly perceptible on the airphoto.

The bauxite at Onverdacht is found in a bed which dips slightly to the north and which is covered with sediments of the Coropina formation. In the south of the area it is situated under a cover of 1.5 to 2 metres but in the north it attains a thickness of more than 30 metres.

Fig. 30. Large swamp overlying Medium-level type bauxite at Onverdacht.

The borders of the bauxite bed are very steep and in the layer itself gaps are found. In places where the bauxite does not occur, kaolin has been found, directly underlying the Coropina formation. In these cases the kaolin has been covered with material from the Coropina formation, which partly has been bleached and here and there shows some small pink stains and sometimes some small concretions of bauxite, nowhere did even a thin bauxite bed develop. The bauxite bed ends suddenly, and does not thin out.

The Coropina clay and the transition zone from bauxite to Coropina clay here and there show sandy lenses. In these lenses in which the sand sometimes show a cross-bedding structure, bauxite-ferrite pebbles have been found too. The lenses only occur in the upper part of the bauxite layer.

After the removal of the soil cover it is necessary to remove in addition the partly indurated transition zone. In this way the depressions in the bauxite surface are uncovered, which bear a strong resemblance to gullys such as the old creek beds, which have been found on the bauxite-ferrite covers of the hills at Moengo and Paranam.

Indications for the existence of sedimentary bauxite in the form of bauxite-ferrite gravel have been found. After a hard cover had been chiseled through in a drilling operation, bauxite-ferrite gravel was found which could be removed without much difficulty. This bed, which had a thickness of about 2 metres, did not contain clay. Fieldwork and drilling operations have shown that the sedimentary bauxite-ferrite in this deposit is only a minor constituent. Generally the bauxite-ferrite is an in situ weathering product of sedimentary clays.

The following three sections were measured at Onverdacht.

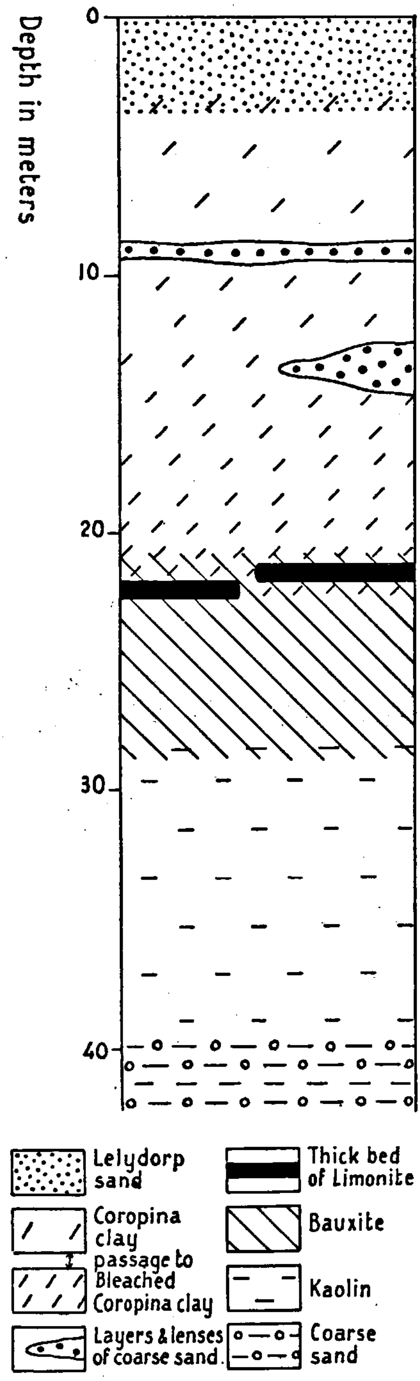

Fig. 31. Section A, Onverdacht.

SECTION A (fig. 31)

From the top down the following beds may be distinguished:

	thickness
Lelydorp sand	4.5 metres
Coropina clay	16.0 metres
Transition zone	1.5 metres
Bauxite-ferrite.	7.0 metres
Transition zone	1.0 metre
Sedimentary clay ...	11 metres
Coarse sands	— —

Lelydorp sands forms the top, the transition to the Coropina clay below it is relatively short. The bottom of the sand bed mostly is formed by almost horizontal, thin beds and lenses of clay. A little lower in the section thin beds of sand are found between the clay; these small beds quickly thin out and finally disappear. The clay is plastic and homogeneous; for 3 to 4 metres a clear lamination may be observed.

The *Coropina clay* consists of grey to yellow-white sandy material, which often has red stains. Sand beds and lenses have been found, which often vary in thickness and sometimes show a cross-bedding structure. Peat and clay beds which are very rich in plant remains were found here also. Besides these plant remains a number of molluscs, such as Ostreas and Venus portesiana[7]) have been found in the Coropina clay.

The small red spots of iron hydroxides are found scattered and in varying frequences. Their dimensions are very variable. Besides small spots, vertical cylinders occur, red-brown in colour, with a length of up to 6 metres and a width of up to 1 metre. Besides these small spots and cylinders large spots of brown-red to dark brown clay were found with surface areas of 3 m^2 or more.

The sand lenses and beds are often cemented by limonite, so that hard banks are formed.

Lower in the section bleaching in the Coropina clay takes place. As soon as this bleaching is observed, we see a number of spots in the bleached clay; in which the bleaching is more intensive than in the surrounding material. The contrast between these lighter and darker parts grows greater downward in the section and becomes still clearer when the spots begin to show a pink colour, whereas the surrounding material remains light-yellow to cream-coloured. In these spots locally concentrations of iron hydroxides appear, which show a relatively rapid expansion.

Quartz grains which in the top of the zone of bleaching still are enclosed normally in the Coropina clay, show solution symptoms downward in the section. They are found partly dissolved in the pores of the clay.

In the transition zone the pink spots as well as the concentrations of iron hydroxides begin to indurate; the relicts of the quartz grains are continually getting smaller.

It is a fact that a number of these quartz grains dissolve only very slowly, and a few have been found practically unaffected very low in the section, sometimes even down into the bauxite.

The hardening process continues gradually, so that the material which surrounds the spots also loses its plasticity. Ultimately a material is produced, which has indurated completely and which consists of pink to cream and brown-red, irregularly shaped small pieces, enclosed in a hardened matrix of yellow to pink-coloured material. In some places a little remnant of bleached clay has been found; the quartz grains have almost entirely disappeared. The pseudo-breccia thus formed consists of bauxite (fig. 32). Such gradual developments can not be observed in many places. The bleaching may take place over a relatively short distance and it has often been observed that complete bauxitization occurs in only slightly bleached Coropina clay.

Ferrite is found in the upper part of the bauxite-ferrite bed. Only occasionally are ferrite beds encountered which continue over a longer distance. Sometimes the ferrite wedges out but mostly it is broken off abruptly and shows boulder-like form with a diameter up to 5 metres.

Continuous banks of limonite are encountered more often; generally they do not occur thicker than 50 centimetres. These limonite banks (fig. 33) are found both in the Coropina clay and in the upper part of the bauxite-

[7]) Dr. D. R. de Vletter, Personal Communication.

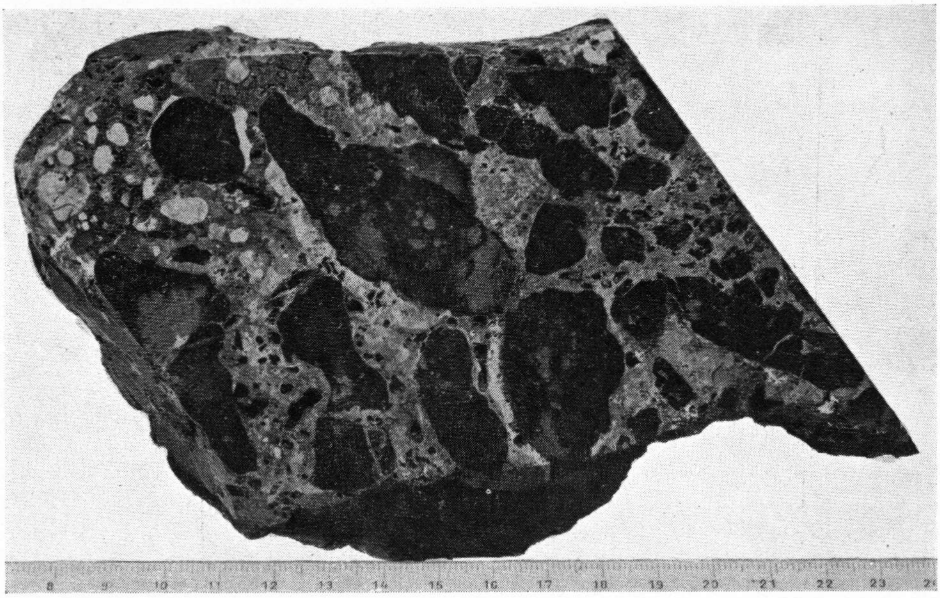

Fig. 32. Pseudo-breccia of bauxite, Onverdacht.

Fig. 33. Limonite bank in the transition zone soil cover — bauxite-ferrite, Onverdacht.

ferrite bed. These banks, as far as they have been found in the bauxite-ferrite bed, may contain large quantities of hematite. Locally faulting occurs, while here and there banks have been shattered completely; later on the fragments have been cemented (fig. 34).

In the ferrite, also, faults are often found, along which bleached Coropina clay has penetrated in many cases. Generally the following structure types may be distinguished in the ferrite:

a. Dense, homogeneous ferrite, brown to red-brown in colour the material is fine-grained. Hematite has frequently been found as a filling of vugs and pores.

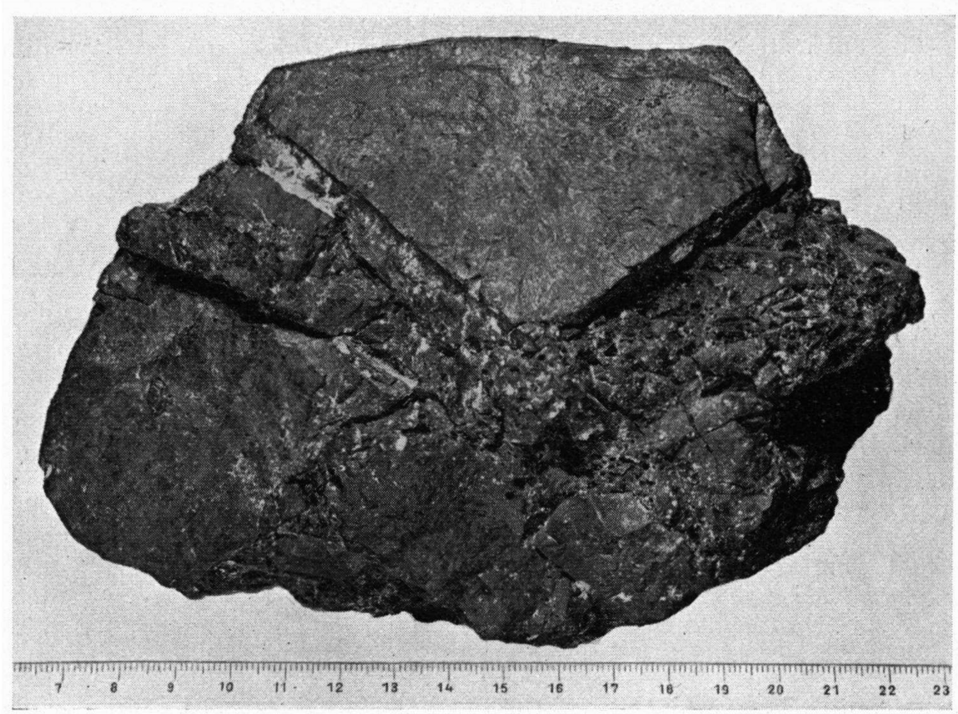

Fig. 34. Part of a limonite bank, consisting of hematite, which has been crushed and later cemented.

b. The porous ferrite shows a very fine spongy structure and is very fine-grained. The pores have a diameter of from 0.1 to 3 millimetres; also vugs are sometimes observed. Hematite occurs here too, mostly covering the walls of the pores.

c. Cellular ferrite. The lamellae are often very thin and extremely brittle, though lamellae have been found of approximately 1 millimetre thick. The intercellular spaces are often empty, but intercellular spaces filled with white clay and bauxite clay have been found also. The lamellea consist of cryptocrystalline hematite.

The transition of ferrite to bauxite may be very gradual as well as very rapid. In the first case the Fe_2O_3-content augments gradually and the transition runs via bauxo-ferrite and ferro-bauxite to bauxite, in the second case the bauxite has a sharp contact with the ferrite (fig. 35).

On the basis of the structure the *bauxite* may be divided into a number of main types:

a. Dense, homogeneous bauxite consists of coarse, fine and cryptocrystalline gibbsite. The coarsely crystalline type has a sugar-grain appearance; it is light yellow to colourless.
b. Porous bauxite has a fine spongy appearance. The bauxite consists of cryptocrystalline and finely crystalline gibbsite. Sometimes the pores still contain some quartz grains (fig. 36).
c. Laminated bauxite, the lamination which always runs horizontally is caused among other things by an alternation of thin beds (up to 5 millimetres thick) of clay and bauxite (fig. 37); very frequently lamination is formed by alternating thin beds with higher and lower Fe_2O_3-content. A different form of lamination is constituted by thin beds of coarse and of finely crystalline gibbsite.
d. The lamellae of the cellular bauxite generally are very thin and consist of finely crystalline gibbsite. The lamellae often have been arranged radially. Between the small leaves of these rosettes and also intercellular, bauxite clay and white clay (kaolin) are often found. Bauxite clay and kaolin sometimes are missing, in which cases the cellular bauxite consists of a number of rosettes (fig 38) grown together.
e. Bauxite clay with concretions. The clay is distinguishable from the white kaolin by its very fast disintegration in water. Mostly the concretions are very irregularly shaped and they are built up of finely- to cryptocrystalline gibbsite. The pores and vugs frequently are filled with coarsely crystalline gibbsite. The bauxite clay itself is of a white colour and consists of very fine-grained gibbsite.

The bauxite types generally are encountered at certain places in the section. The dense, homogeneous bauxite has been found in the top of the bauxite-ferrite bed, where the pseudo-breccia has been found too. Porous bauxite has also been found in the top of the bauxite-ferrite cover, although in smaller quantities. Laminated bauxite is usually found in the centre and in the lower part of the bauxite bed. Generally in the centre and the lower part cellular bauxite is found, mixed and alternated with bauxite clay with concretions.

The *transition zone* consists of cellular bauxite, bauxite clay with concretions and of white clay (kaolin). Downward the kaolin increasingly predominates. Frequently concretions are found, but they disappear soon, after which only kaolin is left. Panning samples of the kaolin contain relatively numerous quartz grains, the number of which in the transition zone is already considerable smaller, while in the bauxite they have practically disappeared.

The *sedimentary clay* (as the X-ray investigation has shown the pre-

Fig. 35. Sharp boundary between ferrite and bauxite, Onverdacht.

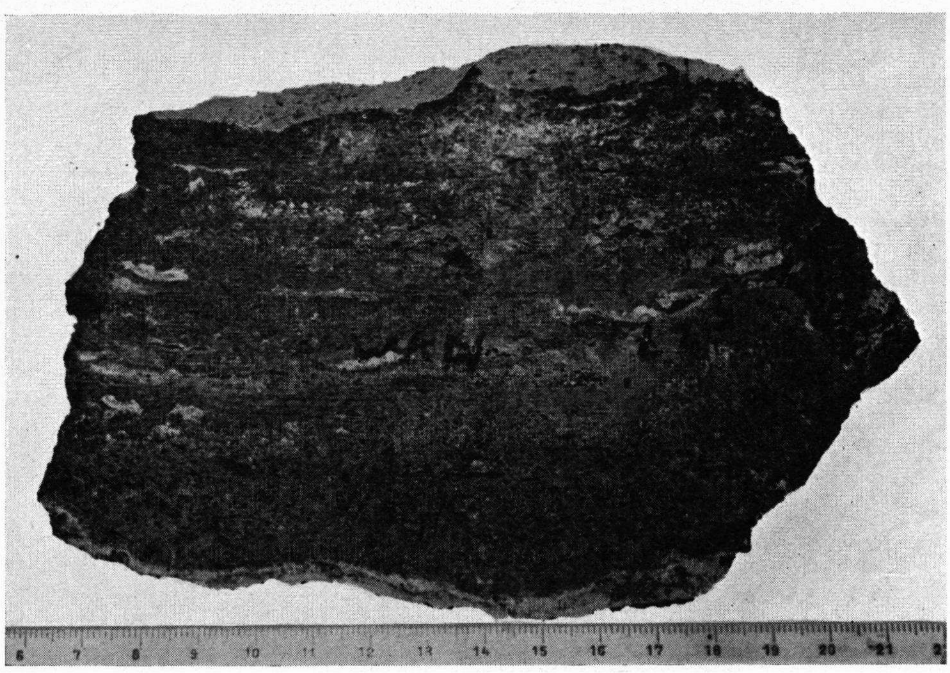

Fig. 36. Porous bauxite, quartz grains are found locally in the pores, Onverdacht.

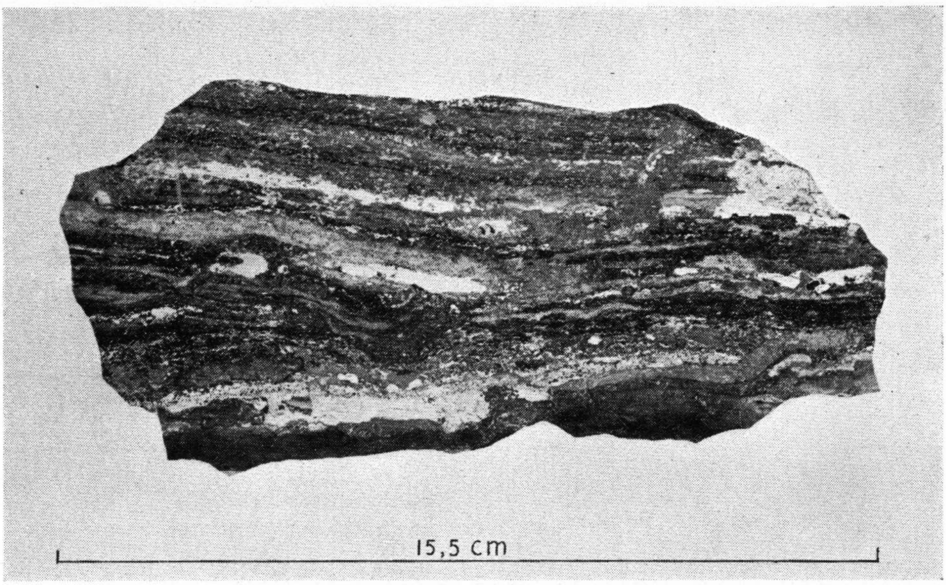

Fig. 37. Laminated bauxite with small intercalations of kaolin, Onverdacht.

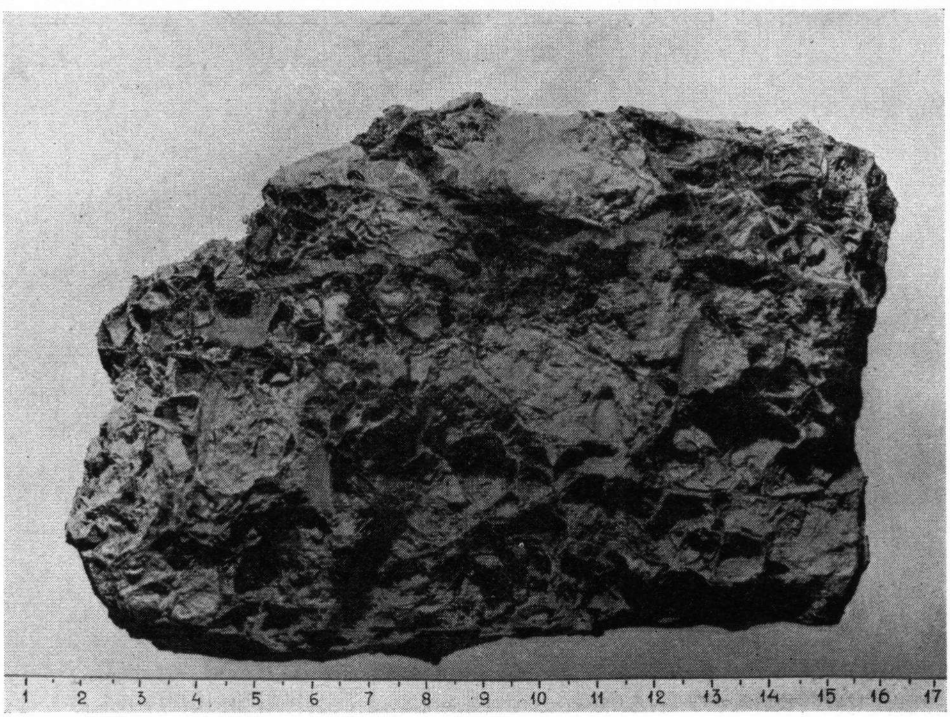

Fig. 38. Cellular bauxite, Onverdacht.

pondering clay mineral is kaolinite, see page 330) attains a thickness of about 11 metres in this section. The kaolin is very plastic and homogeneous. Mostly the colour is white, locally the clay is light yellow to pink, here and there even purple to dark purple. Numerous joints with slickensides have been found in the kaolin.

Upon the joint planes in the top of the kaolin often finely crystalline gibbsite is found. In some places the bauxite extends from the joints. This process may continue, in which case in the top of the transition zone bauxite

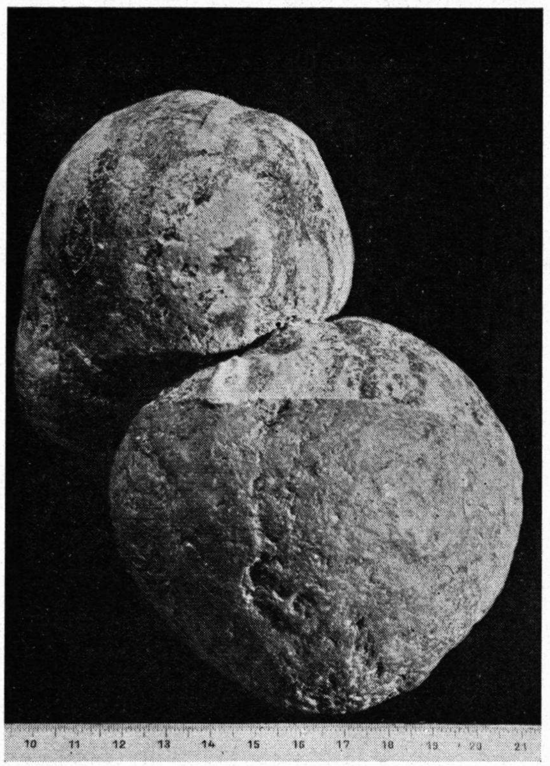

Fig. 39. Two conjoined egg-shaped concretions, Onverdacht.

is found with the same structure as the kaolin. Concretions of bauxite are found in small quantities throughout the kaolin bed.

In some levels there are concentrations of concretions, while in the centre and at the bottom of the kaolin bed, bauxite-beds have been found which have a thickness of from about 5 centimetres to 10 centimetres. Sand lenses and -beds have been found, in the kaolin bed, varying in thickness between about 10 and 80 centrimetres.

Here too, the bauxite eggs form the most striking concretions (fig. 39).

The kaolin overlies *coarse sands*, which have a great resemblance with the sand facies of the Zandery formation. The thickness of this bed is unknown.

SECTION B (fig. 40)

In this section the following beds occur:

	thickness
Lelydorp sand	1.5 metres
Coropina clay	6 metres
Transition zone	0.8 metre
Bauxite-ferrite	5 metres
Transition zone	0.5 metre
Sedimentary clay	16.0 metres
Coarse sand	— —

This section has a great resemblance with section A, but the bleaching zone is limited to a zone of about 2 to 3 metres.

Pale spots of a diameter of 2 to 80 centimetres have been found locally in the Coropina clay. At the bottom of the Coropina clay next to the transition zone rings can be distinguished clearly around bleached spots, which vary in intensity of bleaching. The intensity increases to the centre of the spot. In the transition zone the differentiation in intensity has become still larger and the centre of the spots has hardened. From the outside inward an increasing degree of solution of the quartz grains may be observed.

In this way boulders come into existence which are cemented by bauxite-ferrite at the bottom of the transition zone and which form a massive bauxite-ferrite bed.

In a certain number of boulders the Fe_2O_3-content increases and ferrite is formed, which thus occurs as boulders in the bauxite-ferrite bed. Banks of ferrite were not found, even over short distances.

The other deposits as well as the occurring structure types of bauxite and ferrite agree with the description given in section A.

SECTION C (fig. 41).

Here the cover is formed by a bed of black plastic swamp mud, which is very rich in remains of plants (fig. 42). This bed of a thickness of a few metres rests on a very thin bleached bed which overlies the transition zone and the bauxite. The thickness of the bleached bed and transition zone amounts to 1 metre at most.

In the also very plastic bleached bed have been found separate concentrations of cellular bauxite. The lamellae of the cellular bauxite are very thin and extremely brittle. Downward, the cellular bauxite concentrations increase very quickly to a bauxite bed, which besides this material contains very much bauxite clay. Except for some very small cellular concretions, ferrite has practically not been found.

An Indian axe was found in the bauxite bed which is very rich in plant remains.

Below this swamp the bauxite bed shows two ridges which almost reach the surface (fig. 43).

The bauxite at this locality had a lower percentage of SiO_2 than bauxite from other localities at Onverdacht. The transition bed, the kaolin and the sand did not show important differences with the deposits mentioned in the preceding sections.

The bauxite bed has a slight dip to the north. From the presence of

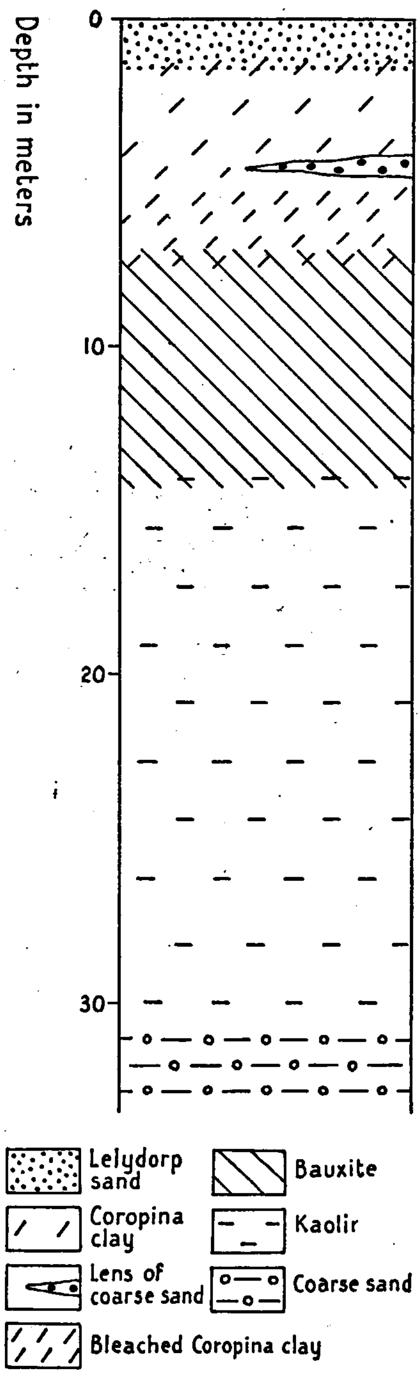

Fig. 40. Section B, Onverdacht.

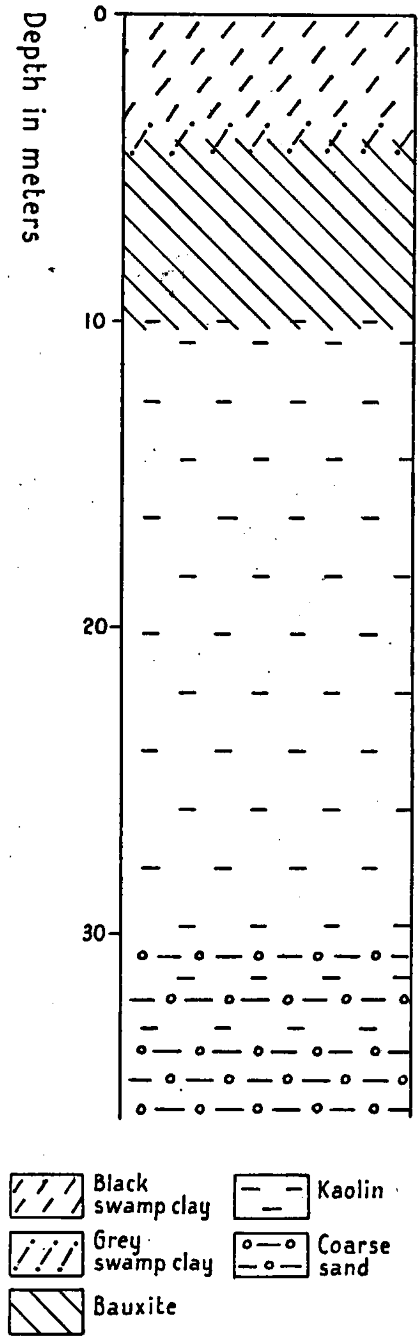

Fig. 41. Section C, Onverdacht.

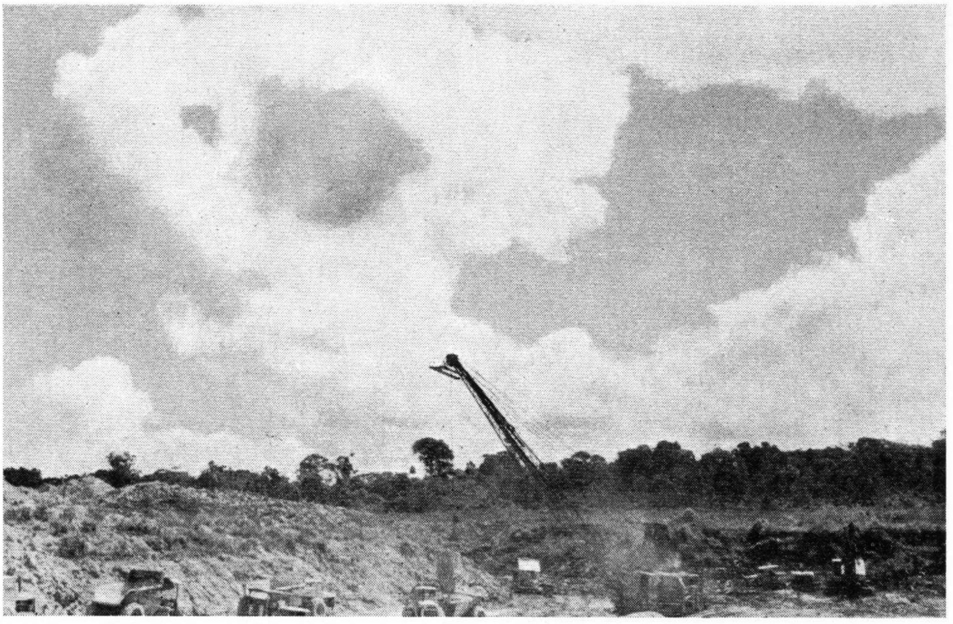

Fig. 42. Removal, with a mechanical shovel, of the swamp clay, which forms here the soil cover over the bauxite, which is removed with a dragline (Onverdacht).

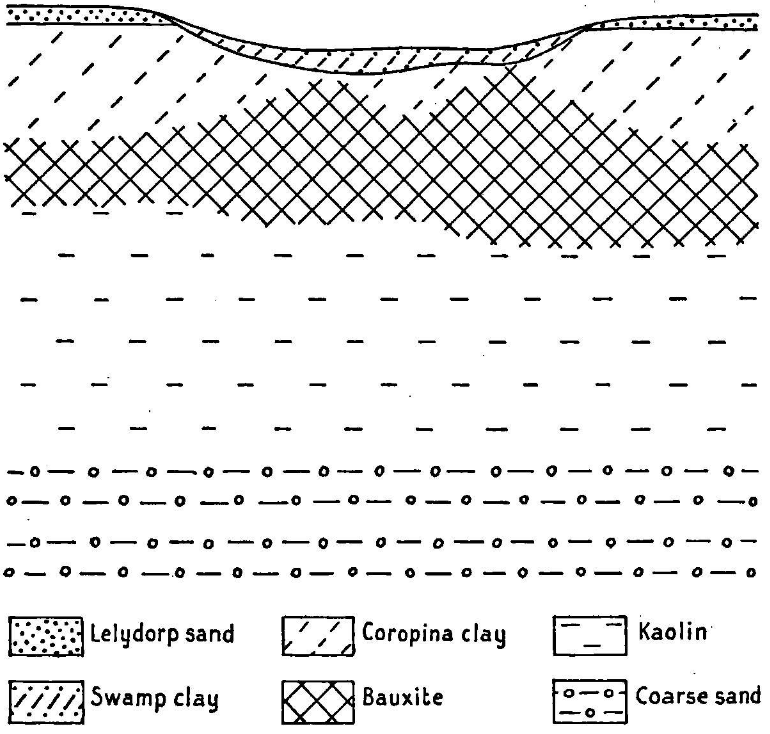

Fig. 43. Schematic section through a swamp showing two ridges in the bauxite underlying the swamp (Onverdacht).

gullys, filled with sand and bauxite-ferrite pebbles, may be concluded that formerly the bauxite-ferrite was situated at the surface as the weathering mantle over the sedimentary clay (kaolin), which is found below the bauxite-ferrite bed.

A large part of this bauxite-ferrite bed has disappeared through erosion. The remnants of the bauxite-ferrite bed which consisted of a more or less continuous cover, was covered by sediments of the Coropina formation.

Probably the Coropina Sea extended to the foot of the Onoribo Hill. All bauxite which was situated below this level was covered with sediments, while the bauxite-ferrite bed which was more elevated, remained uncovered, and has been found as a weathering cover over the hills at Moengo and Paranam.

Thus a fundamental difference can not be attributed to the High-level and the Medium-level type bauxite.

After the covering of part of the bauxite-ferrite bed with clays and sands, the formation of bauxite has continued, as appears from the bleaching and transition zones described in the three sections mentioned earlier.

The bauxite-ferrite layer happened to be situated partly below the groundwater table; a growing of the bauxite-ferrite bed at the cost of the Coropina clay took place, which is also the case with the underlying kaolin.

The bauxite-ferrite covers such as those at Moengo and Paranam, generally show a constant thickness. At Onverdacht the upper limit is relatively irregular, which is also the case with the lower limit in the kaolin, pockets of bauxite-ferrite have been found up to 6 to 7 metres deep. In some places where the bauxite-ferrite underlies a swamp, it is evident that the bauxite-ferrite bed has gone up more or less.

On the basis of a drilling map of the N.V. Billiton Maatschappij at Onverdacht, it was traced how far this is the case generally below swamps. From the data it appeared that a tendency may be detected but it has turned out not to be a general rule.

The material which is subject to bauxitization here, is a sub-recent to recent swamp clay.

E. LOW-LEVEL TYPE BAUXITE

The bauxite deposits at Mackenzie and Ituni (Demerara) (fig. 1 and 44)

The deposits are situated in a terrain which consists practically entirely of material belonging to the White Sand Series.

Mr. C. Barrington Brown [8]), the founder of geological investigation in British Guiana in 1873 mentioned the discovery of "lumps of a reddish-white friable pisolitic rock" near the Demerara River, Bracewell (1947) remarks that this undoubtedly was bauxite. In 1910 Sir John Harrison first recognized and described the occurrence of bauxite on the basis of an analysis published in the Official Gazette of British Guiana. The material was taken from the old Government rubber experimental station at Christianburg.

Bracewell (1947) remarks that the bauxite deposits are situated in a belt running from north to northwest from Kwakani on the Berbice River to the mouth of the Essequibo River. They occur as cappings over an old land area, which by this time has been covered with sediments of the White

[8]) Bracewell, 1947.

Sand Series. The deposits are situated between 100 feet below and 200 feet above sea-level, the highest are found at Ituni.

Concerning the bauxite in British Guiana HARDER (1949) mentions the following:

The bedrock underlying the bauxite deposits (separated by a bed of residuary clay) is of Pre-Cambrian age. A number of intrusive, metamorphic

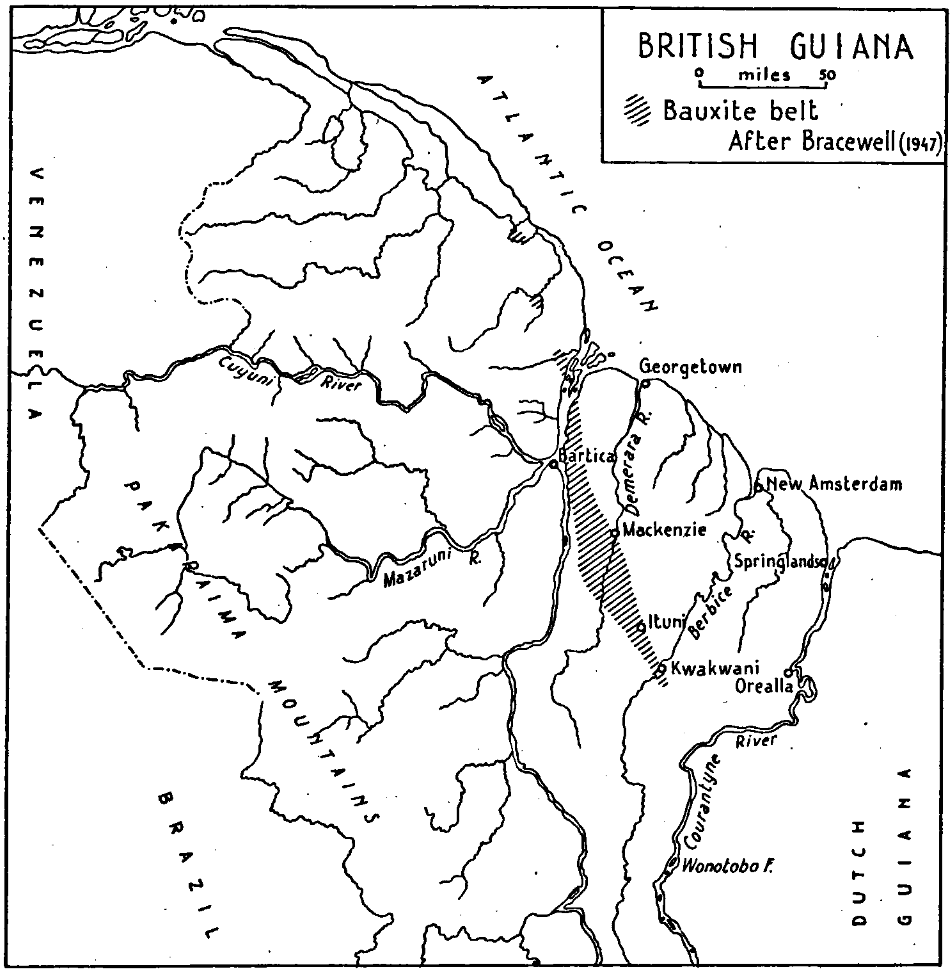

Fig. 44. Disposition of bauxite in Demerara, after BRACEWELL (1947).

and volcanic rocks in this bedrock are of more recent data. The crystalline bedrock consists of acid as well as of basic gneisses and schists; as intrusive rocks are found granites, syenites, diorites and dolerites. Locally the residuary clay is more than 100 feet thick. Here and there the bauxite bed attains a thickness of more than 40 feet. The upper part consists of a siliceous capping, in which bauxite pebbles and larger masses in a bauxite clay matrix are found. The bauxite clay extends downward into the bauxite. Out of the lower part of the bauxite bed, pipes and small veins of bauxite run into the lower residual clay. Bauxite with a low content of SiO_2 forms the centre of the bauxite beds. In places where the bauxite is missing, the cover over the bauxite and the residual clay consists of material belonging to the White Sand Series. This material consists of sand with intercalated clay beds; locally lignite banks have been found in the lower part of the deposit. These sediments attain a thickness of 300 feet in the bauxite district.

GRANTHAM (BRACEWELL, 1947) described part of the White Sand region between the large rivers as "a stratified succession of white, yellow and red sands, quartz gravels, light grey or reddish clays and peaty sands with occasional seams of lignite" and called it the White Sand Series.

The Zandery formation in Suriname agrees with this description. The White Sand Series wedges out to the south against the bedrock.

BRACEWELL mentions foraminifera has been found, forming the only indication of the age. These foraminifera form the transition between species which are found in sub-recent lagoon deposits and the lignite facies of Miocene or Pliocene age in Trinidad.

Except for some outcrops in the Demerara river and a few outcrops at Ituni, the bauxite deposits underlie a cover of sediments of the White Sand Series.

At Mackenzie two sections were measured by the author, one in the Montgomery Mine and a second in the Maria Elisabeth Mine, while data for a third section were gathered at Ituni. All these mines are situated in the White Sand Series.

SECTION A. MONTGOMERY MINE (fig. 45)

The soil cover is formed by material which belongs to the White Sand Series and resembles the material found in Suriname in the Zandery formation. The sands are rather coarse-grained

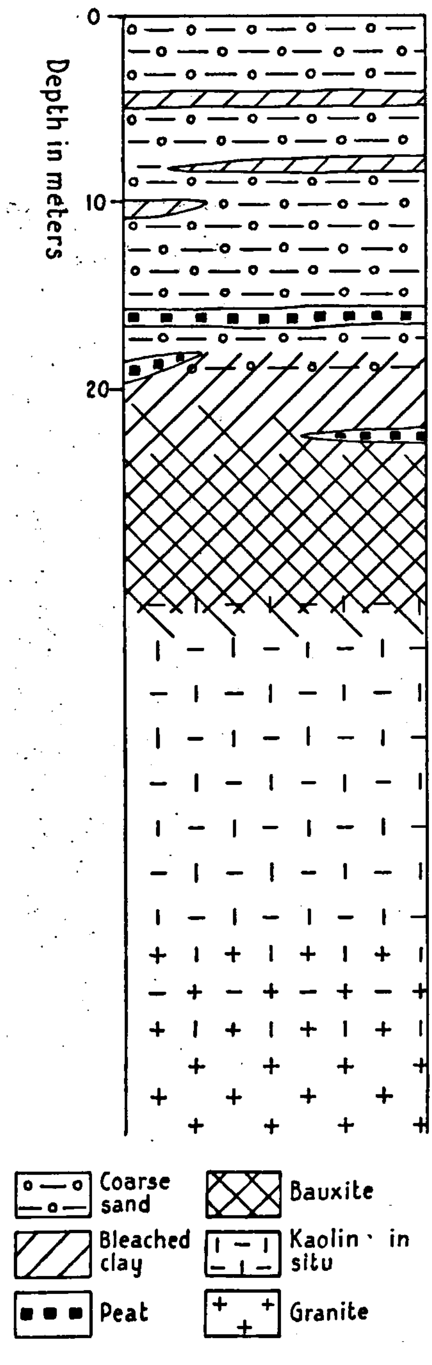

Fig. 45. Section A, Montgomery Mine (Mackenzie).

and in the top of the section they are laminated horizontally. Some beds contain many quartz pebbles, some of which sometimes attain a diameter of 2 centimetres. Lower in the sections clay beds were found, which generally lie more or less horizontal; here and there they plunge under the sands with a slight angle. Still lower in the section more and more clay beds begin to appear, while in the sand often a very well-developed cross-bedding structure may be observed (fig. 46).

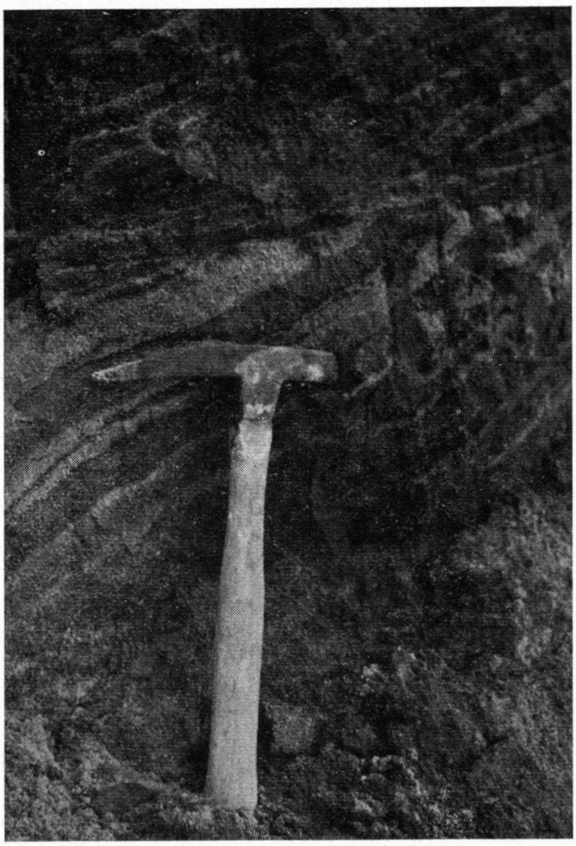

Fig. 46. Cross-bedding structure in the sands of the soil cover (White Sand Series), Montgomery Mine (Mackenzie).

The sands in the top of the section are mostly white, while locally light pink to light brown colours may dominate. Still lower in the section more and more plant remains begin to appear; the sands as well as the clays often show a dark brown to black colour. Small lignite beds are appearing, locally lignite beds occur with a thickness of 3 metres, in which charred tree-trunks have been found. A number of these beds lie horizontal and at a certain distance they wedge out: other beds, however, dip slightly and may be followed into the bauxite (fig. 47).

The bauxite is covered by a transition zone, which varies in thickness from a few centimetres to a few metres. The transition zone consists of bleached clay which contains bauxite concretions. Quartz grains in this transition zone clearly show solution symptoms. The bleaching precedes bauxitization and especially in the thin transition beds bauxitization promptly follows bleaching.

In the case that a lignite bed or a strongly carbonaceous clay bed is situated above the bauxite it was noticed that the bleaching penetrates most sharply into the black carbonaceous beds (fig. 48 and 49). The bauxitization

Fig. 47. Lignite banks pitched in the bauxite, Montgomery Mine (Mackenzie).

is practically immediately perceptible through the spots which consist in the centre already of indurated concretionary material.

In the top of the bauxite bed large pieces of charcoal were found locally which are enclosed in the bauxite. Lower in the bauxite bed remnants of charcoal are found only here and there; mostly small holes were found, which contain small "skeletons" of limonite.

The bauxite here is much denser and more homogeneous in comparison with the High- and Medium-level type bauxite found in Suriname. A horizontal lamination in the upper part and the centre of the bauxite bed also attracts the attention, only locally this is observed at the bottom of the bed.

The bauxite overlies a bed of residuary clay; the transition zone between the bauxite and the residuary clay is much less well-developed than that of the White Sand Series — bauxite. This bed attains a thickness of about 1 metre to 1.5 metres and it contains many bauxite concretions. Washed samples of the lower part of this transition bed contain more quartz than washed

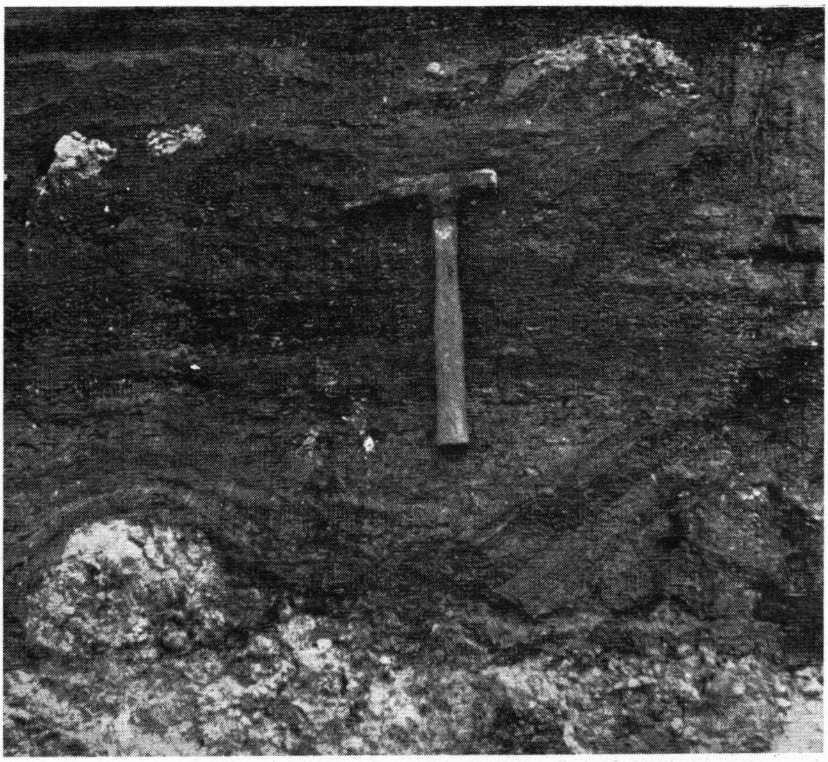

Fig. 48. Bleaching in lignite containing sandy clay in the transition zone of the Montgomery Mine (Mackenzie).

Fig. 49. Bleaching in clay with a high lignite content in the transition zone in the Montgomery Mine (Mackenzie).

samples of the upper part of the bed, the grains out of the upper part show many more solution symptoms in contrast with the grains out of the lower part.

The clay below the bauxite, at least in places where observations were possible, is residual and it is the autochthonous weathering product of solid rock. Laboratory investigation shows that the clay consists for the most part of kaolinite.

The Demerara Bauxite Company put some drilling cores of solid rock at the disposal of the author and these show that the solid rock consists among other things of granite.

SECTION B. MARIA ELISABETH MINE (fig. 50)

Here material of the White Sand Series forms the cover.

Sand beds of different grain size alternate, while intercalations of clay beds occur, which mostly contain many quartz grains. Locally in the sand beds small quartz pebbles were found of up to 3 cm diameter. These have especially been found in the top of the section. Cross-bedding occurs very often here (fig. 51). Organic remains have been found only now and then, at the bottom of the cover there are several limonite beds with a thickness of a few centimetres.

Between this cover, which consists at the bottom of alternating sand and clay beds (the latter may attain a thickness of about 2 metres) and the bauxite bed, a transition zone is found which consists of bleached clay with concretions (fig. 52). The quartz grains show nice solutions symptoms; pores with relicts of quartz grains are found frequently. The bauxite shows a very distinct horizontal lamination and locally contains many impurities in the form of small "skeletons" of limonite.

Locally the bauxite is very granular and contains much bauxite clay. In the bauxite, intercalations of indurated

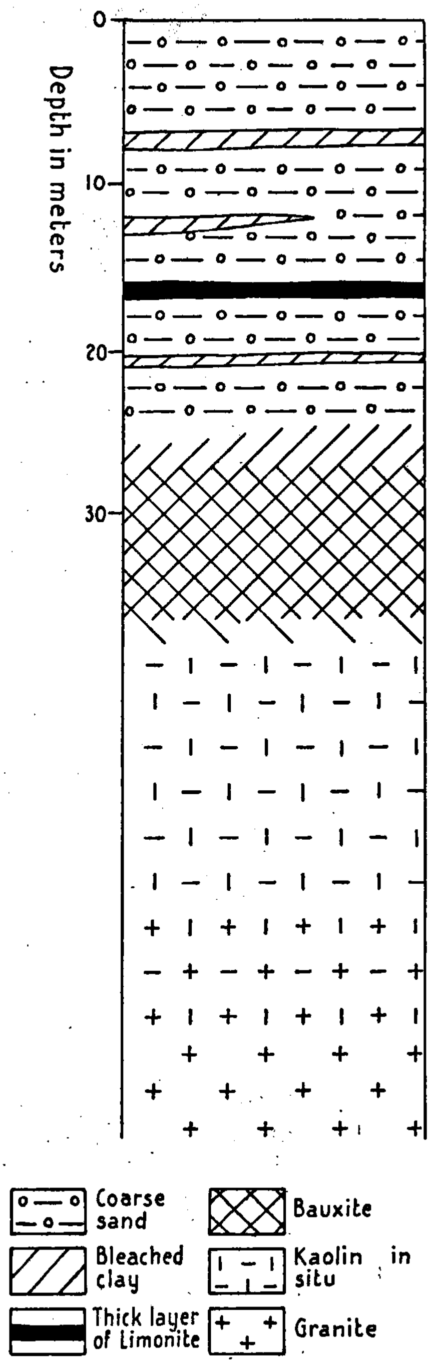

Fig. 50. Section B, Maria Elisabeth Mine (Mackenzie).

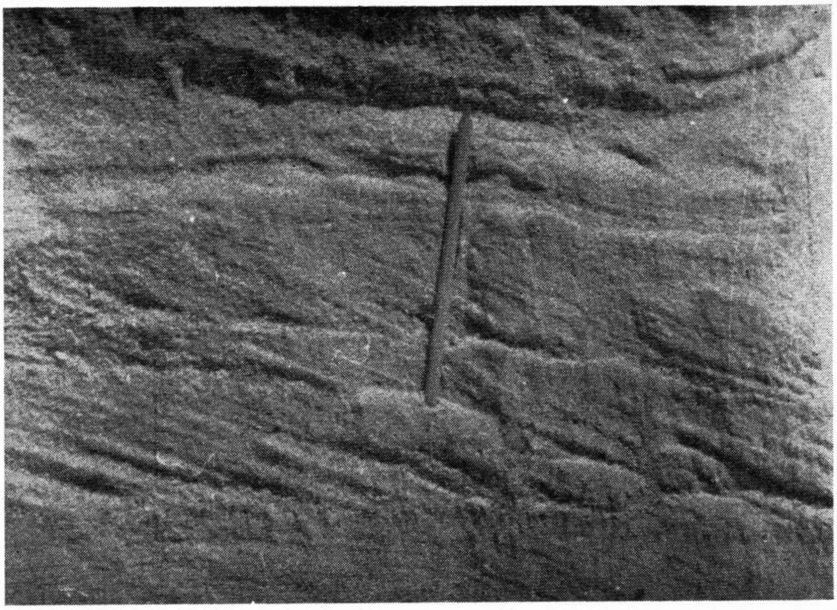

Fig. 51. Cross-bedding structure in the sands of the soil cover (White Sand Series), Maria Elisabeth Mine (Mackenzie).

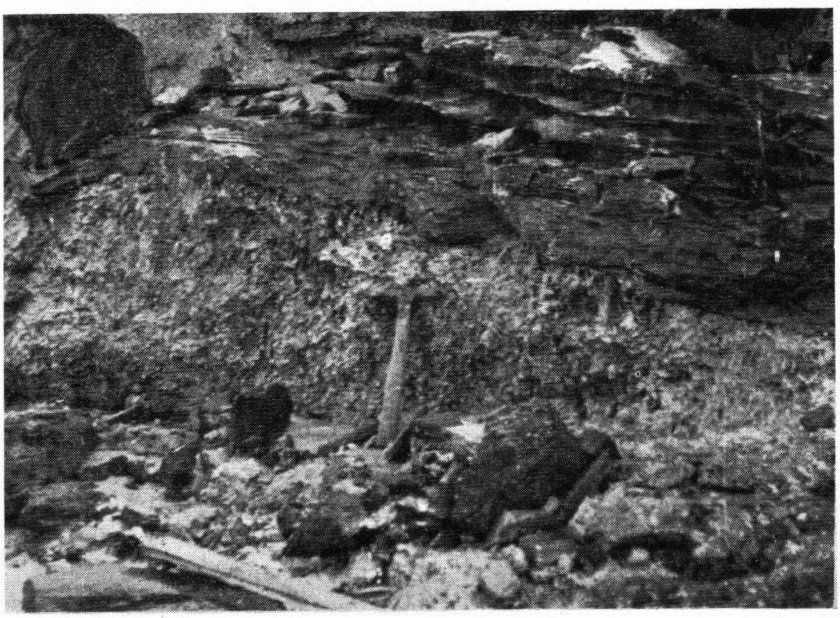

Fig. 52. Transition zone, against which the hammer is placed, stopping abruptly against the lignite containing sandlayer. Maria Elisabeth Mine (Mackenzie).

kaolin occur, which show a great resemblance to the white bauxite clay.

A transition zone between the bauxite and the underlying kaolin is found. The thickness of this bed amounts to one metre at most and downward it contains a decreasing number of bauxite concretions.

In all probability the clay is the autochthonous weathering product of solid rock, which here too, is of a granitic composition, while one of the cores represents a dolerite.

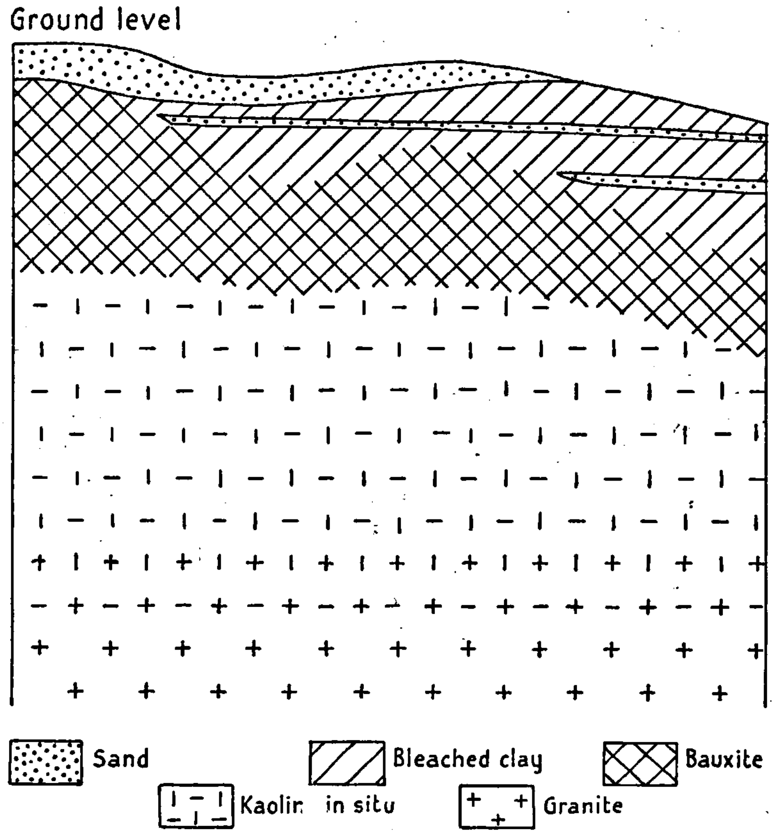

Fig. 53. Section C. Ituni Mine (Ituni).

SECTION C. ITUNI MINE (fig. 53)

At some places the soil cover is missing; elsewhere it has a thickness of a few metres and to the north it increases in size. This cover consists of sand and clay beds and -lenses. The sand is less coarse-grained than that which has been found in the Maria Elisabeth and the Montgomery Mine. Part of the cover consists of material from the White Sand Series, part consists of alluvial material.

The clays show a bleaching which increases downward in intensity. In the transition zone between soil cover and bauxite-ferrite, which in size varies from a few decimetres to about 1.5 metres, quartz grains are found, which often show symptoms of solution. The bauxite concretions increase from the top down and change into a homogeneous bauxite bed.

The surface of the bauxite-ferrite bed is very irregular and it gives strongly the impression, that earlier a large number of creeks existed (fig. 54). This impression is strengthened by the occurrence of pebbles of bauxite-ferrite in the depressions which strongly resemble gullys in the ore-surface. In the top of the bauxite-ferrite bed the ferrite locally has been well-developed.

The occurrence of poorly developed pisolitic bauxite in the upper part

Fig. 54. Irregular surface of the bauxite-ferrite layer at Ituni, caused by old creekbeds.

of the bauxite bed is very striking. Lower in the bed the pisolitic bauxite has not been found. In places where the cover has attained a thickness of about 7 metres and more, this poorly developed pisolitic bauxite was not found either.

The transition zone between bauxite and residuary clay is well exposed; within a zone with a thickness of about 1.5 metres the bauxite changes into the clay, via concretions which decrease in quantity.

The clay is a residual one, a fact which could be ascertained by the occurrence of muscovite nests without any orientation, while the structure shows a very great resemblance with the granite. (The laboratory investigation showed that this clay consists for the most part of kaolinite.)

The drill-cores show that here again the solid rock partly consists of granite.

From the field data appears that here we have two kinds of bauxite. The bottom part of the bauxite-ferrite bed of the Low-level bauxite is the weathering product of solid rock, which is among other things of a granitic composition, whereas the upper part is the weathering product of sedimentary clay.

Once the bauxite, found as a weathering product of the bedrock from which it is separated by a bed of residuary kaolin, formed a peneplain (BRACEWELL 1947), in which phase large parts have disappeared through erosion. The remnants have been covered with sediments which belong to the White Sand Series.

After the covering of the bauxite-ferrite with these sediments the bauxitization process has continued, and the bauxite-ferrite bed has increased in thickness not only at the cost of the underlying kaolin but also of the clay facies of the White Sand Series which forms the lower part of this Series.

Of the three described transition zones between bauxite-ferrite and cover sediments in section A, B and C, the one in the Montgomery Mine is the best developed. Next best is the transition zone in the Maria Elisabeth Mine and then the transition zone at Ituni in places where the cover is but a few metres thick. Of these three transition zones the one at Ituni is situated above the groundwater table and those of the Montgomery Mine and the Maria Elisabeth Mine below the groundwater table. The transition zone in the Montgomery Mine has been influenced by the occurrence of lignite beds in the lower parts of the White Sand Series. We see that the transition zone below these lignite beds is the largest and also that it reaches higher elevations. Often the transition zone lies against a sandy bed, in which case we see in the sand bed thin clay lenses which have been bleached entirely and often partly bauxitized.

That in the Montgomery Mine and in the Maria Elisabeth Mine practically no indications are found that the bauxite formerly was situated at the surface, probably is caused by the well-developed transition zones and by the increase in thickness of the bauxite-ferrite bed, which undoubtedly has eliminated in many places indications, such as pebbles and old creek beds.

F. SOME REMARKS ON THE OBTAINED FIELD DATA

In all cases the bauxite-ferrite rests upon a bed of kaolin, which has a residuary character in the Plateau type and Low-level type, and a sedimentary character in the High-level and Medium-level types. In the field, however, it is impossible to ascertain, whether we have here a sedimentary clay, which has been kaolinized subsequently or a sedimentary kaolin.

The bauxite-ferrite deposits have formed part of considerably larger units and they constitute only the last remnants. For the deposits of the Plateau- and Low-level type a peneplain may be considered; however it is doubtful whether both types have formed part of the same peneplain. The mineralogical investigation indicates that the Plateau type bauxite is older than the Low-level type bauxite. This does not necessarily mean, that two peneplains have to be postulated, because the possibility of two periods of intensive bauxitization during the same peneplain-phase exists also. The difference in elevation between these two types might be explained by the fact, that probably younger movements have had a great influence in the Guianas (SCHOLS and COHEN, 1953).

It could be ascertained, that part of the bauxite-ferrite, belonging to the deposits of the Medium- and Low-level type, was situated on the surface before covering with sediments took place.

The Low-level type bauxite was covered with sediments from the Zandery formation, so that no erosion could take place in contrast with the Plateau type bauxite, where the erosion continued. The fact that the Plateau type was not covered with protecting sedimens and the probably older age may be the reason why the Plateau type was not found in large quantities, in contrast to the Low-level type bauxite.

The bauxites and ferrites of the High-level and Medium-level type are the weathering product of an alluvial plain upon which it has been found as a weathering cover. This alluvial plain is faintly inclined to the north. Both types formed part of the same alluvial plain, which is evident at the Onoribo Hill at Paranam (fig. 29). In both types the bauxization commenced at the same time.

After already a large part of the bauxite had disappeared through erosion, the northern part of the alluvial plain was covered with sediments of the Coropina formation. These sediments wedge out against the remnants of the bauxitized alluvial plain. This northern part, covered with sediments, at present is found back in the form of Medium-level type bauxite; the southern part, which was situated at a higher elevation, at present is found as High-level type bauxite. The Medium-level type bauxite covered with sediments of the Coropina formation, have been saved from further erosion, while the High-level type bauxite has remained exposed to erosion.

Bauxite-ferrite has not been found directly on solid rock or on clay which is not kaolinized. The occurrence of kaolin in the examined deposits seems to be connected closely with the appearance of bauxite-ferrite.

The data on the transition zone between the bauxite and the kaolin show that desilicification plays an important part. After covering of the deposits of the Medium- and Low-level type with sediments, the bauxitization did not come to a standsstill. It is evident, that in the transition zone between the soil cover and the bauxite-ferrite, desilicification is preceded by bleaching, which leads to the formation of bauxite.

At Onverdacht this process was found in sub-recent to recent swamp clays, so that it may be supposed that this bauxitization process has not yet come to a standstill.

The mineralogical composition of the various beds and deposits as well as the changes in mineralogical and chemical composition will be discussed in the following chapter.

In the north—south section (fig. 55) the fundamental position of the various types of deposits of bauxite has been indicated.

It is very unlikely that in Suriname still exist important deposits of the Plateau type. The bauxite-ferrite deposits of this type can easily be discovered on aerial photographs and probably they are now all known with few exceptions of minor importance in northern Suriname. It is possible that in southern Suriname a number of larger deposits may still be found. But even if such deposits were still found, it would be questionable whether they could be worked economically, while the transportation difficulties would also make these deposits less attractive.

The existence of more bauxite deposits of the High-level type is very questionable too. This type may also be recognized relatively easily on aerial photographs; the deposits are located in a belt parallel to the coast within the Coropina and Zandery formations. Aerial photographs are available of the whole area; other deposits of the extent of Moengo or Paranam were not observed.

Small hills of this type have been found, but it is very difficult to distinguish them on an aerial photograph from other small hills in the terrain, which have not been covered by bauxite-ferrite. The small hills covered with bauxite-ferrite may be very important as indicating outcrops of bauxite, which belongs to the Medium-level type, a type which may then be expected in the near vicinity.

The bauxite of the Medium- and Low-level types as has been remarked, have been covered with sediments and thus preserved from further erosion, whereas, at the same time an increase of the bauxite bed at the cost of this soil cover takes place. This sedimentary cover of the deposits makes the discovery by aerial photographs more difficult.

Deposits of the Medium-level type may be expected in the Coropina formation. A combined investigation of aerial photographs and fieldwork together with the performing of a large number of drilling operations will be necessary to obtain a picture of the position of the contact between the Coropina formation and the Zandery formation. On the basis of the data obtained, the most probable position and extension of the remains of the old bauxitized alluvial plain may be ascertained.

Up to now the Low-level bauxite type has not been found in Suriname, but there are no reasons to believe that this type does not exist in Suriname. The occurrence of bauxite-ferrite boulders in the Zandery formation can only point to the existence of bauxite in the vicinity. However, here too, a combined investigation will be necessary to discover the bauxite of this type.

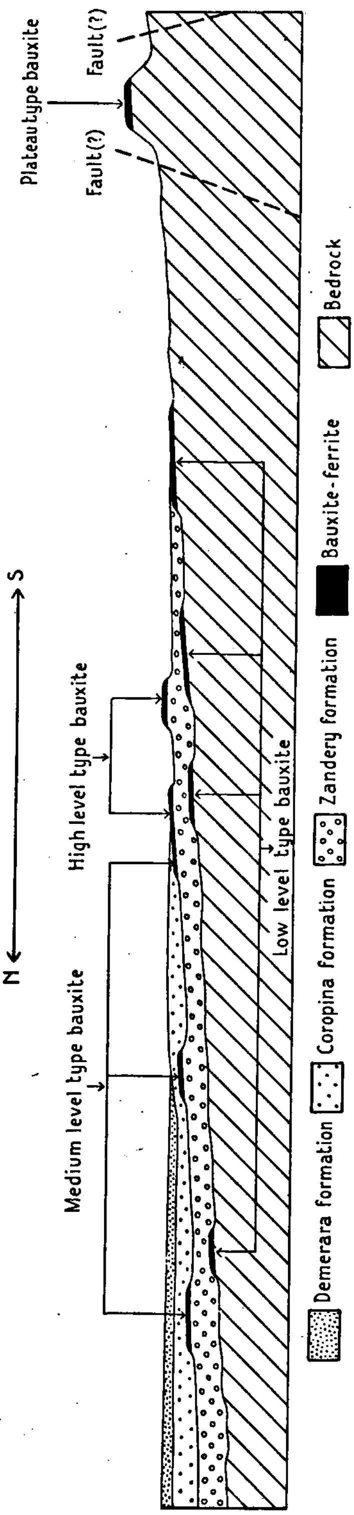

Fig. 55. Schematic section constructed from data from both Suriname and Demerara on the position of Plateau type bauxite, High-level, Medium-level and Low-level type bauxite.

CHAPTER III

MINERALOGICAL AND CHEMICAL INVESTIGATIONS

A. METHODS OF INVESTIGATION

1. The *microscopical* examination in many cases did not give adequate results, either with reflected or transmitted light, because most of the material is very fine-grained to cryptocrystalline. Therefore use was made, in addition, of X-ray, differential thermal analysis and the electron microscope.

2. The *X-ray analysis* was made with equipment of the Enraf [9]). Two cameras were available, one medium-sized Unicam camera (Bradley type) with a diameter of 9 cm and a Nonius Guinier Camera with a diameter of 11.46 cm.

For the Unicam camera the exposure time was one and a half hours, when using the iron tube and manganese filter (λFeKα-radiation = 1.93597 Å) a diaphragm of 0.3, 18 mA en 40 kV. The prepared samples were placed in a tube of Lindeman with an external diameter of 0.25 mm.

For the second camera, the Nonius Guinier camera, the exposure time amounted to 10 to 15 hours, when using a copper tube and a quartz filter (λCuKα-radiation = 1.54050 Å) a diaphragm of 0.2, 18 mA en 40 kV.

This camera has the adventage that 1° is 4 mm, a property which is of importance with minerals which have determinative reflections with a small glancing angle. In addition, four exposures can be made at the same time. The prepared samples are placed in a sample holder in which four windows have been made. Each sample is bedded in canada-balsem between two films of cellophane in one window.

3. For the *differential thermal analysis* an equipment was used, very similar to that described by Arens (1951). The oven is a low resistance type, with 50 V $\sim$ the current volume is regulated every 15 minutes to obtain a temperature gradient of 9.8° C. The sample holder is made of porcelain, in which three holes have been made, two of which are for inert material and the third for the material to be investigated. For the thermal couples use was made of platina — platina-10 % rhodium. The absolute temperature measurement is made by placing one pole of a thermal couple in the inert material (calcined Al_2O_3) while the other pole is kept outside of the oven at a constant temperature of about 10° C. A check is obtained by the method of Faust (1948) using the exothermal reaction in quartz at 573° C. when the modification-α changes into the modification-β. Of the second thermal couple one pole is placed in inert material while the second pole is placed in the material to be investigated. The registration is made by mirror galvanometers on photographic paper.

4. The *electron microscope* (Philips E. K. 1) of the Electronic-microscopical Department of Leiden University, was available for this investigation. The

[9]) N.V. Nederlandsche Röntgenapparatenfabriek.

electron micrographs were taken by Mr. W. G. BRAAMS. The samples to be examined were placed on plastic films, in a suspension in a small drop of distilled water which was then evaporated. Shadowing of the samples was obtained with Pd under a 20° angle, and the exposures were made with 100 kV.

5. The *chemical analyses* are made at the Petrochemical Laboratory of the Geological Institute, Leiden, by Miss B. HAGEMAN.

The changes in chemical composition occurring during the weathering are not clearly demonstrated by the analyses and the calculated Nigglivalues [10]). Concentration and transport however, are outlined by the calculated weathering values si′, fm′, c′, alk′, en ti′ respectively $\frac{si}{al}, \frac{fm}{al}, \frac{c}{al}, \frac{alk}{al}, \frac{ti}{al}$, in which al is considered as constant (HARRASSOWITZ, 1926).

The normative mineral composition is calculated according to the principe of normcalculation of BURRI and NIGGLI (1945), H_2O is not included in the sum 100, but is used for the calculation of the percentages gibbsite, boehmite and goethite.

The following base molecules and theoretic minerals were used.

Ab	Albite	$^1/_{16}$ $(6\,SiO_2 . Al_2O_3 . Na_2O)$.
An	Anorthite	$^1/_5$ $(2\,SiO_2 . Al_2O_3 . CaO)$.
Ant	Antigorite	$^1/_5$ $(2\,SiO_2 . 3\,MgO . 2\,H_2O)$.
Fe-Ant	Fe-antigorite	$^1/_5$ $(2\,SiO_2 . 3\,FeO . 2\,H_2O)$.
At	Amesite	$^1/_5$ $(SiO_2 . Al_2O_3 . 2\,MgO . 2\,H_2O)$.
Mg-Bi	Phlogopite	$^1/_{16}$ $(6\,SiO_2 . Al_2O_3 . 6\,MgO . K_2O . 2\,H_2O)$.
Bi I	Biotite	$^1/_{16}$ $(6\,SiO_2 . Al_2O_3 . 6\,(Fe, Mg)\,O . K_2O . 2\,H_2O)$.
Fe-Bi	Fe-biotite	$^1/_{16}$ $(6\,SiO_2 . Al_2O_3 . 6\,FeO . K_2O . 2\,H_2O)$.
Bo	Boehmite	$^1/_2$ $(Al_2O_3 . H_2O)$.
C	Corundum	$^1/_2$ (Al_2O_3).
Cal	Ca-aluminate	$^1/_3$ $(Al_2O_3 . CaO)$.
Cord	Cordierite	$^1/_{11}$ $(5\,SiO_2 . 2\,Al_2O_3 . 2\,MgO)$.
Fe-Cord	Fe-cordierite	$^1/_{11}$ $(5\,SiO_2 . 2\,Al_2O_3 . 2\,FeO)$.
Cp	Ca-phosphate	$^1/_5$ $(P_2O_5 . 3\,CaO)$.
Cs	Larnite	$^1/_3$ $(SiO_2 . 2\,CaO)$.
En	Enstatite	$^1/_2$ $(SiO_2 . MgO)$.
Fa	Fayalite	$^1/_3$ $(SiO_2 . 2\,FeO)$.
Fo	Forsterite	$^1/_3$ $(SiO_2 . 2\,MgO)$.
Fs	Ferri-silicate	$^1/_3$ $(SiO_2 . Fe_2O_3)$.
Gi	Gibbsite	$^1/_2$ $(Al_2O_3 . 3\,H_2O)$.
Go	Goethite	$^1/_2$ $(Fe_2O_3 . H_2O)$.
Gram	Grammatite	$^1/_{15}$ $(8\,SiO_2 . 5\,MgO . 2\,CaO . H_2O)$.
Hm	Hematite	$^1/_2$ (Fe_2O_3).
Hy	Hypersthene	$^1/_2$ $(SiO_2 . FeO)$.
Hz	Herzynite	$^1/_3$ $(Al_2O_3 . FeO)$.
Kaol	Kaolin	$^1/_4$ $(2\,SiO_2 . Al_2O_3 . 2\,H_2O)$.
Kp	Kaliophylite	$^1/_6$ $(2\,SiO_2 . Al_2O_3 . K_2O)$.
Ms I	Muscovite	$^1/_{14}$ $(6\,SiO_2 . 3\,Al_2O_3 . K_2O . 2\,H_2O)$.
Mt	Magnetite	$^1/_3$ $(FeO . Fe_2O_3)$.
Ne	Nepheline	$^1/_6$ $(2\,SiO_2 . Al_2O_3 . Na_2O)$.

[10]) NIGGLI, P., 1948.

Or	Orthoclase	$^1/_{10}$ ($6\,SiO_2 . Al_2O_3 . K_2O$).
Plag	Plagioclase	Mixture Ab and An
Q	Quartz	1 (SiO_2).
Ru	Rutile	1 (TiO_2).
Sc	Sericite	see Ms I
Sil	Sillimanite (andalusite, disthene)	$^1/_3$ ($SiO_2 . Al_2O_3$).
Sp	Spinel	$^1/_3$ ($Al_2O_3 . MgO$).
Tit	Titanite	$^1/_3$ ($SiO_2 . TiO_2 . CaO$).
W	Water	H_2O.
Wo	Wollastonite	$^1/_2$ ($SiO_2 . CaO$).
Zo	Zoisite	$^1/_{16}$ ($6\,SiO_2 . 3\,Al_2O_3 . 4\,CaO . H_2O$).

In the normative mineral compositions An + Or + Ab = F and
Wo + Hy + En = P.

B. THE CHIEF MINERALS IN THE WEATHERING ZONES IN SURINAME AND DEMERARA

The number of minerals in the weathering zones is rather limited. In the bauxites of Suriname and Demerara are mainly found:

1. *Gibbsite,* $Al_2O_3 . 3\,H_2O$, the crystal system is monoclinic (MEGAW, 1934). Twins occur frequently, both single and polysynthetic; gibbsite is optically positive. WINCHELL (1951) gives as indices of refraction $N_x = N_y = 1.565$—1.577, $N_z = 1.58$—1.595, 2 V is related to the temperature and varies between 0°and 20°.

Use was made in the X-ray investigation of the data published by ROOKSBY (1951).

The reflections 4.9, 4.34, 2.45 and 2.378 kX are determinative.

ORCEL (1935), NORTON (1939), BECK (1950), ARENS (1951) and VAN DER MAREL (1954) published differential thermal data on gibbsite and bauxite which consisted mostly of gibbsite. An endothermal reaction occurs in the range between 280° and 380° C.

On heating, corund is formed via gamma-, delte-, theta- en kappa-alumina. For the complete change to corund it is necessary to apply a temperature of more than 1100° C. during one hour (ROOKSBY, 1951).

We found that gibbsite can be recognized with the electron microscope by its six-sided shape. The flakes have a diameter of between 0.2 and 0.4 μ which is smaller than the diameter of kaolinite, and often they are more or less rounded (see fig. 82).

2. *Boehmite,* $Al_2O_3 . H_2O$, REICHERTZ and YOST (1946) defined the crystal system as orthorombic, by means of X-ray analysis. The mineral has been found in Suriname only in cryptocrystalline form.

The X-ray pattern shows four very strong reflections at 6.23, 3.16, 2.34 and 1.85 kX, which are characteristic (ROOKSBY 1951).

An endothermal reaction is encountered with differential thermal analysis in the range between 450° to 600° C. (VAN DER MAREL, 1954).

From the electron microscope investigation of the heavy fractions (bromoform s.g. 2.90) of the bauxite (which consist almost entirely of boehmite) it was shown in these cases that no clearly visible crystal habit occurs.

In the ferrites occurs as main constituents:

3. *Hematite*, Fe_2O_3. This mineral is always cryptocrystalline and is found often in botryoidal shape.

The X-ray pattern shows a clear picture with characteristic reflections at 3.67, 2.689, 2.508 and 2.198 kX (ROOSKBY 1951).

4. *Goethite.* (FORD 1949), $Fe_2O_3 . H_2O$. Characteristic X-ray reflections are found at 4.15, 2.674 and 2.433 kX (ROOKSBY 1951). An endothermal reaction between 320° and 420° C. is encountered with differential thermal analysis, ORCEL (1935), KERR and KULP (1948), BECK (1950), ARENS (1951), VAN DER MAREL (1954).

With the electron microscope it is shown that two forms occur. In the first place macroscopically needle-shaped goethite, which under the electron microscope also is needle-shaped (see fig. 85) and in the second place goethite, found as dense, fine-grained material which in the field has been mapped as limonite. Under the electron microscope this material is not needle-shaped, but extremely fine-grained and with irregular borders (see fig. 86). The X-ray pattern of both samples is the same, but that of the fine-grained goethite is much less strong.

5. *Siderite*, $FeCO_3$. The occurrence of siderite in the bauxite-ferrite deposits at Mackenzie was mentioned by SNIJDERS [11]). In the samples which were at our disposal, either from Suriname or from Mackenzie, no siderite was found.

6. In the bauxites and the ferrites *anatase* is found as TiO_2-containing mineral. The anatase occurs as cryptocrystalline material and has been found in all bauxite-ferrite samples. With X-ray analyses the reflections at 3.50, 2.38 and 1.89 kX are characteristic (card index [12]).

7. *Rutile* was found only in the clay core of one bauxite concretion. Röntgenographically the reflections at 3.24, 2.48 and 1.69 kX are characteristic (card index [12]).

Rutile and anatase were both found by X-ray analyses in the clays which underlie the bauxite.

As main constituents of the clays underlying the bauxite, are found:

8. *Kaolinite*, $Al_2O_3 . 2\,SiO_2 . 2\,H_2O$, ROSS and KERR (1930). The crystal system is triclinic (BRINDLEY and ROBINSON, 1946). Kaolinite is optically negative, $2\,V = 20°—55°$, $N_x = 1.553—1.563$, $N_y = 1.599—1.569$, $N_z = 1.560—1.570$ (WINCHELL, 1951).

As characteristic reflections with the X-ray analyses were considered those at 7.15, the group at 4.46, 3.57 kX and the two groups of three reflections at 2.55, 2.52, 2.49 and 2.37, 2.33 and 2.28 kX (BRINDLEY, 1951).

Characteristic for a good kaolinite, according to BRINDLEY, are the pair of reflections at 4.17 and 4.12 kX.

The literature on differential thermal analysis of kaolinite is already fairly extensive, e.g. INSLEY and EWELL (1935), NORTON (1939), GRIM and ROWLAND (1942), SPEIL (1945), KERR, KULP and HAMILTON (1951), BECK (1950), VAN DER MAREL (1954). With differential thermal analyses kaolinite shows two reactions; one endothermal reaction in the range between 500° and 650° C. and an exothermal reaction between 980° and 1040° C.

Under the electron microscope kaolinite has a six-sided elongated form.

[11]) Ir. P. SNIJDERS, Personal Communication.

[12]) Alphabetical and Grouped Numerical Index of X-ray Diffraction Data (1954).

Twins occur, and sometimes ragged edges are observed (HUMBERT and SHAW, 1941), KERR, et al. (1951) (see fig. 69).

9. *Metahalloysite* occurs in Suriname in much less abundance than kaolinite. It is mainly found at Onverdacht in the transition zone between soil cover clay and bauxite. Metahalloysite is the name proposed by MAC EWAN (1947) for a mineral of the halloysite group. BRINDLEY and GOODYEAR (1948) use for the halloysite group the general formula $Al_2O_3 . 2\,SiO_2 . 2\,H_2O$, in which $n = 2^1/_4$ to $2^3/_4$ for metahalloysite.

After several hypotheses about the structure of halloysite (MEHMEL, 1935, HENDRICKS, 1938, EDELMAN and FAVEJEE, 1940), BATES, HILDEBRAND and SWINEFORD (1950) in their investigation started from the tubular habit of halloysite, as observed under the electron microscope. In the direction of the b-axis the six hydroxyl ions on one side of the unit cell of gibbsite occupy a distance of 8.62 Å, the corresponding six oxygen ions in the silicon-oxygen sheet in kaolinite occupy a distance of 8.93 Å.

If the adjoining units are less than 3 Å away the six oxygen ions of one unit stretch the opposing hydroxyl ions to fit the cell dimension of 8.93 Å.

As a result of the greater distance of 5.74 Å in halloysite and the presence of interlayer water, the hydroxil ions are only slightly, if at all, subject to stretching forces from opposing oxigen layers of neighboring units. In this case the six hydroxyl ions are free to approach their normal spacing of 8.62 Å while the six oxygens ions on the opposite side of the same unit occupy a distance of 8.93 Å. If the vertical bonds within the unit remain of equal length relative to each other, a curvature must result.

Röntgenographically metahalloysite is distinguished by its wide basal reflections at 7.2—7.5 kX and 3.578 kX and the diffuse line at 4.422 kX, which has a higher intensity than both basal reflections (BRINDLEY, 1951).

Differential thermal investigation was done among others by SPEIL (1945), KERR, KULP and HAMILTON (1951) and VAN DER MAREL (1954). Depending on the amount of adsorbed water an endothermal peak is registered with a variable intensity, between 50° and 200° C. A second endothermal reaction is registered between 500° and 650° C., and an exothermal reaction is registered between 980° and 1040° C. The differential thermal curves of poorly crystallized kaolinite and halloysite show great similarity (KERR, KULP and HAMILTON 1951). Both minerals have an endothermal reaction as a result of adsorbed water. The second endothermal peak is relatively wide for kaolinite and shows a smaller amplitude than with halloysite. In contrast to halloysite the exothermal reaction of poorly crystallized kaolinite is small and rounded. The occurrence of an asymetrical peak with halloysite is not characteristic, as this is also observed with kaolinite (VAN DER MAREL 1954).

SHAW and HUMBERT (1941), (KERR et al, 1951) studied halloysite with the electron microscope. This mineral has a tubular habit, in which it distinguishes itself from kaolinite (see fig. 81).

10. *Chlorite.* The presence of chlorite was noted when examining the weathering zone of bedrock of the weathering section of the Plateau type with the X-ray method. The 14 kX reflection is characteristic.

ORCEL (1927) gives a number of differential thermal curves of chlorites. VAN DER MAREL (1954) mentions an endothermal reaction between 580° and 650° C, and an exothermal one between 800° and 900° C.

Under the electron microscope chlorite shows a not well defined elongated habit, well-developed flakes are rare, usually a more or less ragged border is observed (see fig. 84).

The clays of the soil cover at Onverdacht, which belong to the Coropina formation consist largely of:

11. *Illite.* This is a group name for clay minerals that show a close relationship with the micas (GRIM, BRAY and BRADLEY, 1937). The ratio SiO_2/Al_2O_3 of the illites is higher than that of well crystallized micas. The size of the illite particles is small: one to two microns or less (GRIM, 1953).

Use was made of the data published by GRIM, BRADLEY and BROWN (1951). Illite is distinguished from kaolinite and metahalloysite by the basal reflections at 10 kX. Differential thermal analysis was done, among others by GRIM and ROWLAND (1942), GRIM and BRADLEY (1951), KERR, KULP and HAMILTON (1951), VAN DER MAREL (1954). Illite shows three endothermal reactions respectively in the ranges 150°—200° C., 600°—750° C. and 860° and 920° C. and an exothermal reaction between 900°—950° C.

Electron microscopical investigations show sometimes the hexagonal shape of the flakes (GRIM, 1953), sometimes they are not very well-developed and irregular in shape, but usually distinct outlines are shown (see fig. 79).

C. MINERALOGICAL AND CHEMICAL INVESTIGATIONS OF THE WEATHERING SECTIONS

1. Plateau type bauxite

Mineralogical investigation

For the deposits belonging to this type the weathering section of the Nassaugebergte is representative. This section, which is described in Chapter II page 256 consists from top to bottom of the following layers.

f. Soil cover.
e. Bauxite-ferrite.
d. Transition zone.
c. Residuary clay.
b. Weathering zone of bedrock.
a. Solid rock (basalt).

a. The investigation of the thin sections of the *solid rock* showed the following results. As chief minerals occur hornblende, epidote, quartz, feldspar and chlorite. The hornblende shows locally alteration in chlorite; here and there hornblende had enclosures of ore and epidote which minerals are probably alteration products. The feldspars are chiefly alterated in kaolin, saussurite and sericite. Probably the feldspar consists of plagioclase which opinion is endorsed by the observation of a single not measurable twin. In the thin section a number of little cracks are found which are filled with quartz and chlorite (pennine). Locally concentrations of chlorite are observed to fill small cavities, the walls of which are covered by a thin layer of quartz. Amygdaloïdal structures form an indication for an effusive or volcanic gangue rock.

These very fine quartz veinz are of younger age than the chlorite veins as the latter are intersected by the former. Pennine is sometimes found in very large concentrations and shows now and then alteration in limonite.

As further constituents we encounter pyrite and sometimes apatite.

The texture is holocrystalline, hypidiomorph, fine-grained to very fine-grained. The structure is influenced by dynamo-metamorphism which varies from slight to strongly epimetamorph.

From this investigation was concluded that the original rock consist of a weakly to strongly epimetamorphic chloritized and saussuritized basalt, rich in hornblende.

b. In the *weathering zone of bedrock* three zones can be distinguished. The first zone strongly resembles the unweathered bedrock, even the green colour is preserved. The material consists of a tough green coloured weathering clay which, as indicated by the X-ray examinition, consists of chlorite next to small quantities of feldspar, hornblende and quartz. In the second zone feldspar as well as hornblende have disappeared and the X-ray pattern denotes the presence of chlorite together with a small quantity of quartz. The third zone also shows the structure of the solid rock, the colour is yellowish-white to yellowish-brown. Röntgenanalyses indicated that the weathering clay in this zone mainly consists of kaolin with small quantities of hematite, goethite and quartz.

The occurrence of limonite practically made the examination of the weathering zone of bedrock by thin sections impossible.

c. *Residuary clay,* in which the original texture and structure are not observed, includes the clay layer between the weathered bedrock and the transition zone. X-ray and differential thermal analyses proved this clay to consist mainly of kaolinite. With the electron microscope small tubes of (meta)halloysite were observed in the kaolin. The heavy mineral fraction of the kaolin comprised hematite, goethite, rutile and anatase.

d. In the *transition zone* gibbsite is encountered as small clear grains in which as enclosures small dots of kaolin occur, as well as very small cylindrical concretions consisting of cryptocrystalline to microcrystalline gibbsite and of a yellow to faintly pink colour.

e. The *bauxite,* as found in the bauxite-ferritecap principally consists of gibbsite. Gibbsite occurs in sizes varying between coarse crystalline and cryptocrystalline. After separating the heavy mineral fraction from the bauxite by means of bromoform (s.g. 2.90) the presence of boehmite appeared from X-ray patterns. The heavy mineral fraction consisted of yellow and yellow-brown grains which did nto extinguish between crossed nicols. At the same time the characteristic reflections of gibbsite and anatase were observed. Boehmite is very closely intergrown with gibbsite, pure boehmite could not be separated.

Boehmite is encountered in bauxite in changing quantities from 1 up to 10 % *). The smallest percentages of boehmite are found in bauxite consisting of fine- to coarse-crystalline gibbsite. Higher amounts are encountered

*) Weight percentages.

in bauxites consisting of cryptocrystalline gibbsite, the highest percentages are found in pisolitic bauxite, where the amount of boehmite can run as high as 10 %.

Cryptocrystalline gibbsite is encountered frequently; bauxite consisting of this type of gibbsite is intersected by a great many cracks which are filled with micro- and macrocrystalline gibbsite, the thickness of these cracks is up to about 1.5 millimetres. If these cracks are entirely filled with gibbsite, it may be observed that the crystals are not orientated. This in contrary to the instances where gibbsite crystals merely cover the walls. In this case the crystals are arranged with their longitudinal axes (crystallographic b-axis) perpendicular to the walls. These crystals are found on a thin layer

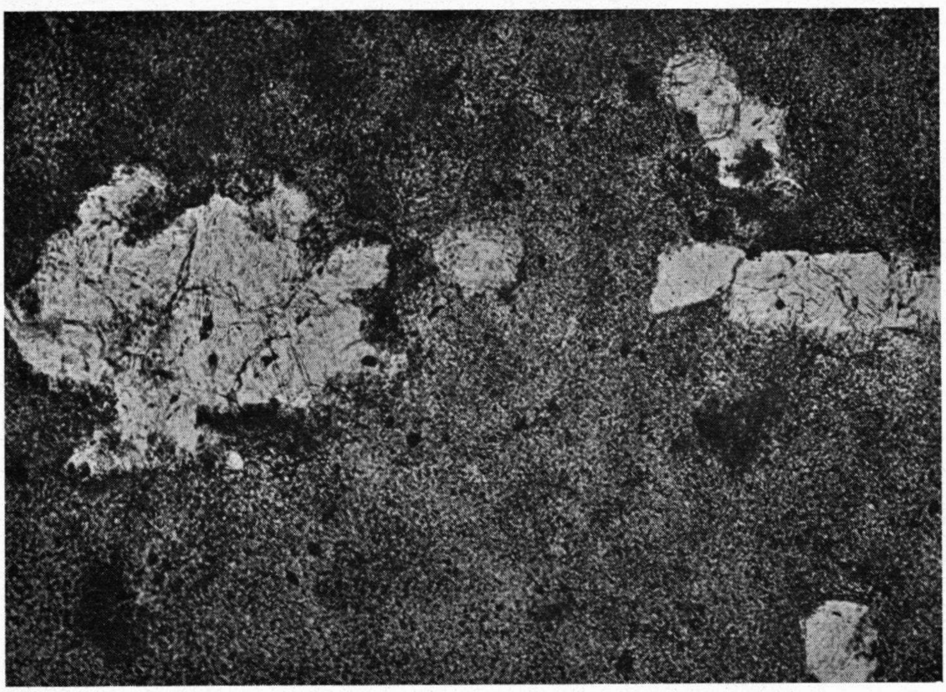

Fig. 56. Thin section of bauxite showing pores in bauxite which are entirely filled with gibbsite. The crystals are not orientated (Nassaugebergte). X-nicols, × 80.

consisting of much smaller crystals which are not orientated. This layer shows a fairly sharply defined boundary with the cryptocrystalline material. An unorientated arrangement is also observed when small cavities are filled with micro- and macrocrystalline gibbsite (fig. 56). Twinning, single as well as polysynthetic, is often observed.

In the pisolitic bauxite cryptocrystalline gibbsite plays an important rôle. The shells of the pisolites namely consist of cryptocrystalline gibbsite.

The core of the pisolites may consist of 2 or 3 oölites or of white clay, which according to X-ray examination is formed by kaolinite and gibbsite.

Sometimes the core occurs as an angular particle. In the pisolites a number of cracks filled with microcrystalline gibbsite are found (fig. 57).

The matrix of pisolitic bauxite consists of fine micro- to cryptocrystalline gibbsite in which kaolin occurs as a contaminant.

The components of the bauxite breccia are crypto- as well as microcrystalline gibbsite, the cement is formed by fine microcrystalline gibbsite locally contaminated with kaolin. Some parts show cracks filled with micro- to macrocrystalline gibbsite. Throughout the entire layer a somewhat plastic clay occurs which, as indicated by X-ray and electron microcopical examination, consists mainly of gibbsite while next to it small quantities of kaolinite and metahalloysite are found.

The principal part of the *ferrites* is made up by hematite and goethite

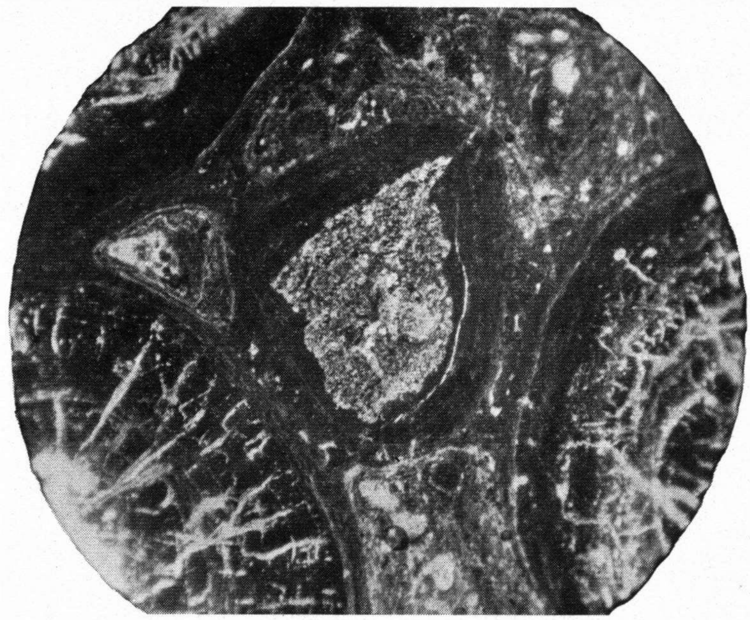

Fig. 57. Thin section of pisolitic bauxite. Pisolites show cracks filled with gibbsite, which do not continue in the matrix. Also in some oölites they do not occur (Nassaugebergte). × 15.

(fig. 58). Almost the entire fraction of the ferrites consists of magnetic hematite. Goethite is found considerably less and is principally encountered in limonite banks. Hematite as well as goethite are often very fine-grained, hematite is often found in botryoidal forms. It appeared that hematite is an alteration product of goethite.

f. In the *soil cover* it appeared that hematite is the principal constituent of the shining iron beans, whereas, goethite is the principal constituent of the dull little iron stones.

Chemical investigation

From the weathering section of the Nassaugebergte, six samples were analyzed [13]).

Analysis I: Solid rock. Weakly to strongly epimetamorphic chloritized and saussuritized basalt, rich in hornblende.

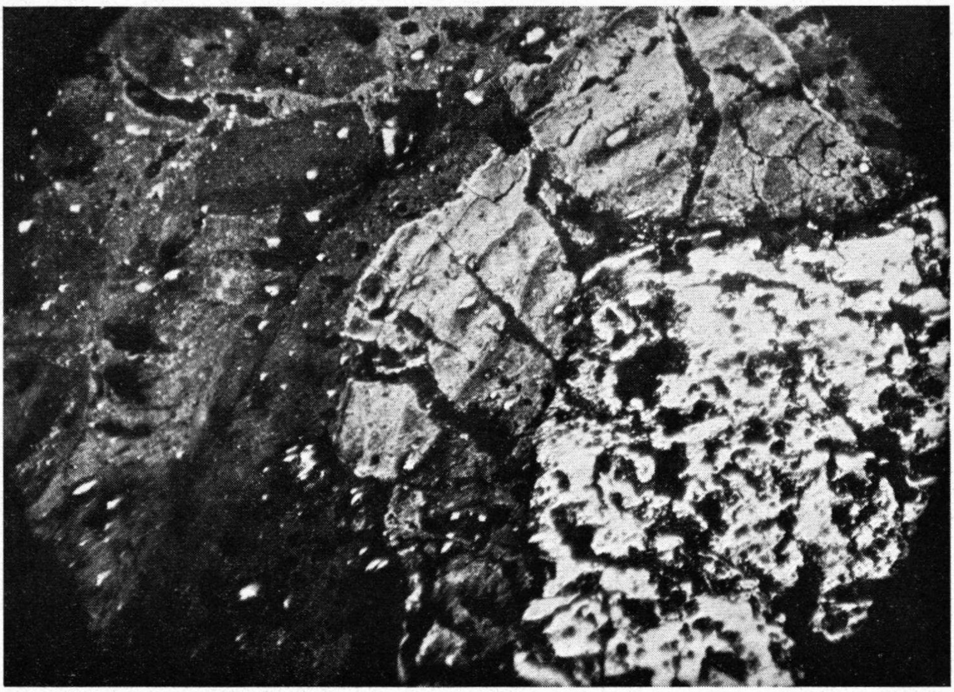

Fig. 58. Polished section of pisolitic ferrite. The centre of the pisolite consists of hematite. The outer shells are formed by goethite and also contain small grains of hematite (Nassaugebergte). × 55.

Analysis II: Weathering zone of bedrock, first zone. X-ray investigation showed that no complete chloritization took place; small quantities of quartz, feldspar and hornblende are still present.

Analysis III: Weathering zone of bedrock, third zone. The X-ray pattern showed, along with kaolinite, small quantities of chlorite, quartz and goethite.

Analysis IV: Residuary clay which, according to the X-ray investigation, consists mainly of kaolinite.

Analysis V: Yellowish white pisolitic bauxite. Röntgenographically it has been determined that this sample consists mainly of gibbsite, whereas, boehmite and anatase are also present in small quantities.

[13]) Owing to special circumstances no ferrite analyses are available.

Analysis VI: Dense, homogeneous bauxite. The X-ray investigation also indicated, apart from gibbsite, the presence of small quantities of boehmite and anatase.

Chemical analyses *, weathering section Nassaugebergte.

	I **	II	III	IV	V	VI
SiO_2	48.75	43.20	48.18	36.20	0.40	0.28
Al_2O_3	14.01	12.04	15.50	32.92	62.96	58.75
Fe_2O_3	3.44	11.91	22.64	13.55	0.63	2.45
FeO	10.80	7.76	trace	0.00	trace	trace
MnO	0.20	0.26	0.00	0.00	trace	0.03
MgO	6.99	5.41	0.34	0.25	0.19	0.10
CaO	7.90	9.30	0.10	trace	trace	trace
Na_2O	2.52	2.15	0.10	0.34	0.55	0.45
K_2O	0.45	0.48	0.31	0.00	trace	0.07
H_2O+	3.53	3.37	8.00	12.97	30.12	29.08
H_2O-	0.10	0.96	3.85	0.56	0.74	0.76
TiO_2	1.10	2.73	1.44	3.41	3.89	8.10
P_2O_5	0.14	0.23	trace	0.13	0.34	0.11
	99.93	99.80	100.46	100.33	99.82	100.18

Normative mineral compositions (mol. %).

Q	5.4	6.2	34.2	—	—	—
F	30.3	16.4	—	—	—	—
Gram	31.5	23.0	—	—	—	—
Zo	9.6	17.8	—	—	—	—
Ant / Am	19.5	24.9	—	—	—	—
Ru	0.9	2.1	3.4	3	3.8	7.7
Hm	2.5	4.8	9.8	3.9	0.5	2.4
Cp	0.3	0.4	—	—	—	—
Kaol	—	4.4	41.8	85.2	1.0	0.8
Gi ***	—	—	—	2.9	82.1	80.1
Bo	—	—	—	—	10.5	7.5
Go	—	—	9.6	3.9	—	—
Accessoria	—	—	1.2	1.1	2.1	1.5
	100.—	100.—	100.—	100.—	100.—	100.—

Nigglivalues.

si	119	101	180	121	1	0.3
al	20	16.5	34	65	97	93
fm	54	55	65	34	2	5.5
c	20	23	—	—	—	—
alk	6	5.5	1	1	1	1.5
ti	2.1	4.5	10.9	8.4	7.7	17.9
k	0.11	0.13	0.6	—	—	0.13
mg	0.47	0.34	0.03	0.04	0.33	0.09

Weathering values.

$$\frac{si}{al} = si', \frac{fm}{al} = fm', \frac{c}{al} = c', \frac{alk}{al} = alk', \frac{ti}{al} = ti'$$

	I **	II	III	IV	V	VI
si′	5.95	6.15	5.29	1.86	0.01	—
fm′	2.70	3.35	1.91	0.52	0.02	0.05
c′	1.00	1.40	—	—	—	—
alk′	0.30	0.34	0.03	0.02	0.01	0.01
ti′	0.11	0.27	0.32	0.13	0.08	0.19

$$\frac{Na_2O}{Al_2O_3} \times 100 = NA \quad \frac{K_2O}{Al_2O_3} \times 100 = KA$$

	I **	II	III	IV	V	VI
NA	29.5	30.2	1.0	1.6	1.5	1.4
KA	3.6	4.3	2.0	—	—	0.2

* Analyzed by Miss B. HAGEMAN, Petrochemical Laboratory, Leiden.
** Magmatype, normalgabbroid (NIGGLI, 1936).
*** Gi = Gibbsite
Bo = Boehmite
Go = Goethite

From the chemical analyses and the weathering values of the solid rock (analysis I) and the first zone of weathered bedrock (analysis II), the relative increase of si, fm, c, alk and ti is demonstrated. This increase as appears from the analyses, is greatest for Fe_2O_3. It is possible that the general increase is caused by chemical variations of the solid rock. The normative mineral compositions show that in the first zone of the weathered bedrock F and Gram have partially disappeared, whereas, Zo, Ant + Am, Ru and Hm are increased and Kaol is formed.

Most remarkable is the great decrease of c and alk in the third zone of the weathered bedrock (analysis III) when compared with that of the first zone. An increase of si and fm is shown by the chemical analyses, however, the weathering values indicate a relative decrease. From ti′ it appears that, in the case of ti, a relative increase took place. The norm of this sample shows that the main mineralogical components are formed by Q and Kaol. The weathering values of the residuary clay (analysis IV) show a desilification in comparison with analysis III. A decrease is indicated for fm, whereas, the increase for ti in analysis IV is actually a relative decrease. The decrease for alk as found in analysis III is continued in analysis IV, although to a lesser extent. From the normative mineral composition it appears that the residuary clay is formed principally by Kaol.

The analyses and weathering values of both of the bauxite samples (analyses V and VI) show an advanced desilification as compared with the residuary clay. A decrease is also shown for fm and alk. It appears from ti′ that in analysis V there is a relative decrease and concentration of ti in analysis VI. The normative mineral compositions of both analyses indicate the predominating mineral is Gi. The percentages Bo of the respective samples are, however, rather high. The mineralogical investigation demonstrated that the analyses V and VI possessed a boehmite content of approximately 4 and 3 % *) respectively.

From the chemical analyses it follows that MgO, Na_2O and TiO_2 are influenced by the weathering process, and, that there is a great decrease for FeO, MnO and K_2O. The influence of weathering is greatest on MgO and Na_2O, whereas, TiO_2 appears to be affected by the weathering process only to a small extent.

The behaviour of Na_2O compared with K_2O is remarkable. From the analyses, the NA and the KA values, it appears that Na_2O shows an increase from the third zone of the weathered bedrock to the residuary clay and the bauxite samples. This is contrary to K_2O, which decreases in this direction.

2. High-level type bauxite

Mineralogical investigation

The weathering section is described macroscopically in Chapter II, page 267. The complete section from top to bottom is as follows:

f. Soil cover.
e. Bauxite-ferrite.
d. Transition zone.
c. Sedimentary clay.
b. Sand layer (locally absent).
a. Weathered bedrock.

a. The *weathered bedrock* is entirely kaolinized, as appeared from X-ray and differential thermal analyses. Next to quartz, found as lenses in this residuary clay, much staurolite is encountered. Locally, large concentrations, of goethite and hematite are found in this kaolin. Pegmatites occur frequently, quartz shows sugarlike weathering. Here and there white spots with rectangular boundaries are found in this quartz which consists entirely of kaolinite. These spots are circa 4 millimetres long and 2—3 millimetres wide, they are probably kaolinized feldspar. In the mostly clearly white kaolin of the pegmatites, weathered tourmalines occur and small books of muscovite about 8—10 centimetres in diameter.

b. The *sand layer,* if present, is coarse-grained. As heavy minerals, next to chiefly staurolite, are found tourmaline, andalusite, disthene, rutile anatase and zircon. Remarkable is the occurrence of small grains of bauxite in these sands.

c. The *sedimentary clay* is mainly formed by kaolinite as indicated by X-ray and differential thermal analyses. Electron microscopic investigation of the clays showed the presence of very small quantities of metahalloysite. Over the entire kaolin layer gibbsite is found. The gibbsite is present as small clear grains, which frequently enclose small specks of kaolin. Furthermore gibbsite is the principal component of the concretions which are found in the kaolin, in which it is found in cryptocrystalline to macrocrystalline form.

Where gibbsite is encountered as a cover of the walls of small cavities and cracks, the longitudinal axes are arranged perpendicular to these walls. The crystals are resting on a thin layer of unorientated fine-grained gibbsite

*) Real mineral composition, weight percentages.

crystals. The gibbsite crystals show single as well as polysynthetic twins.

Quartz grains are found throughout the entire kaolin layer, some show solution phenomena. The heavy mineral fraction of this kaolin has the same components as the layer of sand between the weathered bedrock and the clay, namely, staurolite, tourmaline, andalusite, disthene, rutile, anatase and zircon.

d. In the *transition zone* the quartz grains show an increasingly intensive dissolving, near the top of this zone they are practically absent (fig. 59). Gibbsite increases to the top and occurs as small clear grains enclosing kaolin specks. Cavities and pores in the transition zone nearly always have

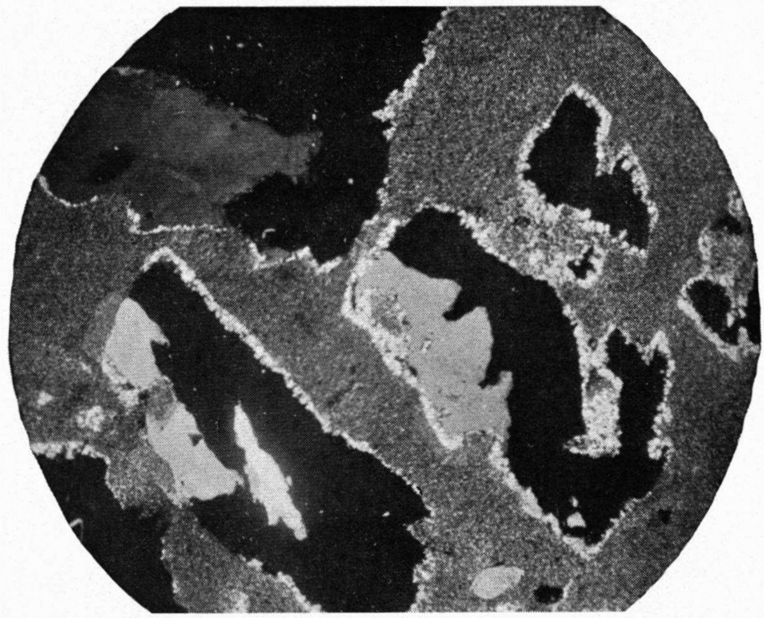

Fig. 59. Thin section of porous bauxite showing the remnants of partially dissolved quartz grains (Moengo Hill). X-nicols, × 50.

a small cover of gibbsite crystals, the longitudinal axes of which (crystallographic b-axis) are arranged perpendicular to the walls. At the same time in this zone bauxite clay is found, together with metahalloysite (which was indicated electron microscopically).

The formation of the cylindrical concretions found in this zone is as follows: In the first stage a tube is found, the wall of which is formed by macrocrystalline gibbsite crystals, arranged with their longitudinal axes perpendicular to the walls. The second stage shows that the gibbsite crystals stay with their longitudinal axes perpendicular to the walls, but between the crystals and the wall a thin layer of unorientated microcrystalline gibbsite is found. In the third stage the change from the unorientated layer of gibbsite in cryptocrystalline gibbsite of a faintly pink colour is seen. While the walls of these tubular concretions are growing, cryptocrystalline gibbsite predominated more and more and finely the entire concretion consists of it.

e. *Bauxite* consists principally of gibbsite. From X-ray analyses of the heavy mineral fraction the presence of boehmite was indicated, although in small quantities (under 1 %).

Gibbsite occurs in granularity from crypto- to macrocrystalline. Micro- and macrocrystalline gibbsite makes out the principal part of the bauxite formed in these sediments. As TiO_2-bearing mineral in the heavy mineral fraction of the bauxites, anatase was indicated with X-ray analyses. Anatase

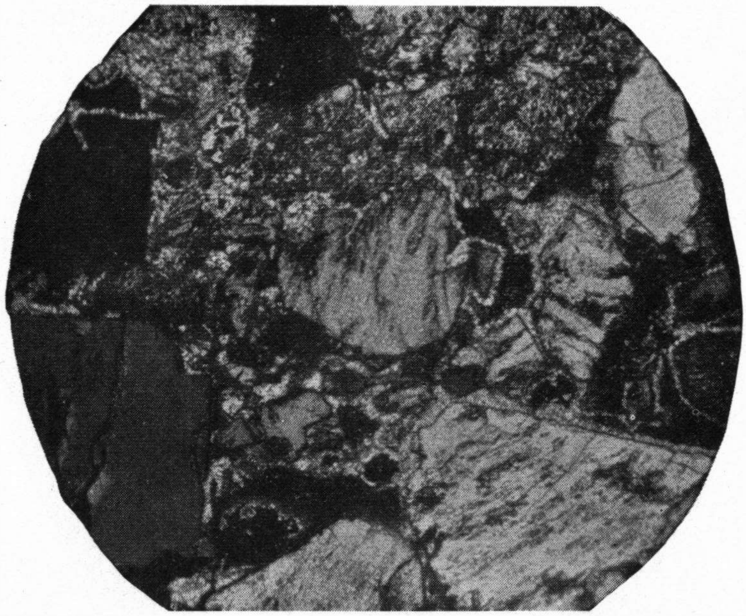

Fig. 60. Thin section of bauxite containing much staurolite. The staurolite shows alteration to gibbsite (Moengo Hill). X-nicols, $\times$ 50.

does not occur as grains, as in the heavy mineral fraction of the kaolin, but as cryptocrystalline granular aggregate which do not extinguish between crossed nicols.

In the bauxite the same heavy minerals are found as in the kaolin. Microscopical investigation showed that a number of them had been subject to weathering and show partially alteration in gibbsite (fig. 60 and 61), as already was mentioned by TER MEULEN (1949).

The thin layers and spots of white clay occurring in the bauxite consist, as indicated by X-ray and electron microscopical investigation, of gibbsite, kaolinite and metahalloysite.

The main components of the *ferrite* are hematite and goethite. Hematite is magnetic and makes out the chief part of the ferrites; goethite occurs

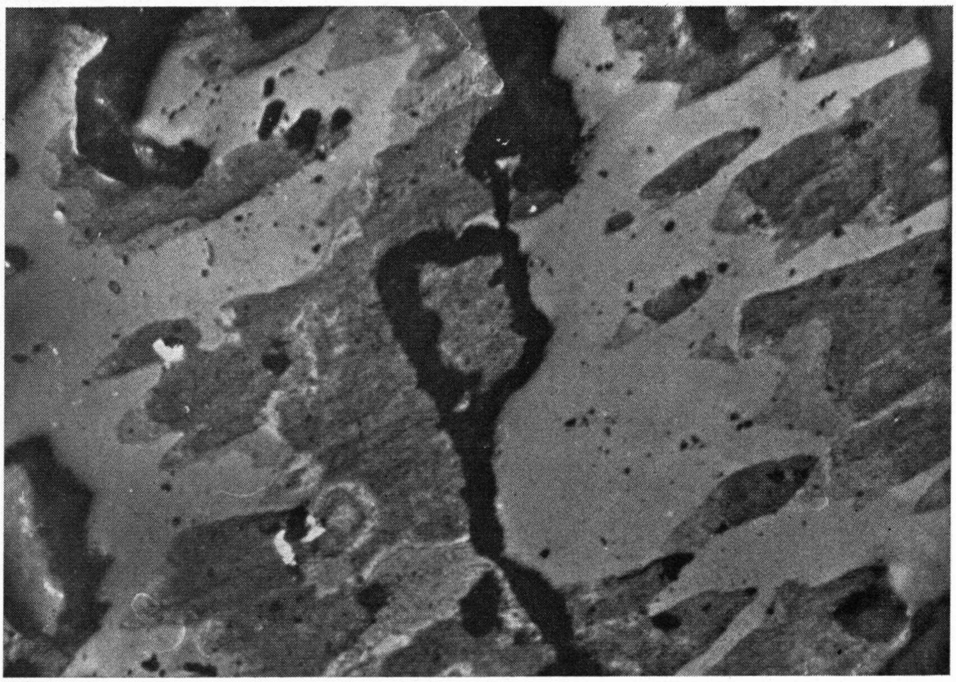

Fig. 61. Polished section, in which the alteration of staurolite to gibbsite is shown (the dark grey material is gibbsite) (Moengo Hill). × 140.

Fig. 62. Polished section of ferrite. In the kaolin, goethite penetrates and alters to hematite (Ricanau Hill). × 85.

to a lesser extent. During the ferritization goethite penetrates into bauxite or kaolin along cracks and joints. This goethite shows alteration into hematite (fig. 62).

The *soil cover* consists chiefly of iron beans and little stones, while bauxite-ferrite pebbles are found as well. In the beans hematite is found as the principal component, in the little stones goethite.

Chemical investigation

Of the four analyses, one was made of a kaolin sample from under the bauxite-ferrite cap of the Ricanau Hill, and one of a bauxite sample from the cap. The two remaining analyses were made of the bauxite shell and clay core of an egg-shaped concretion.

Analysis VII: Kaolin; the sample is taken about 3 metres under the bauxite-kaolin boundary. The X-ray investigation shows the principal component to be kaolinite, whereas, a small quantity of quartz is also present.

Analysis VIII: Dense, homogeneous, pink bauxite, consisting of microcrystalline gibbsite. Röntgenographically, along with gibbsite, small quantities of kaolinite, boehmite and anatase are also observed.

Analysis IX: Bauxite shell of an egg-shaped concretion. The X-ray pattern denotes chiefly the presence of gibbsite, with small quantities of kaolinite and anatase.

Analysis X: Clay core of an egg-shaped concretion. The X-ray investigation indicated that this clay mainly consists of kaolinite, along with gibbsite, rutile and anatase.

Chemical analyses *, Moengo.

	VII	VIII	IX	X
SiO_2	44.34	3.66	6.34	35.92
Al_2O_3	36.55	61.71	58.09	38.56
Fe_2O_3	2.13	0.94	2.97	4.04
FeO	trace	trace	trace	trace
MnO	trace	trace	trace	trace
MgO	0.33	0.34	0.22	0.24
CaO	0.28	trace	0.23	trace
Na_2O	0.10	0.28	0.19	0.37
K_2O	0.28	0.08	0.47	0.08
H_2O+	13.98	31.17	29.86	14.05
H_2O-	0.37	0.14	0.12	0.63
TiO_2	1.93	1.68	1.57	5.60
P_2O_5	0.17	0.19	0.20	0.26
	100.46	100.28	100.40	99.75

Normative mineral compositions (mol. %).

	VII	VIII	IX	X
Q	1.3	—	—	—
Kaol	94.2	9.2	15.8	79.8
Gi	—	86.9	77.9	10.6
Hm	1.7	0.8	2.8	1.7
Go	—	—	—	1.6
Ru	1.6	1.5	1.5	4.7
Accessoria	1.2	1.6	2.0	1.6
	100.—	100.—	100.—	100.—

Nigglivalues.

	VII	VIII	IX	X
si	183	9.6	17	135
al	89	95	91	85
fm	8.5	4	7	13
c	1	—	1	—
alk	1.5	1	1	2
ti	6	3.3	3.2	15.9
k	0.60	0.17	0.63	0.14
mg	0.24	0.48	0.13	0.12

Weathering values.

$$\frac{si}{al} = si', \frac{fm}{al} = fm', \frac{c}{al} = c', \frac{alk}{al} = alk', \frac{ti}{al} = ti'$$

	VII	VIII	IX	X
si'	2.05	0.11	0.19	1.58
fm'	0.09	0.04	0.08	0.15
c'	0.01	—	0.01	—
alk'	0.01	0.01	0.01	0.02
ti'	0.07	0.04	0.04	0.19

$$\frac{Na_2O}{Al_2O_3} \times 100 = NA \quad \frac{K_2O}{Al_2O_3} \times 100 = KA$$

	VII	VIII	IX	X
NA	0.4	0.8	0.5	1.7
KA	0.8	0.2	0.8	0.3

* Analyzed by Miss B. HAGEMAN, Petrochemical Laboratory, Leiden.

The analyses and weathering values of the kaolin (analysis VII), as compared with the same values of the bauxite, show that the desilification took place from the kaolin towards the bauxite. A decrease is also found for fm, c and ti, in which the decrease is greatest for c. In alk, which is already low in kaolin, no relative changes occur. The normative mineral compositions of these two samples coincide with the mineralogical composition.

Analyses IX and X are made of the bauxite shell and the clay core of an egg-shaped concretion. When comparing the analyses and the weathering values of the bauxite shell with those of the clay core, towards this bauxite shell desilification and a decrease for fm and ti are apparent. Towards the bauxite shell, an increase of c is shown. The increase of Na_2O and K_2O of the clay towards the bauxite shell in the analyses is, in fact, a relative decrease as is indicated by the weathering values. Remarkable is the high TiO_2-content of the clay core of the egg-shaped concretion. The norm, calculated for the bauxite shell as well as for the core, checks with the real mineral composition.

From the NA, and the KA values, the kaolin analysis (analysis VII), and the bauxite analysis (analysis VIII) an increase of Na_2O towards the bauxite is apparent, and also the decrease in this direction of K_2O. The clay core (analysis X) shows the reversed picture, as compared with the bauxite shell (analysis IX) of the egg-shaped concretion. Na_2O decreased, and K_2O increased towards the bauxite. At the same time c behaves abnormally, since it is present in the bauxite and not in the clay core.

3. Medium-level type bauxite

Mineralogical investigation

Three sections as observed at Onverdacht, are described in Chapter II, page 286. Sections A and B are representative for the greatest part of these deposits. The weathering section consists of five important layers, namely:

e. Sedimentary clay (soil cover mainly consisting of illite).
d. Transition zone.
c. Bauxite-ferrite.
b. Transition zone.
a. Sedimentary clay (mainly kaolinite).

a. The *sedimentary clay* mainly consists of kaolinite which has been proved röntgenographically and differential-thermically. The electron microscopic examination showed that apart from kaolinite, small quantities of metahalloysite are present.

Gibbsite is found throughout the entire kaolin layer; often it is encountered as relatively clear grains with local enclosures of kaolin. Gibbsite is present in micro- to macrocrystalline form in the numerous smaller and bigger cylindrical concretions. In cases where gibbsite is covering the walls of cracks and cavities, again the longitudinal axes (cristallographic b-axis) of the gibbsite crystals are arranged perpendicular to these walls.

Locally concentrations of quartz grains are found. The heavy mineral fraction of the kaolin consists of tourmaline, rutile, anatase, disthene, andalusite and zircon.

b. In the *transition zone* it is observed from bottom to top that the quartz grains are subject to solution, in general they are almost totally disappeared near the top of the layer.

Very remarkable was the presence of chalcedony about 1.5 metres under the bauxite — kaolin boundary.

c. The main constituent of *bauxite* is gibbsite; boehmite has as well been recorded in the heavy mineral fraction. The quantity of boehmite never exceeds 1 %, some bauxite samples do not contain boehmite at all. Boehmite is present in yellow to yellowish-brown aggregates which do not extinguish between crossed nicols. The X-ray patterns did also show that next to boehmite small quantities of gibbsite and anatase are present.

Gibbsite is found in two distinct granularities, namely macrocrystalline and bauxite clay. Microcrystalline gibbsite is found but in a much lesser extent than in the other deposits. In the cases gibbsite is found covering the walls of cracks and pores, the longitudinal axes of the crystals are arranged perpendicular to the walls (fig. 63). If the gibbsite crystals are found to fill the cracks and pores entirely, the crystals are not orientated.

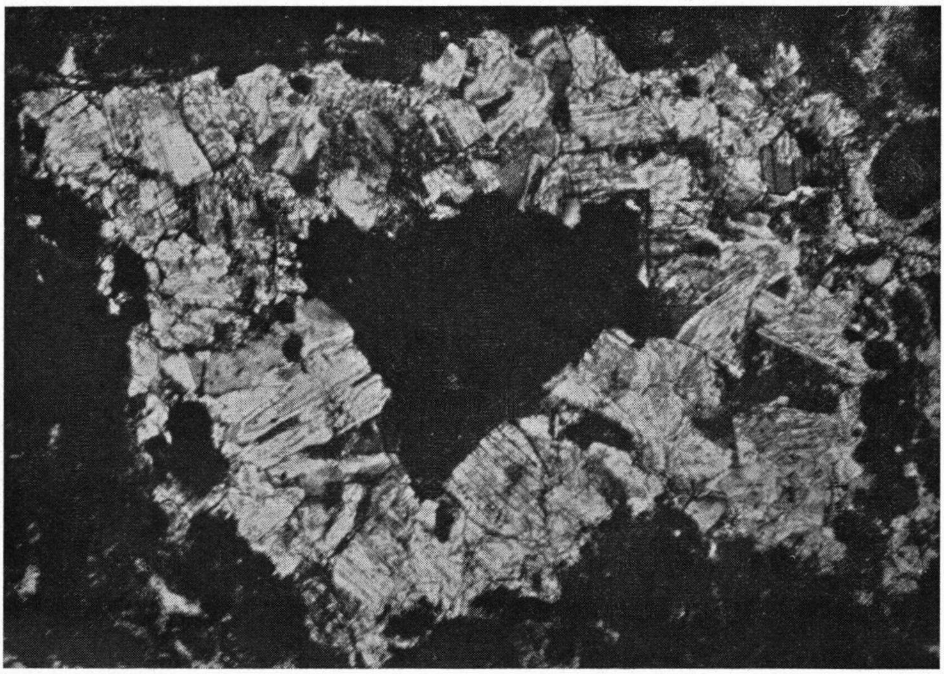

Fig. 63. Thin section showing gibbsite crystals covering the walls of a pore. The crystals are orientated with their longitudinal axes (crystallographic b-axis) perpendicular to the wall. Between these crystals and the wall a thin layer of unorientated gibbsite crystals is seen (Onverdacht). X-nicols, × 30.

Sometimes it was observed that the lamellae of the cellularly bauxite consisted of thin layers of gibbsite alternating with thin layers of kaolinite (the thickness of the layers is up to 0.5 millimetre). The outside layer was in several instances formed by kaolinite.

In the bauxite sometimes remnants of partly dissolved quartz grains are observed.

The same heavy minerals occurring in the sedimentary clays exist in the bauxite (fig. 64).

The clay enclosures and layers in bauxite are formed by kaolinite, meta-halloysite and bauxite clay as was observed by X-ray and electron microscopical examination.

The ferrites consist principally of hematite and goethite. Hematite is magnetic and makes out the principal constituent of the ferrites. Goethite occurs generally to a lesser extent and forms the principal constituent of limonite banks which however appear to consist of hematite over large distances.

d. The *transition zone* bauxite—sedimentary clay (soil cover) consist of metahalloysite and gibbsite while also small quantities of kaolinite are found, which was indicated by X-ray, differential thermal analyses and electron microscopy. Remnants of quartz grains show further solution.

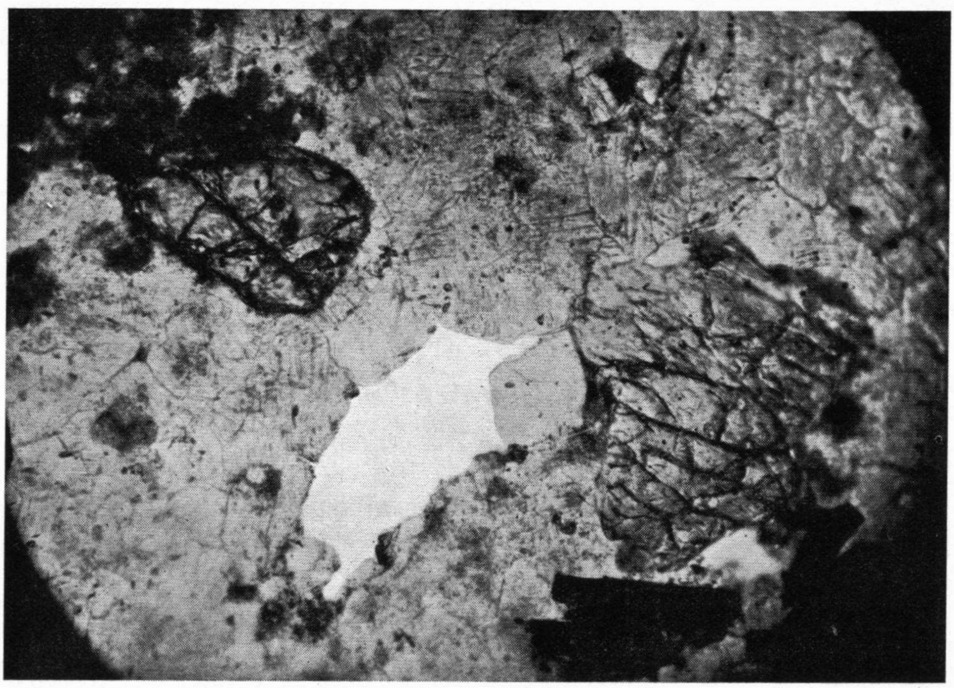

Fig. 64. Thin section of bauxite. The heavy minerals (staurolite and tourmaline) do not show alteration (Onverdacht). × 25.

e. The *sedimentary clay* of the soil cover consists mainly of illite as shown by X-ray and differential thermal analyses. Quartz is found in quantities which may exceed 30 %. Part of the quartz is so fine-grained that it could not be removed from the clay fraction by washing. Not always the for illite characteristic 10 kX reflection was observed in the X-ray patterns. Differential thermal analyses showed always the characteristic reaction for illite. In most cases no reflections for other clay minerals are found. A 7 kX reflection however was recorded in bleached illite clay, whereas, it could not be defined whether this reflection belonged to kaolinite or metahalloysite. The electron microscope proved this mineral to be metahalloysite. The bleaching occurring in this clay is described in Chapter II, page 289. The bleaching in first instance has no influence on the mineralogical constitution of the clay. When bleaching becomes more intensive however, changes do occur. With increasing intensity of the bleaching more and more metahalloysite occurs. At the same time quartz grains show solution symptoms which become more intensive by increasing bleaching intensity. The transition zone underlies these bleached sedimentary clays of the soil cover.

The heavy mineral fraction of the clay included tourmaline, rutile, anatase, staurolite, disthene, andalusite, corundum, glaucophane and zircon.

Chemical investigation

Of this weathering section six analyses are available.

Analysis XI: Illite clay; the sample was taken from the soil cover and showed no bleaching. A few red spots denoted the presence of iron hydroxide. Röntgenographically, illite and quartz were observed.

Analysis XII: Dense, homogeneous bauxite, consisting of micro- to macrocrystalline gibbsite. The sample was derived from the middle of the bauxite layer. The X-ray investigation showed the presence of gibbsite and a very small quantity of boehmite.

Analysis XIII: Coarse-grained gibbsite from the bottom part of the bauxite layer. The X-ray pattern showed the presence of gibbsite, along with small quantities of kaolinite, boehmite and anatase.

Analysis XIV: Transition zone; the sample is taken from the transition zone bauxite — kaolin. Röntgenographically, along with kaolinite, gibbsite and anatase were observed.

Analysis XV: Kaolin; the sample is taken about 5 metres under the bauxite — kaolin boundary. X-ray investigation showed kaolinite as the main constituent.

Chemical analyses *, weathering section Onverdacht.

	XI	XII	XIII	XIV	XV
SiO_2	59.94	trace	1.91	21.36	41.20
Al_2O_3	20.34	66.40	64.51	50.66	39.71
Fe_2O_3	4.77	0.30	0.07	1.85	0.37
FeO	0.40	trace	trace	trace	trace
MnO	0.02	0.03	trace	trace	trace
MgO	0.35	0.39	0.30	0.39	0.18
CaO	0.62	trace	trace	1.21	1.11
Na_2O	0.52	0.31	0.44	0.26	0.20
K_2O	1.49	0.25	0.09	trace	0.06
H_2O+	7.46	31.46	32.02	21.31	14.38
H_2O-	3.04	0.19	0.08	0.57	0.67
TiO_2	1.16	0.51	0.84	2.53	2.05
P_2O_5	0.18	0.10	—	0.18	0.18
	100.29	99.94	100.44	100.32	100.11

Normative mineral compositions (mol. %).

	XI	XII	XIII	XIV	XV
Q	12.2	—	—	—	—
Ill **	82.9	—	—	—	—
Kaol	—	—	4.6	49.2	89.6
Gi	—	81.8	86.7	34.9	4.4
Bo	—	15.4	6.2	9.1	1.7
Ru	0.9	0.5	0.8	2.1	1.7
Hm	—	—	—	1.7	—
Go	3.7	—	—	—	—
Accessoria	0.3	2.3	1.7	3	2.6
	100.—	100.—	100.—	100.—	100.—

Nigglivalues.

si	323	—	1.9	64	163
al	64	97	98	89	92
fm	24	2	1	6	2
c	4	—	—	4	5
alk	8	1	1	1	1
ti	4.9	0.9	1.5	5.6	6.1
k	0.67	0.36	0.13	—	0.25
mg	0.12	0.72	1.00	0.30	0.55

Weathering values.

$$\frac{si}{al} = si', \quad \frac{fm}{al} = fm', \quad \frac{c}{al} = c', \quad \frac{alk}{al} = alk', \quad \frac{ti}{al} = ti'$$

si′	5.02	—	0.02	0.72	1.76
fm′	0.38	0.02	0.01	0.06	0.02
c′	0.06	—	—	0.04	0.05
alk′	0.12	0.01	0.01	0.01	0.01
ti′	0.01	0.01	0.02	0.06	0.07

$$\frac{Na_2O}{Al_2O_3} \times 100 = NA \quad \frac{K_2O}{Al_2O_3} \times 100 = KA$$

NA	4.0	0.8	1.0	1.0	0.8
KA	8.0	0.5	0.2	—	0.3

* Analyzed by Miss B. HAGEMAN, Petrochemical Laboratory, Leiden.
** Ill = illite, calculated according to SiO_2/Al_2O_3 ratio of muscovite (GRIM, 1953) + Na_2O, K_2O and CaO.

As indicated by the analyses and the weathering values, great changes took place form the soil cover (analysis XI) towards the bauxite (analysis XII). A practically complete desilification occurred, whereas, for fm, c and alk a decrease is apparent. From ti′ it follows that relatively no change occurred for ti. As far as Na_2O and K_2O are concerned, it may be remarked that NA and KA are both high in the illite clay and show a decrease towards the bauxite. This decrease is greater for K_2O than for Na_2O.

The analyses XIII, XIV and XV are of bauxite, transition zone kaolin — bauxite and kaolin samples respectively. When examining the analyses and the weathering values it appears that, from the kaolin via the transition zone towards the bauxite, there is a desilification. However, a decrease is also shown for fm, c and ti. For alk the weathering values show, that there is no relative change. NA and KA values show a clear picture of the increase of Na_2O from the kaolin to the bauxite, and also the relative decrease of K_2O in this direction.

In the chemical analyses, MgO is present in all samples.

The normative mineral composition showed too great Bo percentages in the analyses XII, XIII, XIV and XV. The mineralogical investigations showed that boehmite was present in the samples of analyses XII and XIII in quantities of about 1 %, whereas, boehmite was not found in the samples of analyses XIV and XV.

From the mineralogical investigation of the transition zone bauxite — kaolin, it appears that chalcedony occurs locally. The X-ray investigation showed that this chalcedony was not pure, but that kaolin occurred as a contaminant.

The chemical analysis *) is as follows:

Al_2O_3	16.37;	SiO_2	74.48;	Fe_2O_3	2.37;
TiO_2	0.51;	H_2O	6.27.		

From two drillhole-sections samples were analyzed every 50 centimetres. They showed, downwards, the following SiO_2-content:

Drill hole I *)		Drill hole II *)	
4.68	Bauxite	3.99	Bauxite
4.44		4.22	
3.55		7.12	
31.18	Transition zone	19.56	Transition zone
45.20		35.25	
45.43		40.09	
36.50	Kaolin	37.23	Kaolin
38.97		39.27	
39.33		35.42	
40.33		26.10	

In both drill-holes a SiO_2-rich zone is shown under the bauxite.

*) Analyses, Laboratory N.V. Billiton Maatschappij Onverdacht, Suriname.

4. Low-level type bauxite

Mineralogical investigation

In Chapter II, page 299 three sections were discussed which were measured in three different mines at Mackenzie and Ituni (Demerara). From top to bottom these sections consists of:

g. Sedimentary sands and clays.
f. Transition zone.
e. Bauxite-ferrite.
d.' Transition zone.
c. Residuary clay.
b. Weathering zone of bedrock.
a. Solid rock (granite).

a. The result of the examination of the thin sections of the drilling cores of *the solid rock* of the three deposits, is the following:

M o n t g o m e r y M i n e (g r a n i t e).

As primary minerals occur quartz, microcline, plagioclase (oligoclase) and biotite. The quartz is somewhat kataclastic, the biotite is dark olive-green to brown, and sometimes weathered slightly to pennine. The microcline locally shows small amounts of kaolin; in the oligoclase occur rather large amounts of sericite, muscovite and kaolin. It is possible that primary muscovite also occurs. In addition, apatite, ore and zircon are found.
The texture is holocrystalline, hypidiomorph, medium- to fine-grained and the structure is not orientated.
The rock is a granite, a fact which can also be deducted from the chemical analysis (page 388).

M a r i a E l i s a b e t h M i n e (q u a r t z - d i o r i t e).

The primary minerals are quartz, oligoclase, biotite, epidote and Na-potassium-feldspar. The quartz is kataclastic and sometimes somewhat undulating; the albite shows alteration to much sericite, kaolin and some epidote. Na-potassium-feldspar is largely altered to kaolin and sericite, biotite shows alteration to chlorite. In addition, apatite, zircon, titanite and ore are found.
The texture is holocrystalline, hypidiomorph, medium- to fine-grained; the structure is not orientated.
The rock is a quartz-diorite, a fact which is corroborated by the chemical analysis (page 340).
A second drilling core from the bedrock in this mine was placed at the disposal of the writer.
The primary minerals are green hornblende, Na-potassium-feldspar, epidote, titanite, quartz and clinochlorite. The hornblende shows alteration to chlorite. The clinochlorite occurs in veinlets with limonite. The other constituents are ore and limonite.
The texture is holocrystalline, hypidiomorph and of variable grain-size. The minerals are slightly orientated and show flow structure. The rock is a quartzitic epidote-alkali-syenite hornblendite. Probably the rock is from

a lamprophyric dike or basic inclusion, which is also indicated by the analysis (page 340).

Ituni Mine (biotite-muscovite granite).

The primary minerals are microcline, quartz, plagioclase (oligoclase), biotite and muscovite. In the microcline occur myrmekite-like inclusions of quartz. The plagioclase shows alteration to epidote, zoisite, sericite and kaolin; as alteration product of the generally olive-green biotite, pennine is found. Additional constituents are apatite, zircon and ore.

The texture is holocrystalline, hypidiomorph and with a variable grain-size. The structure is not orientated. The rock is a biotite-muscovite granite; the chemical analysis is found on page 341.

b. *Weathering zone of bedrock*; no data are available, as the necessary drilling cores were not at our disposal.

c. *Residuary clay*; X-ray and differential thermal analyses showed that this clay mainly consists of kaolinite. With the electron microscope a few tubes of (meta)halloysite were found. In a few samples of kaolin (Montgomery Mine and Ituni) sericite was found by X-ray. The heavy mineral fraction (bromoform, s.g. 2.90) contains hematite, goethite, rutile and zircon.

d. *Transition zone kaolin—bauxite.* From the bottom to the top gibbsite increases and is found as small clear grains and also in the shape of cylindrical concretions of crypto- to macrocrystalline gibbsite.

e. *Bauxite-ferrite.* The main constituent of the bauxite is gibbsite. In the heavy fraction of the bauxites, boehmite was found by X-ray. This mineral may be present in quantities of up to 2 %. The X-ray analysis also showed that anatase is present. Here again the anatase must be present in the form of yellow-brown aggregates which do not extinguish between crossed nicols.

The gibbsite is found mostly in micro- and cryptocrystalline form.

The small lenses of clay that occur in the bauxite consist of bauxite clay, kaolinite and metahalloysite, according to the X-ray and electron microscope analyses.

The ferrites consist mainly of hematite and goethite. The hematite is again the dominant mineral and is magnetic. The goethite is chiefly present in the limonite beds.

f. In the *transition zone,* to the bauxite occur stains in the kaolin. When these stains have a pink colour and are partly indurated, they contain gibbsite.

g. The *sedimentary clays* of the soil cover consist for a large part of kaolinite, according to the X-ray and the differential thermal analyses. Locally large quantities of quartz grains occur in these clays.

Chemical investigation

From the weathering section of the Montgomery Mine, four analyses are available.

Analysis XVI: Solid rock, granite.

Analysis XVII: Autochthonous kaolin. The sample is taken about 1 metre under the boundary bauxite — kaolin. X-ray investigation showed kaolinite as the main component, whereas, a small quantity of sericite also occurs.

Analysis XVIII: Micro- to cryptocrystalline gibbsite. X-ray showed along with principally gibbsite, small quantities of boehmite and anatase.

Analysis XIX: Kaolin, from a clay lens in the bauxite. X-ray investigation showed the presence of sericite along with predominantly kaolinite.

Chemical analyses *, weathering section Montgomery Mine.

	XVI **	XVII	XVIII	XIX
SiO_2	72.57	43.47	1.42	42.11
Al_2O_3	14.46	39.83	63.00	40.36
Fe_2O_3	1.24	0.25	1.19	0.40
FeO	0.90	trace	0.07	0.11
MnO	0.04	trace	trace	trace
MgO	0.29	0.49	0.38	0.35
CaO	1.17	2.05	trace	trace
Na_2O	3.18	0.32	0.24	0.41
K_2O	5.17	0.06	0.12	0.11
H_2O+	0.72	11.65	31.26	12.72
H_2O-	0.05	0.25	0.07	1.17
TiO_2	0.23	1.64	2.13	2.30
P_2O_5	0.18	0.18	0.16	0.12
	100.20	100.19	100.04	100.16

Normative mineral compositions (mol. %).

Q	30.2	—	—	—
F	57.8	—	—	—
Ms I + Sc	7.5	5.4	—	6.7
Bi	2.9	—	—	—
Ru	0.2	1.3	2.0	1.8
Hm	0.6	0.3	1.1	0.3
Mt	0.4	—	—	—
Cp	0.4	0.4	—	—
Kaol	—	86.2	3.4	84.8
Gi	—	3.5	83.8	5.7
Bo	—	—	8.0	—
Accessoria	—	2.9	1.7	0.7
	100.—	100.—	100.—	100.—

Nigglivalues.

	XVI **	XVII	XVIII	XIX
si	395.1	161	3.7	168
al	46	87	95	94.5
fm	12	4	4	3.5
c	7	8	—	—
alk	35	1	1	2
ti	1	4.5	4.0	6.9
k	0.51	0.17	0.20	0.13
mg	0.20	0.75	0.40	0.60

Weathering values.

$$\frac{si}{al} = si', \quad \frac{fm}{al} = fm', \quad \frac{c}{al} = c', \quad \frac{alk}{al} = alk', \quad \frac{ti}{al} = ti'$$

si′	8.51	1.85	0.04	1.78
fm′	0.25	0.04	0.04	0.04
c′	0.15	0.09	—	—
alk′	0.75	0.01	0.01	0.02
ti′	0.02	0.05	0.04	0.07

$$\frac{Na_2O}{Al_2O_3} \times 100 = NA \quad \frac{K_2O}{Al_2O_3} \times 100 = KA$$

NA	35.2	1.3	1.8	0.7
KA	38.7	0.3	0.3	0.2

* Analyzed by Miss B. HAGEMAN, Petrochemical Laboratory, Leiden.
** Magmatype, Engadinitgranitisch (NIGGLI, 1936).

The weathering values and the analyses show the desilification which took place from the solid rock (analysis XVI) towards the autochthonous kaolin (analysis XVII), whereas, at the same time a decrease is observed for fm and alk. The weathering values show a relative decrease for c and an increase for ti. In the analyses and the weathering values one sees that a further desilification took place from the autochthonous kaolin towards the bauxite (analysis XVIII). The weathering values showed, that c approximately complete has disappeared. Relatively fm and alk did not change, whereas, for ti a small decrease is indicated. The kaolin occurring as a lens in the bauxite, shows a desilification towards the bauxite and a relative decrease of alk and ti in this direction, whereas, fm relatively did not change.

From the values NA and KA, a relative increase appeared for Na_2O from the kaolin towards the bauxite, whereas, K_2O was not affected by the weathering.

MgO is found in all analyses.

The normative mineral compositions generally coincide with the real mineralogical compositions. The Bo-content of analysis XVIII (bauxite) is too high as compared with the results of the mineralogical investigation, which showed a percentage of boehmite of approximately 1 %.

Chemical investigation

Four analyses are available from the weathering section in the Maria Elisabeth Mine.

Analysis XX: Solid rock, quartz-diorite.

Analysis XXI: Solid rock, quartzitic epidote-alkali-syenite hornblendite.

Analysis XXII: Autochthonous kaolin; the sample is taken about 1.5 metres under the bauxite — kaolin boundary. X-ray investigation showed predominantly kaolinite and a small quantity of gibbsite.

Analysis XXIII: Fine- grained bauxite. The X-ray pattern showed a small quantity of boehmite and anatase along with principally gibbsite.

Chemical analyses *, weathering section Maria Elisabeth Mine.

	XX **	XXI ***	XXII	XXIII
SiO_2	72.17	50.39	42.72	0.28
Al_2O_3	15.20	13.47	40.23	63.31
Fe_2O_3	1.39	4.69	0.30	0.46
FeO	1.12	5.97	0.30	trace
MnO	0.03	0.22	0.04	trace
MgO	1.20	7.56	0.20	0.06
CaO	2.92	10.28	1.89	trace
Na_2O	3.56	1.16	0.14	0.40
K_2O	1.26	2.47	0.10	0.24
H_2O+	0.74	2.02	11.43	31.30
H_2O-	0.20	0.14	0.34	0.20
TiO_2	0.26	1.21	2.56	3.49
P_2O_5	0.18	0.20	0.18	0.18
	100.23	99.78	100.43	99.92

Normative mineral compositions (mol. %).

Q	36.9	3.5	—	—
F	45.8	51.3	—	—
Ms I + Sc	8.0	—	1.8	—
Bi I	3.0	—	—	—
Cord + Fe-cord	3.5	—	—	—
P	0.7	38.8	—	—
Ru	0.2	0.9	2.0	3.2
Mt	1.5	5.1	—	—
Hm	—	—	0.2	0.5
Cp	0.4	0.4	—	—
Kaol	—	—	89.6	0.8
Gi	—	—	3.8	84.8
Bo	—	—	—	9
Accessoria	—	—	2.6	1.7
	100.—	100.—	100.—	100.—

Nigglivalues.

	XX **	XXI ***	XXII	XXIII
si	359.3	120.9	159	0.8
al	44.5	19	88.5	97
fm	19	48	3	1.5
c	15.5	26.5	8	—
alk	21	6.5	1	1.5
ti	1.2	2.2	7.2	6.9
k	0.19	0.58	0.33	0.33
mg	0.47	0.56	0.36	0.25

Weathering values.

$$\frac{\text{si}}{\text{al}} = \text{si}', \frac{\text{fm}}{\text{al}} = \text{fm}', \frac{\text{c}}{\text{al}} = \text{c}', \frac{\text{alk}}{\text{al}} = \text{alk}', \frac{\text{ti}}{\text{al}} = \text{ti}'$$

si′	8.07	6.32	1.80	0.01
fm′	0.42	2.51	0.04	0.01
c′	0.35	1.39	0.09	—
alk′	0.47	0.34	0.01	0.01
ti′	0.03	0.12	0.08	0.07

$$\frac{Na_2O}{Al_2O_3} \times 100 = \text{NA} \quad \frac{K_2O}{Al_2O_3} \times 100 = \text{KA}$$

NA	38.2	14	0.5	1
KA	9.1	20	0.3	0.5

* Analyzed by Miss B. HAGEMAN, Petrochemical Laboratory, Leiden.
** Magmatype, Farsunditisch (NIGGLI, 1936).
*** Magmatype, normalgabbroïd to hornblenditisch (NIGGLI, 1936).

The weathering values and analyses of the solid rock (analyses XX and XXI) show towards the residuary clay (analysis XXII) that desilification took place, whereas, for fm, c and alk also a decrease is observed. However, the analyses show an increase of ti, it appears from the weathering values that there is a relative decrease. Towards the bauxite the desilification continued, whereas, the decrease of fm is apparent and alk and ti relatively stay equal.

From the analyses and the values NA and KA it appears that Na_2O as well as K_2O showed an increase towards the bauxite.

The normative mineral compositions coincide with the results of the mineralogical investigation, except for the Bo-content in the bauxite (analysis XXIII). From the mineralogical investigation the boehmite content appeared to be approximately 2 %.

Chemical investigation

Three samples of the weathering section of the Ituni Mine were analyzed. Analysis XXIV: Solid rock, biotite-muscovite granite.

Analysis XXV: Autochthonous kaolin; the sample is taken two metres under the bauxite — kaolin boundary. The X-ray investigations showed a small quantity of sericite and quartz along with predominantly kaolinite.

Analysis XXVI: Dense, homogeneous bauxite. The X-ray pattern denoted that gibbsite is the principal component; small quantities of boehmite, kaolinite and anatase are also observed.

Chemical analyses *, weathering section, Ituni (Demerara).

	XXIV **	XXV	XXVI
SiO_2	71.68	45.45	1.10
Al_2O_3	14.97	36.63	62.50
Fe_2O_3	1.04	1.49	1.19
FeO	0.90	trace	trace
MnO	0.04	trace	trace
MgO	0.05	0.40	0.16
CaO	1.48	2.19	trace
Na_2O	2.79	0.29	0.40
K_2O	5.53	0.06	0.10
H_2O+	0.91	13.15	31.27
H_2O-	0.02	0.31	0.23
TiO_2	0.21	0.48	2.73
P_2O_5	0.18	0.14	0.14
	99.80	100.59	99.82

Normative mineral compositions (mol. %).

Q	30.0	2.4	—
F	58.5	—	—
Ms I + Sc	8.1	5.6	—
Bi I	2.1	—	—
Cp	0.4	0.4	—
Ru	0.2	0.1	2.6
Hm	0.7	1.2	1.1
Kaol	—	87.4	2.8
Gi	—	—	87.0
Bo	—	—	5.5
Accessoria	—	2.9	1.0
	100.—	100.—	100.—

Nigglivalues.

si	391.5	175	2.8
al	48	83	96
fm	9	6.5	3
c	9	9	—
alk	34	1.5	1
ti	0.8	1.4	5.4
k	0.56	0.17	0.12
mg	0.03	0.36	0.29

Weathering values.

$$\frac{si}{al} = si', \frac{fm}{al} = fm', \frac{c}{al} = c', \frac{alk}{al} = alk', \frac{ti}{al} = ti'$$

	XXIV **	XXV	XXVI
si'	8.12	2.11	0.03
fm'	0.18	0.08	0.03
c'	0.18	0.11	—
alk'	0.71	0.02	0.01
ti'	0.02	0.02	0.06

$$\frac{Na_2O}{Al_2O_3} \times 100 = NA \quad \frac{K_2O}{Al_2O_3} \times 100 = KA$$

NA	31.6	1.4	1.1
KA	40.1	0.3	0.2

* Analyzed by Miss B. HAGEMAN, Petrochemical Laboratory, Leiden.
** Magmatype, aplietgranitisch (NIGGLI, 1936).

From the weathering values and the analyses of the solid rock (analysis XXIV) towards the residuary clay (analysis XXV) a great desilification is shown. A decrease for fm and alk is observed, whereas, a relative decrease is indicated for c. Relatively ti did not change.

Towards the bauxite (analysis XXVI) the residuary clay shows an advanced desilification. For fm and alk a decrease is indicated, c has disappeared completely. The analyses and the weathering values indicate a concentration of ti.

MgO is found in all analyses.

From the residuary clay towards the bauxite an increase is shown for Na_2O as well as for K_2O. From the values NA and KA it is apparent than in both cases a relative decrease took place. The normative mineral compositions are equal to the results of the mineralogical investigation, except for Bo in analysis XXV (bauxite). The mineralogical investigation showed a boehmite content of about 1 %.

D. SOME REMARKS ON THE DIFFERENTIAL THERMAL ANALYSES

In the differential thermal analyses of the bauxite samples the double endothermic peak (between 200° and 380° C.) for gibbsite was not always observed. A number of curves from various bauxite samples are recorded in fig. 65. The first curve deals with macroscopic coarsely crystalline, microscopically and röntgenographically pure gibbsite, note: there is no double peak, but a second endothermic reaction is observed between 510° and 590° C.

The curves 2, 3 and 4 are concerned respectively with fine macrocrystalline, microcrystalline and cryptocrystalline gibbsite. Kaolinite is absent in all the samples. Sample 638 regitered in curve 4 contains about

5 % boehmite. One observes in these four curves a lowering of the peak-temperature with decreasing degree of crystallinity, in connection with this the author refers to Arens (1951).

The last three curves were obtained from bauxite samples from three different mines at Mackenzie (Demerara). The samples are micro- to

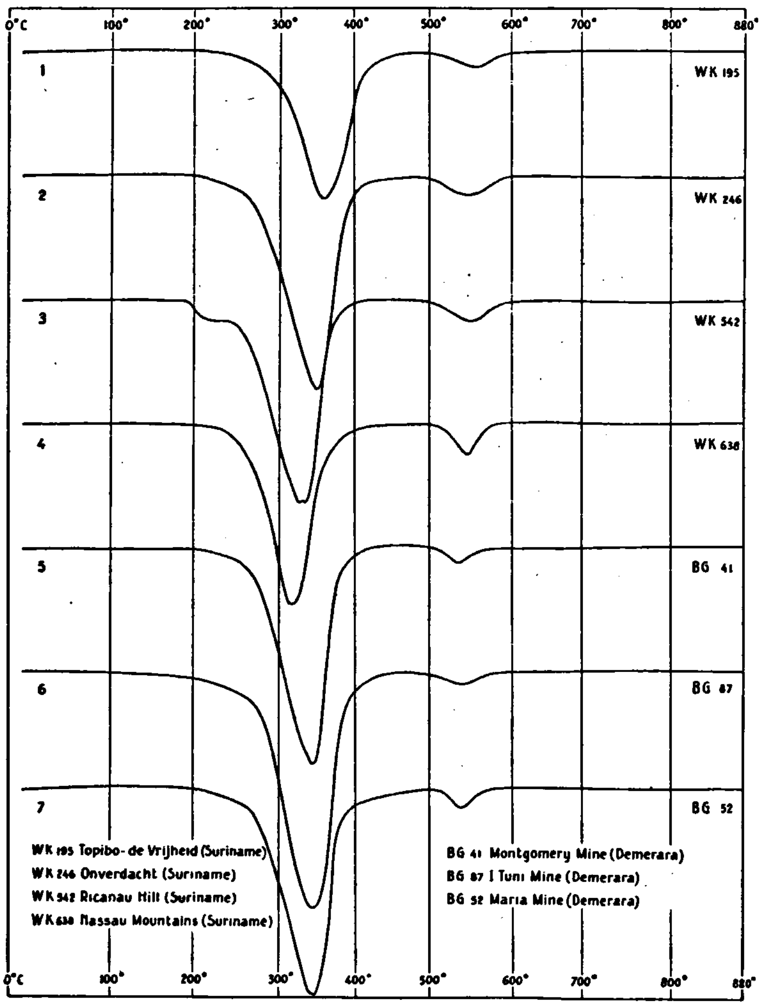

Fig. 65. Differential thermal analyses of bauxite samples. The curves 1, 2, 3 and 4 refer to bauxite samples with a progressive decreasing crystal size of gibbsite. The curves 5, 6 and 7 have been obtained from bauxite samples (Demerara).

cryptocrystalline and contain small quantities of white clay in pores and cracks, boehmite is present in these three samples in quantities no greater than 1 to 2 %.

Fig. 66 contains differential thermal curves for five samples i. e.: four ferrite and one limonite (goethite). The ferrites consist of hematite and gibbsite, the gibbsite content in the curves 8, 9, 10 and 11 varies from less than 5 % to approximately 20 %. The limonite sample (curve 12) consist entirely of goethite, as determined by X-ray. Because the ferrites also generally contain goethite, with a peak-temperature between 320° and 420° C., the differential thermic method of analysis is not suitable for rapid investigation of the purity of ferro-bauxitic and bauxo-ferritic materials

In this chapter under C, I have already dealt with the alteration occurring in mineralogical composition due to bleaching of the soil cover

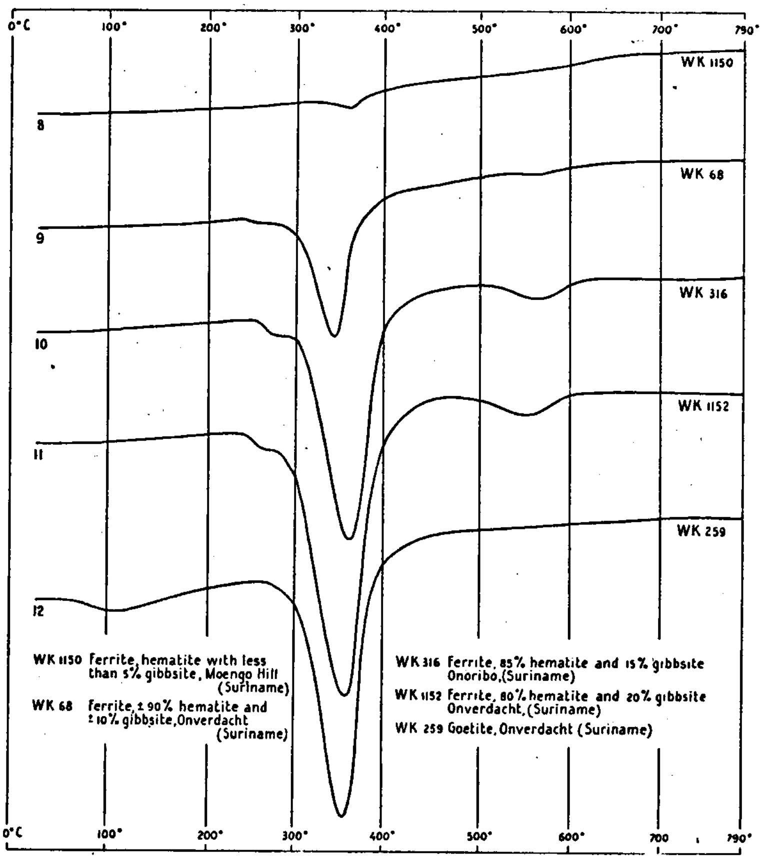

Fig. 66. Differential thermal analyses of ferrite samples. The curves 8, 9, 10 and 11 refer to ferrite, which consists of hematite and progressive increasing percentages of gibbsite. Curve 12 is concerned with goethite.

clays (mainly illite) and in the transition zone between this clay and the bauxite at Onverdacht. Differential thermal analyses gave a clear picture of the percentage increase in metahalloysite in these illite clays and the gradual increase in gibbsite, in clay consisting of metahalloysite. The four curves, 13, 14, 15 and 16 in fig 67 are derived respectively from unbleached illite clay, bleached clay containing not only illite but also metahalloysite, clay consisting of metahalloysite and only a small amount of gibbsite, while the last sample clearly demonstrates the increase of gibbsite.

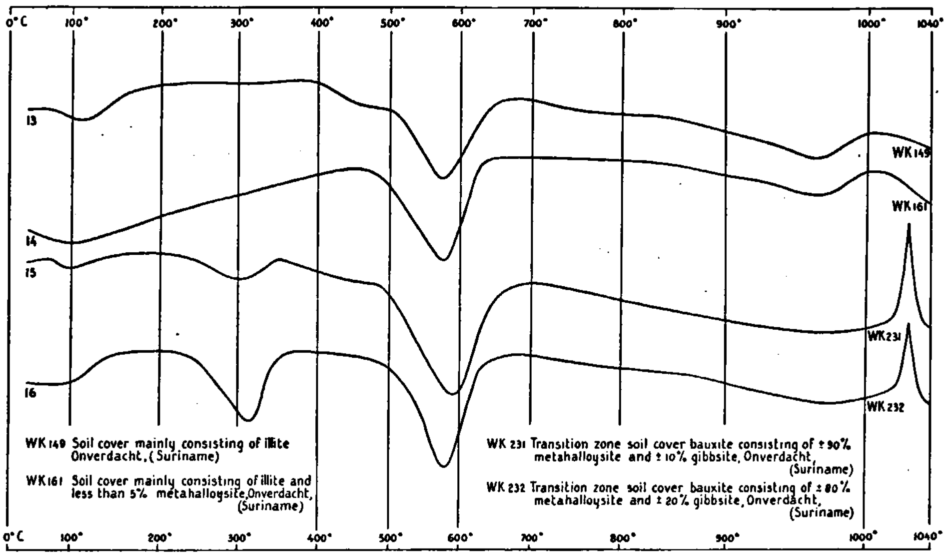

Fig. 67. Differential thermal analyses showing the transition form Coropina clay (illite, curves 13 and 14) via metahalloysite (curves 15 and 16) to gibbsite (Onverdacht).

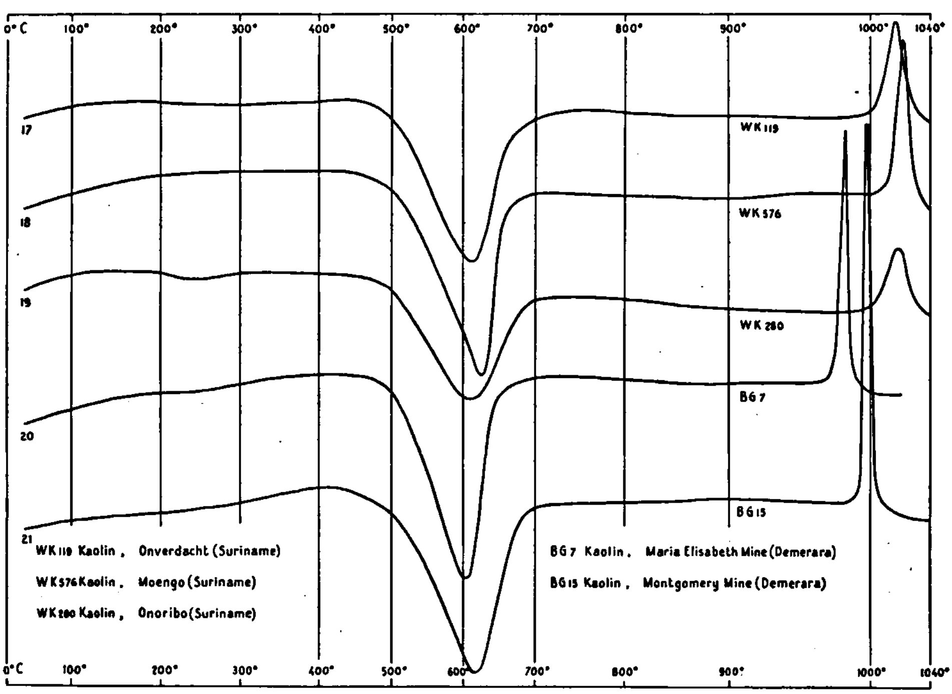

Fig. 68. Differential thermal analyses of kaolin samples showing the difference in the intensity of the recrystallization peak between the sedimentary kaolin (curves 17, 18 and 19) and autochthonous kaolin (curves 20 and 21).

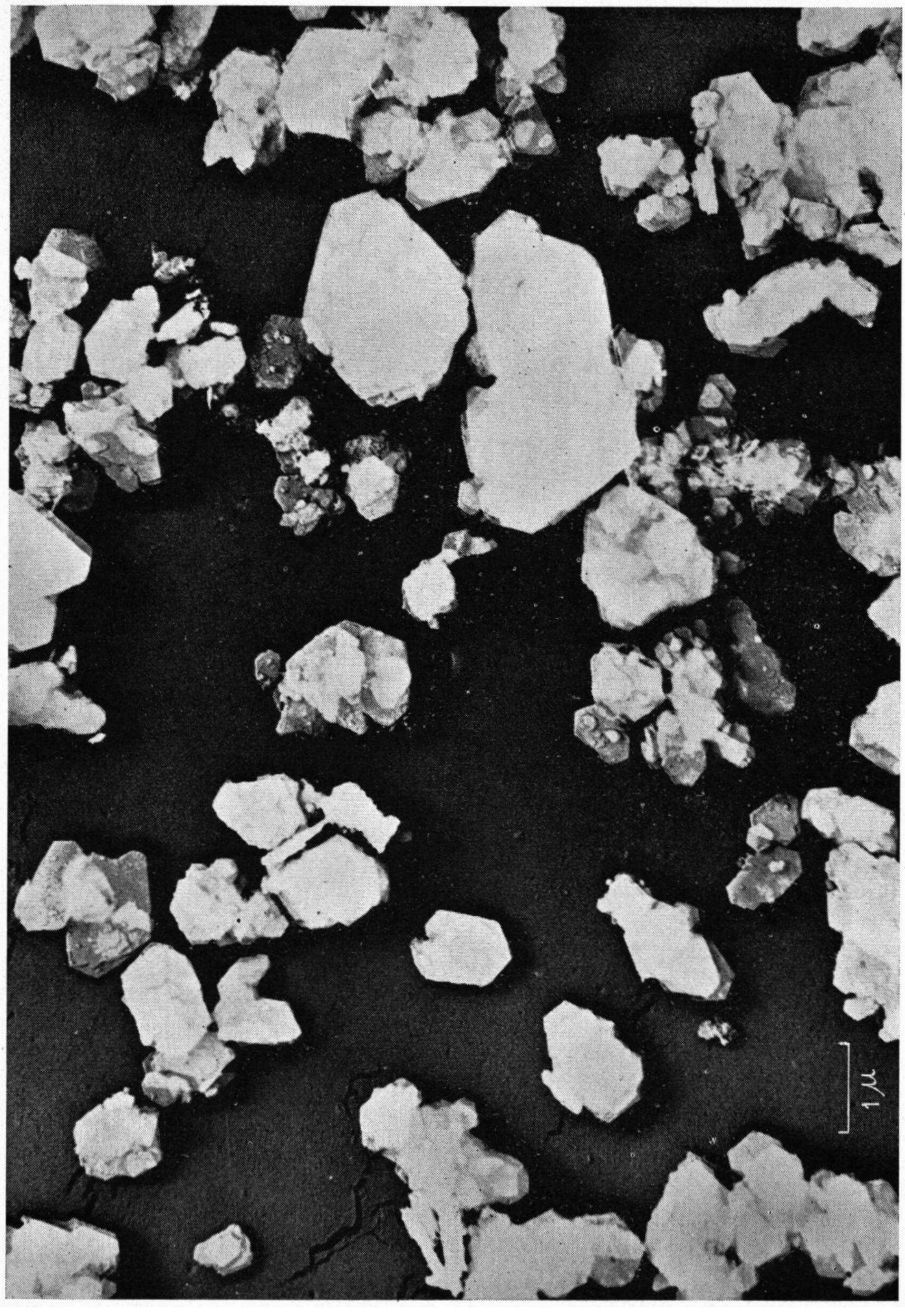

Fig. 69. Electron micrograph of autochthonous kaolin (Montgomery Mine, Mackenzie). Some kaolinite flakes show resorption; besides kaolinite, spatulae of splitted (meta)-halloysite are also seen.

In the analyses of kaolin clays there occurred a number of striking, very intensive recrystallization peaks between 980° and 1040° C. (fig. 68). In connection with this, a number of kaolin samples from Mackenzie showed a noticeably stronger peak than those from the kaolin clays found at Moengo and Onverdacht. It was determined, in the course of the fieldwork, that the kaolin clays at Mackenzie were in situ weathering clays, in contrast to the clays at Moengo and Onverdacht which were sedimentary. A possible explanation to these very intensive recrystallization peaks, could be a better degree of crystallization as well as greater granularity. In connection with this, electron microscopic examination was carried out on these samples, the result of which will be dealt with in this chapter, section E.

E. SOME REMARKS ON THE ELECTRON MICROSCOPICAL INVESTIGATIONS

It was not always possible with X-ray analyses to determine the presence of metahalloysite when it occurs together with kaolinite, the differential thermal method seemed likewise inadequate.

X-ray analyses of clays from the soil cover at Onverdacht was sometimes similarly inconclusive.

I have already reported in this chapter under D the probable differences between kaolin as an in situ occurring weathering product and that occurring as sedimentary clay.

In connection with this, a number of samples were electron microscopically examined with the following results.

From the electron microscopic investigation it appears that autochthonous kaolinite from the Montgomery Mine (Mackenzie, Demerara) occurs in the form of clearly defined six-sided elongated flakes, varying in size between 0.4 and 3.7 μ. Ragged edges occur occasionally, now and then resorption of the flakes is observed. The average size of the flakes lies between 1 and 2 μ, one of the flakes is twinned. On the further not only kaolinite appears but also some flakes of splitted (meta)halloysite (fig. 69).

Fig. 70 is another photograph of kaolinite occurring as an in situ weathering product. The sample is derived from a kaolinized pegmatite in the schists (Bonnidoro serie) on the Haman Hill (Moengo). The flakes display the well-defined elongated six-sided form of kaolinite. One observes resorption in some kaolinite flakes. Some flakes appear to be twinned.

The kaolinite occurring under the bauxite layer of Moengo and Onverdacht, respectively High-level and Medium-level type bauxite deposits, present an entirely different picture. The sample in fig. 71 is derived from Onverdacht, note: the flakes are significantly less well-defined. The size of the flakes runs between 0.1 and 2.5 μ, the average size is about 0.5 μ Some tubes of metahalloysite appear in this sample.

Approximately the same was observed in the kaolin from Moengo. The size of the flakes (which were generally ill-defined) lies between 0.1 and 2.5 μ, the average size is approximately 0.6 μ (fig. 72).

Thus one can see a number of differences between these two kaolin clays. In the first place they differ according to granularity in that the flakes of autochthonous kaolin are larger than those of the sedimentary kaolin. In the second place the flakes of the autochthonous kaolin are geometrically bordered, those of the sedimentary clay are much more irregular.

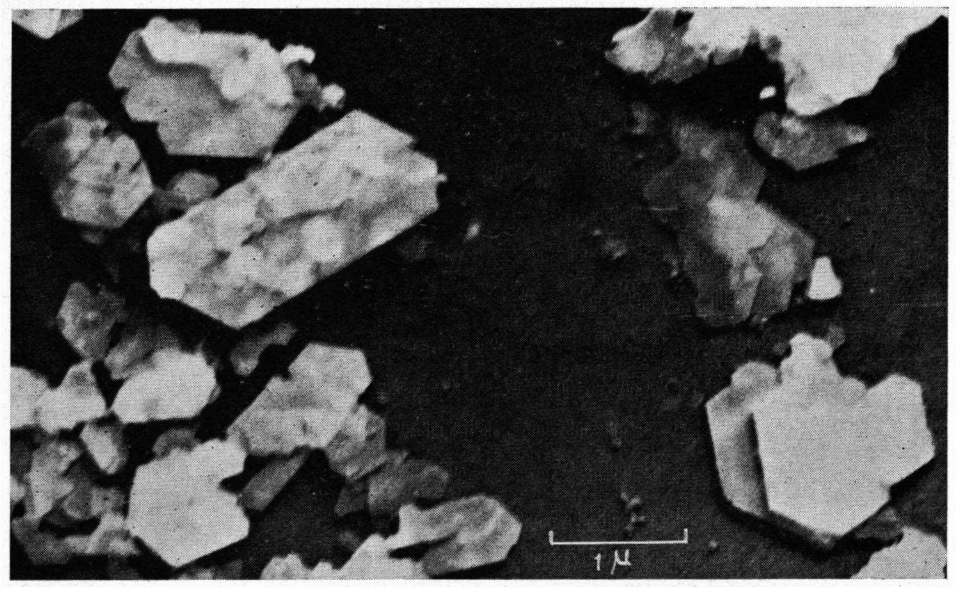

Fig. 70. Electron micrograph of autochthonous kaolin (Haman Hill, Moengo). In general, the kaolinite flakes show a well-defined habitus with the exception of several kaolinite flakes which show symptoms of resorption.

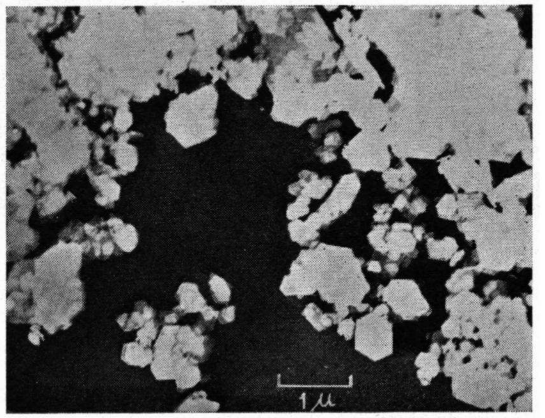

Fig. 71. Electron micrograph of sedimentary kaolin (Onverdacht). The kaolinite flakes are smaller than those of the autochthonous kaolinite and have also ill-defined outlines.

On the basis of these differences I propose that the sedimentary clay, underlying the High-level and Medium-level type bauxites, is a sedimentary kaolin and not a kaolinized sedimentary clay.

Some ragged edges are bordered by crystalline faces as result of twinning or parallel orientated crystalline aggregates, while others are explanable by solution of the kaolinite.

In fig. 73 one can see an aggregate of kaolinite, which shows at several places well-developed resorption symptoms. Solution of kaolinite is very clearly seen in fig. 74, where among others a gap has arisen in the middle of the flake and wherein also a crystal-skeleton is present. Fig. 75 is a better illustration of such a skeleton. Fig. 76 and 77 show aggregates with ragged edges by crystal faces, in fig. 78 a well-developed twinning of kaolinite is recorded.

In the bleaching zone and transition zone of the soil cover into bauxite at Onverdacht, the occurrence of illite, metahalloysite and gibbsite, is

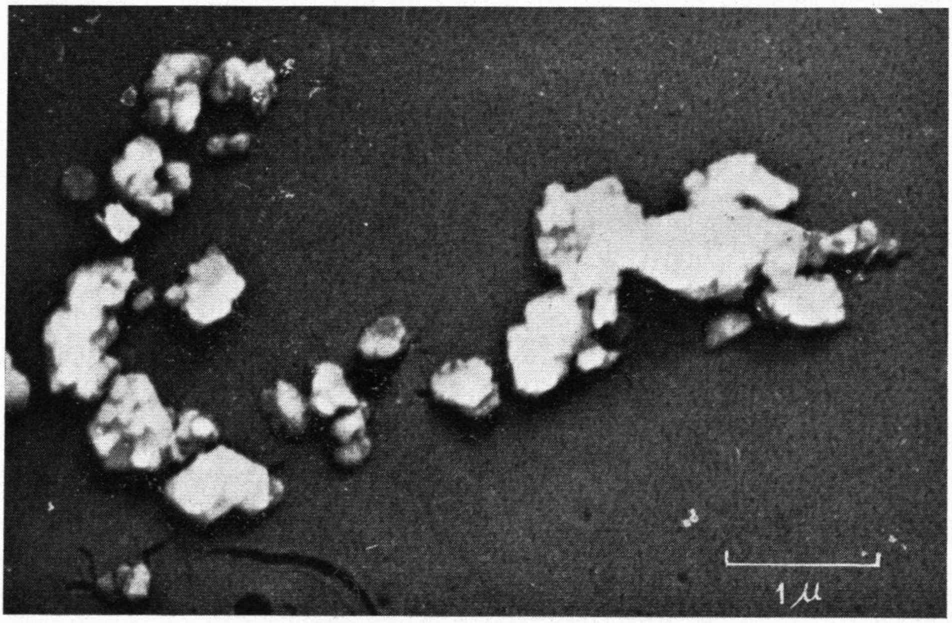

Fig. 72. Electron micrograph of sedimentary kaolin (Ricanau Hill, Moengo). The kaolinite flakes show ill-defined outlines and are smaller than the kaolinite flakes seen at the samples of the autochthonous kaolinite.

differential thermically and röntgenographically observed. Fig. 79 portrays an almost unbleached soil cover clay from Onverdacht, the illite makes sometimes a cloudy impression, some flakes show a clear (if somewhat irregular) border. In the sample one observes not only illite but also metahalloysite, one of the tubes appears to be splitted. The sample illustrated in fig. 80 occurs deeper in the bleaching zone, about 2 metres above the bauxite. One can see that the metahalloysite has increased, furthermore the illite is occasionally very well-defined. Kaolinite is probably present, but this can not be definitely determined.

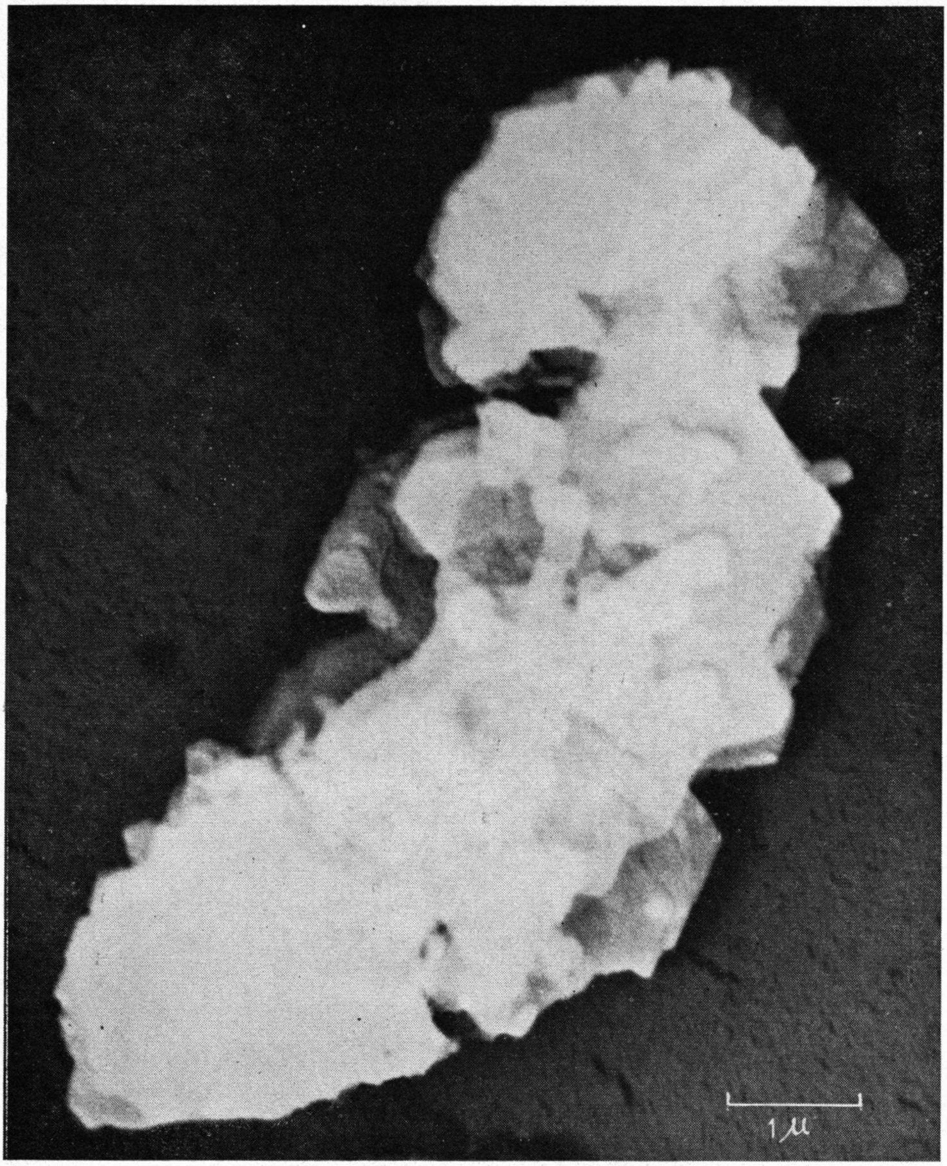

Fig. 73. Electron micrograph of an aggregate of kaolinite, showing symptoms of resorption (Montgomery Mine, Mackenzie).

Above the bauxite layer is a zone consisting almost completely of metahalloysite. Fig. 81 is made of a clay sample about 0.7 metre above the bauxite, on the photo one can see clearly that the metahalloysite consists

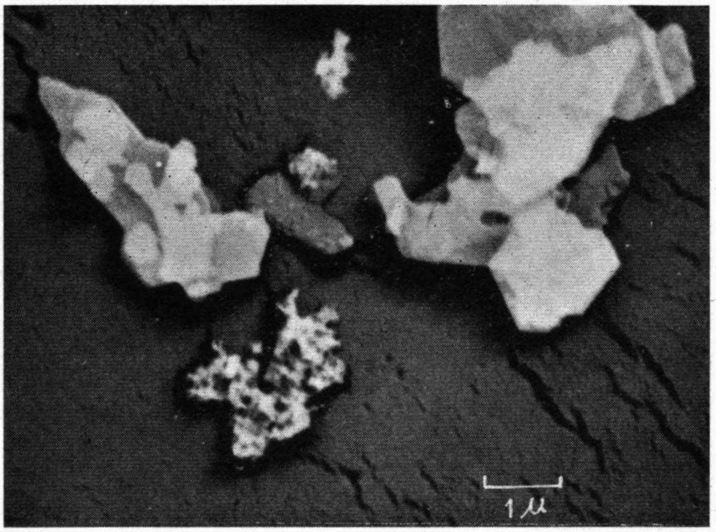

Fig. 74. Electron micrograph of kaolinite (Haman Hill, Moengo). One of the flakes show well-developed resorption symptoms, while a crystal skeleton is also seen.

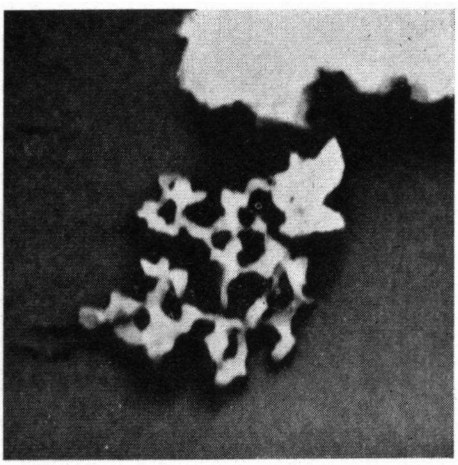

Fig. 75. Electron micrograph of a crystal skeleton in the kaolin of Haman Hill (Moengo). × 3000.

of tubes which on some places are grown together with more or less round patches. X-ray analyses only indicated the presence of metahalloysite and gibbsite, therefore these patches could only consist of gibbsite. One gains

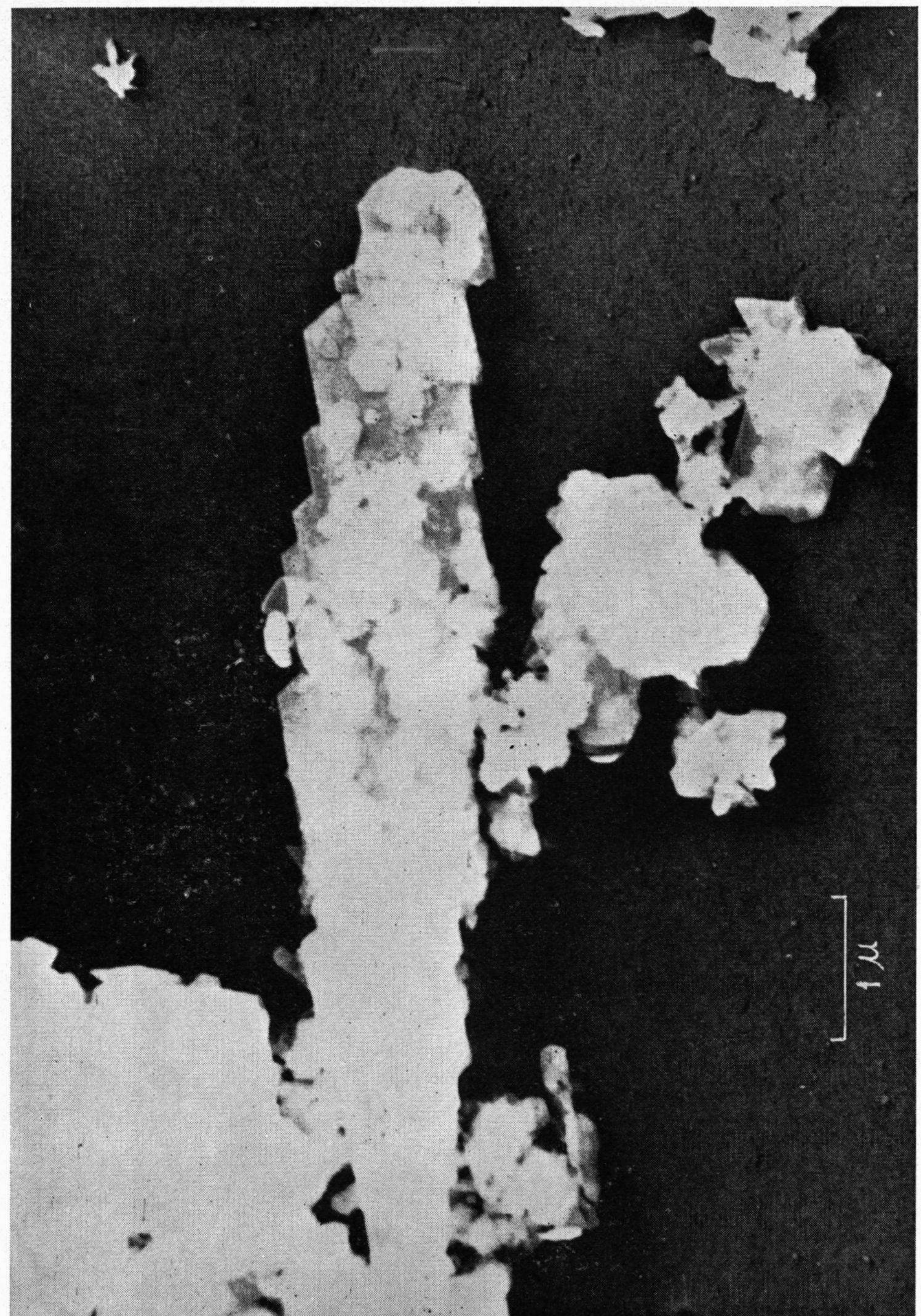

Fig. 76. Electron micrograph of an aggregate of kaolinite (Nassaugebergte).

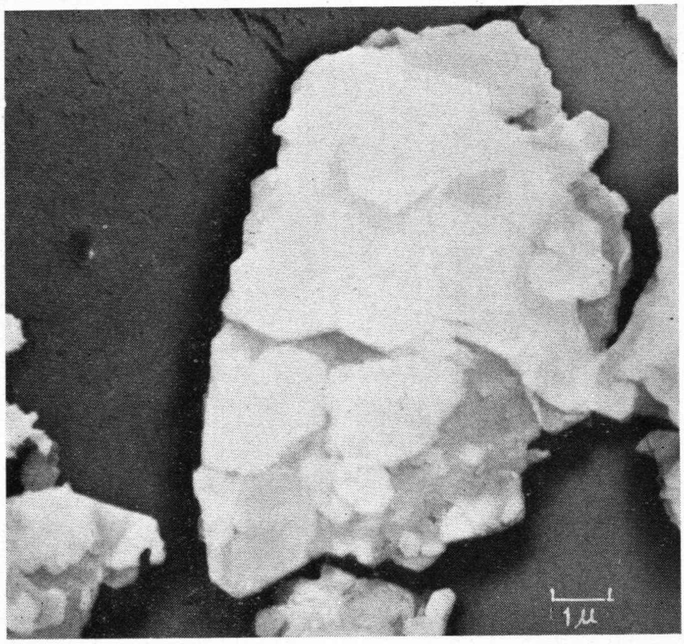

Fig. 77. Electron micrograph of an aggregate of kaolinite showing ragged edges caused by crystals faces, (Maria Elisabeth Mine, Mackenzie).

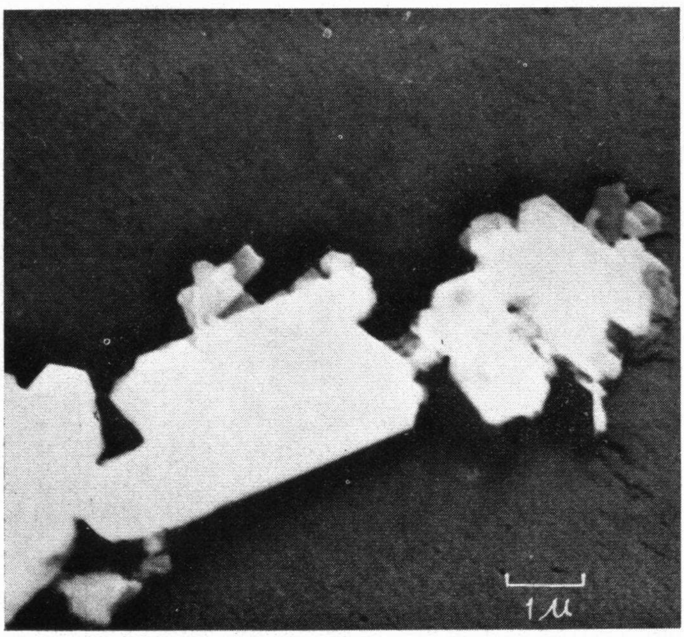

Fig. 78. Electron micrograph of a kaolinite twin (Haman Hill, Moengo).

the impression that these patches grow at the cost of the metahalloysite.

In investigating the composition of the clay enclosures in the bauxite, three minerals were expected namely: gibbsite, metahalloysite and kaolinite.

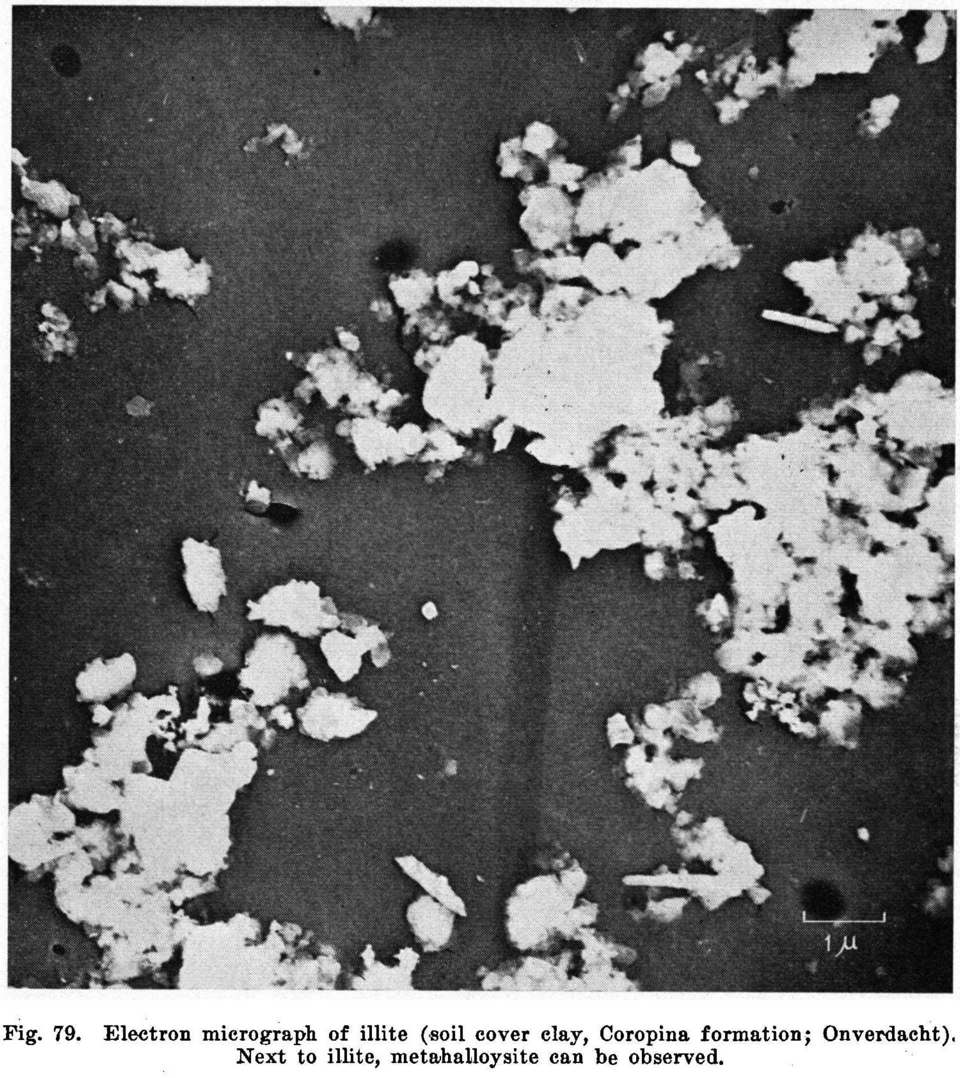

Fig. 79. Electron micrograph of illite (soil cover clay, Coropina formation; Onverdacht). Next to illite, metahalloysite can be observed.

Kaolinite and metahalloysite are known, however a comparative photograph had to be made of gibbsite, for which a röntgenographically pure sample of bauxite clay was used.

Gibbsite occurs as six-sided flakes 0.1 to 0.3 μ large, which frequently appear more or less rounded (fig. 82). Fig. 83 is a photograph of a clay enclosure in bauxite, one sees gibbsite, metahalloysite and kaolinite.

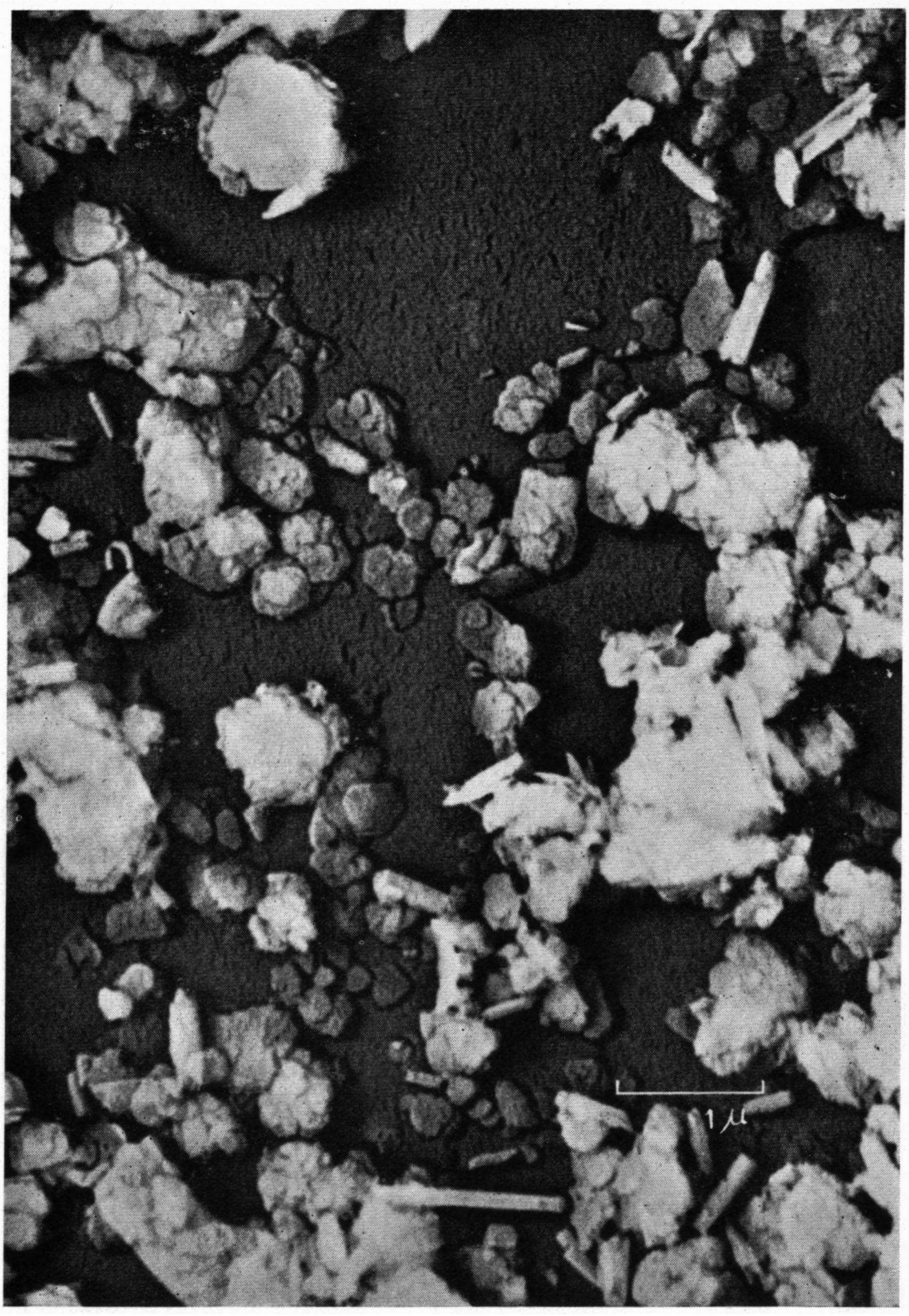

Fig. 80. Electron micrograph of a sample of bleached soil cover clay (Coropina formation, Onverdacht), showing illite and metahalloysite.

Fig. 81. Electron micrograph of the transition zone soil cover clay — bauxite showing metahalloysite and gibbsite, (Coropina formation, Onverdacht).

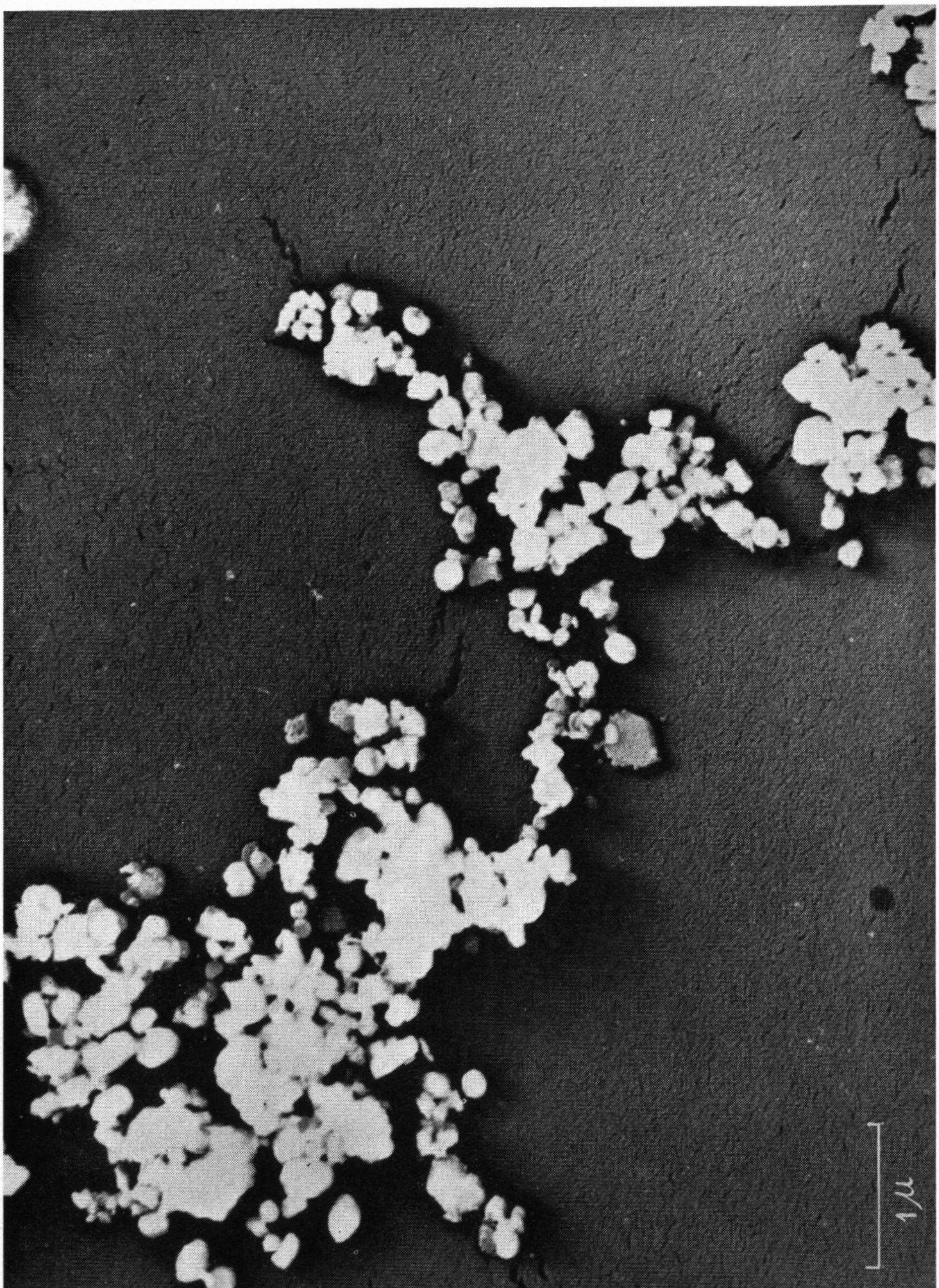

Fig. 82. Electron micrograph of bauxite clay consisting of gibbsite next to small quantities of kaolinite and metahalloysite, (Onverdacht).

Fig. 83. Electron micrograph of a clay enclosure in bauxite (Onverdacht), showing kaolinite, metahalloysite and gibbsite.

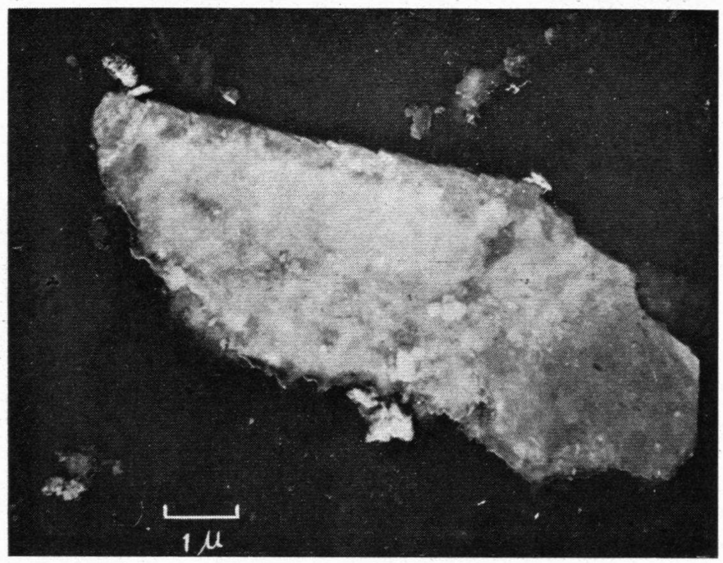

Fig. 84. Electron micrograph of chlorite (weathering zone of bedrock; Nassaugebergte).

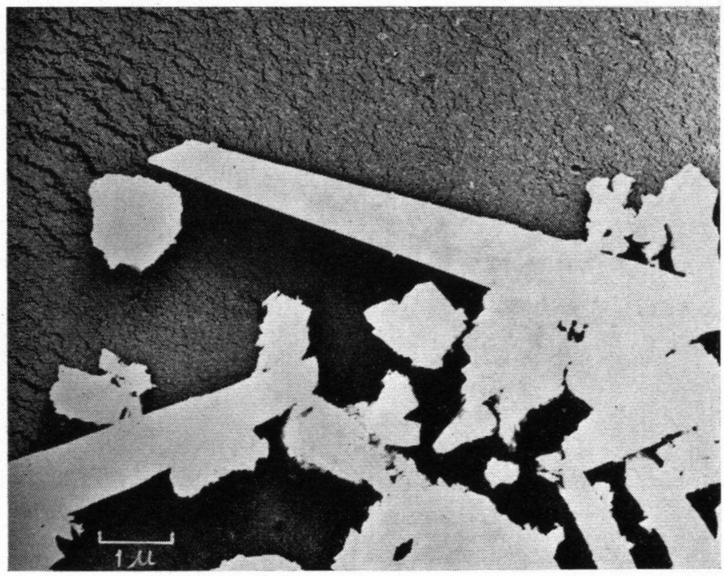

Fig. 85. Electron micrograph of macroscopically needle-shaped goethite (Kleinthal by Pürstein, Bohemen).

Chlorite is an important constituent of the weathered bedrock (Nassau-gebergte), only rarely were clear electron micrographs obtained. In general, irregular shapes are observed which usually show very ragged edges, only occasionally well-defined flakes are found. Fig. 84 is an electron micrograph of a well-defined chlorite flake.

Investigating these samples one must bear in mind the occurrence of

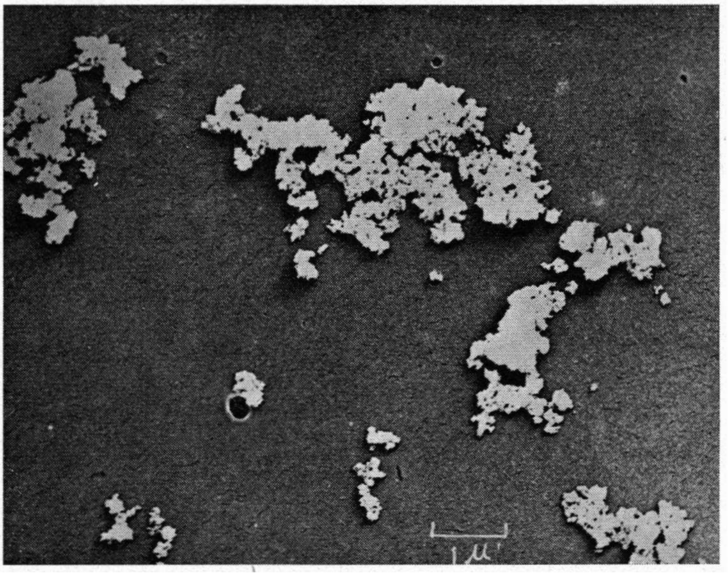

Fig. 86. Electron micrograph of limonite which, according to X-ray analyses, consists of goethite (Onverdacht).

Fe-hydroxides. Two photographs were made, one of a sample of needle-shaped goethite, while the other was a very fine-grained limonite present in a bank at Onverdacht. Both samples displayed the same X-ray pattern (goethite), however that of the limonite was somewhat less intensive. The macroscopically needle-shaped goethite appeared to be electron microscopically also needle-shaped (fig. 85), on the other hand the limonite appeared in a finely granular form, the boundaries of which are very irregular (fig. 86).

F. SOME REMARKS ON THE RESULTS OF THE MINERALOGICAL AND CHEMICAL INVESTIGATIONS

Mineralogical investigation

The number of newly formed minerals in the weathering zones of the different sections is limited. The chief mineralogical components are kaolinite, metahalloysite, chlorite, gibbsite, boehmite, hematite, goethite and anatase.

It appears that in all cases the layer of clay under the bauxite is built up mainly of kaolinite. Metahalloysite occurs in very small quantities.

The basic rocks did not kaolinize right away in the weathering section of the Plateau type but kaolinization was preceded by chloritization.

It could not be determined in the field whether the kaolin underlying the bauxite of High- and Medium-level type was a kaolinized sedimentary clay or sedimentary kaolin. However, electron microscopical analyses indicated the latter.

The main component of the bauxites is gibbsite. The following list of bauxites is arranged according to increasing size of gibbsite crystals:

	Average crystal size
1. Plateau type bauxite	cryptocrystalline
2. Low-level type bauxite	crypto- to microcrystalline
3. High-level type bauxite	microcrystalline to fine-grained (< 1 mm)
4. Medium-level type bauxite .	microcrystalline to middle-grained (> 1 mm, < 5 mm).

Boehmite is generally found in very small quantities in all bauxites. Only in Plateau type bauxites, boehmite can reach as much as 10 %. The boehmite content decreases from Plateau type bauxite, Low-level type bauxite, High-level- to Medium-level type bauxite. The boehmite content of the latter two types is about equal, however, some bauxite samples of Medium-level type did not contain boehmite.

It is evident that the decrease in boehmite content parallels an increase of crystal size in the samples. In the Low-level and Medium-level and High-level type deposits a decreasing boehmite content is observed, whereas, in the field investigation it was proven that these deposits are increasingly younger in the same sequence. Consequently a connection is evident between the boehmite formation and the age of the deposits, a connection already suggested by HARDER (1949).

It is possible to determine the relative age of the different deposits mineralogically. From old to young are distinguished (decreasing boehmite content and increasing crystal size of gibbsite):

1. Plateau type bauxite.
2. Low-level type bauxite.
3. High-level type bauxite.
4. Medium-level type bauxite.

It may be remarked that a considerable difference in boehmite content exists between Plateau type and Low-level type, which percentages are maximally 10 % and 2 % respectively. Accordingly it is doubtful that both types originated in the same peneplain period. It may be accepted that Plateau type bauxites are considerably older than Low-level type bauxites, as was also indicated by field data.

There is only a relatively small difference in boehmite content between Low-level and High-level type bauxites, maximally 2 % and 1 % respectively. A difference in age has already been established by the field investigations.

The difference in boehmite content between the High-level and Medium-level type bauxites is very small, the percentage boehmite for both deposits runs maximally to about 2 %. Boehmite is sometimes totally absent in bauxite of the Medium-level type.

In Chapter II is indicated with field data that both types have been part of the same bauxitized alluvial plain. Locally, very intensive bauxitization at Onverdacht of clays belonging to the Coropina and Demerara formation causes the presence of sub-recent to recent bauxite, lacking boehmite, in the Medium-level type.

It was observed that gibbsite is found covering walls of cavities and cracks: the orientation of gibbsite crystals, with their longitudinal axes (crystallographic b-axis) perpendicular to the walls, makes crystallization from solution probable. Only a few times, walls in cellular bauxite were found consisting of alternating thin layers of gibbsite and kaolinite, on the outside of which not gibbsite, but kaolinite was precipitated. In these cases either resilification or crystallization of kaolinite took place. These observations are closely connected with the formation of bauxite. Consequently the investigation of the transition zone is very important. In the transition zones of kaolin into bauxite in the High-level and Medium-level type deposits it was observed that quartz grains dissolve and generally disappeared near the top of this zone. Locally in this zone chalcedony was encountered as small cylindrical concretions, which proves that part of the dissolved quartz has precipitated from the solutions.

Chemical analyses also indicated that, in a circa 1 metre thick zone under the bauxite, SiO_2-content is higher than in the underlying kaolin. It is noteworthy that part of this SiO_2-rich zone covers the transition zone kaolin — bauxite, in which bauxitization takes place. In the transition zone of the Low-level type bauxite, the electron microscopical investigation shows the dissolving of kaolinite flakes. The same was observed in kaolinite flakes of an autochthonous kaolin clay at Haman Hill. The dissolving of kaolinite was encountered but the ill-defined habitus of the kaolinite flakes made observations difficult in the transition zones bauxite — kaolin of the High- and Medium-level type bauxite.

Illite appeared to be the principal clay mineral encountered, in investigating the soil cover clays (Coropina formation) of the bauxite at Onverdacht. Bleaching of these clays caused the formation of metahalloysite.

The rations SiO_2/Al_2O_3 for illite and metahalloysite are 3.36 to 3.44 (Brown, 1952) and 1. 80 to 2.06 (Brindley, 1952) respectively, so desilification is evident.

Metahalloysite shows alteration in gibbsite, as was observed electron microscopically.

In all bauxite samples which were investigated, anatase was found as TiO_2-bearing mineral. Rutile was found, in only one case, in the clay core of a bauxitic egg.

The components of the ferrites are mainly hematite (magnetic) and goethite. Hematite is the principal component and is an alteration product of goethite.

Chemical investigation

In the chemical analyses, and weathering values (in which al is considered constant) the following is observed:

Al_2O_3:	In the analyses a great increase takes place, but in calculating the weathering values it is considered constant.
SiO_2:	A great decrease takes place towards the bauxite. As is shown by the weathering values of the weathering section of the Nassaugebergte, the desilification begins rather rapidly.

Fe_2O_3:	The analyses and weathering values indicate an increase of Fe_2O_3 in the first zone of the weathered bedrock (Nassaugebergte). However, it is possible that the increase in this zone is secondary. Great concentrations of Fe_2O_3 are found in places where the bauxite is covered with a ferrite-cap.
FeO and MnO:	A rapid decrease is shown in the weathering section towards the bauxite.
MgO:	It is influenced by the weathering process but in all analyses it is observed in small quantities.
CaO:	Towards the kaolin and bauxite, a rapid decrease is shown.
Na_2O and K_2O:	From the solid rock towards the kaolin, they show a great decrease. From the kaolin towards the bauxite the tendency is observed for Na_2O to increase, this is in contrast to K_2O which usually shows a further decrease. It must be mentioned, however, that the analyzed percentages of Na_2O and K_2O are very low.
TiO_2:	Usually it is not influenced much by the weathering process. In the bauxite a decrease or increase is sometimes observed.
P_2O_5:	Very small quantities are found in most analyses.

In the first stage of the weathering process it was observed that from the material which was subject to bauxitization, a decrease of CaO took place towards the bauxite, and simultaneously an intensive decrease was also seen for Na_2O and K_2O. The second stage shows an intensive desilification. In the cases in which the bauxite was not covered with sedimentary clay a great concentration of Fe_2O_3 takes place, which causes the formation of ferrite.

The norm calculations are generally equal to the results of the mineralogical investigation. In many cases the norm of the bauxite samples constitutes an exception, as practically all show too high a percentage of boehmite. This may possibly be explained by variations in H_2O content (without changing the structure) in the gibbsite formule Al_2O_3 $3\,H_2O$.

It is remarkable that the greatest differences were found in the normative mineral compositions of samples of the Medium-level type, which represents the youngest of the three main periods of bauxitization, and where the growth of the bauxite layer with sub-recent to recent bauxite took place most intensively.

CHAPTER IV

SOME NOTES ON THE AGE AND FORMATION OF THE BAUXITE DEPOSITS

Bauxite in Suriname can be roughly divided into two types. The first type, fossil bauxite, has been formed during three main stages of bauxitization. The second type is sub-recent to recent bauxite. After each main phase the intensity of bauxitization decreased, but the process is still continuing.

It appeared from field investigations that the fossil bauxites were part of a peneplain and an alluvial plain. The bauxite deposits of the Plateau type and the Low-level type are formed during a peneplain period, whereas, the deposits of the High-level type and Medium-level type are the remnants of an old bauxitized alluvial plain.

Fox (1932) mentioned the conditions for the formation of laterites, which included bauxite. These conditions can be described as follows:

a. A tropical to sub-tropical climate with alternating dry and rainy seasons.
b. A weakly inclining surface topography, which is not subject to considerable erosion.
c. Rocks with a suitable chemical composition and a structure allowing for penetration of atmospheric water.
d. A long period of contact of the rocks with the infiltrated water.

The Plateau type bauxite, Low-level type bauxite, High-level type and Medium-level type bauxite certainly fit the conditions as mentioned by Fox.

A relative sequence of age of the fossil bauxite could be determined on mineralogical grounds. From old to young this sequence is as follows:

1. Plateau type bauxite.
2. Low-level type bauxite.
3. High-level type bauxite and Medium-level type bauxite.

The soil cover of the Low-level type bauxite is of Miocene to Pliocene age. The fossil bauxites in this case have to be at least Pre-Miocene. Quite probably bauxitization still took place in the Tertiary as it is doubtful whether large quantities of bauxite of this type as they are found in Demerara, would not have disappeared by erosion.

The soil cover clays (Coropina formation) of the Medium-level type bauxite have a thickness of about 30 metres north of Onverdacht. During the formation of this bauxite the sea-level must have been considerable lower than at present. In connection herewith a Pleistocene age is probable, which hypothesis is supported by a C-14 determination of age of a charcoal encountered in the laminated bauxite at Onverdacht. The age of the sample is probably older than 10.000 years, although it must be borne in mind that relatively little material was available. In the field investigation it was proved that High-level type bauxite and Medium-level type bauxite were part of the same alluvial plain, so that also for this type of bauxite a Pleistocene age becomes probable. The determination of the age of bauxites of the Plateau type can only be done relatively, on mineralogical grounds. It will be found that there is a great difference in boehmite content of the Plateau type bauxite and the Low-level type bauxite, which amount to about 10 and 2 % respectively. The difference in boehmite content between Low-level type bauxite (maximally 2 %) and the High-level type and Medium-level type bauxite (maximally 1 %) is very small. Based on the relatively high boehmite content of the Plateau type bauxite, the age may be estimated as Pre-Tertiary.

The three main stages of bauxitization are chronologically as follows:

1. Pre-Tertiary .... Plateau type bauxite
2. Middle- to Lower-Tertiary ...... Low-level type bauxite
3. Pleistocene .... High-level type and Medium-level type bauxite.

In all deposits a layer of kaolin is found under the bauxite. Under the Plateau type and Low-level type bauxite this layer is an autochthonous weathering product of solid rock, whereas, under High-level and Medium-level type bauxite a sedimentary kaolin is found. This sedimentary kaolin is situated on top of kaolinized schists of the Bonnidoro serie, sometimes separated by a sand layer. The heavy mineral fraction of the sedimentary kaolin shows a strong resemblance with the heavy mineral fraction of these kaolinized schists. Consequently it is suspected that the sedimentary kaolin has been derived from these kaolinized schists, which also was supposed by TER MEULEN (1949). The kaolinization of these schists must have taken place before the sedimentation of the partly bauxitized sedimentary kaolin. Because during this bauxitization, kaolinization took place (a kaolinization which is still continued as was observed at Onverdacht in the Coropina clay), this autochthonous kaolin is indicated as fossil autochthonous kaolin.

It is not certain if there was one great period of kaolinization of the schists at Moengo and the bedrock found in the weathering sections of the Plateau type and Low-level type. It is striking that the kaolinization of the basic rock in the weathering section of the Plateau type takes place via chloritization.

A primary and secondary bauxite can be distinguished in the older as well as in the younger bauxites.

Primary bauxite. In the transition zone kaolin — bauxite it has been observed electron microcopically that kaolin is subject to dissolving. In this zone gibbsite increases from bottom to top and generally occurs as clear macro- to microcrystalline grains, sometimes enclosing kaolin. When gibbsite crystals cover the walls of pores and cavities, the longitudinal axes (crystallographic b-axis) of these crystals are arranged perpendicular to these walls. This arrangement indicates crystallization from solutions. Next to gibbsite, chalcedony was found in the transition zone, whereas, chemical analyses showed a higher SiO_2-content in this zone compared with the underlying kaolin.

Gibbsite probably originates from groundwater in which kaolin has previously been dissolved. The surroundings in which solution of kaolin and precipitation of gibbsite takes place bear a great influence on this process. From data published by CORRENS (1949) it appears that solution of kaolin can take place in surroundings with a pH higher than 5 whereas, Al_2O_3 can precipitate as Al-hydroxides in a pH-range from 4 to 8. From a diagram for solubility of SiO_2 as constructed by CORRENS, it appears that this solubility increases with an increasing pH. When solution of kaolin takes place (pH higher than 5) a pH is reached where precipitation of Al-hydroxides is possible, whereas at the same time solubility of SiO_2 has increased and transportation of the silica with the groundwater has become possible.

In Suriname at Onverdacht where the transition zone kaolin — bauxite is located under the groundwater level, a pH of 4.7 was measured in a sample taken in the dry season, of water streaming from the base of the bauxite layer (Analysis by Landbouw Proefstation, Paramaribo). At this location the base of the bauxite was situated about 16 metres below the surface. In the rainy season this pH will increase so that conditions for bauxitization become more favourable. In this way, alternately favourable and less favourable conditions occur for bauxitization.

At Onverdacht it was observed that lamellae of cellular bauxite may consist or alternating layers of gibbsite and kaolin. In some cases the outer layer was formed by kaolin which probably represents the possibility that formation of kaolin takes place under favourable conditions (pH 4 to 5). It appears from field data that this formation of kaolin is restricted. The formation of gibbsite predominates.

Sometimes conditions will be favourable for the precipitation of silica from solutions which is proved by the occurrence of chalcedony in the transition zone. The transport of silica with groundwater is evident among others from investigations by HARRISON (1933) and COOPER (1936).

Recent bauxitization has been observed very clearly at Onverdacht where besides Coropina clays, sub-recent to recent swamp clays are subject to bauxitization. The principal clay-mineral in these clays is illite. As described in the sections of Onverdacht (Chapter II, p. 289) an increasingly intensive bleaching takes place in these clays from top to bottom. From mineralogical investigation it appears that, with more intensive bleaching, metahalloysite is formed, whereas, quartz grains show more and more indications of solution. Electron microscopical investigation indicates that metahalloysite shows alteration into gibbsite. pH-measurements were done in this section, with a Helligen field-pH-meter (colourscale) on several locations in the dry season. These pH-measurements were found to range from about 5.5 to 7. This indicates that conditions for formation of gibbsite in the transition zone soil cover — bauxite are more favourable than in the transition zone kaolin — bauxite, which probably also explains the greater thickness of the former.

It is very remarkable that in the cases where the soil cover clays lie directly on kaolin, no bauxitization takes place. At the most, some bleaching will occur. Consequently, a catalytic influence of the bauxite layer on the bauxitization process is suspected. The decreasing intensity of the bleaching from the bauxite layer to the surface supports this hypothesis.

It was already mentioned in Chapter II, p. 269 that swamps have a tendency to influence bauxitization when they are located not to far above the bauxite. In this case it was observed that the top of the bauxite bulges upward. The low pH of the swamp water will undoubtedly cause a fast kaolinization of the illite clay, (which means desilification with regard to illite). In the dry season, a pH of 3.5 was measured in a sample of swamp-water from a swamp near Onverdacht (Analysis Landbouw Proefstation, Paramaribo).

In the transition zone gibbsite is present in mostly macrocrystalline form. In these zones and also in bauxite samples which are undoubtedly sub-recent to recent, gibbsite was found as only Al-hydroxide.

Secondary bauxite may comprise fossil as well as younger material. The formation of secondary bauxite was very clearly observed on the Nassau-gebergte, where it appeared that bauxite was restricted to the lower parts of the surface where swamps were found. The bauxite, found in these locations is almost entirely white-coloured. On the higher parts in this region, ferrites are often found with a high Fe_2O_3-content. Between these two extremes, a material is encountered consisting of a white core surrounded by ferrite on dry ground, whereas, in swampy and soggy parts of the region, material is found consisting of a ferritic core surrounded by white bauxite.

Under reducing conditions trivalent iron is altered into bivalent iron in the swamps. Iron as a hydroxide is very mobile. PRESCOTT and PENDLETON (1952) observed that bivalent iron hydroxides are not precipitated when oxygen is absent from solutions with a pH lower than 8.1. The iron is transported in this way and will precipitate as soon as it reaches oxydising surroundings. Alteration of the hydroxides into Fe_2O_3 is possible at the surface, (CORRENS, 1949) which explains the great quantities of hematite encountered in the bauxite-ferritecaps of the bauxite deposits.

CHOUBERT (1952) investigated the bacteriological influence on deferritization. By experiments he proved that bleaching (deferritization) is possible and may be of greater importance than suspected.

ABSTRACT

On the basis of the morphology and stratigraphic positions, the bauxite deposits in Suriname and Demerara (British Guiana) were divided into four main groups, namely: 1. Plateau type bauxite, 2. High-level type bauxite, 3. Medium-level type bauxite, 4. Low-level type bauxite.

The age of these deposits is as follows:

Plateau type bauxite	Pre-Tertiary
Low-level type bauxite	Middle- to Lower-Tertiary
High-level and Medium-level type bauxite	Pleistocene

These three main periods of bauxitization have led to the formation of fossil bauxite. After these main periods the bauxitization process, however, has not come to a standstill. It continues even at the present time, although less intensively, so that young, sub-recent to recent bauxite is also found.

In all bauxite deposits a layer of kaolin underlies the bauxite. In the case of the Plateau type and the Low-level type this kaolin has been derived from solid rock. The kaolin situated below the bauxite of High-level and Medium-level type, is a sedimentary kaolin.

In the transition zone between the kaolin and the bauxite, resorption of kaolinite and crystallization of gibbsite is observed.

The growth of the bauxite, at the expense of the soil cover clays has been well observed at Onverdacht, where Coropina clay and sub-recent to recent swamp clays (which clays mainly consists of illite) are subject to recent bauxitization after a preceding kaolinization. One can observe the same bauxitization in the transition zone of the bauxite and the soil cover at Mackenzie (Demerara), where this process also takes place in the kaolin clay of the Zanderij formation.

The chief mineral of the bauxite is gibbsite. Boehmite is also found but in small quantities varying with the age of the type of deposit.

The main constituent of the ferrite is hematite, which is an alteration product of goethite. Goethite is found to a much smaller extent.

It is not probable that unknown bauxite deposits of the Plateau type and High-level type still exists in Suriname. This is in contrast to the Mediu-level type deposits. All of these deposits have most probably not yet been found. Low-level type bauxite is only seen in Demerara. There are indications, in the form of large and small boulders of bauxite and ferrite in the Zanderij formation, which leads us to believe that this type also occurs in Suriname.

SAMENVATTING

De belangrijke bauxietafzettingen in Suriname bevinden zich in de kustvlakte, waar zij worden aangetroffen als verweringsresidu van kleien van de Zanderij-formatie, al of niet bedekt door materiaal uit de Coropina-formatie. In het binnenland treft men eveneens bauxiet aan en wel als verweringskappen van plateaugebergten bestaande uit basische gesteenten. De bauxiet in Demerara (British Guiana) wordt gevonden in een ongeveer Z.O.—N.W. verlopende strook van Kwakwani aan de Berbice rivier naar de monding van de Essequibo rivier.

Op grond van hun morphologie en stratigrafische ligging kunnen in de bauxietafzettingen een viertal typen onderscheiden worden:

1. *Plateau-type bauxiet* vindt men als in situ liggende verweringskappen van basische gesteenten op plateaugebergten, die in hoogte variëren van 300 tot 700 meter; voorbeelden hiervan zijn de bauxietafzettingen op het Nassaugebergte, het Lelygebergte en de Wana Wiero Hills.
2. *High-level-type bauxiet* komt voor als in situ liggende verweringskappen van sedimentaire kaolien over heuvels met platte toppen, die in hoogte variëren van 30 tot 60 meter. Voorbeelden hiervan vindt men te Moengo en te Paranam.
3. *Medium-level-type bauxiet* komt voor in een laag, die gedeeltelijk het verweringsresidu is van de onderliggende kaolien (Zanderij-formatie) en gedeeltelijk van de deklaag-kleien (Coropina-formatie); een voorbeeld hiervan wordt aangetroffen te Onverdacht.
4. *Low-level-type bauxiet* wordt gevonden in een laag, waarvan het ondergedeelte het in situ liggende verweringsproduct is van vaste gesteenten (o. a. graniet), terwijl het bovengedeelte gevormd wordt door het verweringsresidu van sedimentaire kleien van de deklaag (Zanderij-formatie); de bauxietafzettingen te Mackenzie (Demerara) zijn hiervan een duidelijk voorbeeld.

De ligging van de verschillende type van voorkomen ten opzichte van elkaar is weergegeven in fig. 55.

In het veld zijn aanwijzingen gevonden dat de Plateau-type bauxiet en de Low-level-type bauxiet deel uit hebben gemaakt van een peneplain. Het is echter niet waarschijnlijk dat beide typen deel uitmaken van hetzelfde peneplain hetgeen o. a. volgt uit de relatieve ouderdom van de afzettingen, welke bepaald werd op mineralogische gronden. Zoals blijkt uit het profiel door de Onoribo Hill (fig. 29), zijn de bauxietafzettingen van het High-level-type zowel als die van het Medium-level-type, restanten van een oude gebauxitiseerde alluviale vlakte.

Uit de veldgegevens is gebleken dat twee soorten bauxiet voorkomen.

De eerste soort is een fossiele bauxiet, gevormd in drie hoofdperioden van bauxitisatie. Op grond van de veldgegevens en het mineralogisch onderzoek (bij toenemende ouderdom een toenemend boehmiet-gehalte en een afnemende kristalgrootte van de gibsiet) konden de drie hoofdperioden in de volgende chronologische volgorde worden geplaatst:

1. Pre-Tertiair .... Plateau-type bauxiet
2. Midden- tot Onder-Tertiair ..... Low-level-type bauxiet
3. Pleistoceen .... High-level-type bauxiet en Medium-level-type bauxiet.

De laatste ouderdomsbepaling wordt gesteund door de resultaten van het C-14 onderzoek.

De tweede soort bauxiet is jonger dan de drie fossiele soorten, daar na de bovengenoemde hoofdperioden de bauxitisatie niet geheel tot stilstand is gekomen, maar zich — zij het op minder intensieve wijze — tot op de huidige dag heeft voortgezet. In het laatste geval kunnen we dus spreken van sub-recente tot recente bauxiet.

In de verweringsprofielen neemt men waar, dat de bauxiet in alle afzettingen ligt op een pakket kaolien-klei, die in de gevallen van Plateau-type en Low-level-type een residuair karakter draagt, terwijl electronen-microscopisch kon worden vastgesteld dat men bij de High-level en Medium-level-type bauxiet te maken heeft met een sedimentaire kaolien.

De sedimentaire kaolien vertoont in zware fractie een zeer grote overeenkomst met de zich onder deze kaolien bevindende gekaoliniseerde schisten, zoals die worden aangetroffen in Moengo en ten zuiden van Onverdacht en Paranam. De kaolinisatie van het grondgebergte moet hier dus hebben plaatsgevonden voor de afzetting van de sedimentaire kaolien. In verband daarmee wordt in deze gevallen dan ook gesproken van een fossiele autochthone kaolien ter onderscheiding van jongere kaolien, die tijdens de zich voortzettende bauxitisatie gevormd wordt, zoals dit o. a. is waargenomen te Onverdacht. Het kaolinisatie-proces bleek zich hier af te spelen in de deklaag die gevormd wordt door kleien uit de Coropina-formatie en sub-recente tot recente zwamp-kleien.

In alle gevallen bevindt zich tussen de kaolien en de bauxiet een overgangszone waarin, zoals electronen-microscopisch is aangetoond, oplossing van de overwegend uit kaoliniet bestaande klei plaatsvindt, aan welke oplossing eveneens de daar aanwezige kwartskorrels onderhevig zijn. Tevens vindt in deze zone uitkristallisatie van gibsiet plaats. Ook werd in de overgangszone chalcedoon aangetroffen, terwijl uit chemische analyses blijkt, dat hier plaatselijk een hoger SiO_2-gehalte voorkomt dan in de onderliggende kaolien.

Bij het ontstaan van de bauxiet in deze zone wordt gedacht aan oplossingen met een wisselende pH afhankelijk van de seizoenen (droge tijden en regentijden), waarbij een afwisseling van gunstige en minder gunstige perioden optreedt voor respectievelijk het oplossen van kaoliniet en het uitkristalliseren van gibsiet, en omgekeerd.

De recente bauxitisatie werd — zoals reeds vermeld — zeer mooi waargenomen te Onverdacht, waar de kleien van de deklaag (Coropina-formatie en sub-recente tot recente zwamp-kleien) aan bauxitisatie onderhevig zijn.

Bij het mineralogisch onderzoek bleek, dat deze klei waarvan het kleimineraal illiet is, bij de in het veld waargenomen naar beneden toe sterk toenemende bleking, een overgang vertoont in metahalloysiet. Bij het electronen-microscopisch onderzoek van de metahalloysiet kregen wij de indruk, dat deze zich in de overgangszone (in dit geval van de deklaag in de bauxiet) omzet in gibsiet.

Het ontbreken van bauxiet op plaatsen waar de Coropina-formatie direct rust op de kaolien van de Zanderij-formatie en tevens het ontbreken van bauxiet daar, waar de kaolien van de Zanderij-formatie direct rust op het gekaoliniseerde gesteente, doet een katalytische invloed van de bauxietlaag op de recente bauxitisatie vermoeden.

In de gevallen van de Plateau-type bauxiet en de High-level-type bauxiet bevindt zich op de bauxiet een ferrietkap. De ferriet bestaat hoofdzakelijk uit hematiet en goethiet, waarbij opgemerkt moet worden dat de hematiet, die magnetisch bleek te zijn, hier een omzettingsproduct is van goethiet.

In de verweringskappen van het Nassaugebergte en in die van de heuvels te Moengo en te Paranam blijkt de bauxiet-ferriet vaak onderhevig te zijn aan een sterk op karst gelijkende verwering, tengevolge waarvan soms grotten ontstaan.

Tot slot zij opgemerkt, dat het niet waarschijnlijk is, dat zich in Suriname nog onbekende bauxietafzettingen bevinden van het Plateau-type en het High-level-type. Anders is dit echter, waar het bauxietafzettingen betreft van het Medium- en Low-level-type. Het is geenszins uitgesloten dat zich thans nog niet bekende afzettingen van het Medium-level-type bevinden in de kustvlakte voorzover die wordt gevormd door de Coropina-formatie. Low-level-type bauxiet is in Suriname nog niet aangetroffen, het werd tot op heden slechts gevonden te Demerara. De aanwezigheid van grote en kleine blokken bauxiet en ferriet in de Zanderij-formatie in Suriname rechtvaardigt echter het vermoeden, dat ook de Low-level-type bauxiet vertegenwoordigd is.

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