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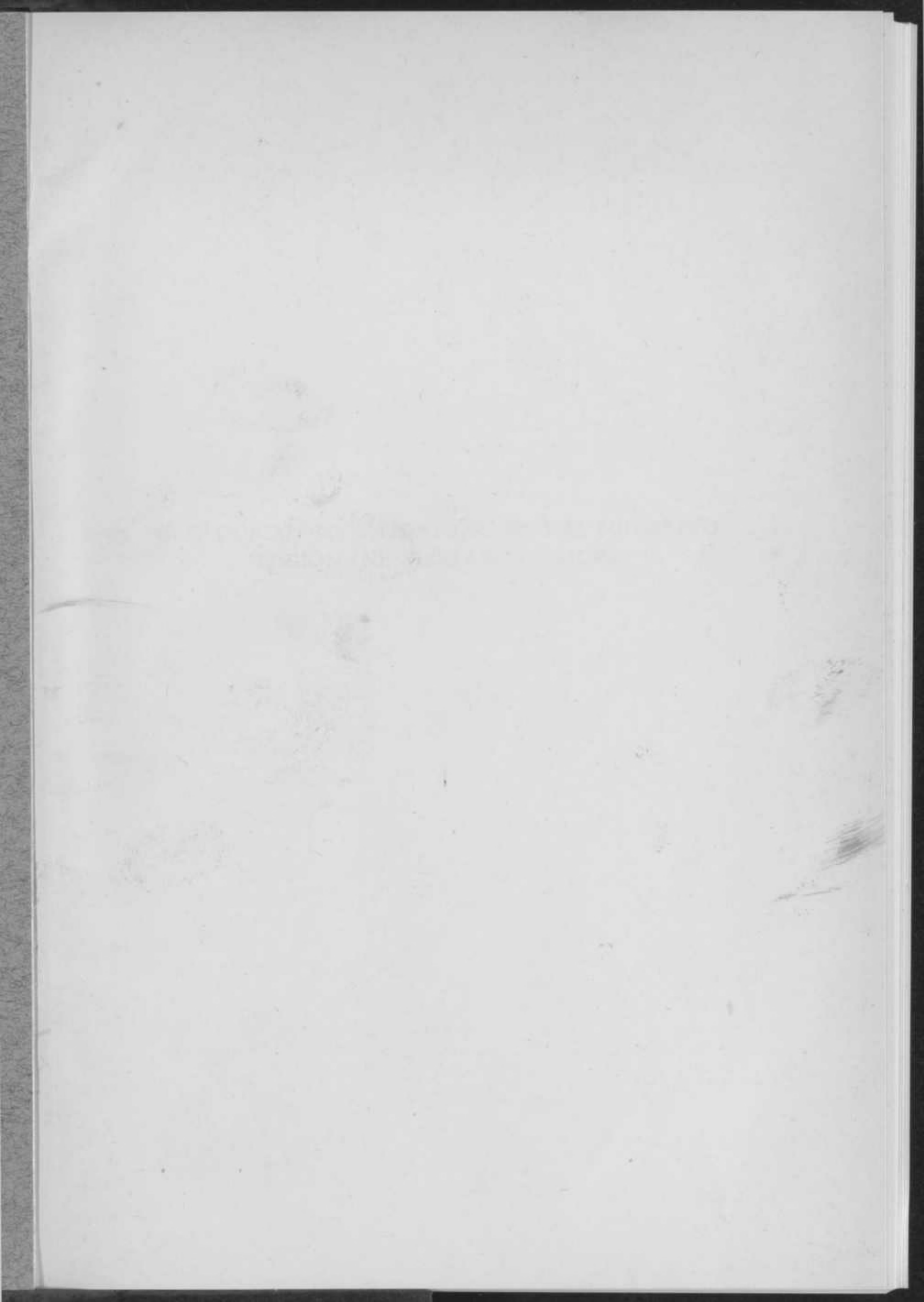
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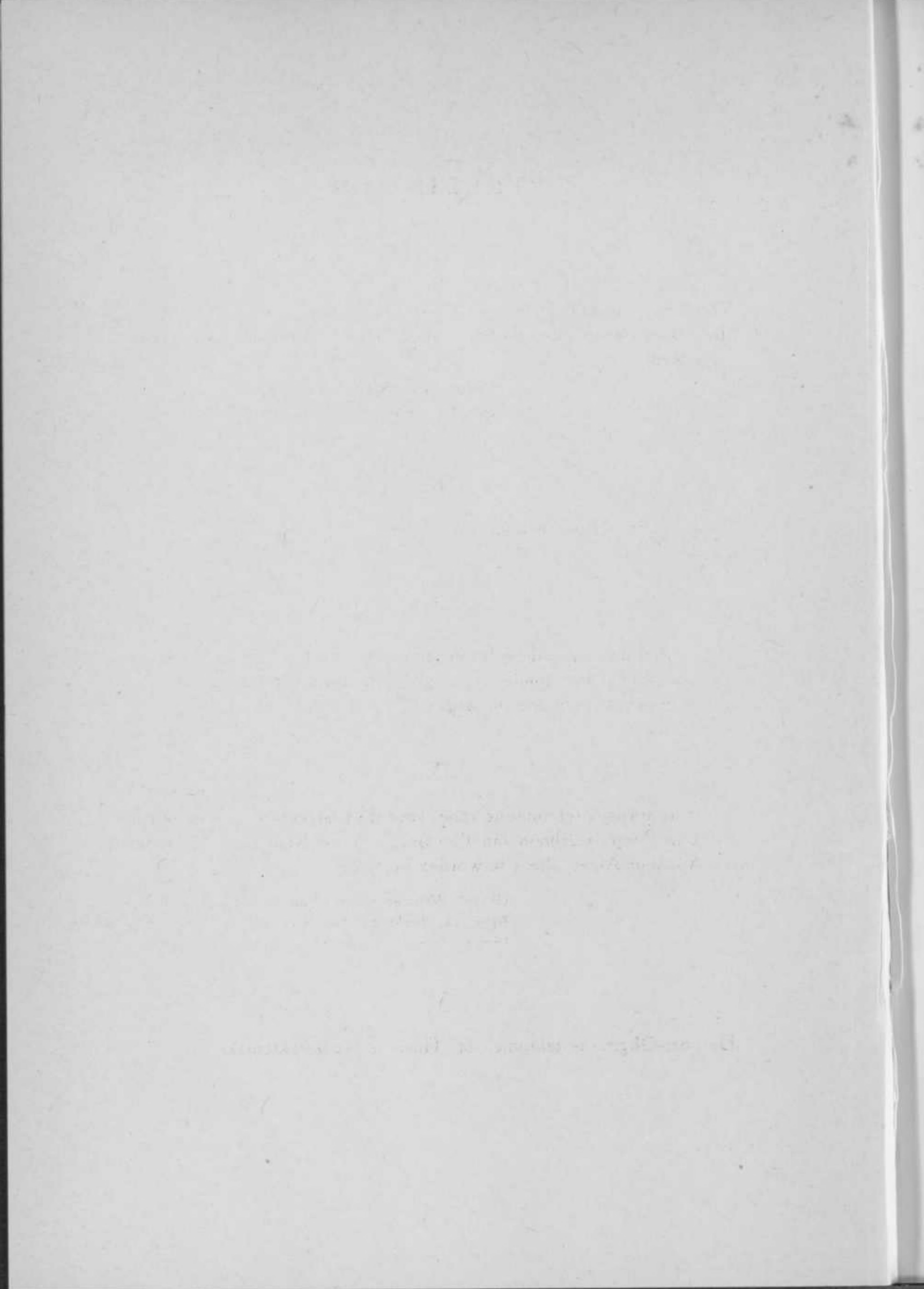


GEOLOGICAL INVESTIGATIONS
IN THE MIOMAFFO REGION
(NETHERLANDS TIMOR)

F. P. VAN WEST

iss. Amsterdam
1941





GEOLOGICAL INVESTIGATIONS IN THE MIOMAFFO
REGION (NETHERLANDS TIMOR)

GEOLGICAL INVESTIGATION OF THE MICHIGAN
REGION (WESTERN PART)

GEOLOGICAL INVESTIGATIONS IN THE MIOMAFFO REGION (NETHERLANDS TIMOR)

ACADEMISCH PROEFSCHRIFT

TER VERKRIJGING VAN DEN GRAAD VAN
DOCTOR IN DE WIS- EN NATUURKUNDE
AAN DE UNIVERSITEIT VAN AMSTERDAM,
OP GEZAG VAN DEN RECTOR-MAGNIFICUS
DR. B. BROUWER, HOOGLEERAAR IN DE
FACULTEIT DER GENEESKUNDE, IN HET
OPENBAAR TE VERDEDIGEN IN DE AULA
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FRANK PETER VAN WEST

GEBOREN TE ROTTERDAM

AMSTERDAM — 1941

N.V. NOORD-HOLLANDSCHE UITGEVERS MAATSCHAPPIJ

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Met gevoelens van dankbaarheid sluit ik dit proefschrift af. Het bood mij de gelegenheid de in het veld en tijdens mijn studiejaren verkregen inzichten en vakkennis in de praktijk te toetsen, terwijl het daarnaast de herinneringen opriep aan de boeiende en interessante maanden doorgebracht op het eiland Timor en aan de hernieuwde kennismaking met de tropische streken, waar ik mijn eerste jeugdijaren heb doorgebracht.

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SAMENVATTING.

In deze samenvatting zijn de belangrijkste geologische resultaten, welke werden verzameld tijdens mijn geologisch onderzoek op het eiland Timor in de maanden Augustus, September en October van het jaar 1937, neergelegd.

Het voornaamste onderzoek werd uitgevoerd in het gebied rond Noil Toko in het landschap Miomaffo, terwijl bovendien een klein gebied aan den weg van Kefamenanoe naar Wini, 3 K.M. van eerstgenoemde plaats afgelegen, in detail werd onderzocht.

In het Miomaffo gebied kan men de volgende eenheden onderscheiden: het Schist-Palelo-complex, de Sonnebait-serie, het Ophioliet-spiliet-complex en het Fatoe-complex. Het jong-Tertiair transgredeert over alle genoemde eenheden.

Het Schist-Palelo-complex is in het Miomaffo gebied de belangrijkste eenheid. Het Miomaffo complex en het oostelijke schist-complex behoren beiden tot deze eenheid. Het Schist-Palelo-complex is opgebouwd uit kristallijne schisten, welke tevens het voornaamste deel hiervan uitmaken, sedimentaire gesteenten en stollingsgesteenten. De kristallijne schisten worden onderverdeeld in: amphibolieten en laag metamorphe groenschisten, welke beide groepen grootendeels uit basische eruptiva zijn ontstaan; verder komen voor amphibool-schisten, epidoot-amphibool-albiet-chloriet-schisten, phyllietische albiet-arkosen rijk aan grafiet, grafiet-phyllieten, grafiet-chloriet-albiet-schisten, grafiet-biotiet-schisten en kwarts-carbonaat-chloriet-muscoviet-schisten, welke schisten allen van sedimentaire oorsprong zijn. Van alle groepen zijn de amphibolieten het best vertegenwoordigd, terwijl de groenschisten in den ruimsten zin, verreweg het belangrijkste deel der kristallijne schisten uitmaken. De hoogste graad van metamorphose wordt bereikt door sommige amphibolieten (andesien-amphibolieten), welke vermoedelijk in de mesozone thuis behoren. Verreweg het grootste deel der schisten zijn evenwel epischisten. Het verdient nog de aandacht, dat de grafiet-biotiet-schisten petrografische kenmerken vertoonen, die er op wijzen dat deze schisten na een regionale metamorphose te hebben doorgemaakt, onder meer directen invloed van een magmahaard kwamen te staan (thermische metamorphose).

De sedimentaire bedekking van de kristallijne schisten bestaat uit sedimenten van verschillenden ouderdom en verschillend karakter; deze worden onderverdeeld in de onder Palelo-serie en de boven Palelo-serie met Eocene afzettingen. De onder Palelo-serie bestaat uit sterk geplooid radiolarieten van verschillende typen, welke sedimenten vermoedelijk in een diepere zee zijn afgezet, terwijl de boven Palelo-serie bestaat uit voornamelijk grof klastische sedimenten, afgezet in neritische tot littorale omgeving. Deze laatste sedimenten zijn grootendeels opgebouwd uit afbraakmateriaal der kristallijne schisten, maar ook uit materiaal afkomstig van de onderliggende radiolarieten; de boven Palelo-sedimenten zijn bovendien rijk aan vulkanisch materiaal van andesietischen tot dacietischen oorsprong. De meest voorkomende gesteenten zijn grauwacken, grauwacke-zandsteen, conglomeraten, harde mergels en tuffen. Een belangrijk kenmerk van deze gesteenten is nog de albitisatie van vele lava-fragmenten, terwijl ook geheele gesteenten gealbitiseerd kunnen zijn. De boven Palelo-serie wordt vaak in contact met onder-Eocene Alveolinen kalksteen en mergels gevonden. Behalve deze karakteristieke onder-Eocene gesteenten treft men ook midden- en boven-Eocene afzettingen in het Miomaffo gebied aan. De midden-Eocene afzettingen zijn vertegenwoordigd door zandige kalksteen en mergels; de boven-Eocene afzettingen zijn gedeeltelijk ontwikkeld in een vulkanische facies (gedeeltelijk vermoedelijk nog midden-Eoceen) en gedeeltelijk in een rif-facies, waarbij de laatste faciesontwikkeling jonger is dan de eerste.

Tot het Schist-Palelo-complex behoren ook verschillende typen van stollingsgesteenten, welke petrologisch tot eenzelfde familie gerekend worden. Zij zijn zeker gedeeltelijk intrusief in het Schist-Palelo-complex. Aangetroffen werden serpentijnen (lherzolieten) waaruit de westelijke Miomaffo is opgebouwd, gangen van kwarts-augiet-albitieten en keratophyren, en albit-diabasen samen met hun vulkanische breccie's. De kwarts-augiet-albitieten en keratophyren werden verschillende malen als intrusief gangen in de kristallijne schisten en de eersten ook in de Palelo gesteenten aangetroffen.

De ouderdom der kristallijne schisten is waarschijnlijk prae-Permisch. Van de sedimentaire bedekking zijn de radiolarieten der onder Palelo-serie vermoedelijk veel ouder dan de klastische sedimenten der boven Palelo-serie, welke laatsten van jong-Mesozoischen ouderdom zijn, maar tot in het Eoceen kunnen doorlopen. De ouderdom der stollingsgesteenten is slechts gedeeltelijk bekend. Zoo zijn de gangen van kwarts-augiet-albitieten post-Cretaceïsch, de keratophyr gangen post-metamorph, evenals vermoedelijk de serpentijnen en lherzolieten. De albit-diabasen

en hun breccie's zijn van onbekenden ouderdom, doch vermoedelijk jong-Mesozoisch.

De Sonnebait-serie is in het Miomaffo gebied voornamelijk vertegenwoordigd door radiolarieten, hoornsteen en *Globigerina*-kalksteen en -mergels, welke sedimenten in een diepere zee moeten zijn afgezet. De ouderdom van een gedeelte dezer gesteenten is zeker boven-Cretaceïsch (*Globotruncana*-fauna), maar een gedeelte is waarschijnlijk wat ouder (jong-Mesozoisch).

Tot het Ophioliet-spiliet-complex worden alle stollingsgesteenten gerekend, welke buiten het Schist-Palelo-complex worden aangetroffen. Hiertoe behoren gabbro's, serpentijnen, albiet-diabasen, kwarts-albietiten en spilietische gesteenten. Een kenmerk van al deze stollingsgesteenten is, dat albiet een veelvoorkomende veldspaat is, welke in de meeste gevallen de oorspronkelijke basische veldspaat moet hebben vervangen.

Het Fatoe-complex bestaat uit Triadische kalksteen, welke tevens de eenige Triadische afzettingen in het onderzochte gebied vormen. De kalksteen worden gedeeltelijk vertegenwoordigd door ongebankte, massieve rif-kalksteen waaruit de verschillende fatoe's zijn opgebouwd. Een andere facies, tevens de belangrijkste in het gebied, is vertegenwoordigd door boven-Triadische brachiopoda-kalksteen met vele exemplaren van *Misolia*. Deze kalksteen vormen min of meer samenhangende strooken in het gebied. De fijnconglomeratistische kalksteen van deze groep bevatten vaak albiet kristallen en rolstukjes van mesocratische stollingsgesteenten, welke albiet als veldspaat bezitten.

Het jong-Tertiair heeft een belangrijke verspreiding in het Miomaffo gebied. Deze jonge serie is opgebouwd uit zachte, lichtgekleurde, fijnklastische sedimenten; grofklastische sedimenten b.v. conglomeraten komen verspreid in de serie voor. Belangrijk zijn de oud-Miocene conglomeratistische kalksteen aan de basis met *Spiroclypeus*, *Lepidocyclina*, *Cycloclypeus*, *Miogypsina* en vele klein-foraminiferen. Eveneens aan de basis van deze jonge serie komen voor harde *Globigerina*-kalksteen. Het voorkomen van conglomeratistische kalksteen aan de basis sluit het voorkomen van *Globigerina*-kalksteen uit, terwijl het omgekeerde eveneens het geval is. De ouderdom van deze jonge serie is gedeeltelijk zeker oud-Mioceen, getuige de genoemde foraminiferenfauna. De bovenste deelen kunnen echter jonger zijn. De geheele serie is sterk door jonge bewegingen beïnvloed.

De tektoniek van het Miomaffo gebied is zeer gecompliceerd, aan-

gezien de prae-Miocene overschuivings-tektoniek door de jongere post-Oligocene breuk-tektoniek werd beïnvloed.

Omtrent de prae-Miocene overschuivings-tektoniek kan worden gezegd, dat de gedane waarnemingen in het Miomaffo gebied overeenstemmen met de waarnemingen uit andere gebieden in Timor. Het is echter van belang op te merken, dat het tektonisch onderzoek der Palelo-serie er op wijst, dat een gebergte vormende periode aangenomen moet worden tusschen de radiolarieten van de onder Palelo-serie en de grofklastische sedimenten der boven Palelo-serie.

De post-Oligocene breuk-tektoniek is in het Miomaffo gebied en ook in het onderzochte gebied bij Kefamenanoe van groot belang. In het Miomaffo breuk-gebied heeft men als hoofdstructuur-elementen het Miomaffo schist-complex in het westen, het oostelijk schist-complex in het oosten en daartusschen de sedimenten van de Noil Toko slenk. De strekking en het karakter der ontstane breukstructuren worden voornamelijk beheerscht door de bewegingen welke deze drie elementen ten opzichte van elkaar hebben uitgevoerd in post-Oligocene tijd. Zoowel het Miomaffo-blok als het oostelijke-blok werden sterk opgeheven ten opzichte van de tusschenliggende Noil Toko slenk. Daarbij werd evenwel het blok van het Miomaffo schist-complex naar evenredigheid sterker opgeheven ten opzichte van de slenk, dan het oostelijke schist-complex.

In het onderzochte gebied aan den weg van Kefamenanoe naar Wini komen dezelfde geologisch-tektonische eenheden voor als in het besproken Miomaffo gebied. De post-Oligocene tektoniek is in dit gebied eveneens verantwoordelijk voor de ontstane structuren. Het Schist-Palelo-complex wordt hier overschoven gevonden op de sedimenten van de bovenste Sonnebait-serie. Tijdens deze overschuiving had overkipping plaats van het Schist-Palelo-complex, hetgeen bewezen wordt door de breccie van Palelo-gesteenten, aan het overschuivingscontact. Normaal behooren de Palelo-sedimenten als sedimentaire bedekking van de kristallijne schisten, op deze laatstgenoemde gesteenten te liggen. De jong-Tertiaire tuffen welke eveneens en vermoedelijk als lenzen aan het overschuivingscontact werden gevonden, bewijzen tevens dat deze structuren van post-Oligocene ouderdom moeten zijn.

Het is tenslotte van belang op te merken, dat de besproken overschuivingsstructuur meer als een vlakke opschuiving moet worden beschouwd, welke vermoedelijk slechts van geringe afmeting is. De regionale overschuivingsstructuren van Timor evenwel, ontstonden in prae-Miocene tijd.

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INTRODUCTION.

During the Geological Expedition of the University of Amsterdam to the Lesser Soenda Islands under leadership of Prof. Dr. H. A. BROUWER, I was charged with the investigation of the interesting Miomaffo region in central Netherlands Timor and also with the surveying of a small region in the neighbourhood of Kefamenanoe (District Miomaffo). The results of these investigations which were carried out in the course of the year 1937, are laid down in the following pages.

It is with great thankfulness that I remember the guidance and help, which I received from Prof. Dr. H. A. BROUWER during the accomplishment of this work. I am equally grateful for the many valuable hours which Prof. BROUWER spent in discussing the various geological problems connected with this work, which laid to so many improvements therein. I am very thankful to Prof. Dr. H. GERTH for the help he gave me in the determination of Tertiary Foraminifera and also for his kindness to read the chapter on Tertiary deposits. I am indebted to Prof. Dr. G. L. SMIT SIBINGA for his valuable suggestions regarding some geomorphological problems. To Dr. W. P. DE ROEVER I am greatly obliged for going into various problems with me and also to D. L. DE BRUYNE for kindly discussing some sedimentary petrographical questions.

I wish to express my sincere appreciation to Mr. G. J. VAN DER KOOL, who was "civiel gezaghebber" at Kefamenanoe during my sojourn on Timor. From him I received the utmost hospitality and coöporation during the three months of my stay in his district.

Finally I should like to thank all, who in one way or another, corroborated to the accomplishment of this work.

The investigation in the Miomaffo region was carried out with the special object of studying the post-Oligocene movements in this region. This has been done with satisfactory results.

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GEOGRAPHICAL AND MORPHOLOGICAL REMARKS.

The explored region is dominated by the E.-W. running mountain ridge of the Miomaffo and forms part of the district of the same name.

The principal village, Noil Toko (585 metres above sea-level) lies on the confluence of the Noil Niti and the Noil Noni, two streams, which carry water throughout the year, a very important fact, because most streams only contain water during the west (= wet) monsoon.

Noil Toko also marks the southern extremity of a depression, which has about a N.-S. direction. This depression is situated between the Miomaffo schist-complex in the west and the eastern schist-complex in the east. Seen from the north and south the Miomaffo ridge stands out against the sky as a perfect horizontal line, which to the west loses itself in the hilly landscape, but to the east terminates abruptly (Plate I, fig. 1). Eastwards from this latter point, there is a sudden fall of several hundred metres to a foreland of a strongly dissected character. This foreland marks the transition of the Miomaffo schist-complex to the proper depression, which is built up of sediments only.

The top region of the Miomaffo ridge is a practically horizontal elongated platform, which is at the utmost about 100 metres in width. It extends from the eastern extremity of the ridge to the west over nearly 1 km, at an altitude of about 1350 metres and is bordered right and left by a drop of some 700 metres into the canyons of the Noil Noni and Noil Niti respectively. It seems acceptable, that this small platform is the remnant of an old peneplain, as will be discussed later.

Remains of fluvial deposits are scattered over the platform, which platform truncates the crystalline schists of the Miomaffo. Going in a westerly direction the effect of the erosion becomes stronger and stronger and the platform loses more and more of its width, till finally even this remnant of an old erosion surface is destroyed.

The western smaller part of the Miomaffo ridge is composed of ultra-basic rocks (mostly serpentines), whereas the eastern part consists of schists only. This lithological difference is reflected in the morphology, the eastern part being very rough, steep and inapproachable, the western part being smooth, rounded and easy to climb.

PLATE I.

Fig. 1.

The Miomaffo ridge seen from the SW. The Fatoe Seinaam in the background of the left part of the photograph is situated on an old erosian surface, which is slightly inclined to the east and in this way forms an acute angle with the horizontal Miomaffo ridge. The difference in top-level between the Miomaffo complex and the eastern schist-complex is also apparent from this picture (photo H. A. BROUWER).

Fig. 2.

The mountain Miomaffo seen from the SE.

Fig. 3.

The meandering Noil Noni seen from a schist ridge of the eastern schist-complex, looking in a north-eastern direction.



Fig. 1.



Fig. 2.



Fig. 3.



The most important feature of the ridge is its E-W. trend. The common strike in Timor of both mountain chains and layers is however NE-SW. This, and the very sharp boundaries of the Miomaffo schist-complex to the north, south and east, give the impression that these boundaries are of younger tectonic origin than the main structural units of the island.

The Noil Niti marks the natural boundary of the Miomaffo schist-complex in the south. The northern bank of the stream is formed by the almost vertically dipping south flank of the Miomaffo ridge, the southern bank by a rather steep, southward climbing slope, composed of a great variety of rocks.

This slope is difficult to climb, because of the extremely chaotic way in which blocks of every kind and size lie about. This last feature can only be explained by assuming a huge landslide along this slope, an occurrence, which is a common feature in Timor.

Different factors promoted the frequent occurrence of such landslides. The most important of these are:

1. The rejuvenation of the erosion-cycle, following upon the uplift of the island.
2. The tectonic fact that everywhere the massive rocks of the Fatoe-complex lie on the softer rocks of the Sonnebait-series.
3. The alternating wet and dry monsoons: at the beginning of the wet monsoon (west monsoon) sudden, torrential rains soak the ground after a long period of drought. This sudden enormous increase of the mechanical erosion upsets many equilibria and it is comprehensible that under these circumstances large packs of sediments lose their hold and go sliding down.

The slope, south of the Noil Niti covers a height of about 300 metres and finally terminates in an old erosion-surface, of which large parts are still covered with fluvial detritus, although the present rivers flow several hundreds of metres lower. The surface mentioned does not possess a horizontal position, but as can be seen from a distance, inclines slightly to the east (Plate I, fig. 1).

When going along the footpath from Noil Toko to Seoam, one reaches this platform at an altitude of about 930 metres (see map), whence it continues in a westerly direction. The platform is at first relatively small, but gradually becomes more important, till it finally extends into an actual plain, which can be followed with interruptions as far as the Lelofoei pass. At the same time a gradual increase in height is observed

as a result of the already mentioned tilted position of the old surface to the east. The maximum height does not exceed 1300 metres and varies between 1200 and 1300 metres, which height is reached somewhere along the footpath from Seoam to Seinaam. The mentioned heights correspond with those which TAPPENBECK (26) gives for a similar erosion-surface in the Mollo region and also with those mentioned from various other localities of the island e.g. the vicinity of Kapan.

All this tends to show that perhaps a more regional meaning might be assigned to the 1200—1300 metre level and that this level appertains to an important, widespread erosion-surface. It is to be borne in mind, however, that any erosion-surface which existed *before* the uplift of Timor, might have been warped and bent *during* the uplift of the island. As a consequence different parts of the old peneplain may now be situated at different levels. The 1200—1300 metre level comprises the most elevated peneplain known from Timor.

The small platform, which is capping the Miomaffo ridge lies at an altitude of about 1350 metres, that is not much above the maximum level of the discussed peneplain. It seems therefore not far amiss to surmise in this small platform another isolated part of this peneplain.

The principal river in the region is the Noil Noni, which has several tributaries of importance, the Noil Niti, the Noil Boé and the Noil Poepmano. Of these only the first two and the Noil Noni itself, carry water throughout the year, which undoubtedly is due to the fact that all three are draining extensive schist regions. The schists are very suitable waterkeepers, while at the same time they deliver their water very regularly.

The whole drainage-system shows all the typical properties of a young system. The valleys are deep and V-shaped, while waterfalls and rapids are frequent. The Noil Niti e.g. possesses three waterfalls, each about 5 to 6 metres high. Where rivers cut their way through the schist areas, they do so in producing deep valleys of several hundreds of metres in depth. These valleys are never straight in course, but are always meandering. These meanders do not prove antecedency, but they are so-called "gliding meanders", a common feature of a young river system (Plate I, fig. 3). The property of gliding meanders in contrast to „incised meanders" (antecedency) is, that the former possess only one steep bank (the outward bank of the meander), whereas of the latter both banks are equally steep.

The climate of Timor is of the monsoon-type and is strongly influenced by its nearness to the Australian continent, especially during the dry

monsoon (or east monsoon). In this period, from May till November, a constant SE wind is blowing, which transports very dry and hot air from the Australian deserts directly to the island. As a consequence all vegetation is withering and most rivers lose their water or carry water only in their headportions. The landscape assumes a desolate and barren character. The vegetation is sparse and only becomes richer in the river valleys or in the neighbourhood of springs. Tropical jungle fails altogether and forests never become very dense and are easily passed through. Moreover there is a certain relation between the vegetation and the geological units exposed at the surface, which expresses itself as follows.

The sharp ridges in the landscape are mostly eroded out of schists. This formation is covered with "alang-alang", among which trees grow in a scattered fashion. The eucalyptus tree is the most common and striking species and can already be recognized from a long way off by its shimmering white bark and sparse foliage.

The rocks of the Fatoe-complex are mainly limestones, which possess the thickest vegetation of trees and bushes. The eucalyptus tree always fails however. Many so-called fatoes are built up out of the limestones of this complex and form huge blocks, which lie isolated in the hilly topography. Another group of rocks belonging to the Sonnebait-series is mainly composed of softer sediments, like clays and marls. They form a softly undulating landscape, covered with a vegetation of grass and trees.

The population is sparse. In the region here considered only a few native villages are found, of which Noil Toko has by far the largest population. This little village is situated very favourably, because water is available throughout the year from the two rivers Noil Niti and Noil Noni. It is the residence of the Radjah (native chief) of the district Miomaffo. The connection with the nearest Government seat, Kefamenanoe, is along a 24 km long motorroad.

The natives are still very primitive. Their agriculture is for the greater part exhausting cultivation, a practice which goes hand in hand with deforestation. This last fact, combined with the dry climate, sparse vegetation and the destructive way in which the erosion operates, thwarts the forming of a thick layer of vegetable earth, except perhaps in the basins of the island, where accumulation is possible. It is therefore clear that the Government tries to raise the standard of agriculture and to promote for instance the cultivation of rice. The lack of water certainly does not favour these efforts and irrigation works are necessary to get the required results. A beginning in this direction is already made, but much is still to be done.

The main agricultural product is maize. It is typical of their primitiveness that the natives do not put up sufficient reserves of this product and are cultivating just enough to keep them going for a year. As a result a famine threatens to break out at intervals, especially after an excessively dry year. This the Government can only prevent by importing rice.

The language of the natives is a Timorese dialect, which is different for every district. Many of them however, are able to speak Malay, the vehicular language in the Indian Archipelago.

A. THE GEOLOGICAL FORMATIONS.

I. The crystalline schists.

II. Pre-Tertiary.

- a. of the Fatoe-complex (Triassic).
- b. of the Palelo-series (younger-Mesozoic and older?).
- c. of the Sonnebait-series (younger-Mesozoic).

III. Tertiary.

- a. old-Tertiary.
- b. young-Tertiary.

IV. The igneous rocks.

I. THE CRYSTALLINE SCHISTS.

The most important part of the mapped region is occupied by metamorphic rocks. They build up the so-called eastern schist-complex and the greater part of the Miomaffo schist-complex. Between the two schist units occur the sedimentaries of the Noil Toko fault trough.

The two schist-complexes are easily accessible in the canyons, which the Noil Noni and the Noil Niti, with their respective tributaries, have carved out in the crystalline schists. All interjacent parts between the different canyons are nearly inapproachable, as a consequence of the very steep slopes of the rough schist topography.

a. Rock-types and distribution.

It could be established from the specimens collected that no essential differences exist between the crystalline schists of the investigated parts of the two schist-complexes. The following rock-types have been recognized:

A. Greenschists.

- 1) Amphibolites $\left\{ \begin{array}{l} a) \text{ Plagioclase-amphibolites.} \\ b) \text{ Epidote-amphibolites.} \end{array} \right.$
- 2) Low-metamorphic greenschists derived from basic igneous rocks.
- 3) Amphibole-schists.
- 4) Epidote-amphibole-albite-chlorite-schists.

B. Other schist-types.

- 5) Schists rich $\left\{ \begin{array}{l} a) \text{ phyllitic albite-arkoses.} \\ b) \text{ phyllites.} \\ c) \text{ chlorite-albite-schists.} \\ d) \text{ biotite-schists.} \end{array} \right.$
in graphite
- 6) Quartz-carbonate-muscovite-chlorite-schists.

The division in greenschists and other schist-types is made, because of the dominant position, which the former group of schists occupies amongst the crystalline schists as a whole. The other schist-types may become locally of greater significance.

The amphibolites form among the greenschists the most important group; especially plagioclase-amphibolites of different types and of different stages of metamorphism are very abundant. The sedimentary epidote-amphibole-albite-chlorite-schists follow in importance on the amphibolites and form undoubtedly a substantial part of the Miomaffo schist-complex. The two groups 2 and 3 are, however, only scantily represented.

The other schist-types become e.g. of greater importance in the Noil Niti, where they are exposed in a long tract upstream, from the spot where tributary number 3 of the Noil Niti joins the Noil Niti. It is also here, that albitic igneous rocks (keratophyres, described on p. 93) occur conformably with the sedimentary schists. It is not certain in the field whether these keratophyres are to be considered as intrusive sills or as somewhat metamorphic albite-rich lavas, which were erupted during the period of the sedimentation of the rocks, of which the crystalline schists were derived. It seems however more probable that they are post-metamorphic as in other parts of the crystalline schists igneous dykes of a resembling composition (quartz-augite-albitites, p. 81) are seen to cut through the schists. The keratophyres mentioned show mostly strong cataclastic effects and they may even become decidedly schistose.

The amphibolites are considered to be metamorphic basic igneous rocks, at least for the greater part. Reason for this assumption will be given in the chapter on petrography and petrology.

Any stratigraphic subdivision of the crystalline schists in the Miomaffo region seems as yet impossible, because of the strong tectonic disturbances to which all schist-units on Timor were submitted. Neither has a definite zonal arrangement been observed.

It is however clear that among the crystalline schists of Timor several stages of metamorphism are represented, ranging from kata-zone rocks over meso-zone rocks to epi-zone rocks. The last two groups of rocks are very important in Timor, while kata-zone rocks were only rarely observed (Booi Mountains and Moetis Mountains). Crystalline schists of the highest stages of metamorphism are up till now unknown from the Miomaffo region, while meso-zone rocks are scarce and epi-zone rocks are by far the most important.

b. Age of the crystalline schists.

To the question concerning the age of the crystalline schists, the investigation of this region could not give a definite answer, as no fossils were found.

But on the ground of the following summary of data and by arguing along much the same lines as TAPPENBECK (26) and DE ROEVER (21) did, a pre-Triassic age seems certain and a pre-Permian age probable.

In the investigated area, the crystalline schists are immediately overlain by the Palelo-series, which is subdivided in the lower and upper Palelo-series (p. 15). The lower Palelo-series consists mainly of radiolarian cherts, while the upper Palelo-series is mainly composed of greywackes, tuffs and conglomerates. The last mentioned conglomerates contain many schist-fragments and also detrital material from the lower radiolarian chert part of the series. This proves therefore that the upper Palelo-series is transgressive over both the crystalline schists and the lower Palelo-series. The rocks of the upper Palelo-series in the investigated region are comparable with those of the Palelo-series in the Mollo region. Of the radiolarian cherts of the lower Palelo-series no equivalents were found in the Mollo region. The upper Palelo-series possesses on the ground of the enclosed *Globotruncana*-fauna, an upper-Cretaceous age, while TAPPENBECK contended even an upper-Jurassic (Oxfordian) age for the lower parts of the Palelo-series in the Mollo region. The age of the radiolarian cherts of the Miomaffo region is not known, but they are supposed to be much older than the upper Palelo-series and to be more closely connected with the crystalline schists (see p. 22). Therefore the crystalline schists are at least of pre-upper-Cretaceous age, while a pre-younger-Mesozoic age may be assumed.

In Triassic sediments of the Kekneno-series, — which series also contains Permian sediments — furthermore occur cataclastic quartz-grains, small fragments of graphite-phyllites and garnet grains (26). This fact might point to a pre-Triassic age of certain crystalline schists. In conglomerates and sediments belonging to the Permian, no schist fragments or detrital minerals derived from crystalline schists were found. This last fact does not necessarily prove however a post-Permian age of the crystalline schists. It is namely equally possible that the crystalline schists were not yet present in the erosion region of the Permian sediments at the time of the laying down of these sediments.

On the ground of the preceding arguments DE ROEVER and TAPPENBECK assumed a pre-Permian age of the crystalline schists and my investigation of the Miomaffo region is not in contradiction with this conclusion.

It remains more or less a problem whether the already mentioned radiolarian cherts of the lower Palelo-series are more closely connected with the upper Palelo-series or with the crystalline schists. Certain

observations in the field (see p. 22) led to the supposition of the existence of a stratigraphical gap between the radiolarian cherts of the lower Palelo-series and the coarse clastic sedimentaries of the upper Palelo-series, in which case the lower Palelo radiolarites may be considerably older than the upper Palelo-series. The intensively folded radiolarian cherts are at the same time considered to be closely connected with the strongly folded crystalline schists and more especially with the low-metamorphic part of the crystalline schists. It is not known, whether there exists a direct transition from the low-metamorphic crystalline schists to the sometimes slightly phyllitic radiolarian cherts, as an actual transition has up till now not been found in the Miomaffo region. This can however also be the consequence of abnormal contacts caused by strong tectonic movements. The existence of a transition of crystalline schists to practically non-metamorphic rocks, which is described from Letti (18) and from Ceram (22), both islands of the Timor-Ceram arc, might be used as an argument in favour of the possible existence of a similar transition in Timor. In Letti part of the transitional rocks contains Permian fossils; the transition in Ceram is very gradual, but in this case no age is given. Thus the possibility remains that the radiolarian cherts of the lower Palelo-series and the low-metamorphic part of the crystalline schists of Timor are of Permian age and the larger higher metamorphic part pre-Permian. TAPPENBECK (26) expresses a similar view, when he writes: "It is possible that these rock-types (low-metamorphic phyllites, quartz-schists etc.) are much younger than the high-metamorphic mica-schists and gneisses".

The tentative table of comparison between the Miomaffo region and Martapoera region in S.E. Borneo (p. 26) is also very suggestive in this respect. The crystalline schists of the Martapoera region are largely composed of greenschists, as is the case in the Miomaffo region. The Alino-formation in the Martapoera region, which is possibly of Permian age on the ground of its similarity to the Permian part of the Danau-formation in Borneo (33), is compared with the radiolarian cherts of the lower Palelo-series.

Finally a few general remarks about the crystalline schists rest to be made.

The Miomaffo complex is — as has been stated in an earlier chapter — accompanied by a body of ultrabasic igneous rocks, principally serpentines. The igneous rocks are probably intrusive into the crystalline schists (p. 45). This association of ultrabasic rocks and crystalline schists is a typical feature of the Timor-Ceram arc of islands.

The low-metamorphic graphitic phyllites, mica-schists and quartzitic schists were probably more exposed in pre-upper-Palelo-time than they are at present, because of the relative abundance of fragments derived from these types of schists in the upper Palelo sedimentaries.

The crystalline schists often show miniature folding, which is also found to be a feature of many schist-pebbles in the conglomerates of the upper Palelo-series. This proves therefore folding of the crystalline schists in pre-upper-Palelo-time. It seems furthermore obvious that the post-Palelo and pre-young-Tertiary deformation caused mainly brecciation, crushing, faulting etc. on an extensive scale. Part of these brecciation processes, however, are to be regarded as the result of still younger (post-Oligocene) movements.

II. PRE-TERTIARY.

Under this heading rocks will be described, which belong to the Fatoe-complex, to the Palelo-series and to the Sonnebait-series. In the investigated region the rocks of the Fatoe-complex are of upper-Triassic age and those of the Sonnebait-series of younger-Mesozoic age. The Palelo-series is partly also of younger-Mesozoic age (upper Palelo-series), but partly is assumed to be older (lower Palelo-series).

a. The Fatoe-complex (Triassic).

The Triassic of the mapped area, is mainly represented by upper-Triassic limestones of the common types known from Timor which belong to the Fatoe-complex.

They are subdivided into:

1. A group, which consists of light coloured, usually beige to whitish, rarely more greyish limestones. They are mostly fine crystalline and even sometimes marble-like. Stratification planes are badly developed or lacking and they are very poor in fossils. The limestones are frequently covered with a black coating and show beautiful karst-weathering. Brecciation is frequently observed, the fractures being filled with calcite. Oolitic structures were only seldom observed. The limestones in question build up the huge, towering fatoes like the Fatoe Oenoep, the Fatoe Seoam and outside the map the Fatoe Seinaam and the Fatoe Kesnaam (Plate II, fig. 1).

2. This group consists of limestones which are frequently entirely composed of corals and shells of molluscs; another variety contains fossils in a much smaller amount. Numerous sections of shells of brachiopods and lamellibranchs occur on the fracture-surfaces of these limestones. The limestones are usually beige coloured, but grey to dark grey colours occur as well. The name "brachiopod-limestones" will be used henceforth to indicate this whole complex of fossiliferous limestones.

The rocks are rarely crystalline, but often strongly brecciated and then extensively veined with calcite. They are furthermore coarsely banked, while more marly banks are seen to alternate with the limestones. The more marly banks are often exceptionnally rich in fossils. A certain type of limestone contains lumps of chert. Weathering covers the limestones often with a yellow to yellow-brown or brown to reddish brown coating.

Many of these limestones show brown spots on the fracture-surfaces.

The best exposure of brachiopod-limestones is to be found at the confluence of the Noil Noni and the Noil Niti, where on the right bank of the Noil Noni lies a nearly 15 m high fatoe, which is entirely composed of the limestones mentioned. The alternately more or less marly character of the banks is here well developed, while the more marly ones are especially rich in coralreef organisms. Several good exposures are found directly west of the footpath from Noil Toko to Seoam. The brachiopod-limestones can furthermore be followed with interruptions in a narrow strip along the front of the eastern schist-complex; they are however totally lacking on the opposite side of the Noil Toko fault trough. They reappear south of the Noil Niti along the path from Noil Toko to Seoam, and here obtain their greatest extension.

The age of the first group of limestones could not be fixed, as no fossils were found in them. We may assume however an upper-Triassic age for these rocks, in view of the far going similarity to upper-Triassic rocks, which occur at many other localities of Timor in the same typical manner, as so-called fatoes. The fossils found in the Fatoe Seinaam — a short distance outside the mapped area — fix the age of this particular fatoe moreover beyond doubt (16).

The brachiopod-limestones possess a fauna, which is poor in species, but rich in number. Characteristic is the brachiopod-genus *Misolia*, which genus is represented in the greatest number; different species of the genus mentioned are probably present. The species *Misolia aspera* KRUMB. is especially abundant and was first described by KRUMBECK from the Fatoe Neisoeaam (District Miomaffo) and the Fatoe Nimassi (District Miomaffo, vicinity of Haoemeni). This author writes concerning *Misolia aspera*:

"This species belongs to the genus *Misolia*, which genus was, for as far as is presently known, exclusively found in Norian (= upper-Triassic) deposits. In the Timor-Archipelago, *Misolia* was found in the lower Norian Fogi deposits and in the partly younger Athyrid-limestones, both in Western-Boeroe."

KRUMBECK (16) mentions *Misolia aspera* as one of his index-fossils of the Timorese coral- and brachiopod-limestones of Norian age. We may thus also fix a Norian age for the brachiopod-limestones of the investigated region.

The stratigraphical relations between the two facies-types 1 and 2 is not clear in the field. KRUMBECK discusses both facies however under one heading and this author remarks about their connection: "It is not known,

whether the banded brachiopod-limestones occur as nests or as larger bodies, intercalated between the dense unstratified fatoe-limestones". Our observations do not confirm this assumption, but are more in favour of the assumption of the existence of two different facies.

A characteristic petrographical feature of the brachiopod-limestones is the occurrence in them of rounded fragments of eruptive material and of many clastic albite-crystals. The eruptive material seems mostly derived from albite-rich igneous rocks, of a mesocratic character. It is to be noted, that DE ROEVER (21, p. 142) found conglomeratic, oolitic fatoe-limestones, which contain however "mostly very small pebbles of greenish to greyish igneous rocks ... which appear to belong to porphyritic sanidine-trachytes".

The extension of the rocks of the Fatoe-complex is greatest west of the trail from Noil Toko to Seoam, as is clearly shown on the map. The described brachiopod-limestones occur mainly immediately west of this trail. Farther to the west were found several other sedimentary rock-types, principally limestones, which are also included in the group of rocks belonging to the Fatoe-complex. The huge landslide, which occurred on this slope destroyed however all previous stratigraphical connections, which may have existed between the brachiopod-limestones and the other sedimentary rocks.

b. The Palelo-series (younger-Mesozoic and older?).

The Palelo-series in the Miomaffo region is subdivided in a lower and an upper part. These parts are lithologically quite different from each other, which make the two parts easily distinguishable in the field. The lower part is further assumed to be much older than the upper part. In connection with the lower part there occur volcanic breccias and igneous rocks, which are probably intrusive into the lower Palelo-series.

a. The lower part of the Palelo-series.

The lower part of the series is mainly composed of radiolarian cherts, while in connection with them there occur volcanic breccias, associated with igneous rocks, which rocks will be discussed separately. The radiolarian cherts are always strongly folded and the contacts with the underlying crystalline schists and the overlying upper part of the series are usually characterized by a crushed zone of several metres. No transgression conglomerate or transition between the crystalline schists and the lower Palelo-series has been found. The very hard and at the same time very brittle cherts are often strongly folded (Plate II, fig. 2). The

PLATE II.

Fig. 1.

View from the east on a Fatoe, which is situated on the erosian plain south of the Miomaffo. The plain is covered by fluvial detritus.

Fig. 2.

Strongly folded radiolarian cherts of the lower Palelo-series, exposed in the Noil Noni a little upriver from Noil Toko (photo H. A. BROUWER).

Fig. 3.

Outcrop of the volcanic breccia, found at the base of the lower Palelo radiolarian cherts and exposed in the Noil Noni, a little below from the place where tributary N^o. 11 joins the Noil Noni.



Fig. 1.



Fig. 2.



Fig. 3.



radiolarian cherts of the lower Palelo-series are developed in two different types, one of which is found at the base of this part. These cherts are usually well stratified and show dark red-brown to dark violet colours inside, but are usually green coated at the outside. They show microscopically many rather badly preserved radiolarian shells in a siliceous and ore-rich matrix. The innumerable fine, dust-like ore particles give to these rocks the red-brown colour.

Upon the dark brown to dark violet radiolarian cherts follows another, totally different type of more thinly stratified, very hard and brittle radiolarian cherts, which show brownish green, bluish grey, grass-green and blue-green colours; they are on the whole much lighter coloured than the underlying cherts. Their stratification planes are often covered with black Mn-stains. They also essentially consist of rather badly preserved shells of Radiolaria, which lie in a frequently more or less marly cementing substance. In the investigated region the transition between the two kinds of chert, has always been found to be marked by a disturbed brecciated zone.

Also belonging to the lower Palelo-series are finely stratified cherty sedimentaries of a more clayey character. They are intensively coloured and show red, chocolate-brown, violet and green colours. The exact relation to the two previously mentioned chert-types is not quite clear, but they have probably an intermediate stratigraphical position. These rocks were found only at two places, namely in the Noil Koko and in tributary Nr. 12 to the Noil Noni. In the latter case they seem to occur between the two different radiolarian chert types.

The age of the radiolarian cherts is not known, as no age-fixing fossils were found in them. They are however assumed to be much older than the younger-Mesozoic upper Palelo-series. The reasons for this assumption will be elaborated on a later page in this chapter.

The most complete sections through the lower Palelo cherts are found in Nr. 10, Nr. 11 and Nr. 12, all tributaries to the Noil Noni. In Nr. 12 are also present the mentioned volcanic breccias and igneous rocks. They occur as lenticular masses between the dark coloured basal cherts. In section III (fig. 5) a more exact description of the succession and way of occurrence will be given.

β. The volcanic breccias.

The volcanic breccias are found in connection with the dark coloured radiolarian cherts at the base of the lower Palelo cherts, close to the contact of cherts and crystalline schists. At one locality the breccias occur

as large lenticular bodies in the midst of slightly schistose albite-diabases. The breccias are always partly composed of fragments derived from these same albite-diabases and this proves that breccias and albite-diabases belong to one and the same eruptive cycle. The age of the volcanic rocks in question could not be established, because it is not known whether they are extrusive or intrusive into the cherts. Strong tectonic movements destroyed the original contacts. The albite-diabases and related igneous rocks mentioned are known to occur at several places in the younger-Mesozoic Palelo-series of the Mollo region, where these rocks are considered to be extrusive and therefore also of younger-Mesozoic age.

The volcanic breccias are very dark coloured when mainly composed of basic igneous rock types (mainly albite-diabases) and lighter coloured when composed of acid, quartz-rich types (mainly quartz-keratophyres and keratophyres). The matrix between the fragments is usually a dark red-brown substance, probably with a high content of iron-compounds. Carbonate and quartz may also figure as cementing substances. The breccias are sometimes coarse and the fragments may attain diameters of several inches. The individual fragments are very angular, while fragments of diverse sizes occur together in the same slide (Plate IV, fig. 1 and 2). This indicates, that the deposit was practically not subjected to water transport and subsequently sorting of the fragments. No schist fragments could be found in the breccias; they are exclusively composed of fragments of igneous rocks.

A tectonic origin of the breccias seems improbable, simply because the breccias do not show any of the petrographical features, which true tectonic breccias ought to exhibit. The breccias as a whole do not show any excessive crushing, milling out or the development of any directed structure, while the cementing substance does not show any recrystallization effects. We therefore came to the conclusion, that these breccias are to be considered as volcanic breccias.

The composing fragments of the breccias are derived from various igneous rock-types, among which are also fragments of the igneous rocks (albite-diabases), which occur together with the breccias. All igneous rock-types contain albite to albite-oligoclase as only plagioclase. The various types are mentioned in an order of decreasing acidity: quartz-keratophyres and keratophyres (both types may occur as strongly schistose fragments), quartz-amphibole-albitites, albite-diabases and spilitic rocks.

It is remarkable that the leucocratic rock-types (keratophyres, quartz-

keratophyres, albitites) all show cataclasis, sometimes to a very high degree (see p. 96), while the other rock-types (albite-diabases, spilitic rocks) have been only very slightly influenced by pressure. Since both groups of rocks occur as fragments in the same volcanic breccia, this petrographical difference must be due to a difference in age between the two groups of rocks and it suggests that the leucocratic igneous rocks must have been submitted to strong tectonic influences before the other group of igneous rocks and the volcanic breccias came into existence.

There remains to be mentioned, that the rhyolite-breccia, which TAPPENBECK described (26, p. 74) and which occurs as hard banks at the base of the Palelo-series in direct contact with the crystalline schists, is similar to the quartz-keratophyres, which occur as fragments in the volcanic breccias at the base of the lower Palelo-series in the investigated region.

The best exposure of the volcanic breccias, combined with albite-diabases, is found in the Noil Noni, upstream from Noil Toko. The breccias here occur as large lenticular masses in the midst of the slightly schistose and brecciated albite-diabases (Plate II, fig. 3). Another good exposure is found in the Noil Koko, north of the Miomaffo. In neither of these cases, however, the direct contact with the crystalline schists is disclosed.

γ. The upper part of the Palelo-series.

The upper Palelo-series is mainly composed of greywackes, greywacke-sandstones, tuffs, marls, shales and conglomerates. All sedimentaries contain volcanic material in varying quantities, while the cementing substance may be chloritic, calcitic, glass-rich or a combination of the three. On the whole, the large content of volcanic material in these sedimentaries, points to a strong volcanic activity during the sedimentation of the upper Palelo-series.

At one place in the Noil Noni were found *Globotruncana*-limestones, cherty limestones and cherts, which must have been deposited in a deeper sea than the previously mentioned rocks. They are moreover practically devoid of volcanic material. It is however not possible to say, where these sediments ought to be placed stratigraphically in the series, because of the locally strong tectonic displacements. It is to be noted that these cherts are different from those described in the lower Palelo-series.

The upper part of the Palelo-series shows its most complete development at the southern side of the eastern schist-complex. Here the best exposures are found in the Noil Noni. Immediately upon the crystalline schists

follows a strip of green, folded radiolarian cherts, about 40 m thick which is all that is left of the lower Palelo-series. The cherts border upon well-stratified greywacke-sandstones of the upper Palelo-series with a transitional crush zone. The upper Palelo sediments are moderately folded; they are further of a monotonous grey-green colour. Faults are numerous and intrusive dykes are sometimes found breaking through the formation along these faults. The intrusives are invariably quartz-augite-albitites of different grain-sizes (see fig. 3). The same quartz-augite-albitites are also known to break through the crystalline schists. The Palelo sedimentaries in this section are mainly greywackes and greywacke-sandstones, with occasionally intercalated tuffs, shales and marls, while conglomerates seem to become more and more important going downstream and are finally seen to dominate. The associated greywacke-sandstones contain sometimes plant-remains, an indication of the shallow water in which these sedimentaries were deposited. The section continues in dark, marly and sometimes even slightly crystalline *Alveolina*-limestones of the lower Eocene. The direct contact between Eocene and Palelo-series is, however, not exposed.

The *conglomerates* will now be described in some detail, because their composition is of importance with regard to the structural evolution of the region.

The conglomerates are for the greater part composed of schist-fragments. The most frequently occurring schist-fragments are derived from graphitic mica-schists and quartziferous schists. Less abundant but still numerous are epidote-chlorite-schists and amphibolites. Practically all these schist-types can be derived from the crystalline schists in the neighbourhood. Besides the abundant schist-fragments there are found few fragments of limestones and radiolarian cherts, many fragments of igneous rocks and much volcanic material. Although we did not encounter similar limestones among the sedimentaries of the Palelo-series, the limestone fragments are nevertheless assumed to be derived from Palelo sedimentaries, because they enclose schist and eruptive fragments, which fact is characteristic of most of the Palelo rocks. The fragments of igneous rocks are mostly derived from augite-andesites, the felspar of which has often been albitized. The lavas of andesitic and also dacitic composition from which these fragments must have been derived were not found in the Palelo-series of the investigated region; lavas of the same types are however known to occur abundantly in the Palelo-series of the Mollo region (26).

Every pebble in the conglomerates can be derived from rocks, which

are known to belong to the crystalline schists and the Palelo-series, or can safely be assumed to be derived from these formations. We come therefore to the conclusion, that pebbles derived from sediments or igneous rocks, which are known to belong to the Keknenno-series, the Sonnebait-series or the Fatoe-complex, are absent from the upper Palelo conglomerates. This analysis of the Palelo conglomerates leads us therefore to the same result as TAPPENBECK, namely that the Keknenno-series, the Sonnebait-series and the Fatoe-complex were not exposed in the region, where the Palelo-formation was deposited in younger-Mesozoic time.

The age of the upper Palelo-series is partly fixed by its position below the overlying lower-Eocene sediments. The presence of the *Globotruncana*-fauna (*Globotruncana* spec., *Globigerina aequilateralis* BRADY, *Textularia* spec. and other small Foraminifera) in certain parts of the upper Palelo-series, points to an upper-Cretaceous age of these parts of the series (27).

No macro-fossils of any kind were found. In the Mollo region the find of numerous (probably Oxfordian) inocerams indicates an upper-Jurassic age for a certain part of the series.

Summarizing we may at least assume a younger-Mesozoic age for the greater part of the upper Palelo-series.

δ. Considerations on the Palelo-series.

As will be apparent from the preceding descriptions, the Palelo-series is composed of two distinctly different parts. The lower part consists essentially of radiolarian cherts, at the base of which sometimes occur volcanic breccias, associated with igneous rocks. The upper part of the series on the contrary is mainly composed of coarse clastic sedimentaries, which are for the greater part rich in volcanic and schist material. This part of the formation is comparable with the Palelo-series as described by TAPPENBECK from the Mollo region (26).

The radiolarian cherts of the lower Palelo-series are practically devoid of detrital material, but are solely built up of radiolarian shells, which lie in a siliceous and at the same time more or less calcareous and chloritic matrix. The cherts are further banded, with bands in different shades. The appearance of the cherts and the fact that no clastic material was found in them, while no clastic sediments alternate with them, seems to point to a sedimentation in deep (bathyal to abyssal) waters. In strong contrast to this is the pronounced clastic character of the overlying upper Palelo-series, which speaks clearly for a neritic and possibly even a littoral environment of sedimentation.

Besides these differences in facies there is also an important tectonical

difference between the lower and the upper Palelo-series. The folding of the very hard and at the same time very brittle cherts is in all sections in which they appear, inside as well as outside the Noil Toko fault trough, extremely intense (Plate II, fig. 2). Outside the Noil Toko fault trough the clastic Palelo-series on the other hand is far less influenced by tectonic forces. The contrast is not so pronounced in the Noil Toko fault trough, where younger movements have obscured the older tectonics.

It is furthermore certain that detrital material of both the crystalline schists and the lower Palelo-series occur as pebbles in the conglomerates of the upper Palelo-series. This proves that the crystalline schists, the lower and the upper Palelo-series belong to the same stratigraphical column.

The preceding observations are at present explained in the best way by assuming a stratigraphical gap between the lower and upper Palelo-series; in that case the upper Palelo-series disconformably overlies the lower Palelo-series and the crystalline schists. Then the strong folding of the lower Palelo-series can be explained as having taken place previous to the deposition of the upper Palelo-series.

It will be remembered (p. 12) that the crystalline schists were submitted to more than one post-crystalline deformation; one of these deformations is certainly pre-upper-Palelo-series. This could be deduced from the crystalline schist pebbles, occurring in the upper Palelo-conglomerates. It may be assumed, that the folding of the lower Palelo cherts took place during a pre-upper-Palelo deformation period. The following facts seem at least to be in accordance with this last supposition.

A considerable part of the crystalline schists of the Miomaffo is composed of low-metamorphic sedimentaries and basic igneous rocks. This is also found to be true for the crystalline schists of the Moetis and Mollo regions. For the crystalline schists in the latter region TAPPENBECK (26) pointed to the possibility, that "the low-metamorphic schists might be much younger than the higher metamorphic mica-schists and gneisses".

In the Moetis region DE ROEVER (21) found moreover locally (along the lower course of the Noil Besasi, near the trail Napak-Oilkaoet) layers of red chert, which seem to occur together with low-metamorphic crystalline schists (phyllitic quartzites with chloritic bands) in a strongly contorted zone.

It seems therefore not improbable that the lower Palelo radiolarian cherts belong to the same stratigraphical cycle as the low-metamorphic part of the crystalline schists. Another indication in this direction is

furnished by the occurrence of slightly phyllitic radiolarian cherts in the lower Palelo-series.

The lower Palelo cherts are then much older than the upper Palelo-series and the question of their geological age is, in view of the above, rather connected with the problem of the age of the crystalline schists and more especially with the low-metamorphic part of the crystalline schists.

TAPPENBECK (26) did not subdivide the Palelo-series of the Mollo region into two parts, because there was no need to do so, as radiolarian cherts in the Mollo region formed only a subordinate part of the total series. That author mentions them nevertheless several times as part of the Palelo-formation and particularly at the base of this series, which is also the normal case of occurrence in the Miomaffo region. The absence or scanty development of the radiolarian cherts in the Mollo region, however, may have a tectonic cause, as they may have been squeezed out. The radiolarian cherts may also have been eroded away in the Mollo region before the laying down of the clastic Palelo-series.

ε. Distribution of the Palelo-series.

The Palelo-series is disclosed along the whole eastern border of the Miomaffo and finds its continuation in the exposures in the Noil Koko, north of the Miomaffo complex, whereas south of the Noil Niti no outcrops are known. The eastern complex is also bordered in the west by an irregular strip of Palelo rocks, especially somewhat north of the Noil Poepmano. This strip wedges out to the north and disappears directly north of the Noil Noni, when definitely entering the Noil Toko fault trough.

Strong tectonic influences of post-Oligocene time were responsible for the remarkable lenslike outcrops of the Palelo-series (and other formations) in the Noil Toko fault trough (see map). Many formation-boundaries on the map are therefore at the same time planes of movement, which in the field are sometimes marked by breccia-banks and other crushing phenomena.

The best exposure of Palelo rocks occurs south of the eastern complex and has been described on a former page. The series here possesses a much less disturbed aspect; here we find at the same time the most complete development of the Palelo-series in the investigated region, although the lower Palelo-series here is only about 40 m thick. The greatest total thickness of the series is reached in this section and amounts to ± 350 m. This latter estimation is mainly applicable to the upper

Palelo-series, because the folding and faulting of this part of the series was not very intense.

Besides the occurrence in the Miomaffo region, which had already been indicated by petrographical descriptions by BROUWER (3), I found an occurrence of Palelo rocks at the eastern side of the eastern schist-complex, exposed in the Noil Nibifel, close to Fatoe Teke (see also p. 33).

The Palelo-series occurs in Timor at several other places, which are described in detail by TAPPENBECK (26). This author described the Palelo-series from the Mollo region, where this series reaches its largest known extension; from the Booi region, where the series continues into the Eocene and lastly from the Lalan-Assoe region.

In all these cases we find the following outstanding similarities:

1) The Palelo-series is always connected with crystalline schists on the one hand and with Eocene deposits on the other hand.

2) The facies of the series remains remarkably constant over large distances. A special characteristic of the series is the large content of volcanic material in all sedimentaries.

3) Albitization is a widespread phenomenon of the detrital material of the sediments and is to be observed e.g. in the lava pebbles of the Palelo conglomerates, but also in the isolated plagioclase-felspar fragments of the Palelo sedimentaries.

In other parts of the East Indian Archipelago similar deposits are found e.g. in the island of Halmaheira (6) and in the Southern arm of Celebes in the so-called Pangkadjene region (14). Both occurrences have been compared with the Palelo-series on Timor by TAPPENBECK (26).

The geological situation in the Pangkadjene region is especially of interest in comparison with that of the Miomaffo region. The crystalline schists of the Pangkadjene region occur in combination with ultrabasic rocks (serpentines). Apparently conformably with the crystalline schists, quartzites and cherty shales are found. The crystalline schists (+ quartzites and cherty shales) are disconformably overlain by a younger (probably Cretaceous) "clayshale-greywacke-arkose-sandstone" formation. This last formation is in its turn disconformably overlain by Eocene sediments. The combination crystalline schists and ultra basic rocks is also found in the Miomaffo region, while the radiolarian cherts of the lower Palelo-series might be compared with the quartzites and cherty shales. The upper Palelo-series is then to be considered as the equivalent of the "clayshale-greywacke-arkose-sandstone" formation. The association with Eocene sediments in both regions completes the similarity.

The region of Martapoera (S.E.-Borneo) also bears a striking resem-

blance to the Miomaffo region (15). The mutual connections between the different stratigraphical units are better disclosed in the Martapoera region. Although in the last-mentioned region more formations have been distinguished, we have broadly outlined a similar stratigraphical succession in the Miomaffo region, which fact is evident from the table of comparison on page 26. The age of the Alino-formation is unknown, but the formation shows many similarities to the Permian part of the Danau-formation of Central and N.W. Borneo (33). On the ground of this similarity a Permian age might be provisionally accepted for the Alino-formation.

The table of comparison (p. 26) is only to be used in a tentative way. Any definite conclusions as to the connections or geological age of the different units are to be discarded, because the two regions in question are geographically far too wide apart to allow of any such deductions.

c. The Sonnebait-series (younger-Mesozoic).

The series is mainly represented by the following deposits:

Red to red-brown cherts and radiolarian cherts, which are sometimes finely banded with bands in different shades:

Pink, violet, yellowish and greenish coloured, often cherty and at the same time marly, dense limestones:

Multi-coloured marls and clays, sometimes with detrital material and which may be wholly composed of Globigerinidae (W. 449).

More exceptional are yellowish, oolitic, usually finely conglomeratic and marly limestones (W. 252, W. 253, W. 433), which contain numerous specimens of *Globotruncana*. The conglomeratic material is largely derived from strongly decomposed igneous rocks, but angular quartz-grains are also present. The marly limestones may pass into conglomeratic limestones (W. 253). The latter contain e.g. also large fragments of *Globotruncana*-marls. Similar conglomeratic rocks of the upper-Cretaceous are described by SIMONS (25, p. 33) in the north-western part of Netherlands Timor.

The described rocks of the Sonnebait-series contain only for a certain part the upper-Cretaceous *Globotruncana*-fauna. Many of the rocks mentioned do not contain this fauna or any other fossils. It remains possible therefore that part of these rocks are of Jurassic or lower-Cretaceous age.

All rocks mentioned are severely crushed and brecciated as a clear proof of the strong tectonic movements to which the rocks were submitted. These movements often caused the forming of lenticles and an extensive

TENTATIVE TABLE OF COMPARISON.

MARTAPOERA REGION (S.E. Borneo).	MIOMAFFO REGION (Timor).		
Old-Tertiary Intrusive rocks. They are intrusive in all previous formations.	EOCENE. POST-UPPER-CRETACEOUS.	Old-Tertiary Intrusive rocks. Quartz-augite-albitites, and keratophyres. These rocks are intrusive into the crystalline schists and the Palelo-series.	EOCENE. POST-UPPER-CRETACEOUS.
Manoenggoel-formation. Partly sedimentary and partly volcanic facies. The former part is composed of conglomerates, sandstones, marls etc. The volcanic part of tuffs, tuff-sandstones, lavas etc., all of andesitic to dacitic character.	UPPER-CRETACEOUS.	Upper part of the upper Palelo-series. Greywackes, conglomerates, tuffs, tuffsandstones, marlstones etc. The tuffaceous material is mainly of andesitic and dacitic origin. The upper Palelo-series is fully comparable with the Manoenggoel-formation.	UPPER-CRETACEOUS.
Orbitolina bearing limestones. Only as detached blocks in the field, and as pebbles in the Manoenggoel-formation.	<i>unconformity</i> MID-CRETACEOUS.		
Plutonic ultrabasic rocks. Mainly peridotites; also pyroxenites, gabbros and diorites with their breccias; more acid varieties are plagioclase-granite and a granodiorite. The rocks are intrusive into the crystalline schists, the Alino-formation and the Panioengan layers.	LOWER-CRETACEOUS.	Plutonic ultrabasic rocks. Mainly serpentines and lherzolites. Probably intrusive into the crystalline schists.	?
Panioengan layers. Greenish to grey marly claystones, polymikt sandstones, marls etc. with Cyliindrites.	UPPER-JURASSIC or/and LOWER-CRETACEOUS. <i>unconformity</i> PERMIAN ?	Lower part of the upper Palelo-series. Greywackes, conglomerates, tuffs, tuffsandstones, marlstones etc.	UPPER-JURASSIC to LOWER-CRETACEOUS. <i>unconformity</i> PERMIAN ?
Alino-formation. Radiolarian cherts, hornstones, cherty shales, claystones, tuff-sandstones and volcanic breccias of an andesitic or diabasic character. Schist material occurs in some sedimentaries.	<i>unconformity</i> PRE-PERMIAN ?	Lower Palelo-series. Radiolarian cherts of different types, which are strongly folded.	<i>unconformity</i> or ↓ ? PRE-PERMIAN ?
Crystalline schists.		Crystalline schists.	

veining with calcite. Recrystallization of the rocks is also observed e.g. in the conglomeratic limestones (W. 252 $\times$, W. 252, W. 253).

Rocks of the Sonnebait-series are only scantily exposed in the Noil Toko fault trough. To the north, where the fault trough is widening, deposits of this series become gradually more important, while they seem to disappear under rocks of the Fatoe-complex to the south. Along the eastern border of the fault trough, a narrow strip of Sonnebait-rocks is exposed. They border (probably with a fault) in the west upon Eocene *Asterocyclina*-limestones and in the east upon upper-Triassic brachiopod-limestones of the Fatoe-complex. Farther south in the Noil Noni a small exposure of multi-coloured Sonnebait-marls is found (section I) and still farther south, slightly north of the Noil Poepmano, occur a few small, lenticular outcrops of the typical pink coloured, somewhat marly limestones as indications of the underlying Sonnebait-series.

The Sonnebait-series appears again in the upper course of the Noil Poepmano in the west. The rocks here are clearly emerging from under the young-Tertiary deposits in the north.

III. TERTIARY.

The Tertiary occupies an important part of the investigated area and especially the young-Tertiary is extensively developed.

The Foraminifera-faunas, which were found in the different rocks, made a subdivision possible. Good sections, however, in which the stratigraphical relations between the different stages could be studied, are lacking in the mapped area, as a consequence of the strong tectonic disturbances to which the different deposits were submitted. The stratigraphy is therefore made on the base of correlation with similar deposits found in other parts of Timor where more complete sections occur as e.g. in the Mollo-, Booi- and Lalan-Assoe-regions (26).

Especially important for the determination of the Foraminifera of both the old- and young-Tertiary is the publication of HENRICI (13). This author gives also several short petrographical descriptions of different Tertiary rock-types, which were collected from the mapped region during previous investigations of the expeditions under leadership of WANNER and MOLENGRAAFF.

The Tertiary is subdivided in old-Tertiary and young-Tertiary.

a. Old-Tertiary.

The subdivision used is the same as the one used by TAPPENBECK (26).

Paleocene deposits were not found in the Miomaffo region, which is in accordance with the fact that deposits of this age have up till now nowhere been found in Timor.

Eocene deposits are subdivided in lower-, middle- and upper-Eocene deposits. In this subdivision¹⁾ we have the lower-Eocene as the equivalent of the upper-part of Tertiary a_1 , middle-Eocene equivalent of Tertiary a_2 , upper-Eocene equivalent of Tertiary b . All stages occur in the mapped area.

Oligocene deposits (substages c and d) are wanting in the Miomaffo-region, as is the case elsewhere in Timor.

The old-Tertiary is therefore in the Miomaffo region only represented by Eocene deposits; they occur mostly as disconnected outcrops. The

¹⁾ The subdivision in stages is the one propagated by VAN DER VLERK and LEUPOLD (29).

only exception to this rule is formed by a narrow strip of lower-Eocene *Alveolina*-limestones and marls, which occur along the greater part of the eastern border of the Miomaffo complex. These limestones and marls appear always to be connected with the Palelo-series.

a. Lower-Eocene (upper T_{a_1}).

The lower-Eocene is mainly represented by dark coloured, brown or violet limestones, marly limestones and marls, which often contain a rich Foraminifera-fauna. Limestones and marls totally devoid of Foraminifera occur however as well. It is moreover clear that the rocks in question must have been formed close to the shore, as they are sometimes full of coral-reef material, thick-shelled molluscs and other organisms. In this way they may even become totally built up of reef-organisms. Detrital material is scarce. The rocks are frequently crushed and brecciated, in that case showing extensive veining with calcite. The pressure also caused the hard limestone banks to break and to form isolated lenticles in the soft marls.

The rocks are very conspicuous in the field, because of their often dark violet colour. The weathering out of the *Alveolinas* as small spindle-like bodies on the surface of the limestone is also a characteristic feature of these rocks. Many of the limestones are real Foraminifera-limestones (*Alveolina*-limestones). They are in that case full of the foraminiferan *Fasciolites oblonga* D'ORB. The usual fauna of these limestones consists of numerous *Fasciolites oblonga* D'ORB, Miliolidae, Textularidae and mostly a few specimens of *Sorites* spec. Corallogene material is often abundant. HENRICI (13) mentions moreover *Orbitolites complanata*, *Amphistegina* spec. and *Lithothamnium*.

Associated with the *Alveolina*-limestones marly limestones and marls full of *Camerina crasseornata* HENRICI occur. *Alveolina*-limestones and *Camerina*-marls are seen to alternate with each other. Notwithstanding this fact, *Fasciolites oblonga* is lacking in the *Camerina*-marls and reversedly *Camerina crasseornata* is lacking in the *Alveolina*-limestones¹⁾.

In the Noil Toko region HENRICI (13) described the same *Alveolina*-limestones and *Camerina*-marls mentioned, apart from each other without knowledge of the connection which exists between them in the field. He was therefore not able to assign a more definite age to *Alveolina*-

¹⁾ HENRICI determined in his specimen 26, which corresponds with my own specimen W 182X, the following micro-fauna: very numerous *Camerina crasseornata*, less numerous *Discocyclina pygmaea* HENR., many Miliolidae and other small Foraminifera and also small corals and molluscs.

limestones and *Camerina*-marls separately as "probably lower-Eocene (Yprésien)". This difficulty does now no longer exist, since we found the *Alveolina*-limestones and the *Camerina*-marls alternating with each other in the field; the joint occurrence proves namely the lower-Eocene age of the marls and limestones.

The dark coloured lower-Eocene limestones and marls are always found in close connection with the upper Palelo-series. No transgression conglomerate was found, but strong tectonic movements, especially in the Noil Toko fault trough, obscured much of former stratigraphical connections. The deposits can be followed along the eastern border of the Miomaffo schist-complex as already stated above, while isolated outcrops occur in the Noil Koko, north of the Miomaffo, and at the southern border of the eastern schist-complex, exposed in the Noil Noni.

The occurrence in the Noil Koko is especially rich in corals, thick-shelled molluscs and other reef-organisms. Especially the marls are very rich in fossils.

The *Alveolina*-limestones in the Noil Noni, south of the eastern schist-complex, are sometimes moderately rich in detrital material and they may become more or less crystalline. The connection with the Palelo-series is in this case not so obvious as usual.

β . *Middle-Eocene* (T_{a_2}).

At several localities in the Miomaffo region were found light coloured, yellow to beige marls, marly limestones and limestones. They are frequently found in the neighbourhood of the dark coloured *Alveolina*-limestones, as described on a previous page. No actual stratigraphical sequence between the two kinds of deposits was however observed.

The rocks in question usually contain a rich micro-fauna, but no macro-fossils. The micro-fauna consists mainly of uninforming Miliolidae, Textularidae and sometimes Radiolaria, while in one case only two species of *Camerina* — *Camerina bagelensis* VERB. and an unknown species of *Camerina* — were found. The occurrence of *Camerina bagelensis* VERB. alone is not sufficient to fix the age of the deposit. TAPPENBECK found however lithologically quite similar marly limestones with *Camerina bagelensis* VERB., intercalated between the middle-Eocene *Alveolina*-limestones of the Mollo region. We therefore place the rocks in question provisionally in the middle-Eocene. HENRICI (13) places rocks with *Camerina bagelensis* in the middle- or upper-Eocene.

The best exposures of the described rocks occur in the Noil Saen and in the Noil Noni, both south of the eastern schist-complex.

In the Noil Saën these rocks are seen in tectonic contact with sedimentaries of the Palelo-series. The rocks in question are well-stratified light yellow, sometimes very hard limestones and marly limestones, with intercalated beige marls. The whole sequence is steeply dipping to the south. The limestones contain a rich micro-fauna of Globigerinidae and few Radiolaria and also numerous sponge spicules.

In the Noil Noni several small exposures of marls and marly limestones with *Camerina bagelensis* VERB., were found. They appear to be intercalated between greywackes of the younger-Mesozoic upper Palelo-series. Strong tectonic movements must here have caused a kind of imbricated structure. Other similar occurrences are found in tributary No. 13 and in the Noil Koko.

A small outcrop of middle-Eocene rocks, together with upper-Eocene rocks, remains to be mentioned from the Noil Toko fault trough (see also p. 35).

γ. Upper-Eocene (T_b).

A totally different facies of Eocene rocks occurs at one locality on the map, namely shortly south of the Fatoe Oenoep. The small isolated occurrence is surrounded by rocks of different age and probably does not represent the real country rock. It is nevertheless mentioned, because it is the only occurrence of this kind found in the mapped area. The outcrop consists mainly of green marly tuffs, brown tuff agglomerates and breccias, which are partly very coarse. The more conglomeratic tuffs contain a Foraminifera-fauna, which consists of *Discocyclina* spec., often of large dimensions, small *Camerinae* and coral fragments. Schist material was not observed in the rocks of this outcrop.

The most important occurrence was found outside the mapped area, in the vicinity of the village Fatoe Teke, situated close to the N.E.-extremity of the eastern schist-complex. The series consists here for the greater part of tuffs, tuff agglomerates and breccias, limestones and greywackes, which are rich in volcanic material. The volcanic material is mainly of an andesitic character, while much volcanic glass, often chloritized is also present. The rocks are usually dirty yellow, brown and green. The yellow and brown colours originate from iron-compounds and the green colours from the chloritic substance. The Foraminifera-fauna, which characterizes these rocks is the same as mentioned above.

This second occurrence is of much greater importance, because in this case the age of this volcanic rock series could be definitely established. In a section, which is exposed in the Noil Nibifel (fig. 1), this series

is namely overlain by light yellow *Discocyclus*-marls and -limestones (with *Discocyclus* spec., *Pellatispira* spec., *Camerina* spec.), which are

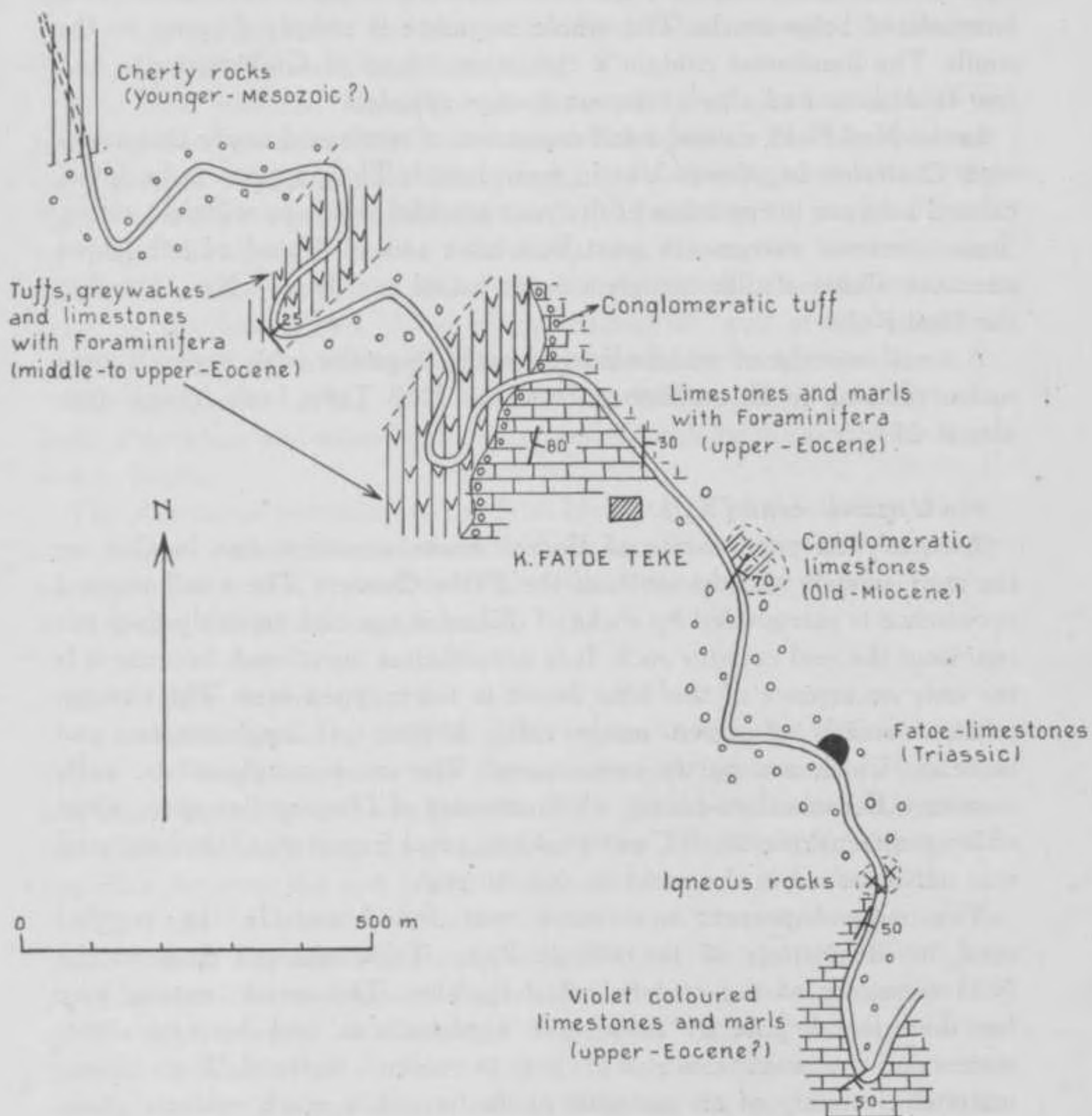


Fig. 1.

Location of several outcrops of Eocene rocks of diverse facies in part of the middle course of the Noil Nibifel.

certainly of upper-Eocene (T_b) age. The absence of volcanic material in the *Pellatispira*-limestones and -marls, is very remarkable, and points to a lapse in the volcanic activity. Between the volcanic series and the

upper-Eocene rocks occurs a transgression conglomerate, which is composed of volcanic fragments. The development of the volcanic series here is partly very similar to that of the sedimentaries of the upper Palelo-series. The only difference is, that schist material is always present in much smaller quantities with regard to the volcanic material. A certain calcareous and tuffaceous greywacke (W. 381) contains small *Discocyclina* spec. and *Camerina* spec., Miliolidae, Textularidae and many other small Foraminifera. The section continues upstream after a badly exposed part, in hard, dark coloured cherts and dark coloured shales, which probably represent the younger-Mesozoic Palelo-series in this area. Finally the crystalline schists of the eastern complex are reached.

The different transitions of the crystalline schists to the Palelo-series and of the Palelo-series to the Eocene are not exposed and therefore could not be examined. It is however quite possible that the lower-Eocene (a_1) is here also present between the Palelo-series and the middle-Eocene (a_2), although this could not be established in this section.

The presence of schist material, of albitized felspar fragments and of fragments of volcanic rocks in the sedimentaries of the volcanic series, are also characteristics of the sedimentaries of the Palelo-series (see p. 24). They are lithologically quite similar to the Palelo sedimentaries, as already stated. It therefore seems a safe conclusion to see in the described Eocene volcanic series the stratigraphical continuation of the Palelo-series into the Eocene. I came therefore to the same result as TAPPENBECK in the Booi-region (26), where the exposures are much better than in the Noil Nibifel. On the ground of the enclosed fauna (*Discocyclina*) the age of this volcanic series may be middle- to upper-Eocene. In view of what is found in the Noil Nibifel, where the volcanic series is overlain by the certainly upper-Eocene *Pellatispira*-bearing limestones and marls (see also below), it seems safe to conclude, that the volcanic series is for the greater part upper-Eocene and possibly partly middle-Eocene. The lacking of *Pellatispira*, however, is according to HENRICI (13), an argument against an upper-Eocene age of a part of the series. But the absence of *Pellatispira* in the volcanic series and the sudden appearance of *Pellatispira* in the overlying limestones and marls, may be also explained by the sudden change in facies.

The same volcanic series has also been found west of the line Nefoneoe-Noil Bianè and is here described by VAN VOORTHUYSEN (30). A similar Foraminifera-fauna, also with *Discocyclina* spec., occurs in the rocks of this series.

It seems therefore clear that this Eocene volcanic series has a much

larger extension than hitherto suspected. This proves at the same time a strong volcanic activity during a great part of the Eocene in large parts of the island, which apparently ceased at the deposition of the upper-Eocene *Pellatispira*-limestones and -marls.

To the upper-Eocene belong also whitish to yellowish reef-limestones and marls full of *Pellatispira*, *Discocyclus* and *Camerina*. Rocks of this kind occur at many localities in the mapped area as detached blocks of sometimes large dimensions ($5 \times 5 \times 15$ m).

The reef-limestones often are sedimentary breccias. The Foraminifera-fauna is very rich and consists of: *Pellatispira inflata*, *Pellatispira crassicolumnata*, *Discocyclus javana* (A and B form), *Discocyclus dispansa*, *Discocyclus pygmaea*, *Camerina* spec., Miliolidae, many other small Foraminifera and corallogene material. *Discocyclus* is frequently the most abundant genus, but *Pellatispira* may also become very important and sometimes is the only type of foraminiferan present. In this last case we sometimes see a simultaneous increase in reef organisms and material.

All occurrences of these rocks are situated on the slope south of the Miomaffo. Several large blocks are found along the footpath from Noil Toko to Seoam. The largest blocks occur along the tributary No. 4 to the Noil Niti.

It is clear from the section in the Noil Nibifel (see fig. 1) described on a previous page, that these upper-Eocene limestones and marls are transgressive on the volcanic series. The upper-Eocene rocks of the Noil Nibifel are in every respect the same as the upper-Eocene rocks in the mapped area.

Another type of rock, which is believed to belong to the upper-Eocene are the *Asterocyclus*-limestones. The rocks in question are moderately marly, brownish yellow, sometimes very hard and homogeneous limestones, which contain besides a mostly uninforming micro-fauna of many Globigerinidae and some Radiolaria, also numerous sponge spicules. The only foraminiferan of importance belongs to a species of *Asterocyclus*, which is exactly the same species as described by TAPPENBECK (26) from the *Asterocyclus*-limestones of the Lalan-Assoe region and which he compared with *Orthocyclus soeroeanensis*. The complete resemblance was established by a comparison of the slides concerned, which comparison revealed at the same time the petrographical similarity of the rocks in question. TAPPENBECK placed the *Asterocyclus*-limestones in the upper part of the upper-Eocene (T_b) and above the just described *Pellatispira*-*Discocyclus*-*Camerina*-limestones. It should be noted however

that direct stratigraphical evidence to confirm the latter assumption beyond doubt seems to be lacking as yet.

The *Asterocyclina*-limestones occur in two large lenticular outcrops in the centre of the Noil Toko fault trough and also in a small isolated outcrop situated between the two former outcrops close to the border of the eastern schist-complex.

The most northerly of the two large outcrops occurs along the motor-road from Noil Toko to Kefamenanoe. The limestones in question occur here together with light violet coloured marls. The small lenticular outcrop is composed of *Asterocyclina*-limestones (W. 453^x), light yellow reef-limestones only with *Pellatispira* (probably *T_b*, W. 452) and reddish-brown marly Foraminifera-limestones with *Camerina perforata* A, *Discocyclina pygmea* and some fragments of *Fasciolites* spec. (probably *T_{a2}*, W. 452^x).

The stratigraphical connections between the limestones mentioned are not clear, because of the strong tectonic movements, which affected them.

Only one specimen from the vicinity of Noil Toko was described by HENRICI (13), which possessed a probable upper-Eocene age. This rock does not correspond with any of the rocks discussed here. The specimen in question is a dense dark grey, brittle, somewhat crystalline limestone with many small Foraminifera and Radiolaria, *Lithothamnium* spec. and sections of *Discocyclina ? pratti*.

There remains to be mentioned a conglomerate (W. 316^x), which was found as a detached fragment close to the spot where tributary Nr. 2 joins the Noil Niti. This conglomerate consists mainly of quartziferous fragments, lying in a calcareous matrix. Most fragments are of pure quartz, often with strain-shadows and crushed; also of quartzitic schists, radiolarian cherts, dacitic and andesitic rocks, felspar and other undefined fragments. Of special interest are fragments of the same *Alveolina*-limestones (*T_{a1}*) as described in the first part of this section. These fragments contain sections of *Fasciolites* spec. The Foraminifera-fauna which occurs in the calcareous matrix between the fragments is composed of *Discocyclina* spec., *Camerina* spec. and *Pellatispira* spec. (probably *T_b*).

b. Young-Tertiary.

The young-Tertiary deposits in the mapped region are well represented by a rather thick series of conglomeratic limestones, *Globigerina*-limestones, conglomerates, marls, clays, tuffs and calcareous tuffs. The

rocks are all very light coloured, mostly white, sometimes rose and also frequently greenish to yellowish. The conglomeratic limestones and the rose to white *Globigerina*-limestones are lithologically quite different from the other rocks of the series. They are the only hard and at the same time the most conspicuous rocks. The marls, clays, tuffs and tuff-marls are all pretty soft; many of them are chalky and come off white.

The young-Tertiary rocks overlie all the other formations of the region disconformably. They usually begin with the conglomeratic limestones, already mentioned from Noil Toko by WANNER (31) and described by HENRICI (13).

a. Conglomeratic limestones and Globigerina-limestones.

The conglomeratic limestones contain various quantities of conglomeratic material of different size and we have therefore all transitions from practically organogene limestones to coarse, multi coloured conglomerates with a calcareous cementing substance. The fragments of the conglomerates are mainly derived from crystalline schists (amphibolites, graphitic mica-schists, mica-schists) and of volcanic rocks (andesitic to dacitic); less frequent are fragments of Mesozoic and old-Tertiary (Eocene) limestones and radiolarian cherts.

The micro-fauna consists of *Spiroclypeus* spec., small *Lepidocyclina* spec. (several species), *Cycloclypeus* spec., *Miogypsina* spec., small Foraminifera and often *Lithothamnium*. The conglomeratic limestones are therefore undoubtedly of a lower old-Miocene age (T_e). The same rocks were described by TAPPENBECK from the Booi and Lalan-Assoe regions. They occur there, as in the mapped area, at the base of the old-Miocene (Beboeloeh transgression).

It is a remarkable fact, that the conspicuous conglomeratic limestones are found along the whole eastern side of the Noil Toko fault trough whereas they are lacking on the opposite side. There we find *Globigerina*-limestones instead of the conglomeratic limestones at the base of the old-Miocene rocks, over a distance of several hundreds of metres. The *Globigerina*-limestones contain a micro-fauna of Globigerinidae, which do not allow us to fix their age. They are lithologically quite similar to certain *Globigerina*-limestones of the Cretaceous of the upper Sonnebait-series and in fact are not easily distinguished from the latter in the field.

The following arguments seem however to justify the conclusion that the *Globigerina*-limestones in question do indeed belong to the young-Tertiary series.

1. In section I, exposed in the Noil Noni, there exists a gradual stratigraphical transition of the *Globigerina*-limestones to the tuff-marls of the young-Tertiary series (see also fig. 2).

2. The *Globigerina*-limestones are always found to be in direct contact with rocks of the young-Tertiary series.

Moreover the *Globigerina*-limestones sometimes contain thin conglo-

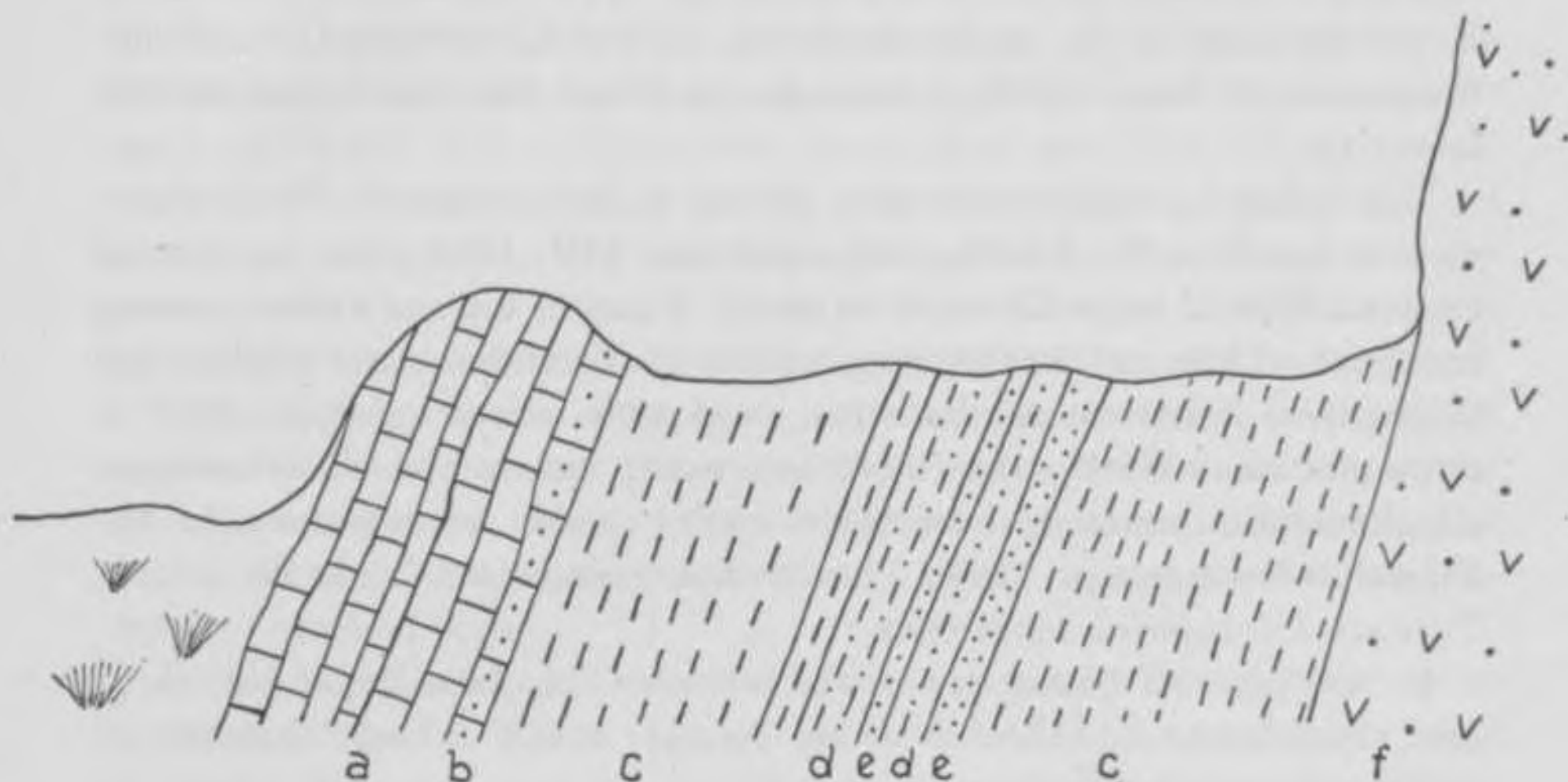


Fig. 2.

The gradual transition of the *Globigerina*-limestones into the other rocks of the young-Tertiary series is shown in the figure above.

The succession is as follows: Salmon coloured to greenish white hard, dense, *Globigerina*-limestones, which show many round globules of Globigerinidae on their fracture surfaces. The cementing substance is of a marly composition (a).

Greenish white *Globigerina*-limestone, almost the same as the preceding rocks. The cementing substance is of a more clayey character. Many small mineral fragments, although still in a very subordinate quantity make their appearance (b).

Light green marls, which contain some Radiolaria, sponge spicules and in larger quantity Globigerinidae. Under the microscope we see moreover very thin layers, which are relatively rich in large *Globigerina* shells and mineral-fragments. The mineral-fragments are mainly of volcanic origin. The cementing substance is very clayey (c).

Light green *Globigerina*-marl, with a certain content of mineral-fragments, also mainly of volcanic origin (d).

Light green, distinctly stratified *Globigerina*-marl. The rock is rich in volcanic material, which is mainly concentrated in thin layers (e).

Calcareous tuff, which certainly belongs to the young-Tertiary series (f).

The proportionate quantity of volcanic material has increased from the lower to the higher parts of this series.

meratic layers, which are mainly composed of volcanic material; schist material is also present in minor quantities (W. 182). The petrographical characteristics of both the volcanic and schist fragments are similar to those found as fragments in the conglomeratic limestones.

The mentioned occurrence of thin conglomeratic layers with detrital material in the *Globigerina*-limestones is an indication that the sedimentation of these rocks took place in an open sea not far from land. BROUWER came to the same conclusion for the Cretaceous *Globigerina*-limestones of Rotti, which sometimes contained also thin conglomeratic layers (5).

The following observation also points in this direction. The conglomeratic bands in the *Globigerina*-limestones (W. 182) show an unusual concentration of large *Globigerina* shells¹⁾ and at the same time a strong reduction of the marly cementing substance. The other parts of the same *Globigerina*-limestone on the other hand show about equal numbers of large and small *Globigerina* shells in a marly matrix and almost without conglomeratic material. SCHUBERT made similar observations in the Bismarck-Archipelago (24). This author found two kinds of young-Tertiary *Globigerina*-limestones.

1. *Globigerina*-limestones in which occur Globigerinidae of both large and small forms (adult and young forms), within a large quantity of clayey cementing substance.

2. *Globigerina*-limestones in which the Globigerinidae are only represented by large forms, while the cementing substance is very subordinate.

SCHUBERT compares the first type with the recent *Globigerina* ooze, formed in the deeper parts of the sea. The second type is considered to be an abnormal sediment, which possibly originated in shallow water, close to the shore. The sorting influence of the surf is considered to be responsible for the homogeneity of the sediment and the accumulation of the larger and heavier *Globigerina* shells.

In the specimen W. 182 the two sedimentation conditions of the types 1. and 2. are combined. This proves that the two types of *Globigerina*-limestones distinguished by SCHUBERT may originate at about the same depth, in our case most probably a shallow depth.

β. The other rocks.

The conglomeratic limestones and *Globigerina*-limestones form only a subordinate part at the base of the series. The larger remaining part is

¹⁾ Some shells of *Orbulina* and *Miliolidae* are also present.

composed of tuffs, calcareous tuffs, conglomerates, marls and green clays. The tuffaceous rocks seem to increase in importance in the higher portions of the series, the conglomerates in the lower portions of the series, while the green clays seem to occur throughout the series. Many of the rocks are rich in volcanic material, which points to a strong volcanic activity during young-Tertiary-time. The richness in detrital material, which is another characteristic of the sedimentaries of this series, speaks in favour of the nearness of land. On the other hand, the occurrence of the *Globigerina*-limestones and the marls with Radiolaria and Globigerinidae speak in favour of a sedimentation in an open sea. The last mentioned rocks however seem to occur mainly in the lower part of the series and in the western parts of the Noil Toko fault trough. The thickness of the series is difficult to estimate, because it is strongly disturbed. From section II a rough estimate of a thickness of 250 metres might be deduced.

The compressive post-Oligocene movements undoubtedly reduced the original distance between the respective places of sedimentation of the conglomerates in the east and the *Globigerina*-limestones in the west. The movements also caused the origination of many faults with the development of crushed zones.

In a general way we may say, that the young-Tertiary series, as exposed in the Noil Niti (section II) and Noil Noni (section I), was evidently deposited in a sea, which became gradually deeper from E. to W. This conclusion is based on the nature and grain-size of the sedimentaries. Conglomerates are e.g. very abundant in the east, marls, clays and *Globigerina*-limestones in the west.

γ. Age of the rocks.

The lower part of the series is of old-Miocene age (T_e), as proved by the Foraminifera of the basal conglomeratic limestones. Thin banks of fine conglomeratic limestone are sometimes intercalated in the lower parts of the series. In the higher parts of the series these banks are lacking and the other rocks are devoid of all fossils. It is therefore not impossible that the higher parts of the series are younger than old-Miocene.

δ. Distribution of the young-Tertiary rocks.

The young Tertiary-series has its largest extension south of the Miomaffo and north of the Noil Poepmano. West of the footpath from Noil Toko to Seoam, we see the young-Tertiary rocks covered by blocks of all kinds and sizes, which must have rolled down the steep slope in the south. The Fatoe Oenoep is situated partly on young-Tertiary rocks and

partly on the crystalline schists, and is believed to have reached its present situation also by gliding (9). Noteworthy are the small outcrops of rose and white *Globigerina*-limestones, which occur along the southern border of the Miomaffo schist-complex.

The young-Tertiary rocks continue north of the Noil Niti, squeezed in between the two complexes. They become gradually less important in a northerly direction and finally are practically absent, probably because they have been eroded away.

The described young-Tertiary series is widely distributed in Timor. This series is particularly well-developed in the Lalan-Assoe and Booi regions (26). Here the rocks are well exposed in several sections; here too, they begin with the conglomeratic limestones, which are sometimes of a very coarse character. This facies seems to be of much greater importance in these regions than in the Miomaffo region, while on the other hand the *Globigerina*-limestones are only found in the latter region. The abundance of tuffaceous rocks in all cases is a clear indication of young-Tertiary volcanism.

The young-Tertiary rocks of the Lalan-Assoe and Booi regions were only slightly folded and mostly only faulted and brecciated. In the Miomaffo region the young-Tertiary rocks are on the contrary strongly influenced by tectonic movements, as a result of post-Oligocene movements.

Several other occurrences from Timor are described by TAPPENBECK (26). That author also made a comparison with similar deposits in other islands of the Timor-Archipelago (e.g. Soemba, Letti).

IV. THE IGNEOUS ROCKS.

In the investigated region the igneous rocks are not so important in comparison with the crystalline schists and the sedimentary rocks. A certain part of the igneous rocks is found to be intrusive into the crystalline schists and the Palelo-series. The remaining igneous rocks are all found outside the crystalline schists and the Palelo-series and occur as isolated outcrops, while the connections with their surroundings are always influenced by tectonic movements. Their tectonic position seems to be between the upper part of the Sonnebait-series and the Fatoe-complex.

All the igneous rocks of the Miomaffo region, except the gabbros, the lherzolites and the serpentines, are rich in albite.

In many respects they show great similarity to the igneous rocks, described by DE ROEVER as "Ophiolite-spilite-complex" in the Moetis region (21).

a. Rock-types and distribution.

The following igneous rock-types were found:

1. Gabbros.
2. Lherzolites and serpentines.
3. Quartz-albitites.
4. Albite-diabases.
5. Keratophyres.
6. Spilitic rocks.

The distribution of the various rocks will be briefly described in the same order.

1. A small outcrop of *gabbroid rocks* is found along the motorroad from Noil Toko to Kefamenanoe. The rocks are here seen to border in the east on rocks of the Sonnebait-series. On the west side many detached blocks of fatoe-limestones are found, which obscure the actual contact that may exist between the igneous rocks and fatoe-limestones.

2. A large body of *lherzolites and serpentines* occurs in contact with the crystalline schists of the Miomaffo. They build up the smaller, western part of this mountain. The crystalline schists are dipping to the east and are seen to disappear under the crystalline schists of the Mio-

maffo. The nature of the contact is not clear, but it is believed, that the ultrabasic rocks are intrusive into the crystalline schists as will be discussed on a later page.

Serpentines were also found as a small outcrop in the central Noil Toko fault trough in the midst of rocks of the Fatoe-complex, and again as a small ridge running N 30° W, which emerges from under the Fatoe Seinaam (outside the map).

3. Dykes of *quartz-augite-albitites* occur at several places in the crystalline schists and in the Palelo-series. Some of them were found in the Noil Noni, downstream from Noil Toko; one in the crystalline schists and the other ones in the Palelo-series. Two further occurrences were found in the Noil Poepmano, also one in the Palelo-series and one in the crystalline schists. Another dyke was found in the Noil Boé in the crystalline schists.

All the examples are of the same mesocratic rock type. They differ only in grain-size and in grade of decomposition. The rocks in question belong to a later stage in the volcanic activity, because they cut also through the entire upper Palelo-series, which is largely composed of volcanic material. Contact-metamorphic phenomena were not found.

BROUWER (3) described similar dyke-rocks, which were also collected in the Noil Noni, downstream from Noil Toko. The felspar of one of these rocks is a plagioclase, which has partly the composition of andesine. This is a strong indication that the albite of the quartz-augite-albitites is to be considered as of secondary origin.

The dykes in the Noil Noni, are shown in fig. 3. It is clear that these dykes must have been intruded during and after the folding of the Palelo-series.

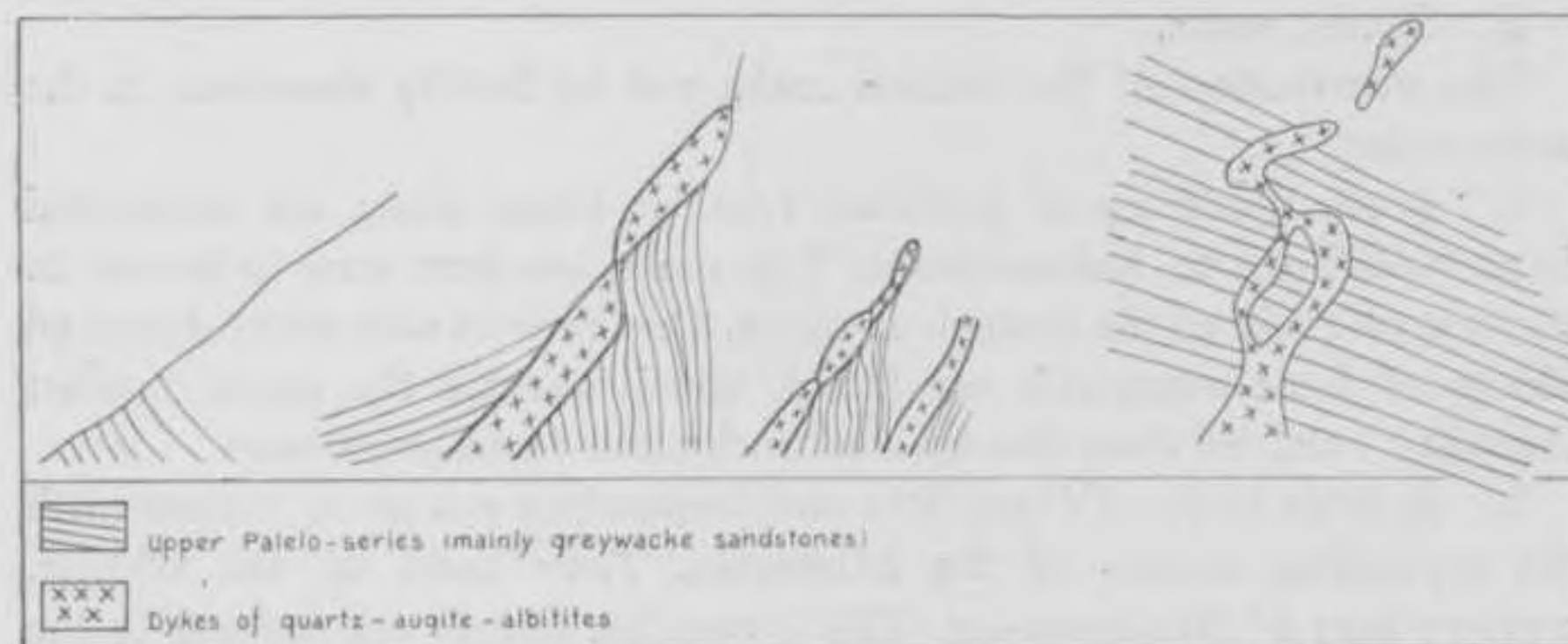


Fig. 3.

Quartz-albitites associated with a more basic (probably albite-diabasic) type, occur along the path from Noil Toko to Seoam. The rocks here occur in direct contact with black, slightly silky phyllites, which are clearly more or less contact-metamorphic; small knots of carbonaceous material have originated in a micro-crystalline, phyllitic groundmass of white mica, felspar and quartz. These rocks occur amidst upper-Triassic brachiopod-limestones of the Fatoe-complex.

Quartz-amphibole-albitites are found as composing fragments of the volcanic breccias at the base of the lower Palelo cherts (p. 84).

4. *Albite-diabases* were found in the Noil Noni, together with the volcanic breccias described on page 17. They seem to occur here at the base of the lower Palelo-series, in which they are probably intrusive. Strong tectonic movements rendered the dark green rocks slightly schistose and obscured the nature of the contact with the surrounding rocks. The same albite-diabases, only sometimes somewhat coarser grained, occur also as composing fragments of the volcanic breccias (p. 92).

A totally different type is a *porphyritic albite-diabase* (probably an albitized porphyritic dolerite), which occurs under the Fatoe-limestones of the Fatoe Seoam.

5. Sill-like intrusions of *keratophyres* occur in the Noil Niti, close to where tributary Nr. 5 joins the Noil Niti and in tributary Nr. 5 itself (fig. 6).

The keratophyres are clearly conformably intercalated between the graphitic phyllites, graphitic arkoses, quartz-carbonate-rocks etc. of the Miomaffo schist-complex. The igneous rocks in question are all more or less crushed and may even become distinctly schistose. In one instance a crush-breccia of a keratophyre and a quartz-carbonate rock was found, which occurs along a plane of movement.

Quite different types of keratophyres and quartz-keratophyres are found as composing fragments of the volcanic breccias, at the base of the lower Palelo cherts (p. 18). These rocks are especially rich in quartz.

6. *Spilitic rocks* are found in contact with the Fatoe Kesnaam. They are porphyritic spilites. The rocks in question are clearly disappearing under the fatoe-limestones, which occur north of the outcrop, while they rest upon multi-coloured marls of the upper Sonnebait-series.

A small outcrop of spilitic rocks occurs a little north of the Noil Poepmano and close to the western border of the eastern schist-complex. The rocks in question are strongly crushed and very much decomposed.

Finally we find spilitic rocks again as fragments in the volcanic breccias

already mentioned several times. These are often porphyritic. They are quite different from the earlier mentioned types.

b. Age of the igneous rocks.

Of all known igneous rocks in the region, only certain types (e.g. quartz-augite-albitites, keratophyres) are found to be intrusive into the crystalline schists and the Palelo-series. No intrusive contacts of igneous rocks with any of the other formations occurring in the region, have been found. It is therefore possible to say more about the age of the igneous rocks which occur in association with the crystalline schists and the Palelo-series, than about the age of the other igneous rocks, which are found outside these formations.

a. The igneous rocks in contact with the crystalline schists and the Palelo-series.

To this group of igneous rocks belong the dykes of quartz-augite-albitites, certain keratophyres, the albite-diabases with their associated volcanic breccias and the ultra basic rocks of the Miomaffo schist-complex.

The dykes of quartz-augite-albitites are intrusive into both the crystalline schists and the lower and upper Palelo-series. The upper part of the Palelo-series is partly of Cretaceous age (p. 21). The dykes in question have therefore a Cretaceous to post-Cretaceous age. The age of the sill-like keratophyres is more difficult to fix, because these rocks are only found to be intrusive into the crystalline schists. They are therefore at least post-crystalline-schists. They are related to the quartz-augite-albitites and may be of about the same age. The albite-diabases occur together with their volcanic breccias at the base of the lower Palelo-series. It could not be established whether these volcanic rocks are extrusive or intrusive in the lower Palelo cherts. They are considered to be at any rate of post-metamorphic age.

The most conspicuous body of igneous rocks, which occurs associated with the crystalline schists, is formed by the ultra basic rocks of which the smaller western part of the Miomaffo ridge is composed. As has already been stated before, no certainty as to the nature of the contact (intrusive or tectonic) was obtained in this case.

The following observations and facts may however be used as converging evidence that the ultrabasic rocks are intrusive into the crystalline schists.

The first important argument is furnished by the fact that albite-rich intrusives are breaking through the crystalline schists and the overlying Palelo-series. We may furthermore assume that the ultrabasic rocks and these albite-rich rocks — including the volcanic breccias which are exclusively composed of fragments of albite-rich rocks — are to be considered as differentiates of a common magma. This magma must in that case have been rich in sodium, apart from the fact whether the albite of the rocks in question is of primary or secondary origin (albitization). As has been pointed out by many authors the alkali content of the undifferentiated ultrabasic magma is demonstrated in the course of its differentiation. The consecutive order of intrusion is usually: serpentines (peridotites, pyroxenites etc.), gabbros, diabases (albite-diabases) and basalts (spilites). A good example of such a magmatic assemblage in the island of Timor is furnished for instance by the "Ophiolite-spilite-complex" of the Moetis region (21).

The more acid derivatives as albitites, keratophyres etc., although rarer of occurrence, are nevertheless to be considered as characteristic for such a magmatic suite (10).

In the Miomaffo region the origination of these albite-rich rocks must in my opinion be seen in direct relation with the mass of ultrabasic rocks of the Miomaffo, in which case the ultrabasic rocks are to be considered as intrusive into the crystalline schists as well.

Apart from the argument expounded above, additional arguments which accentuate the assumption of the post-metamorphic intrusive nature of all the igneous rocks of the mentioned magmatic suite, can be given.

A characteristic feature of the crystalline schists of the Miomaffo namely is the presence of the group of the "prehnite-albite-zeolite" veins. This group of veins occurs in many schist types, independent of the metamorphic stage to which a given type belongs and independent of its composition. It was also observed in several igneous rocks (e.g. albite-diabases). Prehnite, albite and zeolites may each fill a vein separately, and especially prehnite-veins are abundant. Besides the minerals mentioned, the vein-filling may contain the minerals quartz, analcite and pyrite. More rare are datolite-carbonate veins, which are also reckoned to belong to the same group.

The group of "prehnite-albite-zeolite" veins is also observed in the crystalline schists of the Moetis and Mollo regions, while they are also mentioned from the igneous rocks of the Moetis region. They are in every respect the equivalents of the veins in the crystalline schists of the Miomaffo. We may therefore safely attach a more regional significance

to this group of veins and they may probably be considered as a general petrographical feature of the crystalline schists of Timor. The uniform character and the widespread occurrence of this group of veins point clearly to a common origin and therefore they might be very well connected with the mentioned magmatic suite ¹⁾.

A last argument in favour of the intrusive nature of the ultrabasic rocks may be the fact that ultrabasic rocks have been found to be intrusive in the crystalline schists of other islands of the Timor-Ceram arc (22 and 23). This is especially important in view of the many far reaching similarities, which are known to exist between the various islands of that arc.

The ultrabasic rocks may therefore be considered to be younger than the crystalline schists. It is as yet impossible to say, whether the ultrabasic rocks are older or younger than the Palelo-series, which series immediately overlies the crystalline schists. The investigation of the Palelo-series has demonstrated that serpentinous material is sometimes a constituent of upper Palelo rocks, but only in minor quantity, while the fragments are never large enough to prove their direct derivation from ultrabasic rocks beyond doubt. This may be due to the relative "softness" and lack in resistance of the "serpentine"-pebbles as compared to most of the other pebbles, which are usually derived from much harder rock-types. Therefore nothing definite concerning the age of the ultrabasic rocks can be deduced from the composition of the Palelo sedimentaries.

Finally we refer to the resemblance between the Martapoera region (S.-E. Borneo) and the Miomaffo region. Our tentative table (p. 26) shows, that in the Martapoera region the chronological order of magmatic events is as follows: volcanic rocks of the Alino-formation, plutonic igneous rocks (mainly ultrabasic rocks), volcanic rocks of the Manoenggoel formation and finally hypabyssal intrusives. If we assume a similar chronological order of magmatic events for the Miomaffo region, the ultrabasic rocks should have been intruded somewhere during the deposition of the upper Palelo-series, which is of younger-Mesozoic to Eocene age (7).

β. The igneous rocks outside the crystalline schists and the Palelo-series.

In the field these rocks usually are found between rocks of the Fatoe-

¹⁾ It is known that the mineral association of prehnite, albite, zeolites (a.o. analcite) quartz, datolite etc. occurs especially in the veins and cavities of basic igneous rocks and of the rocks in which they are found to be intrusive.

complex and younger-Mesozoic rocks of the Sonnebait-series. The following types belong to this group: gabbroid rocks, serpentines, porphyritic albite-diabases, quartz-albitites and spilitic-rocks. All these igneous rocks are more or less crushed, sometimes to a high degree. Nothing about the age of these rocks can be said, as no intrusive contacts were found.

There exists a great similarity between the igneous rocks, associated with the crystalline schists and the Palelo-series and the igneous rocks of this group. In both groups of rocks occur the same leading types and the same plagioclase: albite. Petrologically they therefore appear to be of one family, although many of them show subordinate structural differences.

Many of the igneous rocks of the investigated region are very similar to rocks of the "Ophiolite-spilite-complex". Under this name DE ROEVER (21) separates a rock series, which in the S.-W. Moetis region consists of strongly crushed igneous rocks of the following types: gabbroid rocks, lherzolites, tremolite-olivine-rocks, serpentines, albitites and alkali-albitites, albitized and analcitized dolerites, andesites and keratophyres, spilites, basalts and spilite-augitites. The igneous rocks of this complex are partly associated with the crystalline schists, while the remaining greater part occurs outside the crystalline schists, with a tectonic position between the upper Sonnebait-series and the Fatoe-complex. In connection with this similarity it seems acceptable, that the discussed igneous rocks of the Miomaffo region belong — at least partly — to the "Ophiolite-spilite-complex".

B. PETROGRAPHY AND PETROLOGY.

In the following chapter petrographical descriptions of the principal rock-types, found in the explored region will be given. Greater use was made of the publications of WICHMANN (32), BROUWER (3), TAPPENBECK (26) and DE ROEVER (21). The writer was moreover allowed to make use of the collections of slides of the two last-named authors, for comparison with his own slides.

The following main groups are distinguished:

- I. Crystalline schists.
- II. Igneous rocks.
- III. Sedimentary rocks.

I. CRYSTALLINE SCHISTS.

The crystalline schists are classified as follows:

A. Greenschists.

1. Amphibolites.
2. Low-metamorphic greenschists derived from basic igneous rocks.
3. Amphibole-schists.
4. Epidote-amphibole-albite-chlorite-schists.

B. Other schist types.

- | | | |
|---|---|--|
| 5. Schists rich
in graphite | { | a. Phyllitic albite-arkoses with graphite. |
| | | b. Graphitic phyllites. |
| | | c. Graphitic chlorite-albite-schists. |
| | | d. Graphitic biotite-schists. |
| 6. Quartz-carbonate-muscovite-chlorite schists. | | |

1. AMPHIBOLITES.

The amphibolites of the Miomaffo region are represented by plagioclase-amphibolites of several types and by epidote-amphibolites.

The plagioclase-amphibolites may be divided into andesine-amphibolites, oligoclase-amphibolites and albite- to albite-oligoclase-amphibolites.

The andesine- and oligoclase-amphibolites are only represented by some rare samples in our collection. The ordinary plagioclase-amphibolites of the Miomaffo region all contain felspar as acid as albite to albite-oligoclase (anorthite content of 0—15 %). The two albite-amphibolites, which BROUWER (3) described from the Miomaffo region, also belong to this group. Epidote-amphibolites are rather abundant. Two samples of this type have also been described by BROUWER (3) from the neighbourhood of Noil Toko.

The plagioclase-amphibolites are fine- to medium-grained, mostly massive rocks coloured in various shades of green. They mostly show a well-developed schistose texture. The andesine-amphibolites, the quartz-rich oligoclase-amphibolite and one of the albite- to albite-oligoclase-amphibolites (W. 331) are on the whole somewhat more coarse-grained

than the other plagioclase-amphibolites. A porphyroblastic structure, with felspar-porphyroblasts in a granoblastic groundmass of felspar and amphibole, is a common feature of the finer-grained type.

The principal minerals are amphibole and plagioclase, while little quantities of minerals of the epidote-group, chlorite, titanite, quartz, rutile and iron ores mostly occur.

The amphibole shows practically the same absorption-scheme in every slide; the intensity of the three absorption colours differs however in most cases, while it seems to be increasing with the increase of metamorphism (see also p. 76). The extinction n_{γ}/c varies between 14° and 18° . The mineral mostly occurs in larger or equal quantities as the felspar and may be rich in inclusions of minute titanite crystals, while numerous inclusions of felspar or minerals of the epidote-group may also occur. The following absorption-scheme is generally applicable and differs only in the intensity of the pleochroism: n_{α} = light yellow, n_{β} = dirty brownish green, n_{γ} = bluish green; $n_{\alpha} < n_{\beta} \leq n_{\gamma}$. When the amphibole is zonal, the core is always lighter coloured and less pleochroic than the rim.

The amphibole is of a more equidimensional habit in the coarser-grained amphibolites, in contrast with the fibrous and sometimes even felty character (W. 424), which is a feature of the finer-grained amphibolites.

The felspar is mostly clear and often porphyroblastic, the latter especially in the finer-grained types. The porphyroblasts are hardly ever free from inclusions of epidote-minerals and amphibole needles. Occasionally zonal plagioclases are observed (e.g. W. 331) with a core richer in albite than the rim, a feature, which is not uncommon in amphibolites. The habit is commonly granular and allotriomorphic, but may also be more or less idiomorphic (W. 331).

The titanite is usually comparatively abundant. The mineral is almost always associated with iron ore, which often occurs as a core of the titanite. Yellow coloured granules of rutile may also figure as a kernel of the titanite crystals, although more seldom. The titanite may occur as a turbid very fine-grained alteration-product of iron ores (leucoxene), with all transitions to well-developed idiomorphic crystals with characteristic outlines. Most common are numerous minute, round to egg-shaped titanite granules, which occur scattered through the rock, frequently in aggregates.

Minerals of the epidote-group are of subordinate importance. They occur as granules and also as small columns scattered through the rock,

but may also have a porphyroblastic habit. In this last case they show good crystallographic outlines.

Quartz is usually absent; if present it occurs in very small quantities. In one instance (W. 249 $\times$) this mineral forms an essential constituent of the rock.

Chlorite is always present in small quantities and always in the same variety with negative elongation. Of the iron ores, ilmenite and/or titanomagnetite are the most abundant, but small amounts of pyrite and limonite are usually present. Further prehnite, albite, zeolites, epidote-minerals, carbonate, pyrite and a mineral with the characteristics of datolite (W. 329) are found as vein-filling minerals.

In the epidote-amphibolites the proportionate amount of plagioclase becomes subordinate with regard to that of the minerals of the epidote-group. Otherwise these rocks do not differ greatly from the plagioclase-amphibolites. They have a granoblastic structure. The amphibole shows the same properties as described above. The minerals of the epidote-group have a granular to columnar habit and quite often show a zonal structure. In this case the core has practically always a higher birefringence than that of the rim, consequently pointing to a higher iron-content of the core. The minerals of this group predominantly show weak birefringence. Segregations of epidote-minerals are not uncommon and may show a fan-like structure (W. 225 $\times$). They may contain numerous inclusions of titanite-granules and amphibole-needles, especially in the finer-grained types (W. 225 $\times$). Titanite is present in the same amount and in the same way as in the other amphibolites. Carbonate sometimes occurs in greater quantity (W. 225 $\times$).

An *andesine-amphibolite* was found as a pebble in the Noil Niti (W. 150 $\times$). Macroscopically the rock is of a dark green colour, with narrow light coloured bands, which are rich in felspar. The rock is of medium grain-size and is traversed by many white zeolitic veins.

Microscopically the structure is granoblastic. The amphibole is strongly pleochroic in the usual colours. The extinction $n_{\gamma}/c = 17^{\circ} - 18^{\circ}$. The mineral has a long-prismatic development. A zonal structure can often be observed, the core being of a weaker colour and less pleochroic than the rim. The core is slightly stronger birefringent than the rim and is sometimes seen to show a slightly smaller extinction angle. This should point to an enrichment of the actinolite molecule in the central part of the crystal (19). The amphibole rarely shows twin-lamellation. Strain-effects are often observed. The plagioclase has a granular habit and often

shows twinning according to the albite and Carlsbad laws. The felspar has an average composition of acid andesine. The mineral is often distinctly zonal; the extinction of the core is slightly smaller than that of the rim. This indicates that the core is richer in the albite molecule. Strain-shadows and sometimes crushing as a consequence of post-crystalline pressure are also observed. In parts of the thin section studied the felspar is subjected to an alteration process, which starts from the zeolitic veinlets, which traverse the rock. In that case the felspar is zeolitized and probably also prehnitized and albitized. Further granules of epidote-minerals have been formed at the expense of the felspar.

The titanite is developed in small granular aggregates, often with a core of yellow rutile or iron ore. The mineral also appears as individual crystals. The minerals of the epidote-group are of a granular to columnar habit and appear regularly distributed through the rock. Two generations may be distinguished: one consisting of rare crystals of the same generation as the amphibole and andesine, the other originated through alteration of the felspar. Chlorite is only present in very small amounts in small nests and is probably of secondary origin.

The *andesine-amphibolite* from the top of the Miomaffo ridge (W. 445), is a dark green, massive and distinctly banded rock.

Microscopically the rock shows a nematoblastic structure with a decidedly schistose texture. The principal minerals are andesine and amphibole, with abundant titanite. Epidote minerals are very scarce.

The properties of the various minerals correspond for the greater part with those described from W. 150 $\times$. The zonal structure of the felspar and the amphibole is however less distinct and the titanite is somewhat clearer of appearance. Moreover apatite occurs sporadically. Cataclasis did not greatly affect this rock and only some small veinlets — filled with a biaxial zeolitic mineral, analcite and probably also albite — traverse the rock in various directions. The albite penetrates into the andesine along cleavages and cracks and seems to replace the andesine.

A *quartz-rich oligoclase-amphibolite* from the Noil Noni, upstream from Noil Toko (W. 249 $\times$) is macroscopically of a dark green colour, moderately massive and distinctly schistose. Small yellow pyrite crystals are visible.

Microscopically the structure is nematoblastic and the texture is schistose. Remarkable of this rock is its moderately high content of quartz, a fact which might point to a sedimentary origin of this amphibolite. The

amphibole is strongly pleochroic with the usual absorption-scheme and has a long-prismatic development. The extinction $n_y/c = 18^\circ$. Zonal structure is not seldom observed, especially in the large crystals, which have sometimes a somewhat poiciloblastic appearance. They enclose numerous minute titanite granules and also very irregular pieces of feldspar. Undulose extinction is sometimes seen as well as bending of the amphibole-fibres, both symptoms of post-crystalline deformation. The amphibole is the most abundant mineral of the rock. Both the plagioclase and the quartz, which minerals are closely associated, occur as somewhat flat and drawn out grains with the longest directions parallel to the schistosity. The borderlines of the closely packed grains are irregular and the grains are seen to penetrate into each other. The layers rich in feldspar and quartz alternate with the layers rich in amphibole, in this way giving rise to the banded character of the rock. The plagioclase is an oligoclase, with a content of $\pm 15\%$ anorthite. Minerals of the epidote-group are fairly abundant and granular to columnar in habit. Idiomorphic grains are relatively abundant. Zonal structure is no rare feature; when present, the core has always a higher birefringence than the rim. The titanite usually occurs in turbid strings of oval to round granules, while more equidimensional aggregates are also present. The strings are seen to run parallel to the schistosity. The grains often still contain a nucleus of iron ore. Small quantities of chlorite of the usual type (with negative elongation), pyrite and limonite occur scattered through the rock. The post-crystalline deformation did not strongly influence this rock. The amphibole crystals suffered some cataclastic deformation and furthermore small cracks traverse the rock, which are sometimes cemented with the same material that is traversed. So when traversing a feldspar crystal, the crack is cemented with feldspar material, always clearer in appearance than the traversed individual, but both showing the same crystallographic orientation. When traversing an amphibole crystal the cementing amphibole is more fibrous and of a slighter different pleochroism than the original amphibole, in this way giving rise to different generations of amphibole.

An *albite- to albite-oligoclase-amphibolite* (W. 331) from the Noil Boé, a tributary to the Noil Noni is a distinctly schistose dark green and massive rock. Whitish feldspar crystals are visible between the dark green prismatic crystals of amphibole-stems.

Microscopically the rock has a granoblastic structure and no directed texture. The principal minerals, amphibole and feldspar, are equigranular

and present in equal amounts. A single porphyroblast of the epidote-group may break the monotony. Titanite grains are as usual scattered abundantly through the rock. The grain size of the rock is comparatively coarse. The amphibole is only weakly pleochroic in the usual absorption-scheme. The extinction $n_y/c = 15^\circ$. The mineral is well-crystallized and sometimes even shows a tendency to idiomorphism. Inclusions are scarce, except some titanite granules. The plagioclase is also remarkably well-developed and very poor in inclusions. In more than one instance the crystals show a zonal build with a core of albite and a rim of albite-oligoclase ¹⁾. The bulk of the plagioclase however is albite. The titanite is present in the usual granular aggregates and occasionally occurs in well-crystallized individuals with characteristic outlines. Minerals of the epidote-group are only present in small quantities. Some well-developed porphyroblasts occur scattered through the rock. Chlorite with negative elongation is scarce and occurs in small nests between the other minerals. Pyrite occurs in well-developed isometric crystals; only occasionally oxidic iron ore is found.

Porphyroblastic albite-amphibolites were collected in the Noil Noni, upstream from Noil Toko (W. 275×, W. 428) and also in the Noil Boé (W. 329, W. 330×). As type specimen the rock W. 330× will be described as an example of this group. The rock is strongly weathered, moderately massive and fine-grained. Schistosity is not obvious.

Microscopically the rock has a porphyroblastic structure, with albite-porphyroblasts in a fine-grained nematoblastic groundmass of granular feldspar and fibrous amphibole. The amphibole is the principal constituent and is moderately pleochroic. The extinction $n_y/c = 20^\circ$. The mineral is short prismatic and of fibrous structure; often different parts of one individual show different interference colours, although all these parts of the crystal show the same extinction angles. The plagioclase is the second important constituent. The bulk of the mineral has a granular habit, but porphyroblasts of some dimension appear scattered through the rock. They are poor in inclusions (mostly amphibole needles) and were often broken by post-crystalline movements. The feldspar has the composition of albite. Weakly birefringence minerals of the epidote-group occur in small quantities, mostly as well-crystallized individuals of porphyroblastic habit. Titanite appears in the usual way as numerous granules of different sizes

¹⁾ This could be proved in a cross-section $\perp n_\alpha$, where the extinction $n_\beta/(010)$ was 14° for the core (nearly pure albite) and 3° for the rim (18% anorthite).

and shapes. They are often associated with iron ore (probably titanomagnetite). This last mineral is comparatively abundant and is often altered into leucoxene or into very fine-grained titanite along its margins. Chlorite and limonite are represented in small amounts. Several veinlets filled with prehnite cross the rock in arbitrary directions.

An *albite-amphibolite* (W. 160) from the Noil Niti, upstream from Noil Toko at the contact between crystalline schists and sediments, is a strongly crushed, dark green and distinctly schistose rock.

Microscopically we see a nematoblastic structure with a schistose, distinctly banded texture. This latter feature however has been partly destroyed by folding and crushing effects. The rock differs from the normal amphibolites in that it contains less of the amphibole mineral, while this mineral is of the same needlelike (long-prismatic) character as described in the amphibole-schist W. 224. The amphibole is furthermore fibrous and only slightly pleochroic (n_α = very light yellow to colourless, n_β = light brownish green, n_γ = light green). Extinction $n_\gamma/c = 16^\circ$. The mineral shows very clear cleavage rifts, especially a cross-parting is remarkably well developed. Many amphibole-prisms have an elongated lenticular form, being thicker in the middle than at the extremities. In places of strong movements the amphibole is seen to have been altered into a chlorite with positive elongation and abnormal blue interference colours (penninite). The plagioclase is the most important constituent of the rock and occurs in slightly sericitized grains and also in porphyroblasts, which are comparatively free of inclusions. The composition of the feldspar is albite. Besides the above mentioned chlorite with positive elongation, a pale-green chlorite with abnormal brown interference colours and negative elongation, rutile, titanite and epidote-minerals appear as accessories. The two minerals rutile and titanite occur in relatively large crystals throughout the rock; the rutile in irregular grains and rods of a yellow colour, the titanite sometimes in lozenge-shaped crystals, but mostly in small coarse-granular aggregates, with distinct pleochroism (colourless to light pink). Both titanite and rutile are closely associated with iron ore. The rock is traversed by several carbonate-veins and has moreover been strongly influenced by pressure.

Epidote-amphibolites were found in the Noil Noni, upstream from Noil Toko (W. 249); in the same river downstream from Noil Toko (W. 225) and in tributary Nr. 9 (W. 410). The rock W. 249 is a transitional type to the plagioclase-amphibolites. The main constituents

are amphibole and weakly birefringent members of the epidote-group. In this rock plagioclase (albite) is still of importance, although not essential. At the same time this rock is one of the few examples known, in which titanite is scarce. Small quantities of quartz, chlorite and iron ore form the remaining constituents. Albite-veinlets traverse the rock in several directions. This rock is very similar to the zoisite-amphibolite described by BROUWER (3, p. 160), which he collected in the Noil Noni, downstream from Noil Toko.

The *epidote-amphibolite* from tributary Nr. 9 to the Noil Noni (W. 410) is a dark green very massive rock, covered with a red brown coating of weathering. Dark green amphibole-crystals stand out clearly against the lighter coloured epidote-crystals.

Microscopically the rock is granoblastic with no definite texture. Amphibole and epidote minerals in equal amounts make out the bulk of the rock. The amphibole is moderately pleochroic in the usual colours. The extinction $n_y/c = 15^\circ$. The mineral is mostly devoid of idiomorphic outlines; it is full of granules of epidote-minerals, which often give the crystal a poicilitic appearance. The minerals of the epidote-group are coarsely granular and usually anhedral. Both strongly and weakly birefringent members of this group are present, the former in excess of the latter. They have a beautifully developed zonal structure with higher birefringent cores and lower birefringent rims. The higher birefringent grains are more or less pleochroic in yellow colours. The mineral contains numerous minute inclusions, which are accumulated in the core. The amphibole and the epidote-minerals are closely intergrown. The titanite is present as usual, although perhaps in somewhat lesser amount. The mineral occurs in well crystallized individuals, often crowded together in small aggregates. Interstitial plagioclase is only present in very little amounts, as well as a little quartz. Veins filled with albite, prehnite and epidote-minerals cross the rock in several directions.

2. LOW-METAMORPHIC GREENSCHISTS, DERIVED FROM BASIC IGNEOUS ROCKS.

To this group belong the albite-chlorite-epidote-carbonate-schists, the albite-chlorite-epidote-amphibole-schists and the amphibole-albite-epidote-chlorite-schists.

The minerals albite, epidote, chlorite, amphibole and carbonate are the main constituents of the rocks of this group; accessories are titanite and

quartz. Amphibole and acid plagioclase were prominent in the former group, while minerals of the epidote group sometimes took over the part of the feldspar, but chlorite never figured yet as an essential constituent. Moreover carbonate becomes important as a composing mineral in certain cases. The rocks mostly possess a porphyroblastic structure, with porphyroblasts of amphibole and/or albite, combined with a sometimes weakly schistose texture. It is in this group of rocks, that sufficient petrographical indications were found to prove their immediate derivation from basic igneous rocks. The rock descriptions will make this more clear.

The amphibole is of a pale green, probably actinolitic, variety. The mineral is always very weakly pleochroic, with an extinction angle n_y/c never differing much from 16° . The absorption-scheme is $n_\alpha =$ colourless, $n_\beta =$ very light brownish green, $n_\gamma =$ light green. The mineral is fibrous and often porphyroblastic. The porphyroblasts are of a very irregular structure; sometimes aggregates of numerous differently orientated fibres are found in their cores. Noteworthy is the invariably close companionship of amphibole and chlorite, an association commonly observed in this kind of rocks. The albite is a mineral present in all types of this group, always in much the same amount. The mineral is of typically clear and quartz-like appearance (neogene albite). In an older stage a mosaic pattern is developed of irregular non-idiomorphic grains of albite, always accompanied by grains of epidote-minerals and carbonate. This is obviously an association derived from the decomposition of lime-bearing plagioclase (W. 421). As recrystallization begins to start more definitely, porphyroblasts of albite begin to originate, which in the end frequently contain a kernel with enclosed granules of epidote-minerals and amphibole needles, but otherwise are practically devoid of inclusions (W. 163).

The minerals of the epidote-group are present in great abundance, as innumerable round grains in the groundmass. The minerals of the epidote-group are generally weakly birefringent; many grains are idiomorphic. Grains with a core, showing higher interference colours than the rim, frequently occur. This fact denotes a higher iron-content of the core. The chlorite appears to be represented in two varieties, one with ultra-blue interference colours and positive elongation, the other with ultra-brown interference colours and negative elongation. The first variety is often seen to be a decomposition product of the amphibole. Both varieties occur together, but one of them is often prevailing over the other. Titanite is present in large amounts, scattered through the rocks in small earthy

looking aggregates of numerous small granules. Its derivation from iron ore seems always clear. Quartz is never more than an accessory.

The following more detailed descriptions of several rock-types belonging to this group, are given in an order of increasing influence of recrystallization.

An *albite-chlorite-epidote-carbonate-schist* from tributary Nr. 7 to the Noil Noni (W. 421) is of a grassgreen colour, very hard and massive. No definite texture could be discerned.

Microscopically numerous larger pseudomorphous masses of carbonate and chlorite are seen amidst an allotriomorphic groundmass of albite, epidote-minerals and chlorite. No definite texture is observed. The rock is considered to be a decomposed basic igneous rock of the "epidiorite" type. The larger masses of carbonate and chlorite may represent the former pyroxene crystals as locally eight-sided outlines and short prismatic habit are observable. Otherwise nothing of the original structure has been preserved and the whole rock is decomposed into an intricate mixture of albite, epidote-minerals, chlorite and carbonate, all appearing in approximately equal quantities, while titanite is an accessory. The neogene albite is quartz-clear and of granular habit. The grains show frequently an irregular extinction (similar to strain-shadows, but in this case only a characteristic of neogene albite) and cleavage is poorly developed, twinning scarce. They appear generally in aggregates with a mosaic pattern. The minerals of the epidote-group appear as innumerable mostly weakly birefringent granules throughout the rock. They are sometimes turbid by admixtures of earthy iron-compounds. Carbonate appears everywhere in the rock, but at the same time forms the principal part of the mentioned pseudomorphs, in which the carbonate is associated with chlorite of two varieties. The mineral adopted the fibrous structure of the original mineral (probably pyroxene), which it replaced together with the chlorite. The chlorite appears in two varieties. One is a strongly pleochroic variety of a fibrous character and a birefringence which shows mostly yellow interference-colours of the first order; the elongation is positive. The second variety is only slightly pleochroic, with abnormal brown interference-colours and negative elongation. The variety with positive elongation seems to be a decomposition product of the original mineral (pyroxene, probably first uralitized); the variety with negative elongation seems to be later than the first named, and to replace it. Titanite is present in the usual abundance and in the usual way, while quartz could not be determined with certainty. Leucoxene is abundant.

An *albite-chlorite-epidote-amphibole-schist* from the Noil Niti (W. 163) is a very dark serpentine-like rock with a homogeneous appearance.

Microscopically large crystals of amphibole are visible in a groundmass of albite, epidote-minerals and chlorite. The texture is weakly schistose. This rock is supposed to be a decomposed and slightly metamorphosed basic igneous rock in which the larger amphibole crystals — at any rate the cores of many of them — are considered to be the amphibolitized remains of former pyroxene crystals. This assumption is mainly based on the following observations. The crystals of amphibole and especially their cores all show more regular boundaries than are commonly observed within rocks of the same mineralogical composition. This fact might be easily explained when assuming the hereditary nature of their outlines. Moreover, many large amphibole crystals are enclosing lath-shaped, more or less idiomorphic albite crystals and also mixtures of fine-grained epidote-minerals and albite, which mixtures possess inside the blastophyres also often clear-cut lath-shaped outlines. This last picture is clearly reminiscent of a well-known structure often encountered in certain basic igneous rocks, namely the ophitic structure (Plate III, fig. 1). It seems therefore obvious that the structure of this metamorphic rock is derived, direct from the igneous ophitic structure. Also the fact that the amphibole-blastophyres are often transverse to the weakly developed planes of schistosity, is in favour of the conception that the structure of the rock is largely of a hereditary nature.

The amphibole is of a pale green, very weak pleochroic and fibrous variety. The extinction $n_r/c = 16^\circ$. The large crystals which are often transverse to the schistosity, hardly ever consist of one uniform crystal, but mostly contain aggregates of smaller crystals and needles of the same mineral in their core. A mixture of chlorite and obviously newly formed amphibole needles are often sprouting from the extremities of the large crystals of amphibole. The epidote-minerals, albite, chlorite and titanite are of the same nature as described in the preceding rock. The albite has a tendency to form porphyroblasts, which becomes a characteristic feature of the next rock W. 163 $\times$. Carbonate is also present, but very scarce, in contrast with the preceding rock W. 421. Chlorite is only present in one variety, the clinocllore variety with negative elongation.

A *porphyroblastic amphibole-epidote-chlorite-schist* from the Noil Niti (W. 163 $\times$) is of a green colour and obviously somewhat crushed. Schistosity is not readily observed.

Microscopically the rock has a porphyroblastic structure, with porphyroblasts of albite and larger crystals of amphibole in a groundmass of albite, epidote-minerals, amphibole and chlorite. No directed texture is visible, possibly because the rock is somewhat crushed. The rock is clearly to be considered as of the same kind and origin as W. 163, but is in a more advanced stage of metamorphism. The groundmass has now become thoroughly recrystallized and the various minerals are all clearly discernible. Moreover, besides the large crystals of amphibole, albite-porphyroblasts were formed. The relative amount of chlorite has diminished considerably in comparison with the preceding rock; instead innumerable needles and small crystals of amphibole originated. The amphibole is of the same nature as described in the preceding rock ($n_v/c = 17^\circ$). The larger crystals also show the same peculiarities as before. The relative amount of the mineral however has increased considerably, while the intimate association of chlorite and amphibole suggests that the chlorite is in some way connected with the origination of the amphibole. The albite is, besides in the usual granular way, present in porphyroblasts, which are practically inclusion-free. The many albite-grains, from which the porphyroblasts have been obviously built up, shifted their inclusions in doing so. Epidote minerals are plentiful and sometimes occur in granular segregations. Chlorite is of the usual type with negative elongation; quartz is present in small amounts; titanite occurs in abundance. The latter mineral is always associated with iron ore.

Post-crystalline deformation caused the forming of albite-veins, which cross the rock in many directions. Moreover crushing phenomena are observable in several minerals.

3. AMPHIBOLE SCHISTS.

The following greenschists are believed to belong to a different class as the preceding amphibolites and greenschists of igneous origin. They can be better compared with the "actinolite-glaucophane rocks" of TAPPENBECK (26). The rocks in question were found in the Noil Noni, downstream of Noil Toko, where they are seen to alternate with graphitic chlorite-albite-schists. The only rock described under this heading (W. 224) is distinguished from the other crystalline schists mentioned by its richness in amphibole.

An *amphibole-schist* was found in the Noil Noni, downstream from Noil Toko (W. 224). The rock is finely laminated and of a light green colour. The thin layers show considerable bending and minute folding.

The surfaces of the stratification planes are covered with light green amphibole-needles, rendering them silky to the touch.

Microscopically the rock shows a fine-nematoblastic structure and a definite schistose texture. Under the microscope the rock shows on the whole an aspect, which is quite different from the one offered by the finer-grained amphibolites, although both kinds of rocks are for the greater part composed of plagioclase and amphibole. Here however amphibole is more predominant. The different aspect of this amphibole-schist is also due to the features of the amphibole, which mineral is apt to form clear-cut small needles and prisms, whereas in the amphibolites the mineral has a tendency to form larger crystals with a more equidimensional development and without well-developed crystallographic boundaries. Furthermore the rock is moderately quartz-rich, another difference from the amphibolites of igneous origin and lastly many quartz and albite grains seem to have retained their original clastic outlines. The amphibole is only slightly pleochroic (n_x = light yellow, n_y = light brownish green, n_z = light green). The extinction $n_y/c = 15^\circ$. The habit is needle-like, the needles often forming fibrous aggregates. The mineral is the principal constituent. The plagioclase is clear albite. The mineral is granular of habit; together with the granular quartz, which is present in approximately equal amounts, it forms the background against which the amphibole-needles are standing out. Accessories are epidote-minerals and titanite granules, the latter mineral as usual in relatively large amounts. The epidote-minerals, mostly represented by clinozoisite, are often porphyroblastic; the porphyroblasts have frequently well-developed crystal faces and are practically free of inclusions, except for a few titanite granules.

The rock was clearly subjected to post-crystalline deformation, which caused the forming of several small veins, filled with prehnite and albite and occasionally also with pyrite. These veins are probably later than a larger quartz-clinozoisite vein, which was even folded before the introduction of the first set of narrow prehnite-veins. Especially in the arches of the folded vein, the quartz shows undulose extinction and abnormal biaxial interference figures. The clinozoisite is closely associated with the prehnite; they seem to be intergrown with each other. The small prehnite-veins are partly running parallel to the axis of the isoclinal minor fold.

4. EPIDOTE-AMPHIBOLE-ALBITE-CHLORITE-SCHISTS.

The rocks in question are for the greater part fine-grained and finely laminated rocks of a green to yellow-green colour. They were found at a

locality in the Noil Niti (W. 294 $\times$, W. 398 $\times$), where they were partly crushed, and in two localities in the Noil Noni (W. 276, W. 276 $\times$), north of the Miomaffo. The constituents are epidote-minerals, amphibole, chlorite, albite, carbonate, quartz, titanite, green mica and iron ores, mentioned in the usual order of decreasing importance. The rocks have a fine nematoblastic, sometimes a granoblastic structure, both of which are sometimes represented in the same slide. This depends on the local mineralogical association (the amphibole-chlorite-epidote-albite assemblage gives rise to a nematoblastic structure, the quartz-carbonate assemblage to a granoblastic structure). The texture is distinctly schistose. The present schistosity planes coincide with the original stratification-planes. Layers rich in coloured minerals alternate with layers rich in the colourless minerals. Sudden changes in the relative concentrations of the different minerals occur quite often in the same slide and in this way quartz-carbonate layers border immediately on epidote-albite-amphibole-chlorite layers. Sometimes lenticular masses of quartz-carbonate occur embedded in an epidote-amphibole-albite-chlorite rock (W. 276 $\times$). The various minerals possess the usual properties of these minerals in similar rocks. One example is to be described more fully.

An *epidote-amphibole-chlorite-albite-schist* from the Noil Noni, north of the Miomaffo (W. 276) is of a pale yellow-green colour, fine-grained and very finely stratified. Macroscopically the rock is still very much like a hard, normal sediment.

Under the microscope the rock has mainly a nematoblastic structure and a schistose texture. The minerals of the epidote-group are commonly of granular habit and frequently form larger crystals. This mineral-group is represented by its strongly birefringent members. The larger grains are quite often zonal, the outer zone having lower interference colours than the core. The pleochroism in yellow colours becomes gradually more pronounced with the increasing birefringence and may become very prominent. The sometimes numerous minute opaque inclusions occasionally show also a zonal arrangement. The amphibole builds numerous fibrous needles in the groundmass and is obviously still in an advancing stage of development. The interference colours are moderate (yellow of the first order), the extinction $n_y/c = 15^\circ$ and the pleochroism is moderate ($n_\alpha = \text{yellow}$, $n_\beta = \text{light green}$, $n_\gamma = \text{grassgreen}$ and $n_\gamma > n_\beta > n_\alpha$). Chlorite occurs in two varieties. One of these shows abnormal blue interference-colours, is only slightly pleochroic and has a positive elongation. This variety seems to be coupled to the amphibole.

The second variety has abnormal violet to brown interference-colours, is strongly pleochroic from light yellow to green. Small quantities of a green mica are remarkable in the rock. This mica is very strongly pleochroic (n_α = light yellow, $n_\beta = n_\gamma$ = dark green), and occurs mainly in the felspar-rich layers. The plagioclase-felspar is undoubtedly principally albite. The mineral is granular, clear and shows only rarely twinning. The quartz in this rock is only present in little amounts and it is often difficult to separate it clearly from the felspar-grains. The titanite is represented in the usual abundance and builds many very small granules between the other minerals. Magnetite forms beautiful porphyroblasts, with perfect crystal faces. Smaller grains of this mineral are numerous in the groundmass.

5. SCHISTS RICH IN GRAPHITE.

Under this heading several graphite-rich schistose rocks of sedimentary origin will be described. They have been subdivided into phyllitic albite-arkoses with graphite, graphitic phyllites, graphitic albite-schists and graphitic biotite-schists.

a. Phyllitic albite-arkoses with graphite.

The phyllitic albite-arkoses are fine-grained, fine-banded, brittle rocks of a dark colour. They are found over a large distance in the Noil Niti (W 296 $\times$, W 296), where they alternate with black shales and probably also with graphitic phyllites. Small yellow crystals of pyrite are often visible macroscopically.

Microscopically the rocks in question are clearly of clastic origin (Plate III, fig. 2). Most of the particles of the colourless minerals still retain their typical clastic outlines. The interstitial sericite- and chlorite-scales bend around the clastic particles. The greater part of these particles is composed of plagioclase (mostly albite), frequently with albite twinning lamellae. Potash-felspar could not be detected with certainty. Quartz fragments are present in far smaller quantity and still scarcer are tourmaline, zircon, titanite, rutile, carbonate and epidote-minerals. The originally clayey cementing substance of the rock has recrystallized and now forms the interstitial phyllitic substance between the clastic fragments. The interstitial substance now consists of sericite, chlorite and a micro-crystalline mixture of quartz and felspar. The rocks are moreover rich in very fine coal-particles.

The rocks have a clastic structure with a definite schistose texture. The following description is characteristic of this type of rock.

In a *phyllitic albite-arkose* from the Noil Niti, close to tributary Nr. 5 (296 $\times$) the plagioclase occurs mainly as clastic fragments, frequently polysynthetically twinned. Part of the micro-crystalline interstitial substance is also feldspar. It is obvious from the different properties that the greater part of the plagioclase is of the composition of albite. The feldspar grains show a beginning of sericitization, carbonatization or kaolinization. Quartz fragments are present in smaller amount than the fragments of feldspar. The quartz particles are slightly undulose and very clear. The mineral occurs also as a constituent of the interstitial substance. Sericite and chlorite are comparatively abundant and are always closely associated. The sericite-scales together with the chlorite-scales clearly indicate the schistose texture of the rock. The sericite shows the usual properties displayed in phyllitic rocks. The chlorite is practically isotropic and of a very light green colour. The coal-like substance is present in great abundance and by its concentration in thin layers still indicates the original stratification-planes. The other minerals are accessory constituents and only present in little quantities. Tourmaline possesses the same properties as in the graphitic phyllites. The pleochroism is very strong from brownish green or olive-green to light brownish green. Zircon occurs sporadically as small prisms. Titanite granules are not as plentiful as usual in the crystalline schists epidote-minerals form grains and little columns scattered throughout the rock. Carbonate is also present as small irregular interstitial patches, but also as a decomposition product in the feldspar fragments.

In these rocks is observed a more or less paracrystalline deformation in which the deformation lasted somewhat longer than the recrystallization. This is evident from the following observations. The original stratification — indicated by thin layers of graphite — is cut obliquely by the schistosity. The schistosity-planes (and also the stratification-planes) are sometimes folded, which folding is caused by differential movements along a set of planes which are oblique to the stratification and the schistosity. Because bending of the sericite-scales is observed near these planes of movement, the last movements along these planes must have continued after the recrystallization of the rock. The carbonate-quartz veins are cutting through all former structures.

b. Graphitic phyllites.

The rocks are very fine-grained and of a black colour. They are much less massive than the previously described phyllitic albite-arkoses and split more easily along the stratification-planes. On their surfaces these planes

possess a dark lustre, caused by many very small sericite- and chlorite-scales. The rocks occur together with the phyllitic albite-arkoses in the Noil Niti and also with the epidote-amphibole-chlorite-albite-schists in the Noil Noni, north of the Miomaffo. They form an important part of the crystalline schists of the Miomaffo. The great preponderance of phyllite-fragments over fragments of other schist-types in the Palelo conglomerates may also be stressed here.

Microscopically the graphitic phyllites have a fine-clastic structure and a definite schistose texture. They are micro-crystalline and only slightly metamorphosed clayey sediments.

The following description is of a *graphitic phyllite* found north of the Miomaffo in the Noil Noni (W. 275).

Felspar and quartz are the most prominent among the constituents. They appear in an intricate micro-crystalline mixture together with chlorite, sericite and carbonaceous matter. The rock is rich in this carbonaceous substance, which shows a changing concentration in different layers, thereby indicating the original stratification. Accessories are titanite, tourmaline, rutile, zircon, pyrite, magnetite and limonite. The titanite is rather abundant and occasionally forms somewhat larger crystals. These crystals are in their rims often full of innumerable opaque inclusions. The larger crystals sometimes gave rise to a kind of eyed structure. This is clearly seen as the black bands bend around the crystals of titanite. In the corners of the mentioned eyes better conditions for the recrystallization of quartz and albite prevailed. The titanite crystals are sometimes broken. Often also the titanite is developed as small turbid aggregates.

The tourmaline is strongly pleochroic (ω = brown, ε = colourless to light yellow) and is often full of inclusions. The mineral occurs scattered through the rock in small frequently idiomorphic prisms, which may show a zonal structure. Rutile occurs in tiny rods of brown colour and zircon was observed as light yellow very small prisms. Pyrite occurs scattered through the rock, mostly with a rim of magnetite. The latter mineral appears also as minute granules in the rock.

c. The graphitic chlorite-albite-schists.

The rocks in question are macroscopically much like the graphitic phyllites. Microscopically however they contain no sericite. They were found in the Noil Noni, downstream of Noil Toko and occur here together with amphibole-schists (W. 224). In this graphitic chlorite-albite-schist (W. 225) the structure is still somewhat clastic, while a foliation

PLATE III.

Fig. 1.

Relict structure in an albite-chlorite-epidote-amphibole-schist, from the Noil Niti (W 163). A large twinned crystal of amphibole encloses rather sharply outlined lathshaped mixtures of very fine-grained epidote-minerals and albite. This structure is strongly reminiscent of the well-known ophitic structure of certain basic igneous rocks, in which feldspar-laths are enclosed by augite-crystals. It is assumed that the metamorphic structure in this greenschist is of hereditary nature. Nicols crossed (31 $\times$).

Fig. 2.

Phyllitic albite-arkose with graphite from the Noil Niti (W 296), showing its clastic character. Nicols crossed (23 $\frac{1}{4}$ $\times$).

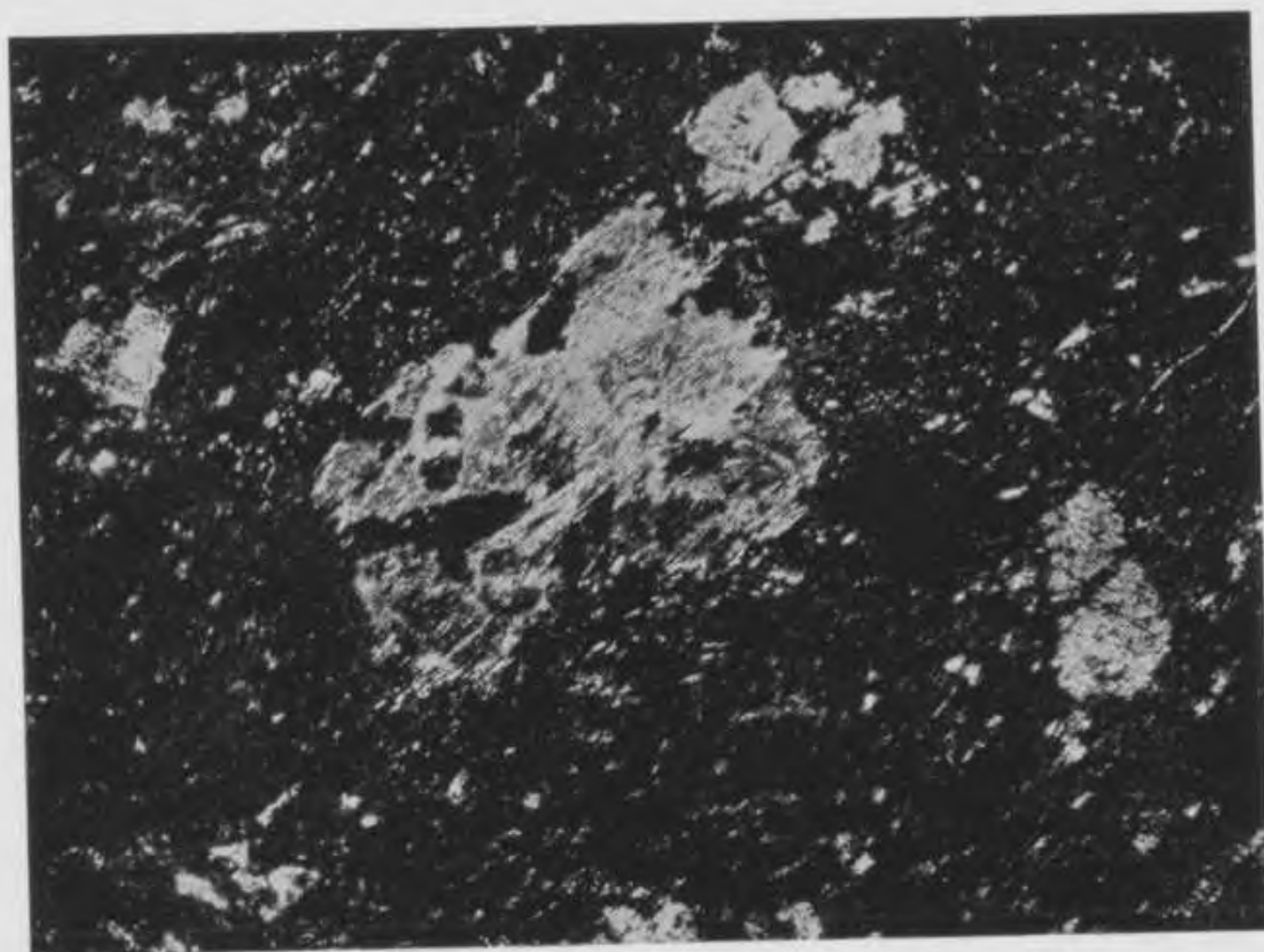


Fig. 1.

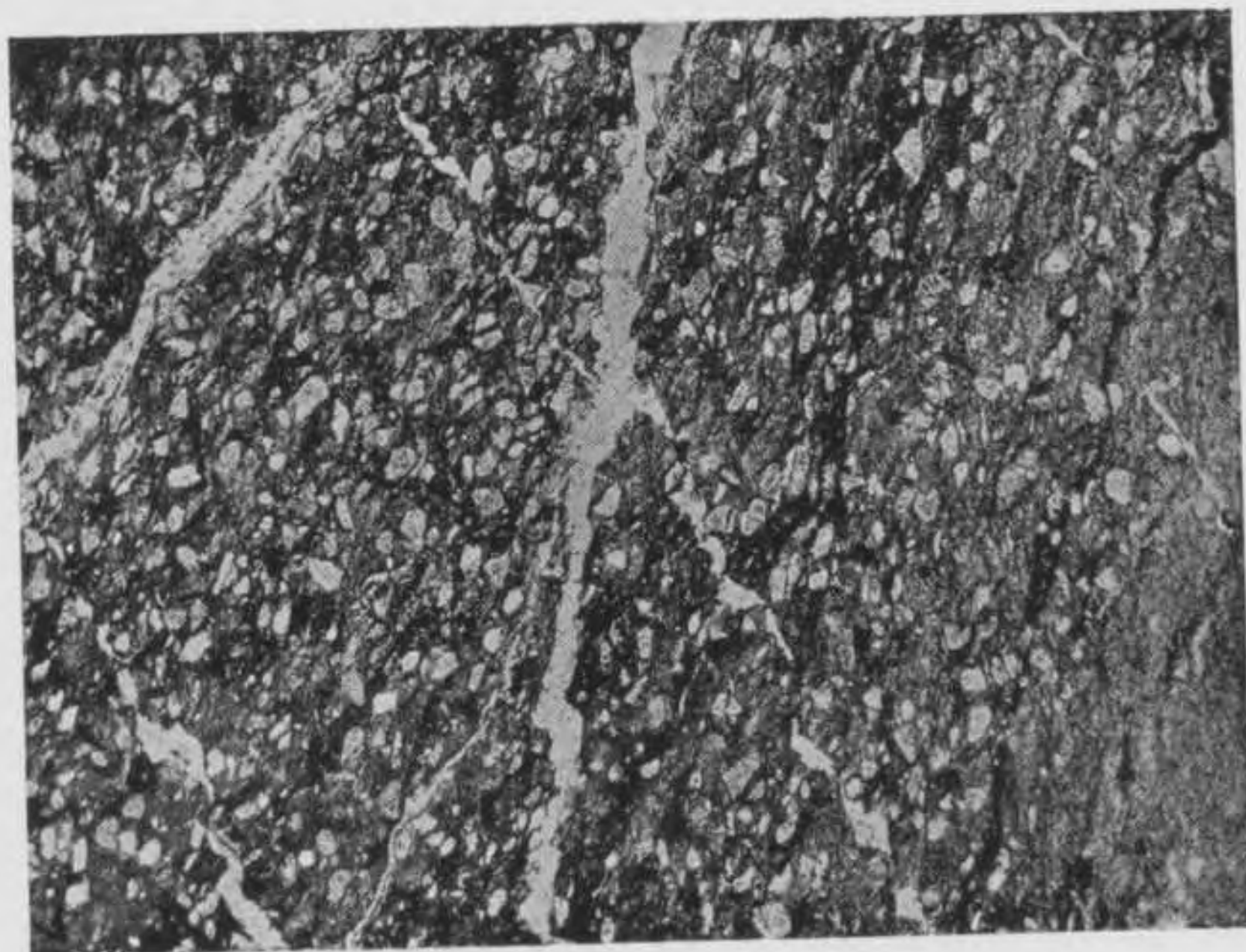


Fig. 2.

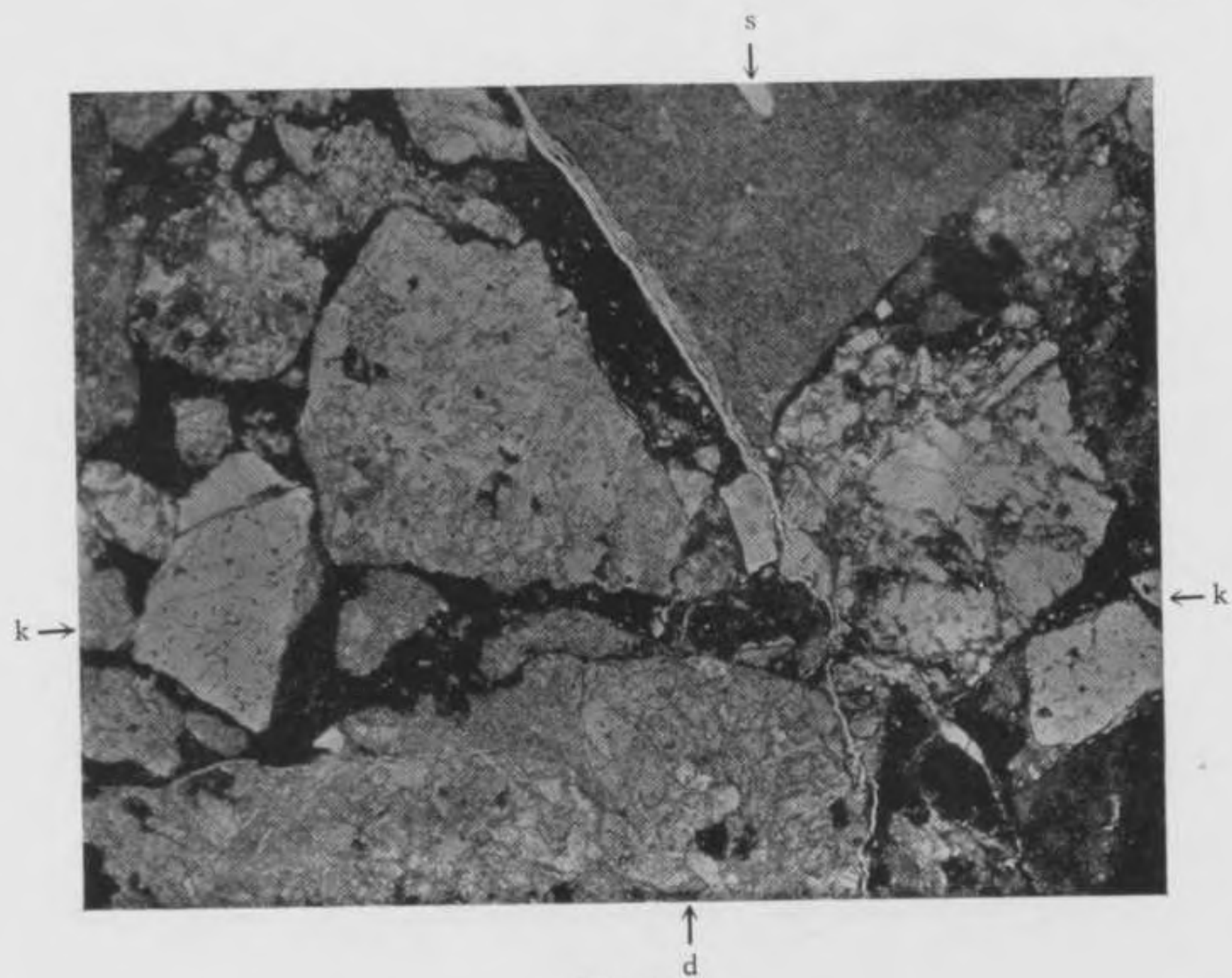


Fig. 1.



Fig. 2.

PLATE IV.

Fig. 1.

Volcanic breccia at the base of the lower Palelo-series, found in the Noil Noni, upstream from Noil Toko (W 443 III A). The individual fragments of the breccia are very angular, while fragments of diverse sizes occur together. Visible are fragments of albite-diabases (d), of spilitic rocks (s) and of keratophyres (k). The fragments of the keratophyres are derived from strongly crushed rocks in contrast with the fragments of the albite-diabases and spilitic rocks. Ordinary light ($17\frac{1}{4} \times$).

Fig. 2.

Same rock as fig. 1. Nicols crossed ($17\frac{1}{4} \times$).

is observed in narrow quartz bands and broad chlorite-albite bands. Plagioclase (albite) is by far the most important mineral. Part of the grains are still more or less clastic in appearance, but recrystallization has already begun to influence their outlines. Twinning is very rarely observed. Chlorite is comparatively abundant and of the usual light green variety, sometimes with abnormal brown interference colours and negative elongation. The mineral occurs dispersed among the albite-grains. Quartz seems to be especially restricted to certain layers in the rock. Small quantities of another variety of chlorite (with positive elongation) and of a strongly pleochroic brownish green mica are also found. Epidote-minerals occur in grains and little columns scattered through the rock, and may locally become of importance. The mineral shows often abnormal interference colours. Titanite is very scarce in this rock.

The rock is crossed by a group of quartz-albite-prehnite-pyrite veins. The albite in many of these veins occurs along the margins, while the other minerals as quartz, prehnite and pyrite, appear in the centres; so the latter minerals may be of later appearance. The quartz of the bands is clearly influenced by pressure (strain-shadows and granoblastic appearance of the grains).

d. Graphitic biotite-schists.

Only one rock of this type has been found (W. 306) in the Noil Niti. It is found in a tectonically strongly influenced zone in the crystalline schists.

The crushed rock is of a dark colour. Narrow white coloured bands, rich in quartz and felspar, are visible and give the rock a stratified appearance. Sometimes biotite flakes can be discerned.

Under the microscope, the bands are alternately mainly composed of quartz, of biotite and of felspar and biotite. Transitions between the two latter kind of bands are gradual; the transition to the quartz bands is more abrupt. The quartz bands are strongly influenced by internal movements in the rock, as a consequence of post-crystalline pressure. The biotite bands are especially rich in graphitic material. The biotite-felspar bands have a typical granoblastic structure and no directed texture. This may be due to post-deformational recrystallization.

The principal minerals are biotite, quartz, plagioclase and carbonaceous matter. Accessories are tourmaline, apatite, zircon, iron ores, carbonate, chlorite, sericite and weakly birefringent minerals of the epidote-group.

The biotite shows a pleochroism from dark reddish brown ($n_\gamma = n_\beta$) to light yellow (n_α). The mineral occurs in anhedral crystals with a flaky

habit. The biotite occurs in two generations. The first generation is the normal constituent of the rock; the second generation occurs in rare and very thin cracks, which are transverse to the schistosity. The biotite often shows an undulose extinction, is often bent and so is distinctly influenced by pressure. All other minerals of the rock may occur as inclusions in the biotite. The biotite is frequently very irregularly orientated. The principal basal cleavage is then not parallel to the foliation, which is indicated by the graphitic layers, which continue through the biotite flakes. Equally often the principal cleavage is parallel to the original stratification. At places in the rock we see that the biotite sometimes shows an alteration into green chlorite.

The quartz is always strongly cataclastic and shows often mortar structures, while recrystallization has taken place. The quartz grains are closely intergrown with each other along very irregular boundaries and the larger grains have become elongated in shape; their longest directions form an oblique angle with the banding of the rock. This proves, that the later tectonic movements (the rock is found along a zone of crushing in the schists) operated under a certain angle with the foliation. Plagioclase in the quartz bands occurs in isolated crystals with very irregular shapes, while their cores are usually wholly filled up with a turbid admixture of graphite, sericite, quartz grains and carbonate. These crystals are usually associated with small biotite flakes (see also below).

The plagioclase of the rock is of a changing basic composition and contains usually 40—55 % anorthite. The basic plagioclase is never idiomorphic, of a granular habit and forms a considerable part of the rock. It occurs mainly concentrated in certain layers together with biotite, while it is only subordinate in the quartz-layers. The plagioclase is blastic, as the graphitic bands are seen to pass uninterruptedly through the felspar grains. It shows often an undulose extinction, bending of the albite twinning-lamellae and sometimes fracturing as a consequence of post-crystalline movements. The mineral is notably less influenced by pressure than the quartz. Twinning according to the albite and pericline laws is common, while in many crystals only pericline lamellae are present. This last fact could be proved by determining the refractive indices of the plagioclase by means of the immersion method. Carlsbad-twins are sometimes observed. Zonal structure is quite often seen. The extinction-angles are in one case for a section $\perp n_y$, for $n_x/(001)$, $+9\frac{1}{2}^\circ$ (40 % anorthite) for the core, $+25^\circ$ (50 % anorthite) for the rim. The

zonal structure is very irregular; the core is always more acid than the rim. Several times is observed: acid core — basic zone — acid rim.

The felspar grains contain inclusions of graphitic substance, biotite scales, tourmaline and apatite prisms. The felspar grains have sometimes a core, which consists wholly of a turbid mass partly consisting of graphitic substance, sericite and probably also granules of epidote-minerals. These felspars with turbid cores occur preferably in the quartzitic layers of the rock. Carbonate occurs regularly distributed in the rock and occurs also as filling of cracks.

Tourmaline occurs in unusual abundance regularly distributed throughout the rock, while the content of tourmaline is notably higher in the graphitic biotite-layers. The crystals are sometimes barrel-shaped and of large dimensions (e.g. length 1.4 mm, breadth 0.2 mm). The core of the crystals is sometimes full of graphitic inclusions, proving that these crystals have originated during the metamorphism. Small, slender and idiomorphic columns are the usual mode of occurrence (ω = dark yellowish green, ϵ = light yellow). The larger individuals faintly show a zonal structure and are often broken. Apatite occurs in less amount than the tourmaline and is also regularly distributed throughout the rock. The crystals are sometimes of the same dimensions as the tourmaline columns and are also sometimes rich in graphitic inclusions, which might prove that they have also like the tourmaline been growing within the rock. A small amount of epidote-minerals is also present, scattered through the rock. The mineral occurs in slender prisms often filled with graphitic substance and shows abnormal blue interference colours. Zircon occurs in small prisms as inclusions in the biotite, which shows pleochroic aureoles around them; some pyrite is also found in the rock.

An indication of post-crystalline pressure are the numerous cracks and veinlets, which run parallel to the schistosity and which are filled with carbonate, analcite, biotite and pyrite. Another constituent of the rock, the origin of which is due to a later impregnation, is a green biotite-like mineral. In the crystalline schists of the Moëtis region, a similar mineral is locally present (21, p. 169 and 171).

6. QUARTZ-CARBONATE-MUSCOVITE-CHLORITE-SCHISTS.

The rock described below is found in the Noil Niti, together with black shales, phyllitic albite-arkoses and epidote-amphibole-chlorite-albite-schists, descriptions of which have already been given.

The *quartz-carbonate-muscovite-chlorite-schist* from the Noil Niti, close to tributary Nr. 3 is a partly crushed rock, of a light green colour. No banding or stratification could be discerned macroscopically.

Under the microscope we see that the rock has an alternately granoblastic and lepidoblastic structure. This depends on the local composition; the quartz-carbonate assemblage giving rise to the first, the sericite-chlorite-albite or phyllitic assemblage to the second structure.

In the quartz-carbonate bands the quartz is granular, allotriomorphic and practically not undulose or only very faintly so. In these bands the carbonate fills the interspaces between the quartz-grains and often shows strain-shadows as well as twinning lamellae. Both minerals are practically present in the same quantities.

In the phyllitic bands albite occurs in small grains, which have a somewhat laminated appearance. Of the same importance are chlorite and muscovite, which occur together in close association. Intermixed with the minerals mentioned, are numerous opaque iron ore grains, which frequently show alteration into leucoxene along their margins and subsequently to titanite. Carbonate is not seldom of importance. Part of the mica-flakes show an irregular orientation with regard to the banding of the rock.

Later movements caused fracturing of the rock and the formation of carbonate veins, while planes of movement obviously preferred the phyllitic bands.

SUMMARIZING CONSIDERATIONS ON THE CRYSTALLINE SCHISTS.

The following groups of crystalline schists occur in the investigated area ¹⁾:

1. Amphibolites.
2. Low-metamorphic greenschists derived from basic igneous rocks.
3. Amphibole-schists.
4. Epidote-amphibole-chlorite-albite-schists.
5. Schists rich in graphite.
6. Quartz-carbonate-muscovite-chlorite schists.

a. Main characteristics of the different groups.

The *amphibolites* form the most prominent group among the green-schists. The greater part of the amphibolites are considered as metamorphic basic igneous rocks. In this respect the author therefore is of the same opinion as BROUWER (4), TAPPENBECK (26) and DE ROEVER (21). Amphibolites which are of sedimentary origin occur however as well. TAPPENBECK (p. 69) mentions e.g. a banded rock in which bands of oligoclase-amphibolite alternate with epidote-bands and quartz-carbonate bands. He concludes in this case that the rock is of sedimentary origin and he assumes the rock to have been derived from a tuffaceous-marl. DE ROEVER (p. 194) concluded that several garnet-amphibolites of the Moetis region are of sedimentary origin. Also in the case of our quartz-rich amphibolites, a sedimentary origin seems more probable. In a former chapter (p. 52) a quartz-rich oligoclase-amphibolite has been described, which might serve as an example.

¹⁾ Much schist material is found also in the sedimentaries of the upper Paleozoic-series and the young-Tertiary rocks. In a conglomerate of the upper Paleozoic-series (W. 332) occur e.g. the following schist fragments:

a *graphite-bearing epidote-chlorite-sericite-quartzite*; a *graphite-bearing biotite-chlorite-quartz-albite-schist* with poeciloblastic development of the albite; a *graphite-bearing sericite-quartz-albite-schist* with a well developed microfolding; an *epidote-albite-chlorite-sericite-quartzite* with a gneissose structure; *quartz-carbonate rocks*; a *crossite-epidote-albite-chlorite-schist*. The minerals occurring in each particular schist-type are mentioned in the order of increasing importance.

The assumption that most amphibolites have been derived from basic igneous rocks is based on the petrographical characteristics of the low-metamorphic greenschists (see below). It could be proved that the latter were derived from basic igneous rocks and it is believed that by an increase in metamorphism amphibolites of the known types originated from similar low-metamorphic greenschists. The low-metamorphic greenschists are thus considered to form the transition between the basic igneous rocks and the amphibolites. No detailed section through the crystalline schists of the investigated region exists in which the successive metamorphic stages, from a basic igneous rock to an amphibolite could be traced, to prove the derivation in the field.

The andesine-amphibolites belong to a higher stage of metamorphism than the oligoclase- to albite-amphibolites. The andesine-amphibolites are similar to several rocks described from the Mollo region.

The epidote-amphibolites include types with a certain content of feldspar, which form the transitional types to the plagioclase-amphibolites. BROUWER (3) described two albite-amphibolites and two zoisite-amphibolites from the neighbourhood of Noil Toko.

The *low-metamorphic greenschists derived from basic igneous rocks* form a group of rocks, in which the prominent minerals albite, chlorite, epidote-minerals, amphibole and carbonate are present in varying quantities. The proportion of the quantities of carbonate, chlorite and amphibole, present in a certain schist-type, is apparently dependent on the stage of metamorphism, reached by the greenschist in question. In this way a certain order of metamorphic stages could be established as is evident from the following short petrographical descriptions.

The lowest representative of this group is an albite-chlorite-epidote-carbonate-schist (W. 421). This rock still shows a considerable resemblance to a normal epidiorite and contains pseudomorphous masses of chlorite and carbonate, which may represent altered crystals of pyroxene, as locally they have faintly retained eight-sided outlines and a short prismatic habit. The groundmass is a fine-grained mass of epidote-minerals, albite and titanite granules, while chlorite is very abundant. Amphibole fails altogether.

The next step is represented by an albite-chlorite-epidote-amphibole-schist (W. 163) in which amphibole already begins to figure as an important constituent while chlorite shows a decrease in its quantitative proportion. The groundmass is not much different from the one above. The albite tends already to a porphyroblastic habit. Remarkable in this

rock are the observed remains of an originally ophitic structure (Plate III, fig. 1 and p. 59). Carbonate is scarce in this rock.

Next come the porphyroblastic amphibole-albite-epidote-chlorite-schists (W. 163 $\times$). The amphibole forms together with the plagioclase the most prominent constituents and chlorite has still further diminished in quantity. The albite sometimes forms large porphyroblasts and the groundmass has by now become thoroughly recrystallized. This porphyroblastic amphibole-albite-epidote-chlorite-schist is already not far from a certain type of albite-amphibolite.

TILLEY (28) described a series of low-metamorphic greenschists from the Start area (Devonshire), which closely resemble the preceding types and which show the same consecutive changes as described above. Moreover the immediate derivation of the greenschists from basic igneous rocks could, in the Start area, be clearly proved in the field.

The *amphibole-schists* can be best compared with the "actinolite-glaucophane rocks" of TAPPENBECK (26). The mineral association is amphibole, albite and quartz, epidote-minerals and titanite. The high content of quartz and also the structure of the rocks point to a sedimentary origin and it is assumed, that the amphibole-schists are derived from quartz-rich marls.

The *epidote-amphibole-albite-chlorite-schists* are low-metamorphic greenschists of sedimentary origin. They are probably derived from thinly stratified rocks, in which the layers were alternately rich in chloritic and calcareous material, which fact is now reflected in the metamorphic rock by layers which are alternately rich and poor in coloured minerals. Certain parts of these rocks are moreover especially rich in albite, carbonate and quartz, which represent the more felspathic parts in the original sediment.

They are of exactly the same type as the epidote-chlorite-schists with actinolite described by DE ROEVER (21) from the Moetis region, but differ from the epidote-chlorite-schists of TAPPENBECK (26). BROUWER (3) and also WICHMANN (32) described similar rocks from the Miomaffo region. A striking point of petrographical similarity between these rocks in the Moetis and the Miomaffo regions is the appearance in both instances, of a peculiar green mica in very small quantities.

The original clastic character is still apparent in most types of the now following rocks and recrystallization mainly affected the interstitial cementing material.

The *phyllitic albite-arkoses* are named so because practically all alkali-felspar fragments are of albite. The fragments mostly still have an

angular, clastic appearance (Plate III, fig. 2). The cementing material recrystallized as a micro-crystalline phyllitic mixture and probably represents the original interstitial clayey substance. The sericite- and chlorite-scales give the rock a somewhat schistose character. The rocks are rich in carbonaceous matter.

The *graphitic phyllites* are only slightly recrystallized clayey sediments of a very fine-grained nature. BROUWER (3) described two graphitoid-rich schists from the Miomaffo region, which show considerable similarity to the types here mentioned. He mentioned the existence of potash-felspar and biotite-flakes in one of them.

The *graphitic albite-schists* are as the name already indicates, almost wholly composed of albite. The albite-grains partly are of a clastic nature. Part of the green chlorite (the penninite-variety with positive elongation), is sometimes associated with a green mica. Sericite is lacking.

The *graphitic biotite-schists* found in the investigated region show several petrographical peculiarities. These rocks were submitted to regional metamorphism, but there are certain indications which point to magmatic influences as well. The biotite-plagioclase bands do not show a directed structure, which points to post-deformational recrystallization in these bands. Tourmaline and apatite occur furthermore in unusual quantities and sometimes in unusually large crystals scattered through the rock, while it seems clear, that they originated within the rock and are not of detrital origin (see p. 69). Basic plagioclase (40—55 % anorthite) occurs in large amount and is not of detrital origin either.

The rock shows a distinct foliation, which is demonstrated by the banding in layers, which contain different amounts of the mineral biotite. The columns of tourmaline, epidote-minerals and apatite lie mostly parallel to the foliation. The undulose extinction and crushed appearance of the quartz proves post-crystalline movements which may be connected with the crushed zone in which this rock was found.

The *quartz-carbonate-muscovite-chlorite-schists* are rocks in which quartz-carbonate bands alternate with chlorite-sericite-albite bands. The rocks are clearly derived from sediments in which quartz-carbonate layers alternated with layers of a more clayey nature.

β. Comparison with the crystalline schists of other regions in Timor.

From the comparison of the crystalline schists of the Moetis (21) and the Mollo (26) regions with those of the Miomaffo region, it is evident that on the whole there is a greater analogy between the crystalline schists of the Moetis region and the Miomaffo region, than between those of the

Mollo region and the Miomaffo region. The Moetis region and the Miomaffo region lie geographically much closer to each other than the Mollo region and the Miomaffo region. Typical kata-zone rocks fail however altogether amongst the rocks of our collection from the Miomaffo region.

γ. Some petrographical observations of general importance.

The intensity of the pleochroism of the amphibole in the several crystalline schists — especially the amphibolites — seems to increase with the mounting degree of metamorphism. At the same time the blue tinge in the absorption-colour of n_{γ} becomes generally more and more pronounced.

A second point of interest is the zonal structure of the minerals amphibole, plagioclase-felspar and epidote-clinozoisite. All three may exhibit this phenomenon in one and the same rock; on the other hand each of the minerals may show the phenomenon separately. In the case of zonal structure the amphibole always shows a core which is of a lighter colour, less strongly pleochroic and less birefringent than the rim. The core is moreover sometimes seen to extinguish somewhat later than the rim (e.g. W. 150×, W. 331). Zonal plagioclases show a core which is richer in the albite-molecule than the rim (e.g. W. 150×, W. 331×). Zonal epidote-clinozoisite has for the greater part a core which is higher birefringent than the rim. Consequently the core possesses a higher iron-content than the rim. The reverse was rarely observed (e.g. W. 410, W. 276).

Remarkable is further the exceptional high content of titanite of many crystalline schists, whether of sedimentary or of igneous origin. Generally it could be ascertained that the titanite was derived from titaniferous iron ore.

The crystalline schists were as a whole, submitted to strong tectonic movements, which caused folding, brecciation and veining. All three phenomena occur on a macroscopical to microscopical scale. It is generally observed that the minute folding is more or less para-crystalline. The minute folding (deformation) lasted somewhat longer than the recrystallization (p. 64). The phenomenon of minute folding is especially well-developed in many graphitic schists. Cataclastic phenomena are further commonly observed in many crystalline schists, either accompanied by recrystallization or not. An excessive form of cataclasis causes brecciation of the rock as a whole. As cataclastic effects are observed undulose extinction, forming of pressure twins in calcite, bending and fracturing of

crystals and mortar-structures. In several schists cracks are observable, which are generally filled up with the same minerals, which build the main body of the rocks. In a given crystal such a crack may be filled up with the same mineral that is traversed. In this way new generations of the various traversed minerals may be introduced.

The occurrence of veins and veinlets filled with post-metamorphic minerals is also a common feature of the crystalline schists. Veins filled with the association prehnite-albite-zeolite are of wide-spread occurrence in the crystalline schists, while each mineral may fill the vein separately. Analcite, pyrite and quartz and epidote-minerals may be sometimes included in the association mentioned. The veins are generally later than the minute folding. This is also true of the cataclastic phenomena.

δ. Stages of metamorphism.

The lowest stages are represented by the low-metamorphic greenschists stages of metamorphism.

The lowest stages are represented by the low-metamorphic greenschists (derived from basic igneous rocks), by the graphitic phyllites, by the quartz-carbonate-chlorite-sericite-schists and also by the phyllitic albite-arkoses. The composition and structure of these rocks place them in the chlorite-zone.

The fine crystalline epidote-amphibole-albite-chlorite-schists are probably to be placed in a somewhat higher stage of metamorphism, because of the occurrence of large quantities of finely disseminated actinolitic amphibole together with small quantities of a green mica. This last fact may, according to HARKER (12), point to a slightly higher grade of metamorphism than that of the rocks just mentioned (see also 21, p. 164—165).

The amphibole-schists and graphitic albite-schists are seen to alternate with each other and therefore belong to a common metamorphic stage. The composition and the structure of the rock-types make it probable that they belong to a slightly higher metamorphic stage.

The graphitic biotite-schist shows certain peculiar petrographical features, which point to magmatic influences on this rock, after its recrystallization by regional metamorphism (see p. 68). The rock in question was furthermore found along a crushed zone while nothing is known about the rocks which occur in direct association with this particular rock. It is therefore not certain in which stage of metamorphism this rock ought to be placed.

The amphibolites of the region are a group of rocks, which differ mutually in grainsize, composition and structure. Their grade of metamorphism is variable and may range from the biotite-stage upwards. The larger part of the epidote and oligoclase- to albite-amphibolites are considered to belong to the stages of metamorphism, which correspond to the biotite and garnet stages of metamorphism. The highest stage of metamorphism is represented by the andesine-amphibolites. The composition of the plagioclase, the properties of the minerals of the latter rocks are all in favour of this assumption. They are quite similar to several plagioclase-amphibolites of the Mollo region, which according to TAPPENBECK (26) occur in direct connection with mica-schists and gneisses of the meso-zone and kata-zone.

So it seems possible to discern a certain order of metamorphism in the many investigated types of amphibolites, although such an order could only be based on petrographical observations. With increasing metamorphism an increase of the basicity of the plagioclase-felspar and changes in the structure of the rock are observed. For instance a porphyroblastic structure is rarer in the higher metamorphic rocks, which have a tendency to equi-granularity, while they show an increase in grainsize. Further there is a gradual change in the optical properties of the amphibole mineral.

II. IGNEOUS ROCKS.

The following types are found in the investigated region:

1. Gabbros.
2. Lherzolites and serpentines.
3. Quartz-albitites.
4. Albite-diabases.
5. Keratophyres and quartz-keratophyres.
6. Spilitic rocks.

1. GABBROS.

The only rock belonging to this group (W. 435) occurs along the motorroad from Noil Toko to Kefamenanoe (p. 41).

Description.

The rock in question is of a dark green colour, very coarse-grained. White felspar crystals are clearly visible against a green background.

Microscopically the rock has a hypidiomorphic structure, which may occasionally become somewhat porphyritic with larger crystals of plagioclase-felspar.

The rock is mainly composed of plagioclase and pyroxene. Accessories are oxidic iron ore, apatite and brown spinel. Secondary products are uralite, chlorite, zeolites (a.o. analcite), albite, leucoxene and epidote-minerals.

The composition of the plagioclase is varying and the anorthite-content generally ranges between 40 and 65 %. Some of the largest crystals belong to bytownite. Often there is a zonal structure of the mineral; the outer zone of one crystal may have the composition of andesine and the core of basic labradorite. The felspar shows twinning according to the albite-, Carlsbad- and pericline-laws. The plagioclase is usually partly or entirely replaced by fibrous zeolitic minerals, isotropic analcite and albite. All three minerals may occur together, but also separately. The replacing minerals penetrate into the crystal along cleavages and cracks. The replacement process frequently starts from the margins of the crystal. At an intermediate stage in this process, the felspar-crystal is broken up by the branching and rebranching cracks and fissures into many isolated felspar fragments, which lie in a matrix of

replacement products. Finally the felspar is entirely replaced by an aggregate of zeolitic minerals (a.o. analcite) and albite. The felspar contains many small inclusions of augite and secondary uralite, which always possess ragged outlines. The inclusions sometimes appear to be arranged along the (010) cleavages. Penetration of secondary uralite along cleavage-cracks is also observed. The pyroxene is of a diopsidic variety. The extinction $n_y/c = 36^\circ$ and the colour is very light green. Inclusions of oxidic iron ore may be very numerous, white felspar-laths are rarer. The pyroxene is short prismatic and often idiomorphic. The mineral is partly or wholly uralitized. This process starts from the margin of the mineral and penetrates along cracks. The uralite has an extinction of $n_y/c = 18^\circ$ and is distinctly pleochroic (n_α = light yellow, n_β = dirty green, n_γ = grassgreen). The mineral forms often aggregates and is very fibrous. The uralite is in turn replaced by chlorite with abnormal blue interference colours and positive elongation (penninite). Sometimes a turbid aggregate of leucoxene occurs in connection with this decomposition process and the result is an aggregate of fibres of uralite and chlorite with some leucoxene. Apatite occurs in long slender six-sided prisms. Iron ore occurs in moderate amount and shows typical skeleton-forms. Leucoxene appears as a decomposition product. Some grains of brown isotropic spinel were also found.

2. LHERZOLITES AND SERPENTINES.

The greater part of the rocks of this type, found in the investigated region, belong to a body which is part of the Miomaffo schist-complex. Outside the crystalline schists several small occurrences are also found.

Partly serpentized lherzolites are represented by W. 219 and W. 257 $\times$, while W. 214 and W. 326 $\times$ are pure serpentines.

Description.

W. 219 and W. 257 $\times$ are of the same character. They contain isolated patches of the still unaltered original rock, which are lying in a mass of serpentine.

The original rock is composed of olivine, monoclinic and rhombic pyroxenes, and brown picotite. Serpentinic minerals replace the primary constituents, while oxidic iron ore is set free at the same time. A higher content of iron renders the serpentine sometimes distinctly pleochroic. The characteristic mesh-structures are a common feature. More detailed descriptions of similar rocks have already been given by DE ROEVER (21, p. 202) and SIMONS (25, p. 71).

3. QUARTZ-ALBITITES.

The quartz-augite-albitites (W. 224×, W. 229×, W. 236×, W. 330, W. 403), which occur as dykes in the crystalline schists and the Palelo-series are reckoned to belong to this class. They are of a too leucocratic character to be placed in the class of the albite-diabases. A small occurrence of quartz-albitites is furthermore found west of the trail from Noil Toko te Seoam (W. 302 (Plate V, fig. 1)). A quartz-amphibole-albitite fragment is further found as a composing fragment of the volcanic breccias, which are found at the base of the lower Palelo-series (W. 443 II C).

Description.

The *quartz-augite-albitites* are fine-grained, greenish rocks of a mesocratic character. The structure is sub-ophitic and sometimes (W. 236×) weakly porphyritic with phenocrysts of plagioclase.

The principal minerals are acid plagioclase, augite and quartz. Oxidic iron ore and apatite are accessories. Of secondary origin are chlorite, prehnite, carbonate, sericite, epidote-minerals, leucoxene, pyrite and limonite.

The feldspar is albite, which occurs in equal amounts as the pyroxene. The mineral has a lath-like habit and is never clear, but is always partly or entirely filled with secondary products as prehnite, chlorite, sericite, carbonate and innumerable dust-like particles. Twinning according to the albite- and Carlsbad-laws occurs. The crystals show moreover a strong tendency to idiomorphism. The mineral is intimately intergrown with the augite (often altered into chlorite), the feldspar-laths penetrating into the augite crystals; sometimes they are entirely enclosed by this mineral. The feldspar crystals are often partly or entirely prehnitized, which process usually starts in the core of the crystal. The prehnite in the core is usually an irregularly built aggregate, but is also sometimes a more homogeneous crystal, which may also fall apart in several separated grains or patches, which show simultaneous extinction.

Micro- to crypto-crystalline graphic intergrowths of quartz and albite are a common feature and often start from the frayed and swallow-tailed extremities of the feldspar-laths, which project into the interstices. Another expression of the same phenomenon is the occurrence of spherulitic intergrowths of albite and quartz (W. 330). The spherulites have a polygonal form and possess a radiate structure of feldspar fibres, probably with interstitial quartz, round a common centre. The outer margin of the growth consists invariably of clear quartz. In several instances the nucleus

of the spherulite is a partly corroded felspar-lath. In this last case we sometimes see a transition from a microcrystalline graphic intergrowth of quartz and albite to a spherulitic structure. The augite has in most cases entirely altered into a strongly pleochroic chloritic or serpentinous mineral, always accompanied by epidote-minerals. In one specimen (W. 330) the augite remained partly fresh and possesses the following properties. The mineral usually forms small crystals of an idiomorphic short-prismatic habit with a distinct cross-parting. The colour is very light yellow-green to colourless. The extinction $n_y/c = 45^\circ$. The prehnite forms aggregates, which are composed of irregular patches, which show irregular extinction and which occur squeezed in between the other minerals. The aggregates occur usually together with epidote-minerals, chlorite, carbonate and quartz in the interstices of the rock. The mineral is often seen to replace the albite (see above). The mineral is colourless, shows parallel extinction, negative elongation, moderate birefringence and a lower refringence than the augite. The quartz is certainly partly of primary origin, although another part may be of secondary origin. The primary origin is proved by the graphic intergrowths with albite. The quartz crystallized as the last mineral in the interstices of the rock and possesses no idiomorphic outlines.

The apatite is abundant in these rocks and appears as characteristic long slender needle-like prisms throughout the rock. Six-sided cross-sections and the more common short prisms do also occur. The apatite-needles are sometimes arranged around a common centre. Oxidic iron ore, often altered into leucoxene, occurs abundantly in the rock, mostly as well developed isometric crystals, but partly in skeleton-forms. Pyrite is also present. Carbonate may occur both as decomposition product of the felspar and as a vein mineral of later introduction.

The rocks are not influenced by tectonic pressure, as can be deduced from the absence of cataclastic phenomena. It could not be established with certainty whether the albite of these rocks is of primary or secondary origin. It is nevertheless believed, that the latter case is the more probable. Albitization is a characteristic feature of the volcanic constituents of the Palelo-sedimentaries, through which these rocks are cutting. BROUWER (3, p. 55) described moreover petrographically very similar dyke-rocks which were also collected in the Noil Noni downstream from Noil Toko. The felspar of part of these rocks, however, belongs to andesine and more acid plagioclases.

The *quartz-albitite* (W. 302, Plate V, fig. 1) is a rather coarse-grained

leucocratic type. Quartz and feldspar are macroscopically clearly visible. The colour of the rock is greenish as a consequence of its content of chlorite.

The structure is holocrystalline and the most important constituents are quartz and plagioclase, which are present in about equal amounts. Subordinate amounts of epidote-minerals, sericite, zircon, apatite and rutile occur regularly distributed through the rock.

The albite is present in more than one generation. The oldest, most important generation is turbid through a beginning alteration in epidote-minerals, sericite and kaolin. Twinning according to the albite- and Carlsbad-laws are commonly observed. The younger generations of albite are of a clear appearance and occur in veinlets, which traverse the older turbid albite crystals but may also form a clear rim around the turbid albite crystals. The younger albite has usually the same optical orientation as the traversed or surrounded albite crystal, but a different orientation occurs as well. The quartz occurs also in more than one generation and the oldest generation is also more or less turbid. The younger quartz shows the same properties with regard to the older quartz as the younger albite with regard to the older albite. The vein-quartz may sometimes show idiomorphism. The younger albite is occurring in the same veinlets as the younger quartz, while carbonate is sometimes also present in the veinlets in crystals which are sometimes idiomorphic against the quartz.

The oldest generation of quartz and albite in this rock are intricately intergrown in a manner which suggests that the quartz has been replacing the albite. The quartz shows lobed edges against the albite and presents convex contacts toward it in very involved patterns extending through the feldspar (Plate V, fig. 1). This may lead to the isolation of quartz fragments in albite and of albite fragments in quartz. The quartz-albite veinlets mentioned are younger than the replacement processes.

Very similar structures have been elaborately described by GILLULY (11) from the albite-granites in Sparta, Oregon. That author is convinced that the structures are of a secondary nature and that they originated through a post-magmatic albitization and silicification of the rock (see also the description of the quartz-amphibole-albite).

Of the accessories zircon is present in small quantities and has developed as small columns and grains, sometimes surrounded by a brown aureole. The mineral occurs sometimes enclosed by chlorite (penninite, with positive elongation) in which it formed pleochroic aureoles. The chlorite is strongly pleochroic and n_α (= brownish green) $<$ $n_\beta = n_\gamma$ (= green). The mineral occurs usually in aggregates, which show lattice structures

or also radiate structures. The mineral is also sometimes vermicular, penetrating into the quartz and feldspar along cracks. The occurrence of rutile needles in the chlorite may also be mentioned. Apatite is present in long and slender hexagonal prisms. Apatite and zircon occur only sporadically throughout the rock. Leucoxene, as decomposition product of titaniferous iron ore and limonite are unimportant secondary products. Besides as inclusions in the albite, epidote-minerals also occur outside this mineral in turbid aggregates and are often associated with chlorite, titaniferous iron ores and leucoxene.

The rock has been influenced by pressure. Crushing of the quartz, with the origination of mortar-structures is observed. Undulose extinction, bending and faulting of albite-lamellae and fracturing of the albite crystals are cataclastic phenomena of minor importance. Recrystallization must have taken place to a certain degree. It is furthermore clear, that the older generations of quartz and feldspar are more strongly influenced by cataclasis than the younger vein generation of the same minerals.

The *quartz-amphibole-albite* (W. 443 III C) is a coarse-grained holocrystalline rock. The principal minerals are albite, amphibole and quartz, of which the amphibole and part of the quartz are of primary origin, while at least part of the albite and the greater part of the quartz are of secondary origin. Accessories are apatite, zircon and oxidic iron ore, secondary accessories minerals of subordinate importance are chlorite, epidote-minerals, leucoxene and carbonate.

The albite is present in two generations. The most important first generation of albite, is turbid, because of innumerable inclusions of a dust-like character, which are for the greater part ore particles, but also amphibole particles, epidote granules, carbonate particles, sericite scales and probably also kaolin. The alteration of the feldspar is never very important. Twinning according to the albite- and Carlsbad-laws is a common feature. Part of the crystals show albite-lamellae, which do not pass entirely across the crystal, but are interrupted at crosslines in a step-like fashion. In this way a structure originates which approaches the structure exhibited by the chessboard-albite.

Secondary albite occurs in veinlets of the rock, the mineral is clear and is seen to have the same orientation as the traversed older turbid albite. Sometimes the albite lamellae of the traversed crystal are copied by the albite in the vein. The veins, which contain the clear albite are also partly filled up with quartz. Similar replacement-processes of albite by quartz, as

have been described for the preceding rock, are found here, but they are less well developed.

Here as in the preceding quartz-albite older turbid quartz and younger, clear vein-quartz are observed. The younger vein quartz also occurs in veins within the feldspar crystals. The youngest generation of quartz, which is associated with carbonate, may show idiomorphic crystals.

The extensive veining with quartz and albite and the strong crushing of the rock make it difficult however to distinguish between the several varieties of quartz. All generations of quartz are influenced by pressure, but the younger generations in a less degree than the older ones.

The amphibole occurs in aggregates of crystals. Crystallographic outlines are usually absent. The amphibole occurs usually together with the apatite, zircon and oxidic iron ore and has frequently altered into a chloritic mineral and epidote minerals. The extinction $n_y/c = 16^\circ$. The absorption-scheme is $n_\alpha =$ light yellow, $n_\beta =$ brownish green, $n_\gamma =$ grass-green ($n_\alpha < n_\beta < n_\gamma$).

The alteration of the amphibole seems usually connected with the veinlets. The scarce zircon occurs in unusual large columns, which are surrounded by a brown aureole probably of decomposed iron particles. The apatite occurs as usual in hexagonal prisms, irregularly scattered through the rock, but is most abundant in association with the amphibole aggregates. The titanite is always secondary and originates from the alteration of titaniferous iron ore. Leucoxene is also present. Epidote-minerals occur usually as scattered grains in the rock, but also in segregations.

The rock has been severely crushed, which is shown by the distinct cataclastic appearance of the rock under the microscope. The minerals show undulose extinction, bending and fracturing of the crystals and are crushed with the forming of mortar structures. The crushing of the rock must have taken place mainly before the introduction into the rock of the younger generation of quartz and albite, as this generation is far less influenced by pressure.

The quartz-albite liquid penetrated the rock along numerous veinlets. The crushed parts of the rock were mended by the quartz-albite liquid and fragments of the rock minerals are now found in a matrix of newly crystallized quartz and albite. Carbonate may occupy the central parts of the veinlets so formed.

About the question of the primary or secondary origin of the first generation of albite nothing can be said with certainty. No rests of the

original feldspar could be found, but many instances are known where partial albitization took place in similar rocks (11). The veinlets with secondary albite and quartz prove, that albite-rich solutions circulated through the rock after its consolidation. The peculiar structures found in this rock and which are especially well developed in the preceding quartz-albite point in the direction of a hydrothermal origin of these rocks in their present state.

4. ALBITE-DIABASES.

DEWEY and FLETT (10) used the name albite-diorite for medium-grained rocks, which contain as characteristic minerals purplish augite (of various shades), albite, and titaniferous iron ores, while a certain amount of olivine may be present as well. So these are dolerites with albite instead of labradorite. The rocks are further always more or less decomposed. The albite-diorites of the Miomaffo region are named in accordance with the nomenclature of DEWEY and FLETT. A porphyritic albite-diorite (W. 255 $\times$) is found in contact with the Fatoe Seoam and is of a type different from the albite-diorites which occur at the base of the lower Paleozoic-series. The former rock contains beautiful pseudomorphs after olivine in contrast with the other albite-diorites, which are devoid of this mineral. As already stated the other albite-diorites are found at the base of the radiolarian cherts of the lower Paleozoic-series (p. 18) together with volcanic breccias, which partly consist of fragments of these diorites (Plate IV).

Description.

The *porphyritic albite-diorite* (W. 255 $\times$) has a porphyritic structure with phenocrysts of albite, augite and olivine-pseudomorphs, which are lying in a groundmass of mainly albite and augite, showing the well known ophitic structure (Plate V, fig. 2). Glomeroporphyritic aggregates of feldspar, augite and olivine-pseudomorphs are observed. Main constituents of the rock are plagioclase, augite, titaniferous iron ores, titanite and aggregates of serpentinous minerals, which frequently exhibit the crystal boundaries of olivine. Besides these minerals colourless mica, carbonate, leucocene and abundant epidote-minerals occur as alteration-products. The minerals feldspar, augite, olivine (-pseudomorphs) and probably also the iron ore occur in two generations of different crystal-sizes.

The plagioclase is albite and the two generations occur as idiomorphic phenocrysts and as euhedral to subhedral feldspar-laths in the groundmass. The feldspar phenocrysts attain sizes of 2,6 mm. The feldspar-laths are

sometimes arranged in sub-variolitic structures. The albite is very cloudy as a consequence of innumerable inclusions of different character, largely derived from decomposition of the albite. Between crossed nicols the mineral shows a conspicuous blotchy character which is caused by the fact that the crystals are built up of patches with a varying degree of birefringence, but with the same optical orientation, as all patches are seen to show the same extinction angle. No remnants of original basic feldspar could be found to prove a secondary origin of the albite. The albite is very clear and transparent in places where the mineral is not decomposed. The alteration products are mainly colourless mica, which occurs frequently in spherulitic growths, carbonate, epidote-minerals and earthy kaolin. Cracks and cleavages in the feldspar are often occupied by light green serpentinous minerals, often distinctly pleochroic and birefringent.

The feldspar is sometimes seen to be clouded by dust of iron ore. The monoclinic augite is of the normal purplish coloured type ($n_g/c = 45^\circ$) and is at the same time the only totally fresh mineral of the rock. Two generations of augite occur, which correspond to the two generations of the albite. The mineral has usually a granular habit, but the later, smaller generation shows often idiomorphic outlines. The phenocrysts of augite are almost colourless, but the later generations are decidedly of a darker colour and sometimes even show weak pleochroism in purplish colours.

A zonal structure is observed in the second generation of augite, which often has an almost colourless core and a darker coloured rim. This structure never becomes very pronounced and differences between the extinction angles of core and rim are practically negligible. Twinning is observed.

Chloritic to serpentinous minerals are of great importance. They originated largely through the alteration of the original olivine and formed aggregates which distinctly retained the crystal boundaries of the original olivine crystals (Plate V, fig. 2). From the number of olivine-pseudomorphs can be deduced that the original rock must have had a high content of the olivine mineral. The olivine-pseudomorphs occur also in two generations, as the feldspar and the augite. The phenocrysts are especially of idiomorphic habit.

The olivine-pseudomorphs are mainly composed of antigorite- and chrysotile-serpentines of varying composition, while certain quantities of epidote-minerals, titanite and carbonate are admixed. The iron-rich varieties of the serpentinous minerals are characterized by a higher birefringence and a stronger pleochroism. The antigorite has a flaky habit,

is stronger pleochroic and birefringent than the fibrous, often spherulitic chrysotile. The pleochroism of the always undulose extinguishing antigorite scales is n_α (= light yellow) $< n_\beta = n_\gamma$ (= grassgreen). The chrysotile mostly occupies the cracks of the former olivine crystal, the fibres being vertical to the sides of the veinlets, while the antigorite replaced the interjacent parts of the original crystal. The smaller olivine-pseudomorphs in the groundmass are usually altered into chrysotile with a spherulitic structure. Titanite is very abundant and occurs in innumerable round and oval-shaped grains and granules throughout the rock. They are derived from the alteration of the titaniferous iron ores, which are still very abundant and often show typical skeleton-forms.

The secondary origin of the albite could not be proved beyond question, as has already been stated above. The original rock must have been of a basic character as is indicated by its original high content of olivine. There exists a great similarity between certain albitized dolerites of the Moëtis region (21, page 236), in which rocks the secondary origin of the albite could be proved. All this makes the secondary origin of the albite in this rock acceptable and we may therefore consider the rock also as an albitized porphyritic olivine-dolerite.

The *albite-diabase* (W. 445 $\times$) is of a dark green colour and strongly crushed. The individual minerals can not be distinguished macroscopically. The rock is macroscopically very similar to certain greenschists of the Miomaffo.

Microscopically the rock is seen to be composed mainly of the minerals albite and augite (or uralite), which are present in equal amounts. The grain-size changes for different parts in the rock and the structure may sometimes become somewhat porphyritic. Augite (or uralite) and albite are intricately intergrown in an ophitic to sub-ophitic manner. Many sharply bounded fragments of augite (or uralite) with the same interference colours, which are separated from each other by felspar fragments or felspar-laths, are frequently seen to extinguish simultaneously. This proves that these fragments belong to one large crystal of augite. Locally the same phenomenon can be observed for a large felspar crystal.

The albite occurs in two generations. The first generation is somewhat cloudy and has a lath-like habit. Many laths penetrate partly or entirely into the augite crystals; the part of the lath lying outside the augite is often broader than the part enclosed by the augite crystal, which phenomenon is probably due to simultaneous crystallization. Twinning according to the albite-, pericline- and Carlsbad-laws is a common feature

of the mineral. The cloudy appearance of the mineral is produced by innumerable inclusions of a different character. The inclusions are of chlorite, carbonate, sericite and kaolin. The chlorite is most abundant and is a practically isotropic, light green variety. This mineral also penetrates into the turbid albite along cleavages and cracks. The influence of tectonic pressure on the rock must be held responsible for the undulose extinction of the feldspar, the bending and the fracturing of crystals (betrayed by the albite-lamellae and the accentuating of cleavages). The feldspar-laths are sometimes radially arranged round a common centre, in this way giving rise to a sub-variolitic structure. The second generation of albite occurs in the veinlets of the rock and is often seen to have the same crystallographic orientation as the cloudy albite (see p. 84).

The augite is of a colourless clear variety with extinction $n_y/c = 45^\circ$. Only part of the mineral is unaltered, but the greater part has been uralitized into a pale green, fibrous amphibole, which is pseudomorphous after the augite. The uralitic amphibole shows an extinction angle $n_y/c = 16^\circ$. The absorption-scheme of the amphibole is $n_\alpha =$ light greenish yellow, $n_\beta =$ brownish green, $n_\gamma =$ bluish grassgreen ($n_\alpha < n_\beta < n_\gamma$). The amphibole is in turn chloritized into a pale green chlorite with positive elongation and abnormal bluish interference colours (penninite). It is of interest to note that the uralitization seems to take place preferably in the vicinity of crystals of primary iron ore. The augite is sometimes directly altered into a chloritic aggregate. The titaniferous iron ore has for a large part altered into leucoxene.

The rock is cut by many small veins, filled with the secondary minerals prehnite, epidote-minerals and carbonate, and sometimes albite and pyrite in small amounts. Parts of the rock are furthermore occupied by a crush-breccia of angular fragments of albite and augite lying in a groundmass composed of the secondary minerals mentioned above. The crushing of the rock is later than the veining, because the veinlets are often cut off by the crush-breccia.

It could not be proved whether the first generation of albite is of primary or secondary origin. The rock exhibits no features which point directly to a secondary origin of the albite as e.g. remains of older more basic plagioclase. The only point in favour of the secondary origin is the occurrence of the veinlets filled with the second generation of clear albite. This proves at any rate the presence of active albite-bearing solutions within the rock.

A decision in favour of the primary or secondary origin of the albite of the albite-diabases mentioned seems as yet not justified.

PLATE V.

Fig. 1.

Quartz-albite from the Ophiolite-spilite-complex, found along the trail from Noil Toko to Seoam (W 302). The photograph shows the intricate manner in which the quartz (light) and the albite (dark) of this rock are intergrown, suggesting the replacement of albite by quartz. The quartz shows lobed edges against the albite and presents convex contacts toward it in very involved patterns extending through the felspar. Nicols crossed ($\pm 68\times$).

Fig. 2.

Porphyritic albite-diabase from the Ophiolite-spilite-complex, Fatoe Seoam (W 255 $\times$). The porphyritic structure is clearly apparent in the picture; phenocrysts of felspar (albite), augite and olivine-pseudomorphs are lying in a groundmass of mainly albite and augite, showing the well-known ophitic structure. The olivine-pseudomorphs are aggregates of chloritic and serpentinous minerals which retained the crystal boundaries of the original olivine crystals. A good example of an olivine-pseudomorph is found in the lower right part of the picture. Ordinary light ($\pm 17\times$).

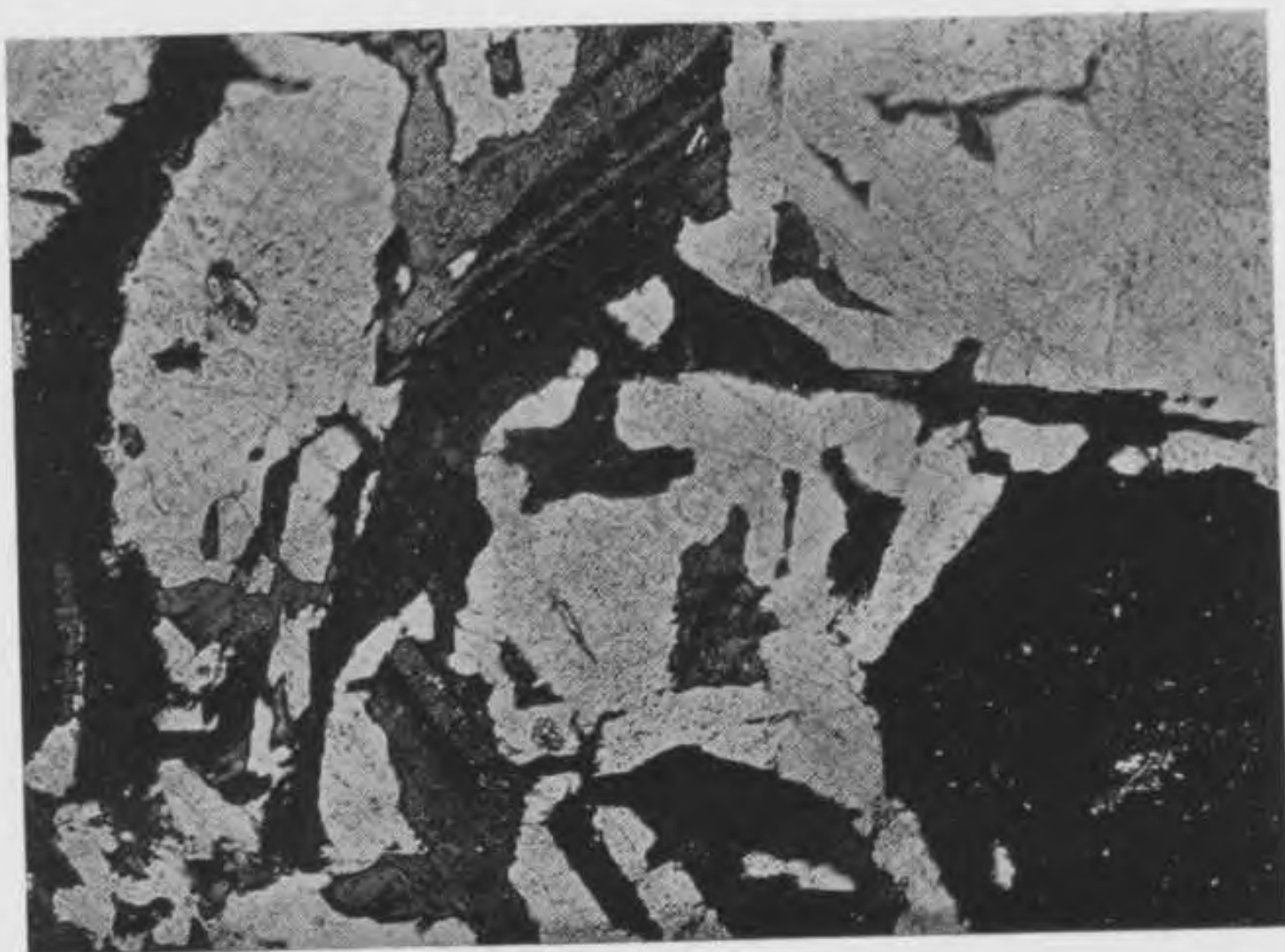


Fig. 1.

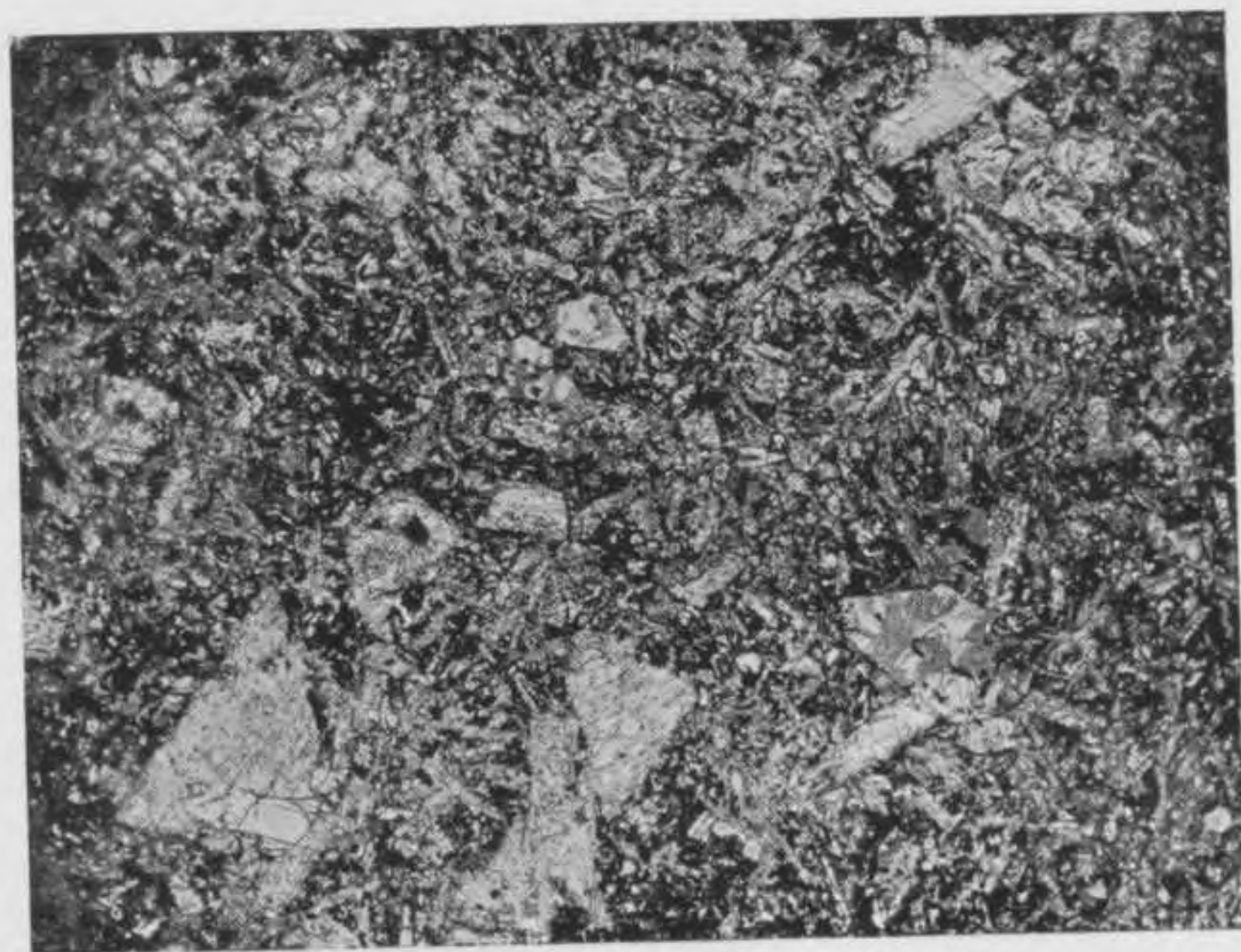


Fig. 2.

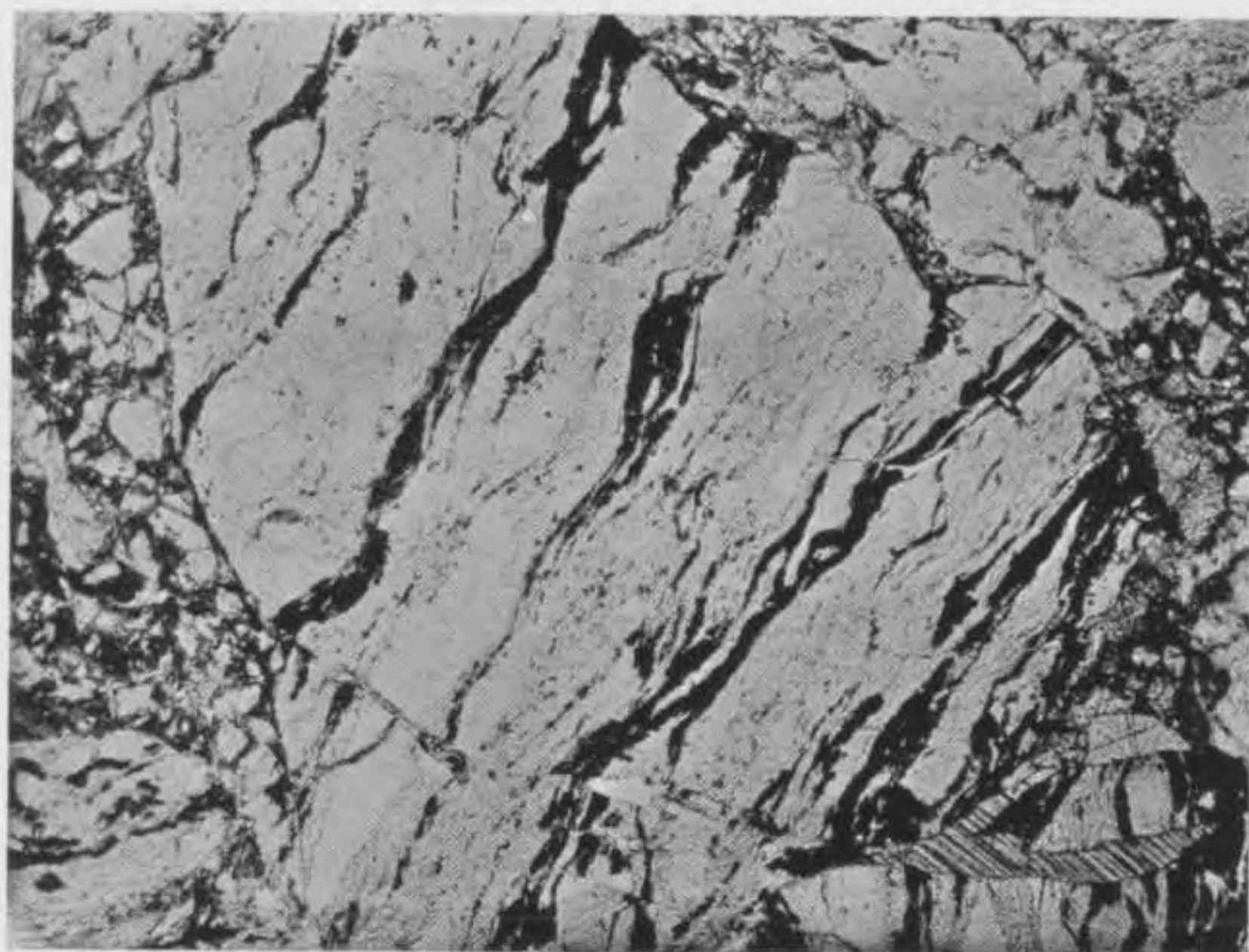


Fig. 1.

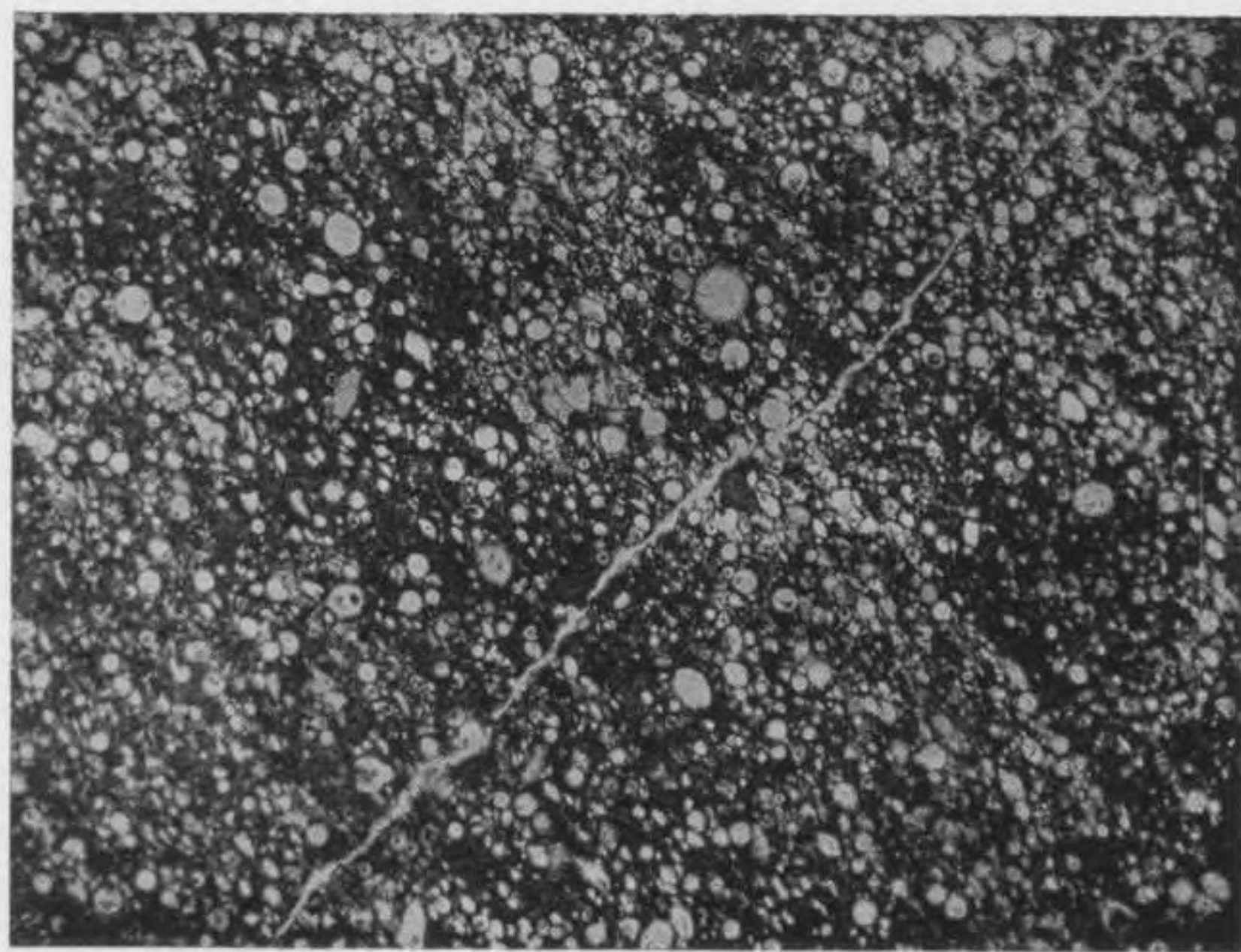


Fig. 2.

PLATE VI.

Fig. 1.

Volcanic breccia of strongly cataclastic keratophyres and quartz-keratophyres, found in the Noil Noni, upriver from Noil Toko (W 443 II b). The large quartz-keratophyre fragment in the centre has developed a strongly schistose texture, indicated by the dark coloured bands of epidote-minerals. Ordinary light ($\pm 23\frac{1}{4} \times$).

Fig. 2.

Radiolarian chert with an ore-rich matrix from the lower part of the Palelo-series. The rock was collected in tributary no. 10 (W 429 $\times$). Ordinary light (19 $\times$).

Many of the fragments, present in the *volcanic breccias* (Plate IV), are of the same type of albite-diabase as described above (W. 445 $\times$).

The grain-size and small changes in the proportion of the content of femic and salic minerals are the only changing features. Some types attain a considerable grain-size (felspar crystals of 0.7 mm). The fragments are on the whole more decomposed than the described rock W. 445 $\times$. All augite has been usually uralitized and chloritized and only the augite outlines have often been faintly retained to prove the derivation from this mineral. This is especially the case in the coarser-grained types. The uralite is always of the same variety as described in W. 445 $\times$. The chlorite occurs in the two varieties penninite and clinocllore. The plagioclase has a composition, varying between albite and albite-oligoclase. The mineral often has a pellucid character but is at the same time never entirely free from inclusions, consisting especially of numerous chlorite scales. Epidote-minerals and carbonate are always present in varying quantities. The same can be said of the oxidic iron ores (usually titaniferous), which have always partly and sometimes entirely changed into leucoxene and titanite.

The fragments are frequently traversed by veinlets, which are filled with epidote-minerals, carbonate and quartz, while smaller veins sometimes contain albite.

Several fragments contain a certain, but never large, content of primary quartz in the interstices, which sometimes forms graphic intergrowths with the felspar of the rock. These rocks are of a more leucocratic type and usually less decomposed. The quartz in the interstices is often accompanied by numerous apatite needles, but the needles occur also irregularly scattered through the rock. The albite is always very clear. The femic constituents are chloritized and nothing can be said of the original femic minerals. The chlorite in these rocks is sometimes of another, spherulitic type and is strongly pleochroic: n_γ (= dark green) = n_β > n_α (= light yellow-brown). Other secondary minerals as epidote-minerals, leucoxene and titanite are very subordinate. These rocks are comparable with the quartz-augite-albitites described earlier. They contain however a lower content of quartz and are of a coarser grain.

5. KERATOPHYRES AND QUARTZ-KERATOPHYRES.

Several samples of keratophyres were collected as sill-like intrusions in the crystalline schists and will be described first. They were found in the nearest vicinity of each other (W. 295, W. 408 $\times$, W. 409 $\times$).

The volcanic breccias, described on page 18, are for a certain part composed of fragments of keratophyres and quartz-keratophyres, which

are of more leucocratic types than the former keratophyres (Plate VI, fig. 1). They will be described later (W. 443× I, W. 443 B).

Description.

The *keratophyres*, which are found to be intrusive in the crystalline schists are greenish, always more or less crushed rocks, which are sometimes somewhat schistose. Macroscopically nothing can be said about the nature or the composition of the rocks.

The following microscopical description is a summary of the slides W. 295, W. 408× and W. 409×. W. 408× is less influenced by tectonic pressure and still shows the original structure of the rock; W. 295 is of a strongly crushed sample and the sample W. 409× has become distinctly schistose.

The rocks are mainly composed of subhedral to euhedral albite crystals with a lath-like habit. The albite lies in a mesostasis of secondary chlorite, carbonate and subordinate leucoxene. The larger part of the chlorite and probably also of the carbonate, are to be considered as alteration products of the original femic constituents. It is very difficult to get a clear idea as to the content of femic constituents of the unaltered original rock. This content, however, must have been smaller than that of an albite-diabase, but greater than that of the keratophyres, which occur as fragments in the volcanic breccias. The keratophyres here described are to be considered as intermediate between the two last mentioned types.

The structure of the rock is somewhat porphyritic (W. 295) with phenocrysts of albite. No texture is discernible, but the felspar-laths are sometimes arranged in sub-variolitic growths. The cloudiness of the albite is caused by innumerable tiny scales of chlorite and sericite. The albite is commonly twinned according to the albite- and Carlsbad-laws. The crushing resulted sometimes in a very clear, second generation of albite, which recrystallized in places of lesser pressure (W. 295).

The pale green chlorite is usually present in two varieties. Both are very weakly birefringent (practically isotropic). One variety shows abnormal bluish interference colours and positive elongation; the other variety shows abnormal brown interference colours and negative elongation. The latter variety of chlorite seems to become gradually more important at the expense of the former variety, in proportion to the higher grade of crushing which the rock has reached. The less crushed rock W. 408× contains practically only chlorite of the former variety, W. 295 both varieties and W. 409× practically only chlorite of the latter variety.

Epidote-minerals are sometimes present in small quantities (W. 408×)

and also quartz, which is probably derived from infiltration, like part of the carbonate. Both last mentioned minerals occur in veinlets, which cut through the rock (W. 409 $\times$). Pyrite is also a rarely observed vein-mineral.

There further seems to be a connection between the cloudiness of the feldspar and the grade of crushing, which the rock has reached. This is very clearly demonstrated in the successive samples W. 408 $\times$, W. 295 and W. 409 $\times$, arranged in the order of increasing influence of pressure. W. 409 $\times$ has developed a definite schistose texture as a consequence of strong crushing forces. Accompanying recrystallization caused the development of abundant sericite, chlorite and carbonate, probably at the expense of the albite. The chlorite (of the clinoclone variety with negative elongation) is intimately intergrown with the sericite. The albite phenocrysts have been broken in fragments, which are now lying in a matrix of chlorite, sericite, carbonate and leucoxene. A part of the chlorite (second generation) must have grown on after the crushing of the rock, as it is found in the cracks of the rock.

Different types of *keratophyres* and *quartz-keratophyres* occur as fragments of the volcanic breccias at the base of the lower Palelo-series; they all belong to very leucocratic types and are practically wholly composed of albite and quartz. The structure is always porphyritic with phenocrysts of feldspar or of feldspar and quartz in a mesostasis of quartz and albite. Femic constituents are very scarce and occur only in very subordinate amounts. The quartz-keratophyres differ from the keratophyres in that the former rocks contain quartz phenocrysts (2).

These keratophyres and quartz-keratophyres are always more or less cataclastic. This feature may even lead to mylonitic textures (Plate VI, fig. 1). The following description is applicable to fragments, which show the least cataclastic effects (W. 443 $\times$ I, W. 443 III B).

The structure of all the keratophyres and quartz-keratophyres is porphyritic with phenocrysts of feldspar (albite to albite-oligoclase) or of feldspar and quartz phenocrysts, as already stated. The groundmass is composed of small feldspar-laths, which lie in an allotriomorphic groundmass of quartz and feldspar. This allotriomorphic mass may sometimes become felsitic. The only femic constituents are chlorite, granules of epidote-minerals and oxidic iron ore, both of which are usually very scarce and are only present in the groundmass. The rocks show frequently flow-textures with parallel arrangement of the albite-laths (trachytic texture).

The plagioclase occurs — as can be deduced from the above — in three generations: as phenocrysts, as small albite-laths embedded in the groundmass and as allotriomorphic albite granules in the groundmass itself.

The phenocrysts are of albite to albite-oligoclase and sometimes show idiomorphic outlines, but these are usually destroyed by cataclasis. Undulose extinction, bending and fracturing is often observed. The plagioclase-lamellae sometimes show stepfaulting. The size of the phenocrysts is of 0.5 to 1.5 mm. Carlsbad-twins are common, while albite-lamellae also frequently occur. The lamellae are always narrow and often short and indistinct. The albite-laths in the groundmass, which form the predominating part of the mesostasis between the phenocrysts, are often well-developed and also twinned according to the albite- and Carlsbad-laws. The laths are of the order of 0.1 to 0.3 mm in length and sometimes larger.

The allotriomorphic micro-granular to felsitic groundmass is composed of an irregular mass of quartz and feldspar grains in about equal amounts. The feldspar is probably also albite, although the only determinable optical property is its low refringence as compared with that of the quartz, while faint albite-lamellae are sporadically developed. It is possible that this groundmass crystallized as a primary micro-granular to felsitic groundmass. It is however equally possible that the groundmass is representing the recrystallized original glass-base of the rock, as all these rocks underwent a certain degree of recrystallization under pressure, which is also shown by the structure of the rocks. In this case the structure of the groundmass should be rather called micro-granoblastic.

The quartz is sometimes present as phenocrysts, which in all cases observed, are more or less influenced by pressure. The quartz in the groundmass is of much greater importance. The mineral here occurs as allotriomorphic granules in equal amounts as the feldspar. The quartz and feldspar granules border upon each other with very irregular outlines and the difference in refringence between the two minerals is the only means of distinction.

Apatite occurs sporadically in small hexagonal prisms; chlorite, epidote-minerals and oxidic iron ore are also present. The chlorite is always very weakly birefringent, pale green and almost non-pleochroic. The mineral shows weak bluish or brownish abnormal interference colours, with respectively positive and negative elongation. This mineral occurs in one instance in larger quantities in the groundmass (W. 443 III B) together with oxidic iron ore. Oxidic iron ore may be abundant and is sometimes the only femic constituent of the rock. The mineral occurs rarely in larger

crystals, but is usually regularly distributed through the rock in numerous particles. Part of it has altered into leucoxene.

The keratophyres and quartz-keratophyres just described are only slightly cataclastic. The cataclasis may become more and more important however and mylonitic textures may develop (Plate VI, fig. 1). All intermediate stages are represented in the various fragments of the breccia (W. 443 IIa, W. 443 IIb). In the course of this development it becomes apparent that the quartz is much more liable to yield to pressures than the felspar. The quartz-phenocrysts are already broken up into a flattened and elongated aggregate, when the albite phenocrysts are still only bent and broken. The breaking down of the felspar seems to take place with the formation of epidote-minerals, which are seen to aggregate along certain bands in the rock, which accentuate the texture. The epidote-minerals in these bands mostly form turbid, very fine-crystalline aggregates. The final stage observed is a micro- to crypto-crystalline groundmass of quartz and felspar in which the angular porphyroclasts of felspar and the elongated and flattened porphyroclasts and aggregates of quartz are lying. The latter are always parallel to the schistosity, which is indicated by the bands of epidote-minerals. Accessories are a little chlorite, oxidic iron ore and titanite. Sometimes small isolated segregations of a pale green amphibole are found. This mineral is without idiomorphic outlines.

6. SPILITIC ROCKS.

Of these rocks three different types were found. One occurs in contact with the Fatoe Kesnaam (W. 212) and is the most leucocratic type. Another is found shortly north of the point where the Noil Poepmano enters the eastern schist-complex (W. 426). The third type occurs as fragments in the volcanic breccia at the base of the lower Palelo-series (W. 443 III A, W. 436^x).

Description.

The *spilitic rock* at the Fatoe Kesnaam (W. 212) is a darkly weathered, very decomposed rock. The rock shows a yellowish green colour on the fracture. Nothing can be said about the composing minerals. Microscopically the rock is composed of plagioclase, augite — which is only partly fresh — chloritic and serpentinous minerals, carbonate, epidote-minerals, oxidic iron ore, leucoxene and titanite.

The rock is strongly reminiscent of the porphyritic albite-diabase described on page 86 (W. 255 $\times$); it is of a finer grain size and shows flow-textures. The structure is porphyritic with phenocrysts of feldspar and less frequently of olivine-pseudomorphs in a groundmass of feldspar-laths with interstitial chlorite. The original structure of the groundmass may have been sub-ophitic. Glomeroporphyritic aggregates of feldspar, olivine-pseudomorphs and subordinate augite occur at several places in the rock.

The plagioclase is present as phenocrysts of 1.5 to 2 mm in a groundmass with feldspar-laths of 0.2—0.3 mm. The feldspar is strongly chloritized and filled with numerous inclusions of different character. Sericitization is rarely observed. Its blotchy appearance is a characteristic feature (see p. 87). The composition of the very turbid feldspar is difficult to ascertain, but the optical properties point to albite. The fresh augite is only of subordinate importance and of the usual variety. The mineral has a granular habit. Part of the serpentinous and chloritic minerals of the rock may be derived from augite and the original content of augite in the rock is therefore not known.

The olivine-pseudomorphs — of serpentinous minerals, carbonate and epidote-minerals — occur also in at least two generations, namely as phenocrysts and as smaller individuals in the groundmass. They still have the boundaries of the original olivine crystals. The characteristic mesh-structures have often been preserved. The serpentinous minerals are of the usual, very weakly birefringent varieties of chrysotile and antigorite. In the groundmass there occurs a large amount of chloritic and serpentinous material, part of which may be derived from augite (see above) but another part may be derived from olivine as well. Oxidic iron ore is abundant in the rock. Large quantities have changed into leucoxene and titanite. Carbonate occurs as an alteration product of the feldspars and also of the olivine. Granules of epidote-minerals are also abundant. The oxidic iron ore, leucoxene, titanite and epidote-minerals are regularly distributed through the rock.

The *spilitic rock* from the vicinity of the Noil Poepmano (W. 426) is a dull coloured, dark red and dark green, strongly crushed, very fine-grained rock. Nothing betrays the eruptive character of the rock.

Microscopically we see a strongly decomposed rock, consisting of plagioclase, augite, oxidic iron ore, epidote-minerals, chloritic minerals, leucoxene, titanite, carbonate and quartz.

The rock is to be considered as a strongly epidotized spilite of a type, which has been elaborately described from the S.W. Moetis region by

DE ROEVER (21, page 254—255). The typical arrangement of the slender felspar-laths is a very characteristic feature. They are bunched together in delicate, slightly diverging aggregates, which are branching and rebranching in a tree-like fashion. The felspar aggregates are also forming sub-variolitic structures. The mesostasis between the felspar-laths is composed of augite-granules, epidote-granules, chloritic minerals, titanite-granules and minute crystals of primary oxidic iron ore. The strong decomposition of the rock made the determination of the composition of the plagioclase impossible. The small extinction-angles of the felspar-laths and the similarity to the spilites of the S.W. Moetis region make it acceptable, that the felspar is albite.

The purplish augite usually occurs as numerous small granules, which are arranged in a string-like fashion between the felspar-laths. Small prisms are occasionally observed. The high oblique extinction angle is distinct. The augite granules have largely changed into chlorite, epidote-minerals and turbid compounds of indefinite composition. The oxidic iron ore also occurs in strings between the felspar-laths.

Epidote-minerals, which are distinctly pleochroic, occur as very important secondary constituents of the rock and also in the vesicles and in the veins of the rock. Chlorite is another secondary mineral of widespread occurrence and may be partly derived from augite, while titanite and also leucoxene originated largely as decomposition products of titaniferous iron ores. The vesicles are filled with epidote-minerals and chlorite. The rock is extensively veined. The veins are filled with carbonate, epidote-minerals and quartz.

The typical olivine-pseudomorphs described by DE ROEVER from similar rocks, were not observed in this rock, but the strong decomposition of the rock may be responsible for this fact and the rock may have had an original content of olivine.

The *volcanic breccias* also contain fragments of spilitic rocks (Plate IV). These rocks are largely decomposed in the same manner as the albite-diabases in the same volcanic breccias. They are composed of the same minerals. The content of femic constituents usually seems higher than in the albite-diabases. Certain types are porphyritic with phenocrysts of albite in a highly decomposed chloritic mesostasis, against which the very small and clear felspar-microlites stand out clearly. The phenocrysts are sometimes micro-phenocrysts of albite and uralite in a still more decomposed, probably originally glass-rich mesostasis, in which felspar-microlites occur in very small quantities.

III. SEDIMENTARY ROCKS.

In the following pages descriptions of sedimentary rocks of the investigated region — especially of rock-types from the lower and upper Palelo-series — will be given. The two specimens described from the upper Palelo-series are chosen, because the phenomenon of albitization is well-shown in them.

Finally the result of a sedimentary petrological investigation of several young-Tertiary rocks and the petrographical description of a young-Tertiary calcareous tuff is given.

1. RADIOLARIAN CHERTS OF THE LOWER PALELO-SERIES.

Radiolarian cherts of the lower Palelo-series occur at several places in the Noil Noni and are always encountered near the boundaries of the schist-complexes (W. 221 $\times$, W. 223 $\times$, W. 332 $\times$). Good exposures are also found in the tributaries Noil Poepmano, Noil Koko, No. 10, No. 11 and No. 12 to the Noil Noni (W. 429 $\times$ in No. 10). In one exposure along the road from Noil Toko to Kefamenanoe W. 427 was found.

Description.

The cherts are partly dark coloured and partly light coloured. The darker ones are more confined to the base, while the light coloured cherts are more abundant in the higher portions of the chert-series. Both varieties are largely composed of radiolarian shells; the basal cherts have usually an ore-rich matrix (W. 429 $\times$, Plate VI, fig. 2), whereas the upper cherts on the contrary are more calcareous (W. 223 $\times$) or sometimes rich in chloritic substance (green colour) or also in clayey substance (W. 427). The radiolaria are practically always recrystallized and the original structures have only rarely been preserved e.g. when the shell has become impregnated with chloritic substance. Pressure effects are sometimes demonstrated by the oval forms of the originally round radiolarian shells and the recrystallization of the cementing substance. The chert may even become weakly phyllitic. This last phenomenon is expressed by the development of numerous very small scales of colourless mica, with a parallel arrangement (W. 427). The last characteristic is important in

view of the assumed connection between the low-metamorphic part of the crystalline schists and the radiolarian cherts (p. 22). Radiolarian chert-breccias are also often found in the Miomaffo region. One specimen (W. 221 $\times$) is of a green colour and is composed of fragments of radiolarian cherts with a chloritic to clayey matrix. Fine banding is a common characteristic of the cherts. The lighter coloured bands possess a higher content of radiolarian shells, than the darker coloured ones.

2. ROCKS OF THE UPPER PALELO-SERIES.

The best exposures of these rocks are also found in the Noil Noni (W. 185 $\times$, W. 186, W. 186 $\times$, W. 187 $\times$, W. 195 $\times$, W. 227 $\times$, W. 227, W. 228 $\times$, W. 228, W. 231 $\times$), in the tributaries to the Noil Noni mentioned above and in the Noil Koko (W. 347, W. 347 $\times$, W. 351 $\times$). In the Noil Saen, tributary to the Noil Poepmano is found another good exposure of upper Palelo-rocks (W. 237, W. 238 $\times$).

Description.

The upper Palelo-series is composed of the following rock-types:

Greywacke-sandstones (W. 195 $\times$, W. 227 $\times$, W. 351 $\times$), clayey greywacke-sandstones (W. 185 $\times$), calcareous greywacke (W. 231 $\times$), glass-rich greywacke alternating with shale (W. 238 $\times$), greywackes (W. 227), marls (W. 186 $\times$, W. 228 $\times$), calcareous crystal-tuff (W. 186, W. 347), andesitic tuff (W. 237), conglomerates (W. 332), *Globigerina*-limestone with green radiolarian chert inclusions (W. 187 $\times$).

The different rock-types are named in an order independently of the relative abundancy of the rock-types in the series.

Petrographical descriptions of diverse rocks of the Palelo-series have been published by BROUWER (3), who described several rock-types, which were all collected in the mapped region. TAPPENBECK (26) described especially volcanic rocks from the Palelo-series in the Mollo region. BROUWER described greywackes, greywacke-sandstones, calcareous sandstones and conglomerates, which were collected in the Noil Noni downstream from Noil Toko. The descriptions correspond in every respect with the rocks mentioned above. It is appropriate to call the attention to a special characteristic of the Palelo-sedimentaries, namely to the phenomenon of albitization.

This phenomenon is demonstrated in many of the volcanic fragments and pebbles of the upper Palelo-rocks (W. 347 $\times$), while in one case the rock itself was also partly albitized (W. 227 $\times$).

The volcanic fragments of the Palelo-rocks largely consist of felspar fragments and of fragments of felspar-rich lavas. The felspar fragments are of albite, of partly albitized plagioclase and of plagioclase without albitization phenomena. The felspar in the lava fragments is also often albite or partly albitized plagioclase or non-albitized plagioclase. The plagioclase is usually of the composition of medium andesine.

It is a peculiar fact that the polymikt sedimentaries as e.g. the greywackes, the greywacke-sandstones etc. are very rich in albite (W. 227 $\times$), whereas the volcanic tuffs still contain a large amount of partly altered or unaltered plagioclase (W. 347 $\times$).

The lava pebbles of the Palelo-conglomerates are usually of porphyritic augiteandesites. The plagioclase is often albitized, but also zeolitized, chloritized and carbonitized. The augite is on the contrary frequently still fresh and unaltered (W. 332).

A *partly albitized, felspar-rich greywacke-sandstone* from the Noil Noni, downstream of Noil Toko (W. 227 $\times$) is a very hard rock of a bluish green colour, in which no stratification is visible. The impression is macroscopically that of a medium-grained leucocratic dyke rock, but under the microscope the clastic origin of the rock is obvious. It is a greywacke-sandstone, which is composed of the following mineral and rock fragments, named in the order of decreasing importance: plagioclase, quartz, fragments of volcanic origin, schist fragments, epidote, chloritic and serpentinous material, and furthermore small quantities of biotite, colourless mica, garnet, apatite, titanite, prehnite and some iron ore. The cementing substance is scarce and consists partly of carbonate and chloritic material and partly of albite. The rock is for about one half composed of felspar fragments and for about one fourth of quartz fragments. The plagioclase fragments have the composition of albite to albite-oligoclase. They are of different appearance. They are sometimes pellucid and sometimes turbid by chloritization, sericitization, carbonatization and other alteration processes. The former group usually consists of fragments derived from crystalline schists. This is revealed by their inclusions, which may consist of graphitic material, of irregular, clear grains of quartz, epidote, titanite and sericite. The turbid albite fragments are partly certainly derived from albite-rich igneous rocks of which small fragments occur also in the discussed rock. The quartz fragments are often undulose and probably for the greater part derived from crystalline schists, although a derivation from certain quartz-rich igneous rock-types may also have formed a source. The schist fragments are mainly represented by some-

times graphitic quartz-albite schists with colourless mica, epidote-minerals and titanite. Graphitic mica-schists, sericite-chlorite-schists and sericite-chlorite-quartzites are more rarely observed. The fragments of volcanic origin are of various types, which contain varying quantities of femic constituents and which also show differences in the habit of the felspar-mineral. The femic constituents are practically always entirely altered into a green chloritic substance, except sometimes the oxidic iron ores. All types are rich in felspar, which mineral usually occurs in small laths, but also as allotriomorphic grains of a micro- to crypto-crystalline groundmass. Many of the igneous rocks are porphyritic and in these types the nature of the felspar could be established as albite. The felspar-laths in the groundmass have small extinctions up to $\pm 7^\circ$ and are probably also albite. Part of the large, turbid albite fragments must have been derived from these igneous rocks (see above). The epidote-minerals are regularly distributed through the rock and occur as rounded fragments, idiomorphic crystals and in turbid aggregates. Part of this mineral is to be considered as of detrital origin, but many of the idiomorphic crystals have been probably formed in situ. The chlorite is of the usual two varieties, penninite and clinochlore. A nearly isotropic variety of blue-green colour is also present, while the chlorite occurs also in indeterminable, turbid aggregates between the rock fragments. A few grains of garnet, of weakly birefringent prisms of apatite (with negative elongation) and of titanite as grains and small aggregates, were also observed. Sericite flakes occur irregularly scattered through the rock and only a few strongly pleochroic, brown biotite flakes occur. Prehnite is present in a small, single aggregate. The cementing substance of the rock is scarce as already stated and consists of carbonate, usually well-crystallized, sometimes showing pressure effects (pressure twin-lamellae) and chloritic material. A peculiarity of this rock is the occurrence of a third kind of cementing substance, namely of albite. This substance is not only encircling the fragments, but is seen to attack them at the same time from all sides. This is clearly seen in the corroded appearance of the attacked fragments, while the substance often penetrates into them independently from cracks and cleavages. In this way the fragments are gradually replaced by the cementing substance, in a metasomatic way. All fragments seem to be affected by this process of replacement, although the felspar and quartz fragments are apparently more susceptible and are clearly more easily replaced than the other fragments. The albitic cementing substance must have been introduced into the rock after its sedimentation. Its refringence is sometimes practically the same, usually somewhat lower

than the refraction of the feldspar fragments in the rock and always lower than that of the balsam. The cleavage is usually well-developed, especially the (001) cleavage. The mineral is biaxial positive; twin-lamellae were not observed. The cementing albite is sometimes seen to show simultaneous extinction over moderately large areas. It is never wholly clear, but full of very small inclusions.

The rock described is obviously a feldspar-rich greywacke-sandstone, which has been partly albitized. It is to be noted that the richness of the rock in albite fragments and in fragments of albitic lavas, has nothing to do with the later albitization process, but that these fragments are primary detrital constituents of the sedimentary rock and were present before the albitization of the rock itself began. They must therefore have been derived partly from albite-rich crystalline schists and partly from albite-rich igneous rocks (see above).

A *calcareous feldspar-tuff* from the Noil Koko (W. 347 $\times$) is of a dark green colour, medium grained and very hard.

Under the microscope the rock is a weakly stratified calcareous tuff. The rock is largely composed of feldspar fragments and fragments of volcanic rocks, while iron ores, chlorite and epidote are present in very subordinate quantities. The fragments are embedded in a calcareous matrix.

The feldspar fragments are of plagioclase with the composition of medium andesine (35 % to 45 % anorthite). The fragments are often idiomorphic. Rounded fragments are rare. They attain sizes of ± 1 mm. A zonal structure and twinning according to the albite-, Carlsbad- and pericline-laws are common features. Combinations of these laws are often observed. The feldspar contains inclusions of isotropic glass. Sometimes perfect small prisms of apatite were observed as inclusions. The plagioclase fragments are derived from andesitic lavas. This is proved by the lava fragments in the rock, many of which are porphyritic with phenocrysts of medium andesine. The plagioclase fragments are often carbonatized and rarely sericitized; sometimes pseudomorphs of carbonate after the feldspar occur. A most interesting phenomenon is the albitization to which most of the feldspar fragments and part of the lava fragments, were subjected. The albitization of the fragments is a process of replacement, which is taking place along different lines. The process often starts somewhere in the plagioclase crystal and from here proceeds onwards. Sometimes the more basic cores are attacked first. The albite is easily recognized because its refringence is much lower than that of

the andesine, while its extinction angles are smaller. The albite forms homogeneous, irregularly bounded masses within the original plagioclase. The twinning of the original feldspar appears to be copied by the albite, while it could be observed in sections of the symmetrical zone, that within any particular twin-lamellae the extinction changes sign when passing the boundary between the albite and the original plagioclase (1). Equally often we see that the andesine fragment is veined with a network of branching and rebranching veinlets filled with a mineral with a much lower refringence than the andesine. The substance in all the veinlets is seen to extinguish simultaneously. The nature of this mineral could not be established but it is probably also albite. This alteration process proceeds outwards from the veins by attacking the remaining parts of the original plagioclase, encircled by the veinlets.

The usually angular lava fragments are mostly strongly decomposed, while many of them are partly or entirely carbonatized. The feldspar constituents in them are always altered into a chloritic mass, while the original iron ores and the glass-base are usually changed into a brownish mass. The feldspar is often still fresh and usually of a lath-like habit. All lava-types are feldspar-rich, while their structure is often porphyritic, with phenocrysts of feldspar; albitization of these phenocrysts is often observed. The composition of the feldspar is usually the same as of the feldspar fragments in the rock (medium andesine). Most lava-types are therefore of an andesitic nature. Keratophyric lavas in which all the feldspar is probably albite, are also present. Their structure is not much different from the normal andesites.

Small quantities of pyrite are present in the rock, while some grains of epidote-minerals and some chlorite flakes occur sporadically. The rest of the rock is composed of the calcareous cementing substance, which is present in subordinate quantities; the feldspar and lava fragments namely form more than half of the rock.

Albitization played an important part in the fragments of this tuff. It could not be established whether the albitization of the feldspar and lava fragments took place after the sedimentation of the tuff.

3. YOUNG-TERTIARY ROCKS.

About 35 sedimentary petrographical analyses were made of diverse rocks of the young-Tertiary series. The results of these analyses are laid down in four tables (see also fig. 4).

Two different mineral associations can be clearly distinguished.

The first and most important association is the augite-hypersthene

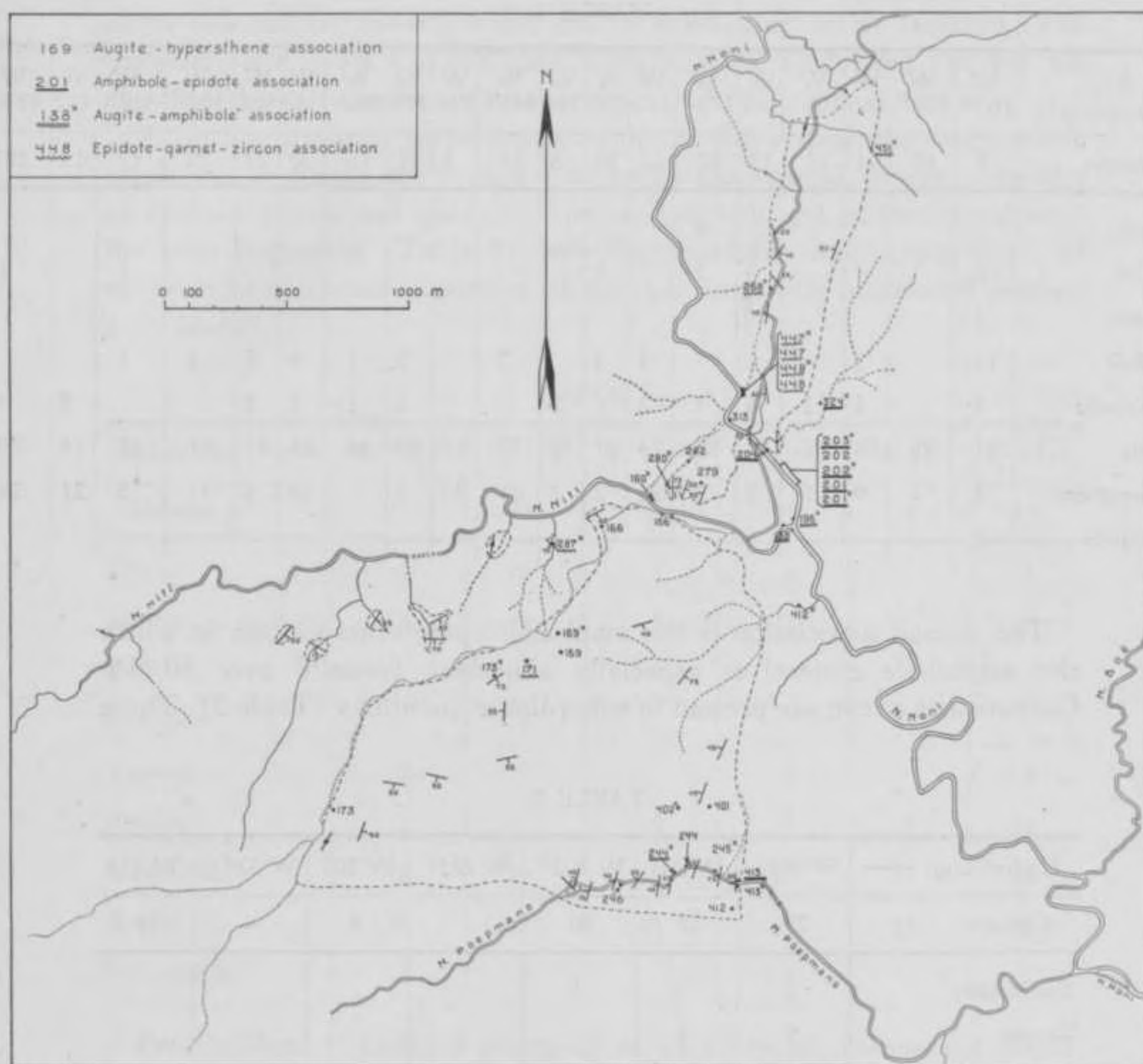


Fig. 4.

Map showing the extension of the young-Tertiary rocks (marked by ---) in the investigated region, with the numbers of the collected samples mentioned in the sedimentary petrographical tables 1—4.

association (tuff association). The relative amount of augite is practically always higher than that of hypersthene, except in one case (W. 245 $\times$). Subordinate quantities of epidote and amphibole are usually present, while garnets sporadically appear. These minerals are partly derived from the crystalline schists (Table 1).

TABLE 1.

No underlining ¹⁾	W 160×	W 166×	W 166	W 169×	W 169	W 173×	W 173	W 202	W 244	W 245×	W 246	W 279	W 280×	W 313	W 401	W 402×	W 412×	W 412	W 413×
Opaque	6	10	4	17	13	62	10	50	8	15	5	15	15	20	22	20	42	13	22
Zircon						4													
Garnet	1					3		1									1		1
Titanite	1																		
Epidote	11		2		1		1	4		2		3	1	4	2	2	1		
Amphibole	2		1	2	6	4	2	6	3			5	1	2	2			5	4
Augite	81	99	88	97	88	86	74	87	88	37	67	89	98	84	91	47	95	74	79
Hypersthene	3	1	9	1	3	3	28	2	7	61	33	3		10	5	51	3	21	16
Monazite	1																		

The second association is the amphibole-epidote association in which the amphibole mineral is especially abundant (usually over 50 %). Garnets and zircon are present in subordinate quantities (Table 2). These

TABLE 2.

Underlining: —	W 201×	W 201	W 202×	W 203×	W 204	W 324×	W 413
Opaque	27	23	20	—	4	—	26
Tourmaline	1		1				
Zircon	2	1		1			
Garnet	5	4	10	1			1
Rutile	1				2	1	
Titanite	2	2		1			
Staurolite							2
Epidote	26	30	38	19	32	16	24
Amphibole	62	61	50	76	66	83	74
Augite		1	1	1			
Hypersthene	1						

¹⁾ for underlining see map.

rocks are almost entirely build up of crystalline schist material. The conglomeratic strata e.g. the basal conglomeratic limestones (p. 36) are showing this association of minerals.

A certain group of rocks shows augite in dominating quantities, while amphibole is usually the second most important mineral. Minor quantities of epidote, zircon and garnet are present as well and of these epidote is the most important (Table 3). We may consider these assemblages of minerals as abnormal variations of the two previously mentioned mineral associations.

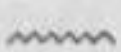
TABLE 3.

<i>Underlining: xxxxxxxx</i>	W 138×	W 171	W 196×	W 244×	W 282	W 451×
Opaque	—	63	40	63	6	33
Zircon	2	18	1	1		1
Garnet	8	4	5	1		3
Rutile		2				
Anatase		1				
Titanite	2	1		2		3
Epidote	12		9	7	2	14
Amphibole	46	19	19	17	17	36
Augite	29	52	65	69	81	43
Hypersthene	3	3		3		

Finally there is found a group of rocks, to which belong the *Globigerina*-limestones (p. 36), which show certain peculiarities in the composition of their heavy mineral assemblages (Table 4). All these rocks show the mineral association epidote-garnet-zircon, while rutile, titanite, amphibole and augite are the most important minerals present in minor quantities. It is however apparent that the mutual relative quantities of the different minerals are extremely variable for every other rock in this group. The relative amount of amphibole e.g. in W. 447×, 25 % and in W. 448× is only 6 %; the relative amount of zircon in W. 447× is 1 % in W. 448×, 23 %. Besides this we see that a decrease in the relative amount of the garnet goes hand in hand with an increase in the relative amount of the zircon, while the reverse is also true. Almost all the heavy minerals from this assemblage can be derived from the crystalline schists

encountered in the Miomaffo region, except the mineral zircon and especially when this mineral is present in larger amounts. This mineral may be derived from rocks of the Sonnebait-series or Kekneno-series.

TABLE 4.

<i>Underlining:</i> 	W 268×	W 287×	W 447×	W 448×	W 448
Opaque	44	33	—	80	49
Tourmaline		3		2	
Zircon	3	45	1	23	30
Garnet	28	6	16	11	5
Rutile	2	4	4	6	8
Brookite	11	1			1
Titanite	7	7	6	6	6
Staurolite					2
Epidote	41	1	43	45	33
Amphibole	7	5	25	6	11
Augite	11	28	5	1	3
Hypersthene					3
Chromite					3

The distribution of the different rock-types is clearly shown on a map (fig. 4) and every mineral association has been marked with a special underlining. It will be noted that the last three heavy mineral assemblages preferably occur along the formation boundaries of the young-Tertiary rocks, where the lower parts of the series are exposed. The tuff association is especially represented in the central parts of the area covered by the young-Tertiary series, where the upper parts of this series are found.

A single specimen of a young-Tertiary tuff will be described in detail. The *calcareous tuff* was found in the Noil Noni (W. 313) close to Noil Toko (fig. 4). The rock is macroscopically a white coloured, fine-grained, weakly stratified sedimentary rock. Dark green crystals of augite are discernible against a white background.

The rock is composed of volcanic fragments lying in a cementing substance of carbonate. The volcanic fragments consist of quartz,

plagioclase, augite and glass-particles. Furthermore small quantities of serpentinous and chloritic minerals, sericite, epidote-minerals and iron ores are found.

The quartz occurs in angular fragments with numerous cracks. The mineral is very clear; the fragments often possess a rim of rose-coloured isotropic glass, pointing to the volcanic derivation of the mineral. The felspar fragments are also very angular, show commonly a zonal structure and are very pellucid. Often they still show idiomorphic outlines and contain irregular inclusions of brownish- or rose-coloured volcanic glass. The composition of the plagioclase is usually that of acid to basic labradorite, but may also reach that of basic bytownite. The augite fragments are far less abundant than the two preceding types of fragments. The augite shows $n_y/c = 50^\circ$; the crystals have usually well-developed crystal-faces. The colour is light yellow-green. Twinning according to (100) is often observed. The augite crystals show also irregular cracks independently of the cleavage, like the quartz and felspar crystals; these cracks are filled with carbonate. The augite contains glass-inclusions as well.

An important part of the rock is composed of a practically isotropic substance, which often shows a stemlike habit. The stems are finely striped over their entire length; they show between crossed nicols only a very weak birefringence. This substance is further distinctly lower refringent than the balsam and is to be considered as slightly devitrified volcanic glass (20). Less important are rounded, brownish, more or less decomposed lava fragments, in which small undecomposed felspar-laths are visible. Of the subordinate iron ores are to be mentioned oxidic iron ores, pyrite and limonite.

The result of a sedimentary petrographical investigation of this rock is given in Table 1 on page 106.

C. FIELD-OBSERVATIONS.

Some general remarks about the situation in the investigated region will be made first, which will be followed by descriptions of the most important sections surveyed in detail in the Noil Noni and its tributaries. We will also describe a small region near Kefamenanoe (p. 119), along the road to Wini, which was mapped in detail because of its importance in connection with the post-Oligocene tectonics.

The mutual boundaries between the various formations in the Miomaffo region are practically all more or less influenced by post-Oligocene tectonics. The majority of the boundaries are nevertheless comparatively easy to follow in the field. The boundaries between the Sonnebait-series and the Fatoe-complex are however very indistinct, as they are usually covered by many rock debris. The areas, which are occupied by rocks of the Sonnebait-series and the Fatoe-complex are for the greater part block-fields and the real country-rock in these areas is only locally exposed. This is especially true for the part of the investigated region, which is situated west of the trail from Noil Toko to Seoam. This part of the region is covered by a slope, which inclines steeply to the north. On this slope a huge landslide must have taken place judging from the chaotic manner in which rocks of many types lie about. The greater majority of the rocks belong to the Fatoe-complex, although isolated occurrences of young-Tertiary rocks, of Eocene limestones and of rocks of the Sonnebait-series are also present. On the map we used the notation of the Fatoe-complex for this whole area.

The region north of the Miomaffo and around the Noil Koko has not been investigated in detail, but it became clear that this region bears a much less chaotic structure than the region south of the Miomaffo and the region in the Noil Toko fault-trough. The crystalline schists, the Palelo-series and the old-Tertiary have here a much larger extension than is indicated on the map, and they seem to be well-exposed, which may be of interest for future investigations.

The drainage of the Miomaffo region is affected by the Noil Noni and its tributaries. The most important part of the sections surveyed in the Noil Noni and in the Noil Niti is where these rivers cross the depression between the two schist-complexes.

I. Section through the Noil Toko fault trough, based on data assembled in the Noil Noni (fig. 5).

In the northern part of the section where the Noil Noni leaves the crystalline schists of the Miomaffo complex, the dark green schists are crushed and folded to a high degree. Thick banks of crushed and brecciated schists are exposed. The breccias increase in number and magnitude, in the direction of the contact between crystalline schists and radiolarian cherts; at the same time fragments of radiolarian cherts become gradually more abundant, until they finally build up the whole breccia. At this point the transition to the lower Palelo-series, which series directly overlies the crystalline schists, is reached. The strike and dip of one particular breccia-bank was N 60° E, 75° S, but on the whole the dip changes frequently, while the strike remains fairly constant. The light brownish-green cherts are strongly folded (Plate II, fig. 2) and well stratified. The whole formation is not more than 70 m thick and frequently crushed, which make the cherts crumble down easily in angular pieces, when struck by the hammer.

With a last crush-breccia the radiolarites pass into sediments of the upper Palelo-series, here of an outspoken conglomeratic facies. The bedded character is still apparent, although tectonic movements reduced the normally several hundreds of metres thick formation to a thickness of not more than 30 m.

Immediately following these Palelo sediments there comes a zone of movement, proved to be the continuation of the first zone of movement in section II. In section II it is still more obvious that the tectonic movements involved must have been of an intense character, as they caused a notable thinning of the Palelo- and Eocene-series. The Eocene is only represented by a totally crushed mass of dark violet to brown marls and limestones, often full of Foraminifera. In this mass, many lens-shaped blocks of different rock-types occur, of which very great blocks of the upper Palelo-conglomerates are the most conspicuous. The prevailing strike of this contact-zone is N 60° E.

At the end of this zone, there occur vertically dipping banks of the greenish white to pink coloured *Globigerina*-limestones, which at the same time mark the beginning of the young-Tertiary deposits. The *Globigerina*-limestones yielded to the pressure in a special way by losing their original banked character, the banks becoming a kind of agglomerate of still connected rocklenses. This is the only section, in which the *Globigerina*-limestones show a gradual stratigraphical transition to the sedimentaries

and tuffs of the young-Tertiary, thereby proving that the *Globigerina*-limestones belong to this series and possess a corresponding age. This fact could also be established microscopically (p. 37, fig. 2). The strike of these vertical *Globigerina*-limestones is N 60° E.

The section continues in greenish clays and marls, calcareous tuffs and tuffs, with sometimes intercalated green schist-conglomerates, of the young-Tertiary. The bulk of the development is formed by the greenish clays and marls and the end of this part of the section is marked by the reappearance (in the Noil Upfoez) of the already described *Globigerina*-limestones. Strike and dip show an increasing adaptation to the N—S striking border of the approaching eastern schist-complex and, from N 60° E, gradually becomes N—S, which is at the same time the actual strike of the lastly named vertical *Globigerina*-limestones.

A little farther there comes a small exposure in strongly crushed practically vertical well-stratified white tuffs and tuffmarls of the young-Tertiary, which pass gradually into another zone of movement of the same character as already described. Lens-shaped fragments of Eocene-limestones, *Globigerina*-limestones etc. occur in a gouge of uncertain composition. At the end of a stretch of non-exposure probably still the same zone of movement occurs; it passes much in the same way as before into well-stratified alternately coarse- and fine-grained schist-conglomerates of a green colour. In the beginning these young-Tertiary conglomerates are mostly vertical, while their strike is varying; they are strongly crushed. Then strike and dip become more regular and for some time the strike N 30° E and dip 35° S remain constant. The green conglomerates are seen to merge into finer-grained sediments, mainly green clays, white to greenish white and yellow tuffs and calcareous tuffs, with occasionally an intercalated bank of a very hard, fine conglomeratic limestone with an old-Miocene Foraminifera-fauna. The young-Tertiary strata border, with a separating crush-zone, on a group of stratified variegated tuffaceous sediments, which in turn border directly on thickly, irregularly stratified upper-Triassic brachiopod-limestones. This crush-zone marks an important, nearly N—S striking longitudinal fault-zone, along which considerable movements must have taken place (p. 128). Many lenticular blocks of multi-coloured marls, probably belonging to the Sonnebait-series are abundant in this crush-zone. The tuffaceous sediments are composed of a few thick bands of a dark green tuff, a greenish-white tuffaceous rock and a light green volcanic glass. The dark green tuff owns its colour to its high content of chlorite. The rocks in question possibly belong to the Eocene volcanic series (p. 31).

The transition of the tuffaceous rocks to the brachiopod-limestones is also very disturbed. The brachiopod-limestones are beautifully exposed in this section. They are often somewhat marly, while real greenish grey marls occur as well. The genus *Misolia* fixes the age of these rocks as upper-Triassic (p. 14). The fatoe situated at the confluence of the Noil Niti and the Noil Noni, consists entirely of these limestones, which are full of corals, brachiopods, lamellibranchs and numerous other organisms. The yellow-, grey- and beige-coloured limestones are distinctly influenced by pressure, which influence caused a partial recrystallization of the limestones. Many of the limestones contain more or less detrital material, mostly felspar crystals of albite (see also p. 15). Remarkable is the change in strike and dip throughout this sequence. The strata immediately bordering the contact-zone have changing strike and dip; they are mostly vertical and their prevailing strike is N—S. But then gradually the strike from N—S becomes NW—SE and finally E—W. At the same time the dips change from vertical to 40° E and finally to 20° N. The eastward dips must be considered as of local importance and are probably due to the strong tectonic movements along the N—S striking fault, which here occurs between the upper-Triassic and young-Tertiary sediments. After a stretch of non-exposure in the section there follow brown-green greywacke-sandstones, which probably belong already to the upper Palelo-series.

After the greywacke-sandstones comes a last short stretch which is not exposed. Then appears an extremely complicated crushed and brecciated zone. A thick bank of totally brecciated brachiopod-limestone (N 30° E, vertical) of the upper-Triassic type, marks the beginning of this zone of movement. Immediately bordering upon it are a few metres of a grey-green to black gouge in which lens-shaped rock fragments occur; the fragments belong to various rock-types, among which schist fragments are the most important.

The crush zone terminates with a crushed bank of a dark green amphibolite, which borders directly on bluish lightgreen to redbrown well-stratified radiolarites of the upper Palelo-series, which are of a different type as compared with the radiolarian cherts described at the beginning of this section. That these cherts really belong to the upper Palelo-series, could be concluded from the rest of the section in which a transition from these radiolarian cherts to sediments which unquestionably belong to this series, is obvious.

The radiolarian cherts are followed by banks of *Globotruncana*-limestone. In this limestone, which consists practically entirely of

Globigerinidae, detrital fragments of green radiolarian cherts occur. The hard chert fragments stand out like knobs on the limestone surface and give the rock the appearance of a tectonic breccia W. 187 $\times$. The remaining part of the upper Palelo-series is mainly composed of grey-wacke-sandstones, calcareous tuffs and marls, all of dark grey to dark green colours.

The whole upper Palelo-series here is no more than about 60 m thick and is everywhere strongly disturbed. The rest of this normally much thicker formation must have been squeezed out by tectonic movements.

The same explanation stands for the few crushed banks of green radiolarite (N 30° E, 30° N), which separate the upper Palelo sediments from the crystalline schists of the eastern schist-complex. The few crushed banks are all that remained of the radiolarian cherts of the lower Palelo-series, which cherts occur between the upper Palelo-series and the crystalline schists (see beginning of this section).

There remains to be mentioned the lens-shaped body of violet coloured marls, which occurs squeezed in between the upper Palelo-sediments and the crushed banks of radiolarite. The marls are probably of Eocene age, because they closely resemble the certainly Eocene marls discussed at the beginning of this section.

The schists of the eastern schist-complex, which immediately follow the last radiolarite crush-breccia, are strongly moved as usual. They consist for the greater part of graphitic schists and epidote-chlorite-albite-schists.

The section is characterized by many zones of movement, the most important of which occur at the transitions to the two schist-complexes. The last 150 meters before the eastern schist-complex are of special interest. Rocks of upper-Triassic age here are found in almost immediate contact with Cretaceous rocks of the upper Palelo-series and are only separated from each other by a small zone of movement. All exposed rocks are practically vertical at the contact, but it seems nevertheless as if the upper-Triassic rocks are here overriding the Palelo sediments (sedimentary cover of the crystalline schists).

II. *Section through the Noil Toko fault trough, based on data assembled in the Noil Niti (fig. 5).*

In the western part of the section the crystalline schists of the Miomaffo complex, show the effect of strong movements. This feature is demonstrated by numerous smaller and larger faults, which mostly show an almost E—W strike and also by brecciated amphibolites, which occur as

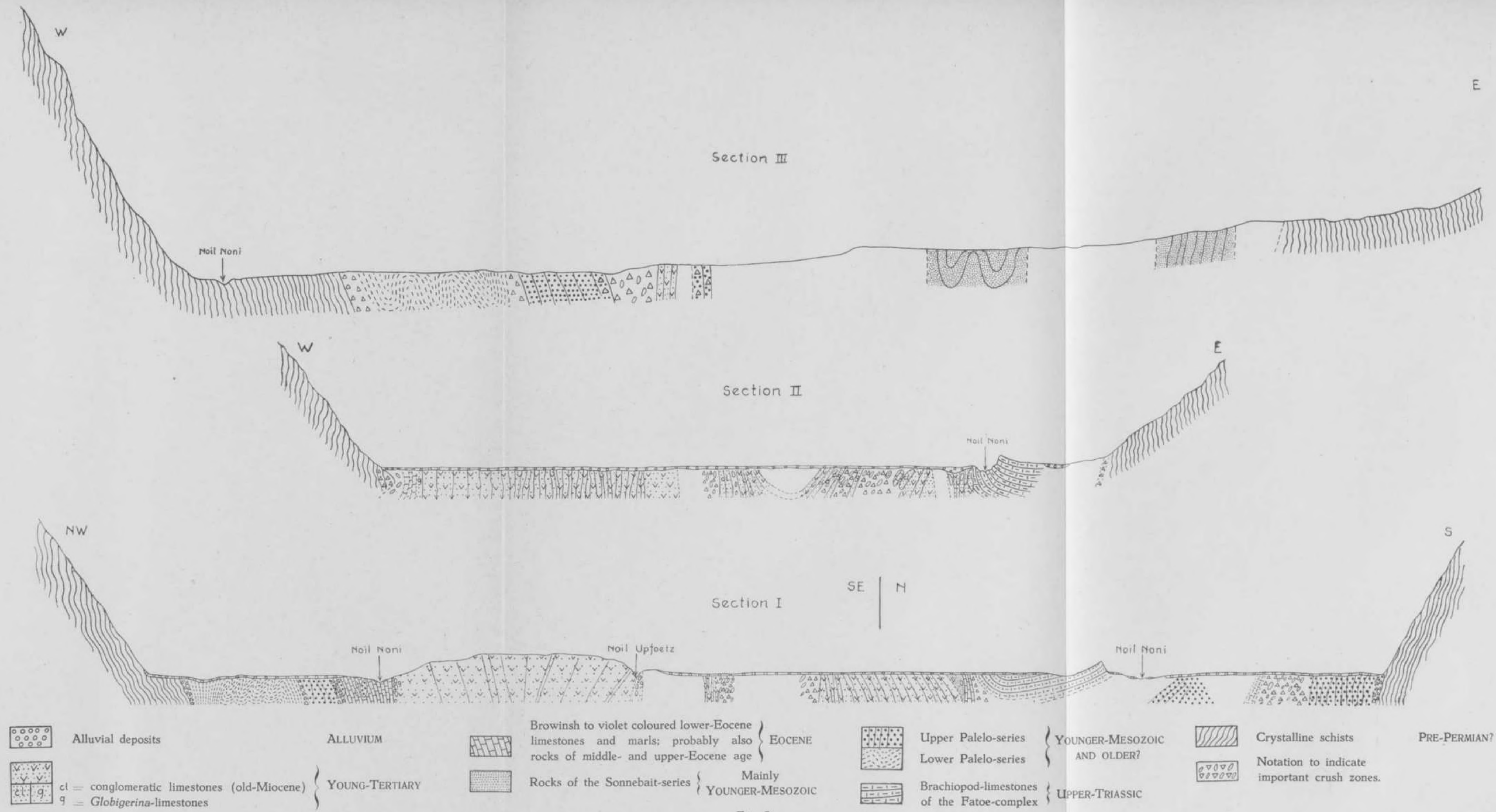
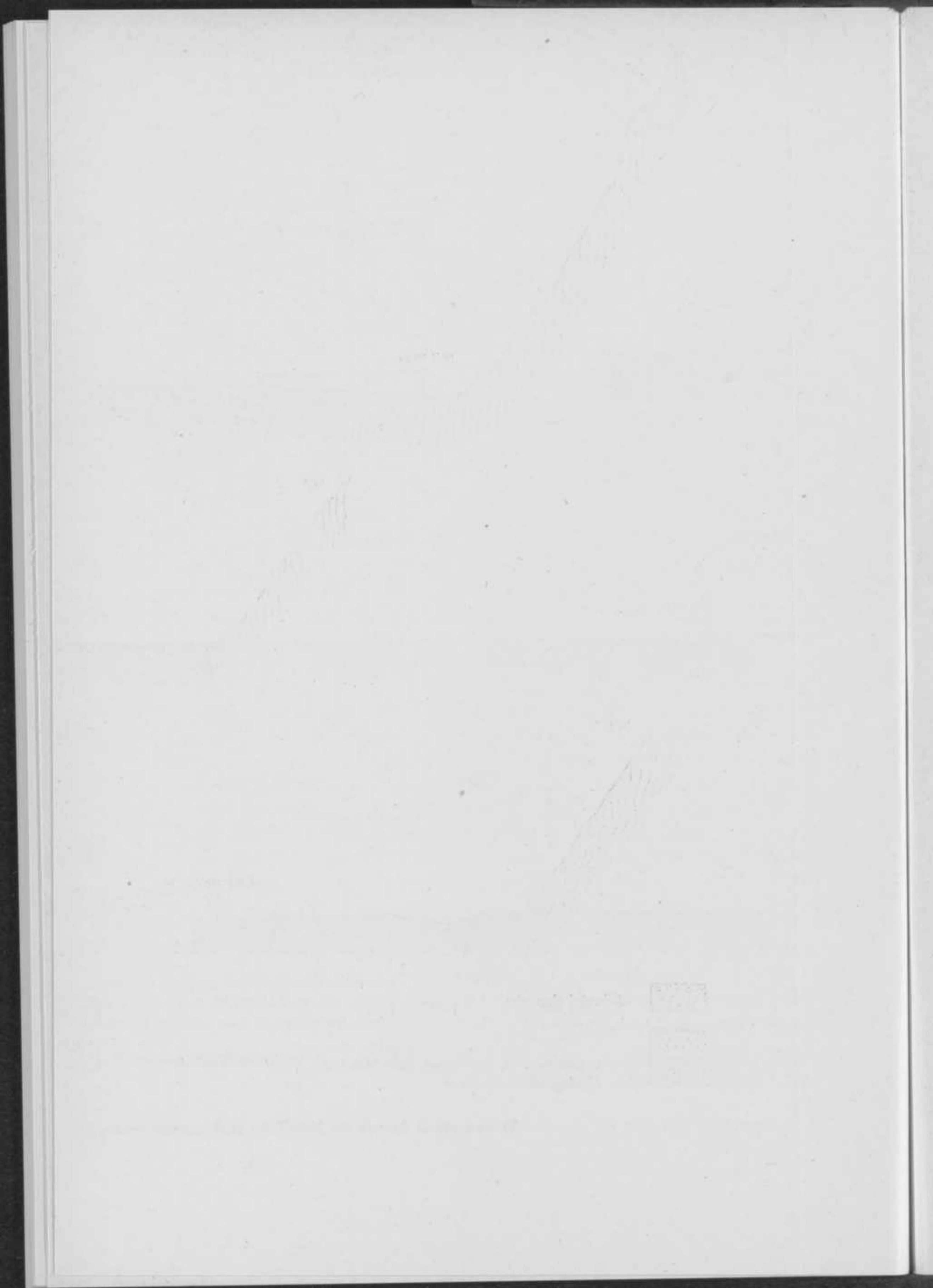


Fig. 5.

Three sections through the Noil Toko fault trough. Section I is based on data assembled in the Noil Noni, section II on data assembled in the Noil Niti and section III on data assembled in tributary N^o. 11. Scale 1:4000.



thick banks or lenticular masses intercalated between the less disturbed amphibolites.

Where the metamorphic rocks of the Miomaffo schist-complex terminate, the section continues in the sedimentaries of the Noil Toko fault trough. The actual contact of amphibolites and sedimentaries, is well exposed and brecciated plagioclase-amphibolites border directly on strongly crushed, dark violet-brown coloured Eocene marls. The Miomaffo schist-complex itself has, at the contact, a wedgelike shape and gives the impression of having partly overridden the sediments in an easterly direction. In connection with this fact it is significant to note the absence of rocks of both the upper and lower Palelo-series, although these rocks occur a short distance north of this point.

The crushed Eocene marls form the beginning of a zone of movement, which is nearly 40 meters thick and which is situated between the Miomaffo complex and the young-Tertiary deposits. The influence of strong tectonic movements is apparent from the way in which many lens-like blocks of Palelo rocks (conglomerates, greywackes), Eocene limestones, young-Tertiary *Globigerina*-limestones and tuffs, lie irregularly in a crushed matrix of violet-brown Eocene marls. Only the young-Tertiary *Globigerina*-limestones form partly still connected strata of a very irregular thickness. The general strike of the vertical contact-zone seems to be N 60° E.

On the described zone of movement follows a part of the section, represented by young-Tertiary deposits, which still have a more or less disturbed character; this last feature is obvious from the changing strikes and dips over short distances, the numerous little faults and fractures and the pressure cracks. At several instances, indications of horizontal movements could be deduced from the horizontal gliding-scratches, which occur on the fault planes of small N 50° E striking faults. It is further important to note the steady increase of grainsize in the sedimentaries. Following on the *Globigerina*-limestones and -marls at the contact are grey and greenish-white tuffs and calcareous tuffs, greenish clays and marls, with sometimes an intercalated stratum of conglomerate; then the conglomeratic deposits begin to dominate more and more, until they make out the whole succession of rocks. The last conglomerate which comes before the second zone of movement, contains pebbles of considerable size, which can attain diameters of 2—4 inches. This second zone of movement is in many respects similar to the first zone. But besides the already described rocks, banks of a rather coarse conglomeratic limestone of old-Miocene age occur in the middle of this zone of movement.

Directly following the second zone of movement there comes a relatively undisturbed series of young-Tertiary deposits, which consists of finely stratified marls, tuffs, clays and conglomerates, all in various shades of green to white. These beds have in the middle of the exposure an almost horizontal position; the exposure is bordered by zones of movement in the west and in the east. The last bank of this series is of the same conglomeratic limestone of old-Miocene age, as mentioned above ($N\ 15^{\circ}\ E, 65^{\circ}\ W$). Immediately bordering upon this conglomeratic limestone there is a third zone of movement, which is the largest of the section; this zone contains lenses of all the rocks already described from the preceding zones. After this zone, which has a very chaotic character and is not so well-exposed as the other ones, the section continues in a last occurrence of young-Tertiary deposits, beginning and ending with banks of the conglomeratic limestone. All the exposed strata are crushed, obviously as a consequence of strong tectonic movements, which occurred between these beds and the adjacent brachiopod-limestones. The last bank of conglomeratic limestone, which borders on the brachiopod-limestones, is drawn out in lenticles; the lens-like blocks are polished and show slickensides. The strike of the vertical contact of the brachiopod-limestones and the young-Tertiary deposits is N—S.

The upper-Triassic limestones have a beige to grey colour and are thickly and irregularly stratified. Their dip is at the beginning to the east, but then changes gradually to the north (see also section I).

The small remaining part of the section is based on the outcrops, which were exposed on the eastern-bank of the river Noil Noni. The section is here therefore somewhat hypothetical, the more so because no strikes and dips could be measured. The first outcrop after the fatoe of upper-Triassic limestones, is of brown, conglomeratic rocks, which probably belong to the Palelo-series. Then follows an outcrop of brecciated brownish green radiolarian cherts, which outcrop is found immediately bordering on the crystalline schists of the eastern schist-complex.

In this section the fact that in post-Oligocene time strong movements must have taken place is clearly demonstrated. The movements must have had a rather important horizontal component. This is evident e.g. at the contact of schists and sedimentaries in the western part of the section, where we may assume a reverse fault (overriding of the upper and lower Palelo-series) and also from the development of numerous small transverse faults, which are transverse to the N. S. striking Noil Toko fault trough.

III. *Section through the Noil Toko fault trough, based on data assembled in tributary Nr. 11 (fig. 5).*

The section starts in the amphibolites of the Miomaffo schist-complex in the west. The amphibolites pass soon with a transitional crush-zone, into the lower radiolarian cherts of dark green to violet colours of the lower Palelo-series (N 30° E, 40° E). The last-mentioned cherts border, with another separating crush-zone, on the thinly stratified here light brownish green radiolarian cherts of the upper part of the lower Palelo-series. This whole sequence of radiolarian cherts is rather strongly folded and borders with another transitional brecciated zone on sediments of the upper Palelo-series (N 10° E, 45° E). This part of the series is but poorly developed and only attains a thickness of about 100 m. Its well-bedded character is obvious and another crush-breccia, in this case of upper Palelo cherts, marks the end of the series and at the same time the beginning of a zone of movement of the same type as already described from the Noil Niti (see section II). Rocks which are drawn out into lens-shaped fragments occur in great abundance and are lying in a matrix of finely crushed rock material. They belong to Eocene limestones and marls, young-Tertiary sediments and upper Palelo-sediments. A breccia of upper Palelo cherts and other sediments mark the end of this zone of movement, which has a prevailing N 40° E strike. Then follows a part of the section in which no rocks are clearly exposed.

Farther to the east there is an exposure in brown-red, thickly bedded, strongly folded hornstones of the Sonnebait-series and which are probably of younger-Mesozoic age. The individual strata are finely banded with red bands in various shades. Strike and dip change over very short intervals and hereby indicate the thoroughly disturbed character of the rocks. Shortly after the hornstones a small outcrop occurs of a dark greenish brown greywacke, of uncertain age. After another stretch of non-exposure there finally follows a series of very compact and fine-grained cherty, flesh-coloured limestones, interbedded with red to redbrown marls and hornstones. A yellow, brecciated cherty limestone, also probably belongs to this series. All the rocks are strongly influenced by pressure, which can be deduced from the lenticular manner in which the strata are drawn out and from the numerous cracks and joints, frequently cemented by calcite. The rocks are typical for the upper Sonnebait-series and are probably of a younger-Mesozoic age (N 60° E, vertical). The section terminates in the crystalline schists of the eastern schist-complex.

IV. Section exposed in Nr. 3 tributary to the Noil Niti, south of the Miomaffo schist-complex (fig. 6).

The tributary in question is a deep gully, which only carries water during the wet monsoon. The section starts in the crystalline schists of the Miomaffo, which here are composed of well-stratified, black-coloured graphitic schists (mainly graphitic phyllites). They are strongly folded and faulted. The section continues upstream for about one hundred meters in the same rocks. The last part is remarkable, because of the intercalated sill-like intrusions of keratophyres. Notwithstanding the strongly moved character of the rocks, the stratification of the intruded schists is still distinct (N 30° E, 40° S.E.). The sequence terminates with a conglomerate largely composed of schist fragments, which seems to be conformable with the older rocks. After a short stretch of non-exposure follows a series of brownish, sandy marls, which do not show a clear stratification. No fossils are found in them, but close to this outcrop, on the right bank of the gully there are many detached blocks of brownish limestones with old-Tertiary Foraminifera. The marls mentioned are therefore believed to be also of old-Tertiary age. The section continues over nearly 100 meters in the same marls, which border on white and rose coloured *Globigerina*-limestones of young-Tertiary age (p. 36). The actual

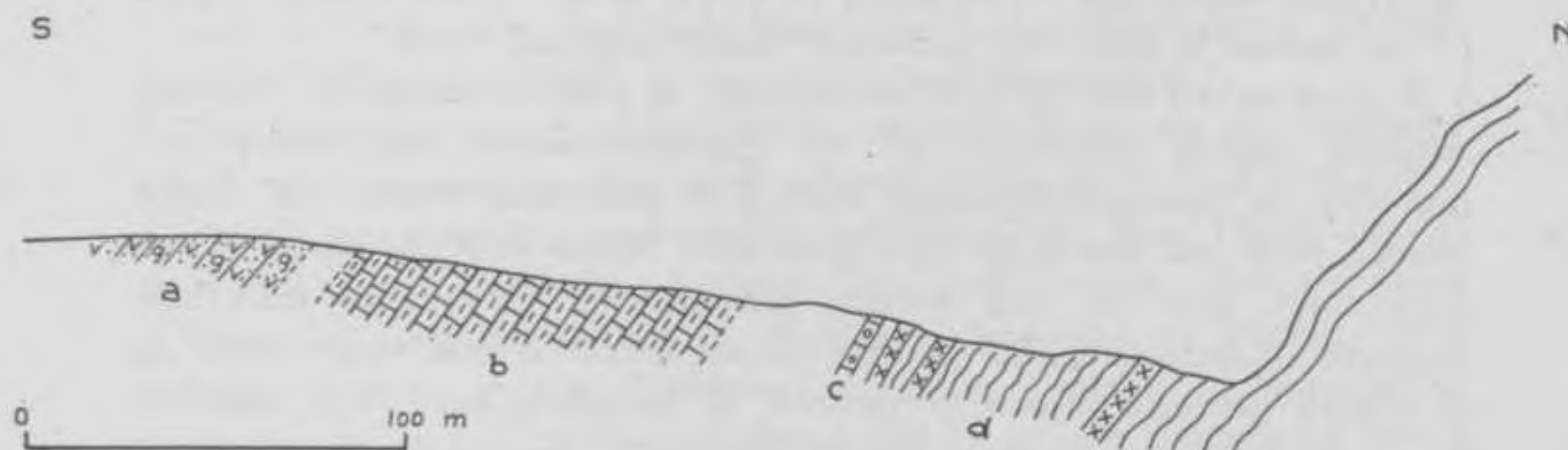


Fig. 6.

Section IV is based on data assembled in tributary No. 3, south of the Miomaffo schist-complex. The section shows the sill-like intrusions of keratophyres in sedimentary schists of the Miomaffo.

- a. Young-Tertiary *Globigerina*-limestones.
- b. Brownish coloured sandy marls, probably of old-Tertiary age.
- c. Conglomerate consisting of schist fragments.
- d. Well-stratified, largely phyllitic schists of the Miomaffo complex, with intercalated sill-like intrusions of keratophyres.

transition between the brownish marls and the *Globigerina*-limestones is not exposed. The *Globigerina*-limestones are the same as those encountered and described in the sections I and II. They are here also strongly influenced by pressure. The section terminates in the chaotic block-field on the slope south of the Miomaffo.

Description of the geological sketchmap and section of the Noen Pene, 3 km along the road from Kefamenanoe to Wini (fig. 7 and 8).

On the map (fig. 7) are indicated crystalline schists, which together with the crushed zone of Palelo rocks belong to the Schist-Palelo-complex (p. 122), rocks of the Sonnebait-series, rocks of the Fatoe-complex, outcrops of igneous rocks, which are assumed to belong to the Ophiolite-spilite-complex and a very small outcrop of young-Tertiary rocks (T).

The crystalline schists are strongly crushed and brecciated and are for the greater part composed of greenschists a.o. amphibole-schists (p. 60) and amphibolites, while graphitic schists are found in the Noil Nonioe, directly upstream from the bridge. The dips and strikes vary strongly. The crystalline schists are along their whole southern front resting upon a crush-breccia, which consists largely of fragments of rocks of the Palelo-series. Angular fragments of 1 to 1½ inch in diameter are lying in a brownish coloured gouge (Plate VII, fig. 3). The fragments are a.o. derived from radiolarian cherts of the lower Palelo-series and greywackes, greywacke-sandstones and probably also other rocks of the upper Palelo-series. All these rocktypes are also known and described from the Palelo-series of Noil Toko (p. 15—21). In the latter region it is also apparent that the Palelo-series is normally overlying the crystalline schists. In the breccia there are also fragments of red *Globigerina*-marls, red cherts and multi-coloured marls, probably belonging to the Sonnebait-series.

The Sonnebait-series is mainly represented by intricately folded, strongly crushed multi-coloured marls, light-coloured, massive, sometimes cherty limestones and brown hornstones. These rocks are probably not older than younger-Mesozoic. The few isolated fatoes are composed of the usual dense, unbanked sometimes somewhat crystalline reef-limestones belonging to the Fatoe-complex. No fossils were found in these rocks, but they are presumably of upper-Triassic age. The two outcrops of igneous rocks marked on the map are reckoned to belong to the Ophiolite-spilite-complex. One of them, the one in the right lower corner of the map, contains porphyritic keratophyres. The small outcrop of young-Tertiary rocks occurs in the bedding of the Noil Nonioe, immediately

north of the bridge. The white-coloured young-Tertiary tuffaceous rocks are crushed, but the stratification is still discernible (N 70° W, 40° N). The rocks are thus dipping under the crush-zone of Palelo rocks in the north. The exact age of the rocks is not exactly known; they may be of Miocene to Pliocene age. They are of the usual types found in the Kefamenanoe region and there are normally transgressive over all older formations.

In the section exposed in the Noil Nonioe (fig. 8) we see that the main tectonic feature of the region is the overthrusting of the Schist-Palelo-unit over rocks of the young-Tertiary series and of the upper Sonnebait-series. It is furthermore apparent, that the eastern boundary of the Schist-Palelo-unit must have been overturned in the course of its overthrusting. The existence of a crush-breccia which consists of rocks of the Palelo-series and which is in the section exposed at the base of the crystalline schists, clearly proves this overturning. Normally namely the Palelo-series — possibly together with Eocene deposits — forms the sedimentary cover of the crystalline schists, as e.g. in the Miomaffo region, Mollo region and Booi region (26). The fact that young-Tertiary rocks are found on the overthrust-plane between Schist-Palelo-unit and upper Sonnebait-series proves beyond doubt that this overthrust structure is of post-Oligocene age.

The second contact between the Schist-Palelo-unit and the upper Sonnebait-series in the upper course of the Noil Nonioe, is not well-exposed. The Fatoe-limestones and the outcrops of the igneous rocks of the Ophiolite-spilite-complex are surrounded by rocks of the upper Sonnebait-series. This is the normal way of occurrence of these rocks and nothing definite about their contacts can be said (see also p. 123 and 124).

The large overthrusts of regional importance in Timor were formed in pre-Miocene time, while the mountain building forces reached their final stage during the Oligocene period (26). It will however be obvious that the movements by which these large overthrusts were formed did not entirely stop at the end of the Oligocene. On the contrary, much evidence exists, which proves that these movements went on till in recent times. The structure described above and the structures of the Noil Toko fault trough to be described later, are the outcome of these post-Oligocene movements, which however are to be considered as of local importance.

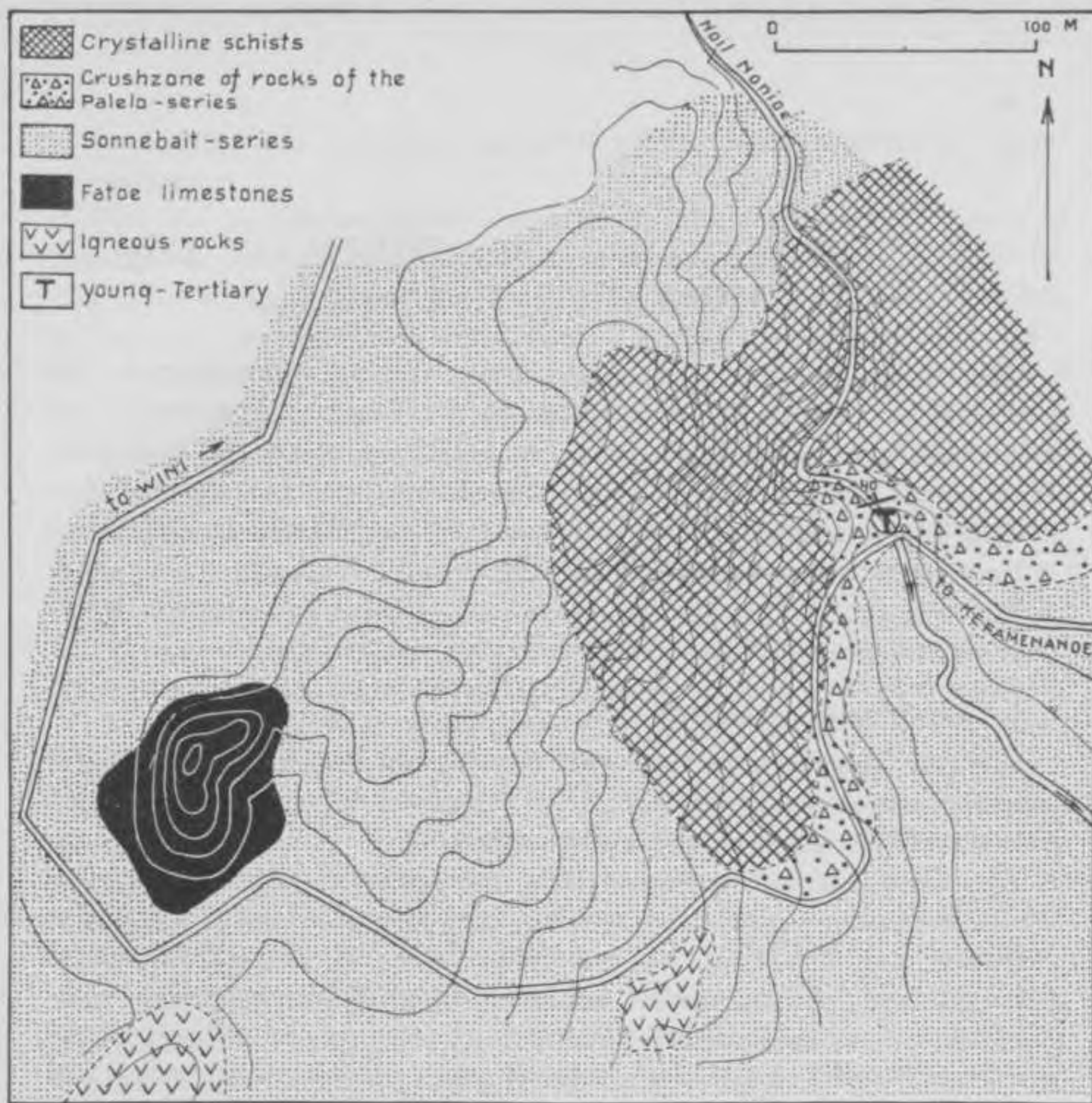


Fig. 7.

Geological sketchmap of the Noen Pene, 3 km along the motorroad from Kefamenanoe to Wini.

N.N.W.

S.S.E.



Fig. 8.

Section through the Noen Pene based on data assembled in the Noil Nonioe and showing the post-Oligocene overthrust-structure of the Schist-Palelo-complex upon rocks of the upper Sonnebait-series (for legend see fig. 7).

D. THE TECTONIC FEATURES OF THE MIOMAFFO REGION.

The tectonics of the investigated region are very complicated. The period of mountain building, in which the overthrust structures of Timor originated, was followed by a period of faulting, to which the Noil Toko fault trough owes its origin. The age of the latter faulting period is indicated by the fact that it also affected the young-Tertiary series, which is transgressive over all pre-Miocene rocks and structures.

We will first discuss the pre-Miocene tectonics and afterwards the post-Oligocene tectonics.

a. Pre-Miocene tectonics.

The pre-Miocene rocks of the investigated region belong to the following major geological units: Schist-Palelo-complex, Sonnebait-series, Ophiolite-spilite-complex and Fatoe-complex.

The Schist-Palelo-complex consists principally of crystalline schists. These metamorphic rocks are overlain by sedimentary rocks of diverse character and age which are subdivided into the lower Palelo-series (of unknown pre-upper-Palelo age) the upper Palelo-series (younger-Mesozoic) and old-Tertiary (Eocene). There are several arguments which prove the connection between these sedimentary rocks and the crystalline schists. All the known occurrences of these sedimentaries are found in intimate connection with the crystalline schists. They are moreover generally found in an order which corresponds with the normal stratigraphical succession within this unit: crystalline schists — lower Palelo-series — upper Palelo-series — Eocene. Another important argument proving the intimate connection between the various parts of the Schist-Palelo-complex is the occurrence of much detrital material from the crystalline schists and of the lower Palelo-series in the clastic sedimentaries of the upper Palelo-series. The Schist-Palelo-complex does not form a continuous stratigraphical series, but smaller and larger stratigraphical gaps exist or are at least suspected to exist between the different parts of this complex. A larger stratigraphical gap is assumed to exist between the lower Palelo-series — which is essentially composed of strongly folded radiolarian cherts, deposited at larger sea-depths — and the upper Palelo-series, which is essentially composed of coarse clastic

sedimentaries rich in volcanic material and deposited in neritic to littoral environments.

The Schist-Palelo-complex contains furthermore various types of igneous rocks which are assumed to belong to one magmatic suite (p. 45). Part of these rocks are found to be intrusive into the crystalline schists and into the Palelo-series. Besides non-felspathic ultrabasic rocks, of which e.g. the smaller western half of the Miomaffo is composed (p. 41), several felspathic types belong to this magmatic suite. The felspathic rock-types are characterized by the presence of albite. In the conglomerates of the Palelo-series part of the albite of the igneous rock pebbles could be proved to be a metasomatic alteration product of original basic plagioclase.

The Sonnebait-series of the mapped area is mainly represented by radiolarian cherts and *Globigerina*-limestones and -marls, which sediments must have been deposited in a deeper sea. The age of part of these rocks is certainly upper-Cretaceous; the other part in the investigated region may be somewhat older (younger-Mesozoic). There exists therefore a remarkable difference in facies between the younger-Mesozoic rocks of the Sonnebait-series and of the Schist-Palelo-complex. This strong difference in facies between two units, which are found bordering upon each other, already indicates the existence of overthrust structures in the Miomaffo region.

To the Ophiolite-spilite-complex are reckoned to belong all igneous rocks, which are found outside the Schist-Palelo-complex. Besides some non-felspathic ultrabasic rocks, only igneous rocks with plagioclase-felspar belong to this group. A characteristic feature of these rocks is that albite plays an important part among the plagioclases, usually as a metasomatic mineral. The age of the Ophiolite-spilite-complex could not be established.

The Fatoe-complex of the investigated region is mainly composed of Triassic limestones, which comprise at the same time the only certainly Triassic deposits found. The limestones are partly represented by unbanked, massive reef-limestones of which the various isolated fatoes are composed. Another facies is represented by upper-Triassic brachiopod-limestones in thick banks, which form more or less connected strips of rocks. The fine conglomeratic limestones of this group often contain albite crystals and small pebbles of albitic rocks.

About the tectonic superposition of the various major units encountered in the Miomaffo region nothing can be said with certainty. This is partly caused by the lack of good exposures and partly because strong post-

Oligocene faulting movements obscured the original contacts, especially in the Noil Toko fault trough. However, several observations concerning the mutual relations of the major geological units can be mentioned here, especially in connection with the results of the investigations of other members of our expedition.

It may be recalled that the Sonnebait-series in other parts of Timor consists of Permian, Triassic and younger-Mesozoic rocks, while the existence of a large scale overthrust between the underlying Kekneno-series and the Sonnebait-series could be definitely proved (21, p. 336). It is remarkable that especially the lower part (Permian and Triassic) of the Sonnebait-series and the entire Kekneno-series — which is the lowest non-metamorphic unit known from Timor — are lacking in the investigated region. Rocks of the Fatoe-complex are found in contact with rocks of all other major units encountered in the investigated region. The mode of occurrence of these rocks suggests that the Fatoe-complex possesses the highest tectonical position of all mentioned units. This observation is well in accordance with the results of investigations in other parts of Timor. Of special importance is the section exposed in the Noil Noni. In this section we find upper-Triassic limestones of the Fatoe-complex in direct contact with rocks of the Schist-Palelo-complex (see p. 114).

The igneous rocks belonging to the Ophiolite-spilite-complex have been found bordering upon rocks of the upper part of the Sonnebait-series and upon rocks of the Fatoe-complex. They have however not been found in intimate connection with the crystalline schists in the way described by DE ROEVER (21). It may however be noted here that the Ophiolite-spilite-complex and the igneous rocks of the Schist-Palelo-complex show a remarkable similarity to each other in composition, while both complexes are bordering upon the same units.

The pre-Miocene units upon which the Schist-Palelo-complex has been found bordering are the Fatoe-complex and the upper part of the Sonnebait-series. Concerning the tectonic position of the Schist-Palelo-complex no definite solution could be obtained. TAPPENBECK (26) found some arguments to assume a low tectonic position for this unit, whereas DE ROEVER (21) is inclined to consider the unit as part of an overthrust sheet between the Sonnebait-series and the Fatoe-complex, together with the Ophiolite-spilite-complex. The investigation of the limited area of the Miomaffo region has yielded no new arguments in support of either of the views just mentioned.

The last period of large overthrusting may, according to TAPPEN-





Fig. 1.



Fig. 2.



Fig. 3.

PLATE VII.

Fig. 1.

View on the eastern schist-complex and the Noil Toko fault trough from the S.W. The shadowy ridge in the left part of the picture belongs already to the Miomaffo-complex (photo H. A. BROUWER).

Fig. 2.

View on the Noil Toko fault trough from the south. The fault trough is situated between the N.E. striking ridge in the left part of the picture (Miomaffo-complex) and the steep slope in the right part of the picture (eastern schist-complex).

Fig. 3.

Crush-breccia of rocks of the Palelo-series, found at the base of the crystalline schists at the road from Kefamenanoe to Wini.

BECK (26), be considered as of Oligocene age. We also found a transgressive young-Tertiary series beginning with old-Miocene conglomeratic limestones, containing material of all older units of the Miomaffo region. The same author already stressed the importance of the Mesozoic periods of diastrophism.

Finally we may point to the results of the tectonic investigation of the Palelo-series in the Miomaffo region. The pelagic radiolarian cherts of the lower Palelo-series are strongly folded, while the clastic rocks of the upper Palelo-series are much less influenced by the mountain building forces. These facts are according to my opinion pointing to a period of diastrophism between the deposition of the lower and the upper Palelo-series.

In concluding the description of the pre-Miocene units and tectonics we may pay some attention to the constitution of the land-surface as it was at the beginning of the Miocene period. In the Miomaffo region we encountered the same pre-Miocene units in the Noil Toko fault trough as in the region outside this fault trough which generally has not been faulted in the same strong way as the fault trough itself. Further in the fault trough each of the major units is found bordering upon the same tectonical units which — according to our observations outside the fault trough — must have adjoined it before the younger faulting period took place. So we may conclude, that the constitution of the land-surface at the beginning of the Miocene was generally the same as we find it now to be in the regions not covered by post-Oligocene deposits.

b. Post-Oligocene tectonics.

The pre-Miocene tectonics developed gigantic overthrust structures of regional importance, whereas the post-Oligocene tectonics are essentially tectonics of faulting. Post-Oligocene overthrusting of local importance has however been observed as is illustrated by the geological sketchmap and section of the Noen Pene, in the neighbourhood of Kefamenanoe (fig. 7 and 8). Certain regions in Timor have been especially affected by the post-Oligocene faulting. The strongly faulted Miomaffo region is different from the Booi region in West-Timor, where no movements of importance seem to have taken place in post-Oligocene time (26).

The young-Tertiary rocks occur in the investigated region in a long narrow strip between the Miomaffo complex in the west and the eastern schist-complex in the east. The area covered by young-Tertiary rocks widens to the S. and SW. The young-Tertiary series is largely composed

of fine clastic calcareous and tuffaceous rocks, while conglomeratic rocks occur throughout the series. The latter rocks are of special importance at the base and in the upper parts of the series. The conspicuous old-Miocene conglomeratic limestones belonging to this series, are only found at the base of the eastern part of the area covered by the young-Tertiary, whereas the basal layers in the western part of the area covered by this series consist of non-clastic *Globigerina*-limestones.

The trend and the character of the developed fault-structures are in the investigated region dominated by the two blocks of the Miomaffo schist-complex in the west and the eastern schist-complex in the east. These two blocks form together with the Noil Toko fault trough the main structural elements of the Miomaffo region. The Noil Toko fault trough widens to the south. Its eastern boundary continues into the eastern boundary of this widening extension. These eastern boundaries are conspicuously straight and run into an approximately N—S direction. The western boundary of the narrow Noil Toko fault trough runs for some distance approximately parallel to its eastern boundary, but in the south the western boundary takes an abrupt turn, which is roughly to the west-south-west. Somewhat south-east of this roughly west-south-west running boundary there occurs a normal fault which is indicated by the northwestern boundary of the sharp wedge of brachiopod-limestones belonging to the Fatoe-complex. The small area between this fault and the mentioned west-south-west boundary, has been downthrown in relation to the Miomaffo complex in the north and the extensive area of young-Tertiary in the south.

The described boundaries are accompanied by parallel longitudinal faults, which are especially well exposed in the various sections through the Noil Toko fault trough (p. 111—117), where they are often indicated by crush-breccias.

Transverse faults, which are transverse to the direction of the Noil Toko fault trough, are not as numerous as the longitudinal faults. Interruptions in the strip-like longitudinal development of the outcrops of various formations as e.g. of the upper and the lower Palelo-series, and of the old-Tertiary, sometimes point to the existence of transverse faults. A transverse fault is e.g. suspected to exist somewhat south of the outcrop of the upper Palelo-series north of tributary Nr. 10. The upper Palelo-series occurs also south of this tributary but then much farther to the west and in a much narrower outcrop. In another instance a similar fault may exist between the tributaries Nr. 11 and Nr. 12.

It is further of interest to note that the axial dip of the Noil Toko fault

trough must be to the south. This is indicated by the southward dip of the young-Tertiary rocks in the central parts of the area in the south and also by the fact that the older underlying sedimentaries become more and more exposed at the surface when going in a northerly direction.

Description of the faults.

The longitudinal faults or faultzones can be studied best in the sections through the Noil Toko fault trough (Nr. I, Nr. II and Nr. III). In these sections numerous faultzones have been found, the general strike of which is approximately from north to south. The dip of the faultzones do not differ much from 90 degrees. Along the majority of these faults strong crushing and brecciation processes have taken place. A closer examination of many of these faultzones shows that blocks and lenses of older rocks have been dragged upwards along them and the older rocks are now found in contact with younger rocks, which form both walls of the faultzone. Blocks and lenses of old-Tertiary rocks and sometimes of rocks of the Palelo-series are found along faultzones in the young-Tertiary. It will be clear, that this kind of contact can only be explained by repeated movements in opposite directions along these faultzones.

In another type of faultzone (shown in sections I and II) the stratified upper-Triassic brachiopod-limestones of the eastern wall have been dragged upwards and are found in contact with the younger rocks of the western wall of the faultzone. This points to a relative downward movement of the brachiopod-limestones. On the other hand it is obvious from their stratigraphical position, that the brachiopod-limestones have been moved upwards with regard to the young-Tertiary. Therefore this contact must also be explained by assuming repeated movements in opposite directions of the strip of older sediments exposed along the western front of the eastern schist-complex with regard to the young-Tertiary of the central Noil Toko fault trough. This longitudinal faultzone is the most conspicuous of the mapped area. It is marked by the lenticular outcrops of rocks of the upper Palelo-series and of the Eocene, which rocks must have been dragged upwards.

It will be apparent from the above that it is not possible to say anything with certainty about the final amount of the vertical movements between the different structural elements in the Noil Toko fault trough.

The longitudinal faultzones are proof of vertical movements, but it is obvious that compressive forces have also been active in the Noil Toko fault trough. This is e.g. indicated by the presence of transverse faults and by minor folding phenomena. In section II we observed small transverse

faults in a conglomeratic bank; the walls of these faults are covered with horizontal gliding scratches. Horizontal gliding scratches on the fault-planes of longitudinal faults were also found; these point to horizontal movements parallel to the direction of the Noil Toko fault trough. Another indication of compression is the wedgelike shape of the extremity of the Miomaffo schist-complex, described in the beginning of section II (p. 115). This wedgelike shape points to the existence of a reverse fault, while the absence of the whole Palelo-series — which series occurs a short distance to the north — can only be explained by assuming that this series has been overridden in an eastern direction by the crystalline schists of the Miomaffo schist-complex.

The following facts give us indications as to the nature of the movements in the Noil Toko fault trough: 1. the topography of the main structural post-Oligocene elements and 2. the extension of the conglomerates at the base of the young-Tertiary series.

It is evident from the remains of the elevated old peneplain, which forms the top of Miomaffo ridge, that this ridge must have been lifted up strongly in post-Oligocene time. Furthermore we know that the basal limestones of the western part of the fault trough, do not show a conglomeratic development, which makes it acceptable, that the Miomaffo schist-complex was not much elevated above sea-level in old-Miocene time.

On the strength of these arguments we may assume a strong rise of the Miomaffo schist-complex since old-Miocene time. The recent topography shows further that the top-level of the Miomaffo schist-complex lies much above that of the eastern schist-complex, which proves that the Miomaffo schist-complex has risen more than the eastern schist-complex with regard to the Noil Toko fault trough. The presence of basal old-Miocene conglomeratic limestones in the eastern part of the fault trough indicates furthermore that the eastern schist-complex was considerably elevated above sea-level in old-Miocene time i.e. that in old-Miocene time the eastern schist-complex had a higher top-level than the Miomaffo schist-complex in the west.

Therefore we are inclined to give the following explanation of the recent tectonical features of the region:

The tectonical features of the region are characterized by a strong elevation of the Miomaffo schist-complex in relation to the eastern schist-complex; the relative subsidence of the Noil Toko fault trough in relation to the eastern schist-complex is far less important than the relative subsidence of the fault trough in relation to the Miomaffo schist-complex.

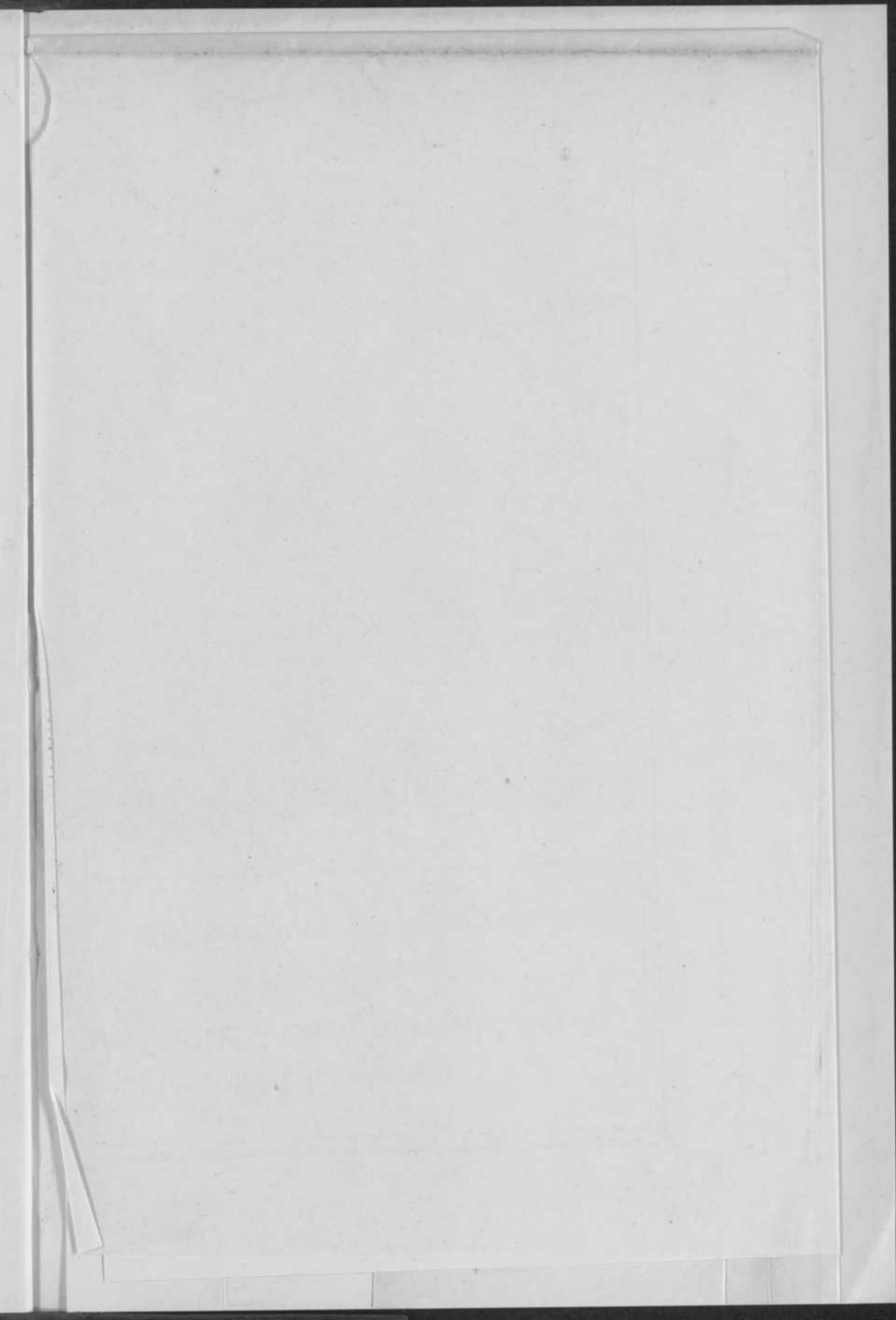
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1. The first part of the paper discusses the importance of the study and the objectives of the research. It also mentions the scope of the study and the limitations. The second part of the paper discusses the methodology used in the study. It includes the data collection methods, the sample size, and the statistical tests used. The third part of the paper discusses the results of the study. It includes the findings of the study and the conclusions drawn from the results. The fourth part of the paper discusses the implications of the study and the recommendations for future research. The fifth part of the paper discusses the limitations of the study and the strengths of the study. The sixth part of the paper discusses the conclusions of the study and the recommendations for future research. The seventh part of the paper discusses the implications of the study and the recommendations for future research. The eighth part of the paper discusses the limitations of the study and the strengths of the study. The ninth part of the paper discusses the conclusions of the study and the recommendations for future research. The tenth part of the paper discusses the implications of the study and the recommendations for future research.



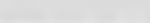
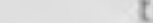
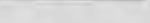
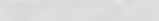
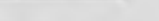
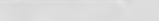
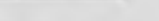
of the Miomaffo region (Neth. Timor)

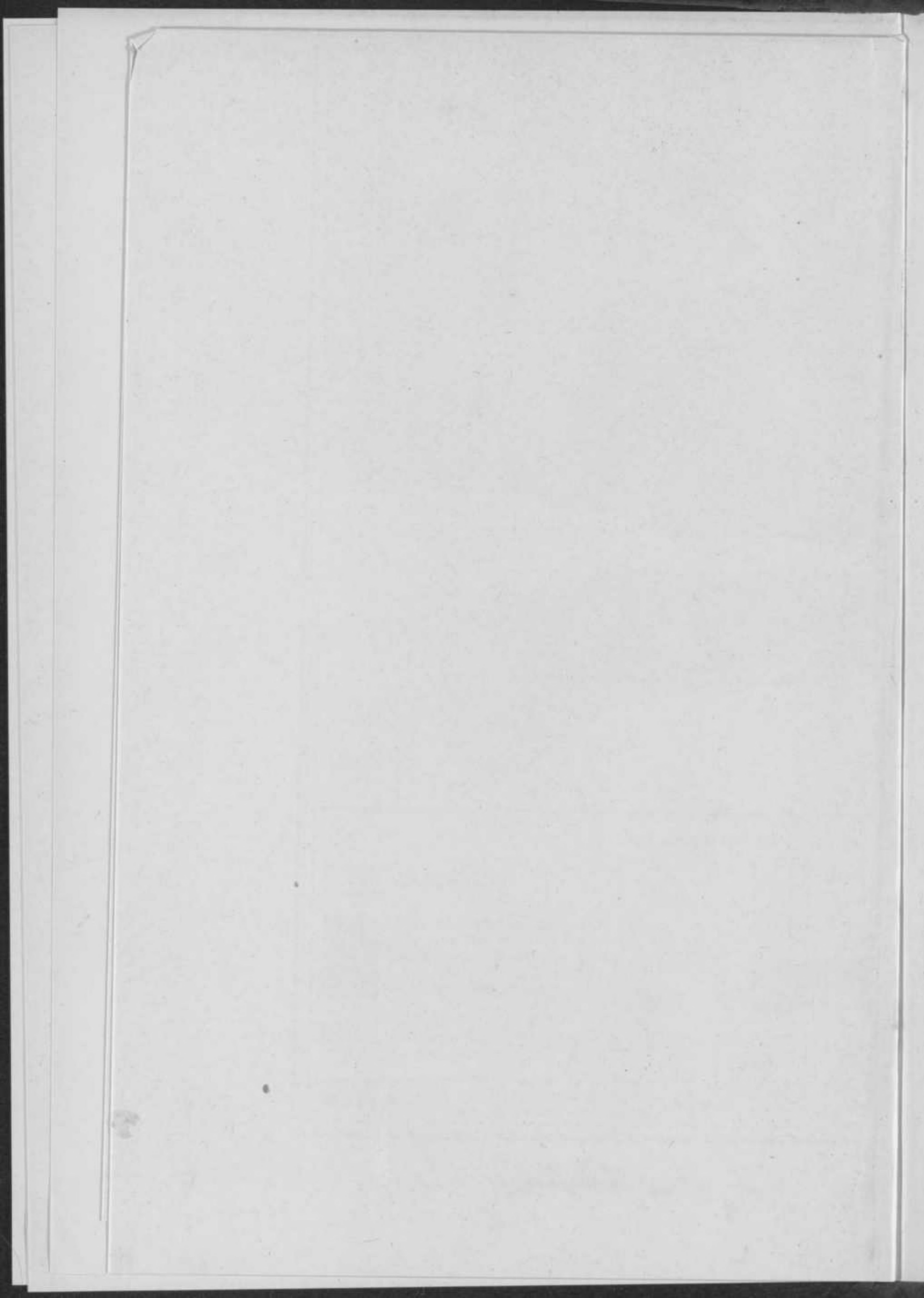
Scale 1 : 20000

Surveyed by F. P. VAN WEST (1937)



The notation between [] gives the probable extension of the Sonnebait-series and the Fatoe-complex

- | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
|  | Alluvial deposits |  | Upper Paleo-series
Lower Paleo-series | } Younger Mesozoic and older? |  | Approximate boundaries of the formations | 2 = Number of tributaries
n = Noil or Nono = river | |
|  | Marls, conglomerates and tuffaceous rocks |  | Igneous rocks and volcanic breccias | |  | Faults | | |
|  | Conglomeratic limestones (old-Miocene) |  | } Mainly consisting of upper-Triassic brachiopod-limestones Reef-limestones of Triassic and possibly younger-Mesozoic age | } Triassic and possibly younger-Mesozoic |  | Probable faults | F = Fatoe | |
|  | Globigerina-limestones | | | |  |  | |  |
|  | T ₁ = lower-Eocene | } Eocene |  |  |  |  | Dip and strike | n = Kampong = (native village) |
|  | T ₂ = middle-Eocene | | | | | | | |
|  | T ₃ = upper-Eocene |  |  |  |  |  |  |  |
|  | Sonnebait-series (here mainly consisting of younger-Mesozoic limestones and cherts) | } Younger-Mesozoic |  |  |  |  |  |  |
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STELLINGEN.

I.

Voor het ontstaan van de meeste voorkomens van anorganische grafiet, is de theorie van CLARKE, als de meest universeel toepasbare te beschouwen.

(THOMAS H. CLARKE, The Origin of Graphite. Econ. Geol., Vol. XVI, pag. 167—183.)

II.

Verscheidene fatoes hebben hun tegenwoordige ligging door glijding verkregen.

III.

Uit het feit dat bepaalde kalksteen en grootendeels uit Globigerinen zijn opgebouwd, mag niet zonder meer geconcludeerd worden dat deze gesteenten in een diepere zee zijn afgezet.

IV.

De stratigrafisch-tektonische tabel voor de gesteenteserie tusschen het autochtone Permo-Carboon van Toscanide I en het Rhät van Toscanide II in de Apuaner Alpen, dient te worden herzien.

(P. DE WIJKERSLOOTH, Bau und Entwicklung des Apennins, besonders der Gebirge Toscanas. Bonn. 1934.)

V.

De post-Oligocene tektoniek op Timor is breuk-tektoniek.

STUDY

There are many ways to study, but the most effective way is to study in a systematic way. This means that you should have a plan for your study and stick to it.

One of the first things you should do is to decide what you want to study. This could be a subject, a topic, or a specific problem.

Next, you should decide how much time you can spend on your study each day. This will depend on your schedule and your other commitments.

Once you have decided what to study and how much time to spend, you can start your study. It is important to start with a clear goal in mind and to work towards it.

As you study, it is important to take breaks and to review what you have learned. This will help you to remember the information and to understand it better.

Finally, it is important to evaluate your progress. This means that you should check to see if you are meeting your goals and if you are understanding the material.

By following these steps, you can be sure that you are studying in the most effective way possible.

VI.

Bij de genese van petroleum spelen uitwisseling van ionen en hydrolyse in kleien een belangrijke rol.

(E. MC. KENZIE TAYLOR, The Bearing of Base Exchange on the Genesis of Petroleum. J. of the Inst. of Petr. Tech., Vol. 14, pag. 825—841, 1928.)

VII.

Er bestaat in vele opzichten groote overeenkomst in de wijze waarop het verband tusschen tektoniek en vulkanisme zich in Zuid-Colorado en in de Zuidelijke Molukken ontwikkelde.

(W. S. BURBANK, Ore deposits of the Western States, pag. 277—301, 1933.)

VIII.

Kristallijne schisten, Palelo-serie en Eoceen vormen op Timor een tektonische eenheid.

IX.

De verklaring der samengestelde gangen en intrusiefplaten in West-Schotland, zooals die door HARKER, BAILEY en THOMAS wordt gegeven, is niet bevredigend.

X.

Teneinde meer eenheid te brengen in de nomenclatuur der kristallijne schisten, verdient het aanbeveling systeem te brengen in de plaatsing der mineraal-voorvoegsels en het mineraal dat het minst voorkomt daarbij voorop te plaatsen.







