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GEOLOGICAL RESULTS OF THE CARSTENSZ EXPEDITION 1936

BY

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with collaboration of D. A. ERDMAN, W. J. JONG, G. L. KROL and C. SCHOUTEN.

A. GENERAL, STRATIGRAPHY, TECTONICS

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SUMMARY.

The observations made during the Carstensz Expedition give the following impression of the geological structure of the Nassau mountains:

1. Possibly Lower Palaeozoic, Upper Palaeozoic, Mesozoic and Tertiary (Tertiary c, d, e and f) rocks were found.

2. A granodioritic intrusion occurs with a contact zone rich in metasomatic hydrothermal ores (copper, gold). The age of this intrusion is Upper Tertiary, probably even younger than the folding of the mountains.

3. The simplest explanation of the tectonical structure is to assume that these mountains are a big overthrusted mass, moved towards the South over the continuation of the Australian continent. The upper parts (Tertiary) of this mass are folded; otherwise, only North dips were observed.

4. The foreland of this tectonical unit probably for the greater part is covered by unfolded Nassau-molasse deposits.

5. The moraines of a rather important Pleistocene glacier are present.

I. INTRODUCTION.

It goes without saying that the author appreciated very much the privilege of being able to make geological observations in the unknown Nassau Mountains of Central New-Guinea. I wish to express my most sincere and cordial thanks to Dr. A. H. COLIJN who invited me to accompany him on this expedition to the Carstensz Group, where the highest mountain of the Dutch East Indies was to be climbed.

It is very difficult to return from such an unknown region with a satisfactory idea of its geological structure, especially in this case, where the principal object of the expedition was to reach the alpine zone and to climb one of its summits. The extremely dense vegetation prevented us from making sidetrips to examine outcrops away from the trail, except near Simpang Bivouac and Basecamp. The fact that we could collect Pretertiary fossils only in two localities was rather disappointing and our ideas of the stratigraphy of the Pretertiary are therefore extremely hypothetical.

On the 23rd October, 1936, Dr. A. H. COLIJN and Dr. J. J. DOZY left Babo on board the Government Steamer „Albatros'' and on the 27th October reached the base of the N. N. G. P. M. aerial survey at Aika, on the South coast of the island. They left Aika by prao on the 29th and two days later started the overland trip. On the 7th November they came into touch with mountain Papuans and erected their Basecamp. On the 7th and 9th November the pilot F. WISSEL, C. E.

dropped provisions from the Sikorsky amphibian plane PK-AKS on Basecamp and Carstenszweide. Having accomplished this task WISSEL left Aika and joined the expedition on foot. The Alpine camp on the Carstenszweide was erected on the 25th November and served as a base for the excursions in the alpine region where Meren Bivouac, Gletscher Bivouac and Doorsteek Bivouac were also built. On the way back to Aika, Alpine camp was left on the 16th December, Basecamp on the 20th and Aika reached on the 24th December. The expedition returned the next day by Sikorsky plane to Babo.

I am very much indebted to my collaborators, D. A. ERDMAN, Dr. W. J. JONG, G. L. KROL and Dr. Ir. C. SCHOUTEN who spent time and trouble in studying the samples, and whose reports contribute essentially to the scientific value of this report. I wish to express my thanks to Prof. Dr. B. G. ESCHER and Prof. Dr. I. M. VAN DER VLERK for their help in publishing this paper, and for the attention Prof. VAN DER VLERK paid to it, by discussing the palaeontological results. I desire to thank my colleague, Mr. L. W. WALPOLE for his help in correcting the manuscript and Mr. J. H. SCHREUDER for the draughting of the map and the profiles.

I wish to acknowledge my gratitude to the Management of the „NEDERLANDSCHE NIEUW GUINEA PETROLEUM MAATSCHAPPIJ'' and of „DE BATAAFSCHE PETROLEUM MAATSCHAPPIJ'' at The Hague for their permission to publish these results.

II. MORPHOLOGY OF THE COASTAL PLAIN AND THE PLATEAU LANDSCAPE.

When we overlook the whole region between Aika and the Carstensz-group, it appears to be composed of three different landscapes:

1. Flat swampy country (± 55 km).
2. Plateau landscape, gently inclined and sometimes deeply dissected (± 15 km).
3. Mountains, which rise steeply and suddenly out of the plateau landscape (± 30 km).

The relations between these landscapes are very simple. The rivers are gradually reducing the high Nassau Mountains in which they cut deep and narrow gorges. They formed one elongated, continuous delta along the foot of the mountains.

Big blocks, deposited directly at the foot of the mountains, (Nassau Molasse) (see fig. 2) form the gently sloping plateau landscape, into which the rivers had to cut their course during later stages. Now they are mostly flowing in cañon-like valleys (Brug Bivouac). The surface of the plateau is very swampy and densely overgrown with thin hard wood with mosses (see fig. 1).

Fig. 1.
Aerial photograph of the plateau landscape showing the confluence of East and West Otomona Rivers. In the background the foot of the mountains.

After having left the plateau country the rivers originating in the central mountains show large beds of pebble banks, between which the water flows in numerous channels and ramifications. In this part, the river loses its pebbles and gravel. This causes it to shift its course again and again, so that the jungle is kept back over a rather wide zone.

After this the waters form a normal meandering river through the forest. They carry only sand and fine mud which is deposited by high floods in the jungle bordering the river. A great amount of this

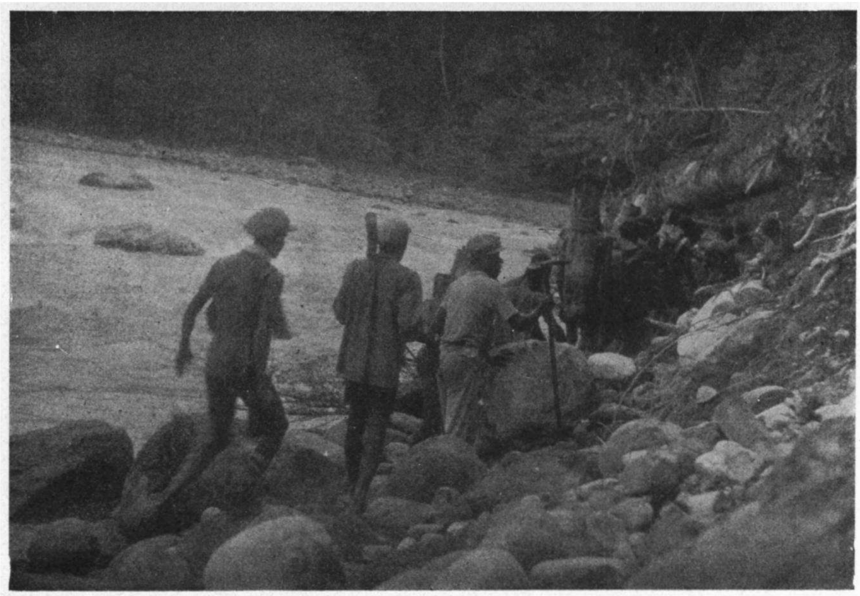

Fig. 2.
Nassau Molasse outcropping on the Otomona River between Prao Bivouac and Brug Bivouac.

material probably reaches the sea, where it forms the numerous banks of the muddy coast and causes its silting and its growth.

It is a remarkable fact that the two last mentioned river types do not pass gradually into each other, but are rather sharply separated. Following the Newerip River upstream, one finds the first pebbles just below Paiva. At this place the jungle suddenly opens, so that the blue silhouettes of the mountains in the distance are visible over the wide pebbly banks of the river.

III. STRATIGRAPHY.

The few outcrops encountered in the densely overgrown mountains, and the great scarcity of fossils, made it impossible for us to build up the stratigraphy in a normal way, by linking together a series of profiles. When it is desired to obtain an idea of the stratigraphical sequence, it is preferable to begin with simple suppositions. A study of the oblique aerial photographs and the dips measured by us shows that all the strata in the area covered by our expedition dip to the North, except the Tertiary rocks of the Carstensz Group. So it is permissible to assume that the rocks occurring to the South are the oldest. This tectonical assumption being admitted, we will start our description with the rocks we found at the southern edge of the mountains, where they rise suddenly out of the plateau landscape.

a) Simpang series.

This series is composed of hard, grey to blue-grey slates, sometimes with a soft silky shine and containing occasional horizons composed of more quartzitic or somewhat calcareous material.

Rocks belonging to this group seem to be widely spread. We found them along the West Otomona River above Simpang Bivouac as far as we explored (± 3 km). On the mountain crest not far in front of the first summit (Eerste Top) we found, in addition to the normal type of slates, a grey slate with fucoïd-like forms and a soft silky shine. Everywhere, the rocks of this series dipped 40°—50° towards the North (fig. 3).

The supposition that the Simpang Series represents the oldest formation met by the expedition is strengthened by the fact that these rocks show the strongest diagenetic alteration of all those collected, without being metamorphic. As they occur to the South of the North dipping Palaeozoic rocks of Basecamp we feel inclined to ascribe them provisionally to a lower Palaeozoic age.

The Simpang Series could possibly be part of the so-called „*Glansleien*'' of ZWIERZICKY (Jaarboek Mijnwezen 1927 — Verh. I) which he considered to be partially of Mesozoic age, on account of an ammonite included in a small pebble of „glanslei'' found in the Brazza River. We did not accept this possibility as we have no reason to compare our Simpang Series, about whose tectonic position nothing is known, with the „Bündner-Schiefer'' of the Alps.

On the crest to the North of the Eerste Top outcrops are completely absent. Through the dense undergrowth of roots and mosses we only very occasionally observed loose blocks. On the way up the Koemaboe from the S. we found a dense grey limestone with small siderite and limonite veins (28) [1]), near the summit a white cavernous

[1]) The figures put in brackets indicate the number of the samples.

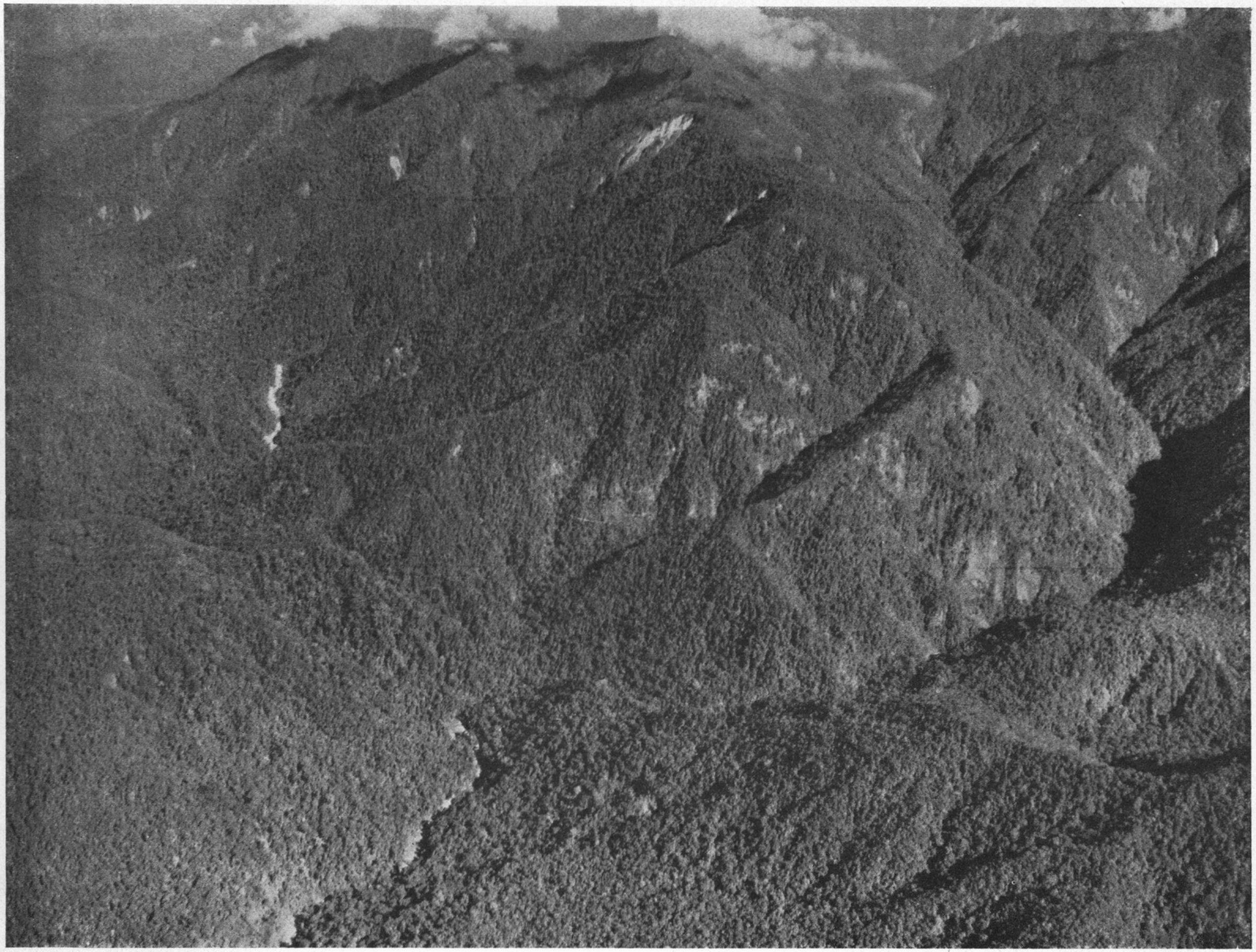

Fig. 3.
Aerial photograph of the foot of the Nassau Mountains near Simpang Bivouac. To the left, the plateau landscape; to the right, the N. dipping Simpang Series.

crystalline limestone, and finally on the Vijfde Top, blocks of a dark grey, finely white-veined, hard claystone and a light grey, hard claystone, weathered white (30 A and B).

b) Upper Palaeozoic.

In the surroundings of Basecamp we found a series of rocks, which we should like to put into one stratigraphic group. A fairly good section can be seen when following the Ponogon river downstream. We observed the following sequence over a straight distance of about 1 km:

3. Hard, dark grey to blue grey, well bedded, sometimes quartzitic clayslates (34), often with thin, lighter coloured intercalated beds. The more quartzitic beds cause cascades.

2. Underlying 3, hard variegated grey conglomerates occur, in layers of one to two meters, alternating with white, finely black-dotted quartz-sandstone (35). The components of the conglomerate are black quartzite and white quartz.

1. At the next curve to the S. of the river thinner bedded, grey to brownish grey sandstones, micaceous sandstones and sandy, thin-bedded micaceous slates are outcropping.

The conglomerates 2 into which the Ponogon eroded a narrow cañon can be followed in the western slope of the valley as a well-developed ridge of the Winangboe Mountain.

The rocks found to the NE of the Zesde Top belong to the same formation. The following similar profile was observed:

3. Dark grey, sometimes finely sandy clayslates (33) which by means of intercalations gradually pass into

2. Grey sandstones with gravel beds and streaks, the components of which are black and white quartzite (32).

1. Grey, yellow to brownish grey weathered, poorly bedded sandstone (31).

In the small brook in which we observed this profile, we were fortunate in finding a loose piece of a grey, brownish yellow weathered, fine-grained sandstone (88), with numerous Brachiopods, among which ERDMAN recognised *Spirifer* spec. and *Chonetes* spec., probably *Ch. variolata* d'Orb.

The age is thus very probably Upper Palaeozoic.

A new series is formed by a group of red coloured rocks occurring further upstream along the Aghawagon. They are dark violet to red sandy shales, fine and coarse sandstones (85) of the same colour, whilst a little further up an outcrop of a light greenish grey quartzitic rock occurs (86), which JONG recognised as a quarz-porphyry crystaltuff. The numerous blocks of a very fine, variegated red sandy shale, stained light green, which rather easily disintegrates and which occurs abundantly in this part of the river, could be placed in the same series. The age of this series is unknown. Their habitus is similar sometimes to the European Buntsandstein or to the Sernifites of the Verrucano.

An equivalent of the grey „mergelzandsteen'' (marly sandstone) mentioned by STEHN and described by BROILI from the Vogelkop of New Guinea was not found.

c) Mesozoic.

Solid Mesozoic rocks were not encountered by the expedition with certainty. In the Aghawagon we found, upstream from Basecamp, not

Fig. 4.
Belemnites in boulder on the Aghawagon River upstream from Basecamp.

far from the landslide, a big block consisting of a very hard, dense, blue-grey quartzitic or hornfels-like rock (87) with splintery fracture, composed, according to JONG, of chlorite and finely divided magnetite. Several canaliculate Belemnites occurred in this block (see fig. 4). The occurrence of such big blocks of very hard rocks was striking in this part of the river, which is situated just to the South of the escarpment of a series of resistent beds showing a nice outcrop in the steep South flank of the Zaagkam Mountain. We could follow this outcrop over a large distance to the West. We assumed that we had to deal with the escarpment of a group of Mesozoic rocks.

The following rocks possibly belong to this group:

1. Dark grey, dense limestone, cleaving into parallelepipeda (82). Where the above mentioned escarpment crosses the valley of the Aghawagon in the gorge near bivouac no. 9, some high walls are formed by this limestone.

2. White to light greenish grey, well striped, and well bedded, very hard quartzitic sandstone and quartzite, with sometimes light brown weathering and iridescent colouring. Big blocks occur in the Aghawagon.

3. Other huge blocks consisting of dark red and white sandstone and conglomerates with, from time to time, dense, red inclusions.

4. Grey, sometimes poorly bedded, hard, very fine grained quartzitic rocks, with pyrites on numerous cracks and veins. These rocks occur in the gorge near bivouac no. 10. They are contact-metamorphic shales (40, 41, 81).

When attempting to compare the above mentioned rocks with those already known, it must be borne in mind that they may be altered by contact influences. This is obviously the case with the dark blue-grey quartzitic or hornfels-like rock containing Belemnites (87). Perhaps we might compare this rock and the dark grey, dense limestone of bivouac no. 9, with the black limestone containing Ammonites and Belemnites, mentioned by MARTIN (lit. 5, see also WANNER, lit. 11) from the Setakwa and the Noordrivier.

d) Tertiary.

The alpine zone of the Carstenz Group consists almost entirely of Tertiary limestones. Due to the scarce vegetation they could be studied rather easily.

The base of the Tertiary formation could not be observed on account of a dioritic intrusion. However, if we assume that the sediments of the Platenspitsen and the mountain crest West and Northwest of bivouac no. 11 represent the Lower Tertiary, it follows that organic limestones and dolomitic limestones must have been present, since we found a silica-slate with layers of grossularite and epidote (80) representing a calcareous mudstone, rich in organic remains, and a forsterite marble (43) probable derived from an impure dolomitic limestone by contact metamorphism.

The oldest unchanged rocks which we found were light ochreous yellow to light grey, dense limestones with abundant *Fasciolites (Borelis)* (53, 54 and 26). The big weakly-vaulted anticline of the Noordwand and the small, steep anticline of the Wachter seem to be formed by these rocks.

This thick series is limited by a grey, sometimes coarse, sandstone of at least 1 m in thickness. It is well exposed near Doorsteek Bivouac and Dajakpas. At the foot of the Wachter Mountain we found near Groene Meer a sandy limestone with *Fasciolites*. It is possible that the sandstone bed itself escaped our attention in the Merendal.

The age of these limestones, according to the determinations of ERDMAN and KROL, may be Tertiary a, b, or c. Sample 54 at first caused some difficulty as it contained *Fasciolites* together with *Spiroclypeus*. According to LEUPOLD and VAN DER VLERK (Martin feestbundel, Leidsche Geologische Mededeelingen V) *Spiroclypeus* occurs in the Upper Tertiary only, whereas *Fasciolites* lived during Tertiary a, b, and c. So we are obliged to accept the opinion of TAN SIN HOK, according to whom a type of *Spiroclypeus* occurs in the Lower Tertiary too.

Above the Lower Tertiary limestone a group of light yellowish grey limestone occurs. They are quite different from the limestone containing abundant *Fasciolites*, so that all the samples (55, 56, 59 and 64) may be grouped together. According to the determination of the foraminifera, the period they have in common is Tertiary d, which we assume to be the age of this group of rocks. We found this formation in the Merendal and near Doorsteek Bivouac. Tectonic features between Blauwe Meer and Merenglacier make it possible that an undisturbed section is not present. However, no intercalations of Lower Tertiary or of the limestone with large Lepidocyclines were found, so that the dislocation is not very important.

The next younger series is formed by a zone of dense, light yellow limestones full of very large Lepidocyclines (58). This zone can clearly be studied in the Middenkam S. of the tongue of the Merenglacier. This same zone occurs in the southern part of the mountain wall on the East side of the Carstenszweide. Here, however, it is metamorphosed by the influence of the dioritic intrusion into a coarse crystalline limestone. Only on the weathered surface the large forams can still be recognised. The age may be Tertiary d and e. In the upper part of this zone in the Middenkam beds of a grey, more marly limestone are intercalated (57). Their age is e_4—e_5 according to ERDMAN and KROL, so that we propose a Tertiary-e age for the whole zone.

A gradual transition leads to the monotonous, dense, yellow limestones which fill up the syncline of the Gele Dal. At the base of these limestones in the mountain wall on the eastern side of the Carstenszweide some samples were collected to which an e_5 age might be ascribed. In the yellow limestones of the Gele Dal a bed of nodular-weathering, somewhat marly limestone occurs. This bed forms a gully with a good vegetation in contrast with the mostly bare limestone rocks. Badly preserved fossil Gasteropods, Lamellibranchs and Echinoids were found. ERDMAN determined the age, by means of an Echinoid, as probably Upper Miocene, which can be compared with upper f to g.

We can summarize our knowledge of the Tertiary of the Carstensz Group as follows:

	Probable age	Description: sample numbers in stratigraphical position	Age according to palaeontologists
Upper Tertiary	Upper e—f	Yellow, monotonous limestones of Gele Dal with an intercalation of a nodular, somewhat marly limestone D 62	Upper Miocene—upper f—g
		at the base samples D 45	e_4—e_5 possibly e_5
		D 46	e_4—e_5 probably e_5
		D 47	e_3—e_5
	lower e (e_1—e_4)	Somewhat light grey, marly intercalations D 57	e_4—e_5
		in the upper part of a dense yellow limestone with big Lepidocyclinae D 58	d—e
		D 48	d—e—f
	d	Light yellowish to light grey limestones D 59	d—e
		D 55	a—b—c—d
		D 64	c—d
		D 56	d—e (?)
Lower Tertiary		grey sandstone	
	c and older?	Light ochreous yellow, to light grey limestone with numerous Fasciolites D 53	a—b—c
		D 54	a—b—c

Lower Tertiary limestones, particularly those with ***Fasciolites,*** seem to be widely spread in the eastern part of the Moluccas and New Guinea. They are not only mentioned from the Central Snow Mountains, but also from Etnabaai, Northern New Guinea, Vogelkop, Misool and Halmaheira.

Samples of an Upper Tertiary age were collected by WOLLASTON in the southern slope of the Carstensz Mountains. They are described by BULLEN NEWTON. Possibly they belong to the same Upper Tertiary limestones which we found in the Gele Dal.

e) Quaternary.

1. *Nassau Molasse.*

The composition of the incised plateaus, representing an old talus of the mountain range, could be studied in the small brooks and along the Otomona River. An upper layer often seems to consist of white clay containing sand and sandy clay. Below these deposits very coarse conglomerates must occur, as the rivers and even the small brooks not originating in the mountains flow over and between large rounded blocks of various rocks (fig. 2).

We propose to adopt the name „Nassau Molasse'' for these deposits as they occur at the base of Nassau Mountains. As to the age no data are available. Upper Tertiary could be possible. We prefer a Quaternary age on account of the apparent absence of folding.

2. *Glacial deposits*[1]).

A second group of Quaternary sediments consists of glacial deposits. Meren- and Carstensz-glacier show a series of young moraines, with or without a scarce vegetation. The name „Gele Dal'', is derived from the yellow colour of the almost bare moraine clay, which characterizes the upper 1—1½ km of that valley. The moraines in the neighbourhood of the Blauwe Meer carry some more vegetation of grasses and mosses.

Older moraines can be found further down in the Merendal and around the Dajakweide, which is a terminal basin filled up with peatbog. But even lower than these localities the traces of ancient glaciers could be observed, e.g. glacial striae and „roches moutonnées'' at the Carstenszweide and the last moraines at a much lower altitude. At 2390 m we found, above bivouac no. 9, an outcrop of a light grey boulder clay in a landslide. The clay contained blocks of various sizes, from some centimeters up to a meter in diameter and of very differing compositions; limestones and eruptive rocks, as well as contact-rocks, occurred. Moreover, some blocks with glacial striae and more or less facetted pebbles were found. From time to time the material was cemented.

These moraines form striking longitudinal, gently arched ridges in the field (see lit. 3, fig. 8). The lowest point where moraine material was observed with certainty is situated in the cañon a little above bivouac no. 9. Probably even the ridge opposite bivouac no. 8 is built up by the same material. So the glacier certainly reached downward to ± 2200 m and possibly even to ± 1900 m. Also other valleys, e.g. Bakopadal, opening towards the N. of the Carstensz Mountains, show well developed old moraines (see fig. 5).

Obviously we can attribute a Pleistocene age to these glacial deposits. The recent valley system existed previously. In the cañon opposite bivouac no. 10 we observed old river gravels underneath the moraine

[1]) For further particulars, see DOZY, lit. 3.

deposits. The glacier tongue was about 15 km longer than the recent tongue of the Merenglacier.

3. *Alluvial deposits.*

The Carstenszweide, nowadays a grassy moorland, is a valley filled up with post-glacial deposits. In the sinkholes on the eastern side, a

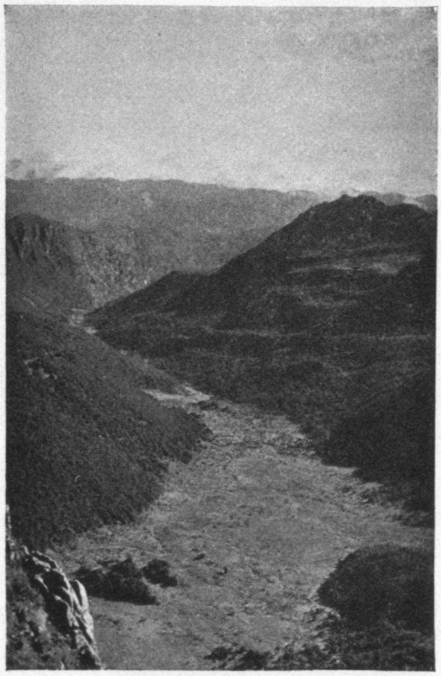

Fig. 5.

Bakopa valley looking towards the North from a point near Doorsteek Bivouac. On the East and West sides probably Pleistocene moraines can be observed. The bottom of the broad U-shaped valley is filled up with swamp.

dark to bluish grey clay with plant remains was observed. Finely bedded gravel layers also occur. Locally rusty coloured sediments and beds rich in limonite prevail.

IV. IGNEOUS ROCKS.

An extensive dioritic intrusion was found on the place where we expected the boundary between the Mesozoic and the Tertiary sediments. In the recent rockfall to the NE of bivouac no. 10 we found contacts of an augite-granodiorite with a hornfels which originated from pelitic sediments (81). The bottom of the valley further to the NE consists of diorites [1]), partially covered by moraine deposits. The clear stratification which can be observed in the Platenspitsen and the crest to the NW of the valley indicates a sedimentary composition for the higher mountain ridges.

Proceeding to the North-east it seems that in the vicinity of bivouac no. 11 the intrusion reached a higher altitude. The rock walls forming a cirque at the origin of the Aghawagon valley consist of diorite. On the western side of the narrow valley, coming from the Carstenszweide, some marble (43) lenses were found, which form striking ridges. The big mass of the diorite seems to end near the Ertsberg, although on the East side of the entrance to the Carstenszweide some apophyses still occur.

A detailed description of the igneous rocks and the ores will be found in the sections of JONG and SCHOUTEN, so that only a brief description is given here.

The intrusive mass seems to consist of hornblende- to augite granodiorites and syeno-diorites or monzonites. The only dyke we observed (between Dajakpas and Doorsteek Bivouac) showed an hornblende-augite granodiorite-porphyry. As we found numerous blocks of diorite-porphyries together with blocks of our supposed Mesozoic formations, it might be that more dykes occur further to the South in the zone where our so-called Mesozoic formations are outcropping. The pebbles collected at Prao Bivouac gave the same impression: hornblende- and augite-granodiorites and porphyries.

Very interesting is the contact of these diorites with the surrounding rocks. Argilaceous sediments changed into hornfelses (40, 41, 81), limestones into marbles (50, 67), sometimes containing forsterite and wollastonite (43) or grossularite, diopside and epidote (38, 49) and marly limestones into cipollines (68). The rather smooth grass-covered Grasbergen, which form a striking morphological element amidst the limestone mountains, are built up by light grey to white, sometimes streaky rocks containing a blue component (lazulite) and showing sulphur-yellow colours when weathered. These rocks perhaps are of argilaceous origin, altered by pneumatolytic influences.

The hydrothermal influence of these diorites must have been extremely important. The contact zones are very rich in metasomatic ores. The Ertsberg shows a black wall of ore with large green patches of malachite. There are gold-containing copper ores in which we could recognise in the field chalcopyrite, malachite, lazulite and bornite. Dr. C. SCHOUTEN investigated these ores, and the reader is referred to his article. The Ertsberg seems to be covered by a cap of limestone. Since at the foot of the mountain no other rock but ore was outcropping, the width of the deposit might be of the order of a 100 meters

[1]) Diorite is here used as a field designation for the whole of the igneous rocks, when no microscopic determination could be made.

(see fig. 6). Also the contact zone at the foot of the Grasbergen is rich in ores. On the NW side of the Carstenszweide several ferruginous springs, occasionally with limonite terraces, occur. The water of the southern brook, coming from the Grasberg, has a very pronounced iron taste.

But even at greater distances from the intrusion the hydrothermal influence must have been appreciable. Pyrite on veins and cracks is very wide-spread and blocks of the rock-slide above bivouac no. 10 show nice eaxmples of this. Springs coloured brown by limonite and smelling of H_2S occur on the Aghawagon near the landslide upstream from Basecamp. The red clay with which the Kapaukoes sometimes like to rub their faces probably originates from such springs. WOLLASTON in the Otakwa valley found a warm sulphur-spring.

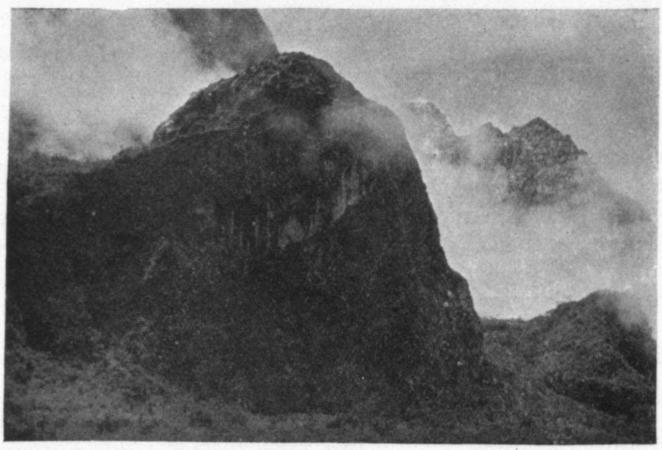

Fig. 6.

Ertsberg. The dark mountain wall consists of ores, which are capped by light coloured limestone.

The age of the intrusion can be fixed by several facts:

1. The Lepidocyclina-limestone of the southern part of the mountain-wall to the East of the Carstenszweide shows a coarse crystalline texture and is almost marmorised (48) under the influence of the contact.

2. In the depression between Dajakpas and Doorsteek Bivouac a diorite-porphyry dyke (63) penetrates Lower Tertiary limestone.

3. It seems that the intrusion did not influence the tectonical structure of the region. The syncline of the Gele Dal seems only to be interrupted by the Grasbergen. In its prolongation a similar syncline can be observed.

4. The steeply dipping beds (ca. 60° to 70°) of the Platenspitsen seem to be replaced by diorite at a lower altitude.

Our conclusion is that the intrusion must be younger than the Upper Tertiary beds, showing contact metamorphic influence, and younger than the interrupted structures, although probably not all tectonic movements ceased after the intrusion had taken place. In the small ravine to the N of the lens of marble, north of bivouac no. 11, a fractured zone was observed, between marble and diorite. Also where in the brooks to the W of the Carstenszweide the contact between the intrusive rocks and the marbles can be observed, the rocks seem to be partially fractured and sometimes show an almost mylonitic appearance. Possibly this phenomenon is caused to a certain extent by the intrusion itself. An important thrust or fault is not probable, as the prolongation of such a fault could not be observed in the limestones to the N of the Dajakweide, Dajakpas or in the surroundings of Doorsteek Bivouac.

Young eruptive rocks were supposed to be rather scarce in this part of New Guinea. ZWIERZICKY (Lit. 11, pag. 43) mentions andesitic dykes. So we are obliged, as in other parts of our Archipelago, to attribute a more important rôle to this young volcanism than we did until now.

V. TECTONICS.

The few scattered observations that we were able to make, render it impossible to give a clear idea of the tectonical structure of this region. The only thing we can do is to give the simplest explanation in accordance with our observations, and to recommend it as a working hypothesis for future investigations.

An examination of the profiles reveals the striking fact that these mountains seem to be rather simple in structure. All our measurements S of the Gele Dal show a dip to the N or NE, except one outcrop above bivouac no. 7, which has a S dip. The relationship between this dip and those in its neighbourhood is not clear. Not taking into account the Simpang Series we meet from S to N first Palaeozoic, then Mesozoic and at last Tertiary rocks. We found no indications of repetitions or intercalations of Tertiary sediments to the S of the diorite massif. In the small tributaries, which we were able to investigate, no Tertiary pebbles were found, which could not be explained as provenant from the central mountains.

Along a rather straight line the mountains rise suddenly from the plateau landscape to altitudes of more than 1000 m. We could expect here the crown of an over-folded nappe, either by reversed dips to the South or by the occurrence of younger beds. Instead we found what are probably the oldest rocks dipping uniformly to the N (see fig. 3). To explain this phenomenon we might assume an upthrust or overthrust at the foot of the mountains.

The Nassau molasse conceals the foreland from observation. On a point near Brug Bivouac, however, possibly Lower Tertiary limestone is outcropping (89) along the river below the Molasse conglomerates. In connection with this it would be interesting to know if HELDRING observed solid Tertiary on the Observatieheuvel (Jaarboek Mijnwezen Ned. Indië 1911).

ZWIERZICKY supposes a zone of Neogene limestones and psammites at the foot of the mountains. Whether these sediments were deposited

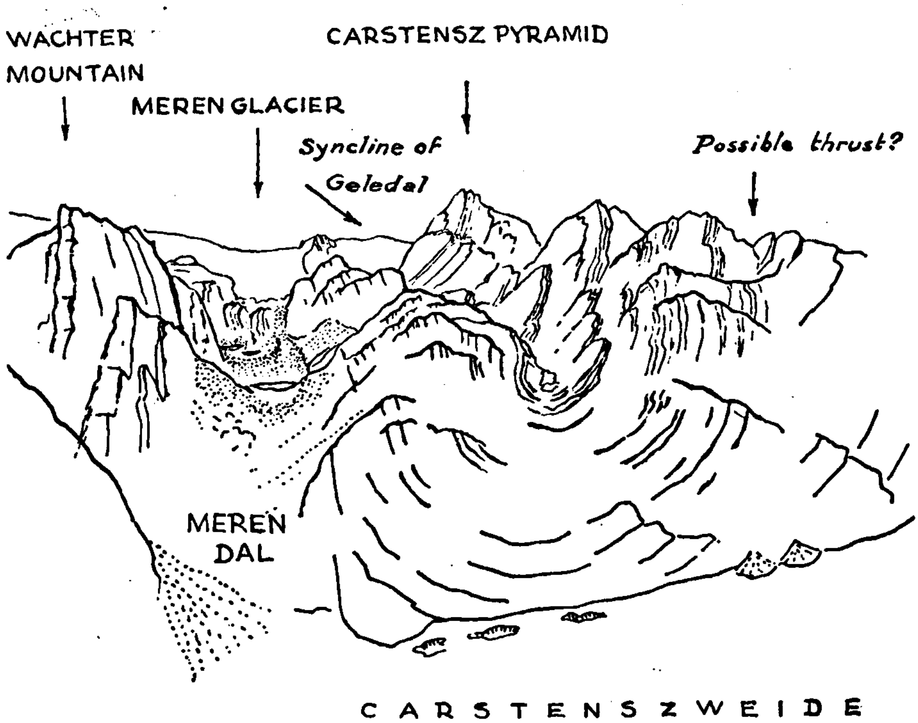

Fig. 7.

Syncline of Gele Dal, seen from the Grasberg.

before or after the principal folding of the mountains is unknown. Even when folded Upper Tertiary is present, such a large gap remains between the Simpang Series and the foreland that an important thrust can easily be accepted.

The Tertiary central mountain chain seems to have a more complicated structure.

Proceeding from S to N we see the conspicuous syncline the axis of which coincides with the Gele Dal and on the S limb of which the summit of the Carstenszpyramide is situated (fig. 7). Locally in the Wachter Mountain a narrow anticline occurs, which is situated on the southern limb of the feebly vaulted, broad anticline of the Noordwand.

To the N of this Noordwand we observed a mountain ridge formed by the continuation of our Tertiary sediments and dipping rather steeply to the N (see fig. 16). Beyond this ridge to the NE a somewhat peneplained plateau occurs, the geological composition of which it would be interesting to know. It is clear, however, that the whole feature strongly resembles the root of an alpine structure, followed by another element.

Fig. 8.

Aerial photograph taken in a NW direction. In the foreground the eastern crest of the Carstenszpyramide, the summit of which lies near the left margin of the picture. The thrust runs from the nevé below the Carstenszpyramide to the lower border of the picture and is clearly marked by the tectonic unconformity. The nevé's in the background are lying on the S. flank of the anticline of the Noordwand. Between these and the Carstenszpyramide the asymmetric anticline in the Wachter Mountain can be observed.

In this picture of the tectonical structure, some local irregularities occur. The most important is the duplication occurring in the S limb of the syncline of the Gele Dal, caused by a wedge-like upthrust which is clearly visible on the photographs of the southern slope of the Carstensz Group. It can be followed to the East below Wollaston- and van de Water-glaciers (see figures 8 and 9), but to the West it pro-

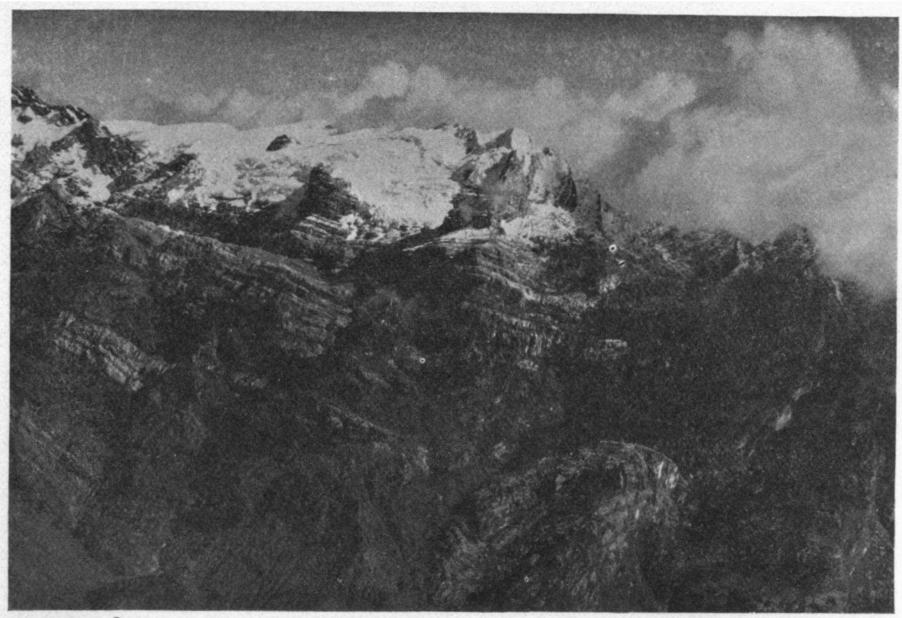

Fig. 9.
Aerial photograph of Southern slope of Carstensz Group between Carstenszpyramide and Oost-Carstensztop, taken in a NW direction and showing duplication of S. limb of the syncline of Gele Dal.

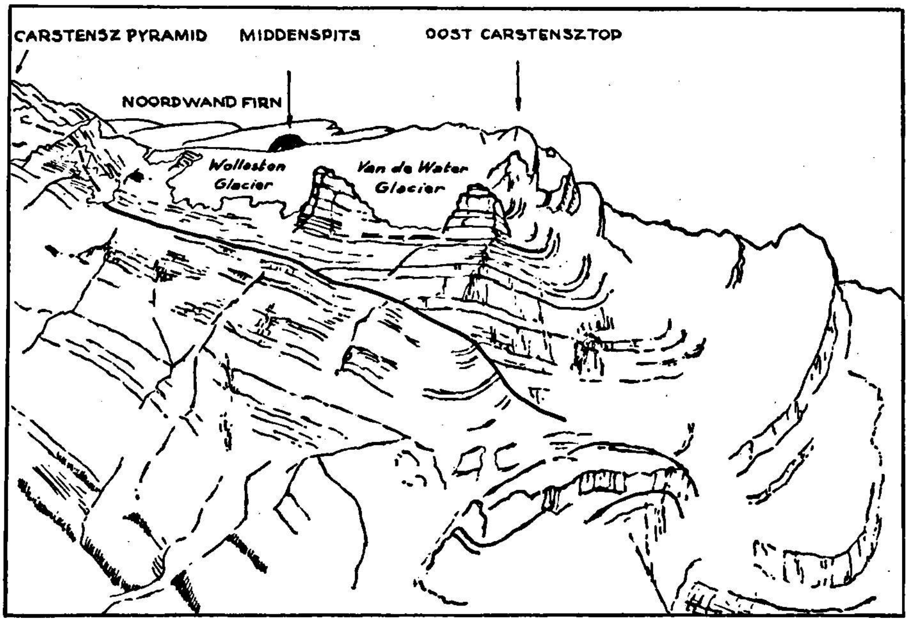

Fig. 9a.
Explicatory sketch to figure 9.

bably loses its importance. We were unable to locate it with certainty in the mountain slopes to the East of the Carstenszweide, nor in the mountain pass to the West of the Carstenszpyramide.

Towards the West the Tertiary structures culminating in the Carstensz Group lose their importance: the anticline of the Noordwand flattens out and shows an axial plunge in this direction, and no equivalent of the Wachter anticline occurs.

Proceeding to the SW from Doorsteek Bivouac the prolongation of the syncline of the Gele Dal is clearly developed, but instead of the duplication of its S limb, which we could not observe near Carstenszweide, a narrow anticline followed by a small syncline seems to be present. We were able to observe these structures from the Grasberg (see fig. 10). The syncline shows a very large S limb, on which Idenburgtop is situated.

To the South of Idenburgtop a new element occurs, which was not

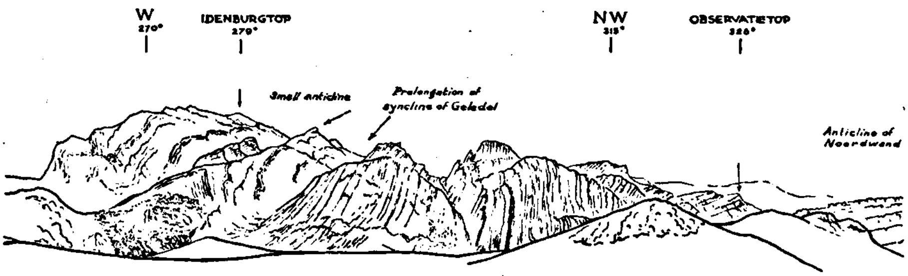

Fig. 10.

Panoramic view to the W. and NW of the mountains between Idenburgtop and Observatietop, seen from the S. Grasberg.

observed in the section passed by our expedition. A flatly vaulted anticline is bordered to the South by a sharply folded syncline. On the aerial photographs these structures can easily be recognised (see fig. 11). On a reconnaissance flight we got the impression, that the prolongation of the last mentioned structures towards the W forms Mount Leonard Darwin and the mountains to the North of it. It is not impossible that they are developed in Tertiary sediments in that region.

We conclude that the Nassau Mountains probably comprise one big tectonical unit, which is bordered at the southern rim of the mountains by an overthrust or upthrust. The apparently excessive thickness of sediments occurring in this unit may be explained by imbrication. The upper parts of the overthrusted mass show folding, which culminates in the Carstensz Group, where the structures are narrowest and the southern limb of the syncline of Gele Dal is even duplicated.

Fig. 11.

Aerial photograph of the structures South of Idenburgtop, taken in NW. direction. In the foreground to the left the so-called „Mesozoic" escarpment.

VI. CORROSION PHENOMENA.

Before concluding this report it is desirable to mention the frequent karst and corrosion phenomena observed in these limestone mountains.

None of the glaciers has a normal glacial stream. All melt-water and rainwater disappears directly in the limestone. Even the Carstensz-weide has a subsurface drainage, as the water disappears into several sinkholes on the East side. Only the most southern brook rising on the Grasberg flows normally over the southern part of the Carstensz-weide. Large springs must be present at the upper border of the diorite intrusion, as cascades fall down over the high diorite walls of the „cirque'' near bivouac no. 11 in the Aghawagon valley.

Chemical erosion of the limestone shows interesting features. The following five different types were observed:

1. Normal lapiés („Karren).
2. Microlapiés („Mikrokarren'') (fig. 12). Steep and sharp edges of stone, such as mountain crests and narrow plates of normal lapiés, show numerous fine sharp points and needles about 1 to 2 cm apart.
3. „Ridge corrosion''. Long vertical ridges, which are sometimes composed of narrower ridges, alternating with wider furrows averaging 10—20 cm across. This type occurs particularly on very steep slabs and rock walls.
4. „Step-corrosion'' („Trapjes-corrosie'') (fig. 13). On gently sloping surfaces small flat terraces have been formed which are bounded by steep sides 1 to 3 cm high.
5. „Corrosion tables'' (fig. 14 and 15). On a polished limestone surface, the glacier left no moraine, only some large blocks. These blocks protected the underlying limestone from local solution so that they rest on a pedestal, like glacier tables. The height of the foot is 20 to 40 cm. This phenomenon was observed in Gele Dal, just outside the region covered by the last extension of the glacier.

Fig. 12.
Microlapiés (Mikrokarren) on normal lapiés in the Gele Dal.

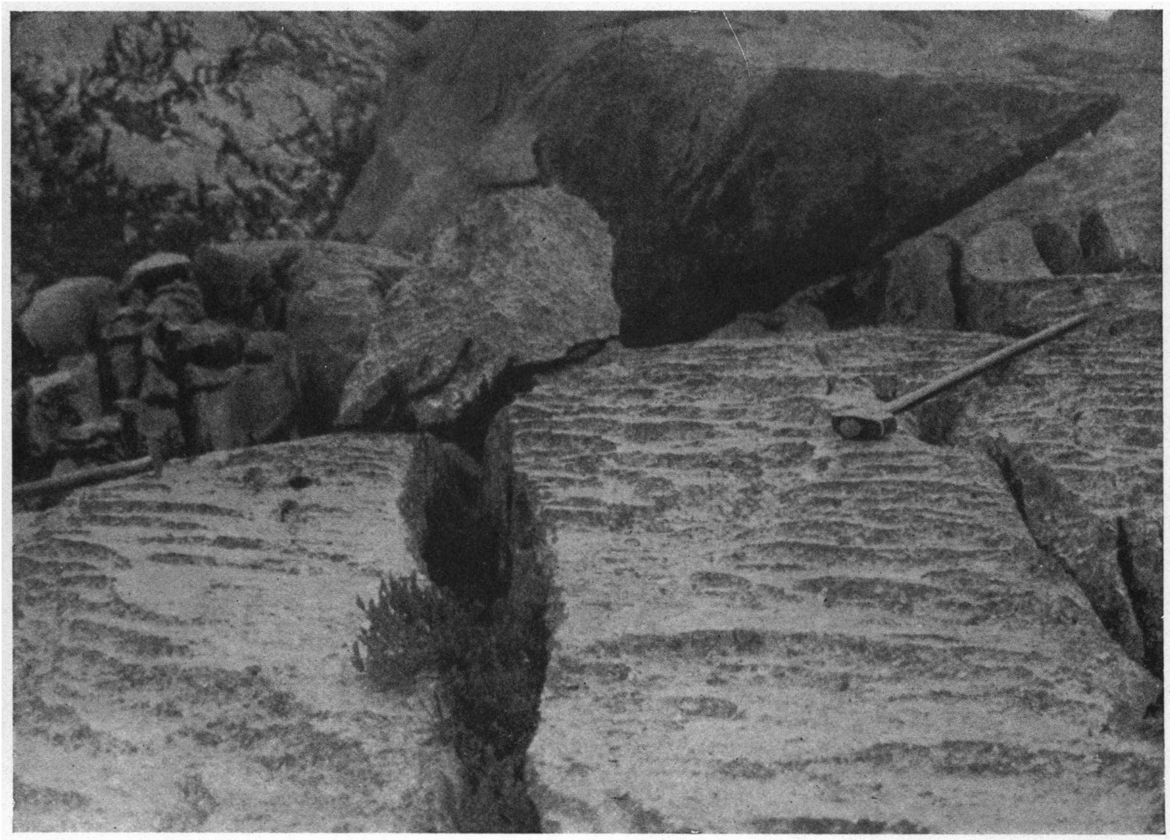

Fig. 13.
Step corrosion (Trapjes-corrosie) on limestone in the Gele Dal.

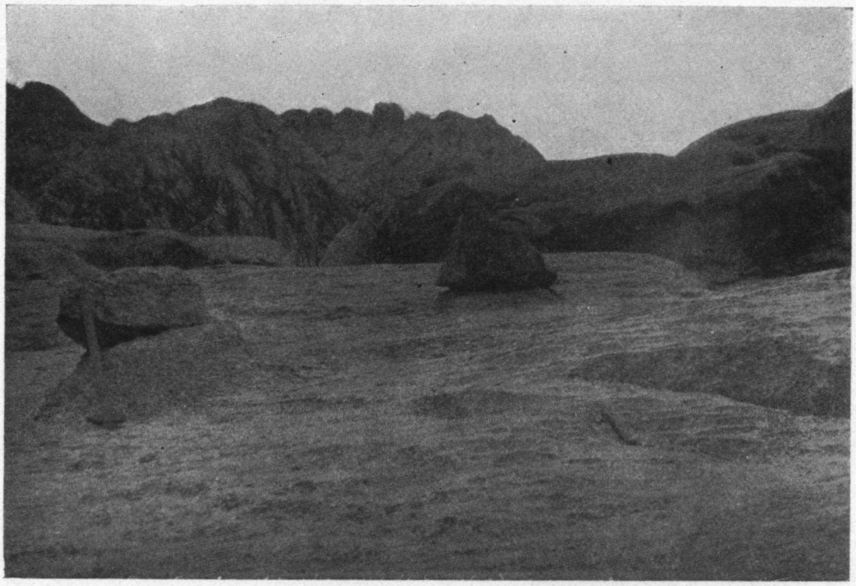

Fig. 14.
Corrosion tables in the Gele Dal.

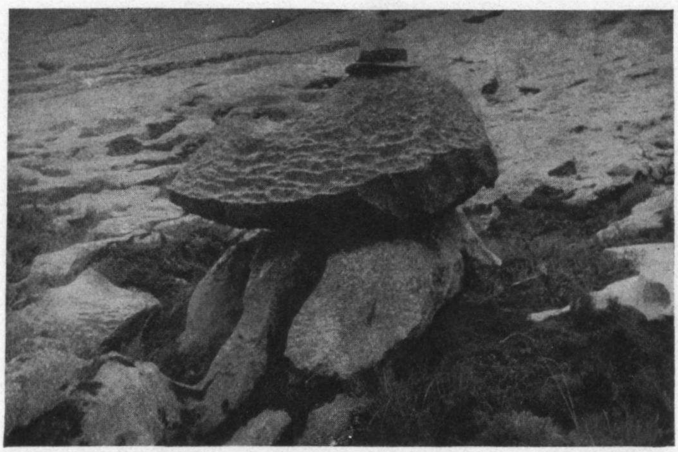

Fig. 15.
Corrosion table showing-step corrosion in the Gele Dal.

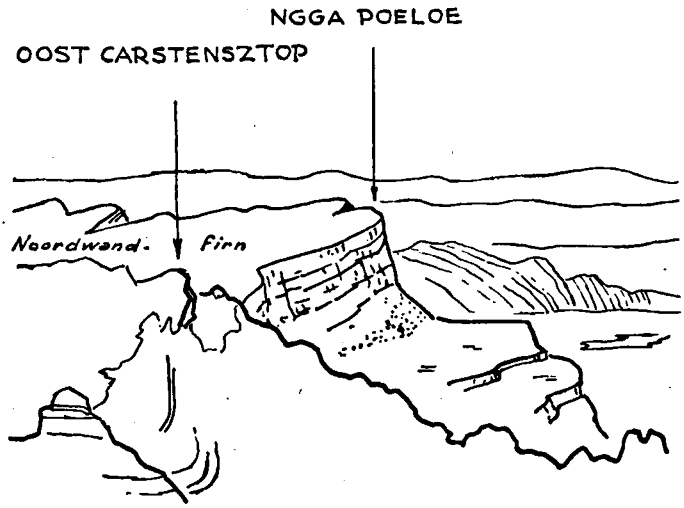

Fig. 16.
Sketch from an aerial photograph in NNW .direction showing the NE. dipping „root-like'' mountains to the North of Ngga Poeloe.

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B. PALAEONTOLOGY.

1. DE FOSSIELE MOLLUSKEN EN MOLLUSCOIDEN VAN DE CARSTENSZ-EXPEDITIE, 1936,

DOOR

D. A. ERDMAN.

D 88 A en B. Grijze, bruingeel verweerende fijne zandsteen met tallooze Brachiopoden.

Vindplaats: N.E. van den Zesden Top.

Fossielinhoud: In dit gesteente zijn duidelijk 2 vormen van Brachiopoden te onderscheiden; n.l. een bolle vorm en een veel breedere platte vorm.
De eerste vorm is vermoedelijk een *Spirifer* species, maar uit de afdrukken en steenkernen is geen verdere determinatie direct mogelijk.
De platte vorm is een *Chonetes* soort, vermoedelijk *Chonetes variolata* d'Orb. Deze soort is in Djambi gevonden van Jong-Palaeozoïschen ouderdom. De eenige andere Chonetes soort, die deze exemplaren eventueel zouden kunnen zijn (*Ch. strophomenoïdes* WAAG.) is eveneens van Jong-Palaeozoïschen ouderdom, zoodat een ouderdom van

Ouderdom: Jong-Palaeozoïsch,
niet ongemotiveerd is. Zekere determinatie is door het onmogelijk zijn van waarneming van kleine kenmerken zeer lastig.

D 62. Fossielen uit knollige kalksteen.

Vindplaats: Gele Dal.

Fossielbeschrijving: Behalve eenige ondetermineerbare Gastropoden-steenkernen komen enkele Lamellibranchiaten voor. Deze zijn: *Spondylus* sp., *Pecten* sp., en *Ostrea* sp.
Eveneens komen eenige Echiniden in deze verzameling voor, 3 stuks. Deze zijn vermoedelijk van één soort. Van Nw. Guinea zijn door mij geen Echiniden vondsten in de literatuur opgemerkt. Be-

doelde exemplaren behooren tot de Regulares, en komen sterk overeen met *Pleurechinus javanus* Martin, beschreven in zijn: „Die Tertiärschichten auf Java". De ouderdom hiervan is

Vermoedelijke Ouderdom: Jong Mioceen.

Deze exemplaren gelijken tevens op de in het Rijks museum voor Geologie te Leiden uitgestalde soort *Opechinus Madurae* JEANNET. Hierover heb ik geen literatuur kunnen vinden.

2. DE TERTIAIRE GESTEENTEN VAN DE CARSTENSZEXPEDITIE,

DOOR

D. A. ERDMAN en G. L. KROL.

D 20.	Koraalkalksteen.
Vindplaats:	Rolsteen Prauwbivak.
Foraminiferen:	geen.
Koralen.	
Echinidae.	
Ouderdom:	niet te bepalen.
D 22.	Groengrijze, bruin verweerende kwartszandsteen.
Vindplaats:	rintis langs Otomona beneden Simpangbivak.

Hierin werden geen fossielen gevonden.

D 26.	Donkergrijze, iets kristallijne kalksteen, licht grijsgeel verweerend.
Vindplaats:	Rolsteen in de beek ten N. van Simpangbivak.
Foraminiferen:	Miliola sp. Operculinella sp. Operculina sp. Heterostegina sp. Neoalveolina pygmaea Hanzawa.
Algen:	Lithophyllum sp.
Ouderdom:	Tertiair a_2, b, c, d, e.
Opmerkingen:	Neoalveolina is in eenige kleine exemplaren duidelijk aanwezig.

Buiten de stratigrafisch niet begrensde, niet verder te determineeren Heterostegina sp., Operculina sp., en Operculinella sp., komt geen soort in dit gesteente voor.

D 45. Dichte bruingrijze kalksteen.

Vindplaats: E-wand Carstenszweide.

Foraminiferen:
Textularia sp.
Miliola sp.
Trillina howchini Schlumb.
Operculina sp.
Carpenteria sp.
Lepidocyclina (Nephrolepidina) sp. sp.
Miogypsina (Miogypsinoïdes) dehaarti v. d. Vl.

Algen: Lithophyllum sp.

Ouderdom: Tertiair e_4—e_5.

Opmerkingen: Met zekerheid is Miogypsina dehaarti waargenomen. Van de Lepidocyclinae zijn geen horizontale doorsneden aanwezig, doch de verticale doen vermoeden, dat L. inflata Prov. en L. verbeeki N. et H. eronder voorkomen.
De mogelijkheid is dus aanwezig dat de ouderdom alleen e_5 is.

D 46. Grijze soms donkergrijze tot bruingrijze zwak kristallijne kalksteen.

Vindplaats: E-wand Carstenszweide.

Foraminiferen:
Textularia sp.
Operculina sp.
Spiroclypeus leupoldi v. d. Vl.
Gypsina plana Carter.
Carpenteria sp.
Lepidocyclina (Nephrolepidina) sp. sp.
Lep. borneensis Prov.
Lep. angulosa Prov.
Lep. inflata Prov.
Miogypsina (Miogypsinoïdes) dehaarti v. d. Vl.

Algen: Lithophyllum sp.

Echinidae: stekel, verschillende vormen.

Ouderdom: Tertiair e_5.

Opmerkingen: Er bevinden zich in deze plaatjes equatoriale sneden van Lepidocyclinen, die wijzen op Nephrolepidina; op welke grondslag tot determinatie van de bovenstaande species kan worden besloten.
Evenals bij D 45 is e_5 het meest waarschijnlijk.

D 47. Blauwgrijze dichte kalksteen.

Vindplaats: E-wand Carstenszweide.

Foraminiferen:	Operculinella sp. Operculina sp. Heterostegina sp. Spiroclypeus leupoldi v. d. V. Gypsina plana Carter. Carpenteria sp. Lepidocyclina sp. Miogypsina (zonder lat. kamers).
Algen:	Lithophyllum sp.
Ouderdom:	Tertiair e_3—e_5.
D 48.	Grijs verweerende, witte, gedeeltelijk kristallijne kalksteen.
Vindplaats:	E-wand Carstenszweide.
Foraminiferen:	Lepidocyclina sp.
Koralen?	
Algen.	
Ouderdom:	Tertiair d, e, f.
Opmerkingen:	Het gesteente lijkt opgebakken en de structuren zijn aan deze Lepidocyclinen niet te zien, daar de opvulling uit calciet bestaat.
D 53.	Donker okergrijze, lichtgeel verweerende zandige kalksteen.
Vindplaats:	S-wand Wachter.
Foraminiferen:	Operculina sp. Camerina sp. Neoalveolina sp.
Algen:	Lithophyllum sp.
Ouderdom:	Tertiair a, b, c, d.
D 54.	Licht okergele tot grijze dichte kalksteen.
Vindplaats:	S-wand Wachter.
Foraminiferen:	Textularia sp. Miliola sp. Spiroclypeus sp. Neoalveolina pygmaea Hanzawa.
Ouderdom:	Tertiair a_2, b, c, d, e.
Opmerkingen:	Het gesteente schijnt nogal door druk beïnvloed te zijn, zoodat de foraminiferen niet duidelijk meer te zien zijn en slechts het genus, niet de species bepaald kon worden. Zoodoende kon niet worden bepaald of deze Spiroclypeus tot de „pustulate'' groep van TAN SIN HOK behoort. Op grond hiervan blijft het mogelijk, dat deze Spiroclypeus zoowel Tertiair a, b, c, d, als Tertiair e zou zijn. De volmaakte afwezigheid van Lepidocyclinae en Miogypsinae als negatieve in-

dicatie, en de stratigraphische ligging onder D 53 geven ons het recht dit gesteente een Oud-Tertiairen ouderdom toe te kennen.

D 55. Lichtgrijze, zwak mergelige kalksteen.
Vindplaats: S. oever Blauwe meer, Merendal.
Foraminiferen: Operculinella sp.
Operculina sp.
Heterostegina sp.
Spiroclypeus sp.
Camerina sp. sp.
Camerina pengaronensis Verbeek.
Amphistegina sp.
Ouderdom: a, b, c, d.
Opmerkingen: De Spiroclypeus behoort tot de „pustulate'' groep van TAN SIN HOK (de Mijningenieur van Ned. Indië October 1937) en kan volgens dit artikel ook in het Oud-Tertiair voorkomen.
Het gesteente maakt eenigszins den indruk van detritische afkomst te zijn. (inspoeling ??)

D 56. Dichte okergrijze kalksteen.
Vindplaats: Blauwe meer.
Foraminiferen: Operculinella sp.
Operculina sp.
Heterostegina sp.
Spiroclypeus sp.
Amphistegina sp.
Lepidocyclina sp.
Ouderdom: Tertiair d—e.

D 57. Lichtgrijze, zwak mergelige kalksteen.
Vindplaats: N. zijde van den Middenkam ten S. van de tong van den Merengletscher.
Foraminiferen: Operculinella sp.
Operculina sp.
Heterostegina sp.
Spiroclypeus sp.
Fasciolites sp.
Carpenteria sp.
Lepidocyclina (Nephrolepidina) sp.
Lepidocyclina (Eulepidina) sp.
Miogypsina (Miogypsinoïdes) dehaarti v. d. Vlerk.
Algen: Lithophyllum sp.
Echiniden: stekels.
Ouderdom: Tertiair e_4, e_5.

D 58. Lichtgele dichte kalksteen.
Vindplaats: N. zijde van den Middenkam ten S. van de tong van den Merengletscher.

Foraminiferen:	Operculinella sp. Operculina sp. Carpenteria sp. Lepidocyclina (Eulepidina) sp.
Ouderdom:	Tertiair d, e.
D 59.	Grijze kalksteen.
Vindplaats:	Aan den voet van den Merengletscher.
Foraminiferen:	Operculinella sp. Operculina sp. Gypsina plana Carter. Carpenteria sp. Lepidocyclina (Eulepidina) sp.
Algen:	Lithophyllum sp. (zeer veel).
Ouderdom:	Tertiair d, e.
Opmerkingen:	DOZY vermeldde Camerina. Deze werd in het door ons onderzochte monster *niet* aangetroffen.
D 60.	Grijze, iets mergelige kalksteen.
Vindplaats:	Moraine Merengletscher (los blok).
Foraminiferen:	Operculinella sp. Operculina sp. Camerina sp.
Ouderdom:	Tertiair a, b, c, d.
D 61.	Monsters uit moraine.
Vindplaats:	Moraine Merengletscher.
Foraminiferen:	Operculina sp. Camerina sp.
Ouderdom:	Tertiair a, b, c, d.
D 64.	Lichtgrijze kalksteen.
Vindplaats:	Doorsteekbivak.
Foraminiferen:	Operculina sp. Camerina sp. (reticulata). Camerina intermedia F. et M. Cam. fichteli Mich. Cam. divina Doornink.
Ouderdom:	Tertiair c, d.
D 89.	Lichte, geelgrijze tot witte kalksteen.
Vindplaats:	Brugbivak.
Foraminiferen:	Camerina sp? cf. Marginopora sp. (volgens DOZY).
Ouderdom:	Tertiair a, b, c, d.

C. PETROGRAPHY.[1])

1. DESCRIPTION OF ROCK-SAMPLES,

BY

W. J. JONG.

1. The igneous rocks.

A large dioritic intrusion occurs between bivouac no. 11 and the Ertsberg. Only two specimens of the solid rock were available, both light-coloured, little weathered rocks.

No. 42, from the waterfall N.E. of bivouac no. 11, is a hornblende-syenodiorite (monzonite), containing 44 % plagioclase, 35 % orthoclase, 5 % quarz and 16 % mafites, chiefly a green hornblende with an extinction-angle of 18° ($n\gamma/c$) [2]).

The hornblende contains inclusions of biotite, sphene and apatite. Sphene moreover occurs in rims along the hornblende and around ilmenite grains, biotite in small flakes is scarce. Zircon and apatite in fair-sized crystals are rather frequent. The anorthite-content of the felspar, as determined by means of the U-stage, is 35—40 %. I here want to express my thanks to Mr. J. W. L. BRUEREN and Mr. L. DORSMAN, to whom I am endebted for these and most of the following determinations.

The plagioclase possesses a zonal structure and a well developed hypidiomorphic habit, orthoclase and quartz often occurring in the interstitial spaces between the plagioclase. The felspar, especially the orthoclase, shows some signs of strain, such as an undulous extinction and a certain amount of shattering. Some sericite and epidote in the felspar, a little calcite and a few flakes of penninite are the only secondary minerals present.

No. 79, from a locality half way between the Ertsberg and bivouac no. 11 is a porphyritic augite-granodiorite. The hand-specimen contains numerous specks of sulphides along cracks. Under the microscope the texture is decidedly porphyritic, large zonal plagioclases (35—40 % An, U-stage) and diopsidic augites being embedded in a fine-grained matrix (grain-size: 0.03—0.05 mm) of plagioclase, quarz and orthoclase. Diopside grains are frequent in the groundmass too, now and then associated with flakes of penninite in a radiating arrangement. The larger grains of augite show signs of corrosion. Large grains of a

[1]) The authors wish to express their thanks to Mrs. A. Gerzon—Caffé for reading the proofs of the English text of this section.

[2]) When percentages are quoted, they have been determined on a Leitz 4-spindle integrating stage.

bright-green, pleochroic epidote (pistacite) often partially replace the augite. In some places some uralitic hornblende has formed. Rutile, pyrite and apatite are common accessories, sphene appears both in isolated grains and as an inclusion in the augite.

The rock probably represents the marginal facies of a larger intrusion.

A smaller intrusion occurs in the marbles, a few hundred meters NW of the Ertsberg, near the entrance of the Carstenszweide. The

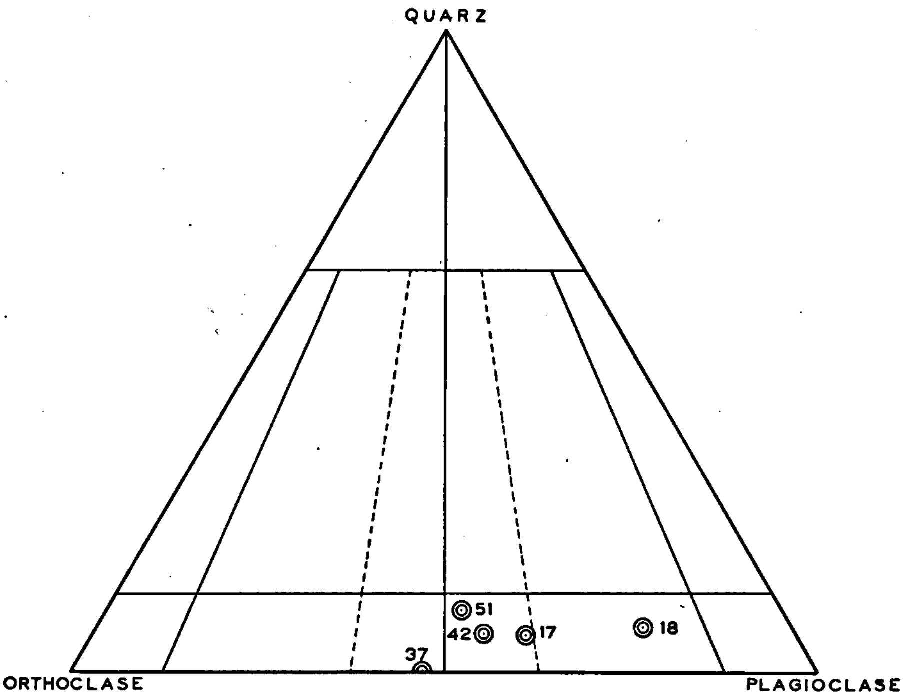

Fig. 17.

Mineralogical classification of the non-porphyritic igneous rocks (according to Niggli).

The families in the four lower fields are, from left to right: alcali-granites, granites, syenodiorites (or gabbros), diorites (or gabbros). The dotted lines indicate the boundaries of the intermediate monzonite-family.

rock (no. 51) possesses a finer grain and is darker in colour than no. 42. Specks of epidote and sulphides may be distinguished with the naked eye, the former giving a greenish hue to the hand-specimen.

It is a quarz-bearing augite-monzonite [1]), plagioclase and ortho-

[1]) The term monzonite is here used in the sense of NIGGLI (Schw. Min. Petr. Mitt. XI, 1929, p. 296 seq.) to denote a rock containing plagioclase and orthoclase in nearly equal amounts, irrespective of the anorthite-content of the former. Cf. also: HATCH and WELLS, Textbook of Petrology, 8th ed., vol. I, p. 226 and HOLMES, Nomenclature of Petrology (1928), p. 162. See fig. 17.

clase being present in nearly equal amounts, (30 and 27 % resp.) The mafite-content is higher than in the previous specimens (37 %), quarz is only a minor constituent (6 %). The more basic character also appears from the anorthite-content of the plagioclase (60—70 % An, U-stage).

The texture is monzonitic: plagioclase and diopsidic augite tend towards an idiomorphic development, with orthoclase and a little quarz filling the interstices. Alteration of the felspar has produced kaolinite and colourless epidote, the augite locally has been replaced by an aggregate of pleochroic epidote and clinozoisite, wtih rims of sphene and ilmenite around it. Occasional flakes of biotite, zircon and apatite are accessorial constituents. Pyrite is frequent. A small vein of this mineral,

Fig. 18.

Augite-Monzonite (37),
Pleistocene moraine near bivouac 9, ± 37 ×.
Augite and plagioklase with interstitial orthoclase. The opaque mineral is pyrite, moreover there is some biotite and apatite and a few grains of epidote.

with rims of limonite, and a slightly anomalous pale-brown garnet may be due to post-intrusive autometamorphism. On both sides of this vein, the alteration of the augite and the felspar is stronger and a few grains of bright-green pleochroic epidote are to be found.

In the vicinity of the large intrusion two loose blocks of similar rocks were found. No. 37, from the pleistocene moraine near bivouac no. 9, is a medium-grained, light-coloured rock with a brownish tinge due to weathering, and showing rounded patches of dark-green epidote, about half an inch in diameter.

It is an augite-monzonite with a well developed monzonitic texture (fig. 18) composed of 40 % orthoclase, 35 % plagioclase and 25 %

mafites. The anorthite-content of the felspar is less than in no. 51 (40—50 % An, U-stage), it is also poorer in mafites. The zonal plagioclases are surrounded by large xenomorphic orthoclase crystals. The latter often enclose augite crystals and plagioclase laths, a perthitic structure is not uncommon. Except augite, biotite is present either in fair-sized crystals or in minute flakes, scattered throughout the section. The presence of abundant bright-green pleochroic epidote, sometimes completely replacing the augite, might indicate some amount of assimilation. In the plagioclase the secondary epidote is also bright-green, and it occurs in larger grains than usual. Some serpentine in radiating aggregates and a little uralite have formed in the augite. Zircon, apatite, sphene, ilmenite and some hematite are frequent accessories.

No. 81 from a recent rock-slide, just North of bivouac no. 10, shows the contact between a porphyritic augite-granodiorite, very similar to no. 79, and a sandy shale. The igneous rock possesses a well developed porphyritic texture. The phenocrysts are large zonal plagioclase (40 % An, U-stage) and diopsidic augites. The microgranitic matrix is composed of orthoclase, plagioclase and quarz. Pyrite, apatite and sphene are accessorial. Alteration of the felspars has produced kaolinite and epidote, in the augite uralite, serpentine and clinozoisite have resulted. Bright-green epidote partly replaces the augite and also frequently occurs in isolated grains. It may be due to assimilation, as in previous instances. The specimen contains a lot of sulphides, especially chalcopyrite, that have been deposited along fissures.

A third intrusion is connected with the ore-deposits at the foot of the Grasberg, near the Western end of the Carstenszweide. No. 72, a grey, rather weathered rock, was collected near the ore-bearing contact rock (cf. the description in Dr. SCHOUTEN's report, section C 2, sub nos. 70 and 71). It is a biotite-granodiorite-porphyry, though in the hand-specimen phenocrysts can hardly be distinguished. Under the microscope zonal plagioclases (35 % An, U-stage) and dark brown biotite phenocrysts can be made out, embedded in a microgranitic groundmass of plagioclase, orthoclase and quarz. Biotite, in minute flakes and in larger flaky aggregates, is abundant. Pyrite, zircon and apatite, with a dusty aspect due to minute inclusions, appear as accessories, the latter being quite frequent. Alteration of the felspar has produced sericite and kaolinite, sericite prevailing in the groundmass. The biotite is unaltered, it encloses a few grains of ilmenite and pyrite.

No. 69, from a locality a little more to the E, is much weathered, but the microscopical aspect is nearly identical. Biotite is still more abundant, it occurs in a brown and a green variety. Larger crystals are only found among the latter, but they are scarce.

Blocks of similar rocks were found in the talus of the northern brook of the Carstenszweide. No. 76 presents a much fresher aspect; felspar phenocrysts are clearly visible in a dark groundmass. The microscopical aspect resembles that of nos. 72 and 69.

In the aggregates of green biotite, spinel may be found in minute green octahedra. Magnetite has taken the place of pyrite, and it is rather frequent. As in the previous specimens, apatite is frequent too.

No. 78, from the identical locality, belongs to the same type. Here we find a few phenocrysts of orthoclase. The hand-specimen is rather rich in quarz. Some fluorite may be distinguished, in the section it is intergrown with biotite flakes. These are concentrated in patches, but they do not form such compact aggregates as in the preceding specimens (fig. 19).

The abundance of biotite in minute flakes or in aggregates, that might be derived from some other mafic constituent, leads me to suppose that these rocks have suffered some thermal metamorphism. No evidence of a younger intrusion in these parts however is available, but

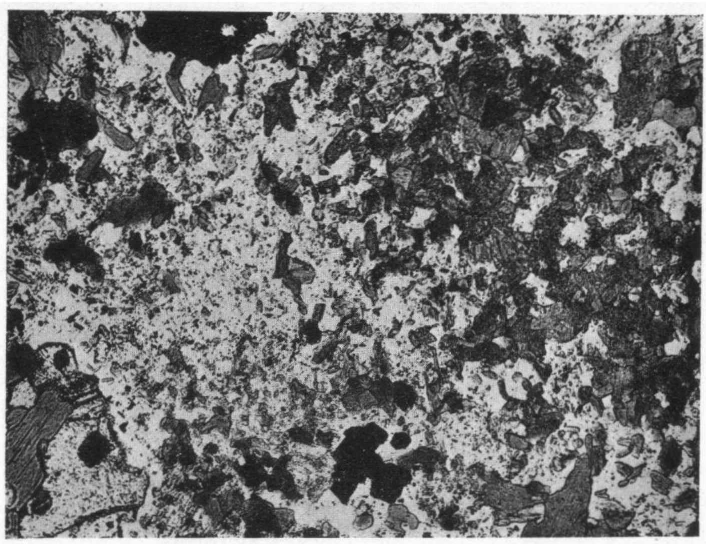

Fig. 19.
Biotitised granodiorite-porphyry (78), Carstenszweide, ± 90 ×
Biotite flakes in a granodioritic groundmass, in the lower left-hand corner large grains of apatite. The opaque mineral is pyrite.

its presence cannot be excluded on the base of the scanty field-information. Anyway, this hypothesis would give a reasonable explication both of the pneumatolytic metamorphism in the Grasberg-region and the signs of post-intrusive changes in the igneous rocks of the Carstenszweide.

A dyke of granodiorite-porphyry near the Dajakpas, NW of the Carstenszweide, stands by itself: on the map no connection with the intrusions further South is shown. It consists of a very light-coloured rock (no. 63) with a brownish weathering crust, speckled with little needles of augite and hornblende. Felspar phenocrysts and grains of pyrite can also be identified with the naked eye.

Under the microscope numerous phenocrysts of a remarkably fresh plagioclase (30—35 % An, U-stage) are seen to be embedded in a very fine-grained microgranitic groundmass of plagioclase laths, orthoclase and a little quarz (fig. 20) (grain-size: 0.015—0.03 mm). Small augite grains are disseminated throughout the matrix. A few small phenocrysts of orthoclase and quarz may be observed. Among the phenocrysts diopsidic augite and hornblende are present in nearly equal amounts. The extinction-angle of the augite is 45°, in the hornblende it does not exceed 18° (both n_γ/c). The hornblende is distinctly pleochroic ($n_\gamma = n_\beta$: dark brown-green, n_α: yellow-green) and shows signs of resorption. Though some uralite has formed in the augite, the bulk

Fig. 20.
Granodiorite-porphyry (63), Dajakpas, ± 14 ×.
Phenocrysts of plagioklase, diopsidic augite and brown hornblende in a granodioritic matrix. Part of the hornblende has been altered, pyrite is conspicuous.

of the hornblende is decidedly of a primary origin. Aggregates of colourless epidote in minute grains, clinozoisite, ilmenite and leucoxene, sometimes also a little serpentine, suggest by their outline that they have been derived from hornblende. Large grains of clearly epigenetic pyrite, apatite and some accessorial biotite are the remaining constituents.

Among the pebbles collected near the Prao Bivouac a few specimen of igneous rocks were found, some of which clearly resemble rocks previously described. Still, some specimens belong to entirely different types.

No. 15 is a hornblende-diorite-porphyry, somewhat resembling the dyke-rock of Dajakpas (no. 63) though the matrix is coarser (grain-size: 0.03 mm) and it is poorer in mafic phenocrysts.

The plagioclase is slightly more calcic (50—55 % An, U-stage) and possesses a well-developed zonal structure. The hornblende however belongs to an altogether different variety. It is hardly pleochroic at all, the colour being a very pale green. The extinction-angle reaches 20° (n_γ/c). The matrix is composed of a more sodic plagioclase (30—40 % An), of orthoclase and of hornblende needles. Its texture might be called pilotaxitic. Apatite, pyrite and zircon are accessorial. The alteration of the hornblende has produced some epidote, serpentine, calcite and siderite, the felspar is slightly kaolinised.

Nos. 17 and 18 are intrusive rocks, resembling those of the large intrusion, especially no. 42. The former is a fine-grained hornblende syenodiorite (monzonite) composed of 48 % plagioclase (35—40 % An, U-stage), 30 % orthoclase, 17 % pale-green hornblende and 5 % quarz, neither showing special features. Sphene, pyrite with limonite, zircon, ilmenite and rather large apatite are accessorial. Alteration of the hornblende has produced the usual chlorite, epidote and zoisite.

No. 18 is a slightly more calcic rock, a hornblende-augite-syenodiorite. Abundant plagioclase (40 % An, U-stage), orthoclase, diopsidic augite and pale-green hornblende, form the bulk of the rock (Mode: 63 % plag., 17 % orth., 14 % mafites, 6 % quarz). Among the accessories, biotite, zircon, sphene, apatite, pyrite and ilmenite with leucoxene must be mentioned. The texture is granitic as in nos. 42 and 17. Alteration has produced some kaolinite and epidote in the felspar, chlorite and some uralite in the augite. The hornblende has altered to serpentine. Calcite is also due to secondary changes, some bright-green pleochroic epidote might result from assimilation.

No. 21 C is a much altered granodiorite-porphyry. Plagioclase crysstals (40 % An, U-stage) up to an inch long, lie embedded in a dark phanerocrystalline groundmass of quarz, orthoclase and some plagioclase. The dark constituents have been completely replaced by aggregates of chlorite, epidote, zoisite, calcite and ilmenite with leucoxene. The original mineral probably was hornblende; it must have been abundant in the matrix. Some bleached biotite and a little apatite are accessorial. The groundmass is rich in sericitised orthoclase and quarz, suggesting a more granitic composition than in nos. 79 and 81. The alteration of the felspar phenocrysts has resulted in kaolinite, sericite and epidote.

No. 16 is a greenish rock of doleritic appearance. Slender plagioclase crystals, elongated augite grains without definite crystallographical boundaries and rather large orthoclase unite in a kind of sub-ophitic texture (fig. 21). Locally the grain-size is smaller, a second generation of felspar and augite forming an interstitial matrix. The plagioclase is an andesine (30—35 % An, U-stage), the augite is of the bazaltic type, with a peculiar brown colouring along the edges, due to microscopical inclusions. The extinction-angle is as high as 48° (n_γ/c), the axial angle is small. A rim of ilmenite grains frequently surrounds the augite. Alteration of the augite has produced colourless epidote in minute grains, clinozoisite and a lot of serpentine, the felspar presents a turbid aspect due to the production of sericite, chlorite, quarz, calcite and epidote. Ilmenite is abundant in skeletal forms, surrounded by a broad rim of leucoxene. The appropriate name for this rock, no counter-part of which was found in situ, would be a mela-augite-monzonite, perhaps from a lamprophyric dyke.

2. The contact-metamorphi rocks.

Evidence of contact metamorphism is to be found both in the calcareous and in the argilaceous deposits of the district.

It has been strongest in the tertiary limestones, NE of the Ertsberg, where it has produced marbles, lime-silicate-marbles and lime-silicate-rocks.

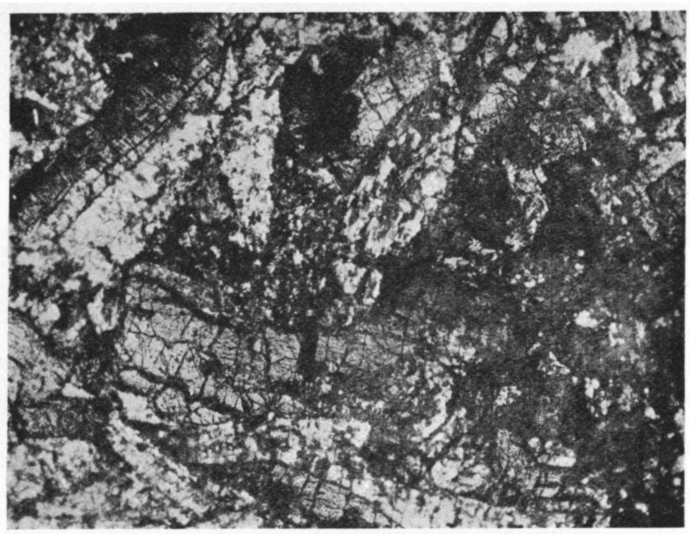

Fig. 21.

Sub-ophitic mela-augite-monzonite (16), Pebble near Prao Bivouac, ± 27 ×. Elongated augite crystals and felspar, the opaque mineral is ilmenite.

The samples nos. 45—50, all from the Eastern wall of the Carstensz-weide, represent various degrees of metamorphism in the vicinity of the monzonite intrusion. Nos. 45—47 are just ordinary foraminiferal limestones, as described by Mr. KROL and Mr. ERDMAN elsewhere (p. 98, 99) in this publication. No. 48 is a little more crystalline already, but only nos. 49 and 50 have been strongly metamorphosed. No. 50 is a pure, coarsely crystalline marble, composed of rather even-sized calcite grains, with sinuous, interlocking boundaries. It contains numerous cavities, lined with calcite. Dolomite is absent.

The original limestone must have been rather pure, whereas no. 49 originally probably was a calcareous sandstone rather than a limestone.

It is now a brownish to green, rather dense rock, of quarzitic aspect, composed of quarz, grossularite, wollastonite, epidote and calcite. The composition it not uniform, it ranges from a grossularite-epidote-calcite-hornfels to a grossularite-wollastonite-hornfels.

Quarz always is an essential constituent, with either grossularite [1]) or wollastonite accompanying it (fig. 22 and 23). It occurs in rounded grains of uniform size. Grossularite appears in well-developed crystals, often strongly anomalous, with zonal colouring, ranging from faintly yellow to pale-brown. Epidote occurs in aggregates of small colourless grains. Calcite, sometimes full of epidote and grossularite, acts as a cement between the quarz grains and the garnet crystals. Locally it encloses some quarz. The quarz in places exhibits a well-defined hexa-

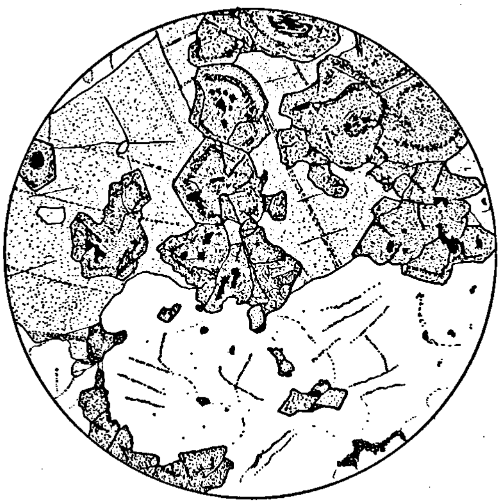

Fig. 22.

Grossularite-epidote-calcite-hornfels (49 ×),
E-wall Carstenszweide, ± 45 ×.
Garnet and calcite above, quarz with garnet and epidote below.

gonal outline against the calcite, so that some recrystallisation must have occurred. Wollastonite appears in isolated grains between the grossularite in one section, in another it takes the place of calcite and acts as a cement. It then occurs in fibrous to columnar, more or less radiating aggregates. In this case grossularite is scarce and epidote is almost absent, while calcite is altogether lacking. We may account for this difference by assuming a more argilaceous cement locally to have prevailed in the original rock. Pyrite and apatite are accessorial.

A boulder of grossularite-epidote-diopside-rock (no. 38) derives from the pleistocene moraine near bivouac no. 9. In the dark coloured

[1]) The refractive index is about 1.8, rather high for grossularite, so that some admixture of andradite may be assumed.

rock we can distinguish with the naked eye both epidote and calcite in well defined clear crystals, besides some translucent brown garnet, sulphides and a dark prismatic mineral, probably belonging to the augite-group. The microscope reveals idiomorphic bright-green pleochroic epidote, with zonal colouring, anomalous pale-brown to faintly yellow or green grossularite and altered diopside, cemented by cor-

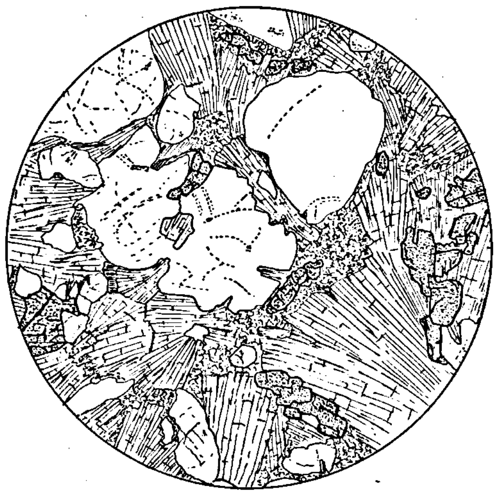

Fig. 23.

Grossularite-wollastonite-hornfels (49 B), E-wall Carstenszweide, ± 45 ×. Wollastonite with quarz and grossularite.

dierite, calcite locally taking its place (fig. 24). Alteration of the diopside has produced clinozoisite and uralite. Sulphide grains and apatite are frequent accessories. The cordierite, often closely intergrown with diopside and grossularite, clearly shows pseudo-hexagonal twinning.

The anomalous association of diopside and cordierite (cf. HARKER, Metamorphism, 1932, p. 100 and 94) may be explained by assuming that metamorphism is due to a minor intrusion, quick cooling having set in, leading to the preservation of metastable associations. There is no question but the two minerals occur side by side, and not in separate parts of the section.

The diopside-grossularite-rock, enclosed as a xenolith in hand-specimen no. 79 from the locality between the Ertsberg and bivouac no. 11, may also be brought to this group of contacts. The augite-granodiorite, described above, locally shows bands and streaks of a greenish colour, that under the microscope are dissolved into an aggregate of small diopside-grains, some brown to yellow garnet, sphene and finely granular quarz. Wollastonite and epidote appear locally. In the vicinity of these aggregates the igneous rock is richer in diopside in small grains and in green epidote. Sphene too is more frequent there.

The aggregates enclose larger diopside crystals, identical to those of the igneous rock. We may assume chips of calcareous shale to have been metamorphosed, and to a certain extent assimliated, by the intruding magma.

In another section we find bands of garnet and diopside, alternating with layers of diopside and a little epidote, and others, entirely made up of garnet. The latter is not anomalous and rich in concentrically arranged opaque inclusions (ilmenite?). Perhaps andradite would be a more correct designation. In one place, close to the contact, spinel occurs in minute octahedra, together with a few grains of corundum.

In the same neighbourhood, near bivouac no. 11, a block of lime-

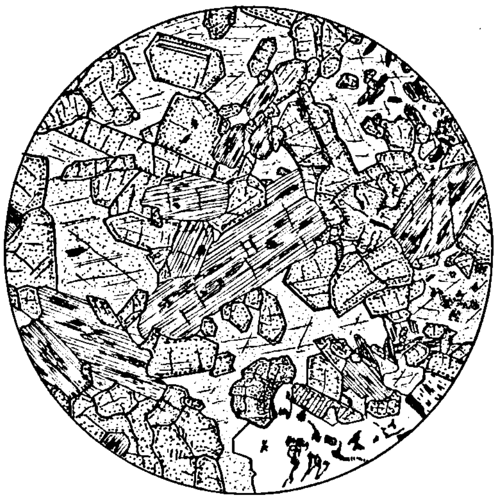

Fig. 24.

Epidote-diopside-rock (38),
Pleistocene moraine near bivouac no. 9, ± 7 ×.
Diopside and epidote, cemented by calcite, some cordierite and a crystal of grossularite below.

silicate-hornfels was found, that might be compared to a calc-flinta (no. 80). It is a crypto-crystalline rock, liver-coloured, with streaks and bands of greenish colour. The general aspect is that of a mudstone. In an extremely fine-grained siliceous matrix, hardly exhibiting any polarisation, we find numerous fine-grained aggregates of epidote, with some sphene, and either grossularite or wollastonite, or both. The general outline of these aggregates suggests, that they have resulted from the metamorphism of organic remains of a calcareous nature, such as sections through Lamellibranchiate shells, foraminiferal casts, etc.

In places a few angular quarz fragments are to be found. Some cavities are filled with larger grains of quarz, accompanied by grossularite or epidote (pistacite) and surrounded by rims of sphene (fig. 25). They might be explained by the dissolution of larger shell-fragments.

The dimensions are about 1 by 4 mm. Locally some calcite has crystallised, pyrite being accessorial. The original rock probably was a calcareous mudstone, rich in shell-fragments.

The magnesia-content of all these rocks is not so very high. An example of the metamorphism of an impure magnesian limestone, or dolomite, is offered by a specimen (no. 43) from a small calcareous lens in the large intrusion, outcropping in the Southern wall of the gorge near bivouac no. 10. It has been changed into a forsterite-marble, a light-grey to white, crystalline rock, with darker and less crystalline parts.

It is composed of calcite in grains of fairly uniform size (about

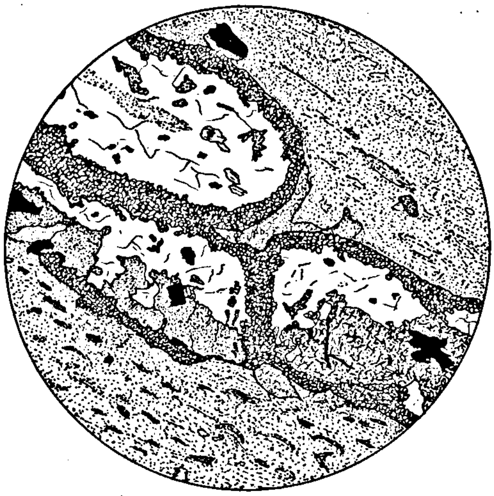

Fig. 25.

Calc-flinta (80), loose block near bivouac no. 11, ± 45 ×. Lenses of quarz and garnet or epidote, with rims of garnet, in a banded siliceous matrix with epidote and garnet. The opaque mineral is pyrite.

0.5 mm), with slightly undulating boundaries and small rounded grains of forsterite (size: 0.05—0.1 mm), chiefly concentrated along the boundaries of the calcite grains (fig. 26). The darker parts consist of a dense, fibrous aggregate of wollastonite and sometimes tremolite, enclosing a few grains of diopside. Some serpentine occurs along the borders of a narrow calcite-vein.

An analysis of this rock was made by Mr. N. HEERTJES (analysis A, mean of two determinations). As will be seen from the molecular proportions, calculated in the second column, there is not sufficient carbon-dioxyde to saturate the lime. If we use the magnesia to form forsterite with the silica, there still remains an excess of the latter, after forming wollastonite with the remaining lime.

The molecular ratio of $CaO + MgO : SiO_2$ is nearly 3:2, so that both ortho- and metasilicates must be present. It follows that some magnesia must have gone into metasilicates with the lime, f.i. in diopside and tremolite.

A second analysis (B) by Dr. CATH. KOOMANS shows less excess of lime. It was made of a different fragment and it is evident from the differences in the values for magnesia and lime, that the composition of the rock is by no means uniform, the magnesia being distributed rather irregularly. Still, the second analysis again proves, that some magnesia must have gone into metasilicates (compare the molecular proportions in the fourth column).

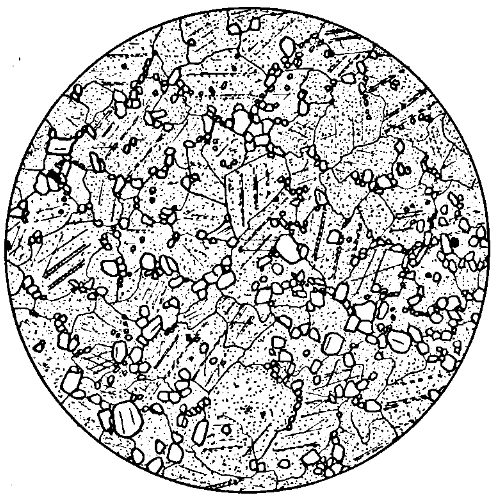

Fig. 26.
Forsterite-marble (43), gorge near bivouac no. 11, ± 45 ×.
Forsterite and calcite and a few grains of pyrite.

ANALYSIS OF FORSTERITE MARBLE.

	A (N. HEERTJES) Weight %	Mol. Prop.	B (Dr. CATH. KOOMANS) Weight %	Mol. Prop.
SiO_2	32.88	548	32.40	540
TiO_2	0.00		n.d.	
Al_2O_3	0.00			
Fe_2O_3	1.13	7	0.85	
FeO	0.24	3		
CaO	33.18	595	27.95	500
MgO	18.65	466	24.44	611
Na_2O	n.d.		n.d.	
K_2O	n.d.		n.d.	
H_2O +	0.36	20	n.d.	
H_2O —	0.03	2	n.d.	
CO_2 (MORGAN)	14.15	322	15.81	362
Total	100.62		101.45	

To preclude the possibility of humite having been mistaken for forsterite, the sample was tested for fluorine, but the results were negative, which proves the absence of noticeable humite or kindred minerals.

Another group of metamorphosed calcareous sediments is to be found on the Carstenszweide, near the N. brook.

No. 67 is a coarse-grained marble, coarser still than no. 50. It is a very pure marble, containing only a few grains of pyrite. Metamorphism has not been very strong, a cast of a Brachipod, probably a *Terebratulina spec.*, still could be loosened without difficulty from the hand-specimen.

No. 68 is a brecciated marble, with patches of darker colour, composed of argilaceous material. The calcite grains vary widely in size, they are smallest near the borders of the darker patches. The latter

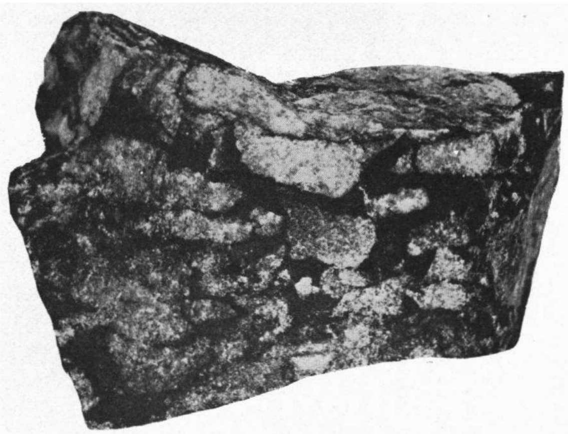

Fig. 27.
Brecciated marble (68),
Carstenszweide, nat. size.

are composed of quartz, sericite and some chlorite, in a matrix of finely granular calcite. Carbonaceous matter too is concentrated in these parts, pyrite being evenly distributed in small grains. The original rock must have been some kind of brecciated argilaceous limestone. The hand-specimen somewhat resembles the cipolino-marbles from Tuscany (fig. 27).

In neither of the two last specimens the mineral composition furnishes conclusive proof of metamorphism having been caused by contact, but the situation between the thermal-metamorphosed of the Ertsberg and those of the Grasberg, renders this assumption the most probable.

Examples of contact metamorphism in argilaceous sediments are scarce.

No. 81, from the recent landslide N. of bivouac no. 9, shows the contact between a metamorphosed sandy shale, with a calcareous cement and a porphyritic augite-granodiorite, as described above.

Metamorphism has only been slight, the argilaceous part of the cement has hardly been altered, but some tremolite in radiating aggregates and a few grains of bright-green epidote have formed from the calcareous part. Except quarz, both orthoclase and plagioclase are present, the grain-size varies from 0.025 to 0.075 mm. Pyrite, zircon and some ilmenite are accessorial, the former also probably being due to the contact.

No. 40 and 41, both from the vicinity of bivouac no. 10 have been slightly influenced by the adjoining intrusion.

No. 41 is a compact, very hard shale, with conchoidal fracture; it presents a quartzite-like appearance. Under the microscope the cryptocrystalline argilaceous matrix, enclosing some angular quarz-fragments, is seen to be rich in sericite. Pyrite too is frequent, some grains are surrounded by biotite. It contains moreover an appreciable amount of finely distributed opaque substance, probably of carbonaceous nature, more or less concentrated in ill-defined spots. Still, we could hardly speak of a „spotted shale'' yet.

No. 40 is more sandy and the influence of metamorphism has been stronger. It is composed of rounded to sub-angular quarz-grains (size about 0.15 mm) in an extremely fine matrix of quarz, sericite and some chlorite. Numerous rounded or irregular spots of brownish colour exhibit a moderate birefringence in minute flakes. We may assume, I think, that owing to an incomplete metamorphism, recrystallisation has been arrested in an early state. Still, some biotite and rutile have formed, moreover there are a few small grains of andalusite. The larger muscovite blades might be of detritic origin, or might be due to the vicinity of the contact, the former seeming the most probable. Orthoclase and plagioclase, both sericitised and zircon are certainly of detritic origin. Pyrite is frequent. A few grains of black green tourmaline might also be detritic.

In the Grasberg-area we find an interesting rock, the origin of which is not yet altogether clear. It was found at the foot of the mountain (no. 73), on the sides (no. 74) and on the summit (no. 75). On the map it is included, together with the slightly metamorphosed granodiorite-porphyries (nos. 69 and 72), under the designation: Marginal zone of the Grasberg.

It is a fine-grained crystalline rock, light- to dark-grey, with tiny specks of hematite and larger grains of a blue mineral, lazulite. The latter also occurs in veins and pockets in a powdery aggregate of minute flakes of white mica. Under the microscope it is seen to be composed of fine-grained quarz and white mica (fig. 28 and 29). Fluorine being absent, the latter probably is muscovite. The quarz grains are sometimes rounded, but irregular sinuous outlines prevail. The muscovite often appears in a dense mass of minute flakes, forming a network between the quarz grains. Elsewhere in the section it fills narrow veins in fibrous aggregates. The lazulite occurs in grains of irregular outline, up to a few mm in diameter. Sometimes it surrounds a grain of corundum. The latter mineral moreover appears in granular aggregates, distinguished by their high refringence and the mottled aspect under crossed nicols. A few rounded grains of zircon and some blades of bleached biotite are certainly of detritic origin. Hematite is abundant in fair-sized blades.

The origin of the lazulite presents some difficulties. Most authors (DANA, DOELTER, GROTH, NIGGLI) confine themselves to the statement that it occurs in veins and pockets in slates, quartzites and pegmatites. LACROIX holds that in Central Madagascar it is connected with granitic metamorphism. (Mineralogie de Madagascar I, p. 357), whereas SCHNEIDERHÖHN considers its presence in the Brazilian itabirites a proof of the sedimentary origin of the latter. According to GAMPER (Jahrb. der Geol. Reichsanstalt, 1878, p. 611, cited by HINTZE, Handb. d. Mine-

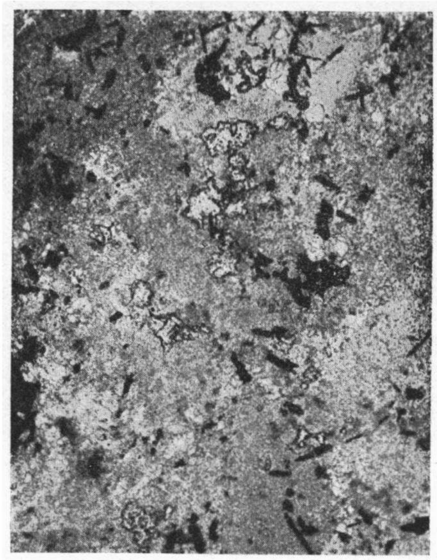

Fig. 28.
Lazulite in muscovite-quarz-rock (75), Grasberg, ± 27 ×, Lazulite (relief!) and hematite in a matrix of quarz and white mica.

ralogie, I, 4 (2), p. 1129) it may form when phosphate-containing solutions react with aluminous matter.

In the present instance some such mode of origin seems the most probable. We may assume with HARKER (Metamorphism, p. 128), that phosphates can be introduced in connection with pneumatolysis. Emanations containing the chloride might react with water to form the acid, the latter usually going into apatite. But lime being absent, it might well react with the aluminous and ferrous constituents of an argilaceous sediment, thus producing lazulite [1]). Pneumatolytic activity might be

[1]) In a more recent publication, HEGEMANN and STEINMETZ are inclined to exclude a pneumatolytic origin of the lazulite in the quarz-veins of Werfen, also studied by GAMPER, loc. cit. (Centralbl. f. Min., A, 1927, p. 47). SCHREITER, however, studying specimens from the Serra do Roberedo (Portugal), again connects the lazulite with granitic metamorphism. (Centralbl. f. Min., A, 1929, p. 111).

invoked also, together with recrystallisation of the micaceous substance of the original rock, to explain the abundance of white mica along cracks and veins. .

The temperature, however, cannot have been very high, as the hematite has not been reduced to magnetite. Also, lazulite appears to form at comparatively low temperatures (cf. HINTZE, loc. cit.).

On the whole, a slight hydrothermal or pneumatolytic metamorphism of an argilaceous sediment, rich in alumina, under the circumstances

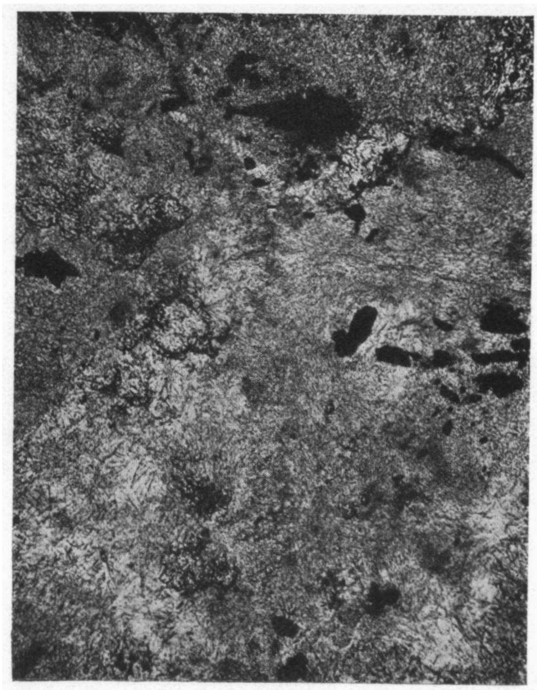

Fig. 29.

Lazulite near a vein of larger muscovite flakes in muscovite-quarz-rock (75) from the Grasberg, ± 90 ×.

appears to give a reasonable explanation of the mode of origin of the rock.

Whether metamorphism is due to the porphyritic intrusion of the Carstenszweide, or to a hypothetical, later intrusion, referred to above, must remain an open question.

In the talus of the brook on the Carstenszweide a block of a much weathered rock (no. 77) was found, of yellow to ochreous colour. It is composed of quarz and sericite, impregnated with limonite. Locally larger quarz grains (up to 0.5 mm) are cemented by limonite. I am inclined to call it a sandy shale, altered under the infuence of the ferruginous springs, mentioned by DOZY (Section I, p. 84). In places some biotite has formed and hematite has taken the place of limonite, indicating a beginning metamorphism.

The hard, black rock with Belemnites (no. 87), found N. of Basecamp, is a metamorphosed ferriferous sediment. The density is rather high (ca. 3.6) and it is magnetic. It consists of magnetite and chlorites. The magnetite appears in octahedra of up to 0.05 mm, the chlorite occurs between the magnetite and by itself fills larger cavities of rounded or curved outline, often surrounded by a rim of magnetite (fig. 30). Among the chlorites we can distinguish a slightly pleochroic, pale-green variety with low birefringence (negative penninite) and a darker green

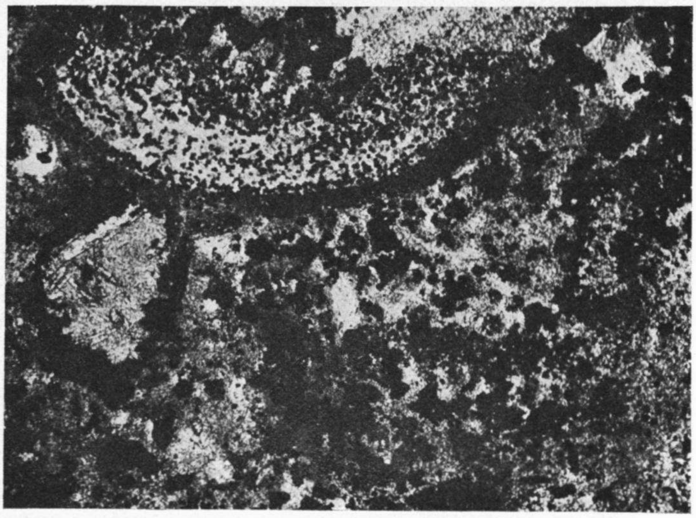

Fig. 30.

Chlorite-magnetite rock (87), North of Basecamp, ± 27 ×. The cavities are filled with negative penninite, the bulk of the chlorite in the matrix might be thüringite.

variety, strongly pleochroic (dark blue- or olive-green to colourless) and with higher birefringence, up to 0.01. The refractive index is higher also. It probably is thüringite. Minute flakes of a mineral with strong birefringence and pleochroism (brown to colourless) probably are biotite. Locally some clinochlore, distinguished by the negative sign of its elongation, was found.

Disseminated in the chlorite we find grains and prisms of a colourless mineral with high refractive index and moderate to strong birefringence, optically biaxial, both positive and negative grains being found. Epidote appears the most probable diagnosis. Some grains, showing anomalous interference colours, might be zoisite. The presence of these minerals indicates some content of lime in the highly ferriferous original rock. Recrystallised quarz in small grains appears locally.

3. The sediments.

The calcareous sediments of Tertiary age, outcropping in the Carstensz Mountains proper, having already been studied by Mr. KROL and Mr. ERDMAN, they were not further examined.

As is evident from the contact-metamorphosed types, previously mentioned, the facies as a rule is rather sandy, though pure limestones are not uncommon.

We will here confine ourselves to a description of the older sediments.

Older Paleozoic (Simpang Series).

The Simpang slates proper (no. 25) are rather light coloured and possess a silky shine on the cleavage-planes. No. 25 was collected on the river, a little upstream from the bivouac. Under the microscope it is seen to enclose a noticeable quantity of finely granular calcite, besides recrystallised quarz and sericite in a cryptocrystalline matrix, that does not affect the polarised light. Some penninite and limonite are present too, moreover detritic zircon and a little opaque matter, the nature of which could not be ascertained, though it it probably carbonaceous.

No. 23 A from the immediate vicinity of Simpang Bivouac, is a fine-grained calcareous sandstone, intercalated in the Simpang slates. It is composed of angular to sub-angular quarz-fragments, in grade ranging from silt to fine sand, cemented by calcite. Some sericite and patches of argilaceous substance can also be observed. Apatite, zircon, blackish green to brown tourmaline, ilmenite and biotite are of detritic origin. Some opaque substance might be organic. The specimen contains veinlets of calcite.

Another type of intercalation is represented by no. 23, from the same locality. It is a compact dark-grey mudstone, with numerous cubes of pyrite. It is made up of quarz and chlorite (negative penninite) in an extremely fine-grained aggregate, in which abundant calcite in small grains lies embedded. Hence it rather resembles the typical Simpang slates, represented by no. 25, but it lacks their fissility.

No. 24, from the Simpang River near the bivouac, is a quartzitic sandstone, a light-grey rock, with distinct bedding, but compact in the hand-specimen. It is entirely composed of quarz grains (size about 0.1 mm) cemented by complementary quarz and by recrystallised argilaceous matter, chiefly sericite. Limonite is rather abundant, the outline of the grains suggests a paramorphism after siderite. A few grains of zircon, magnetite and tourmaline are of detritic origin. Graphite occurs in little streaks between the grains.

Near the Vierde Top two blocks of limestones were found. No. 28 is a dark compact limestone with veins of calcite and siderite. No. 29 is a medium-grained crystalline limestone, of cavernous appearance, enclosing a few prismatical crystals of quarz. In the section too, some quarz appears in the interstitial spaces between the calcite.

The supposedly Upper-Paleozoic strata near Basecamp appearing to be entirely devoid of calcareous intercalations — as far as can be judged from the available samples — we may conclude, I think, that these limestones ought to be referred to the Simpang Series, where calcareous sediments are at least not uncommon.

Younger Paleozoic.

Near the Vijfde Top, a soft sandy shale of light to dark-grey colour it outcropping. It is composed of abundant angular quarz-fragments (0.06—0.15 mm) in a nearly isotropic argilaceous cement, showing a beginning recrystallisation of quarz and sericite. Biotite, zircon and tourmaline occur in a few isolated grains of detritic origin. Limonite and carbonaceous matter appear in streaks between and around the quarz grains. I am inclined to include this sample in the Upper Paleozoic, as it is entirely devoid of calcite.

Dr. DOZY tentatively ascribes the same age to the shales and sandstones outcropping in the vicinity of Basecamp.

Among these, Nos. 33, 34 and 84 are dark-grey, somewhat sandy shales, with indistinct cleavage, No. 84 contains some plant remains. The microscope reveals the presence of numerous small angular quarz-fragments (up to 0.15 mm) and a few flakes of bleached biotite. The bulk of the rock is made up of a finely crystalline aggregate of quarz and minute flakes of sericite and chlorite (probably delessite[1])), rich in carbonaceous matter. Weathered glauconite occurs in brownish green, nearly isotropic grains of irregular outline. Limonite is irregularly distributed in streaks and stains, zircon and magnetite occur in small grains of detritic origin.

Layers of sandstone and rudaceous sandstone are intercalated in the slates.

No. 31 is a fine, brown argilaceous sandstone, composed of rounded quarz-grains, often with undulous extinction, some detritic muscovite, biotite and plagioclase, cemented by a fine-grained matrix of sericite and quarz.

Limonite occurs in strings and as a weathering-product of glauconite grains; ilmenite and zircon are detritic.

No. 32 is a similar sandstone, with strings of gravel. Except the common quarz- and plagioclase-fragments of varying size, we find small pebbles of granoblastic quarz, of silicified sandstone or of a fine-grained quarz-mosaic. The latter probably are pebbles of lydite, some indistinct circular structures might be Radiolaria.

The cement is composed of quarz, sericite and delessite, the latter sometimes in granular aggregates. Moreover we find some weathered

[1]) Delessite is here used for a brown to greenish chlorite, with positive sign of the elongation, — hence optically negative —, weakly pleochroic and with a birefringence up to over 0.010. This is contrary to the practice advocated by WINCHELL, Elements of Optical Mineralogy, II, 279, (1933) and followed by ROSENBUSCH-MÜGGE, but in accordance with CHUDOBA-WEINSCHENK, NIGGLI and LACROIX.

glauconite grains. Carbonaceous matter is not abundant. Limonite pervades the entire section, staining the cement and the quarz grains, or merely coating the latter.

No. 83 does not contain any gravel, but in its composition it resembles no. 32. The cement contains both sericite and delessite and it is richer in glauconite. A few fragments of lydite were also found.

No. 35 is still more rudaceous. It contains numerous pebbles of lydite (up to an inch in size). The cement is more recrystallised than in the previous samples. Sericite appears in large patches, here and there some complementary quarz acts as a cement. Detritic pyrite, ilmenite and zircon are accessorial. The limonite-staining is less pronounced, glauconite and carbonaceous matter are scarce.

The brown sandstone with numerous casts of Brachiopods (no. 88) described alsewhere in this publication (cf. p. 96) was found in the same neighbourhood, and it resembles no. 31.

All these samples: Nos. 30—35, 83, 84, contain felspar and most of them enclose little pebbles of various rocks, especially lydite. Weathered glauconite is also present in all of them, so that sedimentation must have taken place in a marine environment, but quite near to the coast.

For Upper-Paleozoic time we may conclude therefore to an increased importance of terrigenous material.

The variegated red sandstone (no. 85) and sandy shales, outcropping a little farther North, when seen under the microscope do not present any peculiarities. The macroscopical resemblance to the South-alpine sernifites is confirmed. Rounded grains of quarz, either of one crystal or of several grains in a granoblastic pattern, orthoclase and plagioclase are cemented by limonite, with delessite and some quarz-cement in the interstitial spaces. Among the sand grains a few again resemble the quarz-mosaic of a lydite. The grain-size varies widely in the various specimens ranging from silt to medium-grained sand.

No. 86 was collected still further upstream. It is a quarz-porphyry-crystaltuff, a compact, greenish to grey rock of quartzitic appearance. It occurs in thick layers, without cleavage. In a matrix of devitrified glass, exhibiting an indistinct ash-structure (fig. 31), when viewed in ordinary light, we find numerous fragments of quarz, orthoclase and plagioclase phenocrysts. (The anorthite-content of the latter is ca. 30%). Fragments of a microfelsitic matrix or of hardly divitrified glass may also be found. Moreover some quarz pebbles and a little biotite of detritic origin are present.

Mesozoic.

Besides the metamorphosed specimens, already described, among which nos. 40 and 41 probably belong to this age, only one specimen of Mesozoic rocks was available (no. 82, from the river near bivouac no. 9).

It is a very hard, black, siliceous limestone, exhibiting a parallelepipedal cleavage. The microscope reveals numerous small angular quarz-fragments in a cryptocrystalline calcareous matrix, speckled with small calcite grains (grain-size 0.025—0.1 mm). The section is obscured by organic matter of bituminous nature [1]); pyrite is abundant.

Among the pebbles collected near Prao Bivouac a few specimens of siliceous rocks were found, that do not resemble any samples collected in situ.

No. 19 is an extremely tough quartzite, with a bedded aspect due to darker coloured streaks. It contains a layer of black chert, with splintery fracture and vitrous lustre, about half an inch in width, enclosing a nest of cream-yellow calcite and crossed by narrow veinlets of quarz.

The quartzite is composed of small angular quarz-fragments (grain-size about 0.05 mm) and a few larger, rounded grains, up to 0.25 mm

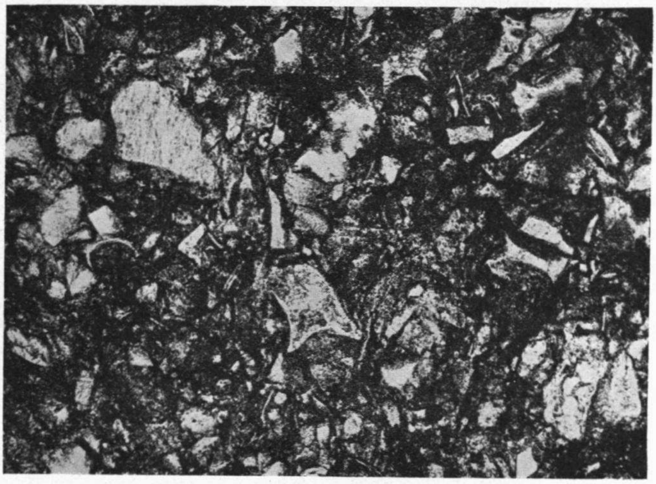

Fig. 31.

Ash-structure in quarz-porphyry-crystal-tuff (86).
Upstream of Basecamp, ± 70 ×.

in diameter, cemented by sericite, brown-green delessite and an ill-defined argilaceous substance, partly also by complementary quarz. Tourmaline appears in fair-sized grains, some biotite might be detritic, so is the zircon. The darker bands are rich in limonite, biotite and opaque matter, among which graphite, pyrite and magnetite can be distinguished. Pyrite also appears frequently in the lighter parts.

The chert-layer consists of an extremely fine-grained quarz-mosaic, with irregular patches of larger grains with sutured jointings. Here and there this matrix is so cryptocrystalline as to be isotropic, but the refractive index is too high for opal. The absence of a well-developed

[1]) After extraction with chloroform, the latter is weakly fluorescent in ultra-violet light. Cf. Royer, Bull. Soc. fr. Min. 53 (1930), 515.

fibrous habit makes it difficult to decide whether quarz or chalcedony prevails. In ordinary light a number of irregular rounded patches of a darker colour can be observed, which under crossed nicols remain nearly dark. In this siliceous matrix, isolated rhombohedra of calcite lie embedded, disseminated throughout the section. Their size is about 0.3 mm. An opaque substance, probably of organic nature, occurs in angular patches; hematite is present in a few isolated grains.

No. 21 A is a cavernous, banded hornstone, with alternating layers of lighter and darker colour, ranging from white to dark-grey. It is probably a silicified limestone.

The quarz in the section forms a fine-grained mosaic, in which irregular aggregates of larger grains occur. These correspond to lighter coloured parts, when seen in ordinary light. The pigment probably is of organic nature.

2. THE EXAMINATION OF THE ORE-SAMPLES

BY

Dr. Ir. C. SCHOUTEN (Delft).

Three small ore-samples from the Ertsberg and from the Carstensz-weide were examined with the ore-microscope. About twenty polished surfaces were prepared.

It is to be regretted that the specimens, especially those from the Carstenszweide (No. 70) are strongly weathered. Only remnants of the most resistant sulphides have been preserved. Sample No. 52 from the Ertsberg, however, for the greater part still consists of the original primary sulphides, though even here signs of weathering are evident.

According to the available field-evidence, the ores appear to be limited to the contact between dioritic intrusions and limestones, the latter being partly altered into marbles or lime-silicate-rocks. The ores therefore can be classified among the contact-metasomatic deposits. This conclusion is born out by the microscopical examination. A few fragments of the igneous rocks also were polished to identify some specks of sulphides that could be distinguished macroscopically. (Nos. 72 and 51).

We will treat the results of the examination of these rock-fragments and of sample No. 70 first, as we can be brief about them.

No. 51. Dioritic intrusion in marble, near the Ertsberg.

The specks of sulphides (0.5 to 0.01 mm diameter) entirely consist of pyrite. Without exception this has been partly altered into limonite by weathering, proceeding both from grain-boundaries and from small cracks.

No. **72.** Dioritic intrusion near the Carstenszweide.

This rock contains a large number of grains of sulphides, the dimensions however are extremely small, from 0.5 to 0.002 mm. In order of frequency — in so far as this can be ascertained from a single fragment — we mention:

Marcasite: Radiating or fibrous, sometimes granular aggregates, now and then showing a skeleton-like habit.

Arsenopyrite: Granular aggregates or small massive grains, often idiomorphic or hypidiomorphic.

Pyrite: Mostly in minute isolated crystals, now and then finely intergrown with arsenopyrite or marcasite.

Chalcopyrite: Irregular patches, the shape of which is determined by the adjacent minerals of the igneous rock. Sometimes occurring in small specks, round or ellipsoidal in shape, enclosed in pyrite or arsenopyrite.

Rutile: In minute grains, occurring rather frequently.

Pyrrhotite and molybdenite: In traces, as tiny inclusions in pyrite or arsenopyrite.

The mineral assemblage, especially the presence of marcasite, proves that the sulphides, for the greater part at least, have been deposited later by ore-bearing solutions, so that they cannot be considered primary constituents of the igneous rock.

No. 70. Ore from the Carstenszweide.

This sample has been strongly oxidized and leached. The material has become porous to such an extent, that only after boiling in a special mixture of resin and shellac, tolerable polished sections could be prepared. Only the more resistant minerals: quartz, magnetite and pyrite have been preserved. In the available samples no traces of other sulphides, that possibly might have been present, could be distinguished in the cavities produced by the leaching.

It could not be ascertained therefore whether, like in sample No. 52, copper ores were present in the primary ore.

Some of the polished sections only showed very porous quartz, with small remnants of pyrite. Others were less porous and were formed entirely by an intergrowth of pyrite and magnetite. The magnetite occurs in masses of wholly or partly idiomorphic grains of various sizes. The remaining space is entirely taken up by pyrite. So the boundaries of the pyrite grains are defined by the magnetite-shapes, whereas small idiomorphic magnetite crystals are enclosed in the pyrite.

No. 52. Samples from the Ertsberg.

These we can treat more fully. The ore can be diagnosed a gold-bearing copper ore.

The following primary minerals have been found: magnetite, chalcopyrite, bornite and in small quantities: hematite, gold, galenobismutite. Goethite, covellite, lepidocrocite, chalcopyrite II, bornite II, malachite and cuprite are secondary constituents.

Primary Minerals.

Magnetite. The magnetite can be rather massive. The grains generally are wholly or partly idiomorphic, polygonal in shape and show zoning (grain-size 0.25 to 1 or 2 mm). The magnetite therefore has developed as idioblasts in the nearly completely replaced limestone. By careful observation in oil immersion, very faint differences in colour between the various zones of the magnetite crystals may be distinguished. Probably these are due to small changes in the chemical composition. Owing to differences in resistance, the zonal growth becomes more pronounced by weathering. In the oxidation zone therefore, some zones are changed more readily into goethite or lepidocrocite than others.

Small grains of hematite and many irregularly shaped patches of chalcopyrite occur in the magnetite. The well known martitisation along certain crystallographical planes has nowhere been observed. In some of the polished sections made from strongly oxidized samples the magnetite contains numerous minute cavities which are probably developed by leaching of the copper minerals by supergene solutions.

Chalcopyrite and bornite. Most of the polished sections are rich in one or both of these minerals. Sometimes they form nearly the whole of the specimen. Both occur in large lobe- or tongue-shaped patches. The two minerals show smooth and undulating contacts. They are rather coarsely intergrown. When enclosed in massive magnetite, however, the chalcopyrite as a rule is finely disseminated between the magnetite grains. The boundaries of the chalcopyrite specks are then entirely determined by the surrounding magnetite grains. It seems that the last limestone remnants between the idioblastic magnetite grains have been replaced by chalcopyrite. The resulting texture gives the false impression of an interstitial filling of cavities in a finely grained panidiomorphic magnetite mass.

Chalcopyrite moreover occurs in abundant microlites in the bornite. These are arranged in various ways, and they will be treated more fully together with the secondary bornite. At the same time we will mention a special variety of chalcopyrite, that originates from weathering of the bornite.

In the oxidation zone a great part of the chalcopyrite seems to be lixiviated.

Gold. Of course the number of specimens is insufficient and the gold specks are too scanty to get an exact idea of the mode of occurrence of the gold. We can say however that perhaps the gold-content may prove to be considerable. In comparison with other gold ores, the polished surfaces that have been examined give the impression that the gold-content might be f.i. 10 g per t.

However, no great value can be attached to this figure.

The observed gold properly must be called electrum but the rather deep yellow colour indicates that the silver-content cannot be very high.

Taking it roughly the proportion of the two metals might be expressed by the formulae AuAg or Au_2Ag.

Electrum generally occurs in patches with smooth boundaries; tongues are scanty or absent. As a rule the metal is enclosed in the various copper minerals or in the hydrated iron oxides of the weathered ore. Electrum was observed between the copper minerals as rounded patches or filiform or tabular corpusculae of up to 0.25 mm. On the other hand the dimensions of the nearly globular specks enclosed in the chalcopyrite sink as low as 0.02 to 0.005 mm.

First indications lead to the supposition that gold and silver are of primary origin. The samples however are too few in number to allow a definite statement.

The gold-content of several pulverised ore-fragments tested in the crucible proved to be 9.8 g per ton. But this analysis too is only of restricted value, as the available lumps cannot be considered a representative sample. The figure is only mentioned here to indicate a certain order of magnitude.

Galenobismutite, molybdenite and native bismuth.

These three minerals were only sparingly observed as extremely fine inclusions of 0.02 to 0.001 mm diameter in the chalcopyrite but they are worth mentioning, because elsewhere the presence of native bismuth, bismuth-sulphosalts and molybdenite in gold-bearing copper ores is well-known too.

Secondary minerals.

The various primary sulphides have been more or less leached, altered or replaced by supergene solutions. Pyrite, marcasite and bornite have been much more vigorously attacked than chalcopyrite and magnetite.

Limonite (Lepidocrocite and goethite). Pyrite is replaced by limonite. Especially no. 51 shows quite clearly the intermediate stages of this alteration. Of course marcasite is decomposed even more readily. As a rule it has already been weathered completely in a stage where remnants of pyrite are still abundant. Part of the magnetite too has been converted into limonite.

It cannot always be detected easily whether the greater part of the goethite and the lepidocrocite results from alteration of the pyrite or the magnetite, both minerals being cubic and their sections showing identical outlines. Especially when the goethite and the lepidocrocite show inherited zonal structures, in most cases it is extremely difficult to decide which of the two minerals has been replaced. The more so, as samples from the transition zone are lacking. On comparison with the primary ores, we may assume with reasonable certainty that limonite has formed by replacement of sulphides when it exclusively fills interstices between the magnetite grains in massive ore. On the other hand, when magnetite and limonite zones alternate in one grain, we may conclude that the magnetite itself has been partly replaced.

Lepidocrocite and goethite may form in three ways, i.e. from copper- or iron-sulphides and from magnetite. The crustifications of limonite on the walls of cracks and cavities show radial-fibrous structures, whereas normal granular arrangement prevails in the massive parts. Cuprite now and then is intergrown with the hydrated iron oxides. Malachite and other carbonates occur in interstices and veinlets, either in the massive magnetite aggregates or in partly weathered sulphides.

The rhombohedral arrangement of some skeleton-like limonite remnants shows clearly that in that case carbonates have been replaced.

In the centre of the sample the cracks in the various sulphides are as a rule filled by limonite, sometimes however by carbonates.

In some polished sections lepidocrocite and chalcopyrite are the main components. The lepidocrocite shows a zonal structure. Here and there it still carries fine magnetite-laths in zonal arrangement. Outline and size of the lepidocrocite aggregates, the zonal structure and the enclosed magnetite laths, give confirmatory evidence that this lepidocrocite has been derived from magnetite. It is remarkable that in spite of the vigorous attack by supergene solutions most of the chalcopyrite has been preserved. A rather wide marginal cavity, separating the chalcopyrite from the lepidocrocite, indicates that an appreciable part of the chalcopyrite must have been dissolved, though the remnants do not show much signs of weathering. Here too cubic shapes of the limonite indicate pseudomorphism after pyrite.

Chalcopyrite, bornite and covellite. The first two minerals have already been discussed among the primary minerals. However, they also occur frequently as secondary constituents and then exhibit some peculiar structures and colours. To distinguish them from the primary minerals cp I and bn I we will label them cp II and bn II.

An entire chapter could be devoted to the curious weathering-phenomena in the bornite and to the discussion of the various crystallographical and chemical problems involved. However, a full treatment of these questions seems premature. We wil only refer to the extensive literature on this subject by Graton and Murdoch [1]. Zies, Allen and Merwin [2]), Schwartz [3]), Ramdohr [4]), Ramdohr and Schneiderhöhn [5]), Geyer [6]) and Schouten [7]) and we shall only briefly mention some interesting features.

Starting from grain boundaries and cracks, covellite extensively replaces bornite. Thus two patterns can develop: a kind of „craquelé'' structure and a very regular reticulate or lattice structure. The first prevails along the grain-boundaries and along the cracks or fissures whereas the latter occurs farther towards the centre of the grains. In the „craquelé'' structure all cracks are filled with covellite. This pattern therefore reminds one of the well known pseudo-structure of bornite,

[1]) Trans. Am. Inst. Min. Eng. 1913 p. 26.
[2]) Econ. geol. 1916 p. 407.
[3]) Econ. geol. 1928 p. 381.
[4]) Arch. f. Lagerst.kunde 1924 H. 34.
[5]) Lehrbuch der Erzmikroskopie.
[6]) Sv. Geol. Undersökning 1924 No. 321.
[7]) Econ. Geol. 1934 p. 611 and: Metasomatische Probleme, 1937.

often developing on etching. It is the first stage in the replacement of bornite by covellite.

The lattice pattern shows similarity with the structure of regularly arranged chalcopyrite laths in bornite or with the so called „lamellar chalcocite pattern'', so well known from literature. Originally the bornite (bn I) contains innumerable laths of chalcopyrite (cp I), microlites, perpendicular to each other, though sometimes they form parallelograms or triangles. Hence these cp I-inclusions are probably arranged along (100). During the replacement the long covellite scales grow in such a way that they bisect the angles between the chalcopyrite laths. At the same time a distinct cleavage parallel to the long axis of the covellite scales develops.

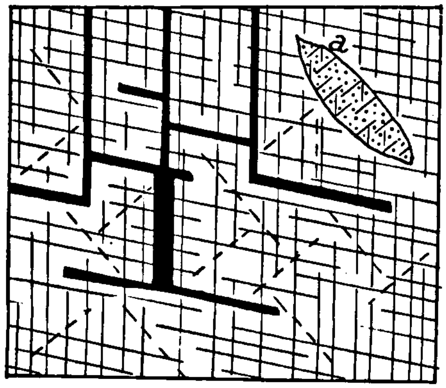

Fig. 32.

white = covellite formed from bn I;
heavy black lines = cleavage planes;
thin black lines = direction of the long axes of the covellite blades,
dotted lines = cpI-microlites in primary bn I;
near a: dotted surface = remnant of bn;
small black lines = secondary chalcopyrite (cp II).

In this stage the remnants of the bornite (bn II) look yellow brown when in contact with the reddish brown primary bornite (bn I): some of the Cu has already been leached.

The long axes of these lenticular bn II-remnants are usually arranged parallel to the original cp I-inclusions.

In this bornite remnants new chalcopyrite inclusions (cp II) develop, also parallel to (100). In the walls of the cracks some times abundant new chalcopyrite (cp II) occurs with the covellite: bornite being replaced simultaneously by covellite and chalcopyrite (fig. 1). In this metasomatic covellite mass the primary cp I-laths remain unattacked for a long time. Text-figure 32 illustrates several of these relations (see also fig. 33). In other polished surfaces little or no covellite was observed. This is the case especially in strongly oxidized samples primarily rich in magnetite but poor in bornite.

When examined with low- or medium-power objectives these samples seem to contain a new creamy yellow mineral. It is less yellow than chalcopyrite and has lower reflectivity. In oil immersion with high-power objectives it becomes evident that the supposed new mineral really is an extremely fine intergrowth of cp II and bn II, with prevailing triangular pattern (fig. 32 B and D).

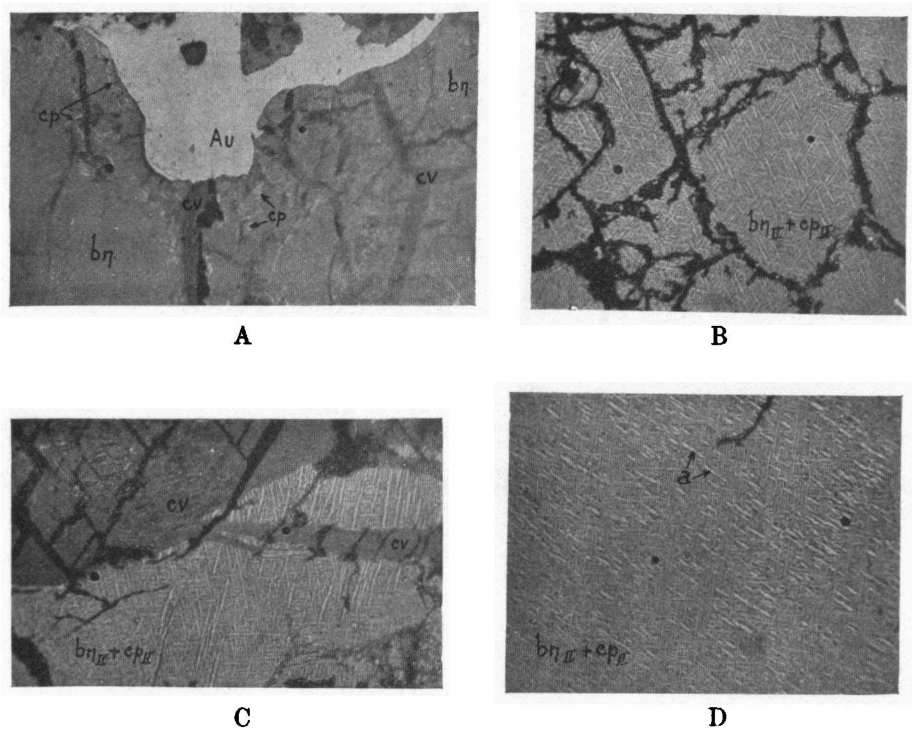

Fig. 33.

A. White, Au = gold; gray, bn = bornite; dark gray, cv = covellite; black = pits; small white needles, cp = chacopyrite II. ± 250 ×.

B. Reticulate intergrowth of cp II (white) + bn II (gray matrix) ± 1500 ×. No traces of bn I are left. Black = irregular shrinkage cracks.

C. Same as fig. 33B. Lenticular cp II-inclusions (A) occupying a third direction in the reticulate intergrowth. ± 1500 ×.

D. Same as fig. 33B. Gray and dark gray, cv = covellite. Black = cleavage planes and cracks. ± 1500 ×.

A possible explanation for this structure might be the break-down of a solid solution. The evidences of weathering- and replacement-phenomena however are absolutely convincing and we may be certain that this pattern is the result of decomposition and replacement by the action of supergene solutions. These sulphide masses therefore can be called neither bornite nor chalcopyrite, we must call them cp II + bn II. Some rather strongly weathered samples exclusively contain this cp II + bn II-intergrowth together with magnetite and limonite.

The sulphides are then separated from the oxides by a marginal cavity. While bornite as a rule is replaced rather extensively by bn II, covellite, cp II + bn II and limonite, chalcopyrite is much less attacked; only rarely it is accompanied by some covellite blades.

The microscopical pattern of the cp II + bn II depends on the section. Usually the fine laths of cp II form triangles, but parallelograms and squares also occur. In the interior of these geometrical figures rounded or ellipsoidal inclusions of cp II occupy a third direction (fig. 33 C). The cp II + bn II-intergrowths frequently are full of small irregular cracks, pointing to a loss of volume caused by the leaching of the copper from the original bornite molecule. (See fig. 33 B.)

Thus in the oxidation zone we here find a reversal of the reactions usually occurring in the cementation zone: no enrichment of copper by the formation of sulphides richer in Cu, but on the contrary: loss of copper, perhaps along with some precipitation of iron (bn → cp). It is not improbable (cf. my publication cited above) that this reaction is caused by concentrated solutions of ferro-ferrisulphate.

SUMMARY.

The ore-samples can be called contact-metasomatic gold-bearing copper ores. In so far as we may conclude from a sample which is by no means representative — a few loose lumps of ore from the surface were only available — the copper-content appears to be high (0—40%), while the gold-content might be rather considerable (0—15 gr. per ton).

The bulk of the ore consists of magnetite and hydrated iron oxides, chalcopyrite and bornite, with some gold and traces of rare bismuth minerals.

The samples are strongly weathered, limonite being formed abundantly in the oxidation zone, along with some copper oxides. The transition zone carries a large amount of covellite besides two new varieties of bornite and chalcopyrite.

The numerous peculiar patterns, developing in these copper-iron sulphides, altered by the action of supergene solutions, are very typical.

Even if the ore should prove to occur in large quantities, an economical exploitation will hardly be possible owing to the remote position of the locality. The costs of transport would be too high. Moreover the metallurgy of the ore would not be simple, as can be inferred from the mineral assemblage and from the data obtained by the microscopical examination.