Communs geol. Surv. S.W. Africa/Namibia, **4** (1988), 53--58

K-Ar DATING OF THE MARIENHOF AND BILLSTEIN FORMATIONS IN THE REHOBOTH BASEMENT INLIER, SWA/NAMIBIA

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ABSTRACT

$^{40}K/^{40}Ar$ ages are reported from the Marienhof and Billstein Formations in the Rehoboth basement inlier at the southern margin of the Damara Orogen. K-Ar reference lines for Marienhof phyllites sampled close to the Areb shear zone yielded ages between 495,3 ± 5,0 Ma and 532,8 ± 5,3 Ma. Individual mineral ages of white micas from Marienhof quartzites and a single biotite from a Marienhof rhyolite range between 506,4 ± 5,1 Ma and 528,6 ± 5,5 Ma, while individual mineral ages obtained for white micas of the Billstein Formation range between 504,8 ± 5,2 Ma and 519,0 ± 5,5 Ma. The results of this study are in agreement with the results of earlier workers who proposed that folding and metamorphism reached the southern margin of the Damara Orogen at about 530 Ma.

1. INTRODUCTION

1.1 Marienhof Formation

The name 'Marienhof Series' was first introduced by De Kock (1934) for an assemblage of metamorphic, sedimentary and volcanic rocks which underlie the area to the west of Rehoboth (Fig. 1). According to SACS (1980), the Marienhof Formation is the lowermost unit of the Rehoboth Sequence which comprises the Marienhof, Billstein and Gaub Valley Formations. The Marienhof Formation is separated from the older Neuhof Formation by a sedimentary unconformity (Schalk, pers. comm., 1987) and is in turn unconformably overlain by the Nückopf and Billstein Formations. Intrusion by the Piksteel Intrusive Suite and the Gamberg Granite Suite provides a minimum age for this formation of about 1 064 Ma (Seifert, 1986; Mailing, 1978; Schalk, pers. comm., 1987).

Outcrops of the present Marienhof Formation occur to the west of Rehoboth between the farms Marienhof 577, Aroams 315 and the town of Rehoboth. To the south-west of Rehoboth a narrow strip of the Marienhof Formation crops out as far as Auchas East 522. A large xenolith of the Marienhof Formation occurs within the Piksteel Intrusive Suite on the farm Omdraai 210. Between the villages of Rehoboth and Dordabis, rocks as-

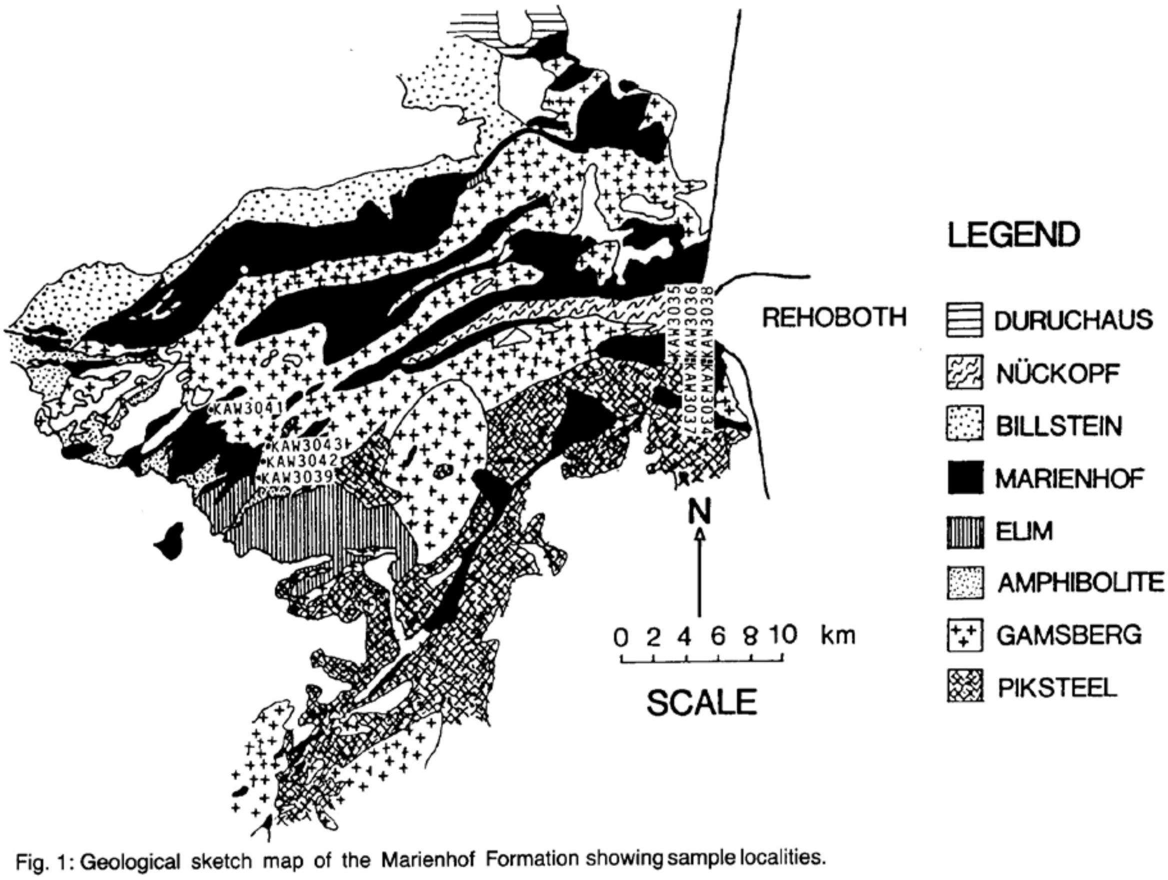

Fig. 1: Geological sketch map of the Marienhof Formation showing sample localities.

signed to the Marienhof Formation occur as a chain of inselbergs and as strongly weathered schists below the Nückopf Formation.

1.2 Billstein Formation

The Billstein Formation, which was established by a working group of SACS (1980), forms the middle section of the aforementioned Rehoboth Sequence.

The Billstein Formation only occurs north of an imaginary line drawn between the farms Aroams 315 in the west and Opdam 284 in the north-east of the northern part of the Rehoboth basement inlier (Fig. 2). The strata have been intensely thrust faulted and strongly folded to form several nappe structures. This formation may attain a thickness of 1 500 m (SACS, 1980) and either overlies the Marienhof Formation unconformably or rests with a tectonic contact on younger rocks of Namibian age. Rocks of the Damaran Sequence of Namibian age unconformably overlie the Billstein Formation.

2. LITHOLOGY

2.1 Marienhof Formation

The Marienhof Formation with its estimated thickness of up to 2000 m (SACS, 1980) consists of a series of white and grey quartzites, sericite-quartzites, quartzitic conglomerates, phyllites and some minor amounts of acid and basic volcanic rocks which have been metamorphosed under regional greenschist facies conditions.

The very fine- to coarse-grained quartzitic rocks may preserve original sedimentary structures and are predominantly composed of quartzitic rock fragments in a very fine-grained quartzitic matrix. These rocks consist of 95-99 % recrystallized quartz, 0-3 % albite, 1-3 % white mica and accessory magnetite, epidote, biotite and chlorite. The metamorphic growth of white mica and biotite is parallel to the penetrative schistosity which also parallels the original bedding. The conglomerates consist mostly of quartzitic components embedded in a fine-grained quartz matrix. Granitic, acid volcanic, amphibolitic and phyllitic components may be present. Greyish phyllites, up to several hundreds of metres thick, are closely associated with the quartzitic rocks and represent the pelitic portion of the Marienhof Formation. In contrast to the quartzites, these phyllites are often strongly altered due to weathering and therefore often form topographic depressions. They are very fine-grained and are composed of 45-60 % sericitic white mica, 25-40 % quartz, 2-9 % albite, 1-2 % chlorite, 2-7 % magnetite-haematite and accessory epidote. Chloritoid is a rare constituent. Thin section investigations by the authors have shown that deformation of the phyllites is complex and comprises at least three phases.

Layers of porphyritic rhyolite with a thickness of up to several tens of metres are interbedded with the Marienhof sedimentary sequence. Perthitic potassium feldspars are embedded in a fine- to very fine-grained matrix consisting of quartz, albite, biotite, chlorite, muscovite, magnetite and scattered accessory epidote and zircon.

Basic magmatic rocks, now present as highly altered amphibolites, have also been found within the sedimentary sequence. They are composed of amphiboles (in the process of alteration to chlorite and epidote), strong-

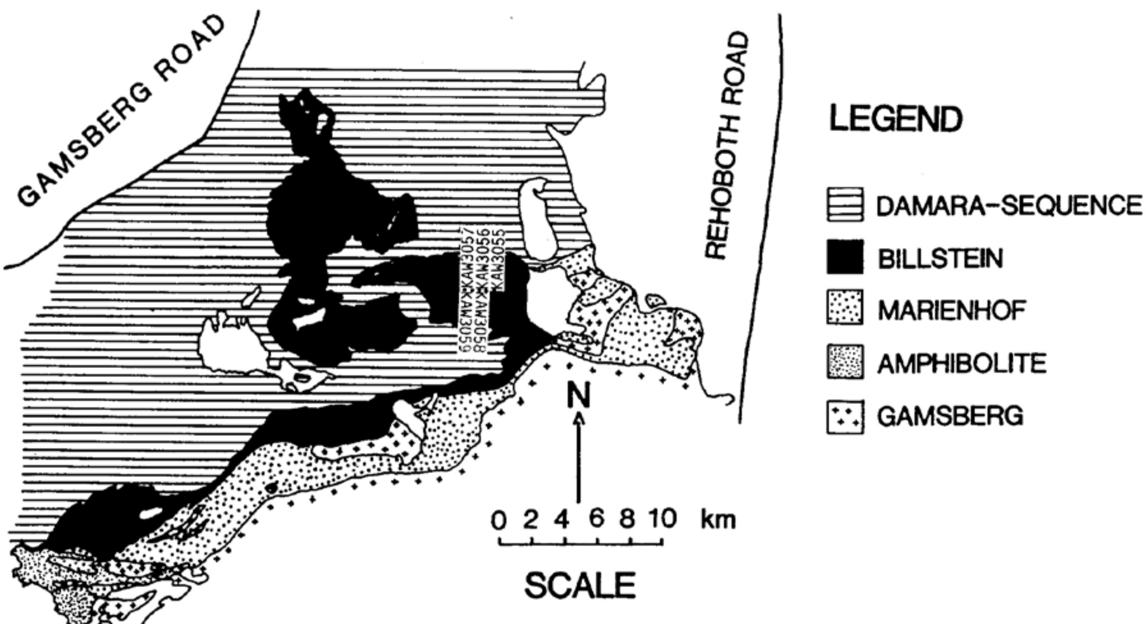

Fig. 2: Geological sketch map of the Billstein Formation showing sample localities.

ly saussuritised plagioclase, sphene and magnetite.

2.2 Billstein Formation

The Billstein Formation consists of a series of quartzitic conglomerates comprising quartzitic, granitic and basic rock fragments, gritty quartzites, sericitic quartzites, partly garnet-bearing mica schists and sericitic phyllites which are often also garnet-bearing. The phyllites may contain staurolite in addition (Schalk and Hoffmann, pers. comm., 1987). Numerous layers of basic rocks and some of quartz porphyry are included in the sedimentary sequence. Since most of the magmatic rocks within the Billstein Formation have been altered to amphibole (± biotite) schists, amphibolites and mica schists with a schistosity parallel to the bedding of the surrounding sediments, -it is not yet clear whether these magmatic rocks represent synsedimentary lavas or post-depositional sills. On the farm Kwakwas 251, the Billstein succession has been intruded by reddish, fine-grained granite of the Gamsberg Granite Suite (Schalk, pers. comm., 1987), thus indicating that its original deposition is of pre- to late-Sinclair age. According to field and petrographic observations by the authors, the Billstein Formation underwent at least three major phases of deformation.

3. SAMPLE COLLECTION AND PREPARATION

Metamorphic conditions have never reached Rb-Sr blocking temperatures for white micas in the Marienhof and Billstein Formations, as shown by the mineral parageneses of these formations, and the country rock is mostly strongly altered. Accordingly, the use of the K-Ar method was favoured in order to date the last metamorphic event in the northern part of the Rehoboth basement inlier. Large samples (30-50 kg each) of three Marienhof quartzites, five Marienhof phyllites and a single Marienhof rhyolite were collected in the vicinity of the Areb shear zone whose main branches partly cut across the sampled outcrops (Fig. 1). In addition, four samples of garnet-bearing Billstein mica schists and one sample of a sericitic Billstein quartzite with masses of about 50 kg each were collected on the farm Kwakwas 251 (Fig. 2).

The samples were crushed and the white micas were subsequently separated from the Marienhof quartzites and Billstein quartzites and mica schists by the use of sieves, a dry shaking table and magnetic separators. Biotite was separated in the same way from Marienhof rhyolite. As the grain size of the Marienhof phyllites (<100 microns) was much too small to use standard separation techniques for micas, an enrichment of the sericitic white micas was attained by the multiple use of Atterberg cylinders. The resulting separates of different degrees of purity (as shown by their K-content) were analysed separately in order to compare these results with the results obtained for the very finely ground whole-rock aliquots of the samples.

4. ANALYTICAL TECHNIQUES

The K-content of the samples was determined in duplicate on an Ingold flame photometer with a reproducibility of ± 1 %. From an aliquot of each sample the Argon was extracted and purified in a Pyrex line constructed by Flisch (1982, 1986) before it was analysed by the isotope dilution method (Kirsten, 1966; Dalrymple and Lanphere, 1969) on a VG MM1200 static vacuum mass spectrometer. Up to 99,9997 % pure ^{38}Ar (Schumacher, 1975) served as a spike for the calibration of the measurements. Mass discriminations, air corrections and blank corrections were calculated on a PDP11 system programmed by R. Siegenthaler. The K-Ar ages were calculated according to the age equation

$$t = \frac{1}{\lambda^{40}K} \cdot \ln \left[+ \frac{\lambda^{40}K}{\lambda^{40}K^{e}} \cdot \frac{^{40}Ar_{rad}}{^{40}K} \right]$$

where

$\lambda^{40}K = 5{,}543*10^{-10}a^{-1}$ (total ^{40}K decay constant)
$\lambda^{40}K^{e} = 0{,}581*10^{-10}a^{-1}$
(Steiger and Jäger, 1977).

The isotopic ratios of atmospheric Argon that were used are:
$(^{40}Ar/^{36}Ar)atm = 295{,}5$
$(^{38}Ar/^{36}Ar)atm = 0{,}1869$
(Steiger and Jäger, 1977).

5. RESULTS

5.1 Marienhof Formation

The individual ages obtained for the 2-30 micron and 30-80 micron fractions of the analysed phyllites range between 496,5 ± 5,0 Ma and 523,8 ± 7,2 Ma (Table 1). A reference line calculated on the basis of the $^{40}Ar/^{36}Ar$ and $^{40}Ar/^{36}Ar$ ratios shows a correlation coefficient of 0,9991, an intercept at $^{40}Ar/^{36}Ar = 959{,}8$ and yields an age of 500,6 ± 5,0 Ma (Fig. 3). However, a reference line in the $^{40}Ar_{rad}$mol/g versus ^{40}Kmol/g diagram after Harper (1970) gives an older age of 530,9 ± 5,3 Ma with a correlation coefficient of 0,991 (Fig. 4). The intercept of the reference line in Fig. 4 is slightly negative, viz. - 0,0297 $*$ 10^{-8} mol$^{40}Ar_{rad}$/g. The intercepts of the reference lines in the $4^{40}Ar/^{36}Ar$ versus $^{40}Ar/^{36}Ar$ and $^{40}Ar_{rad}$mol/g versus ^{40}Kmol/g diagrams, which are slightly different from their theoretical values of 295,5 and 0, respectively might be indicative of slight Argon diffusion within the Marienhof phyllites.

Since it was impossible to produce very pure mica separates due to the very small grain size of the phyllites, a whole-rock aliquot of each phyllite was analysed

TABLE 1: Tabulation of K-Ar results obtained for the Marienhof Formation (Age corr. = Individual ages corrected for the loss of $^{40}Ar_{rad}$ using $^{40}Ar/^{36}Ar$ corr. ratios determined on the basis of the Harper diagram of Fig. 7).

Sample KAW	^{40}K $*10^{-8}$mol/g	$^{40}Ar_{rad}$ 10^{-8}mol/g	$^{40}Ar_{rad}$corr. 10^{-8}mol/g	$^{40}Ar_{rad}$ %	^{36}Ar $*10^{-12}$mol/g	Age Ma	Error Ma	Age corr. Ma
3034 Phyllite								
Whole Rock	14,386736	0,470192	0,503682	99,64	5,79936	489,6	5,0	519,9
30–80 Microns	12,477646	0,417787	0,451277	99,73	3,96154	500,1	5,2	534,8
2–30 Microns	19,908616	0,667370	0,700860	98,74	0,291027	500,6	6,1	522,4
3035 Phyllite								
Whole Rock	11,551176	0,384992	0,418482	97,54	0,331856	498,1	6,4	535,6
30–80 Microns	17,281992	0,603880	0,637370	98,69	0,275133	519,1	7,3	543,9
2–30 Microns	19,460896	0,646181	0,679671	99,41	0,131116	496,5	5,3	518,8
3036 Phyllite								
Whole Rock	14,207648	0,476011	0,509501	99,37	0,103566	500,4	5,5	530,9
2–30 Microns	21,520408	0,748134	0,781624	99,16	0,217156	516,7	5,4	536,7
3037 Phyllite								
Whole Rock	12,476464	0,422025	0,455515	99,11	0,129652	504,6	5,0	539,2
30–80 Microns	13,998712	0,486824	0,520314	99,59	7,02684	516,9	6,1	547,6
2–30 Microns	21,401016	0,755639	0,789129	99,02	0,257163	523,8	7,2	543,8
3038 Phyllite								
Whole Rock	12,267528	0,407079	0,440569	99,54	6,60608	496,2	5,3	531,5
2–30 Microns	16,207464	0,538854	0,572344	98,95	0,196647	497,0	5,4	523,8
3039 Quartzite								
White Mica	21,848736	0,756672		99,46	0,141178	515,0	5,4	
3041 Rhyolite								
Biotite	9,805068	0,340769		99,12	0,103921	516,6	5,3	
3042 Quartzite								
White Mica	20,177248	0,720083		99,66	8,42901	528,6	5,5	
3043 Quartzite								
White Mica	21,192080	0,719813		99,74	6,37674	506,4	5,1	

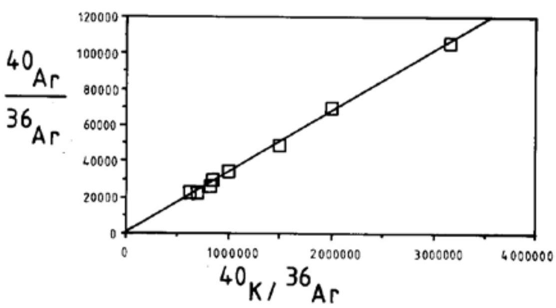

Fig. 3: $^{40}Ar/^{36}Ar$ versus $^{40}K/^{36}Ar$ diagram for the 2–30 micron and 30–80 micron fractions of the Marienhof phyllites.

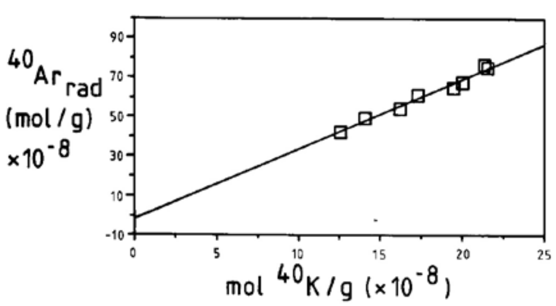

Fig. 4: $^{40}Ar_{rad}$mol/g($*10^{-8}$) versus ^{40}Kmol/g($*10^{-8}$) diagram for the 2–30 micron and 30–80 micron fractions of the Marienhof phyllites.

in order to determine the effects of impurity on the ages obtained for the mineral separates. Ages determined for these whole-rock aliquots range between 489,6 ± 5,0 Ma and 504,6 ± 5,0 Ma and correspond surprisingly well with the data from the mineral separates. This indicates that grinding did not cause a significant loss of Argon in the whole-rock aliquots of the Marienhof phyllite samples. In the $^{40}Ar/^{36}Ar$ versus $1/^{36}Ar$ diagram (Fig. 5) which contains all the data obtained, the intercept of a linear regression line drawn through the scattered data points is at $^{40}Ar/^{36}Ar$ = 9861. This intercept, together with the high percentage of radiogenic ^{40}Ar (see Table 1), allows one to exclude the possibility that the reference line in the $^{40}Ar/^{36}Ar$ versus $^{40}Ar/^{36}Ar$ diagram represents an air mixture line. Fig. 6 shows the calculated reference line of 495,3 ± 5,0 Ma for all the phyllite fractions in the $^{40}Ar/^{36}Ar$ versus $^{40}Ar/^{36}Ar$ diagram.

The correlation coefficient of the plotted data is 0,999 and the intercept of the calculated reference line is at $^{40}Ar/^{36}Ar$ = 1 065,8. The Harper $^{40}Ar_{rad}$mol/g versus ^{40}Kmol/g diagram (Fig. 7) for all the analysed phyllite fractions shows a slightly older age for the reference line of 532,8 ± 5,3 Ma with a correlation coefficient of 0,995 and an intercept at $^{40}Ar_{rad}$mol/g = - 0,0335 $_*$ 10^{-8} which may suggest a diffusive loss of Argon. Individual sample ages which have been recalculated to allow for

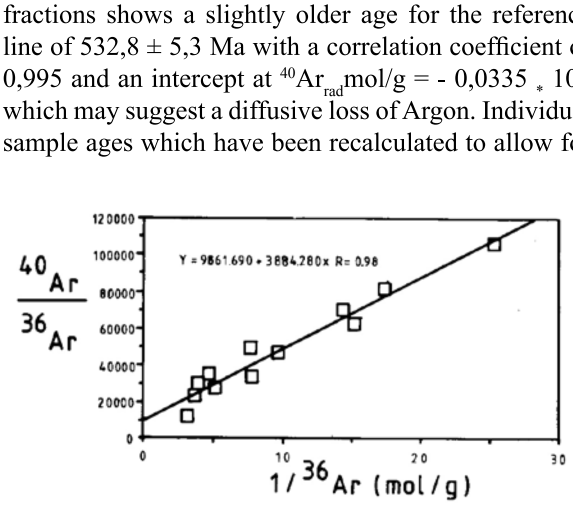

Fig. 5: $^{40}Ar/^{36}Ar$ versus $1/^{36}Ar$ diagram for all the Marienhof phyllite analyses.

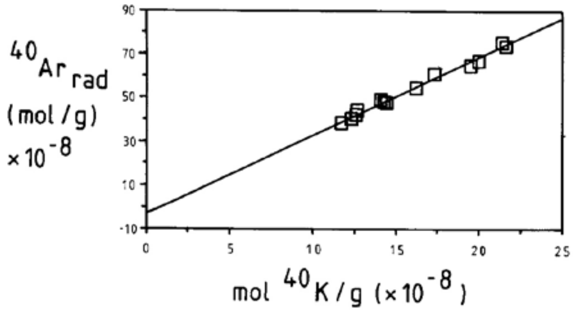

Fig. 7: $^{40}Ar_{rad}$mol/g(*10^{-8}) versus ^{40}Kmol/g(*10^{-8}) diagram for all the Marienhof phyllite analyses.

this possible Argon loss vary between 519,9 Ma and 547,6 Ma (Table 1).

The individual ages for white micas from quartzites are in agreement with the results obtained for the phyllites and range from 506,4 ± 5,1 Ma to 528,6 ± 5,5 Ma (Table 1). In addition to the results obtained for minerals separated from metamorphosed sedimentary rocks, the analysis of biotites from a Marienhof rhyolite yielded an age of 516,6 ± 5,2 Ma (Table 1).

5.2 Billstein Formation

The individual white mica K-Ar ages obtained for the Billstein Formation range from 504,8 ± 5,2 Ma to 519,0 ± 5,5 Ma (Table 2). The calculated reference lines in diagrams of $^{40}Ar/^{36}Ar$ versus $^{40}Ar/^{36}Ar$ (Fig. 8) and $^{40}Ar_{rad}$mol/g versus mol^{40}K/g (Fig. 9) - yield ages of 512,9 ± 5,1 Ma and approximately 481,3 ± 4,8 Ma respectively, and neither reveal significant Argon loss nor show significant Argon inheritance for the measured white mica separates. The intercept of the reference line in the $^{40}Ar/^{36}Ar$ versus $^{40}Ar/^{36}Ar$ diagram (Fig. 8) of $^{40}Ar/^{36}Ar$ = 282 is slightly low when compared to the $^{40}Ar/^{36}Ar$ ratio of 295,5 of the atmosphere, which still lies within the analytical error of the measured value due to the very small amount of ^{36}Ar found in samples with less than 1 % of air-Argon contamination. The slightly positive intercept of the $^{40}Ar_{rad}$mol/g versus mol^{40}K/g reference line at approximately $^{40}Ar_{rad}$mol/g = 0,05 * 10^{-8} is also not indicative of significant inherited Argon (Fig. 9) as slope and intercept of the reference line could not be determined with sufficient accuracy due to the small spread in the ^{40}K concentrations of the individual samples.

6. DISCUSSION

The coherent age pattern shown by individual minerals and whole-rock samples (489-532 Ma) from the Marienhof Formation suggests that lower greenschist facies conditions (i.e. 300 ± 50°C) were reached in the area between Marienhof 577 and the town of Rehoboth during the Damaran Orogeny. The $^{40}Ar_{rad}/^{40}K$ reference line age of 532,8 ± 5,3 Ma of the Marienhof phyllites as well as individual mineral ages of 516,6 ± 5,3 Ma for a biotite separated from a Marienhof rhyolite and 506,6 - 528,6 ± 5,5 Ma for white micas from Marienhof quartzites are all in agreement with the conclusions drawn by Clifford (1967) and Weber *et al.* (1983) that folding and metamorphism reached the southern margin of the Damara Orogen about 530 Ma ago. The somewhat younger individual ages of 489,6 - 523,8 ± 7,2 Ma determined for the different size fractions from the Marienhof phyllites may perhaps be explained by minor loss of Argon at temperatures below the blocking temperatures consequent to later tectonic movements along the Areb shear zone. This assumption is supported by a recalculation of the ages of these samples

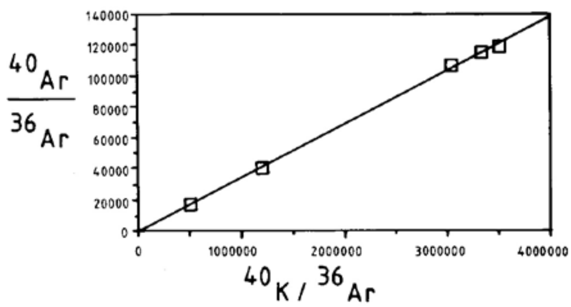

Fig. 8: $^{40}Ar/^{36}Ar$ versus $^{40}K/^{36}Ar$ diagram for white micas of the Billstein Formation.

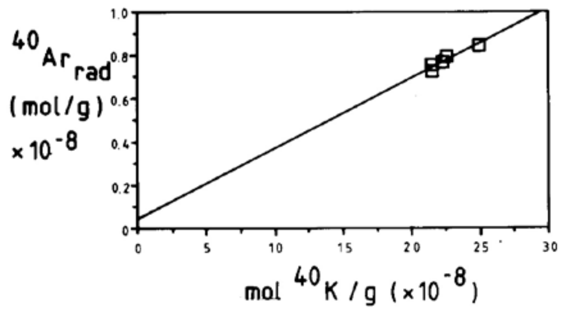

Fig. 9: $^{40}Ar_{rad}$mol/g(*10^{-8}) versus ^{40}Kmol/g(*10^{-8}) diagram for white micas of the Billstein Formation.

TABLE 2: Tabulation of K-Ar results obtained forthe Billstein Formation.

Sample KAW	40_K *10^{-8}mol/g	$^{40}Ar_{rad}$ *10^{-8}mol/g	$^{40}Ar_{rad}$ %	^{36}Ar *10^{-12}mol/g	$^{40}Ar/^{36}Ar$	Age Ma	Error Ma
3055 White Micas	22,475544	0,785338	99,73	0,074076	106314	519,0	5,5
3056 White Micas	22,296456	0,768772	98,33	0,444947	17 573	513,1	5,7
3057 White Micas	21,460712	0,744687	99,75	0,064587	11 5 596	515,9	5,3
3058 White Micas	21,430864	0,725340	99,27	0,180844	40 404	504,8	5,2
3059 White Micas	24,982776	0,849760	99,76	0,071282	119 507	507,0	5,1

allowing for this loss of radiogenic ^{40}Ar which puts the individual ages at between 518,8 and 547,6 ± 7,3 Ma thereby showing better agreement with the aforementioned conclusions.

The mineral ages of 504,8 - 519,0 ± 5,5 Ma obtained for the analysed white micas of the Billstein Formation fall within the age range obtained for the Marienhof samples, thereby suggesting that the Billstein Formation underwent a similar metamorphic overprint during the Damaran Orogeny.

7. ACKNOWLEDGEMENTS

This study was carried out as part of a University Research Project sponsored by the Geological Survey of SWA/Namibia. We wish to thank Prof. E. Jäger and Dr. R.McG. Miller for supervising the project. The many helpful discussions with colleagues at the KAW laboratory and members of the Geological Survey are greatly appreciated. We would further like to thank M. Flisch, B. Hoal and A. le Roex for critically reading and correcting the manuscript.

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