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Report: Geochemical, Rb-Sr and V-Pb isotope studies of some acid volcanics from the Rehoboth Basement Inlier, Namibia

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This report shows that all the analysed acid volcanics of the Rehoboth Basement Inlier are high-K rhyolites of mostly peraluminous nature. According to their element distribution patterns they may represent more evolved Gamsberg-, Piksteel- and Weener-type magmas. Post-genetic K-metasomatic processes are indicated by high K_2O/Na_2O ratios of the analysed specimens. A Rb/Sr isochron for rhyolites of the Nückopf Formation yielded an age of 948.0 ± 24.7 Ma. U/Pb dating on zircons from rhyolite dykes crosscutting the MarienhofFonnation yielded an age of 1210 ± 7 Ma.

Introduction

Acid volcanics occur throughout the Rehoboth Basement Inlier and are found as large extrusive masses of the Nückopf Formation as well as volcanic dykes crosscutting the Marienhof Formation, the Weener and Piksteel Intrusive Suites and the Gamsberg Granite Suite. Prior to SACS (1980), the Nückopf volcanics were assigned to various other formations. De Kock (1934) described parts of these volcanics as “quartz-porphyries” on his map of the western Rehoboth area while Handley (1965) and Martin (1965) expanded the Skumok Formation to accommodate these volcanics. De Waal (1966) subdivided and included the “quartz-porphyries” of De Kock (1934) in the Sinclair Formation. Schalk (1970) assigned these volcanics to the lower part of the Grauwater Formation and described them as “Nückopf Porphyry of the Grauwater Formation”.

The generally weakly metamorphosed volcanics of the Nückopf Formation overlie the intensely tectonised and metamorphosed succession of rocks of the Gaub Valley, Billstein, Marienhof, Elim and Neuhof Formations and the Mooirivier Complex. The Nückopf volcanics have been intruded by members of the Gamsberg Granite Suite which are believed (SACS, 1980) to be genetically associated with the former.

U-Pb age determinations by Burger and Coertze (1973, 1973-74, 1975-76), Burger and Walraven (1975-76) and Hugo and Schalk (1971-1972) yielded ages for the Nückopf volcanics ranging between 932 ± 50 Ma and 1770 ± 35 Ma. Some acid dykes on the farm Nauzerus yielded a Rb-Sr isochron age of 1030 Ma with a very high initial $^{87}Sr/^{86}Sr$ ratio of 0.732 (Reid *et al*, 1988). According to U-Pb and Rb-Sr age determinations by Reid *et al* (1988), Seifert (1986) and Burger and Coertze (1973, 1973-74, 1975-76), the age of the Gamsberg Granite Suite ranges between 1079 ± 25 Ma and 1210 Ma while the age of the Piksteel intrusives ranges between 1170 ± 29 Ma and 1725 ± 74 Ma. The initial $^{87}Sr/^{86}Sr$ values of the Gamsberg Granite Suite range between 0.700 and 0.708 while those of the Piksteel intrusives range between 0.704 and 0.710 according to Seifert (1986) and Reid *et al* (1988). Rb-Sr dating of the Weener Intrusive Suite by Seifert (1986) and Reid *et al* (1988) yielded ages between 1206 ± 102 Ma and 1871 ± 143 Ma with initial $^{87}Sr/^{86}Sr$ ratios ranging between 0.700 and 0.705.

The aim of this report is to elucidate the age relations of some acid volcanics within the Rehoboth Basement Inlier and to compare their geochemical properties to those of the Weener and Piksteel Intrusive Suites and the Gamsberg Granite Suite.

Sample collection and description

Sample localities are shown on Fig. 1, while farm names and coordinates of all localities are listed in Table 1. Seven whole-rock samples of Nückopf volcanics (KAW3164-KAW3169) were collected in areas assigned to the Nückopf Formation on Schalk’s unpublished 1:50 000 maps of the Rehoboth area. Two whole-rock samples, hereafter referred to as “Marienhof rhyolites”, were taken from rhyolitic dykes crosscutting the Marienhof Formation on the farm Marienhof 577 (KAW3040 & KAW3041). Six samples, hereafter referred to as “Gamsberg, Piksteel or Weener rhyolites”, were taken from rhyolitic dykes crosscutting the Gamsberg Granite Suite (G30) and the Piksteel (P7, P10, P14) and Weener Intrusive Suites (W4, W5). The mass of the wholerock samples for Rb-Sr analysis was 30-40 kg, while samples for geochemical analysis weighed 3-5 kg each.

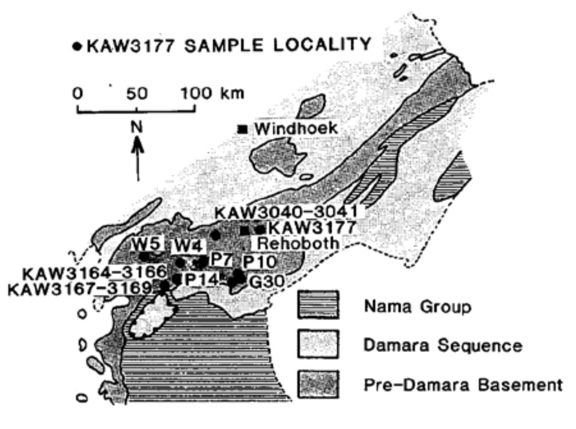


Fig. 1: Map of sample localities.

E 1: Major and trace element analyses of rhyolites from the Rehoboth Basement Inlier. No data recorded where concentration is below detection limit. Total Fe expressed as Fe_2O_3. No trace element analyses were carried out on sample W5.

e	G30	PO7	P10	P14	KAW3040	KAW3041	KAW3164	KAW3165	KAW3166	KAW3167	KAW3168	KAW3169	KAW3177	WO4	WO5
gy	Rhyolite	Rhyolite	Rhyolite	Rhyolite	Rhyolite	Rhyolite	Rhyolite	Rhyolite	Rhyolite	Rhyolite	Rhyolite	Rhyolite	Rhyolite	Rhyolite	Rhyolite
	Groendraai	Dymoeb	Karikomasis	Groendraai	Marienhof	Marienhof	Auchas	Auchas	Auchas	Stofbakkies	Stofbakkies	Stofbakkies	Rehoboth DG	337	Namibgrens
	23°41′20″S 16°58′00″E	23°40′00″S 16°42′14″E	23°40′34″S 16°56′50″E	23°42′33″S 16°59′55″E	23°24′05″S 16°47′39″E	23°23′31″S 16°46′37″E	23°47′55″S 16°28′19″E	23°47′15″S 16°27′35″E	23°47′13″S 16°25′42″E	23°48′14″S 16°18′46″E	23°48′26″S 16°20′09″E	23°48′25″S 16°20′10″E	23°19′37″S 17°11′28″E	23°40′57″S 16°29′25″E	23°37′31″S 16°15′51″E
	77.08	76.39	75.75	77.49	75.46	75.05	74.38	78.86	75.27	75.88	77.80	78.53	79.28	77.05	76.57
	0.13	0.12	0.18	0.10	0.27	0.29	0.34	0.21	0.29	0.27	0.25	0.10	0.12	0.25	0.15
	11.56	11.86	11.98	11.89	12.36	12.24	13.20	12.03	12.27	13.71	12.31	12.63	11.99	10.47	12.05
	0.97	1.02	1.11	0.83	2.51	1.55	2.04	1.24	1.55	1.61	1.23	0.75	1.46	1.34	0.96
	0.02	0.03	0.04	0.02	0.04	0.04	0.03	0.03	0.04	0.03	0.03	0.05	0.02	0.05	0.02
	0.31	0.30	0.36	0.17	0.16	0.12	0.18	0.14	0.12	0.46	0.32	0.15	0.16	0.56	0.28
	0.30	0.14	0.53	0.34	0.64	0.91	0.12	0.07	0.92	0.08	0.45	0.16	0.27	1.27	0.42
	2.52	2.94	2.78	4.05	3.53	3.68	3.46	2.79	3.69	2.42	2.38	3.46	3.91	0.82	3.35
	5.50	5.48	5.37	4.74	4.61	5.04	5.75	5.68	5.06	4.67	5.41	4.80	4.32	6.46	4.50
	0.02	0.02	0.05	0.02	0.02	0.05	0.08	0.05	0.05	0.12	0.04	0.01	0.01	0.05	0.04
	0.30	0.62	0.43	0.31	0.58	0.73	0.26	0.21	0.73	1.24	0.63	0.30	0.21	0.36	0.41
	98.71	98.92	98.58	99.96	100.18	99.70	99.84	101.31	99.99	100.49	100.85	100.94	101.75	98.68	98.75
	14	29	13	12	39	26	15	17	14	13	15	28	31	12	
	105	125	131	82	442	538	217	178	275	188	175	104	239	172	
	42	42	36	41	95	82	20	32	36	19	24	15	78	27	
	55	43	62	64	63	243	59	33	116	92	83	81		464	
	318	225	336	157	79	36	171	171	109	154	167	180	145	190	
	31	48	48	14		21	16	23	21	32	33	52	42	15	
						34	18	17			19			35	
	17	11	16	8	21	22	12	12	9	16	12	14	18	13	
		23	19		73	48	21	20		36	26	26		26	
					22	75	14	12	9	9	9	9	10	17	
	131	17	90	12	47	37								119	
	11	15	4				34	24	12	16	13	4	10	14	
			76		117	154								72	
			33		62	55									
	195	646	268	178	934	452	1202	707	1228	1325	1354	457		1277	
			58		93	58								71	
						7									

on limits:
Zr 23, Y 5, Sr 16, U 31, Rb 14, Th 13, Pb 16, Ga 5, Zn 18, Cu 9, Ni 12, Co 3, Cr 26, V 26, Ce 46, Nd 26, Ba 40, La 44, Sc 7, S 216

The Nückopf rhyolites are generally fine- to very fine-grained, partly recrystallised rocks. Porphyritic potassic feldspar, plagioclase and quartz of up to 2 mm in diameter are set in a fine-grained quartz-feldspar-sericite matrix. Most of the samples show a slight foliation. Widespread fissures are mostly filled with quartz and calcite.

The "Marienhof rhyolites" are fine- to very fine-grained meta-rhyolites with some relict potassic feldspar phenocrysts of up to 3 mm in diameter and rare plagioclase phenocrysts of up to I mm in diameter. The completely recrystallised matrix consists of quartz, feldspar, sericite, biotite/chlorite, epidote minerals and accessory magnetite/hematite and zircon. The zircons are heterogenous in size, shape and colour and often carry small inclusions of opaque minerals. The zircoh crystals are quite commonly surrounded by white alteration rims. K-Ar analyses of biotites from sample KAW3041 yielded an age of 516.6 ± 5.3 Ma (Ziegler and Stoessel, 1988) which is indicative of the Damaran metamorphism which affected the Marienhof samples.
Compared to the samples described above, the analysed "Gamsberg, Piksteel and Weener rhyolites" have a completely different appearance. These rhyolites closely resemble De Kock's (1934) dykes of quartz-porphyries which he described as crosscutting several granites in a "southern belt of eruptive rocks". With the exception of slight cataclasis, these rhyolites are practically undeformed and show only minor signs of alteration. Potassic feldspar of up to 1 cm in diameter, plagioclase and quartz phenocrysts are set in a fine- to very fine-grained matrix consisting of quartz, feldspar, sphene, ± biotite, ± sericite. In comparison to the other samples, the two "Weener rhyolites" show a slightly higher mica content and signs of stronger alteration.

Analytical techniques

The concentrations of 11 major and 20 trace elements of all samples were determined at the University of Fribourg, Switzerland using a Philips PW1400 X-ray fluorescence spectrometer. Loss on ignition was determined by heating of an aliquot of each sample for two hours at 1150°C.

The whole-rock Rb-Sr analyses were carried out on an aliquot of the samples which was previously ground under alcohol in an agate mill for at least 18 hours. The Rb and Sr concentrations and isotopic ratios were determined according to the method of Jäger (1979). Rb was measured on a "Ion Instruments" solid source mass spectrometer while Sr concentrations and compositions were determined on a "VG Sector" thermal ionisation mass spectrometer.

The U-Pb data were obtained by analysing different fractions of zircon separates. The zircons were separated from the samples KAW3O40 and 3041 by the use of a Wilfley table, heavy liquids (Bromoform and Methylene Iodide), and a Frantz magnetic separator. Different size fractions of zircons were obtained by the use of sieves. A selection of the purest crystals was then picked by hand from the separates. The still heterogenous fractions were washed in nitric and hydrochloric acid. After the addition of a highly pure ^{205}Pb/^{235}U spike, about 1 to 5 mg of the zircon concentrate were dissolved in PTFE-bombs according to the method of Krogh (1973). Element separation was also carried out following the method of Krogh (1973). U and Pb were then measured on a "VG Sector" thermal ionisation mass spectrometer. A common-Pb correction for the age of 1210 Ma was carried out using the two stage model of Stacey and Kramers (1975). The analytical total blank of Pb of modem composition is below 0.18 ng.

All the curve fitting calculations in this study were performed according to York (1969) with equally weighted samples and no correlation of errors. Constants used for data correction and age calculations are those of Steiger and Jäger (1977).

Results

Geochemistry

The results of all the geochemical analyses are listed in Table 1. The tabulated limits of detection are those obtained due to regression statistics (Reusser, 1987) and not the considerably lower values resulting from matrix dependent count statistics.

All the analysed samples can be classified as alkali rhyolites according to the chemical nomenclature system for magmatic rocks of De La Roche *et al* (1980) and Streckeisen (1981). With K_2O contents >4.3 wt% all the specimens would be termed high-K rhyolites according to the classification scheme of Ewart (1979), confirming the early work of De Kock (1934) who classified the "quartz-porphyries of the southern eruptive

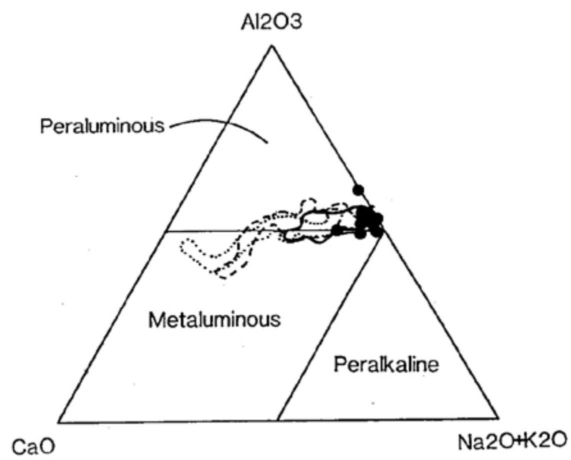


Fig. 2: Mol% Al_2O_3-CaO-(Na_2O+K_2O) ternary diagram after Shand (1927) for the analysed rhyolites (filled circles) in comparison with the fields for Gamsberg-, Piksteel- and Weener-type magmas (Fields for plutonic rocks after Stoessel and Ziegler, 1988); same symbols as in Fig. 3.

belt" as potash-rhyolites.

In the $CaO-Al_2O_3-(Na_2O+K_2O)$ ternary diagram (Fig. 2) most of the analysed samples plot in the field for peraluminous rocks since their Al_2O_3 contents exceed that of (Na_2O+K_2O+CaO), while three samples plot in the bordering area of the fields for peraluminous and metaluminous rocks. The data also plot well within the compositional fields representing the Gamsberg, Piksteel and Weener granitoids according to Stoessel and Ziegler (1988). It is noteworthy that all the rhyolites plot towards the low-CaO end of the ternary diagram thus indicating their enrichment in $Na_2O + K_2O$ in comparison with the Rehoboth granitoids.

With the exception of the "Marienhof rhyolites", the analysed rhyolites also plot in the same fields as the Piksteel, Gamsberg and Weener intrusives in the tectonic discriminant Nb+Y versus Rb diagram of Pearce *et al.* (1984) (Fig. 3). This diagram indicates the close relationship of the analysed rhyolites with the Piksteel, Gamsberg and Weener magmas.

A slightly different picture is shown by the AFM ternary diagram (Fig. 4) where the analysed volcanics plot close to the end members of the evolution trends of the Piksteel, Gamsberg and Weener granitoid suites after Stoessel and Ziegler (1988).

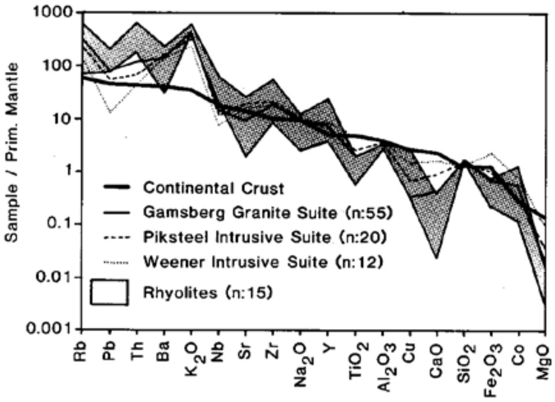


Fig. 5: Mantle-normalised element concentration patterns of rhyolites from the Rehoboth Basement Inlier compared with average crust and average patterns of Gamsberg-, Piksteel- and Weener-type magmas after Stoessel and Ziegler (1988).

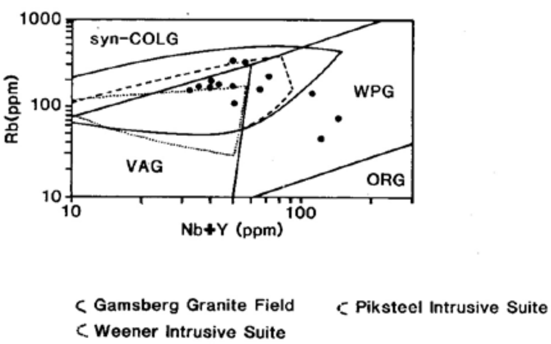


Fig. 3: Nb+Y *vs.* Rb diagram after Pearce *et al.* (1984) for the different analysed rhyolites (filled circles) compared with the Gamsberg-, Piksteel- and Weener-type magmas (Fields for pultonic rocks after Stoessel and Ziegler, 1988).
(syn-COLG = syn Collison Granites; WPG = Within Plate Granites; VAG = Volcanic Arc Granites; ORG = Ocean Ridge Granite).

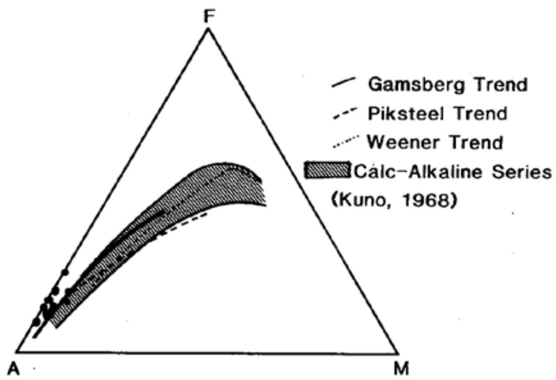
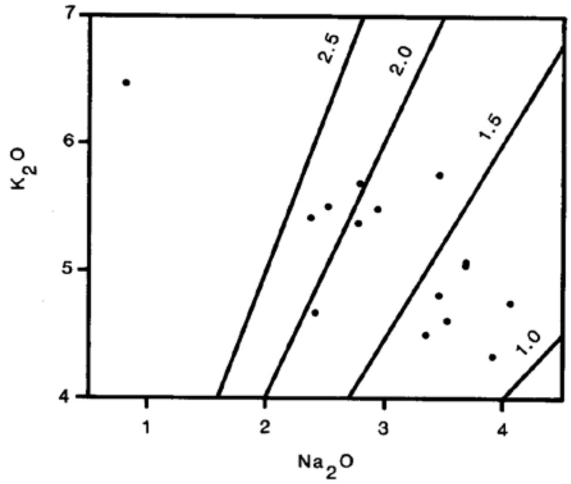


Fig. 4: AFM ternary diagram for the analysed rhyolites (filled circles) compared with the magmatic evolution trends for the Gamsberg-, Piksteel- and Weener-type magmas (Stoessel and Ziegler, 1988).

In Fig. 5 the mantle-normalised element concentration patterns of the analysed specimens and the average patterns of the Gamsberg, Piksteel and Weener intrusives are plotted in order of increasing compatibility after Taylor and McLennan (1985). With the exception of Ba and Sr which are slightly depleted, most of the elements of the rhyolites reflect a slightly more advanced stage of magmatic evolution as shown by the enrichment in Rb, Pb, Th, K_2O and Nb and depletion in Na_2O, TiO_2, CaO, Fe_2O_3, Co and MgO in comparison with the average values of the Gamsberg, Piksteel and Weener magmas.

The behaviour of the alkalis in Fig. 6 and Fig. 7, viz. the high K_2O/Na_2O ratios (1-2.5), the slightly negative correlation of K_2O and Na_2O and the scatter in K_2O+Na_2O contents with increasing SiO_2, may indicate post-genetic K-metasomatic processes similar to those described by Buletti (1985) in the Southern Alps. Such an assumption is supported by the work of Behr *et al.* (1983) who described metasomatic alteration processes



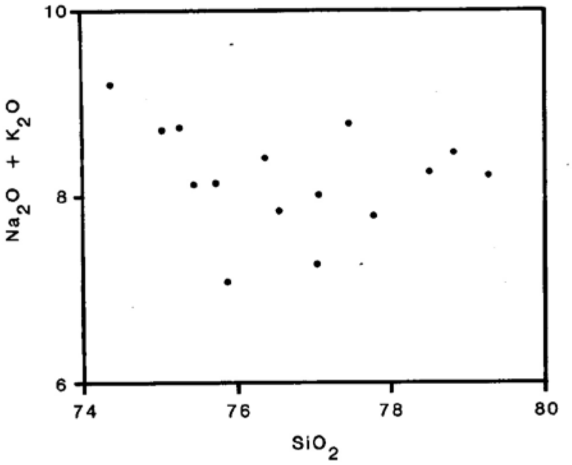


Fig. 7: SiO_2 *vs.* Na_2O+K_2O diagram for the analysed rhyolites.

in the Duruchaus Formation which were related to pre-Damaran volcanics of the Rehoboth Basement Inlier.

From the present data it may be deduced that the rhyolites represent highly evolved magmas which are related to the generation of the large granitic bodies found throughout the Rehoboth Basement Inlier, and that post-genetic metasomatic processes may have affected the analysed rhyolites.

Rb-Sr isotope analyses

The results of the Rb-Sr analyses of 7 Nückopf rhyolites are listed in Table 2. With the exception of KAW3166 which deviates slightly towards higher $^{87}Sr/^{86}Sr$ ratios, probably as a result of strong penetration by small calcite filled veins, the data plot on or close to a reference line of 948.0 ± 24.7 Ma in the $^{87}Rb/^{86}Sr$ versus $^{87}Sr/^{86}Sr$ isochron diagram (Fig. 8). The reference line has an intercept I at $^{87}Sr/^{86}Sr$ = 0.7079 ± 0.0051 and a correlation coefficient R of 0.998. The age of 948 Ma broadly coincides with U-Pb age determinations on the Nückopf Formation by Burger and Coertze (1973, 1973-74, 1975-76) and Burger and Walraven (1975-76) who obtained ages between 932 ± 50 Ma and 1770 ± 35 Ma (with a majority of ages ranging between 932 ± 30 and 1232 ± 30 Ma) for various occurrences of Nückopf volcanics in the Rehoboth Basement Inlier. The initial $^{87}Sr/^{86}Sr$ ratio of 0.7079 is within the range of values (0.700 - 0.710) obtained for Piksteel and Gamsberg intrusives (Seifert, 1986; Reid *et al.* 1988) and is slightly higher than the initial values of 0.700 - 0.705 for the Weener Intrusive Suite (Seifert, 1986; Reid *et al.*, 1988), but falls well below the initial value of 0.732 for acid dykes of Nauzerus (Reid *et al.* 1988). Since metasomatic processes may have affected the analysed rhyolites, it is possible that these processes may have changed the properties of the observed Rb-Sr isochrons. An indication of the existence of such processes is given by the high initial $^{87}Sr/^{86}Sr$ ratio of 0.732 obtained by Reid *et al.* (1988) for acid dykes from Nauzerus.

TABLE 2: Tabulation of Rb-Sr results for volcanics from the Nückopf Formation.

Sample KAW	Rb ppm	Sr ppm	$^{87}Sr/^{86}Sr$ ± 2 σ	$^{87}Rb/^{86}Sr$ ± 2 σ	Rb/Sr
3040	85.4	74.9	0.75554 ± 2	3.134 ± 33	1.140
3041	35.2	245.2	0.72188 ± 1	0.416 ± 4	0.143
3164	178.8	62.0	0.82721 ± 22	8.448 ± 84	2.886
3165	177.9	35.5	0.91631 ± 8	14.808 ± 148	5.015
3166	118.2	120.3	0.75757 ± 1	2.855 ± 29	0.982
3167	163.4	96.8	0.76430 ± 1	4.913 ± 49	1.689
3168	181.7	89.2	0.78548 ± 1	5.941 ± 59	2.038
3169	193.1	81.7	0.79303 ± 1	6.892 ± 69	2.362
3177	152.9	14.3	1.14280 ± 42	32.273 ± 323	10.700

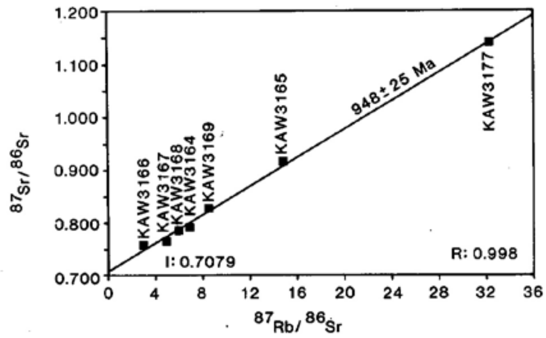


Fig. 8: $^{87}Rb/^{86}Sr$ *vs.* 87Sr/86Sr isochron diagram for rhyolites from the Nückopf Formation.

A two point isochron may be calculated from the Rb-Sr results obtained for the rhyolites from Marienhof 577 (Table 2). The isochron age of 813 Ma and intercept of $^{87}Sr/^{86}Sr$ = 0.71705 are in conflict with the results of the U-Pb analyses discussed below. The relatively high initial $^{87}Sr/^{86}Sr$ ratio and the young age may be best explained by post-genetic metasomatic processes which have affected the Rb-Sr system.

U-Pb isotope analyses

The results of the analysed zircon fractions of KAW3040 and KAW3041 are listed in Table 3. The apparent $^{206}Pb/^{238}U$, $^{207}Pb/^{235}U$ and $^{207}Pb/^{206}Pb$ ages obtained are discordant and range from 746 Ma to 1107 Ma. In the Concordia diagram of Wetherill (1956), the analysed zircon fractions plot on a Discordia intersecting the Concordia at 1210 ± 8 Ma and 349 ± 13 Ma (Fig. 9). The sample points are located at about half the distance between upper and lower intercepts of the Discordia with the Concordia and therefore reflect about 40-60% loss of radiogenic Pb from the analysed zircons. The Concordia diagram of Tera and Wasserburg (1972) confirms the results of the Wetherilll diagram since the Discordia defined by the analysed zircons intersects the Concordia at 1210 ± 7 Ma and 350 ± 12 Ma (Fig. 10).

TABLE 3: Tabulation of the U-Pb results for zircons from rhyolitic dykes crosscutting the Marienhof Formation

Sample KAW	Fraction Microns	U ppm	Pb_{rad} ppm	Pb_{nonrad} ppm	$^{206}Pb/^{204}Pb$ Measured	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
						Atomic ratios				Apparent ages		
3040	>112	206	33.1	15.9	131.252	0.1470	1.550	0.07646	0.1972	884	950	1107
3040	>95 mag	264	35.1	9.6	219.455	0.1227	1.247	0.07373	0.1893	746	822	1034
3040	95-112 mag	257	39.2	6.8	331.991	0.1395	1.456	0.07571	0.1916	842	912	1087
3041	<75 unmag	334	52.4	4.0	730.483	0.1414	1.483	0.07607	0.2111	853	924	1097
3041	>75 unmag	273	40.9	5.7	409.692	0.1367	1.420	0.07534	0.1970	826	898	1078

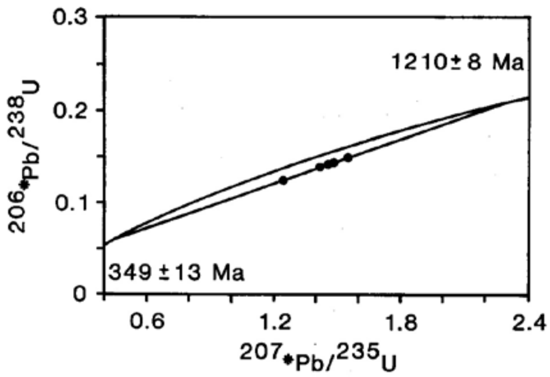


Fig. 9: Concordia diagram of Wetherill (1956) for zircons from rhyolitic dykes crosscutting the Marienhof Formation.

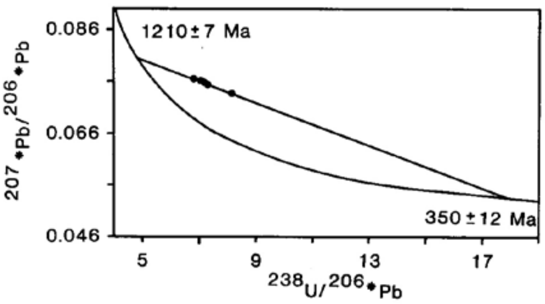


Fig. 10: Concordia diagram of Tera and Wasserburg (1972) for zircons from rhyolitic dykes crosscutting the Marienhof Formation.

The upper intercept age of 1210 ± 7 Ma represents a minimum age for the formation of the zircons and is much older than that of the two point Rb-Sr isochron age discussed in the previous section. The lower intercept age of 350 ± 12 Ma is probably geologically meaningless since a continuous diffusive loss of lead cannot be ruled out for the analysed zircons. Damaran metamorphism, indicated by a K-Ar age of biotites of 516.6 ± 5.3 Ma for sample KAW3041 (Ziegler and Stoessel, 1988), probably also affected the Rb-Sr systems in the sample locality of KAW3040 and KAW3041, and resulted in a relatively young Rb-Sr age of 813 Ma. The U-Pb system of the analysed zircons, although having suffered from lead loss, still reflects the probable age of intrusion of the studied rhyolitic dykes into the Marienhof Formation. The U-Pb age of 1210 ± 7 Ma is therefore regarded as a reliable minimum age for the Marienhof Formation.

Conclusions

All the analysed volcanic rocks from the Rehoboth Basement Inlier are high-K rhyolites with predominantly peraluminous characteristics. Although rhyolites were sampled from different localities and formations they all show similar geochemical properties. A close relationship to Gamsberg-, Weener- and especially Piksteel-type magmas may be deduced from element distribution patterns although it appears likely that the rhyolites represent more evolved magmas. Post-genetic K-metasomatic processes have to be considered for the rhyolites based on their high K_2O/Na_2O ratios. The Rb-Sr isochron age of 948.0 ± 24.7 Ma obtained for Nückopf rhyolites and the U- Pb age of 1210 ± 7 Ma of zircons from rhyolitic dykes crosscutting the Marienhof Formation indicate that the extrusion of the volcanics is related to the intrusion of individual plutons in the Rehoboth basement inlier whose ages range between 1079 ± 25 and 1871 ± 143 Ma according to various workers. The relatively high $^{87}Sr/^{86}Sr$ initial value of 0.7079 of the Nückopf volcanics, if not the result of metasomatic processes, suggest that a relationship of these volcanics to the Gamsberg and Piksteel intrusives with initial $^{87}Sr/^{86}Sr$ ratios ranging between 0.700 and 0.710 is more likely than one to the Weener Intrusive Suite whose initial $^{87}Sr/^{86}Sr$ values range between 0.700 and 0.705.

Furthermore, a minimum age of 1210 ± 7 Ma for the Marienhof Formation is also provided by the U-Pb results obtained for zircons from dykes crosscutting the Marienhof Formation.

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