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Cretaceous/Tertiary Volcanism in North Greenland: the Kap Washington Group

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THEME 1: Magmatic Provinces around the Eurasian Basin: Interplay with Tectonism

Summary: The bimodal, alkaline volcanic suite of the Kap Washington Group (KWG) at the northern coast of Greenland was investigated during the BGR CASE 2 expedition in 1994. Geochemical and Nd and Sr isotopic data are presented for basalts to rhyolites of the KWG and of related basaltic dykes cutting Lower Paleozoic sediments. In the εvδ(t) vs. (87Sr/86Sr)t diagram, the KWG basalts and rhyolites follow a common mixing trend with increasing crustal contamination from basic to acid volcanites. Assimilation of pre-existing crustal rocks during formation of the rhyolitic melt is documented by Nd model ages of 0.9-1.2 Ga and by different fractionation trends for the basalts and the rhyolites in the Y vs. Zr diagram. Petrographical and geochemical features indicate intra-plate volcanism which was active most probably during a continental rifting phase. A new Rb/Sr whole rock age on rhyolites of 64 ±3 Ma, corresponding to the result of LARSEN (1982), confirms that the volcanic activity lasted until the Cretaceous-Tertiary boundary. 40Ar/39Ar dating on amphibol separates from a comendite yielded strongly disturbed age spectra with a minimum age of 37.7 ±0.3 Ma. This age is interpreted to date a hydrothermal overprint of the volcanic rocks related to compressive tectonics which led to the overthrust of basement rocks over the Kap Washington Group.

INTRODUCTION

Volcanic and pyroclastic rocks of the Kap Washington Group (KWG) were investigated during the BGR CASE 2 expedition in 1994.

The KWG was first described by DAWES & SOPER (1970) and mapped in detail by BROWN & PARSONS (1981). The KWG is confined to a relatively small area at the northern coast of Greenland between Lockwood Ø in the west and Kap Cannon in the east (Figs. 1a, 1b). The volcanic suite overlies Cretaceous and Permo-Carboniferous sediments and is in turn overthrust from the south by early Paleozoic metasediments of the North Greenland fold belt. Furthermore, a basaltic dyke swarm cuts basement rocks to the south and southwest of the KWG. The dykes continue with minor frequency to southeast up to the Frigg Fjord area (Figs. 1a, 1c). The so-called "greenstones of unknown age" (HIGGINS et al. 1981, GGU 1992) found in small discontinuous zones in the western Frigg Fjord segment of the Harder Fjord fault zone are interpreted as an E-W trending dyke affected by the fault zone and of the same age as the dyke swarm (ESTRADA 2000).

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PETROGRAPHY AND GEOCHEMISTRY

Chemical analyses were carried out at the BGR laboratories. The detailed XRF whole-rock analyses are available from the first author on request.

Accordant with BROWN et al. (1987), the volcanism is bimodal with a basic group (basalts, tephrites, trachybasalts) on the one hand and an acid group (rhyolites, trachytes, quartz-trachytes) on the other hand (Fig. 2). The acid and basic volcanites occur as lava flows and dykes. The acid volcanism was connected with extrusive activities (ignimbrites, lapilli tuffs, ash-flow tuffs, pyroclastic sandstones).

The basalts show a vertical trend typical for alkaline rocks in the TiO_2 vs. Zr/P_2O_5 diagram of FLOYD & WINCHESTER (1975) and all volcanic rock samples have Nb/Y ratios >0.7 which is indicative of an alkaline character of the whole volcanic suite (WINCHESTER & FLOYD 1977).

A part of the rhyolitic and trachytic lavas and pyroclastites from Kap Washington and Kap Kane is characterized as peralkaline rocks by an agpaitic index (mol $[Na_2O+K_2O]/Al_2O_3$) >1 (1.01-1.2) and by minerals like riebeckite and aegirin. These subordinate rocks plot mainly into the comendite field in the SiO_2 vs. Zr/TiO_2 classification diagram of WINCHESTER & FLOYD (1977). The peralkaline, comenditic rocks are distinguished by relative high contents of trace elements such as Zr and Y (Fig. 3), Ce, La, Nb, Zn.

In geochemical discrimination plots for geotectonic setting, according to MESCHEDE (1986), PEARCE (1982), PEARCE & CANN (1973), the KWG volcanites correspond to intra-plate lavas. This is shown in the Nb-Zr-Y plot after MESCHEDE

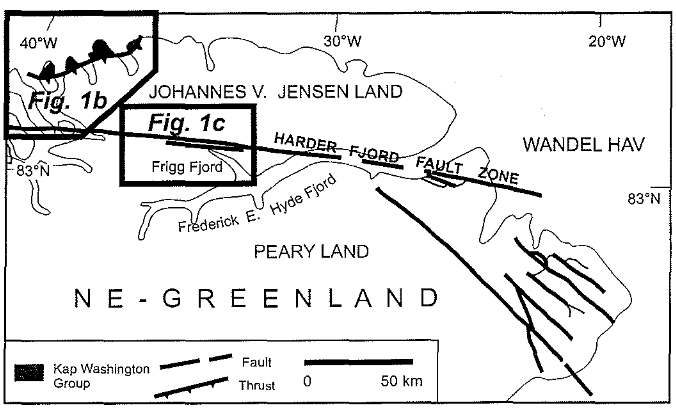

Fig. 1a: Location map for the geological maps Fig. 1b and Fig. 1c.

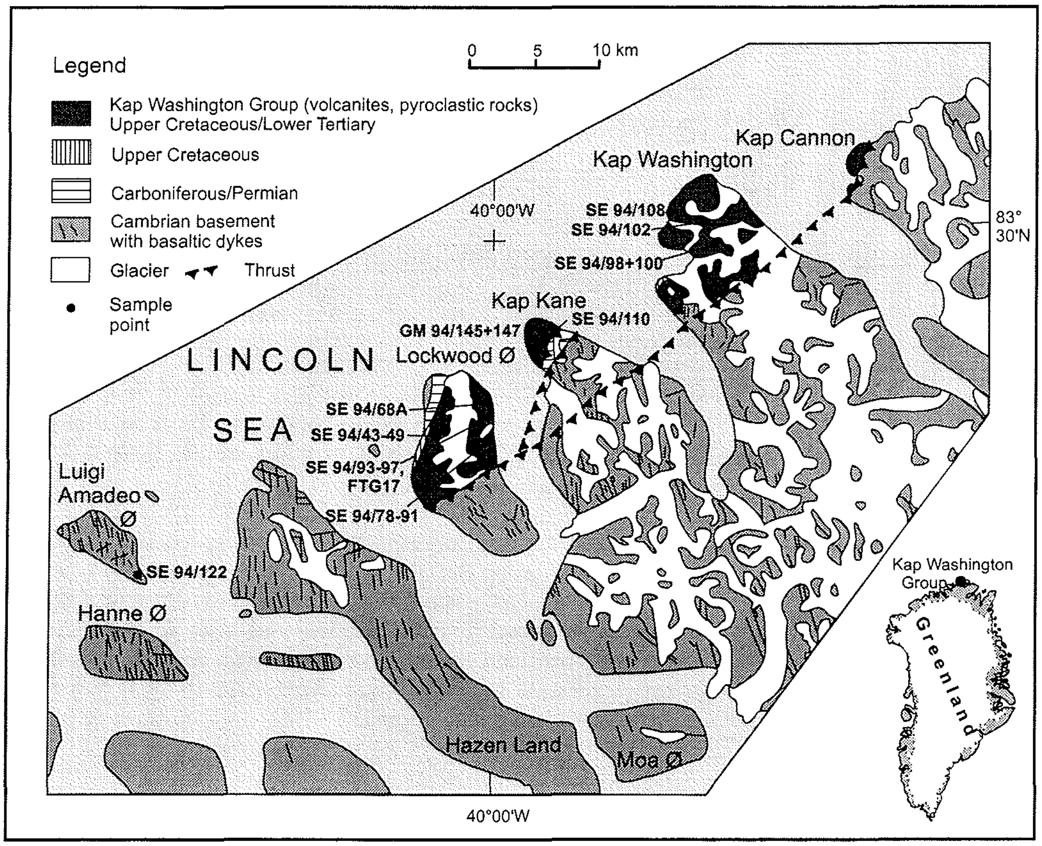

Fig. 1b: Simplified geological map of the Kap Washington area, North Greenland, with the sample points from Table 1 (based on Geological map of Greenland 1 : 500 000, sheets 7 and 8, GGU 1992).

(1986) (Fig. 4). Accretionary lapilli in pyroclastic rocks from Kap Washington indicate subaeric fallout deposits.

The basaltic dyke rocks have a very similar chemical composition as the KWG basalts and show also alkaline and intraplate geochemical characteristics (SOPER et al. 1982, ESTRADA 2000).

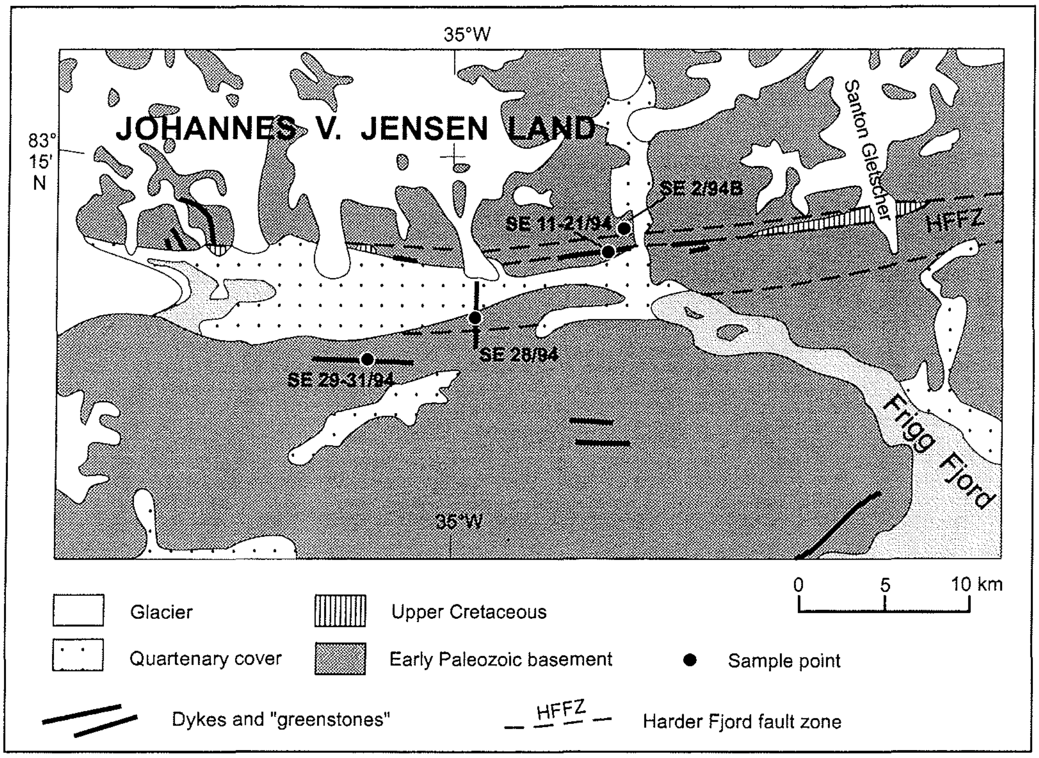

Fig.1c: Simplified geological map of the Frigg Fjord area, North Greenland, with the sample points from Table 1 (based on Geological map of Greenland 1 : 500 000, sheet 8, GGU 1992 and on field observations during CASE 2).

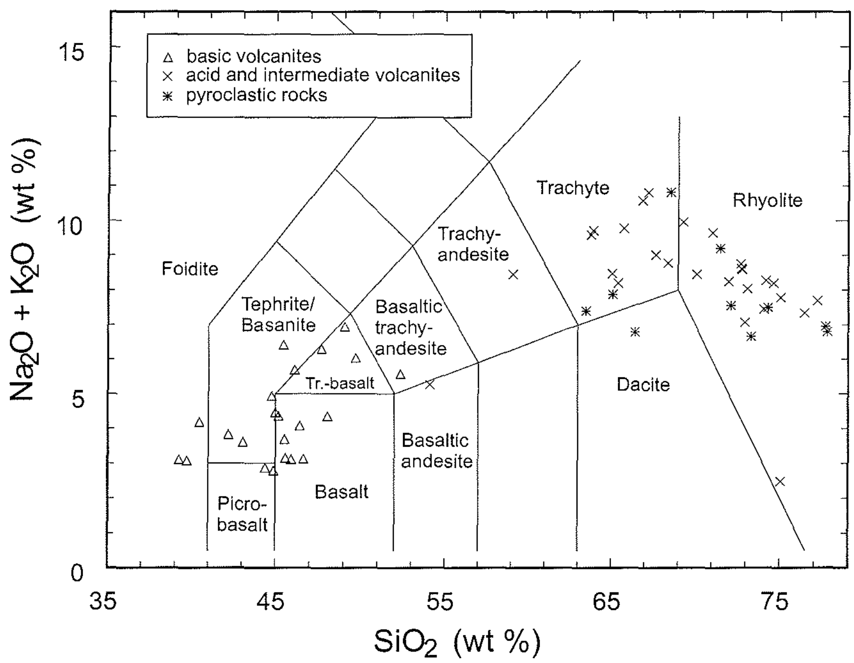

Fig. 2: Kap Washington Group volcanites in the (Na_2O+K_2O) vs. SiO_2 classification diagram (after LE MAITRE 1989), (Rock samples with SiO_2 <43 wt. % are altered and carbonate-rich.).

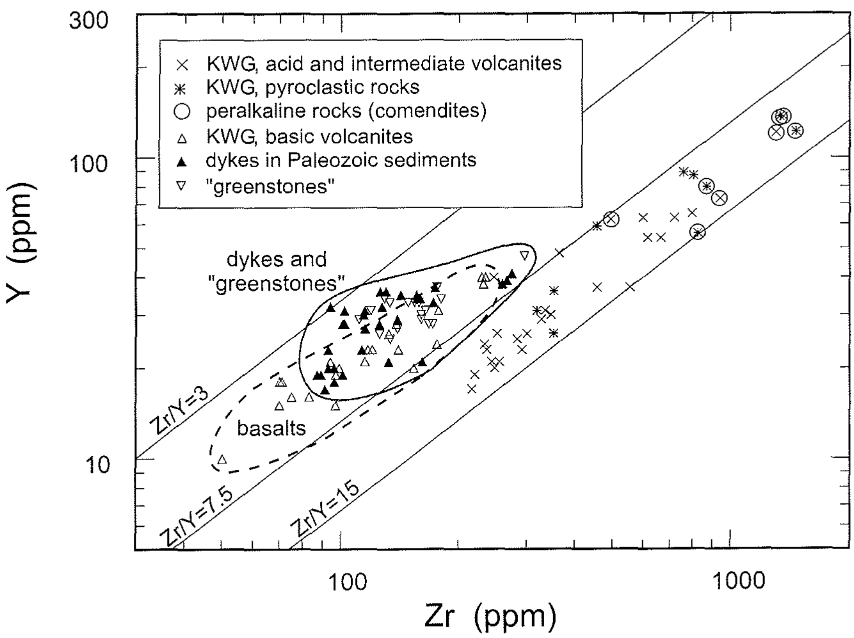

Fig. 3: Y vs. Zr diagram for Kap Washington Group volcanites and related dykes.

EVOLUTION OF THE VOLCANITES

Sr and Nd isotopic data of 33 samples of KWG volcanic rocks and related basaltic dykes are presented in Table 1.

In the $\varepsilon_{Nd}(t)$ vs. $(^{87}Sr/^{86}Sr)t$ diagram, calculated back to the time of extrusion of the rhyolites at 64 Ma (Fig. 5), the KWG basalts and rhyolites follow a common mixing trend with increasing crustal contamination from basic to acid volcanites which fits well in the variation range of intra-continental plate basalts. The basic endmember of the mixing line could be isotopically similar to the MOR basalts. The Nd model ages of the acid volcanites range from 0.9 Ga to 1.2 Ga (Tab. 1) indicating assimilation of Proterozoic crustal material. Crustal assimilation in generating the rhyolitic magma is also documented by different fractionation trends for the basalts and the rhyolites in the Y vs. Zr diagram (Fig. 3).

The basaltic dykes (including the "greenstones") form a different, almost horizontal trend in the $\varepsilon_{Nd}(t)$ vs. $(^{87}Sr/^{86}Sr)t$ diagram. The Nd isotopic signatures correspond to those of the basic volcanites but the $^{87}Sr/^{86}Sr$ ratios show a significantly larger variation towards more radiogenic values. Such trend could be produced by mixing of the basic magma with a crustal component having similar $\varepsilon_{Nd}(t)$ or significant lower Nd/Sr ratio but more radiogenic Sr isotopic ratio. The basaltic dykes and the basic volcanites follow the same fractionation trend in the Y vs. Zr diagram (Fig. 3) suggesting the magma of the ba-

Sample No.	Locality	Rock type	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	$(^{87}Sr/^{86}Sr)_{64 Ma}$	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	ε_{Nd}(64 Ma)	T_{DM} (Ga)
KWG acid volcanites													
SE 94/43	Lockwood Ø	rhyolite	159,9	22,83	20,32	0,72506	0,70659	9,0	55,6	0,0974	0,512576	-0,4	0,95
SE 94/46	Lockwood Ø	rhyolite	166,7	21,65	22,34	0,72627	0,70596	17,9	105,7	0,0985	0,512609	0,3	0,89
SE 94/48	Lockwood Ø	rhyolite	85,5	55,76	4,44	0,71055	0,70651	8,5	46,2	0,1110	0,512494	-2,1	1,09
SE 94/49	Lockwood Ø	rhyolite	217,2	18,27	34,53	0,73692	0,70553	15,4	94,3	0,0985	0,512570	-0,5	0,96
SE 94/81	Lockwood Ø	rhyolite (dyke)	150,3	106,4	4,09	0,70923	0,70551	4,8	32,2	0,0899	0,512599	0,2	0,90
SE 94/79	Lockwood Ø	rhyolite (dyke)	155,1	92,82	4,84	0,70984	0,70544	5,1	34,0	0,0905	0,512604	0,2	0,90
SE 94/80	Lockwood Ø	rhyolite (dyke)	175,2	30,53	16,63	0,71975	0,70463	12,5	63,5	0,1190	0,512617	0,3	0,89
SE 94/91	Lockwood Ø	quartz-trachyte	168,7	256,83	1,90	0,70719	0,70546	4,9	31,5	0,0940	0,512536	-1,1	1,01
SE 94/93	Lockwood Ø	quartz-trachyte (dyke)	155,2	194,06	2,32	0,70795	0,70584	5,5	34,5	0,0958	0,512419	-3,4	1,19
SE 94/68A	Lockwood Ø	trachyandesite (dyke)	15,3	331,84	0,13	0,70531	0,70519	7,9	50,9	0,0935	0,512617	0,5	0,87
GM 94/145	Kap Kane	trachyte	141,6	315,56	1,30	0,70745	0,70627	7,3	43,9	0,1007	0,512397	-3,9	1,23
GM 94/147	Kap Kane	comendite	219,6	52,02	12,24	0,71874	0,70761	16,1	108,2	0,0897	0,512800	4,1	0,54
SE 94/98	Kap Washington	comendite	312,0	8,56	106,43	0,78874	(0.6920)	33,2	181,2	0,1104	0,512848	4,8	0,46
SE 94/100	Kap Washington	comendite	96,5	13,93	20,12	0,73238	0,71409	15,1	73,1	0,1246	0,512874	5,2	0,43
SE 94/108	Kap Washington	comendite	115,9	6,40	52,64	0,75083	0,70297	13,5	75,5	0,1078	0,512827	4,5	0,50
KWG basic volcanites													
SE 94/45	Lockwood Ø	basalt	74,04	391,4	0,5477	0,70617	0,70567	3,7	21,6	0,1034	0,512670	1,4	0,80
SE 94/78	Lockwood Ø	trachybasalt	104,12	638,2	0,4723	0,70524	0,70481	7,6	42,9	0,1064	0,512704	2,1	0,73
SE 94/83	Lockwood Ø	tephrite	34,24	1152,9	0,0860	0,70461	0,70453	n.d.	37,4		0,512723		
SE 94/97	Lockwood Ø	basalt	36,72	570,2	0,1865	0,70462	0,70445	6,5	27,6	0,1422	0,512913	5,8	0,36
SE 94/94	Lockwood Ø	basalt	51,25	820,5	0,1809	0,70514	0,70498	11,4	53,1	0,1296	0,512815	4,0	0,54
FTG 17	Lockwood Ø	trachybasalt	60,57	1068,4	0,1641	0,70539	0,70524	6,5	37,6	0,1045	0,512711	2,2	0,72
SE 94/110	Kap Kane	basalt	13,27	711,9	0,0540	0,70394	0,70389	4,6	21,0	0,1332	0,512878	5,2	0,42
SE94/102	Kap Washington	basalt	79,47	487,1	0,4723	0,70397	0,70354	6,0	29,2	0,1231	0,512884	5,4	0,40
Dykes in Early Paleozoic sediments													
SE 2/94B	NW of Frigg Fjord	dolerite	30,49	469,74	0,1879	0,70609	0,70593	8,8	38,5	0,1373	0,512924	6,1	0,33
SE 28/94	W of Frigg Fjord	olivine-dolerite	14,72	451,23	0,0944	0,70575	0,70566	n.d.	33,2		0,512837		
SE 29/94	W of Frigg Fjord	dolerite	9,63	728,36	0,0383	0,70837	0,70834	8,4	38,1	0,1333	0,512809	3,9	0,56
SE 31/94	W of Frigg Fjord	dolerite	7,16	747,91	0,0277	0,70904	0,70901	8,7	40,7	0,1282	0,512805	3,9	0,57
SE 94/122	Luigi Amadeo Ø	porph. basaltic dyke	20,46	559,32	0,1059	0,70626	0,70616	8,7	40,7	0,1282	0,512899	5,7	0,38
"Greenstones"													
SE 11/94	NW of Frigg Fjord	dolerite	6,28	411,71	0,0442	0,70499	0,70495	8,0	33,9	0,1426	0,512884	5,3	0,42
SE 13/94	NW of Frigg Fjord	dolerite	22,85	528,55	0,1252	0,71049	0,71038	8,0	33,9	0,1421	0,512872	5,1	0,45
SE 14/94	NW of Frigg Fjord	dolerite	4,55	476,61	0,0277	0,70540	0,70537	7,6	31,8	0,1432	0,512876	5,1	0,44
SE 15/94	NW of Frigg Fjord	dolerite	19,47	529,74	0,1065	0,70964	0,70954	11,2	49,7	0,1354	0,512852	4,7	0,48
SE 21/94	NW of Frigg Fjord	dolerite	5,70	621,71	0,0265	0,70931	0,70929	5,8	23,8	0,1452	0,512898	5,5	0,40

Tab. 1: Rb-Sr and Sm-Nd data of Kap Washington Group volcanites and related dykes. Sr and Nd were separated from 50-100 mg of powder using standard ion exchange techniques and analysed as metal species on a MAT 261 multicollector mass spectrometer in static mode. Nd and Sr isotope ratios were normalized to $^{146}Nd/^{144}Nd = 0.7219$ and $^{88}Sr/^{86}Sr = 8.3752$, respectively. The isotopic ratios measured for isotopic standards are $^{143}Nd/^{144}Nd = 0.511834(17)$ for LaJolla and $^{87}Sr/^{86}Sr = 0.710237(16)$ for NBS 987. The routine total blanks were: Sr <1 ng and Nd <1 ng. Analytical errors at 95 % confidence level are ±2 % for $^{87}Rb/^{86}Sr$, ±0,06 % for $^{87}Sr/^{86}Sr$, ±0.014 % for $^{143}Nd/^{144}Nd$. T_{DM} values were calculated according to the 2-stage model of DEPAOLO et al. (1991).

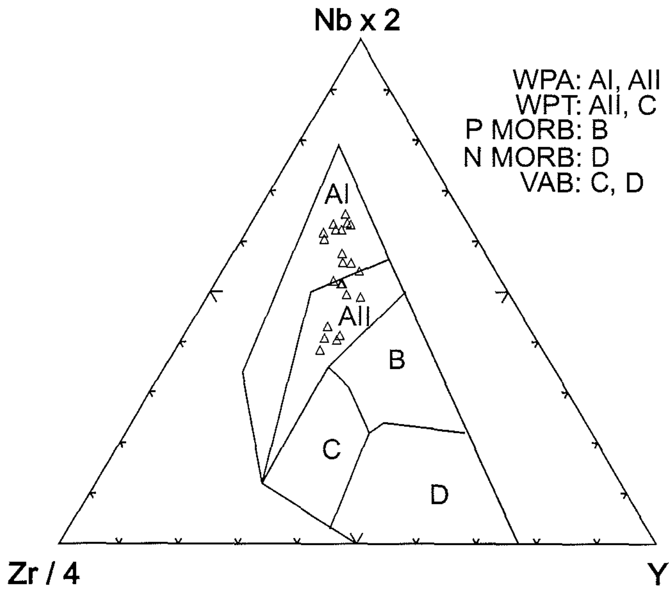

Fig. 4: Kap Washington Group basalts in the Nb-Zr-Y diagram for geotectonic setting (after MESCHEDE 1986).

sic volcanites to be the basic endmember. Because the Nd/Sr ratios of the basic volcanites are rather low (0.03-0.1) it seems unrealistic to assume a much lower ratio for the crustal component. Consequently, we have to assume $\varepsilon_{Nd}(t)$ of +4 to +5 for the crustal component to explain the isotopic trend of the basaltic dykes. The high $\varepsilon_{Nd}(t)$ value implies that the crustal component must be relatively young. This is confirmed by the Nd model ages which are around 0.5 Ga (Tab. 1). Taking 0.5 Ga for the age of the crustal material its model $\varepsilon_{Nd}(^{64}\text{ Ma}) \approx +4.5$ (DEPAOLO 1991) would fit the condition for the assimilated crustal material. Even moderate increased Rb/Sr ratios (≈ 2) would increase the average $^{87}Sr/^{86}Sr$ ratio from 0.703 to 0.750 during 0.5 Ga in that crustal component. Probably assimilation took place within the magma chamber in deeper crustal levels because there are no lower Paleozoic intrusives known in the study area. In contrast to the acid volcanics, there is no indication of assimilated Proterozoic crustal material in the dykes.

The comendites have high $\varepsilon_{Nd}(t)$ values comparable to those of the basic volcanites. Due to the high $^{87}Rb/^{86}Sr$ ratios considerable age corrections must be made on the measured $^{87}Sr/^{86}Sr$ ratios. Therefore, the age corrected Sr isotopic ratios may not give the correct initial values.

The fractionation trend in the Y vs. Zr diagram (Fig. 3) shows that the basic volcanites and the comendites are not part of a cogenetic suite. On the other hand the different $\varepsilon_{Nd}(t)$ values rule out the possibility that the comendites are extremely fractionated residua of the rhyolites. The Nd model ages around 0.5 Ga suggest an early Paleozoic age for the source material of the comendites. The $\varepsilon_{Nd}(64\text{ Ma})$ values of about +4 to +5 found for the comendites correspond well with the model value for a 0.5 Ga old crust. The variation of the Sr isotopic ratios can be explained by partial melting of such pre-existing crustal material. Additionally, the Sr isotopic ratios may be affected by a later hydrothermal overprint indicated by the Ar/Ar data on amphibole separated from one comendite (see below). If the Sr/Nd ratio in the fluid was substantial higher than in the rocks only the Sr isotopic ratios will be affected by the fluid/rock interaction.

Tentatively we may suppose the source rock of the melt of the comendites to be the same as for the crustal contaminant of the basic dykes.

A similar trend in the Sr-Nd isotopic relationship has been observed for comendites in the Naivasha basalt-comendite complex (East African rift, central Kenya) (DAVIES & MACDONALD 1987). Based on Pb isotopic data those authors conclude that the basalts and comendites are not part of a cogenetic suite but explain the origin of the comendites by crustal melts of basement and overlying volcanoclastic rocks.

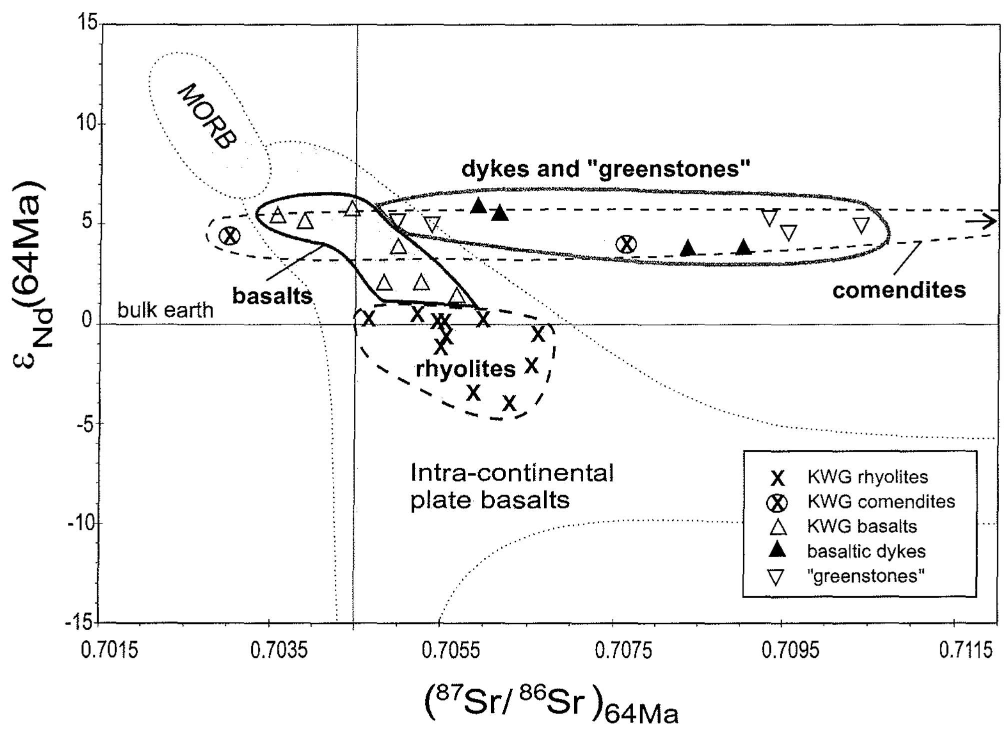

Fig. 5: Kap Washington Group volcanites and related dykes in the $\varepsilon_{Nd}(t)$ vs. ($^{87}Sr/^{86}Sr$) diagram. (Fields for MORB and intra-continental plate basalts after WILSON 1989).

AGE OF VOLCANISM

Plant microfossils in intercalated shales indicate a Late Cretaceous (Campanian or Maastrichtian) age of volcanism (BATTEN et al. 1981). Previous Rb/Sr whole rock age determinations on rhyolitic lavas and pyroclastites from Kap Kane and Kap Washington yielded 64 (3 Ma (2σ) (LARSEN 1982). New Rb/Sr analyses on 10 whole rock samples of rhyolites and trachytes mainly from Lockwood Ø (Tab. 1) define an errorchron (MSWD = 6.3) yielding an age of 64 (3 Ma (2σ enhanced error) and ($^{87}Sr/^{86}Sr$)i = 0.7058 (0.0005 which corresponds to the former result of LARSEN (Fig. 6). These new age result confirms that the volcanic activities at Lockwood Ø, Kap Washington and Kap Kane are coeval and lasted until the Cretaceous-Tertiary boundary.

$^{40}Ar/^{39}Ar$ DATING

From a peralkaline rhyolite (comendite) from Kap Washington (sample SE 94/100, Tab. 1) the amphibole was separated for 40Ar/39Ar dating. The gray, "spotted" rock contains abundant aggregates (about 1 mm in size) of fine needles (about 0.025 mm in length) of the Na-amphibole riebeckite, phenocrysts of perthite (up to 2 mm) and aggregates of titanite/leukoxene in a very fine-grained matrix of alkali-feldspar, quartz and accessory opaque minerals. Microprobe investigations of the riebeckite show that two different types of amphibole exist: Na-rich amphibole (13.2 wt.% Na_2O on average) with very low K_2O and Na-poor amphibole with 6.4 wt.% Na_2O on average and about 0.6 wt.% (0.1-1.3 wt.%) K_2O.

$^{40}Ar/^{39}Ar$ incremental-heating experiments performed on 2 aliqoutes of mixed amphibole - K-feldspar ± matrix separates yielded highly disturbed age spectra with total-gas dates of on average 41.2 ±0.2 Ma (Fig. 7). The minimum ages of 37.7 ±0.3 Ma (late Eocene) is interpreted to date a hydrothermal overprint of the volcanic rocks. This overprint is tentatively related to compressive tectonics which led to the overthrust of basement rocks over the KWG.

K/Ar whole rock ages of 34.9 (3.5 Ma and 32.3 (3.2 Ma (early Oligocene) on rhyolites with cataclastic texture were interpreted by DAWES & SOPER (1971) as minimum age of the volcanic

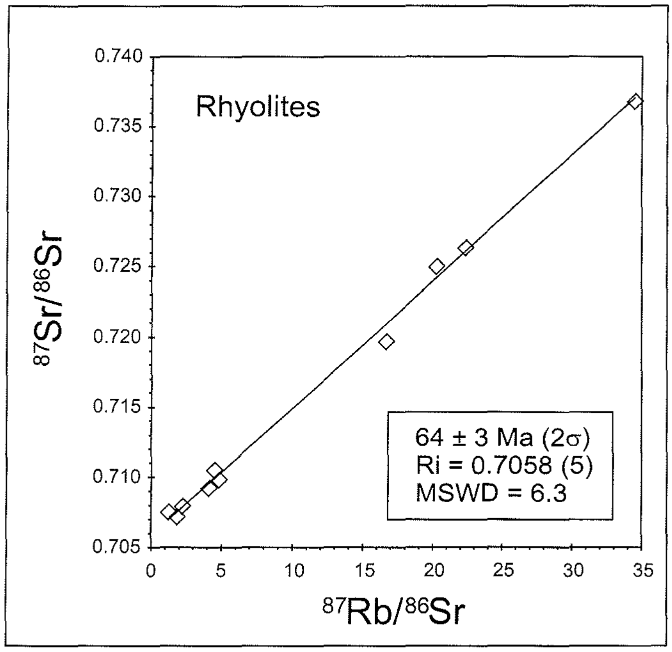

Fig. 6: Rb-Sr isochron of Kap Washington Group rhyolites.

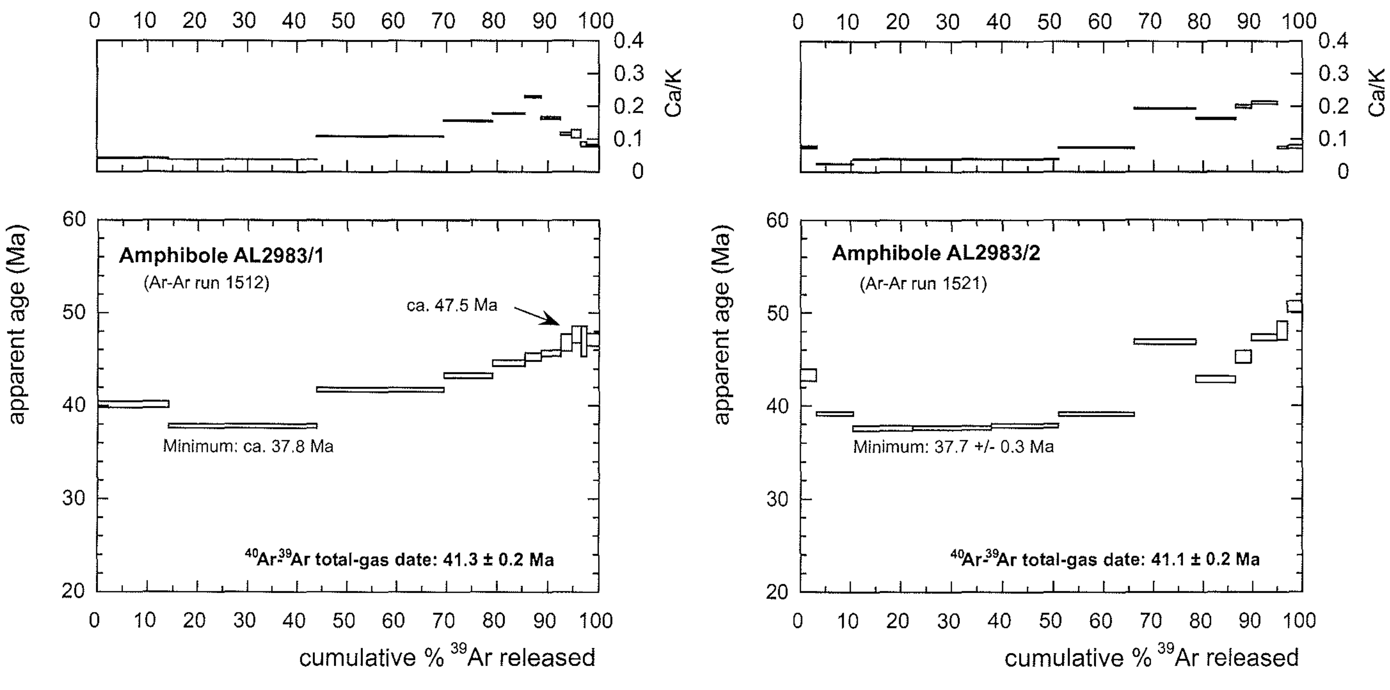

Fig. 7: $^{40}Ar/^{39}Ar$ age spectra of amphibole separates from a Kap Washington Group comendite.

consolidation and maximum age for the thrust movements. Alternatively those ages are discussed by SOPER et al. (1982) as dating erosion and cooling during post-thrusting uplift.

DISCUSSION

The volcanism in north Greenland was active during the latest Cretaceous (biostratigraphically: Campanian-Maastrichtian) until earliest Tertiary (Rb/Sr whole rock dating: 64 Ma). Petrographical and geochemical features indicate that the KWG volcanites as well as the dyke swarm both could be characterized as intra-plate volcanites. Most probably these volcanites are related to a continental rifting phase (compare also BROWN et al. 1987 and SOPER et al. 1982). The extensional regime responsible for the volcanic activity in North Greenland was followed by a phase of compressive tectonics during the Paleocene to Eocene (SOPER et al. 1982). The compressive deformation led to the overthrust of basement rocks over the KWG and to its local affection by brecciation, cleavage and hydrothermal alteration.

The mainly N-S trending dyke swarm indicates E-W extension of continental lithosphere (SOPER & HIGGINS 1991). On predrift reconstructions some authors prefer a link between the volcanic activities in North Greenland and the early rifting along the Nansen spreading axis (e.g. SOPER et al. 1982) having started at about 56 Ma (magnetic anomaly 24), whereas other authors suggest an association with the extensional events in the Makarov Basin where spreading began in the Late Cretaceuos (about 80 Ma, magnetic anomaly 34) (e.g. BROWN et al. 1987). In the latter case, the KWG volcanites and dykes would represent a direct onshore continuation of an oceanic spreading axis (SOPER & HIGGINS 1991).

On the other hand, the relation to the "neighbouring" Upper Cretaceous Hansen Point volcanics (TRETTIN & PARRISH 1987) of the Canadian northwestern Ellesmere Island can be of interest. These rocks form a bimodal, alkaline volcanic suite consisting of alkali-olivine basalts, trachybasalts, trachytes, rhyolites and peralkaline rhyolitic ignimbrites. Petrographically and geochemically, these rocks compare well to the KWG volcanites (ESTRADA et al. 1999). Furthermore, the Turonian to Maastrichtian age of the Hansen Point volcanics (TRETTIN & PARRISH 1987, EMBRY 1991) would be roughly coeval to the KWG volcanites. Using available plate reconstructions for the Late Cretaceous (SRIVASTAVA & TAPSCOTT 1986, TESSENSOHN & PIEPJOHN 1998) the formation of both alkaline igneous provinces is probably linked to two branches of a continental rift zone which predates the opening of the Eurasian basin of the Arctic Ocean starting about 56 Ma ago.

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