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ON THE GENESIS OF SOME LEUCHTENBERGITE-BEARING METAMORPHIC ROCKS AND THEIR PHASE RELATIONS

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ABSTRACT. — The genetic problems of the leuctenbergite-bearing rocks and their metamorphic mineral compatibilities are discussed in the present paper, on the bases of some leuchtenbergite occurrences the authors had the occasion of analysing in the Austridic basement of the Eastern Alps.

These rocks have a very peculiar chemical composition, and often are characterized by the coexistence of a Mg-rich phase (leuchtenbergite) and an Al-rich phase (kyanite).

As regards their genesis, the hypotheses based on metasomatism seem to be unable to explain the leuchtenbergite occurrences considered in the present paper. On the contrary, those based on isochemical metamorphism at the expenses of weathered and hydrothermally altered volcanic materials seem to represent a feasible tool for the explanation of the main chemical features of these rocks.

As regards their metamorphism, the mineral compatibilities involving leuchtenbergite are discussed in the ambit of SiO_2-Al_2O_3-MgO-K_2O-Na_2O-H_2O system.

RIASSUNTO. — In questo lavoro vengono discussi i problemi genetici delle rocce a leuchtenbergite e le loro compatibilità mineralogiche. L'occasione è stata offerta dallo studio che gli autori hanno effettuato su alcuni affioramenti del basamento austroalpino delle Alpi Orientali. Queste rocce, che appartengono a sequenze litologiche diverse, hanno composizione chimica veramente peculiare (figg. 1, 2 e 4; tab. 1). Spesso, sono caratterizzate dalla coesistenza di una fase ricca in Mg (leuchtenbergite) ed una fase ricca in Al (cianite) (figg. 3, 5 e 6).

Per quanto riguarda la loro genesi, vengono scartate, almeno per le località qui studiate, le ipotesi basate sul metasomatismo in quanto tale processo è incapace di spiegare in modo soddisfacente la formazione di leuchtenbergite nei casi studiati. Per contro, vengono messi in evidenza fatti a favore di quelle ipotesi che considerano il metamorfismo isochimico di rocce provenienti da materiale vulcanico alterato e idrotermalizzato. Dette ipotesi infatti spiegano in modo più verosimile le caratteristiche chimiche delle rocce prese in considerazione. Esistono tuttavia difficoltà per chiarire tutti i dettagli dei processi chimici in grado di determinare la formazione di materiali così peculiari, corrispondenti a miscele argillose di composizione particolare.

Per quanto riguarda le condizioni metamorfiche, vengono fatte alcune considerazioni circa il grado metamorfico delle rocce a leuchtenbergite considerate in questo lavoro. La paragonite è assente, e questo fatto può essere ricondotto a uno dei seguenti motivi chimici e/o fisici:

— grado metamorfico: la temperatura fu più alta di quella compatibile con la stabilità dell'associazione paragonite + quarzo (situazione descritta in fig. 3);
— particolare chimismo delle rocce: i tenori in sodio nelle rocce erano troppo bassi, e conseguentemente i punti rappresentativi delle rocce erano confinati nel volume cuneiforme ky-mu-leucht (situazione descritta in fig. 6);
— effetti combinati delle due situazioni sopra descritte.

Pertanto c'è incertezza sul grado metamorfico delle rocce a leuchtenbergite considerate in questo lavoro, e dati utili a riguardo possono essere desunti solo dalle rocce incassanti.

In ogni caso si dimostra che le rocce in oggetto non furono sottoposte a metamorfismo di alta pressione in quanto, per il loro particolare chimismo, avrebbero sviluppato paragenesi tipiche della facies dei « white schists » (fig. 7).

Introduction

Leuchtenbergite-bearing rocks are worthy of special attention both for their very peculiar bulk composition — which suggests special genetic constraints — and for the metamorphic phase equilibria involving this chlorite, which has an unusual chemical composition.

These rocks may be classified into two main groups: leuchtenbergite-bearing quartzites, in which kyanite often occurs, and leuchtenbergite-bearing schists which are called « leucophyllites » in the Eastern Alps

(STARKL, 1883).

The genetic problems of the leuchtenbergite-bearing rocks and their metamorphic mineral compatibilities are discussed in the present paper, on the basis of some leuchtenbergite occurrences which the authors had the occasion to analyse in the Austridic basement of the Eastern Alps (LELKES et al., 1982; SASSI & VISONÀ, 1981).

These occurrences are:

1. «Leucophyllites» and leuchtenbergite-kyanite-bearing quartzites from the Sopron area (W. Hungary): these rocks are associated mainly to acidic gneiss (« Grobgneis ») and micaschists; they belong to the easternmost Austridic basement of the Eastern Alps.

2. «Leucophyllites» from the Fertorakos area (W. Hungary) which are associated with acidic gneisses and amphibolites; they also belong to the Austridic basement of the Eastern Alps.

3. «Leucophyllites and leuchtenbergite-bearing» (kyanite-free) quarzites from the Giovo-Jaufen Valley (Vipiteno-Sterzing area, Italy), which are associated with stratiform acidic gneisses; they belong to the Austridic Merano-Mules basement complex.

The genetic interpretations presented in this paper refer strictly to the leuchtenbergite-bearing rocks taken into consideration, and virtually to other leuchtenbergite occurrences having similar petrographic and geological features. In fact, the possible existence of leuchtenbergite-bearing rocks unrelated to the genetic processes outlined here cannot be excluded.

On the contrary, the basic frame of the metamorphic phase relations given below should be generally valid, being applicable — in principle — to all rocks of whatever origin which do belong to the same chemical system and which underwent the same metamorphic conditions.

Chemical data

Any attempt to investigate the genetic process(es) of these rocks cannot disregard their bulk chemical composition as the fundamental point.

Table 1 shows the chemical content of 28 samples of leuchtenbergite-bearing rocks: 19 of them come from the Sopron-Fertorakos area, 3 from the Giovo-Jaufen Valley, and 6 from scattered localities in the Eastern Alps (Austria).

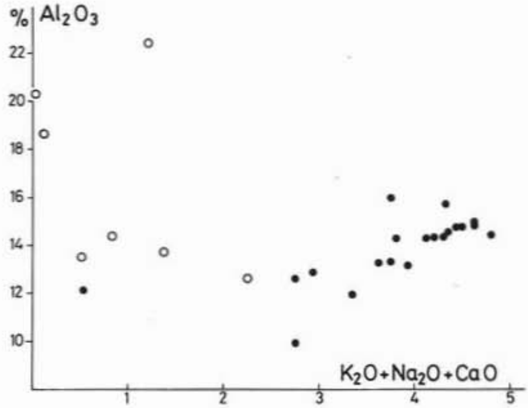

Fig. 1. — Leucophyllites (*dots*) and kyanite-bearing quartzites (*circles*) have significantly different values of the $Al_2O_3/(K_2O + Na_2O + CaO)$ ratio.

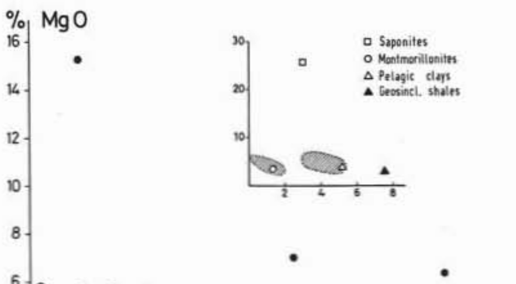

Fig. 2. — High MgO plus $K_2O + Na_2O + CaO$ values are typical of the leucophyllites (*dots*) in comparison with the kyanite-bearing quartzites (*circles*). The inset shows the compositional fields of these two types of rocks and the location of the data points representing some clay materials.

The main compositional feature of these rocks is represented by very low iron and sodium contents accompanied by a high magnesium content. Potassium is also low in the leuchtenbergite-bearing quartzites, while it clusters around 3 % in the so-called « leucophyllites ».

As a result of these compositional constraints, a Mg-rich mineral phase (i.e. leuchtenbergite) appears, and sometimes coexists

TABLE 1

Chemical composition of some leuchtenbergite rocks from the Eastern Alps

	LEUCOPHYLLITES													
	V 3	V 4	V 6	V 14	V 15	W S_2	W S_3	W E_2	K 7	K 8	K 9	K 10	F 5	KO 34
SiO_2	74.09	75.64	73.41	66.86	73.30	74.49	75.17	74.53	74.23	73.15	77.52	78.64	68.50	60.70
TiO_2	0.15	0.15	0.20	0.53	0.25	tr.	tr.	tr.	0.14	0.08	0.25	0.65	0.50	0.05
Al_2O_3	14.46	14.34	14.31	15.75	15.98	14.80	14.29	14.56	14.31	12.63	11.93	9.93	14.90	12.10
Fe_2O_3	0.20	0.62	0.51	1.82	0.09	0.57	0.40	0.31	0.18	0.33	0.30	0.83	1.68	0.77
FeO	0.71	0.17	1.25	0.60	0.69	tr.	tr.	tr.	0.61	0.41	0.03	1.05	1.56	1.00
MnO	0.01	0.01	tr.	0.02	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	0.02	0.25
MgO	3.24	2.67	3.16	6.31	2.97	2.05	3.34	2.44	3.29	6.97	4.29	3.18	3.40	15.30
CaO	0.52	0.48	0.16	0.51	0.29	0.51	0.66	0.26	0.21	0.22	0.32	0.20	0.84	0.01
Na_2O	0.83	0.22	0.52	0.78	0.43	0.13	0.13	0.27	0.55	0.09	0.17	0.25	0.38	0.22
K_2O	3.44	3.50	3.61	3.03	3.04	3.98	3.32	3.84	3.03	2.42	2.86	2.32	3.40	0.30
P_2O_5	0.11	0.14	tr.	0.09	tr.	tr.	tr.	tr.	0.11	0.01	0.08	0.12	0.05	0.05
L.O.I.	2.75	2.46	2.52	3.59	2.57	3.63	2.82	3.46	2.93	3.70	3.12	2.71	2.91	6.97
Tot	100.51	100.40	99.65	99.89	99.61	100.21	99.67	99.67	99.48	100.00	100.87	99.88	98.09	97.66

	LEUCOPHYLLITES						QUARTZITES						
	SR 24	SR 30	SR 86	VD7	VD 8	VD 10	V 8	W S_4	K 5	K 6	F 4	SR 38	SR 39
SiO_2	73.71	75.84	78.28	74.33	73.52	73.86	76.23	74.77	65.47	76.52	75.40	71.50	72.65
TiO_2	0.13	0.12	0.10	0.11	0.88	0.11	0.24	tr.	1.20	0.28	0.45	0.15	0.22
Al_2O_3	14.72	13.20	12.78	13.24	13.33	14.77	14.48	15.60	22.43	13.50	13.70	20.31	18.64
Fe_2O_3	0.85	0.48	0.18	0.41	0.18	0.21	0.38	1.51	0.41	0.23	0.78	0.08	0.04
FeO	0.09	0.13	0.17	0.86	0.95	0.63	0.18	tr.	0.27	0.21	0.82	0.11	0.03
MnO	0.01	0.005	0.005	0.01	0.01	tr.	tr.	tr.	tr.	tr.	tr.	0.001	0.001
MgO	2.63	3.01	3.05	3.85	4.19	2.99	5.58	4.17	5.53	5.60	2.40	5.35	5.86
CaO	0.32	0.37	0.37	0.12	0.30	0.34	0.14	tr.	0.12	0.10	0.39	0.01	0.12
Na_2O	0.15	0.17	0.06	0.23	0.31	0.27	0.53	0.13	0.17	0.35	0.10	tr.	tr.
K_2O	4.01	3.39	2.50	3.27	3.17	3.82	0.18	2.12	0.90	0.08	0.90	0.02	0.05
P_2O_5	0.19	0.15	0.16	0.06	0.16	tr.	tr.	tr.	0.02	0.02	0.05	0.06	0.09
L.O.I.	2.79	2.76	2.73	3.14	3.25	2.91	2.36	2.51	3.83	2.99	2.32	2.37	2.59
Tot.	99.60	99.63	100.38	99.63	100.25	100.18	100.30	100.81	100.33	99.86	97.26	99.96	100.29
Occurrence of Ky			X				X	X	X	X	X	X	X

Source of data: V = VENDEL (1972); W = MODJTAHEDI and WIESENEDER (1974); K = KISHASI (1977); FAZEKAS (1976); KO = KOSA; VD = SASSI and VISONÀ (1981); SR = new data.

with an Al-rich mineral phase (i.e. kyanite).

Figs. 1 and 2 display, better than any further comment, those which seem to be the compositional requisites linked to the appearance of leuchtenbergite.

The genetic problem

Two main approaches are possible when discussing this problem, one based on metasomatic alterations under metamorphic conditions, and the other based on isochemical metamorphism of protoliths of suitable bulk composition.

A) METASOMATIC HYPOTHESES

In the Eastern Alps, the appearance of leuchtenbergite has commonly been related to metasomatic processes. As a consequence, a discussion of the main metasomatic hypotheses is necessary, in order to evaluate the contribution they may give to an understanding to the genetic problem of the leuchtenbergite rocks.

1. *Mg-metasomatism related to shear zones*

VENDEL (1972) and MODJTAHEDI & WIESENEDER (1974) proposed that leuchtenbergite-bearing rocks derive from acidic orthogneisses, due to a supply of Mg^{2+}, Si^{4+}, OH^-, and removal of Na^+, K^+, Fe^{3+}, Ti^{4+} and Ca^{2+}, related to shear zones.

Such a hypothesis can clearly be described by means of mineral equations. However, it meets several difficulties, at least as regards the leuchtenbergite occurrences considered in the present paper. These difficulties include:

— leuchtenbergite-bearing rocks unrelated to deformational processes are more common than post-crystalline deformation and shear zones associated to leuchtenbergite-bearing rocks; furthermore, sheared and strongly deformed orthogneisses not accompanied by the appearance of leuchtenbergite are also common;

— some leuchtenbergite-bearing rocks occur as lens-shaped bodies, a shape which is not appropriate for the shear zones and tectonized belts;

— there is no geological evidence of possible Mg sources; when amphibolites are associated with the leuchtenbergite-bearing rocks (as in the Fertorakos area), they also are Mg-rich and not Mg-depleted;

— some authors propose the chloritization of biotite in the surrounding acidic gneisses and metasediments as a possible source of Mg. Such a hypothesis encounters the difficult fact that, in the rocks mentioned, the Mg contents are commonly lower in the biotites than in the replacing chlorites;

— there is no geological evidence concerning the fate of the chemicals which have presumably been removed;

— there is neither mineralogical nor textural evidence for the intermediate stages which should be expected in the case of metasomatic alterations on the basis of the hypothetized mineral reactions;

— based on Goldschmidt's « mineralogical » phase rule as adjusted for the open systems by KORZHINSKY (1950; see also THOMPSON, 1955), and on the assumption that a large number of elements behaved as mobile components in the rock systems considered, the stable condition should be represented by $p = 1$. This expectation is contradicted by the common occurrence of 2-, 3- and 4-phase stable assemblages in the considered leuchtenbergite-bearing rocks.

As a conclusion, Mg metasomatism related to shear zones can only represent, perhaps, the cause of some local leuchtenbergite occurrences, but cannot explain either most of them or the occurrence specifically dealt with here.

2. *Mg enrichment due to removal of other elements*

Removal of some chemical elements during special events (e.g. hot water circulation in developing shear zones) may produce an indirect drastic increase in the remaining chemical elements. However, such processes imply that the removed elements should be those commonly displaying mobile behaviour, while the relatively immobile elements should be left and enriched.

In the ambit of the assumed hypothesis, Mg should have been enriched in the considered rocks. Consequently, all elements which are more mobile than Mg (Fe, Ca, F, Na, K, etc.) are expected to be drastically depleted, while those which are less mobile than Mg should have been enriched (Ti, Al, P and Si, in order of decreasing mobility, according to Korzhinsky's scale, 1955).

Such expectations are satisfied only partially. For example, Na contents are systematically very low, but K shows consistent behaviour only in a few rocks (quartzites) which are not the richest in leuchtenbergite (i.e. not the assumedly more Mg-enriched). On the other hand, the relatively immobile elements (with respect to Mg) do not display any enrichment: their contents are those which commonly may be found in granitoid rocks or in semipelitic sediments, or closely match them.

In conclusion, such a hypothesis cannot represent a workable guideline for understanding the leuchtenbergite-bearing rocks.

B) Isochemical hypotheses

An alternative line of reasoning may be based on the assumption that the leuchtenbergite-bearing rocks behaved as closed systems during their metamorphism. In such a case, the main problem is the recognition of possible protoliths, the chemical composition of which has original or acquired features identical to those of the leuchtenbergite-bearing rocks.

The very unusual bulk composition of the latter makes the research of possible protoliths rather difficult. However, some plausible hypotheses may be proposed:

1. *Evaporitic mudstones*

Mudstones associated with evaporite deposits have been proposed by SCHREYER (1977; see also KULKE, 1976) for explaining the unusual chemical composition of the so-called white schists, which have a very similar bulk composition to that of the leuchtenbergite-bearing rocks (compare fig. 7 in this paper with fig. 1 in SCHREYER, 1977). Such hypothesis could certainly explain some occurrences of these rocks, but it does not seem suitable for the occurrence considered in this paper. In fact, the general context and rock association in the area taken into consideration are not those which would be expected in an evaporitic paleoenvironment (e.g. RICCI LUCCHI, 1980).

In any case, such a hypothesis does not provide any contribution to the explanation of the leuchtenbergite-bearing quartzites.

2. *Chert-bearing bentonites from basic volcanics*

Hydrothermal activity and weathering can produce saponitic bentonites at the expense of basic pyroclastics and volcanic rocks (MCKIE, 1959). Such bentonites often include cherts.

The basic rocks may indeed represent a potential source for Mg and Al, while hydrothermal activity may account for the depletion of Fe and the enhancement of Mg contents. Montmorillonite and chlorite, with minor saponites and kaolinite, may be assumed as the most significant clay minerals occurring in such clayey mixtures. Finally, deposition of cherts in lacustrine environment (« limnoquartzites ») may be the possible explanation of the stratiform occurrences of leuchtenbergite-bearing quartzites.

The leuchtenbergite-bearing rocks derived from the outlined chert-bearing bentonites are expected to be mostly « leucophyllites » and minor quartzites, which should be associated to basic metavolcanics and « normal » metapelites and metasemipelites. However, the association with metabasic rocks could be considered not a crucial point, seeing that clayey sediments are easily involved in resedimentation processes.

The above-outlined picture seems to fit quite well some of the leuchtenbergite occurrences considered in this paper, specifically that from the Fertorakos area (LELKES et al., 1982). The occurrence there of leuchtenbergite-bearing amphibolites, which could represent only partially altered volcanic rocks, is worthy of emphasis.

3. *Chert-bearing bentonites from acidic volcanics*

Hydrothermal activity and weathering may alter acidic rocks into bentonites and associated kaolins, mainly accompanied by the formation of the so-called « limnoquartzites » (e.g. MARTIN VIVALDI et al., 1969; MATYAS, 1974; KRAUS & ZUBEREC, 1977; GRIM & GÜVEN, 1978). The consequent chemical reworking of the original rocks results in a concentration of Mg and a depletion of alkalis, starting from chemical systems which were Fe-poor originally.

The leuchtenbergite-bearing rocks derived from the above-outlined bentonitic mixture are expected to be « leucophyllites » and quartzites, which should be associated with acidic metavolcanics.

In this case too, however, re-sedimentation processes could easily obliterate the original contiguity with the parent volcanic rocks.

Several leuchtenbergite occurrences dealt with in this paper fit quite well into the above-delineated situation. The frequent association with acidic stratiform gneisses — which could represent volcanogenic rocks — is worthy of mention.

Phase compatibilities in the kyanite zone

The bulk composition of the leuchtenbergite-bearing rocks may be adequately represented by the system SiO_2-Al_2O_3-MgO-Na_2O-H_2O. In fact, Fe is commonly low and enters the lattice of Fe-poor mineral phases, specifically muscovite and leuchtenbergite. The above-quoted chemical system

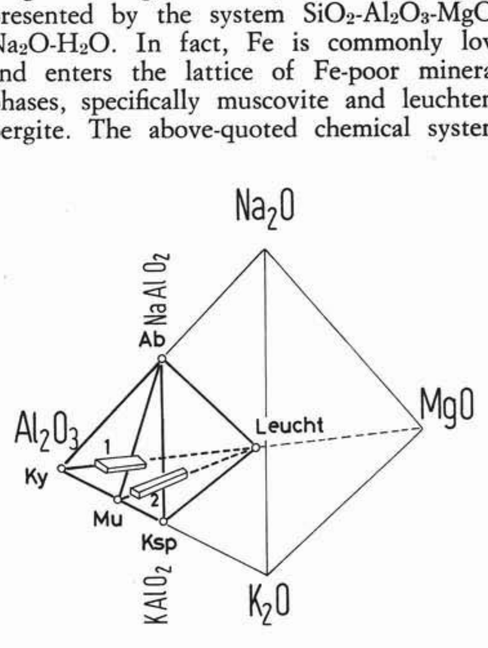

Fig. 3. — Mineral compatibilities and compositional volumes of the quartzites (1) and leucophyllites (2) in the Al_2O_3-Na_2O-K_2O-MgO tetrahedron.

may be represented by the four-component volume Al_2O_3-MgO-K_2O-Na_2O.

At a metamorphic grade higher than that of the upper stability of paragonite + quartz, the mineral compatibilities in this volume are shown in fig. 3. The following stable mineral assemblages involving leuchtenbergite may be deduced:

a) Ky-ab-mu-leucht
b) ab-mu-Ksp-leucht
c) Ky-mu-leucht
d) Ky-mu-leucht
e) ab-mu-leucht
f) mu-Ksp-leucht
g) ab-Ksp-leucht
h) Ky-leucht
i) mu-leucht
l) Ksp-leucht
m) ab-leucht
n) leucht

In order to make the position of the data points more evident, within the above-considered chemical system their location in the Al_2O_3-K_2O-MgO and Al_2O_3-Na_2O-MgO triangles is shown in fig. 4. It follows that the data points are mostly scattered within two very flat volumes lying on the Al_2O_3-K_2O-MgO plane, one being bounded to the Al_2O_3-MgO edge (volume 1 in fig. 3) and the other running along the muscovite-leuchtenbergite tie-line (volume 2 in fig. 3).

This situation is in perfect agreement with the mineral compatibilities shown in fig. 3:

— the data points falling into volume 1 represent kyanite-bearing quartzites having mostly the three-phase mineral assemblage « *d* »;
— those falling into volume 2 represent kyanite-free « leucophyllites » having mostly the two-phase mineral assemblage « *i* ».

Limiting assemblages (i.e. 4-phase assemblages) are not common in the rocks considered. Consequently, the chemical composition of the solid solution phases is expected to be controlled by the rock bulk composition in most of the analysed samples. Such an expectation seems to be satisfied: for example, muscovite composition (as deduced from cell spacing measurements: GUIDOTTI & SASSI, 1976) is very variable, the Na/(Na + K) ratio ranging from 0 to 0.12 (four

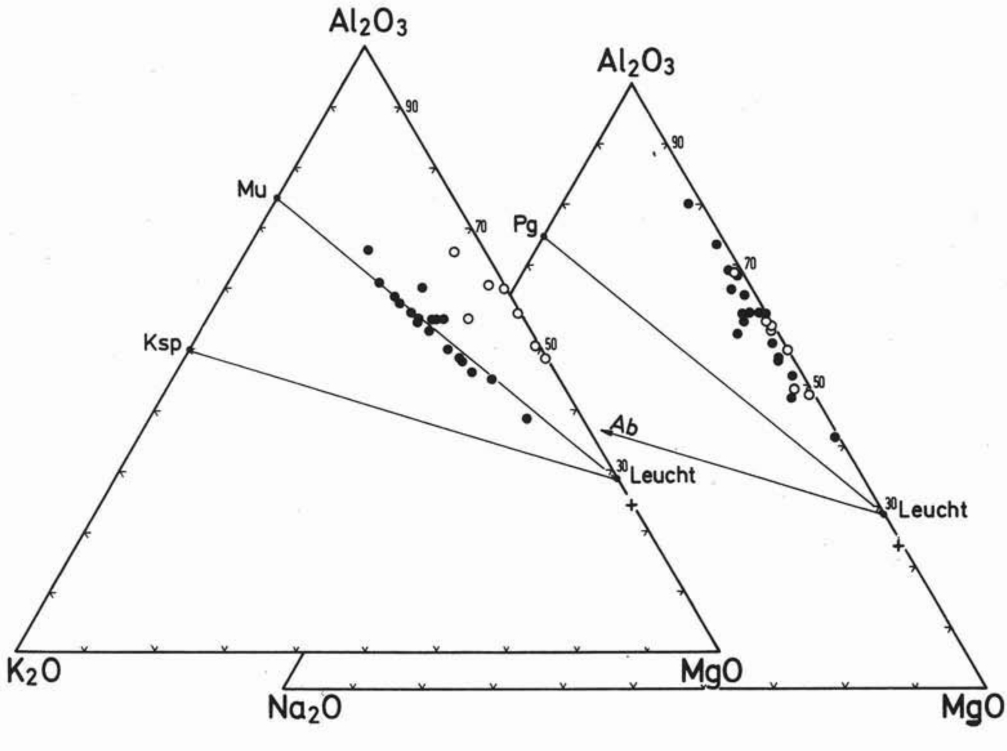

Fig. 4. — Both leucophyllites and quartzites have very low Na_2O contents, lying close to the Al_2O_3-MgO side in the Na_2O-Al_2O_3-MgO triangle. When the K_2O-Al_2O_3-MgO triangle is considered, leucophyllites (*dots*) plot along the muscovite-leuchtenbergite tie-line, while quartzites (*circles*) mostly along the MgO-Al_2O_3 side.

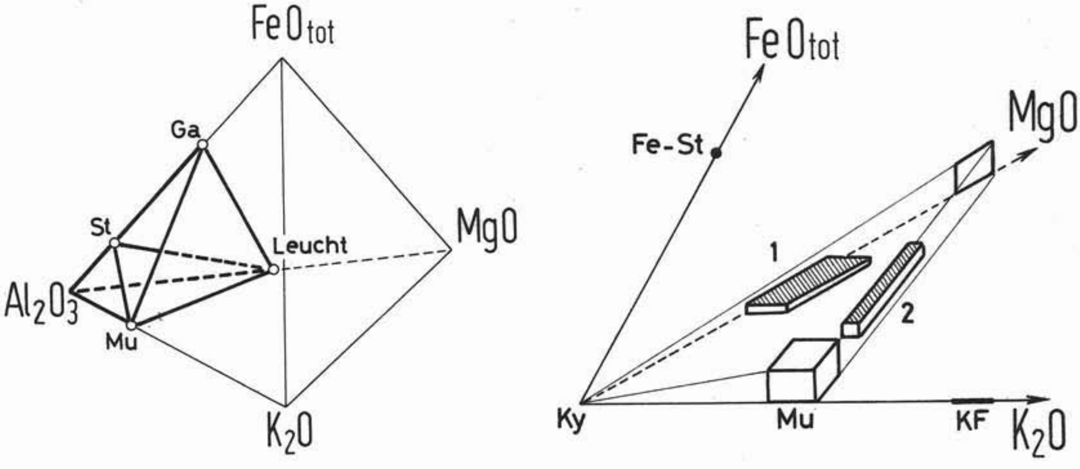

Fig. 5. — Mineral compatibilities involving leuchtenbergite in the Al_2O_3-MgO-FeO-K_2O tetrahedron. The inset shows the compositional volumes of the quartzites (1) and leucophyllites (2): both lie inside the wedge-shaped volume determined by the compositional volume of muscovite and the two-dimensions compositional field of leuchtenbergite.

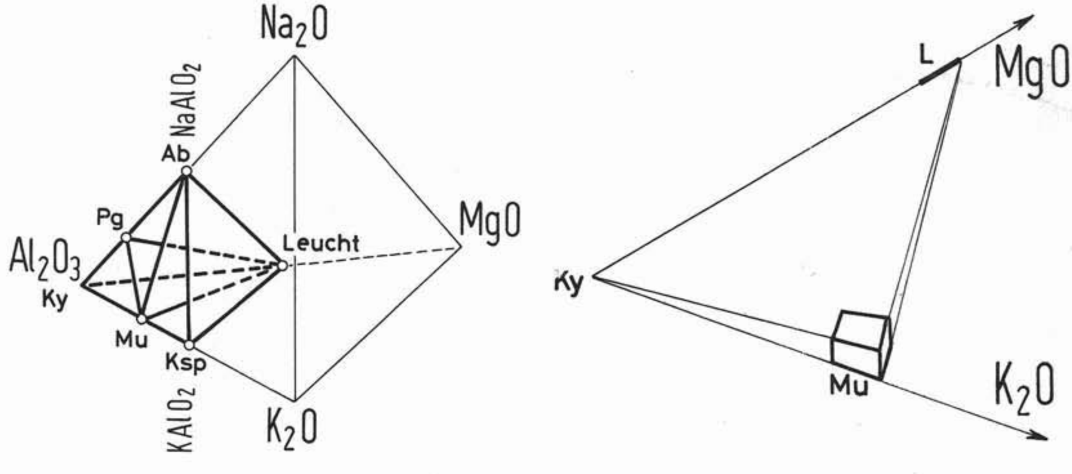

Fig. 6. — Mineral compatibilities involving leuchtenberegite in the Al_2O_3-MgO-Na_2O-K_2O tetrahedron, at temperature of stability of paragonite + quartz. The inset shows the wedge-shaped volume determined by the compositional volume of muscovite.

measurements) and *RM* from 0.02 to 0.08 (seven measurements).

When Fe is taken into consideration as an additional component, the topology in the Al_2O_3-K_2O-MgO-FeO (or Fe_2O_3) tetrahedron should be explored.

1. If a highly oxidized system is asumed, hematite should be considered as the main Fe-bearing phase. Consequently, the appearance of Fe^{2+} mineral phases (e.g. almandine, Fe^{2+}-staurolite) could be inhibited. Therefore, local situation of very high PO_2 could explain the lack of such phases in the rocks considered.

This possibility is partly supported by the common occurrence of magnetite in the rocks considered (e.g. VENDEL, 1972).

2. If normal PO_2 values must be admitted for most of the rocks considered (as seems to be the case), the lack of Fe-rich mineral phases (almandine, biotite, staurolite) should be a combined effect of the very

low Fe-contents in the rocks and the distribution of such low contents among two or three phases: muscovite, chlorite and ores. In other words, the effects of the solid solutions affecting muscovite and leuchtenbergite change the theoretical kyanite-muscovite-leuchtenbergite plane into a very flat, wedge-shaped volume, into which the rock data are scattered. Volumes 1 and 2 of fig. 3 are included within this wedge-shaped kyanite-muscovite-leuchtenbergite field. As a consequence, the stable mineral assemblages in the rocks considered do not include any Fe-rich phase: it is only represented by kyanite-muscovite-leuchtenbergite (volume 1) or muscovite-leuchtenbergite (volume 2), albite being a possible additional phase (fig. 5).

3. When temperature is lower, the topology in the Al_2O_3-MgO-K_2O-Na_2O tetrahedron changes, due to the appearance of paragonite. Therefore, in a thermal range in which paragonite + quartz are stable, the following mineral assemblages involving leuchtenbergite are expected to be stable (fig. 6):

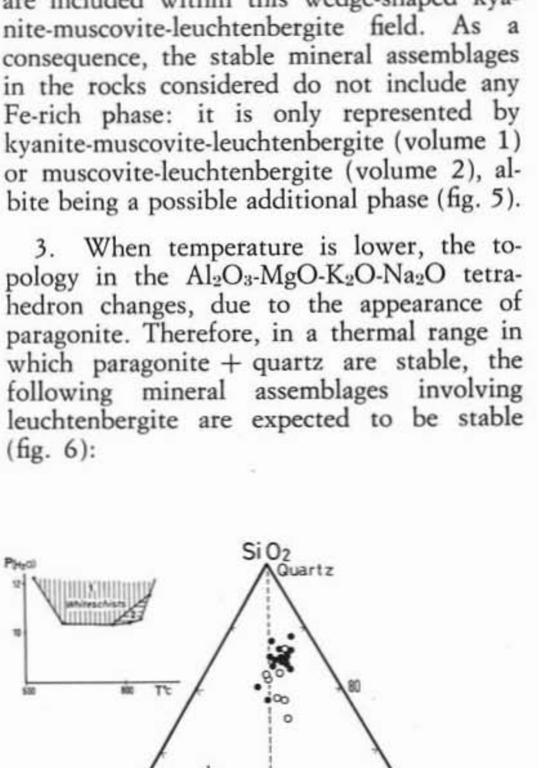

Fig. 7. — The data points of the leucophyllites (*dots*) and kyanite-bearing quartzites (*circles*) are plotted in the MgO-Al_2O_3-SiO_2 (+ H_2O) diagram. The mineral compatibilities of the « white schists » (as defined by SCHREYRER, 1974, 1977) are also shown. The leucophyllites and quartzites taken into consideration have the same bulk composition as the « white schists », but were affected by different metamorphic conditions.

a) Ky-pg-mu-leucht
b) pg-ab-mu-leucht
c) mu-kf-ab-leucht
d) ky-pg-leucht
e) pg-ab-leucht
f) ky-mu-leucht
g) mu-kf-leucht
h) pg-mu-leucht
i) ab-mu-leucht
l) ab-kf-leucht
m) ky-leucht
n) ab-leucht
o) pg-leucht
p) mu-leucht
q) kf-leucht
r) leucht

4. When water pressure is sufficiently high, the rocks considered in this paper should be altered into the so-called « white schists », as defined and further discussed by SCHREYRER (1974, 1977). Fig. 7 shows, in the ambit of the MgO-Al_2O_3-SiO_2-H_2O system, the mineral compatibilities in the white schists and the location of the data points representing the bulk composition of the leuchtenbergite-bearing rocks in Table 1.

Concluding remarks

The leuchtenbergite-bearing rocks deserve more attention than they have been given hitherto, due to their peculiar chemical composition and the common co-existence in them of a Mg-rich phase (leuchtenbergite) and an Al-rich phase (kyanite).

As regards their genesis, the hypotheses based on metasomatism seem incapable of giving significant contributions to the leuchtenbergite occurrences considered here. On the contrary, those based on isochemical metamorphism at the expense of weathered and hydrothermally altered volcanic material seem to represent a feasible tool for the explanation of their main chemical features, notwithstanding the difficulty of clearing up all chemical details related to the formation of suitable clay mixtures.

As regards the metamorphic conditions, the only comment which is worthy of being added concerns the metamorphic grade of the leuchtenbergite-bearing rocks considered in the present paper.

Paragonite has never been detected in them. This fact may be related:

— either to the metamorphic grade: i.e. the temperature was higher than that of the upper stability of paragonite + quartz (situation described in fig. 3);

— or to bulk composition constraints: i.e. the Na contents are too low, and consequently the data points of the rocks

are confined into the wedge-shaped, ky-mu-leucht volume (fig. 6);
— or else to the combined effect of the two above situations.

Great uncertainty therefore exists regarding the metamorphic grade, and data from the surrounding rocks are necessary in order to clear up this important problem.

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