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A PETROGRAPHICAL AND MINERALOGICAL INVESTIGATION OF THE ROCKS OF THE BUSHVELD IGNEOUS COMPLEX IN THE TAUTESHOOGTE-ROOSSENEKAL AREA OF THE EASTERN TRANSVAAL

by

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ABSTRACT

This study comprises a petrographical and mineralogical investigation of rocks from an area 850 sq. km in size, situated about 80km northeast of Middelburg. Roughly half of the area is occupied by rocks of the epicrustal phase of the Bushveld Complex, and consists largely of Rooiberg Felsite and granophyre as well as leptite, microgranite and granodiorite. Numerous veins of fine-grained granite traverse the leptite which is considered to be highly metamorphosed felsite. These veins of fine-grained granite probably owe their origin to the melting of the leptite. The coalescence of these products of melting gave rise to the thick sheet of granophyre between the leptite and the felsite.

Rocks of the Layered Sequence occupy the eastern half of the area and consist of the Main and Upper Zones which were subdivided into various subzones on the basis of characteristic rock types and marker horizons. Mineralogical investigations are restricted to the minerals from rocks of the Layered Sequence, namely orthopyroxene, plagioclase, apatite and the sulphides of the Upper Zone.

In Subzone A of the Main Zone, the orthopyroxene is present as cumulus crystals, but it changes in texture to ophitic in the lower half of Subzone B where small discrete grains of inverted pigeonite are also developed. Inverted pigeonite is present in the upper half of Subzone B and in rocks of the Upper Zone, whereas the orthopyroxene-pigeonite relationships in Subzone C of the Main Zone are a repetition of those observed in the underlying rocks. The phase-change from orthopyroxene to pigeonite takes place over a transition zone in which both phases crystallized from the magma. It is envisaged that the first pigeonite to have crystallized from the magma at high temperatures had a lower Fe/Mg ratio than the hypersthene precipitating at slightly lower temperatures, with the result that the early formed pigeonite was unstable and reacted with the magma to form hypersthene. This caused the formation of groups of grains of hypersthene which are optically continuous over large areas and which may contain a few blebs of augite exsolved from the original pigeonite. A few pigeonite grains were effectively trapped in other minerals, mostly augite, and consequently escaped reaction with the liquid. These inverted to hypersthene at the appropriate temperature and contain numerous exsolution-lamellae of augite. As fractional crystallization of the magma continued, it moved further into the stability

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field of pigeonite and out of the stability field of hypersthene with the result that the formation of hypersthene by the reaction of pigeonite with magma was replaced by inversion of pigeonite to hypersthene. This inverted pigeonite is also present as groups of grains optically continuous and contains pre-inversion exsolution-lamellae of augite orientated at random, and post-inversion exsolution-lamellae which are orientated parallel to the (100) plane of the orthopyroxene throughout a unit. The inverted pigeonite is orientated in such a way that its crystallographic c-axis lies close to or in the plane of layering. This is explained as being due to the load pressure of the superincumbent crystal mass during the inversion.

Textural features of the plagioclase revealed interesting information on the postcumulus changes in the rock. Reversed zoning, interpenetration and bending of plagioclase crystals as well as the presence of myrmekite are described. These are considered to be due to increased load pressure prior to and during crystallization of the intercumulus liquid. It is considered that the various types of pegmatoids may have originated by an increase in pressure on the intercumulus liquid which was concentrated to form pipe-like bodies by lateral secretion or filter pressing.

Cumulus apatite is developed in the olivine diorites of Subzone D of the Upper Zone. From unit cell dimensions it seems as if it changes in composition from a fluor-rich hydroxyapatite at the base of this subzone to a relatively pure hydroxyapatite 70m below the roof. There seems to be a substantial increase in the fluor content of the apatite in the topmost 70m of the intrusion.

Rocks of the Upper Zone contain considerably more sulphides than those of the Main Zone. This is ascribed to an increase in the sulphur content of the magma owing to fractional crystallization. The magma reached the saturation point of sulphur when rocks of Subzone D of the Upper Zone started to crystallize with the result that these rocks contain numerous small droplets of sulphide which constitute on an average about 0,5 per cent by volume of the rocks. A concentration of the sulphides in these rocks would not yield a deposit of economic interest because of the unfavourable composition of the sulphide phase, which consits of more than 90 per cent pyrrhotite. Sulphides in the rocks below this subzone are intercumulus and a concentration could be of economic importance because the sulphide phase contains appreciable amounts of chalcopyrite and pentlandite. Although no economic concentration of sulphides are known from the

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Upper Zone, this study has revealed the presence of a mineralized anorthosite below Lower Magnetitite Seam 2 which contains in places up to 1 per cent Cu, 0,18 per cent Ni and 1,6g/ton platinum metals.

Continuous, slow convection and bottom crystallization probably gave rise to the homogeneous rocks of the Main Zone. Injection of a considerable amount of fresh magma took place at the level of the Pyroxenite Marker which resulted in a compositional break and gave rise to a repetition in Subzone C of the rocks of the Main Zone below this marker. The oxygen pressure during crystallization of the magma was probably low, causing a gradual enrichment in iron in the magma and gave rise to the appearance of magnetite at the base of the Upper Zone. Intermittent increase in the oxygen fugacity is considered to be important in the formation of magnetitite seams.

As a result of fractional crystallization the volatile content of the remaining magma gradually increased. This is seen firstly, by the appearance of biotite secondly by the appearance of cumulus apatite and droplets of sulphide and lastly by hornblende in the rocks of the Upper Zone. Some water-rich residual liquids apparently also intruded the overlying leptite, causing additional melting of the latter and the formation of irregularly shaped veins and pockets of granodiorite.

A lateral change in facies of the rocks of the Layered Sequence in a southerly direction is described. This is considered to be due to crystallization of the magma at slightly lower temperatures because of the more effective heat loss where the magma chamber was thinner.

Two parameters of differentiation for layered intrusions are proposed, viz. a modified version of the differentiation index and a modified version of the crystallization index. The former seems more applicable for intrusions such as the Bushveld Complex, whereas the latter seems to be more applicable for intrusions in which there is a considerable development of ultramafic rocks. These two parameters can also be used to indicate the differentiation trend if they are plotted against height in the intrusion.

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SAMEVATTING

Die studie behels 'n petrografiese en mineralogiese ondersoek van gesteentes afkomstig van 'n gebied 800 vk. km in grootte wat ongeveer 80km noordoos van Middelburg geleë is. Die epikrustale fase van die Bosveldkompleks word in die westelike helfte van die gebied aangetref en bestaan grootendeels uit Rooibergfelsiet en granofier, asook leptiet, mikrograniet en granodioriet. Talle are van fynkorrelrige graniet sny oor die leptiet wat as 'n hoogs gemetamorfoseerde felsiet beskou word. Hierdie are van fynkorrelrige graniet het waarskynlik ontstaan weens die opsmelting van leptiet. Samevloeiing van die opsmeltingsprodukte het vermoedelik oorsprong gegee aan die dik plaat van granofier wat tussen die leptiet en die felsiet aangetref word.

Die oostelike helfte van die gebied word beslaan deur die Hoof- en Bosone van die gelaagde opeenvolging wat onderverdeel is in verskeie subsones op grond van kenmerkende gesteentetipes en merkerlae. Mineralogiese ondersoeke is beperk tot minerale van gesteentes van die gelaagde opeenvolging, naamlik ortopirokseen, plagioklaas, apatiet en sulfiede van die Bosone.

Ortopirokseen is in gesteentes van Subsone A van die Hoofsone teenwoordig as kumulus kristalle, terwyl dit in die onderste helfte van Subsone B groot ofitiese kristalle vorm. In laasgenoemde gesteentes word ook klein korrels van ortopirokseen aangetref wat deur inversie van pigeoniet ontstaan het (inversie-pigeoniet). Inversie-pigeoniet is die Ca-arm pirokseen in die boonste helfte van Subsone B van die Hoofsone en in gesteentes van die Bosone, terwyl die ortopirokseen-pigeoniet verhouding in Subsone C van die Hoofsone 'n herhaling is van die wat in die onderliggende Subsones A en B waargeneem is. Die faseverandering van ortopirokseen na pigeoniet vind plaas in 'n oorgangssone waarin altwee minerale gelyktydig aangetref word. Dit word veronderstel dat die eerste pigeoniet wat uit die magma gekristalliseer het, 'n laer Fe/Mg verhouding gehad het as hipersteen wat by 'n effens laer temperatuur gekristalliseer het met die gevolg dat die vroeë pigeoniet onstabiel was en met die magma gereageer het om hipersteen te vorm. Dit het die vorming van groepe van hipersteenkorrels tot gevolg gehad wat in dunseksie opties kontinu is oor groot gebiede (ofities) en wat 'n paar spikkels ougiet mag bevat wat uit die oorspronklike pigeoniet ontmeng het. 'n Paar van die pigeonietkorrels is vasgevang deur ander minerale, meesal ougiet, en het gevolglik reaksie met die vloeistof vrygespring. Hulle is omgesit

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in hipersteen by 'n laer temperatuur en bevat talryke ontmengingslamelle van ougiet. Met verdere fraksionasie het die magma uit die stabiliteitsveld van hipersteen en in die stabiliteitsveld van pigeoniet beweeg, met die gevolg dat reaksie van pigeoniet met die magma vervang is deur inversie van pigeoniet om hipersteen te vorm. Korrels van hierdie inversie-pigeoniet is ook teenwoordig as groepe wat opties kontinu is en bevat voor-inversie ontmengingslamelle van ougiet wat 'n willekeurige oriëntasie besit en na-inversie ontmengingslamelle wat parallel aan die (100) vlak van die ortopirokseen georienteer is. Hierdie hipersteen wat van pigeoniet ontstaan het, is so georiënteer dat sy kristallografiese c-as na aan of in die vlak van die gelaagdheid lê. Dit word toegeskryf aan belastingsdruk tydens die inversie vanweë die oorliggende massa kristalle.

Dit is gevind dat veral teksture wat deur plagioklaaskristalle geopenbaar word belangrik is by afleidings aangaande die na-kumulus veranderinge in die gesteentes. Omgekeerde sonebou, deurdringingsverskynsels en gebuigde plagioklaaskristalle asook die teenwoordigheid van mirmekiet word toegeskryf aan 'n toename in die belastingsdruk voor en tydens kristallisasie van die interkumulus vloeistof. Die verskillende tipes pegmatoïede mag hulle oorsprong ook te danke hê aan 'n toename in druk op die interkumulus vloeistof wat deur laterale afskeiding en uitpersing gekonsentreer is om pypvormige liggame te vorm.

Kumulus apatiet word aangetref in die oliviendioriete van Subsone D van die Bosone. Van eenheidseldimensies is afgelei dat die samestelling verander van 'n fluoorryke hidroksielapatiet aan die basis van die subsone na 'n relatief suiwer hidroksielapatiet 70m vanaf die top van die intrusie. In die boonste 70m is daar blykbaar weer 'n aansienlike toename in die fluoorinhoud van die apatiet.

Die gesteentes van die Bosone bevat aansienlik meer sulfiede as die van die Hoofsone, wat toegeskryf kan word aan 'n toename in die swaelinhoud van die magma weens fraksionele kristallisasie. Die magma was tydens kristallisasie van die gesteentes van Subsone D van die Bosone versadig aan swael met die gevolg dat talle klein druppels van sulfiede wat ongeveer 0,5 volume-persent van die gesteentes uitmaak, hierin aangetref word. 'n Konsentrasie van die sulfiede in die gesteentes sal nie 'n ekonomies belangrike afsetting vorm nie vanweë die ongunstige samestelling van die sulfiedfase, wat uit meer as 90 persent pirrotiet bestaan. Sulfiede in gesteentes onder hierdie subsone is interkumulus maar omdat hulle heelwat meer chalkopiriet en pentlandiet bevat, sou konsentrasies daarvan van ekonomiese waarde wees. Alhoewel tot nog toe geen ekonomiese konsen-

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trasie van sulfiede in die Bosone gevind is nie, word 'n gemineraliseerde anortosiet onder die Onderste Magnetitietband No. 2 beskryf wat op plekke tot 1 persent Cu, 0,18 persent Ni en 1,6g/ton Pt-groep metale bevat.

Onafgebroke, stadige konveksie en kristallisasie naby die vloer het vermoedelik oorsprong gegee aan die homogene gesteentes van die Hoofsone. Inplasing van 'n aansienlike hoeveelheid vars, ongedifferensiëerde magma het plaasgevind na kristallisasie van gesteentes van Subsone B van die Hoofsone wat 'n onderbreking in die differensiasieverloop tot gevolg gehad het, en gelei het tot 'n herhaling in Subsone C van die gesteentes onderkant die Piroksenietmerker. Die suurstofdruk tydens die kristallisasie van die magma was waarskynlik redelik laag en het 'n geleidelike verryking van yster in die magma tot gevolg gehad wat oorsprong gegee het aan die verskyning van magnetiet aan die basis van die Bosone. Magnetitietbande het vermoedelik ontstaan weens 'n verhoging in die suurstoffugasiteit wat met tussenposes plaasgevind het.

'n Toename in die vlugtige bestanddele in die magma weens fraksionele kristallisasie kan gesien word aan die verskyning van, eerstens, biotiet, tweedens, apatiet en druppels van sulfiede, en derdens, horingblende in die gesteentes. Van die laaste waterryke vloeistowwe het vermoedelik ook die dakgesteentes geïntrudeer en addisionele opsmelting van die leptiet veroorsaak wat gelei het to die vorming van onreëlmatige are en liggame granodioriet.

'n Laterale fasiesverandering van die gesteentes van die gelaagde opeenvolging in 'n suidwaartse rigting word beskryf. Dit word toegeskryf aan kristallisasie van die magma by effens laer temperature weens die meer effektiewe hitteverlies waar die magmakamer dunner was.

Twee parameters van differensiasie vir gelaagde intrusies word voorgestel, naamlik, 'n gemodifiseerde differensiasie-indeks en 'n gemodifiseerde kristallisasie-indeks. Eersgenoemde blyk meer doeltreffend te wees vir intrusies soos die Bosveldkompleks terwyl laasgenoemde meer doeltreffend blyk te wees vir intrusies waarin meer ultramafiese gesteentes ontwikkel is. Hierdie twee parameters kan o.a. ook gebruik word om die differensiasieverloop aan te dui as hulle teen hoogte in die intrusie geteken word.

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