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THE AGES OF THE GOODHOUSE GRANITE AND GREY GNEISSES FROM THE MARGINAL ZONE OF THE RICHTERSVELD PROVINCE AND THEIR BEARING ON THE TIMING OF TECTONIC EVENTS IN THE NAMAQUA MOBILE BELT

by

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ABSTRACT

The marginal zone of the mid-Proterozoic Richtersveld Province along the Orange River near Goodhouse, South Africa contains grey gneisses and anatectic granites that were dated by the U-Pb and/or Rb-Sr methods.

Zircons from two widely separated localities of gneisses, considered on geological grounds to be older than the Orange River Group supracrustal sequence and the Vioolsdrif granitoids, define a Concordia intercept age of 1 862 ± 17 Ma. This date, regarded as a minimum age, is indistinguishable from published ages for the Vioolsdrif granodiorite.

Anatectic granitoids considered to be derived from migmatisation and palingenesis of the Vioolsdrif granitoids, and collectively termed Goodhouse granite, define a Rb-Sr whole-rock isochron with an age of 1 846 ± 76 Ma and an initial $^{87}Sr/^{86}Sr$ ratio of 0,704 5 ± 0,001 3. This age is compatible, within error, with the Concordia intercept age of 1 868 ± 41 Ma determined from zircons of two Goodhouse granite samples. Derivation of the Goodhouse granite from the Vioolsdrif granitoids is compatible with Sr-isotopic data and with geochemistry.

Since the Goodhouse granite cuts the penetrative fabric in the Orange River supracrustal suite and in the Vioolsdrif granitoids the above Rb-Sr age of 1 846 ± 76 Ma establishes a minimum age for this fabric while its maximum age is 1 880–1 900 Ma. If correlations of structures across the Province boundaries are correct these data constrain the timing of the main fabric in the neighbouring Namaqua Province. Alternatively the structure in the western Richtersveld Province reflects a local tectono-metamorphic event.

CONTENTS

I. INTRODUCTION

The age and tectonic evolution of the Namaqua mobile belt of south-western Africa has been a matter of considerable speculation in recent years.

Nicolaysen and Burger (1965) first proposed that the mobile belt was formed during an extensive and severe tectono-metamorphic event some 1 000 Ma ago. This interpretation was apparently corroborated by subsequent geochronological data, mainly $^{207}Pb/^{206}Pb$ minimum ages between 950 and 1 200 Ma on zircons from high-grade gneisses (Barton and Burger, 1983), and by a detailed investigation of the geochronology and deformation history of a small area around the famous Copper District of Okiep in Western Namaqualand (Clifford *et al.*, 1975).

Structural and geochronological work over the last ten years indicates that the mobile belt consists of three distinct tectono-geochronological entities which were defined, from east to west, as the Kheis, Namaqua and Richtersveld provinces (Fig. 1; Kröner and Blignault, 1976).

The Kheis Province constitutes the marginal zone of the Namaqua belt with the Kaapvaal craton where Archaean rocks were tectonised and thermally overprinted together with a mid-Proterozoic cover of sedimentary and volcanic strata at about 1 000–1 200 Ma ago (Botha *et al.*, 1979). *The Namaqua Province* consists of medium- to high-grade granitoid gneisses and supracrustal assemblages which display polyphase folding and metamorphism and which are known lithostratigraphically as the Namaqua Metamorphic Complex. It is from the high-grade rocks of this domain that most of the 950–1 200 Ma ages were obtained. *The Richtersveld Province* constitutes a wedge-shaped segment within the western part of the mobile belt (Kröner and Blignault, 1976, see Fig. 1) and is composed largely of low- to medium-grade metavolcanics and minor metasediments which are intruded by the Vioolsdrif intrusive suite, ranging in composition from gabbro-peridotite to leucogranite. The granites and granodiorites that constitute the major rock types of this suite have been dated by Welke *et al.* (1979) and by Reid (1979). The former authors assign a preferred age of 1 885 ± 20 Ma to the entire Vioolsdrif Suite, while the latter author assigns an age of 1 900 ± 30 Ma to the intermediate rock types (diorite, tonalite and granodiorite) but considers the leucocratic rock types to be younger at ~1 730 Ma. In view of the low metamorphic grade of most of the Richtersveld Province, in contrast to the neighbouring Namaqua Metamorphic Complex, it has been suggested that the high-grade rocks of the latter region predate the igneous rocks of the Richtersveld Province, and that the pervasive ~1 000 Ma ages reflect reheating on a grand scale (Joubert, 1971).

This view received further support from large-scale regional correlation of specific lithologies and deformation events when Vajner (1974) suggested that the metasediments of the Kheis Group, regarded by him as older than 3 000 Ma, can be followed from the Kheis Province into the eastern Namaqua Province, and that the oldest structures seen in the Kheis rocks predated the deposition of the *c.* 2 200–2 600 Ma old Ventersdorp Supergroup.

In contrast, however, Blignault (1977) considered that the first deformation recognised in the Namaqua gneisses postdates the intrusion of the Vioolsdrif Granite and is therefore younger than about 1 850 Ma. Furthermore, Botha *et al.* (1976) demonstrated that the Kaaien quartzites, regarded by Vajner (1976) to belong to the Kheis Group, correlate with the *c.* 2 000 Ma old Matsap–Waterberg Group.

The problem was reviewed by Kröner (1976) who pointed out that regional chronologic correlation of fold phases is a doubtful practice and that there is no convincing field or geochronologic evidence that supports a correlation of all metasedimentary quartizites in the Namaqua–Richtersveld–Kheis region at present.

All these arguments were presented without much information on the detailed field and age relationships between the high-grade gneisses of the Namaqua Province and the lower grade rocks of the Richtersveld Province. This prompted further work in the marginal zone of these two tectonic domains in order to resolve the following questions:

(i) are the lithologies of the Orange River Group as found in the Richtersveld Province older, contemporaneous or younger than the supracrustal rocks found in the Namaqua Province, and
(ii) was the strong penetrative fabric, which is particularly well developed in the marginal regions of the Richtersveld Province, imprinted during the 1 000–1 200 Ma event or earlier?

The authors report here on geochronological investigations of an important intrusive unit, the Goodhouse granite, and of older grey gneisses which enabled them to clear up some of the controversies in the geological interpretation of the region.

II. GEOLOGICAL SETTING

The tectonic and metamorphic boundary between the Richtersveld and Namaqua provinces is transitional within a marginal zone and is marked by a progressive increase in penetrative deformation and metamorphism towards the high-grade Namaqua terrain (Blignault, 1977; Kröner and Blignault, 1976; Ritter, 1980).

In the Henkries–Goodhouse area near the Orange River the transition is marked by a prograde metamorphic imprint from the nearly unmetamorphosed volcanics and intrusives near Vioolsdrif to amphibolite-grade banded gneisse near Ghaams and Henkries. Around Henkries the main rock types are biotite-hornblende-plagioclase gneiss and muscovite-plagioclase-microcline gneiss (a pink gneiss, often with sillimanite nodules). Metasediments associated with the metavolcanic units are rare and consist mainly of lenses of quartzite, at one place occurring together with sillimanite schist. To the east, however, the proportion of metasedimentary layers increases and thin bands of quartzite, calc-silicate rocks and lenses of limestone are inter-layered with the gneisses of volcanic origin. It appears that these metasediments become progressively more important east of Ramansdrift where they have been correlated with the Bushmanland sequence of the Namaqua belt (Joubert, 1976).

All the gneisses bear a strong foliation which is also developed in all members of the Vioolsdrif Intrusive Suite except for some small ultrabasic bodies. The granitoid plutons frequently have a sheet-like form and alternate with the metavolcanics described above. The most widely distributed rock type is a hornblende-bearing granodiorite with frequent mafic xenoliths that is associated with a biotite-bearing adamellite. When intensely deformed, both rocks give way to hornblende and/or biotite gneisses with strongly aligned xenoliths.

Near Swartberg the Vioolsdrif granodiorite intrudes a banded grey biotite gneiss which contains small intrafolial folds. Since such gneisses are also found to be intruded by the Vioolsdrif granodiorite in another part of the marginal zone some 50 km farther north-east on the farm Witputs 258 in Namibia (Fig. 1), these rocks may constitute an originally widespread basement. Although the possibility is not excluded that they represent metamorphic equivalents of the lower Orange River Group lavas we favour the basement interpretation since the metamorphic event responsible for the banding predates the Vioolsdrif granodiorite whereas the exposed Orange River lavas only display local pre-Vioolsdrif folding but no significant pre-Vioolsdrif metamorphism.

Both the supracrustal strata and the igneous rocks grade into a migmatitic assemblage in the outer marginal zone of the Richtersveld Province, and anatectic processes produced heterogeneous nebulitic granite or granodiorite, often with inclusions of older granitoid gneisses, deformed metavolcanics and granitoids belonging to the Vioolsdrif Suite (Bertrand, 1976). This distinctive rock type was named the Goodhouse granite by Bertrand (1976) and the main outcrop area extends from Henkries to east of Goodhouse. Very good exposures west of Swartberg Mountain near Henkries show clear evidence that the Goodhouse granite cuts the

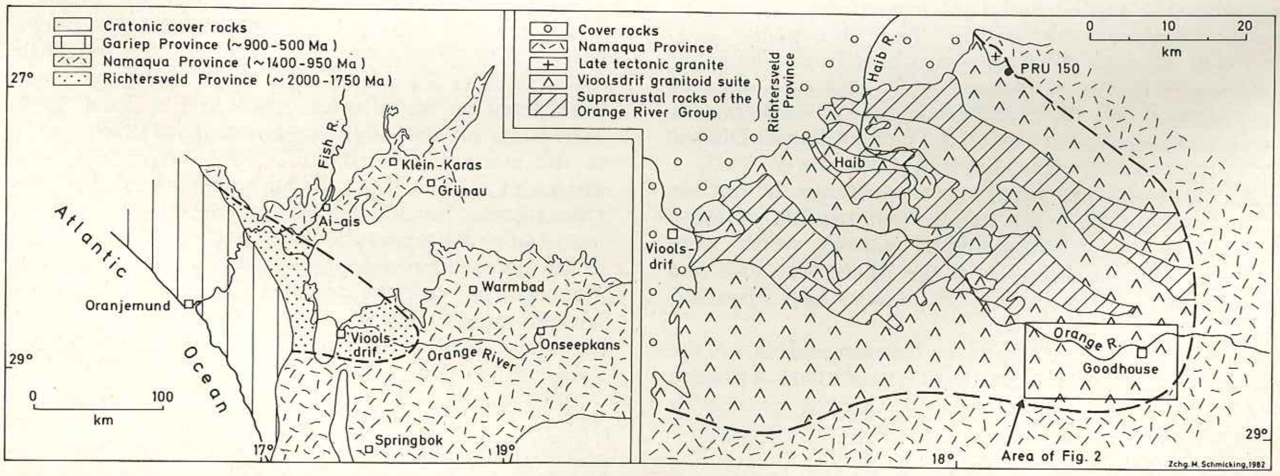

Figure 1

Sketch map of the Richtersveld and Namaqua tectonic provinces (after Blignault, 1977), showing location of Fig. 2 and of dated gneiss sample PRU 150.

foliation in both the Vioolsdrif granitoids and in the supracrustal rocks and must therefore postdate the tectonic event which produced this fabric (Bertrand, 1976).

In the Ghaams–Omdraai region one can study the progressive migmatisation of the metavolcanic strata, which ranges from the appearance of flecky structures through a diktyonitic structure (veinlets of leucosome cutting the older foliation) to an almost homogeneous granite or granodiorite. In cases where both the supacrustals and Vioolsdrif granites are migmatised together, it is almost impossible to determine from which parent rock type the Goodhouse granite was derived.

Under the microscope the migmatites and anatectic granites display typical metamorphic textures with a globular blastic shape of oscillatory-zoned plagioclase. These rock types are always rich in secondary muscovite and epidote.

The prograde metamorphic imprint from the low-grade supracrustal and igneous rocks near Vioolsdrif to the banded gneisses and migmatites is clearly associated with a single deformation event which produced the northerly to north-easterly dipping mineral foliaton. This fabric can be followed to the east and south into the neighbouring Namaqua Province, and has been correlated with the F_2-structures as defined by Joubert (1971).

Since the foliation was imprinted on the Vioolsdrif Igneous Suite it must be younger than the emplacement age of 1 880–1 900 Ma of this suite. The Goodhouse granite clearly cuts this foliation and its age will therefore set a younger age limit to the post-Vioolsdrif tectonic event.

III. GEOCHRONOLOGY

Zircon fractions of two samples of grey gneiss, one from the foothills of Swartkop Mountain near Henkries (PRU 130), the other from farm Witputs 258 (PRU 150), were analysed in the Geochronology Laboratory of the CSIR in Pretoria (A.J.B.) and in the CNRS Geochronology Laboratory of the University of Montpellier, France (A.K.). Five whole-rock samples of Goodhouse granite collected by J.M.B. were analysed by the whole-rock Rb-Sr method at the BPI in Johannesburg (E.S.B.) and zircons from two of these samples were analysed at the CSIR (A.J.B.).

The locations of all samples are shown in Fig. 1 and Fig. 2, and analytical data are presented in Tables I and II. Analytical procedures for the zircon work at the CSIR and the Rb-Sr work at the BPI are given in Allsopp *et al.* (1979); those for the analyses of very small zircon fractions of sample PRU 150 are detailed in Lancelot (1975). The Rb/Sr ratios for the Goodhouse granite samples were calculated from concentrations determined on a SMI Spectraspan III A inductively coupled plasma spectrometer (ICP) at the University of Mainz, following a technique described by Walsh (1980). Calibration was achieved using international standards BCR-1, AGV-1, W-1, GSP-1 and the Oxford standard AGX-6, and isotope dilution data on the same samples (see Table II) shows the accuracy to be better than one per cent in most cases. Isochron calculation follows the linear regression method of York (1969), using a correlation coefficient of zero and the decay constants recommended by Steiger and Jäger (1977). Errors in the ages and initial $^{87}Sr/^{86}Sr$ ratio reported are given at the 2-sigma level.

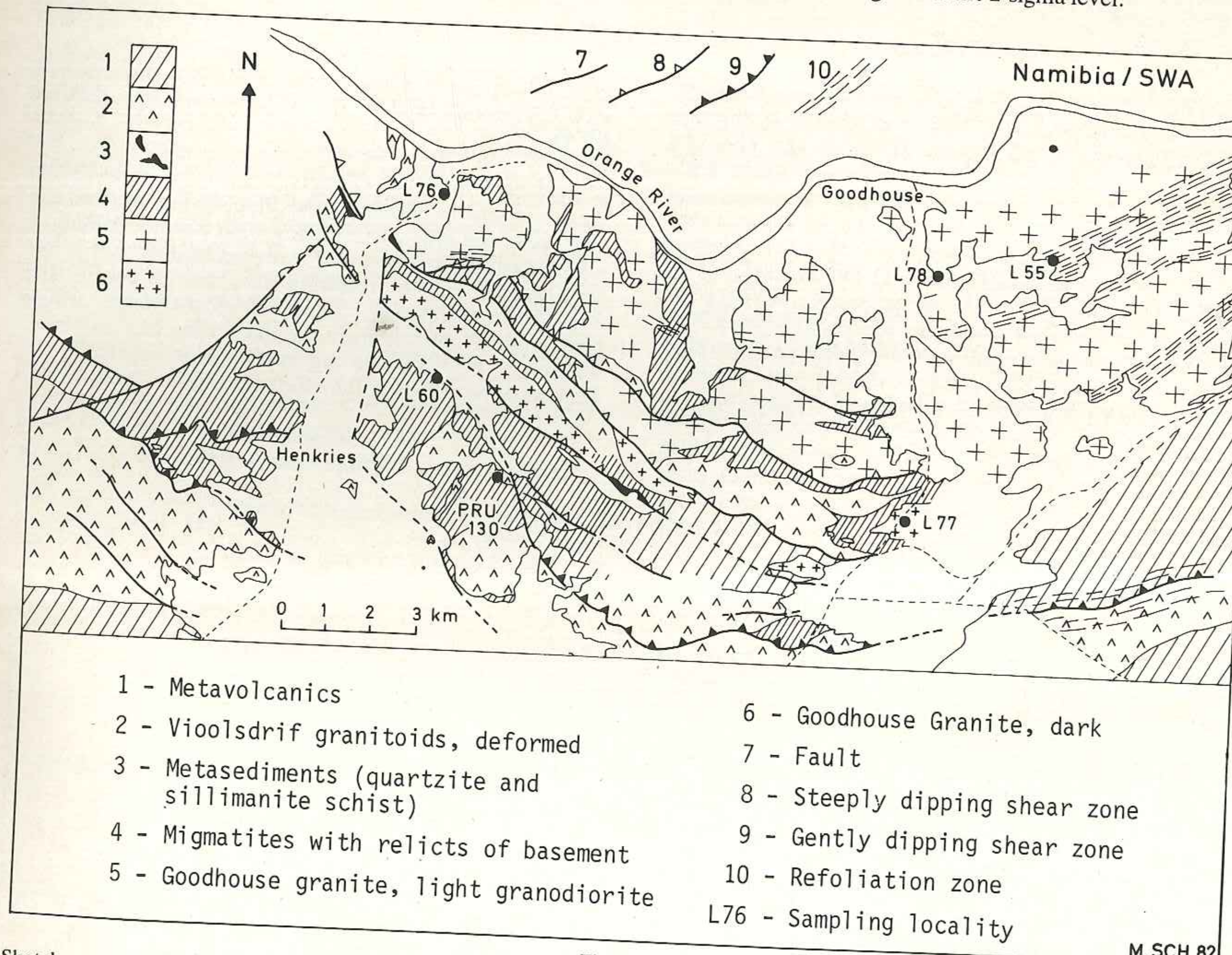

Figure 2

Sketch map of the Goodhouse–Henkries area showing major rock types, tectonic boundaries and sample locations (modified from Bertrand, 1976).

TABLE I
U-Pb Isotopic Data and Calculated Ages for Zircon Fractions of Grey Gneisses (PRU 130, PRU 150) and of Goodhouse Granite (L 60, L 78)

Sample	Total conc. (ppm)		Isotopic ratios (atomic)			Calculated ages (Ma)			Atomic ratios	
	U	Pb	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	$^{207}Pb/^{235}U$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{206}Pb/^{238}U$
PRU 130 (composite)	532,6	48,6	6 144	706,4	689,5	1 853	865	532	1,348	0,086 1
PRU 130 (<50 μ)	705,6	114,1	7 616	872,8	680,3	1 845	1 248	933	2,419	0,155 7
PRU 130 (50–75 μ)	505,5	100,3	9 183	1 063	1 046	1 869	1 394	1 106	2,945	0,187 1
PRU 150 (<75 μ)[1]	547,3	146,5	889	112,5	126,8	1 859	1 585	1 387	3,764	0,240 1
PRU 150 (>75 μ)[1]	2 628,0	166,8	1 730	205,6	191,1	1 834	661	372	0,918	0,059 4
L 60 (composite)	778,5	166,8	3 210	376,7	355,3	1 850	1 443	1 185	3,143	0,201 7
L 60 (<50 μ)	730,9	171,3	3 874	453,1	389,8	1 856	1 523	1 296	3,480	0,222 7
L 78 (composite)	488,1	138,1	5 914	686,7	1 407	1 862	1 591	1 397	3,793	0,242 0
L 78 (<50 μ)	428,6	117,2	5 651	654,0	1 280	1 854	1 567	1 365	3,681	0,235 9

1. Analysed by A.K. at Montpellier; all other analyses by A.J.B. at CSIR. Accuracy $^{207}Pb/^{235}U$ and $^{206}Pb/^{238}U$ ratios: CSIR data 1 %, Montpellier data 0,5 %.

TABLE II
Rb-Sr Isotopic Data for the Goodhouse Granite

Sample	Rb (ppm)[1]	Sr (ppm)[1]	$^{87}Rb/^{86}Sr^{1}$	$^{87}Rb/^{86}Sr^{2}$	$^{87}Sr/^{86}Sr$
L 55	166	335	1,439	1,443	0,742 84
L 60	188	250	2,187	2,170	0,762 67
L 76	160	326	1,425	1,422	0,742 24
L 77	99,7	341	0,848	0,820	0,727 14
L 78	128	422	0,879	0,883	0,727 77

1. ICP data (analyst: A.K.) as used in regression.
2. Isotope dilution (analyst: E.S.B.) for comparison. $^{87}Rb/^{86}Sr$ ratios are atomic ratios; accuracy assumed ±1 %. $^{87}Sr/^{86}Sr$ ratios normalised to $^{87}Sr/^{86}Sr$ = 8,375 (analyst: E.S.B.); accuracy assumed ±0,000 5.

A. Grey Gneiss

The composite zircon fraction and two further size fractions of the grey gneiss basement sample PRU 130 define a chord (MSWD = 0,32) which passes through Concordia at the origin and at 1 861 ± 28 Ma. The data points for two size fractions of the other grey gneiss PRU 150 also define a line passing through the origin and intersecting Concordia at 1 861 ± 26 Ma. All five fractions together define a chord (MSWD = 0,12) with an upper Concordia intercept age of 1 862 ± 17 Ma (Fig. 3).

The data points define a chord passing through the origin within experimental error. This could be indicative of recent Pb-loss as a result of mineral dilatancy, perhaps associated with recent uplift (Goldrich and Mudrey, 1969), and/or it may be due to laboratory procedures; in either case the indicated Concordia intercept age is strictly a minimum age. The zircon samples analysed in Montpellier were washed in acetone and 7-N HNO_3 prior to dissolution, and Briqueu *et al.* (1980) have shown that this procedure may, in certain cases, cause Pb-leaching and thus enhance the degree of discordance by shifting the data points on straight lines towards the origin in the Concordia diagram. We therefore conclude that the ages for the two gneiss samples PRU 130 and PRU 150 from widely different localities in the marginal zone of the Richtersveld Province are identical, but that the figure of 1 862 ± 17 Ma must be regarded as a minimum age in view of the above constraints.

Both grey gneiss samples were taken from rocks which are intruded by the 1 880–1 900 Ma old Vioolsdrif granodiorite, and this is therefore a minimum age for the grey gneisses. We are thus unable to demonstrate on isotopic grounds that the pre-Vioolsdrif grey gneisses are older than the intrusive suite although field relationships clearly show this to be the case. One could argue that the grey gneisses may represent a tectonised early phase of the Vioolsdrif igneous suite, but this is unlikely since the first event generating a penetrative tectono-metamorphic fabric (i.e. metamorphic banding and mineral alignment)

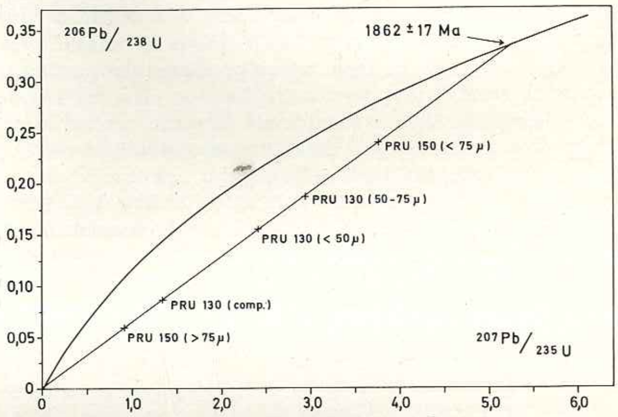

Figure 3
Concordia diagram for zircon fractions from grey gneiss samples PRU 130 (near Henkries) and PRU 150 (farm Witputs 258, see Fig. 1).

recognised in both the Orange River Group rocks and in the associated intrusives is post-Vioolsdrif granodiorite in age, while our grey gneisses show tight isoclinal folding of a metamorphic banding and a regional fabric that is not seen in the nearby volcanics and that is cut by the Vioolsdrif intrusives. Since a post-Orange River Group/pre-Vioolsdrif metamorphic event has not been identified regionally we are confident in regarding the gneisses as basement despite the inconclusive age data.

B. Goodhouse Granite

The four zircon fractions from samples L60 and L78 of

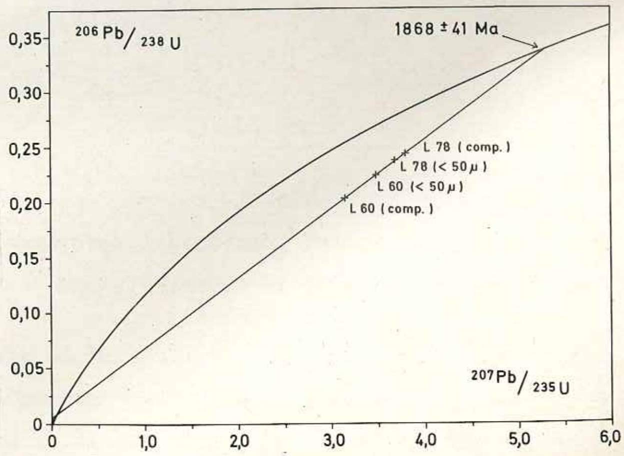

Figure 4
Concordia diagram for zircon fractions from the Goodhouse Granite.

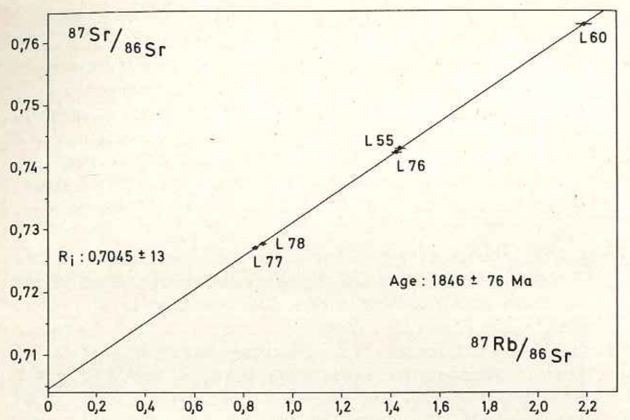

Figure 5
Rb-Sr isochron diagram for samples from the Goodhouse Granite (for location of samples see Fig. 2).

the Goodhouse granite, collected near Henkries, define a chord with a slightly positive lower Concordia intercept and an upper intercept at 1 868 ± 41 Ma (Fig. 4). A diffusion line pattern is not indicated and, as in the case of the gneiss samples, recent lead loss is suspected. The above age, indistinguishable from that of the grey gneisses, is therefore a minimum age.

Five whole-rock Rb-Sr determinations, including the two samples on which zircon age measurements were made, define an isochron (MSWD = 0,10) with an age of 1 846 ± 76 Ma and an initial $^{87}Sr/^{86}Sr$ ratio of 0,704 5 ± 0,001 3 (Fig. 5). This age is compatible, within error, with the zircon age for the two samples L60 and L78 and in view of the good agreement between the U-Pb and Rb-Sr results the simplest explanation is that the above ages reflect the primary event that generated the Goodhouse granite. The possibility of a slightly older age cannot, however, be excluded; this would imply resetting of the Rb-Sr systematics at a time coincidentally in agreement with the minimum U-Pb ages. In any event, migmatisation and anatexis in the Goodhouse area must date back to at least 1 850–1 870 Ma ago.

Derivation of the Goodhouse granite from the Vioolsdrif granodiorite is not incompatible with the Sr-isotopic data and is supported by geochemistry. The major element compositions of the dated Goodhouse granite samples are presented in Table III together with the average composition for 12 samples of Vioolsdrif granite from the Vioolsdrif area (Reid, 1977), five samples from the north-eastern Richtersveld and four samples from the south-eastern Richtersveld (Ritter, 1980). As can be seen the standard deviations for all major elements overlap with those of the Goodhouse granite although there is a tendency for a slight increase in SiO_2, K_2O and Na_2O and a decrease in total Fe in the latter.

In the AFM diagram of Fig. 6 data for the Goodhouse granite samples fall into the same field as the Vioolsdrif igneous suite, thus supporting the close compositional

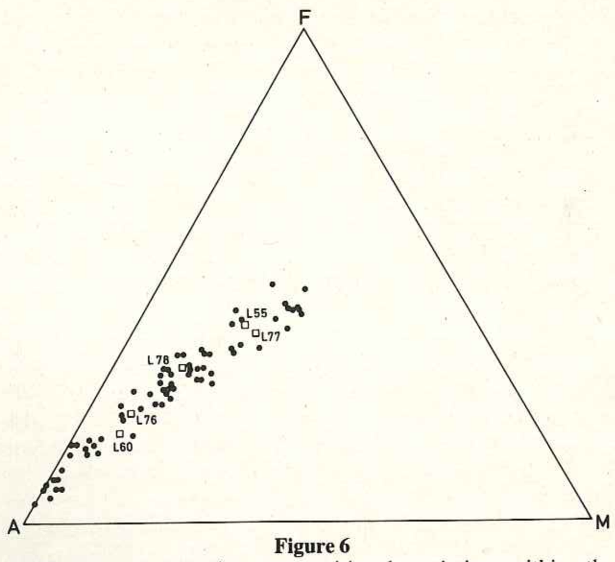

Figure 6
AFM diagram showing compositional variation within the Vioolsdrif granitoids (●) analysed by Reid (1977) and Ritter (1980), and the Goodhouse Granite (□) of Table III.

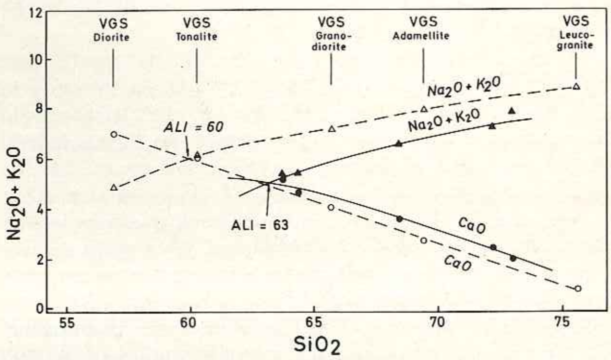

Figure 7
Harker diagram showing alkali trend of Vioolsdrif (open symbols) and Goodhouse granitoids (full symbols). ALI = Alkali-lime-index.

TABLE III
Major Element Compositions for Dated Samples of Goodhouse Granite, compared with Vioolsdrif Granite

Oxide	L 55	L 60	L 76	L 77	L 78	Average Goodhouse Granite	Average Vioolsdrif Granite
SiO_2	63,83	72,98	72,21	64,41	68,44	68,37 ± 4,25	66,44 ± 2,02
TiO_2	0,65	0,34	0,36	0,78	0,49	0,52 ± 0,19	0,56 ± 0,15
Al_2O_3	16,88	14,02	14,58	16,40	15,35	15,45 ± 1,20	15,60 ± 0,73
FeO	3,60	1,73	1,84	3,77	2,67	2,72 ± 0,95	2,95 ± 0,70
Fe_2O_3	1,55	0,17	0,40	1,45	0,94	0,90 ± 0,61	1,60 ± 0,55
MnO	0,12	0,04	0,06	0,10	0,08	0,08 ± 0,03	0,08 ± 0,03
MgO	2,61	0,86	0,83	2,97	1,64	1,78 ± 0,98	1,98 ± 0,58
CaO	5,21	1,93	2,45	4,53	3,58	3,54 ± 1,37	3,89 ± 0,53
Na_2O	3,41	2,45	3,22	2,85	2,80	2,95 ± 0,38	3,04 ± 0,35
K_2O	1,91	5,37	3,94	2,54	3,87	3,53 ± 1,35	3,80 ± 0,55
P_2O_5	0,23	0,12	0,11	0,19	0,14	0,16 ± 0,05	0,19 ± 0,08

Average Goodhouse Granite: mean of L 55–L 78.
Average Vioolsdrif Granite: mean of 12 analyses of Reid (1977) and 9 samples of Ritter (1980).
Analysis of Goodhouse granites by optical spectroscopy, Centre de Géologie et Géophysique, Université de Montpellier, France.

relationship between parent and daughter. However, in the Harker diagram of Fig. 7 the alkali trend for the Goodhouse granite is significantly different from that of the parent suite and the alkali-lime index is increased to about 63. This feature supports the suggestion that the Goodhouse granite is derived from anatexis of the Vioolsdrif granitoids and is not a differentiated member of the suite. It is of interest to note that the leucocratic granite at Klein Helskloof in the eastern Richtersveld, is also considered to represent the product of anatexis of the Vioolsdrif igneous suite (Ritter, 1980).

IV. CONCLUSIONS

Since the Goodhouse granite clearly cuts the main penetrative fabric in the Orange River supracrustal suite and in the Vioolsdrif granitoids the Rb-Sr age for this granite of 1 846 ± 76 Ma establishes a minimum age for the fabric, irrespective of whether the Goodhouse age actually refers to the time of anatexis, intrusion or resetting. The maximum age for this fabric is given by the age of the Vioolsdrif suite, i.e. 1 880–1 900 Ma. The Klein Helskloof granite, with a minimum age of 1 740 ± 40 Ma (Welke *et al.*, 1979), postdates the penetrative S_2 fabric in the neighbouring Vioolsdrif granodiorite (Ritter, 1980), and provides a similar constraint on the age of the fabric.

Joubert (1976) considered the main fabric and metamorphism in the neighbouring Namaqua Province to be older than the deformation in the Richtersveld Province and therefore suggested that the Namaqualand Metamorphic Complex is overlain by rocks of the Richtersveld Province. Clifford *et al.* (1975), on the other hand, assign the main Namaqua deformation to the Kibaran event at about 1 200 Ma ago. We cannot resolve this age descrepancy within the Namaqua Province since correlation of structural elements is still unresolved, but we question Joubert's (1976) proposed age relationships in view of our data and the isotopic studies of Barton (1983) from the Namaqua Province. It appears that the main fabric in the Goodhouse area may be older than that in adjacent rocks of the Namaqua Province.

Both Bertrand (1976) and Joubert (1976) suggest that the metavolcanic-metasedimentary succession near Goodhouse grades into the classical Bushmanland sequence of the Namaqua Province to the east. However, this is now considered unlikely since near Goodhouse the supracrustal rocks cannot be younger than about 1 850 Ma as they bear the imprint of the tectono-metamorphic event dated through the Goodhouse Granite, while the real Bushmanland sequence is apparently not older than ~1 300 Ma (Köppel, 1980).

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REFERENCES

Allsopp, H.L., Köstlin, E.O., Welke, H.J., Burger, A.J., Kröner, A., and Blignault, H.J. (1979). Rb-Sr and U-Pb geochronology of late Precambrian–early Palaeozoic igneous activity in the Richtersveld (South Africa) and southern South West Africa. *Trans. geol. Soc. S. Afr.*, **82**, 185–204.

Barton, E.S. (1983). Reconnaissance isotopic investigations in the Namaqua mobile belt and implications for Proterozoic crustal evolution — Namaqualand geotraverse. *Spec. Publ. geol. Soc. S. Afr.*, **10**, 45–66 (this volume).

– – – –, and Burger, A.J. (1983). Reconnaissance isotopic investigations in the Namaqua mobile belt and implications for Proterozoic crustal evolution — Upington geotraverse. *Spec. Publ. geol. Soc. S. Afr.*, **10**, 173–191 (this volume).

Bertrand, J.M. (1976). 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. *Precambrian Res. Unit, Univ. Cape Town, Thirteenth Ann. Rep.*, 61–70.

Blignault, H.J. (1977). The tectonic evolution of the Richtersveld and Namaqua Provinces in the Ai-Ais and Haib River areas, South West Africa. *Bull. Precambrian Res. Unit, Univ. Cape Town*, **23**, 197 pp.

Botha, B.J.V., Grobler, N.J., Linstrom, W., and Smit, C.A. (1976). Stratigraphic correlation between the Kheis and Matsap formations and their relation to the Namaqualand Metamorphic Complex. *Trans. geol. Soc. S. Afr.*, **79**, 304–311.

– – – –, Smit, C.A., Linstrom, W., and Grobler, N.J. (1979). Metamorphic zonation in the Matsap, Kheis and Namaqua domains east and west of the Kaaien Hills, northern Cape Province. *Trans. geol. Soc. S. Afr.*, **82**, 55–66.

Briqueu, L., Lancelot, J.R., Valois, J.P., and Walgenwitz, F. (1980). Geochronologie U-Pb et genèse d'un type de minéralisation uranifère: Les alaskites de Goanikontès (Namibie) et leur encaissant. *Bull. Cent. Rech. Explor. Prod. Elf-Aquitaine*, **4**, 759–811.

Clifford, T.N., Gronow, J., Rex, D.C., and Burger, A.J. (1975). Geochronological and petrogenetic studies of high-grade metamorphic rocks and intrusives in Namaqualand, South Africa. *J. Petrol.*, **16**, 154–188.

Goldrich, S.S., and Mudrey, M.G. Jr. (1969). Dilatancy model for discordant U-Pb ages (Abstr.). *Geol. Soc. America Proc. for 1969 Ann. Meeting*, **Pr. 7**, 80.

Joubert, P. (1971). The regional tectonism of the gneisses of part of Namaqualand. *Bull. Precambrian Res. Unit, Univ. Cape Town*, **10**, 220 pp.

– – – – (1976). The relationship between the Namaqualand Metamorphic Complex and the Kheis Group. *South African Jour. Sci.*, **72**, 312–313.

Köppel, V. (1980). Lead isotope studies of stratiform ore deposits of the Namaqualand, N.W. Cape Province, South Africa, and their implications on the age of the Bushmanland Sequence. *Proc. Fifth Quadrennial IAGOD Symposium. E. Schweizerbart, Stuttgart*, 195–207.

Kröner, A. and Blignault, H.J. (1976). Towards a definition of some tectonic and igneous provinces in western South Africa and southern South West Africa. *Trans. geol. Soc. S. Afr.*, **79**, 232–238.

– – – –, and – – – – (1978). The Namaqua mobile belt within the framework of Precambrian crustal evolution in southern Africa. *In:* Verwoerd, W.J., Ed., Mineralization in metamorphic terranes. *Spec. Publ. geol. Soc. S. Afr.*, **4**, 181–188.

Lancelot, J.R. (1975). *Les systèmes U/Pb: chronomètres et traceurs de l'èvolution de roches terrestres.* These d'Etat, (unpubl.), Univ. Paris VII, 280 pp.

Nicolaysen, L.O., and Burger, A.J. (1965). Note on an extensive zone of 1 000-million-year old metamorphic and igneous rocks in South Africa. *Sci. de la Terre*, **10**, 497–576.

Reid, D.L. (1977). Geochemistry of Precambrian igneous rocks in the lower Orange River region. *Bull. Precambrian Res. Unit, Univ. Cape Town*, **22**, 397 pp.

– – – – (1979). Age relationships within the Mid-Proterozoic Vioolsdrif batholith, lower Orange River region. *Trans. geol. Soc. S. Afr.*, **82**, 305–312.

Ritter, U. (1980). The Precambrian evolution of the eastern Richtersveld. *Bull. Precambrian Res. Unit, Univ. Cape Town*, **26**, 276 pp.

Steiger, R.H., and Jäger, E. (1977). Subcommission on geochronology: convention of the use of decay constants in geo- and cosmochronology. *Earth Planet. Sci. Lett.*, **36**, 359–362.

Vajner, V. (1974). The tectonic development of the Namaqua belt and its foreland in parts of the northern Cape. *Bull. Precambrian Res. Unit, Univ. Cape Town*, **14**, 201 pp.

– – – – (1976). Progress report on the statistical evaluation of structural data from the Namaqua foreland, northern Cape. *Precambrian Res. Unit, Univ. Cape Town, Thirteenth Ann.*

Rep., 7–18.

Walsh, J.N. (1980). The simultaneous determination of the major, minor and trace constituents of silicate rocks using inductively coupled plasma spectrometry. *Spectrochim. Acta*, **35B**, 107–111.

Welke, H.J., Burger, A.J., Corner, B., Kröner, A., and Blignault, H.J. (1979). U-Pb and Rb-Sr age determinations on middle Proterozoic rocks from the lower Orange River area, south-western Africa. *Trans. geol. Soc. S. Afr.*, **82**, 205–214.

York, D. (1969). Least squares fitting of a straight line with correlated errors. *Earth Planet. Sci. Lett.*, **5**, 320–324.

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