VII. MODAL ANALYSES. (Folder IV)

1. Introduction

The purpose of this study was to determine, firstly, whether broad trends exist in the variations of components of the more "normal" rock types, secondly, whether there are any noticeable differences in the modal composition of rocks of this area and those of the area mapped by Molyneux farther north, and thirdly, whether changes in the abundance of the minerals are reflected by a change in their composition or texture.

The aim was not to determine exact variations in the mineral composition of the rock types, as the spacing of the rock specimens in the stratigraphical column are too irregular and too far apart. Furthermore, counts of several thin sections of the same sample are necessary for exact determinations of compositions because of the uneven distribution of certain mineral phases like orthopyroxene and clinopyroxene in specimens from Subzone B and parts of Subzone C of the Main Zone. The distribution of the large orphitic orthopyroxene grains in these parts of the sequence is similar to the distribution of intercumulus pyroxene in a mottled anorthosite, and point count analyses on several thin sections of the same rock will therefore result in a variation of the proportions of the components.

One hundred and ninety-two thin sections were "analysed" by means of a Swift Automatic Point Counter (Appendix I). The number of points counted varies between 1500 and 1800 per section over an area of approximately 320 sq mm. The degree of accuracy of the point count can be determined from the IC numbers (i. e. the number of identity changes on a 40mm traverse) and the curves given by Chayes (1956, p. 77).

Although the IC numbers fluctuate considerably from one section to the next (Appendix I), the average IC number lies between 55 and 60. The estimated average analytical error for a particular mineral is therefore between 2, 5 and 3 per cent and thus above the average analytical error of 2, 45 per cent which is considered by Chayes (1956, p. 84) to be a reasonable value for reconnaissance work of this nature. To attain an average mineral analytical error of between 2 and 2, 45 per cent, it is necessary to count two sections of each specimen with IC numbers of between 40 and 60, whereas point counts of three sections are required for specimens with an IC number between 35 and 40. This is essential because the variation in proportion of the components from one thin section to the next of the same specimen is greater for a coarse-grained rock than for a finer-grained one.

If the variation among thin sections of the same specimen is small, then the accuracy of the analyses is enhanced by an increase in the number of points counted per section, but as the within-specimen variation increases, the influence of the number of points counted diminishes rapidly (ibid., p. 90). The analytical error which is due to the within-specimen variation can therefore only be overcome by increasing the number of thin section counts for each specimen.

2. Main Zone

a) Plagioclase

The plagioclase content of the greater part of the Main Zone is fairly constant, fluctuating between 60 and 70 per cent by volume of the rock. The high values above the Merensky Reef indicate the abundance of anorthositic rocks in the lower 100m of this zone. Only in Subzone C is there a slight tendency for the normal gabbroic rocks to contain less plagioclase.

b) Pyroxene

A striking result of this study is the inverse relationship between orthopyroxene and clinopyroxene in most of the rocks of the Main Zone. The same relationship, although not quite as clear, seems to exist between plagioclase and clinopyroxene. This tendency is only observed in normal gabbroic rocks and not in interlayered anorthosite and pyroxenite. Although speculative, these relationships seem to indicate that some sort of equilibrium existed between the various crystallizing phases and that crystallization of one phase influenced the abundance of the other phases. Where orthopyroxene crystallized early, as in the rocks of Subzone A, it caused an enrichment of Ca but a depletion of Fe and Mg in the magma, resulting in a relatively high plagioclase content and a low clinopyroxene content. Where clinopyroxene crystallized before orthopyroxene, as in Subzone B, it caused a depletion of Ca, Fe and Mg in the magma with the result that the rocks of this subzone contain less orthopyroxene and plagioclase than those of Subzone A. Crystallization of one phase at a higher level in the magma chamber and the settling of this phase to the bottom of the chamber, would disturb this equilibrium of the crystallizing phases and cause the various phases to be present in any proportion.

Nucleation of several phases at the top of the chamber, i.e. in a cool environment, and transportation of these crystals by convective overturn to the warmer, lower part (bottom) of the chamber would result either in the melting of these phases or in overgrowths of more stable high temperature phases, thus causing the reversed zoning which is frequently observed, especially in the plagioclase of the Main Zone. The latter alternative of overgrowth necessitates extremely slow convection which would cause wide rims of the higher temperature phases. The reversed zoning is, where present, only confined to thin outer rims of the crystals and is probably due to postcumulus overgrowths as described in more detail on p. 94. Small crystals of pigeonite associated with or enclosed in clinopyroxene in the presence of primary orthopyroxene in a large section of the Main Zone would indicate that such a mechanism was operative, but in the section dealing with the mineralogy of the orthopyroxene (p. 83), this association is explained more satisfactorily in another way.

Jackson's concept (1962, p. 96-99) of bottom crystallization and variable depth convection, is a mechanism which explains cyclic units in basal portions of layered intrusions and it is doubtful whether such a mechanism was responsible for the thick accumulation of the relatively homogeneous rocks of Subzone B of the Main Zone. It must, however, be pointed out that a much more detailed investigation of the abundance and composition of coexisting phases is necessary to determine whether variable depth convection was operative during crystallization of the Main Zone or not. Slow continuous convection and crystallization at the bottom of the intrusion, as illustrated by Jackson (1961, p. 94-95) seems the best explanation of the observed relationships against the background of our knowledge at present.

These broad trends in the variation of the pyroxenes can, to some extent, be related to the textural relationships between these coexisting phases. For the greater part of Subzone A, the orthopyroxene is present as cumulus crystals, and predominates over clinopyroxene irrespective of whether the latter is cumulus or intercumulus. The only exception is found for a short distance in the sequence following the appearance of cumulus clinopyroxene at about 350m above the Merensky Reef. The lower half of Subzone B is characterized by large "ophitic" orthopyroxene grains and by the presence of small "inverted" pigeonite grains enclosed in or surrounded by clinopyroxene. In this zone of transition from primary orthopyroxene to inverted pigeonite, clinopyroxene usually predominates over orthopyroxene. Where "inverted" pigeonite proper appears in the sequence, the orthopyroxene content increases with a decrease in the clinopyroxene content.

In Subzone C, which may be regarded as a repetition of Subzones A and B, similar relationships hold true, except for the first 100m above the Pyroxenite Marker. Where small amounts of pigeonite, now inverted to orthopyroxene, are present as well as "ophitic" primary orthopyroxene, there is a pronounced increase in the clinopyroxene content and where large amounts of orthopyroxene which originated from pigeonite by inversion, appear in the sequence 50m below Subzone A of the Upper Zone, the clinopyroxene content drops considerably. This relationship persists up to the Main Magnetitite Seam, but where magnetite appears in larger quantities in the rocks above this seam, the orthopyroxene and clinopyroxene content of the rocks of the Upper Zone seem to fluctuate sympathetically.

c) Accessory constituents

The accessory constituents of the Main Zone are quartz, biotite, opaque minerals, K-feldspar and apatite. Of these, quartz is by far the most abundant accessory mineral, but it seldom exceeds 1 per cent by volume of the rock. The maximum concentration was found in specimen PB3801 where it constitutes 4, 3 per cent of the rock. It is present as typical intercumulus material occupying isolated patches in the section, but is optically continuous over large areas, indicating that the interstitial spaces are interconnected over large areas even at concentrations below 1 per cent.

Second in abundance is biotite. This mineral is not always a primary product of the intercumulus liquid, but seems to have originated owing to reaction between the liquid and solid phases, mostly interstitial ore. Interstitial ore minerals, K-feldspar and apatite are practically never present in amounts exceeding 0, 2 per cent by volume.

An interesting result of the modal analyses is the distribution of these accessory minerals in the Main Zone. There is a remarkable concentration of these minerals in the lower 2300m of the Main Zone in comparison to the upper half of this zone which is practically devoid of these constituents. It follows that crystallization of the lower half of the Main Zone was of such a nature as to effectively trap the intercumulus liquid, whereas during crystallization of the remainder of the zone very little or no intercumulus liquid was trapped, probably as a result of more effective adcumulus growth of the main constituents.

In the southern part of the mapped area, magnetite appears in small quantities in the rocks directly underlying the Pyroxenite Marker. Ten km farther to the south, Groeneveld (1970, p. 39), found similar rocks in the Main Zone, and although the Pyroxenite Marker seems to be absent in this area, there is a distinct compositional break above this horizon (ibid., Fig. 1, p. 38). Groeneveld also noted the predominance of orthopyroxene over clinopyroxene in these magnetite-bearing rocks, a characteristic which also prevails in the correlated magnetite-free rocks of the succession under discussion, and he also pointed out that this is in contrast with the magnetite-bearing rocks of the Upper Zone where clinopyroxene usually exceeds orthopyroxene.

3. Upper Zone

a) Plagioclase

The plagioclase content of the "normal" gabbroic rocks of this zone is generally slightly lower than that of similar rocks in the Main Zone, namely, ± 55 per cent, compared with between 55 and 70 per cent for the Main Zone. This difference may be due to the large amount of anorthosite and anorthositic rocks, the crystallization of which could be held responsible for a general depletion in the constituents of plagioclase during formation of the more normal rock types. This is also borne out by a trend which occurs repeatedly in the Upper Zone, namely, thick accumulation of plagioclase-rich rocks followed by relatively plagioclase-poor rocks (less than 50 per cent by volume), e.g.:

i) Anorthositic rocks of the lower part of Subzone B (4080-4150m) followed by the feldspathic pyroxenite below Seam 6 (4200m).

ii) Anorthositic rocks between 4700 and 4800m are followed by relatively feldspar-poor rocks between 4825 and 5025m.

iii) Anorthosites over and underlying Seam 15 are followed by feldspar-poor olivine-bearing rocks between 5550 and 5600m.

iv) Feldspar-rich rocks between Seams 17 and 21 are followed by feldspar-poor rocks directly above Seam 21.

Although the reverse of this trend may also be observed, as for instance at 4250 and 5050m, the above trend is much more pronounced. More detailed modal analyses are however necessary to verify this observation, and may reveal several more of these cycles.

Another feature worthy of mention, is the association of anorthosites and anorthositic rocks with the magnetitite seams. This was previously observed by

Molyneux (1964 and 1970). Apart from this association, the more normal olivine-free gabbroic rocks which occur between the magnetitite seams tend to have a relatively high feldspar content (4000-4300m, 4700-5125m, 5400-5500m and 5800-5950m). This is often difficult to discern in the field as a few per cent of magnetite, distributed evenly throughout an anorthositic rock imparts a deceptively dark colour to that rock.

b) Orthopyroxene

Although the rocks of the Upper Zone may contain up to 35 per cent orthopyroxene, they usually contain less of this mineral than do those of the Main Zone, a tendency which was also noted by Groeneveld (1970, p. 39) in the area to the south. That this may in part be due to the presence of magnetite is borne out by the absence of magnetite in specimens G649 and G625, both of which contain more than 20 per cent orthopyroxene. The fine-grained norite (G314) underlying Seam 8, on the other hand, contains appreciable amounts of cumulus magnetite. There is also no indication that the abundance of olivine or clinopyroxene is in any way influenced by the presence of magnetite in the rock.

In contrast to the rocks of the Main Zone where there is an inverse relationship between the orthopyroxene and clinopyroxene content, no such trend was observed in the rocks of the Subzones B, C and D of the Upper Zone. The trend of the Main Zone persists up to the Main Magnetitite Seam, but from here onwards, there is even a tendency for these two minerals to fluctuate sympathetically, which is especially noticeable in Subzone B.

c) Clinopyroxene

Clinopyroxene is the most abundant ferromagnesian mineral in the Upper Zone and normally exceeds orthopyroxene by a few per cent where both are present. In the presence of olivine, however, clinopyroxene tends to be subordinate. It attains its highest concentration of 52 per cent in the feldspathic pyroxenite (G649) of Subzone B, a feature also observed by Molyneux some 40km to the north (1970, Fig. 12, p. 33).

d) Olivine

Olivine makes its first appearance in this area about 4525m above the Merensky Reef, at a height some distance below the Sisal Troctolite Marker of Molyneux (1970, p. 25). No olivine-bearing rocks were found below this horizon and it seems as though the olivine-bearing gabbros of Subzone A, described by Molyneux (1970, p. 24) from Magnet Heights, are not developed in this area.

The olivine content of the olivine-bearing rocks at the base of Subzone C fluctuates considerably. The data for this horizon are, however, not very accurate because of the difficulty to distinguish, in the field, between olivine-bearing and olivine-free rocks at this level in the intrusion. The remainder of Subzone C is practically devoid of olivine except for very small amounts below Seam 11 and a more prominent layer above this seam which is also present in the Magnet Heights area.

Approximately 75 per cent of all the rocks of Subzone D are olivine-bearing. The olivine content in these rocks is for the greater part fairly constant, usually between 15 and 20 per cent except for the topmost 200m of the intrusion where it drops to nil directly below the roof. Where magnetitite seams are present in the sequence (Seam 15 and between Seams 17 and 21) there are very few or no olivine-bearing rocks present.

As mentioned previously, there is a distinct "facies" change in the upper half of Subzone D towards the west and the south, so much so, that the magnetite gabbros below Seam 21 make way for olivine diorites on Doornpoort 171 JS (bore-hole DDH1 and 2) and on Paardekloof 176 JS. The presence of small amounts of olivine in the sequence between Seams 17 and 21 on Duikerskrans 173 JS and Onverwacht 148 JS may already be a manifestation of these changes in a generally southerly direction.

e) Apatite

Small idiomorphic crystals of apatite appear in fairly large quantities at the base of Subzone D. Lower down in the sequence, apatite was observed sporadically in the intercumulus material as small anhedral grains, as low down as 100m above the Merensky Reef. Of interest is that only the olivine-bearing rocks of Subzone D contain large amounts of cumulus apatite, although one sample of the ovicular olivine diorite (G279) contains no apatite at all.

The apatite content of the olivine diorite in the lower half of Subzone D was found to be fairly constant, fluctuating between 4 and 6 per cent (Folder IV). The highest apatite concentration of 8,5 per cent was found in the rocks directly overlying Seam 21. Upwards from here it drops rapidly to about 0,5 per cent in the topmost differentiates of the intrusion.

f) Magnetite

The magnetite content of the normal gabbroic rocks of Subzone A is in the vicinity of 2 per cent or less, compared with the 7 per cent or more of most rocks higher up in the sequence. The only exception is the extremely fine-grained gabbro (G415) in the middle of this subzone. In Subzones B, C and D the magnetite content remains remarkably constant, irrespective of whether the rock is olivine-bearing or anorthositic. Only the feldspathic pyroxenite and some anorthosite layers were found to have a low magnetite content. This is however only a broad trend. Where anorthosites underly magnetitite seams, they are usually impoverished in magnetite, whereas most of the magnetitite seams have a gradational contact at their top. Positioning of the samples with respect to magnetitite seams therefore influences the magnetite content considerably.

g) Hornblende

Hornblende only becomes a major constituent of the Upper Zone in the dioritic rocks above Seam 21. It increases fairly rapidly above this seam and has an average concentration of about 20 per cent in the top 100m of the intrusion.

h) Accessory minerals

The most common accessory mineral in the Upper Zone is biotite, whereas in the Main Zone it is quartz. The other accessory minerals, K-feldspar and quartz, are only sporadically present in the greater part of the sequence and are developed in larger quantities in the topmost 300m of the intrusion. They may be considered as major constituents only in the top 10m of the intrusion (enlarged portion, Folder IV).

4. Conclusion

Comparison of the modal variation of constituents of the sequence studied, with a similar study by Molyneux (1970, Fig. 12) shows that there is a reasonable agreement in variation of the constituents in rocks of the Upper Zone. The broad trends observed in the rocks of the Main Zone are, on the other hand, not discernable in Molyneux's section. This may in part be due to the wider spacing of specimens.

The following differences between the two sections are however, worth recording:

i) The rocks of Subzone A of the Upper Zone contain more magnetite in the north than in the south.

ii) Olivine-bearing rocks do not seem to be developed below the Main Magnetitite Seam in the south.

iii) Orthopyroxene is more abundant in the Upper Zone in the north, especially in rocks above Seam 21.