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Metabasalts from the Central Part of the Hohe Tauern (Austria): Genetic implications from Sr-isotope and trace element studies

V. Höck and S. Scharbert*)

With 6 figures and 4 tables

Abstract

Sr isotope analyses from all Mesozoic volcanic units (ophiolitic and non-ophiolitic) of the central Tauern window show a wide variety of $^{87}Sr/^{86}Sr$ ratios. Some of the variability is due to alteration processes. Nevertheless, the variations between the magma groups seem to reflect the original signature of the Sr-isotope ratios. The ophiolitic basalts and probably magma subgroup B1 with the lowest $^{87}Sr/^{86}Sr$ ratios represent magmas derived from a depleted mantle source. The metabasalts of magma subgroup B2 with higher Sr isotope ratios, and elevated Sr, Rb, K and HFS element abundances were derived from a more enriched source. The same is true for the metabasites of the Fusch facies. Those from the Brennkogel facies with the highest $^{87}Sr/^{86}Sr$ ratios cannot be assigned with certainty to a magma group and seem to have suffered major geochemical changes hiding the original characteristics.

Zusammenfassung

Analysen von Sr-Isotopen aus allen mesozoischen ophiolithischen sowie nicht-ophiolitischen Vulkanitvorkommen im mittleren Tauernfenster zeigen eine weite Streubreite der $^{87}Sr/^{86}Sr$-Verhältnisse. Ein Teil dieser Streuung ist wohl auf Alterationsprozesse zurückzuführen. Trotzdem dürfte ein Teil der Variabilität, speziell die Unterschiede zwischen den Magmagruppen auf die ursprüngliche Isotopenverteilung zurückzuführen sein. Die ophiolitischen Basalte sowie die der Magmauntergruppe B1 mit den niedrigsten $^{87}Sr/^{86}Sr$-Verhältnissen können aus einem verarmten Mantel hergeleitet werden. Die Metabasalte der Magmauntergruppe B2 mit ihrem höheren Sr-Isotopenverhältnis und relativen Anreicherungen an Sr, Rb, K sowie der HFS-Elemente stammen aus einer etwas angereicherten Mantelquelle. Das gleiche gilt für die grobkörnigen Metabasite der Fuscher Fazies. Die Interpretation der Metabasite aus der Brennkogel Fazies bereitet Schwierigkeiten, da sich diese Basalte keiner der bisherigen Magmagruppen zuordnen lassen, aber auch keine eigenständige Gruppe formen. Die sehr hohen $^{87}Sr/^{86}Sr$-Verhältnisse sowie die Spurenelement-Verteilung weisen auf geochemische Veränderungen hin, die die ursprünglichen Charakteristika weitgehend maskiert haben.

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*) Adress of the authors: Dr. V. Höck: Institut f. Geowissenschaften Univ. Salzburg, Hellbrunnerstr. 34, A-5020 Salzburg.
Dr. S. Scharbert: Lab. f. Geochronologie, BVFA Arsenal, Faradaygasse 3, A-1030 Wien.

Introduction

Radiogenic isotopic tracers (e.g. $^{87}Sr/^{86}Sr$) are not affected by processes such as closed system crystal fractionation or equilibrium partial melting (FAURE and POWELL 1972). Thus, isotopes from fresh oceanic basalts have been successfully used in the last years to clarify the structure of the upper mantle beneath the oceans and to elucidate possible mixing phenomena (e.g. O'NIONS an PANKHURST 1974, WOOD et al. 1979, DUPRE and ALLEGRE 1980, 1983, WHITE and HOFMANN 1982). Most of these studies have been carried out in relatively young basalts from the ocean floor and ocean islands from the Atlantic, the Pacific and the Indian oceans revealing mantle heterogeneities on various scales (ZINDLER et al. 1979, 1984, MACHADO et al. 1982, HAMELIN and ALLEGRE 1985).

Apart from the investigations in the recent ocean basins isotope studies have been also successfully applied to ophiolites of different ages and various localities (e.g. COLEMAN 1977, LANPHERE et al. 1981, MCCULLOCH et al. 1981, RAUTENSCHLEIN et. al. 1985, RICHARD et al. 1980, THIRLWALL and BLUCK 1984). This paper is a first step in combining Sr isotope data with trace elements of Mesozoic ophiolites and non-ophiolitic metabasalts and tuffs in the metamorphosed Bündnerschiefer Formation of the Tauern window.

Geological setting

The metabasalts studied in the central portion of the Tauern window are part of the Mesozoic Bündnerschiefer Formation, which can be subdivided into the Hochstegen-, Brennkogel-, Glockner- and Fusch-facies types (FRASL and FRANK 1966). The latter three comprise basic and sometimes ultrabasic magmatic rocks.

All these rocks underwent several stages of metamorphism during the alpidic orogenic events and were transformed into metamorphic equivalents. Magmatic mineral or textural relicts are very rare and can only sporadically be recognized in coarse-grained rocks.

Three coherent magmatic units have been distinguished in the middle part of the Hohe Tauern by HÖCK, 1980, 1983, and HÖCK and MILLER, 1980, 1987 (Fig. 1): they comprise metamorphosed ophiolites including serpentinites, gabbros and basalts (unit I and II) and banded tuffs, tuffites and basaltes (unit III) of non-ophiolitic origin.

The former two are situated in the central part of the Tauern window at the southern and northern escarpment respectively. They rest tectonically on calcschists, which grade toward the north into the more clastic sediments (quartzites, breccias, black phyllites) of the Brennkogel facies, today a deeper structural unit (FRASL and FRANK, 1966, FRANK, 1969). The latter is believed to have formed at the northern margin of the south-Penninic ocean and comprises some prasinites besides the metasediments. The volcanic rocks of unit III are originally embedded in calcschists which overlie the ophiolites in the northeastern and eastern part of the Tauern window. In the northeast they are in turn tectonically covered by clastic sediments and coarse-grained gabbroic rocks of the Fusch facies (FRASL and FRANK, 1966; FRANK, 1969), which has probably developed along the southern margin of the south-Penninic ocean. The volcanics from the Fusch facies and from unit III are of

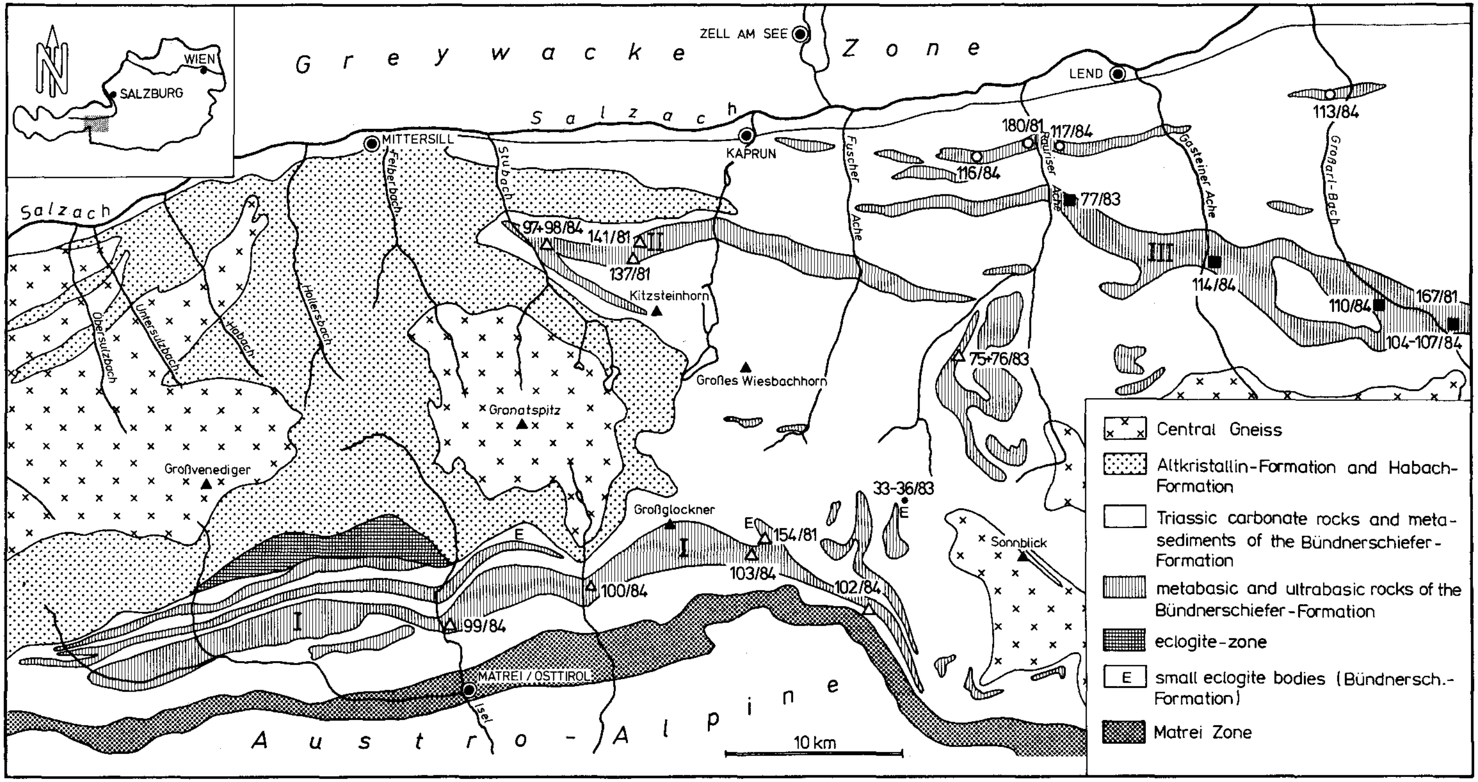

Fig. 1: Geological sketch map of the central portion of the Tauern window showing the distribution of the Mesozoic volcanic units and the sample locations. I and II mark the ophiolite units, III unit III. The sample numbers are given with the following symbols:
open triangles: ophiolites of unit I and II (magma group A)
black squares: samples from unit III (magma subgroups B1 and B2)
open circles: metabasites of the Fusch facies (magma group C)
black circle: metavolcanics of the Brennkogel facies.

non-ophiolitic origin. They were described in more detail by HÖCK, 1983 and HÖCK and MILLER, 1987. The prasinites from the Brennkogel facies are difficult to classify because of their ambiguous geochemistry.

The age of the ophiolites and the non-ophiolitic metabasites is not well constrained because of the metamorphism and deformation destroying fossils and primary minerals equally. Based on the overall similarities with their counterparts in the Western Alps (KOLLER and HÖCK 1988) a contemporaneous origin with the Jurassic ophiolites from the Western Alps, Corsica and Ligura (195–140 M.a. according to ABBATE et al. 1984) seems probable.

Lithology and petrography

The ophiolite sequence

Units I and II are remnants of a former oceanic lithosphere and exhibit despite their moderate thickness all the features of an ophiolite body consisting of serpentinite at the base, metamorphosed ultramafic and mafic cumulates including leucogabbros followed by metamorphic basalts and tuffs, which are in turn overlain by a relatively thick (up to a few hundred meters) metasedimentary cover. The serpentinites and ultramafic cumulates are present as small lenses and bodies at the structural base of units I and II. In some places they are tectonically isolated, but elsewhere they are still in primary connection with the overlying metabasalts.

They consist of amphibole (actinolite to magnesio-hornblende depending on the metamorphic grade), albite/oligoclase, epidote, chlorite, sphene and in some cases minor carbonate, ± quartz and mica. A transitional zone, several meters thick, between the metabasalts and the sedimentary cover shows an increase in the number of calcschist intercalations within the prasinites. This boundary is marked in places by a thin quartzite horizon (metachert?).

Non-ophiolitic metabasites

The geological situation within unit III is different from units I and II (FINGER and HÖCK 1982, HÖCK 1983, FINGER and HÖCK 1985). In contrast to the continuous magmatic pile in the ophiolites, up to five cycles of basic magmatic rocks interstratified with sediments are present, each with a thickness between 20 and 150 m. Serpentinites and gabbros are generally missing. Each magmatic cycle comprises tuffs, tuffites and sometimes metabasalts, alternating on a meter scale. The rocks consist of albite, chlorite, epidote, sphene, minor quartz and some calcite. Sometimes these minerals (chlorite, albite or epidote) form monomineralic or bimineralic bands on a millimeter scale. Amphiboles are ubiquitous in the metabasalts but are rare in the tuffs or tuffites.

In contrast to the large ophiolite units (I, II) and unit III the other occurrences of metabasites are small elongated or lensshaped bodies generally only a few meters thick. For example, the Fusch metabasics are coarse-grained rocks consisting of albite, tremolite, chlorite, clinozoisite and sphene with relicts of magmatic clinopyroxene. Their gabbroic textures suggest that they could have intruded into the clastic sediments as shallow sills.

The metabasalts of the Brennkogel facies are generally fine grained, coarse varieties are rare. Textural and mineralogical relicts of an earlier eclogitic (blueschist) stage are sometimes preserved (FRANK et al. 1987).

Geochemistry

The new geochemical analyses carried out together with the Sr isotope determinations (see Tab. 1–3 for the major and trace elements of selected analyses) are in good agreement with earlier analyses and are consistent with the interpretations given by HÖCK 1983, HÖCK and MILLER 1987 and KOLLER and HÖCK 1988, which were based on field evidence, petrological and geochemical studies. Three magmatic types could be distinguished, which are reviewed shortly in the following paragraphs:

Group A comprises the ophiolitic basalts of unit I and II (Tab. 1), with element abundances and ratios comparable with N-type MORB.

Group B includes metabasalts and metatuffs of unit III (Tab. 2). Magmas of this group can be divided in a low Nb (B1) and a high Nb (B2) subgroup respectively (see Tab. 2) according to FINGER and HÖCK 1985. The former is only slightly enriched compared with N-type MORB, the latter subgroup has a strong withinplate character.

Tab. 1: Chemical analyses of major and trace elements of ophiolitic basalts from unit I and II

wt%	137/81	154/81	75/83	76/83	98/84	99/84	100/84	102/84
SiO_2	48.42	47.58	51.22	48.41	50.06	48.96	47.29	48.84
TiO_2	1.23	1.94	1.63	1.47	1.51	1.27	1.14	1.24
Al_2O_3	16.07	16.69	14.89	16.41	16.19	15.95	17.44	15.90
FeO*	7.86	8.58	8.74	8.28	8.68	8.65	7.85	8.07
MnO	0.13	0.13	0.15	0.20	0.20	0.22	0.14	0.24
MgO	8,16	6.00	6.52	7.25	5.32	7.90	6.20	8.39
CaO	12.06	9.78	10.45	11.94	10.67	10.35	12.65	10.05
Na_2O	2.29	3.01	2.96	2.63	3.69	2.93	3.25	3.36
K_2O	0.12	1.50	0.09	0.17	0.27	0.04	0.19	0.05
P_2O_5	0.13	0.49	0.29	0.16	0.19	0.17	0.11	0.15
LOI**	3.15	3.95	2.25	2.61	2.37	3.02	3.42	3.33
total	99.62	99.65	99.19	99.53	99.15	99.46	99.68	99.62
ppm trace elements								
Nb	4	4	5	1	1	2	1	1
Zr	87	92	134	105	106	94	79	88
Y	31	32	40	31	38	31	26	28
Sr	134	160	180	190	152	156	123	166
Rb	2	4	1	7	8	4	7	3
Ni	111	117	98	123	81	119	127	129
Cr	336	284	233	288	307	325	332	352
Ba	16	10	23	47	43	29	28	25

* FeO = Fe_{tot} ** loss on ignition

Tab. 2: Chemical analyses of major and trace elements of metabasites from unit III

wt%	167/81	77/83	105/84	107/84	110/84	114/84
SiO_2	47.39	45.60	47.10	47.30	46.09	46.04
TiO_2	1.31	1.03	1.91	1.58	1.87	1.67
Al_2O_3	16.71	18.70	16.19	16.98	15.00	14.34
FeO*	8.11	7.36	9.44	8.30	9.89	9.38
MnO	0.17	0.16	0.23	0.24	0.19	0.19
MgO	5.59	7.07	7.78	5.39	5.31	4.89
CaO	14.35	10.77	9.05	10.57	12.45	13.51
Na_2O	2.21	2.60	2.72	3.26	2.68	3.09
K_2O	0.18	0.37	1.25	0.31	0.24	0.26
P_2O_5	0.17	0.11	0.44	0.30	0.22	0.20
LOI**	3.45	6.56	3.43	5.69	4.68	5.88
total	99.64	100.33	99.54	99.92	98.62	99.45
ppm trace elements						
Nb	34	2	36	16	2	3
Zr	156	85	147	142	147	135
Y	36	21	33	33	45	42
Sr	444	181	188	275	190	366
Rb	19	8	16	9	6	8
Ni	406	115	129	153	98	103
Cr	155	255	220	301	241	198
Ba	205	42	189	75	61	64

* FeO = Fe_{tot} ** loss on ignition
Samples No. 77/83, 110/84, 114/84 are low Nb basalts (magma subgroup B1)
Samples No. 167/81, 105/84, 107/84 are high Nb basalts (magma subgroup B2)

Group C is restricted to the Fusch facies (Tab. 3) in the central and northeastern part of the Hohe Tauern with a clear enrichment in trace element abundances, thus resembling T- to E-types MORBs.

Metabasalts from the Brennkogel facies (Tab. 3) cannot be simply assigned to one of the former groups nor do they form a distinct group of their own. Some analyses have characteristics of group A, some of group C and are believed to be tectonic slivers derived from different tectonic environments.

The magma groups can be demonstrated quite well on an Y vs Zr diagram (Fig. 2), where they form ± linear arrays reflecting the different Zr/Y ratios of each group (HÖCK 1983, HÖCK and MILLER 1987).

Results of the Sr isotope analyses

All large coherent units including the coarse metabasites from the Fusch facies and the prasinites from the Brennkogel facies have been sampled for Sr-isotope analyses (sample localities are shown in Fig. 1). Alltogether 27 rock chips have been investigated, 11 from the ophiolitic metabasalts of unit I and II, 8 from unit III and 4 each from the Fusch facies and the Brennkogel facies.

Tab. 3: Chemical analyses of major and trace elements of metabasites from the Fusch facies (180/81–117/84) and the Brennkogel facies (33/83–36/83)

wt%	180/81	116/84	117/84	33/83	35/83	36/83
SiO_2	47.98	50.31	46.94	47.57	44.58	44.82
TiO_2	1.97	1.25	1.48	1.59	1.21	1.21
Al_2O_3	16.25	17.99	14.86	17.96	17.11	16.64
FeO*	9.12	9.16	10.03	8.90	8.35	9.08
MnO	0.20	0.13	0.20	0.19	0.21	0.15
MgO	6.38	5.04	9.08	7.29	6.87	6.65
CaO	10.89	8.51	9.20	9.25	10.14	11.29
Na_2O	3.59	4.14	3.13	2.33	3.41	3.53
K_2O	0.45	0.98	0.40	0.05	0.25	0.52
P_2O_5	0.35	0.14	0.19	0.18	0.12	0.13
LOI**	2.75	2.52	4.04	5.24	7.81	5.38
total	99.93	100.17	99.55	100.55	100.06	99.40
ppm trace elements						
Nb	17	7	10	7	3	2
Zr	111	99	108	120	97	95
Y	24	22	24	33	29	27
Sr	578	277	252	254	211	246
Rb	11	36	15	1	21	25
Ni	53	33	205	64	106	125
Cr	197	252	267	234	189	197
Ba	122	159	100	109	51	84

* FeO = Fe_{tot} ** loss on ignition

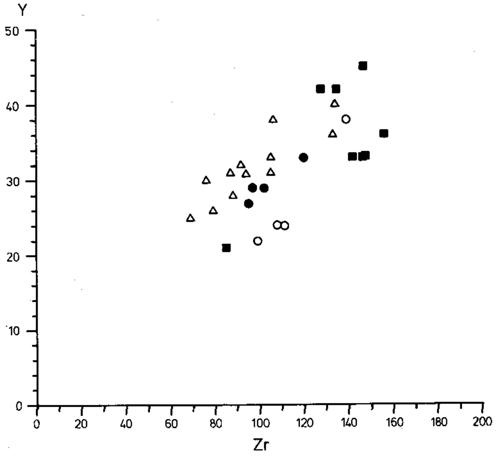

Fig. 2: Y vs Zr diagram. Y and Zr of all magma groups are positively correlated forming ± linear arrays with slightly different Zr/Y ratios. Symbols as in Fig. 1.

The major elements have been determined on fused glasses by the electronmicroprobe at 20 KV and 50 nA. The data reduction followed the method of BENCE and ALBEE, 1968. The trace elements, including Rb and Sr, were analysed by XRF and corrected according to NISBET et al., 1979. The Sr isotopes were measured on unspiked samples, partly with a VG MM30 thermion mass spectrometer in Vienna. Samples reporting six digits have been measured with a VG Sector mass spectrometer with triple collector at the Laboratory for Isotope Geology at the University of

Tab. 4: Rb, Sr and Sr isotope compositions of some Mesozoic metabasalts (metatuffs) from the central part of the Hohe Tauern

Samp.	Rb ppm	Sr ppm	^{87}Rb/^{86}Sr	^{87}Sr/^{86}Sr	(^{87}Sr/^{86}Sr)$_0$
Ophiolites unit I and II					
137/81	2	134	.043	.70380 ± 17	.70369
141/81	1	310	.009	.70373 ± 12	.70370
154/81	4	160	.073	.70414 ± 9	.70396
75/83	1	158	.016	.703494±235	.703455
76/83	7	190	.106	.704116±233	.703858
97/84	12	151	.232	.704717±233	.704155
98/84	8	152	.152	.704734±236	.704366
99/84	4	156	.074	.703073±229	.702894
100/84	7	123	.164	.703394±233	.702996
102/84	2	166	.035	.703564±226	.703480
103/84	2	156	.037	.703439±236	.703340
unit III					
167/81	19	444	.125	.70480 ± 14	.70449
77/83	8	181	.127	.703756±228	.703447
104/84	25	338	.214	.705286±228	.704768
105/84	16	188	.246	.704977±239	.704382
106/84	14	249	.162	.704850±226	.704457
107/84	9	275	.094	.704921±218	.704692
110/84	6	190	.091	.703888±215	.703667
114/84	8	366	.063	.704033±215	.703880
Fusch facies					
180/81	11	578	.055	.70570 ± 11	.70556
113/84	4	426	.027	.706050±235	.705984
116/84	36	277	.376	.706737±221	.705828
117/84	15	252	.172	.705292±226	.704876
Brennkogel facies					
33/83	1	254	.011	.70650 ± 9	.70647
34/83	6	247	.071	.70776 ± 9	.70758
35/83	21	211	.291	.70613 ± 9	.70542
36/83	25	246	.294	.70695 ± 10	.70624

^{87}Rb/^{86}Sr values are calculated from XRF data and measured Sr isotope data
^{87}Sr/^{86}Sr rations are measured relative to NBS 987 standard of .71014
(^{87}Sr/^{86}Sr)$_0$ are calculated for an assumed age of 170 M. a.

Bern. Since NBS 987 standard yields lower values in Vienna and higher values in Bern all ratios have been recalculated to the official $^{87}Sr/^{86}Sr$ ratio of 0.71014. Most samples measured in both laboratories gave identical values within the limits of error.

The initial $(^{87}Sr/^{86}Sr)_0$ for an assumed age of 170 M.a. have been calculated with $^{87}Rb = 1.42 \times 10^{-11} \times a^{-1}$ (STEIGER and JÄGER 1977). Possible age variations (±20 M.a., see ABBATE et al. 1984) of the ophiolites or the non-ophiolitic basic rocks would have only little influence on the initial isotope ratios and will not alter the conclusions.

The Rb and Sr concentrations, the $^{87}Rb/^{86}Sr$ ratios, the measured $^{87}Sr/^{86}Sr$ ratios and the $(^{87}Sr/^{86}Sr)_0$ ratios are given in Tab. 4.

Several points can be made by a first inspection of the data:

1. The $(^{87}Sr/^{86}Sr)_0$ ratios exhibit a wide range from .702894 (lowest value; ophiolites of unit I) to .70758 (highest value; prasinites of the Brennkogel facies).
2. The ratios can be grouped according to their geological setting and the characteristic magma groups (Fig. 3), with the ophiolites of unit I and II showing the lowest values. The ratios from the metabasites of unit III are intermediate but do not form a coherent cluster. They fall into two subgroups according to magma subgroups B1 and B2, the former being indistinguishable from the ophiolites. The Sr isotope ratios from the Fusch facies and the Brennkogel facies reach the highest values. Each group shows a relatively wide variety of $^{87}Sr/^{86}Sr$ ratios.
3. The Sr isotope ratios of the ophiolites fall at least in part into the variability range of those from recent oceans. They are partly comparable with the values from the Atlantic and the Indian ocean (DUPRE and ALLEGRE 1980, 1983, WHITE and HOFMANN 1982, HAMELIN and ALLEGRE 1985) but show an extension to higher ratios.

Discussion

In discussing the petrogenetic significance of the Sr isotope variation in magmatic rocks the question of alteration processes is a crucial one. In fact, the problem to what extent a regional metamorphosed basalt or tuff has undergone premetamorphic chemical alteration is difficult to assess. In the absence of mineralogical and petrographical criteria chemical parameters provide the only hints.

It has been pointed out by HÖCK and MILLER 1980, 1987, HÖCK 1983, and HÖCK and KOLLER 1988 that in the Tauern window especially the ophiolitic basalts of MORB-type are slightly altered in their SiO_2, CaO, MgO, Na_2O and K_2O abundances, but are rather unaffected by alteration processes in respect to their high-field-strength (HFS) elements. This is indicated by the good positive correlation of elements such as Ti and Zr or Y and Zr. These elements vary only slightly and are close to unity when normalized to MORB (normalizing values are taken from PEARCE 1980). The low-field-strength (LFS) elements Sr, K, Rb, Ba show some enrichment or depletion (.5 to 3 times MORB). Larger deviations occur, but are rare. It should be noted here that the Sr variation is small and generally in the range of 1 to 1.5 times MORB.

The situation of the non-ophiolitic metabasalts and tuffs in unit III, the Fusch facies and the Brennkogel facies is slightly different. There is at least in part a

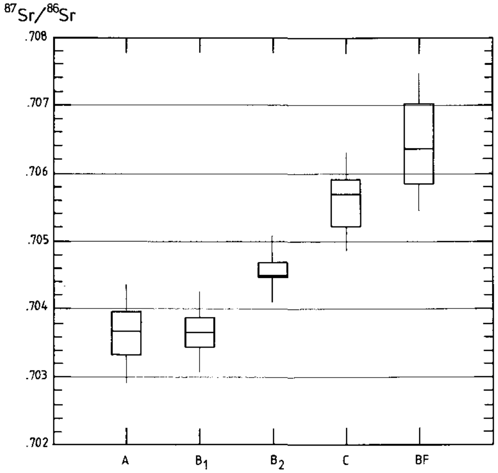

Fig. 3: Box and whisker plot of each magma group displaying the range of the initial $^{87}Sr/^{86}Sr$ ratio (170 M.a.). The box covers the middle 50% of the data values, the whiskers extend to the extremes, the central line is the median. Symbols:
A: ophiolites (magma group A)
B1: metatuffs of unit III (magma subgroup B1)
B2: metabasalts and metatuffs of unit III (magma subgroup B2)
C: metabasites of the Fusch facies (magma group C)
BF: metabasites of the Brennkogel facies.

systematic increase in the concentration of the HFS elements and only a small scatter within each group, but often a large variation of Sr, K, Rb, and Ba.

It might be concluded from the element behavior that the variability of the major elements and trace elements such as Sr, Rb, Ba is due to some extent to (premetamorphic?) alteration processes, whereas the so-called immobile elements were not significantly affected. Despite the variability of the LFS elements original differences between the magma groups are still recognisable.

It has been shown by numerous studies (HART et al. 1974, COHEN and O'NIONS 1982, MCCULLOCH et al. 1980, 1981, RAUTENSCHLEIN et al. 1985), that the $^{87}Sr/^{86}Sr$ ratio is also subject to alteration. The increase in the $^{87}Sr/^{86}Sr$ ratios is often ascribed to mixing with seawater leading to a severe effect and a wide variety of $^{87}Sr/^{86}Sr$ ratios depending on the water/rock ratio (MCCULLOCH et al. 1981). In respect to the reported $^{87}Sr/^{86}Sr$ ratios in Tab. 4, the variability within the different groups is at least partly caused by some alteration processes and should be interpreted with care.

The same grouping as with the trace elements is displayed on a $^{87}Sr/^{86}Sr$ vs Zr/Y diagram (Fig. 4), where the clusters of the different magma groups do not only reflect different Zr/Y ratios but also the between-group variation in the $^{87}Sr/^{86}Sr$ ratio. The relatively wide range of $^{87}Sr/^{86}Sr$ compared with the small variability of Zr/Y ratio within each group could be due to alteration processes.

The ophiolitic basalts have the lowest $^{87}Sr/^{86}Sr$ initial ratios. Apart from possible uncertainties because of the alteration, these values are consistent with those described from recent oceanic basins. Sr isotopes reported from the Pacific and the

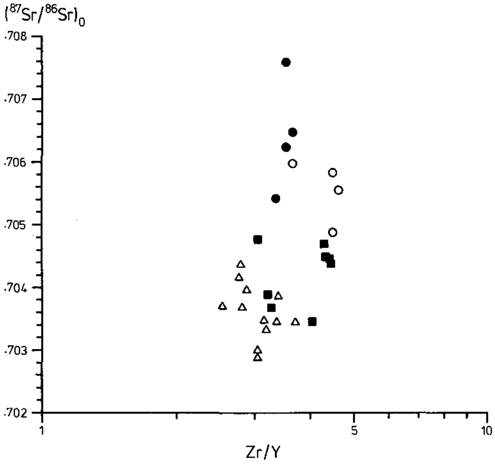

Fig. 4: $^{87}Sr/^{86}Sr$ vs Zr/Y diagram showing the variability of the initial $^{87}Sr/^{86}Sr$ ratios (170 M.a.) of each magma group compared with the Zr/Y ratios. The wide range of $^{87}Sr/^{86}Sr$ ratios especiallay in the metabasites of the Brennkogel facies indicates some alteration. Symbols as in Fig. 1.

central part of the Atlantic are generally lower but those from the North and South Atlantic and from the Indian Ocean are well in the range of the values from the ophiolitic basalts in the Tauern window.

The same is true for the samples of magma subgroup B1 in unit III. They are geochemically similar to the ophiolitic basalts and show the same range of Sr isotopes. This corroborates the earlier assumption (HÖCK, 1983, HÖCK and MILLER, 1987) that despite the fact that magmas of subgroup B1 are not ophiolitic magmas, they have an affinity to the ophiolitic magma source. But the origin of magma group B as a whole is obviously more complex, because the magma subgroup B2 represents rather a within-plate component as indicated by the high Nb, the high Zr/Y ratio and the high $^{87}Sr/^{86}Sr$ ratio.

Similar features are observed in the Fusch metabasics (magma group C) which must be separated from magma subgroup B2 on the basis of their preserved gabbroic texture and the clastic sediments they intruded. Apart from their higher Zr/Nb ratio and their similar Zr/Y ratio the Sr isotope ratio is significantly higher than that of B2.

Still enigmatic are the metabasalts from the Brennkogel facies. As mentioned above they are ambiguous to interpret and are not clearly related to one of the other groups. Their Zr/Y and Zr/Nb ratios are only slightly above and below group A magmas respectively. Their Rb abundances vary, the K and Sr values are intermediate, but their Sr isotope ratios are the highest of all. All these facts point to a strong alteration possibly with an intensive seawater exchange.

In contrast to the missing correlation between the Sr isotopes and the HFS elements (e.g. Fig. 4) a fair positive correlation of the $^{87}Sr/^{86}Sr$ ratio with Rb and $^{87}Rb/^{86}Sr$ (Fig. 5) and a negative correlation with 1000/Sr (Fig. 6) can be observed. This is interpreted at least partly as a primary feature. The considerable and systematic variation of Rb and Sr abundances between the groups and the increase in Sr/Zr or

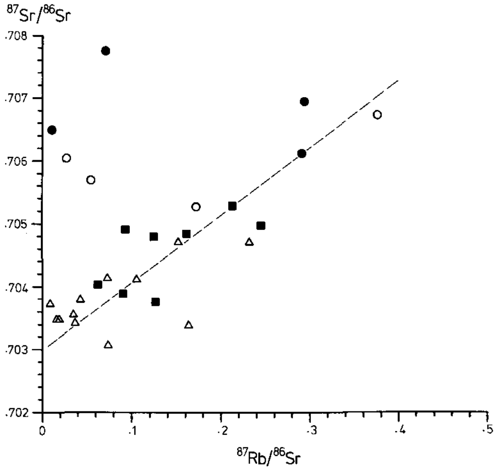

Fig. 5: ^{87}Sr/^{86}Sr vs ^{87}Rb/^{86}Sr plot. Except of two samples from the Fusch facies and two from the Brennkogel facies, the measured Sr-isotope ratios are positively correlated with ^{87}Rb/^{86}Sr. Symbols as in Fig. 1.

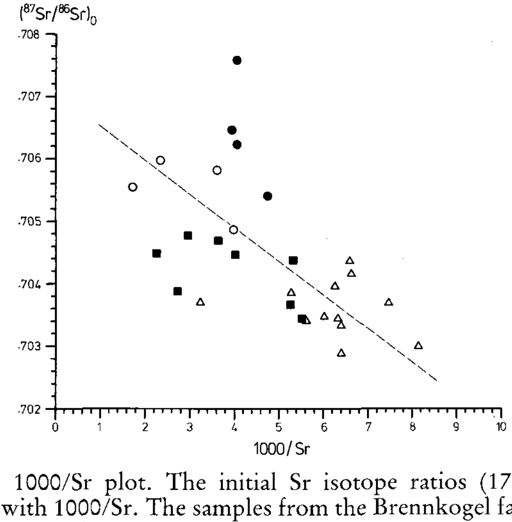

Fig. 6: ^{87}Sr/^{86}Sr vs 1000/Sr plot. The initial Sr isotope ratios (170 M.a.) are negatively correlated with 1000/Sr. The samples from the Brennkogel facies plot slightly above this trend. Symbols as in Fig. 1.

Rb/Zr ratios from group A to C probably reflects source variations despite some alteration, since these ratios should not change very much with varying degrees of partial melting of mantle sources or fractionation of primary basaltic magmas (except for extensive plagioclase fractionation or accumulation). This sympathetic increase in the Sr isotopes is to a certain degree also likely to indicate the heterogeneity of the mantle source under the Mesozoic Penninic ocean.

The within-group variation is possibly caused by seawater alteration. When the least alterated samples are taken into account it becomes even more clear, that the within-group variability is reduced while the general characteristics between the groups are preserved.

Conclusions

When all aspects of Sr isotope variations in the Mesozoic ophiolites and non-ophiolitic magmas are summarized, it may be concluded that some alteration took place in the basalts and tuffs, probably shortly after their eruption, as exemplified by the variability of the LFS elements. Nevertheless, the primary relations were not masked completely, particularly the variations between the magma groups seem to reflect the original signature of the Sr isotopes. The ophiolitic basalts with the lowest $^{87}Sr/^{86}Sr$ ratios represent magmas derived from a depleted mantle source. A similar conclusion can be drawn for magma subgroup B1, while the metabasalts of magma subgroup B2 with higher Sr isotopes, and elevated Sr, Rb, K and HFS element abundances were derived from an enriched source. The same is true for the metabasites of the Fusch facies. Those from the Brennkogel facies with the highest $^{87}Sr/^{86}Sr$ ratios are not assigned to a certain magma group and seem to have suffered geochemical changes hiding the original characteristics.

Notwithstanding the alteration problems the isotope data combined with field evidence and geochemical data corroborate the hitherto published models (HÖCK and MILLER, 1987, KOLLER and HÖCK, 1988) that the Penninic ocean formed as a small ocean basin with the ocean floor basalts (ophiolites) derived from a depleted mantle. The mantle source, however, has been heterogeneous in time (?) and space giving rise to an intensive magmatic activity, exhibiting apart from the ophiolites, a wide compositional range of basaltic tuffs and lavas.

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