Zeitschrift: Schweizerische mineralogische und petrographische Mitteilungen = Bulletin suisse de minéralogie et pétrographie

Band: 59 (1979)

Heft: 3

Artikel: Amphibolites from the Central Alps : REE-patterns and their relation to the possible parent rocks

Autor: Schubert, K.

DOI: https://doi.org/10.5169/seals-46067

Schweiz. mineral. petrogr. Mitt. 59, 299–308, 1979

Amphibolites from the Central Alps: REE-Patterns and their Relation to the possible Parent Rocks.

by *K. Schubert*

Abstract

15 amphibolites from the Central Alps have been analysed for the lanthanoids La, Ce, Sm, Eu, Tb, Yb, Lu and for the trace elements Sc, Cr, Co, Ni, Hf and Fe.

Possible parent rocks for the amphibolites are defined by the absolute and relative REE-abundances of unaltered magmatic and sedimentary rocks of various proveniences.

The REE-patterns of the amphibolites are compared to these and a cautious interpretation of rock type and tectonic setting is suggested.

The REE-patterns of the samples of the Lepontine region, which are believed to be of mesozoic age, resemble those of LIL-element depleted ocean-ridge type tholeiitic basalts and of slightly LIL-element enriched tholeiitic basalts commonly associated with plate margins.

1. INTRODUCTION

A pertinent question for geochemistry is the nature of the parent equivalents of amphibolites and other metamorphosed rocks.

The possibly occurring mobility of major and trace components during alteration and metamorphic processes constrains to use data of more immobile elements to solve such problems. Lanthanoids especially are considered to be such more immobile elements (F. A. Frey et al., 1968; Philpotts et al., 1969; Herrmann & Wedepohl, 1970; Herrmann et al., 1974). Systematic investigations of submarine basalts have shown that significant changes in the REE-abundances may result from seawater interaction:

The palagonitization of basaltic glasses results in La and HREE (heavy REE) depletion, whereas Ce possibly increases slightly. The alteration of crystalline basalts may result in a slight increase of LREE (light REE) (F. A. Frey et al., 1974).

Zeolithization significantly changes the LREE-contents of basaltic lavas (Wood et al., 1976).

* Geochemisches Institut der Universität Göttingen, Goldschmidtstr. 1, D-3400 Göttingen.

The breakdown of basaltic glasses causes the mobility of the REE's during zeolithization (MUECKE et al., 1977), and finally leads to negative Ce-anomalies, the significance of which depends on the exposure times of the lavas to seawater (MENZIES et al., 1977; HELLMAN & HENDERSON, 1977; LUDDEN & THOMPSON, 1978).

There seem to be no changes of the REE-abundances as a consequence of regional metamorphism of higher metamorphic grades (500°–580°C and 3–4 kb, corresponding to the low grade to medium grade specifications of WINKLER [1976]), whereas most of the other trace elements and major components become considerably mobile under these conditions (MUECKE et al., 1977).

So if an estimate can be made of what had happened to the parent rocks, lanthanoids may well indicate the parental rocks of the amphibolites.

2. LOCATIONS OF THE SAMPLES

The samples are from the Lepontine area (Central Alps). Here the highest degrees of alpine metamorphism occur, decreasing from the root zone to the outer parts of this region (WENK & KELLER, 1969). The investigated samples belong to different metamorphic grades and their occurrences are spread over the Lepontine area, although there is an accumulation of sampling points in the root zone (6/15; see fig. 1).

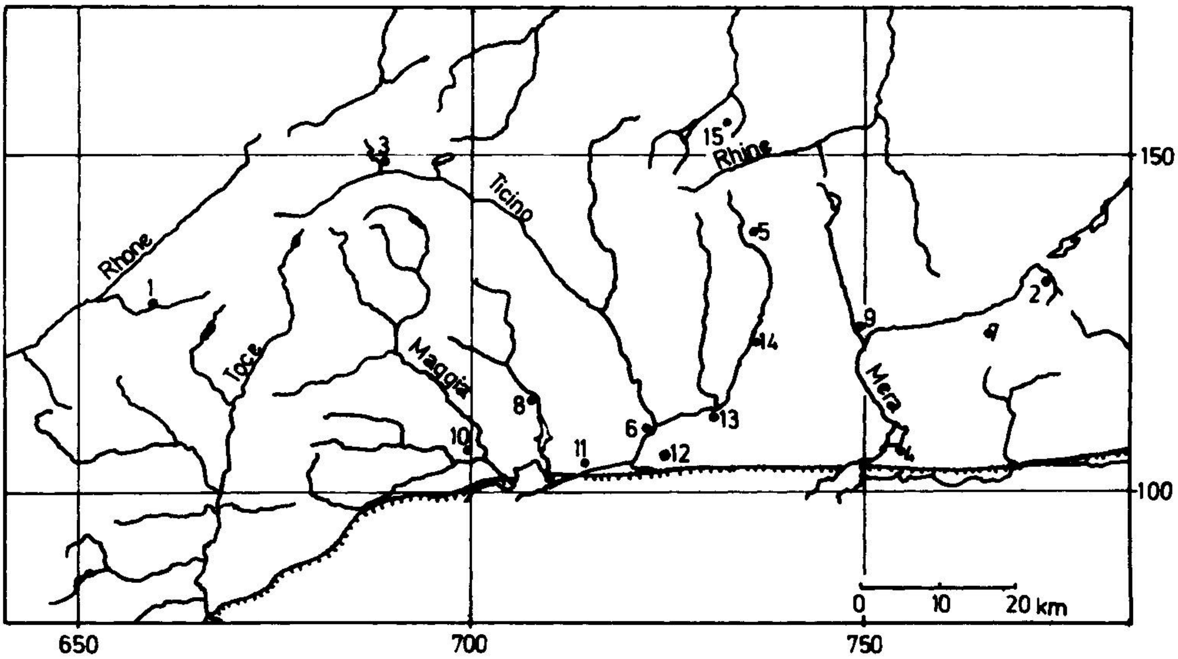

Fig. 1: Locations of the samples from Central Alps (1-As 912, 2-Brg 73, 3-GdT S 580, 4-Mera 34, 5-Mis 52, 6-Riv 17, 7-Sci 186, 8-Shlz A22a, 9-Spluga 11d, 10-Wurz 166, 11-Wurz 176, 12-19.7.69-01; 13-20.7.69-02, 14-22.7.69-01, 15-29.9.69-01). After Wenk & Keller (1969), and Wenk et al. (1974).

3. EXPERIMENTAL

100 mg of each sample, enclosed in a quartz-glass tube have been analysed by INAA for La, Ce, Sm, Eu, Tb, Yb, Lu, Sc Co, Hf and Fe.

Cr and Ni have been assayed by AAS and flameless AAS (Ni). Irradiations have been performed by the FR 2 reactor of the Kernforschungszentrum Karlsruhe with a neutron flux of $3 \cdot 10^{11}$ [$n \cdot cm^{-1} \cdot sec^{-1}$] and 72 h irradiation time, and by the Triga Mark I reactor of the Institut für Nuklearmedizin, Medizinische Hochschule Hannover, with a neutron flux of $2 \cdot 10^{12}$[$n \cdot cm^{-1} \cdot sec^{-1}$] and 8 h irradiation time.

The nuclides ^{46}Sc, ^{59}Fe, ^{60}Co, ^{140}La, ^{153}Sm, ^{175}Yb, ^{177}Lu have been assayed 7–9 days after irradiation; the nuclides ^{46}Sc, ^{59}Fe, ^{60}Co, ^{141}Ce, ^{152}Eu, ^{160}Tb,^{181}Hf 40 days after irradiation. Detecting time was 12 hours per sample using a planar Ge(Li)-detector with <2.5 keV resolution at 1.333 MeV.

The methods of preparing the samples for irradiation and detection are mostly similiar to those published by JACOBS et al. (1977).

The averages and error calculations of 15 USGS W-1 reference samples, which have undergone the same preparing procedures for irradiating and detecting parallel to the amphibolites are given in table 1.

Table 1: Averages and error calculations of USGS W-1 analyses of 9 runs. Averages in µg/g (Fe in wt. -%).

	n	$X_{(n)}$	X_F	S_r
$_{21}Sc$	15	35.1	35.1	2.2
$_{26}Fe$	15	7.71	7.76	2.7
$_{27}Co$	15	43.8	47	2.9
$_{57}La$	11	10.4	9.8	6.0
$_{58}Ce$	9	22.8	23	5.6
$_{62}Sm$	12	3.4	3.6	5.2
$_{63}Eu$	14	1.03	1.11	5.5
$_{65}Tb$	13	0.57	0.65	17.0
$_{70}Yb$	11	2.1	2.1	6.2
$_{71}Lu$	11	0.39	0.35	10.1
$_{72}Hf$	15	2.5	2.67	11.8

n = number of analyses
$X_{(n)}$ = average of n analyses
X_F = values of Flanagan (1973)
S_r = relative uncertainty at the 95% confidence level

4. RESULTS AND DISCUSSION

The values of the assayed elements are given in table 2. The values of the major elements have been published by WENK & KELLER (1969) and WENK et al., (1974).

Table 2: Trace element analyses of the samples from the Central Alps (values in µg/g, Fe in wt-%)

Probe	$_{21}$Sc	$_{24}$Cr	$_{26}$Fe	$_{27}$Co	$_{28}$Ni	$_{57}$La	$_{58}$Ce	$_{62}$Sm	$_{63}$Eu	$_{65}$Tb	$_{70}$Yb	$_{71}$Lu	$_{72}$Hf
As 912	41.5	701	7.7	49.5	115	3.5	14.7	3.1	1.08	0.54	3.0	0.53	2.3
Brg 73	37.8	246	6.9	42.2	47	3.6	12.6	3.6	1.39	0.60	3.0	0.52	2.8
GdT S 580	45.7	106	10.6	43.2	21	10.4	48.0	5.9	1.75	1.50	5.2	0.91	3.9
Mera 34	25.5	98	5.8	20.9	6	19.2	48.3	6.8	1.39	1.19	3.0	0.49	5.1
Mis 52	33.5	147	7.7	29.8	26	13.8	29.3	5.4	1.55	0.84	3.7	0.65	3.9
Riv 17	36.5	468	7.7	41.4	81	5.1	22.7	3.1	1.14	0.60	2.9	0.56	2.5
Sci 186	43.2	304	8.8	54.8	126	3.7	24.0	3.5	1.32	0.53	3.3	0.71	2.4
Shlz A22a	31.9	n.b.	7.6	38.3	n.b.	11.5	28.7	4.2	1.00	0.68	3.5	0.57	3.5
Spluga 11 d	21.2	65	4.5	18.6	5	19.8	43.3	5.7	0.95	1.07	3.4	0.49	5.6
Wurz 166	40.0	286	8.1	41.6	60	5.3	22.7	3.9	1.46	0.77	3.7	0.72	3.2
Wurz 176	34.9	201	8.3	44.9	77	6.5	28.9	3.5	1.54	0.76	2.5	0.49	3.1
19.7. 69-01	32.1	197	6.3	38.0	73	3.2	12.9	2.8	1.03	0.49	2.3	0.43	2.4
20.7. 69-02	36.8	423	7.2	40.8	87	3.7	16.5	3.1	1.16	0.69	2.8	0.45	2.8
22.7. 69-01	35.2	911	6.6	40.8	97	4.5	19.3	2.0	0.56	0.28	1.2	0.24	1.3
29.9. 69-01	37.4	359	8.2	65.5	252	7.7	20.3	2.2	0.82	0.45	2.5	0.45	1.6
δ (%)	0.3		0.6	1.4		3.4	4.3	3.9	2.8	16.0	6.9	4.9	12.6
s (%) (1 δ)	1.8		1.9	2.5		3.8	4.7	4.2	3.4	16.4	7.2	5.3	12.9

δ (%) = relative error from counting statistics (average of the investigated samples)
s (%) = relative standard deviation (1δ) (average of the investigated samples)
(GdT S 580 contains garnet; Mera 34 is a gneiss; 22.7.69-01 contains quartz; 29.9.69-01 is a metaschist. Special petrographic descriptions are given in WENK et al., 1974.)

4.1 The possible Parent Rocks of Amphibolites

BALASHOV et al. (1972), demonstrated that amphibolites were formed mainly by mafic and intermediate volcanic rocks and graywackes, using the chemical composition of the major minerals of these rocks.

This can be proved by a diagram, using the correlation of the REE-fractionation (La/Yb-ratio) and the total amount of the assayed REE (ΣREE) (fig.s 2 & 3).

The compiled fields of basalts of different tectonic setting and the projection of the representative points of the analyzed amphibolites into these fields lead to 3 types of chondrite-normalized REE-patterns (values of HASKIN et al., 1971) (fig. 4):

a) no fractionation of LREE's referred to HREE's, or light LREE-depletion, as is typical for spreading centers;

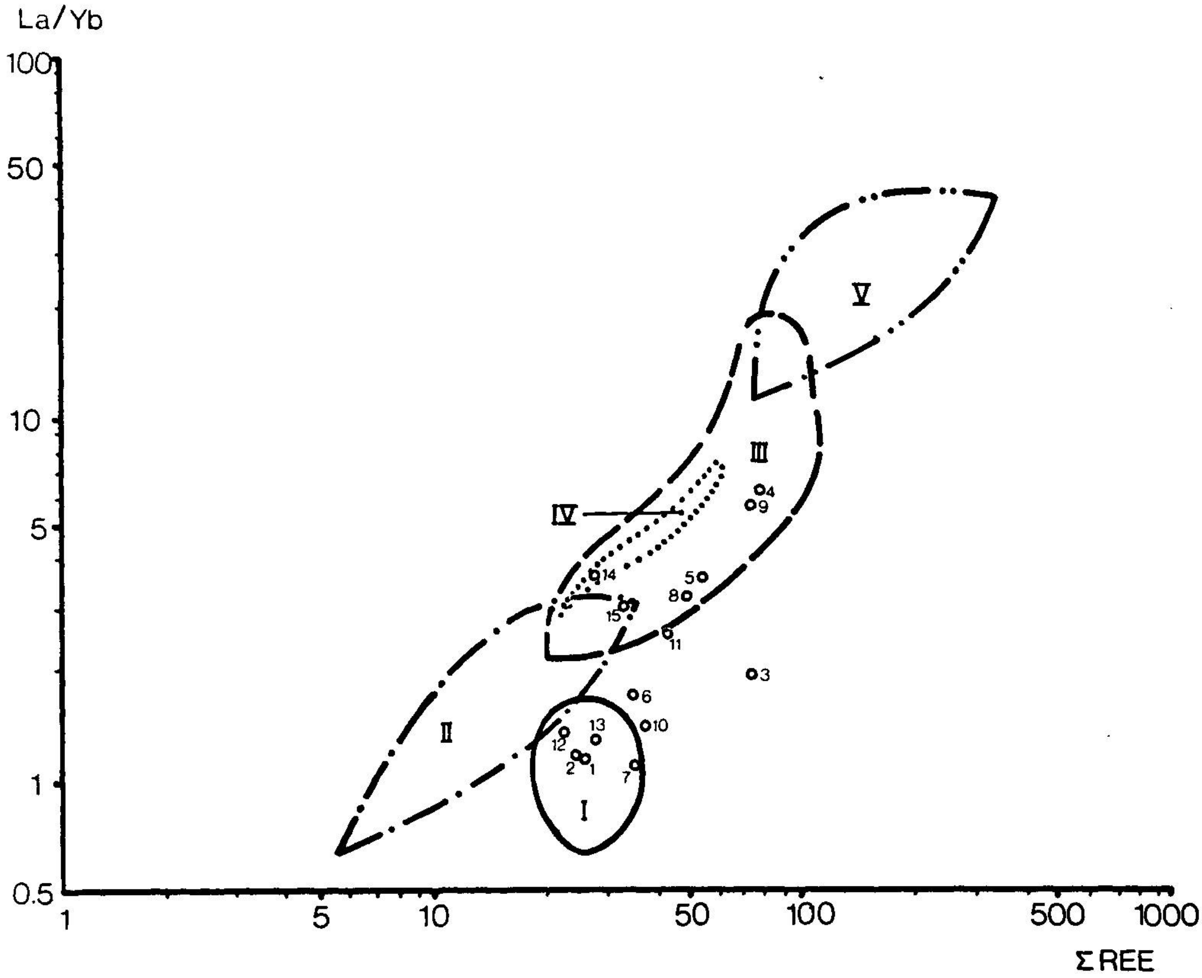

Fig. 2: La/Yb - ΣREE - diagram of magmatic rocks (ΣREE = La+Ce+Sm+Eu+Tb+Yb+Lu) values in μg/g
I) field of ocean ridge type tholeiitic basalts
II) field of ocean island tholeiitic basalts
III) field of plate margin and continental tholeiitic basalts
IV) field of high-Al_2O_3 basalts
V) field of alkali-olivine basalts
circles - samples from Central Alps.
Data used for compilation are from:
Balashov (1976), Dostal et al. (1976), Frey et al. (1968), Green et al. (1969), Haskin et al. (1966), Herrmann (1970).

b) light to little fractionation of LREE's referred to HREE's, as is common with plate margins;

c) distinct fractionation of LREE's referred to HREE's, regarded typic for within-plate basalts.

4.2 The Amphibolites of the Central Alps

The REE-abundances of seven samples possess the group a)-specifications and seem to be similiar to REE-patterns regarded as typical for ocean ridge type tholeiitic basalts.

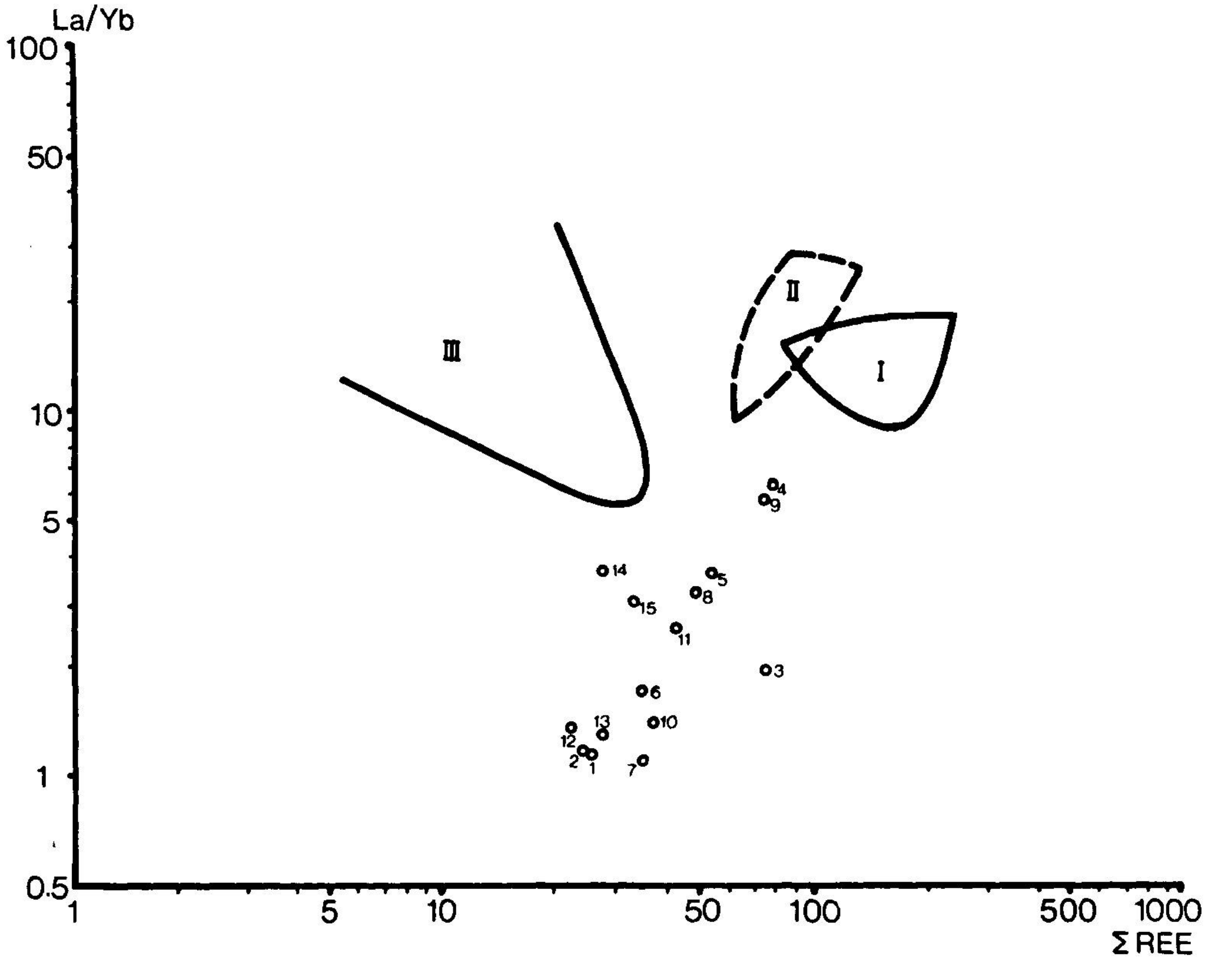

Fig. 3: La/Yb-ΣREE - diagram of sedimentary rocks (ΣREE = La+Ce+Sm+Eu+Tb+Yb+Lu) values in μg/g
I) shales
II) graywackes
III) calcareous sediments
circles - samples from Central Alps.
Data used for compilation are from:
Balashov (1976), Dypvik & Brunfelt (1976), Ronov et al. (1974), Wildemann & Condie (1973), Wildemann & Haskin (1973).

The rest of the samples are group b)-specified and similiar to light LIL-element (LIL = Large Ion Lithophile) enriched tholeiitic basalts, commonly occuring in plate margin areas (4.1). This grouping corresponds with the positions of the representative points in the La/Yb vs Σ REE-diagram of fig. 2.

No representative points are found in the area of sedimentary rocks as far as compiled in the diagram of fig. 3.

The points of 8 samples are positioned on a straight correlation line concerning their fractionation and total amount of REE's. This line is interpreted as a scale of the degree of partial melting, and may indicate a strong dependence of the magma evolution from the tectonic setting.

The majority of the samples (9/15) have normalized to chondrites minor La-values compared to Ce, and the LREE's (except La) of the group a)-samples are

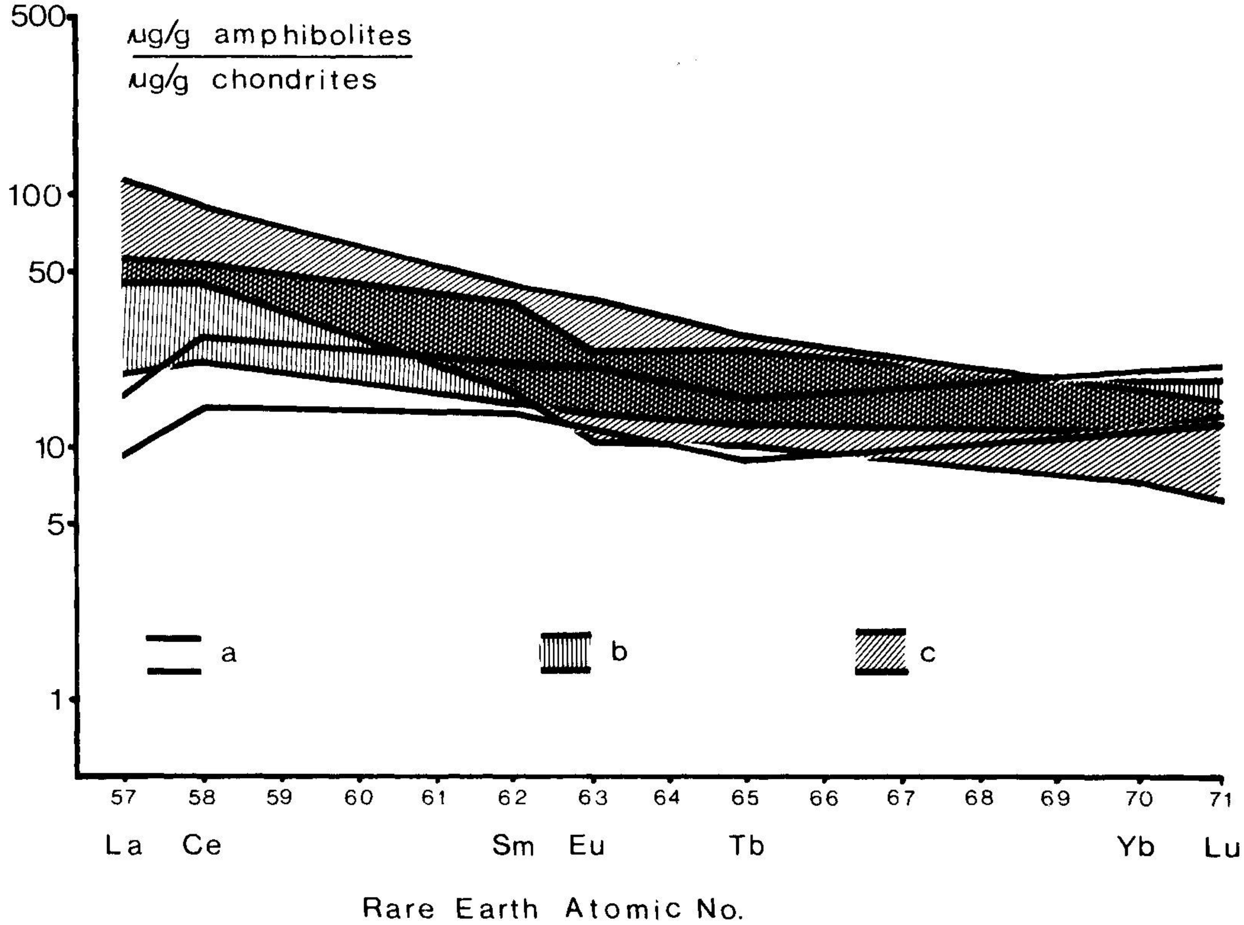

Fig. 4: REE distribution and fractionation patterns of the investigated samples from the Central Alps.
a) unfractionated
(samples: As 912, Brg 73, Riv 17, Sci 186, Wurz 166, 19.7.69-01, 20.7.69-02)
b) little fractionated
(samples: GdT S 580, Mera 34, Mis 52, Shlz A22a, Spluga 11d, Wurz 176)
c) markedly fractionated.
(A set of 10 amphibolites of Central Brazil is included to get higher significance. Data are from Schubert, K.: Zentralbrasilianische Amphibolite; in preparation [1979]).

distinctly fractionated in contrast to the unfractionated HREE-group. These phenomena markedly resemble those of palagonitization of LIL-element depleted basaltic glasses, described by F. A. Frey et al. (1974) (see 1.). Thus, it must be concluded that the group a)-amphibolites originally possessed lower LREE-amounts, which confirms their abyssal character.

The alteration effects of the samples showing no signs of palagonitization might be neglected. There are no marked negative Ce-anomalies as should be if distinct changes of LREE's had happened in the crystalline phase (Ludden & Thompson, 1978; see 1.). Only the sample Mis 52 suggests such a slight anomaly.

In spite of the classification by REE's being quite clear, there are other trace elements, which seem to give another picture of the parental magmas for some samples.

The high Cr and Ni abundances and lower Hf-values of the samples 22.7.69-01[1]) and 29.9.69-01[1]) could suggest oceanic gabbros as parent rocks (THOMPSON, 1973). REE-patterns of gabbros vary in a wide range and cannot be distinguished from those of tholeiitic basalts in some cases. F.A. FREY et al. (1974) found similiar abundances for basaltic glasses.

In general the trace element abundances of Sc, Co, Hf, Cr. Ni of the examined amphibolites of the Central Alps are within the expected range depending on the classification of the supposed parent rocks.

4.3 Arrangement to the evolution of the Alps

The data of the age of alpine rocks (HUNZIKER, 1974) and the model described by DIETRICH et al. (1974) and similiarly by other authors (M. FREY et al., 1974; OXBURGH & TURCOTTE, 1974) requests an expansive oceanic lithosphere from the Jurassic to the lower Cretaceous, a compression phase and following subduction for the Cenomanian to the Eocene.

This possible interpretation is confirmed by BIKLE and NISBET (1972). Their ophiolites from the Penninic zone of the Tauern-Window were of oceanic character and were interpreted as possible relicts of a mesozoic ocean basin.

Thus the interpretation of the presented values is quite close to what could be expected, and it is not going too far, to suppose the parent rocks of the amphibolites of the Central Alps to be LIL-element depleted ocean ridge type tholeiitic basalts and light LIL-element enriched tholeiitic basalts common with plate margins.

5. SUMMARY

The amphibolites of the Central Alps are orthoamphibolites of mesozoic age.

Their REE-abundances resemble those of LIL-element depleted ocean-ridge type tholeiitic basalts, and those of slightly LIL-element enriched tholeiitic basalts commonly associated with plate margins. Thus, their parental rocks are suggested to be tholeiitic magmas of these tectonic settings.

These results can be arranged without difficulty to the beginning of the alpine evolution, beginning with a spreading of oceanic lithosphere, which is followed by a compression phase and subduction.

[1]) These two samples have been omitted in the diagram of fig. 4 because of their low REE-abundances being not in the range of the other amphibolites of similiar REE-fractionation. These two data sets would enlarge the range of the field b, so it would be no longer of significance.

Acknowledgements

Many thanks to Prof. Dr. A.G. Herrmann, who provided much help by discussing methods and results.

I am grateful to Prof. Dr. E. Wenk, Basel, Prof. Dr. G. Müller, Clausthal-Zellerfeld, and Dr. H. Roeser, for providing the samples. Irradiations were granted by means of the Gesellschaft für Kernforschung m.b.H., Karlsruhe, and by the Institut für Nuklearmedizin, Medizinische Hochschule Hannover. The Deutsche Forschungsgemeinschaft supported the experimental part of this work by a research grant. Special thanks to Dr. J.W. Jacobs, St. Louis, disposing a peak-analysis computer program, and to Dipl. Math. G. Siebrasse, Göttingen, supplying and make it run at the UNIVAC 1108 of the Gesellschaft für wissenschaftliche Datenverarbeitung m.b.H., Göttingen. Detections have been made at the ZIL, Universität Göttingen. Thanks to Dr. Wolf and coworkers (Karlsruhe), to Dr. D. Junker and Mr. Kretzschmar (Hannover), to Dr. W. Gelbke, Dipl. Phys. K.H. Becker, L. Richter and E. Speer (Göttingen), providing irradiations and technical support.

References

BALASHOV, YU. A.: Geokhimiya Redkosemel'nykh Elementov. Isdatel'stvo Akademii Nauk SSSR, Moskva.(1976)

BALASHOV, YU. A., KREMENETSKIY, A. A., SHVETS, V. M.:Geochemical criteria of the nature of precambrian amphibolites. Geochem. Intern. *9*, 918-931. (1973).

BICKLE, M.J., NISBET, E.: The oceanic affinities of some alpine mafic rocks based on their Ti-Zr-Y contents. J. Geol. Soc. *128*, 267-271.(1972)

DIETRICH, V., VUAGNAT, M, BERTRAND, J.: Alpine metamorphism of mafic rocks. Schweiz. mineral. petrogr. Mitt. *54*, 291-332.(1974)

DOSTAL, J., DUPUY, C., COULON, C.: Rare earth elements in high - alumina basaltic rocks from Sardinia. Chem. Geology *18*, 251-262.(1976)

DYPVIK, H., BRUNFELT, A.O.: Rare earth elements in lower paleozoic epicontinental and eugeosynclinal sediments from the Oslo and Trondheim regions. Sedimentology *2*, 363-378.(1976)

FLANAGAN, F.J.: 1972 values for international geochemical reference samples. Geochim. Cosmochim. Acta *37*, 1189-1200.(1973)

FLOYD, P.A.: Rare earth element mobility and geochemical characterization of spilitic rocks. Nature *269*, 134-137.(1977)

FREY, F.A., HASKIN, M.A., POETZ, J.A., HASKIN, L.A.: Rare earth abundances in some basic rocks. J. Geophys. Res. *73*,6085-6098.(1968)

FREY, F.A., BRYAN, W.B., THOMPSON, G.: Atlantic ocean floor: Geochemistry and petrology of basalts from legs 2 and 3 of the Deep-Sea Drilling Project. J. Geophys. Res. *79*, 5507-5527.(1974)

FREY, M., HUNZIKER, J.C., FRANK, W., BOCQUET, J., DAL PIAZ, G.V., JÄGER, E., NIGGLI, E.: Alpine metamorphism of the alps. Schweiz. mineral. petrogr. Mitt. *54*, 248-290.(1974)

GREEN, T.H., BRUNFELT, A.O., HEIER, K.S.: Rare earth element distribution in anorthosites and associated highgrade metamorphic rocks, Lofoten-Vesteraalen, Norway. Earth Planet. Sci. Lett. *7*, 93-98.(1969)

HASKIN, L.A., FREY, F.A., SCHMITT, R.A., SMITH, R.H.:Meteoric, solar and terrestrial rare earth distributions. Phys. Chem. Earth *7*, 167-321.(1966)

HASKIN, L.A., HELMKE, P.A., PASTER, T.P., ALLAN, R.O.: Rare earth in meteoritic, terrestrial and lunar matter. Activ. Anal. Geochem. Cosmochem., Proc. NATO Advan. Study Inst., Oslo, 201-218.(1971)

HELLMAN, P.L., HENDERSON, P.: Are rare earth elements mobile during spilitization? Nature *267*, 38-40.(1977)

HERRMANN, A.G.: Yttrium and Lanthanides. Handbook of Geochemistry, Vol. II/2, Springer Verlag, Berlin, Heidelberg, New York.(1970)

HERRMANN, A.G., WEDEPOHL, K.H.: Untersuchungen an spilitischen Gesteinen der variskischen Geosynkline in Nordwestdeutschland. Contrib. Mineral. Petrol *29*, 255–274.(1970)

HERRMANN, A.G., POTTS, M.J., KNAKE, D.: Geochemistry of the rare earth elements in spilites from the oceanic and continental crust. Contrib. Mineral. Petrol *44*, 1–12.(1976)

HUNZIKER, J.C.: Rb-Sr and K-Ar age determinations and the alpine tectonic history of the Western Alps. Mem. Ist. Geol. Mineral. Univ. Padova *31*, 3–39.(1974)

JACOBS, J.W.: Computer program for analyzing gamma-spectra, with description. unpublished (1974)

JACOBS, J.W., KOROTEV, R.L., BLANCHARD, D.P., HASKIN L.A.: A well tested procedure for instrumental neutron activation analysis of silicate rocks and minerals. J. Radioanal. Chem. *40*, 93–114.(1977)

LUDDEN, J.N., THOMPSON, G.: Behaviour of rare earth elements during submarine weathering of tholeiitic basalt. Nature *274*, 147–149.(1978)

MENZIES, M., BLANCHARD, D., JACOBS, J.: Rare earth and trace element geochemistry of metabasalts from the Point Sal Ophiolite, California. Earth Planet. Sci. Lett. *37*, 203–215.(1977)

MUECKE, G.K., PRIDE, C., SARKAR, P.: Rare earth element geochemistry of regional metamorphic rocks. Second Symposium on the Origin and Distribution of the Elements. Paris, UNESCO, May 10–13, 1977. To be published in the Conference Proceedings, Pergamon Press.

OXBURGH, E.R., TURCOTTE, D.L.: Thermal gradients and regional metamorphism in overthrust terrains with special reference to the Eastern Alps. Schweiz. mineral. petrogr. Mitt. *54*, 641–662.(1974)

PHILPOTTS, J.A., SCHNETZLER, C.C., HART, S.R.: Submarine basalts: some K, Rb, Sr, Ba, rare-earth, H_2O, and CO_2 data bearing on their alteration, modification by plagioclase and possible source materials. Earth Planet. Sci, Lett. *7*, 293–299.(1969)

RONOV, A.B., BALASHOV, YU.*A., Girin, Yu.P., Bratishko, R.Kh., Kazakov, G.A.: Regularities of rare-earth element distribution in the sedimentary shell and in the crust of the earth. Sedimentology 21*, 171–193.(1974)

THOMPSON, G.: Trace element distributions in fractionated oceanic rocks, 2. gabbros and related rocks. Chem. Geol. *12*, 99–111.(1973)

WENK, E., KELLER, F.: Isograde in den Amphibolitserien der Zentralalpen. Schweiz. mineral. petrogr. Mitt. *49*, 157–198.(1969)

WENK, E., SCHWANDER, H., STERN, W.: On calcic amphiboles and amphibolites from the Lepontine Alps. Schweiz. mineral. petrogr. Mitt. *54*, 97–142.(1974)

WILDEMANN, T.R., CONDIE, K.C.: Rare earth in archean graywackes from Wyoming and from the Fig Tree group, South Africa. Geochim. Cosmochim. Acta *37*, 439–453.(1973)

WILDEMANN, T.R., HASKIN, L.A.: Rare earth in precambrian sediments. Geochim. Cosmochim. Acta *37*, 419–438.(1973)

WOOD, D.A., GIBSON, I.L., THOMPSON, R.N.: Elemental mobility during zeolite facies metamorphism of the tertiary basalts of eastern Iceland. Contrib. Mineral. Petrol. *55*, 241–254.(1976)

WINKLER, H.G.F.: Petrogenesis of metamorphic rocks. 4th Ed., Springer Verlag, Berlin, Heidelberg, New York.(1976)

Manuscript received September 3, 1979.