Chamber of Mines
Precambrian Research Unit
13th Annual report 1975
University of Cape Town

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5.3. Granitoids and deformation sequence in the Goodhouse-Henkries area. A new interpretation of the relationship between rocks in the Vioolsdrif-Goodhouse area and the Namaqualand and Bushmanland gneisses

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ABSTRACT

The study of good exposures near Henkries has led to the following conclusions:

- the Vioolsdrif suite as a whole can be considered as a pretectonic intrusive complex emplaced within a subcontemporaneous volcanogenic pile;
- to the east, sedimentary layers (mainly quartzites and sillimanite schists) are interlayered with the volcanics, leading to the classical Bushmanland sequence;
- after the main deformation and metamorphism, a migmatite is widely developed in the Henkries area leading, in places, to a newly formed palingenetic granitoid (Goodhouse granite);
- furthermore, a basement can be recognised, folded and metamorphosed before the emplacement of the Vioolsdrif suite.

From these data it appears that the Richtersveld area belongs to the Namaqualand mobile belt and can only be defined as an "igneous province" but not as a "tectonic province".

INTRODUCTION

This report deals with the first results of fieldwork carried out in September and October 1975, after a two-day introductory trip with A. Kröner. No laboratory study has been carried out at this stage and I will briefly discuss the main field observations summarized on the map (Fig. 9). The aim of this study was mainly to investigate the structural setting of the "Richtersveld nose" near Goodhouse (Blignault *et al.*, 1974) and to compare the data of this area with the southern contact of the Vioolsdrif granite and Orange River Group volcanics, south of Vioolsdrif and south-east of Eksteenfontein.

ROCK TYPES

1. Metavolcanics

In the Henkries area the volcanics are always foliated and metamorphosed up to amphibolite facies. They are correlated with the Haib Formation, but the transitional rock types to these presumed metamorphic equivalents have not

Fig. 9 - Sketch map of the Henkries-Goodhouse area.
1 - metavolcanics; 2 - Vioolsdrif suite; 3 - metasediments; 4 - migmatites; 5 - Goodhouse granite; 6 - Goodhouse granodiorite; 7 - fault; 8 - steeply dipping shear zone; 9 - gently dipping shear zone; 10 - refoliation zone.
Areas quoted in text:
1 - Location of Fig. 2 Western edge of the Swartberg mountain; 2 - Gams-Omdraai section; 3 - good exposure of the metavolcanic sequence; 4 - diktyonitic textures in Vioolsdrif granodiorite; 5 - good exposure of banded gneisses; 6 - metasediments of the Gemsbokhoek stream; 7 - Rooiberg; 8 - Gemsbokhoek; 9 - Ramansdrift; 10 - Koisabees; 11 - good exposure of the Goodhouse granodiorite.

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been observed. The best exposures are in the Gams-Omdraai section, on the western side of the Henkries road, east of Witkop and south and east of Ramansdrift near Rooiberg. They are characterised by an alternation of three main rock types with a very weak (or no) small-scale layering: quartz-rich metarhyolites, homogeneous biotite-hornblende gneisses and muscovite gneisses (with sillimanite nodules), highly weathered with a yellowish colour, mapped as "pink gneisses" on the official map.

In places, these rocks alternate with sheets of deformed xenolithic granodiorite and pretectonic crosscutting meta-aplites which are difficult to distinguish from the metarhyolites.

2. Metasediments

Metasediments are very rare and consist mainly of some lenses of quartzite associated with sillimanite schists in one place (Fig. 9). To the east, however, thin bands of quartzite and calc-silicate rock are interlayered with biotite and muscovite gneisses of volcanic origin near Ramansdrift. On the farm Koisabees quartzite, garnet-bearing quartzite and limestone occur, associated with Rooiberg-type metavolcanics.

3. Vioolsdrif igneous complex

All the rock types defined in the Vioolsdrif area (De Villiers and Burger, 1968) and studied by Blignault (1974) and Reid (1974) are present in the study area, but with a highly deformed fabric. Various discordant U-Pb zircon dates suggest an age of formation at about 1900 My (Welke *et al.*, in prep.).

Basic and ultrabasic bodies occur as small plugs surrounded by the main foliation either within other intrusives or within metavolcanics, especially in the eastern part of the area.

The hornblende-bearing xenolithic granodiorite is the most widely distributed rock type, often associated with a biotite-bearing adamellite. When highly deformed, these rocks give way to a hornblende and/or biotite gneisses where the xenoliths are still often recognisable.

4. Biotite banded gneisses (grey gneisses) and sillimanite-cordierite gneisses

These two rock types have been encountered especially in the Swartberg mountain, east of Henkries and are intimately associated with migmatites and with Vioolsdrif granodiorites. The banded grey gneisses can only be distinguished from the later migmatites on a structural basis; their banding is crosscut in some places by the granodiorites, it contains small intrafolial folds and the banded gneisses and granodiorite were deformed together before partial melting generated the younger migmatites. These relationships will be described on an example in the next section. In the north-western part of the Swartberg, banded gneisses are associated with sillimanite-cordierite-muscovite gneisses which are nebulitic in texture and were probably generated during the late migmatisation event. They are associated with some continuous layers of sillimanite schists belonging to the same pre-Vioolsdrif formation as the banded gneisses. Within the two formations some thin and boudinaged amphibolites occur, often transformed to an epidote-bearing amphibolite.

5. Migmatites and migmatitic Goodhouse granite

As previously mentioned, the migmatites are often difficult to distinguish from the banded gneisses. Some criteria may be used, such as:

(i) the grain size is often coarser in the migmatite than in the banded gneisses;

(ii) the vein to schlieren structure;

(iii) the presence of large amounts of muscovite;

(iv) xenoliths of deformed Vioolsdrif granite and remnants of grey banded gneisses;

(v) the paucity of a fabric at mineral scale and lack of a true planar fabric (surfaces look more like a recrystallised flow structure than the result of a penetrative deformation).

In some places a late leucocratic mobilisate, more or less aplitic in composition, crosscuts all the previous structures and shows a schlierenitic banding parallel to the margins of the veins. The most distinctive criterion is, however, the grading of these migmatites of different kind to a nebulitic granite or granodiorite.

The granite itself may be called *Goodhouse granite* because the main outcrop area extends from Henkries to east of Goodhouse. It is heterogeneous in composition and the most important rock type in volume is a light granite, but granodiorite also occurs with a peculiar texture characterised by clastic grains of felspar "swimming" in a non-orientated fine-grained matrix.

THE MIGMATITIC EVOLUTION OF THE MAIN ROCK TYPES

1. The southern part of the Swartberg mountain is underlain by a heterogeneous igneous complex, including ultrabasics, diorites, granodiorites and adamellites related to the Vioolsdrif suite, whose crosscutting relationships with the banded grey gneisses are particularly clear on the south-western edge of the outcrop. Furthermore, the omnipresent, northerly dipping foliation cuts unconformably across the assemblage of the different rock types within the igneous complex. From these observations one can conclude:

(i) that a pre-Vioolsdrif basement clearly deformed and metamorphosed before the emplacement of the Vioolsdrif igneous complex existed;

(ii) the pre-tectonic character of the Vioolsdrif complex in relation to the main deformation event generating the northerly dipping regional foliation.

The central part of the mountain is the most interesting and can be considered as a key area for the understanding of the relationships between the pre-Vioolsdrif banded gneisses, the deformed igneous rocks of the Vioolsdrif suite and the late tectonic migmatite. Very good exposures have been found in the streams on the western edge of the mountain (but exposures of the same structures can be found also in the Gemsbokhoek, west of Goodhouse).

The broad structure, exposed in the core of a late, post-foliation open fold steeply dipping to the north-east, is sketched in Fig. 10. More details about the small-scale relationships between the different rock types will be given in a forthcoming paper, after the study of thin sections. One must emphasise, however, that there is beautifully exposed evidence of the late-tectonic (with respect to the main regional foliation) character of the migmatite which grades into the newly formed Goodhouse granite. This interpretation is strengthened by the occurrence of remnants of both deformed granodiorite and previously folded banded gneiss within the migmatite.

2. Metamorphic and migmatitic evolution of the metavolcanics

The best exposures showing gradation from large-scale banded metavolcanics to migmatites are in the Gams-Omdraai section. In this area large-scale isoclinal folds with axial-plane foliation emphasised by the alternation of meta-rhyolite and meta-dacite (or meta-andesite) have been found. One can follow the progressive migmatisation, ranging from the appearance of flecky structure (mainly in the more acid rock types) through a diktyonitic structure (veinlets of leucosome crosscutting the foliation) to an almost homogeneous granite or granodiorite. In this section, except south of Gams, the pretectonic Vioolsdrif intrusions are very scarce.

Another good section lies in the first ridge to the west of the Steinkopf-Henkries road. The structural pattern is more complicated here than in the Gams area because of the occurrence of pretectonic crosscutting aplite in the volcanic sequence and because of numerous sheets of Vioolsdrif intrusion now deformed parallel to the foliation of the surrounding rocks. Migmatites also occur in the central part of a thick layer of deformed adamellite. They can either be the result of a local remelting of the adamellite or, more probably, of a sheet-like association of volcanics and adamellite. At one place, a deformed xenolith-bearing granodiorite remobilised in a diktyonitic way can be seen (see Fig. 9). In such cases restricted late-tectonic melting of the granodiorite is possible, but in most cases granodiorites and diorites occur as remnants or xenoliths within the migmatite.

In every case it is almost possible to determine from which rock type the migmatite and the migmatitic granite or granodiorite was derived. In small outcrops, however, it is not easy to determine their origin, because of the small-scale interpenetration of rock types due partly to the tectonic, but also to the primary sheet-like shape of the pre-tectonic Vioolsdrif intrusives.

3. Do the banded grey gneisses and associated sillimanite-cordierite gneisses belong to a prevolcanic basement?

The igneous rocks of the Vioolsdrif suite can be seen to intrude the

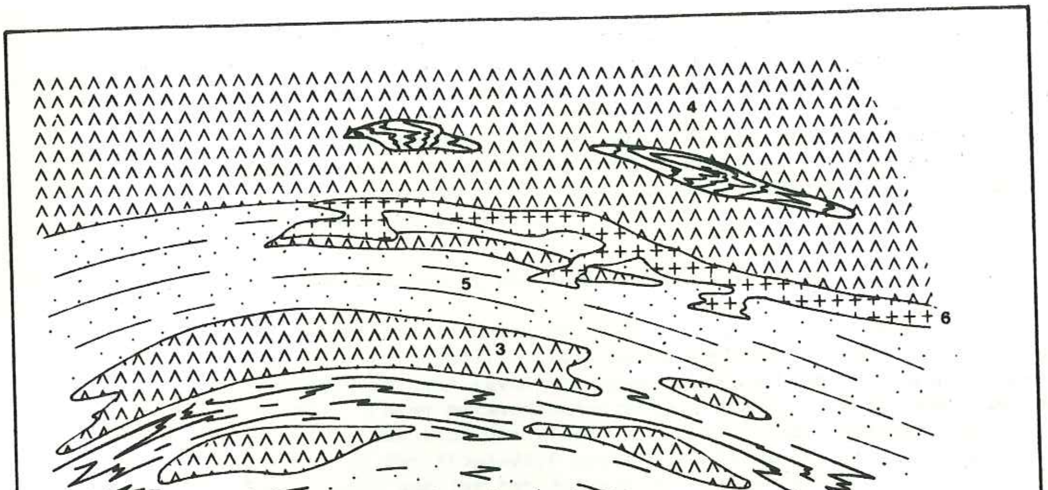

Fig. 10 . Idealized section of the west of the Swartberg mountain. 1 - banded grey gneisses; 2 - xenolith of banded grey gneisses within the migmatite; 3 - Vioolsdrif granodiorite; 4 - granodiorite grading upwards to a more heterogeneous complex with diorites and ultrabasics; 5 - migmatite; 6 - aplitic leucosome; 7 - xenoliths of deformed Vioolsdrif granodiorite within the migmatite.

the volcanics of the Haib formation near Vioolsdrif. The grey gneisses are also intruded by the same igneous complex, but nowhere has the relationships between metavolcanics and grey gneisses been observed. The assumption of a basement-cover relationship is only supported by the difference between, on the one hand, the monometamorphic appearance of the metavolcanics and the complete lack of folded structure predating the main isoclinal folding generating the regional foliation and, on the other hand, the pre-Vioolsdrif folding associated with an old melting - or at least metamorphic differentiation - seen in the grey gneisses.

If we can rely on the texture and composition of the migmatite and of the migmatitic Goodhouse granite, the whole area from Henkriesmond to Ramansdrift may be derived from this kind of basement rock preserved as remnants in numerous places. On the contrary, to the south of the AA' shear zone (Fig. 9), the migmatite and the new granite seem to be mostly derived from volcanics and pre-

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DEFORMATION SEQUENCE, IGNEOUS AND METAMORPHIC HISTORY

1. Early structures

As discussed in the preceding section these structures occur in the banded grey gneisses and probably reflect multiphase folding and a metamorphic evolution which are difficult to reconstruct from the small remnants preserved within the migmatite.

2. Emplacement of the Vioolsdrif suite

After the effusion of lavas, the probably co-magmatic Vioolsdrif suite was emplaced (Reid, 1974). It must be emphasised that, as in the north-western Richtersveld, the lavas are associated with metasediments occurring in thin strings. These metasediments become gradually more important to the east and seem to grade into the classical Bushmanland sequence (Joubert, 1974b). Knowing the age of the Vioolsdrif granite emplacement, it is possible to assume a mid-Proterozoic age for the Bushmanland sequence and its volcanic equivalents in a distinct geotectonic setting represented by the Richtersveld volcanics (Orange River Group).

3. Main deformation and prograde metamorphism

In the studied area and in all the surroundings, the main deformation is characterised by a northerly-dipping foliation, gently dipping and refolded in the southern part, (open folds in Koisabees and Nam), steeply dipping near the Orange River. Mineral lineation and minor folds as well as scarce large-scale folding as at Gams, are orientated N30 to N50. The greater part of the Henkries-Goodhouse area was subjected to high-grade metamorphism reaching the melting temperature of rocks of granite composition and incipient melting of granodiorite, but the muscovite always remained stable. Sillimanite and cordierite occur both in basement and cover rocks.

4. Open folds

With respect to the main foliation and area between Henkries and Ramansdrift is monoclinal, but open folds occur to the south (on the farm Koisabees) with an approximately E-W horizontal axis and in the Swartberg mountain with a steep N50 trending axis, very close to the trend of the previous mineral lineation. The relationships of these folds to the shear zones are not clear and it is likely, as suggested by Joubert (1974a), that they are related to large-scale transcurrent faulting like the Pofadder Lineament.

5. Shear zones and refoliation zones near Ramansdrift

The regional pattern of these structures can be seen on Fig. 9 and it must be pointed out that, on a larger scale, the whole area from Vioolsdrif to Goodhouse shows the same pattern; the shear planes are almost vertical when the shear trends NW, but in the E-W segments of the shear the planes are dipping 60° to 30° to the north. Furthermore, there is a change in attitude in individual shears from the west to the east. In the west the shears are vertical and NW-trending, becoming gradually more E-W in trend and less steeply dipping and crosscut by other NW vertical faults eastward in the same way as the westernmost shear zone. The resulting network is broadly parallel to the Pofadder Lineament and on the farm Witsputs the northern contact of the Richtersveld is a major shear, formed under brittle conditions and juxtaposing weakly deformed and metamorphosed Vioolsdrif granitoids in the south and high-grade gneisses to the north.

Near Henkries a small-scale observation of the shears shows the following relationships:

(i) post-metamorphic cataclastic textures accompanied by a retrogressive metamorphism (chlorite) and by late recrystallisation randomly-orientated hornblende (garbenschiefer textures);

(ii) veinlets of quartz emphasising distension features and often folded along a north-east sub-vertical axis. Sometimes quartz rods show slickensides orientated E-W. In all the observed exposures these structures seem to be related to a dextral movement along the shear zones, even when the shear planes are not vertical;

(iii) the width of cataclastic rocks is variable, but in the studied area is never more than fifty meters. Often the shear zones can be very thin.

The map (Fig. 9) shows the progressive disappearance of the shear zone to the east of Goodhouse. This feature must be compared with the appearance, even west of Goodhouse, of refoliation zones accompanied by folding postdating the main foliation. These refoliation zones are widely developed between Goodhouse and Ramansdrift. In this area the Goodhouse granite can be confused with Vioolsdrif granitoid because the former is as deformed as the bulk of the Vioolsdrif intrusives. Fortunately, the close association migmatite-granite and, on a small scale, the clear post-main foliation character of the foliation in the granite (mostly seen in the surrounding rocks near Ramansdrift), permitted the distinction between the two granites. This feature is very important because one cannot use the foliation as a marker for the correlation of structure over a large area and two foliations can be confused in the field even if they have quite a distinctive significance.

BRIEF COMPARISON WITH OTHER AREAS: THE SOUTHERN MARGIN OF THE RICHTERSVELD NOSE

Short trips have been undertaken to the Bleskop and Eksteenfontein areas to compare the structural and lithological pattern along the southern margin of the Richtersveld nose so clearly defined by the occurrence of granitoids of the Vioolsdrif suite.

1. The Bleskop area

From a lithological point of view, there are very few similarities with the Henkries area, except for the granitoids of the Vioolsdrif suite. The bulk of the gneisses exposed on the southern edge of the granite area seems to be of sedimentary origin with a prominent development of alumina-rich types such as sillimanite schist and gneisses with minor quartzites.

Compared with Henkries, the fold structures are more complicated, but shear zones are lacking. Two phases of folding can be distinguished, both with northerly dipping axial planar foliation. The first phase gave way to the main foliation, both in the Vioolsdrif granitoid and in the gneisses. There is no evidence of an earlier folding event in the gneisses. It was followed by a scarcely distributed, late-tectonic migmatisation and probably by the crystallisation of the peculiar widely distributed nodules or cordierite-sillimanite (and anthophyllite in some places); when undisturbed by a later deformation these nodules are randomly orientated in the foliation plane.

The first phase foliation is crosscut by bodies and sheets of muscovite-bearing leucogranite deformed afterwards by the second phase of folding. The second phase varies in style from one place to another and may be accompanied, as shown in the river north-west of Bleskop, by an important penetrative deformation and recrystallisation. It could be the northern equivalent of open folds occurring north of Steinkopf and developed in the quartzites.

2. The Eksteensfontein area

As at Henkries, the Vioolsdrif granodiorite is highly deformed and associated with metavolcanics where late-tectonic migmatization occurs at places. Unfortunately, the relationships with the southernmost outcropping gneisses (mainly banded grey gneisses and quartzites) are obscured by the occurrence of north-south trending shear zones related to the Pan-African event of the Gariepian belt.

CONCLUSIONS

According to the evidence described in this paper, the Richtersveld area is part of the Namaqualand tectonic province. The only differences are:

(i) the presence of a pre-tectonic igneous complex associated with effusive volcanics;

(ii) the decrease in metamorphic grade - strictly speaking the metamorphism related to the main phase of deformation - from the south to the north.

The northern margin of the Richtersveld may be compared with the Pofadder Lineament or, according to Toogood (1974), may be the extension of the lineament, which emphasises a break in the structural and metamorphic pattern. The numerous shear zones occurring to the south have the same significance.

Many problems remain to be solved, especially in the stratigraphic relationships between the Orange River Group, the Bushmanland sequence and the Namaqualand gneisses. Some data from the Henkries area support the assumption that the Orange River Group may be equivalent in age to the Bushmanland sequence. Furthermore, there is a strong probability of a basement underlying the volcanics, which could be the equivalent of some of the Namaqualand gneisses.

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