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MAGMATIC GENESIS OF ANDALUSITE IN PERALUMINOUS GRANITES. EXAMPLES FROM EISGARN TYPE GRANITES IN MOLDANUBIKUM

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RIASSUNTO. — In graniti peraluminosi tipo Eisgarn della Moravia l'andalusite è idiomorfa, isolata o a piccoli accumuli e dimostra con estrema evidenza tessiturale la sua crescita da fuso. Questa osservazione si collega ad analoghi casi portoghesi, canadesi e calabresi, dove però l'evidenza tessiturale è meno evidente e frequente.

Nei monzograniti peraluminosi moravi, per lo più leucocratici, con muscovite (1,5-7 %), andalusite (tr. — 2,5 %) e sporadici sillimanite e pseudomorfi da cordierite, la genesi magmatica dell'andalusite trova sostegno, in positivo: 1) nelle tessiture che indicano precocità di cristallizzazione libera del minerale; 2) nella correlazione inversa andalusite/muscovite, che pone in alternativa la cristallizzazione dei due minerali evidentemente in funzione di aH_2O; 3) nella reazione discontinua andalusite → muscovite, probabilmente in rapporto al crescere di aH_2O con la cristallizzazione; 4) nella petrologia teoretica dei sistemi granitoidi peraluminosi che prevedono varie condizioni di cristallizzazione magmatica degli Al-silicati; in negativo: 5) nell'altissima improbabilità tessiturale, giaciturale e petrologica che l'andalusite possa essere considerata una fase relitta di anatessi.

Per considerare l'andalusite come magmatica è costrittivo riferirsi a dati sul sistema Al_2SiO_5 come quelli di RICHARDSON et al. o GREENWOOD, ma non ai dati di HOLDAWAY o ALTHAUS, i quali appaiono incoerenti con la genesi o con una significativa persistenza dell'andalusite in un magma.

ABSTRACT. — In the peraluminous Eisgarn type granites of Moravia the andalusite is idiomorphic, isolated or in small clusters and gives extremely clear textural evidence of its growth from the melt. This observation can find support in the similar cases of Portugal, Canada and Calabria (Southern Italy), where the textural evidence is, however, less clear.

In the Moravian peraluminous monzogranites, mainly leucocratic, with 1.5-7 % muscovite, from traces up to 2.5 % of andalusite and rarer sillimanite and cordierite pseudomorphics, the magmatic genesis of andalusite finds positive support: 1) in the textures which indicate the early crystallization of the mineral; 2) in the inverse andalusite/muscovite correlation, which indicates that the crystallization of the two minerals is alternative as a function of aH_2O; 3) in the discontinuous andalusite → muscovite reaction, obviously in relation to the increase in aH_2O with crystallization; 4) in the theoretical petrology of peraluminous granitoid systems which envisage various magmatic crystallization conditions for the Al-silicates; and negative support in the fact that: 5) it is extremely improbable, on textural and petrological grounds, that andalusite could be an anatexis relic.

In considering the magmatic origin of andalusite, we must refer to the Al_2SiO_5 system of RICHARDSON et al. or GREENWOOD, as a contrast to those of HOLDAWAY or ALTHAUS which are inconsistent with the magmatic genesis or with a significant persistence of andalusite in the magma.

Introduction

Amongst the plutonic rocks of the Moldanubikum Massive in Moravia there is an abundance of two mica granites known as « Eisgarn type ». They frequently contain andalusite and altered cordierite (KOUTEK, 1926; DUDEK et al., 1962; DUDEK, 1964), they are linked to Sn-W mineralization (BERNARD-DUDEK, 1967; SATTRAN-KLOMINSKY, 1970; SATTRAN, 1981) and they have an Hercynian age, 297 MA for biotite (BERNARD-KLOMINSKY, 1975). Similar peraluminous granites, with the same features, are also frequent in the Bohemian Massive (e.g. FIALA, 1964). They are considered to be in epiplutonic position (DUDEK-SUK, 1965; SATTRAN, 1981).

We have not found any special petrological studies on the peraluminous character of these rocks, nor on the genetic problems of the andalusite and muscovite within them. In this paper we want to use some very

TABLE 1
Modal composition of peraluminous granites from Moravia

	Mrákotín			Řásná		Lipnice	Dudek et al. (1962)
	2	3	4	6	7	8	(9 samples)
Qz	27.2	35.5	32.9	34.8	33.7	29.8	29.8 - 36.8
Kf	26.3	31.4	27.7	34.4	33.7	26.3	27.4 - 33.6
$P(An_{20})$	35.6	23.2	29.9	21.3	24.0	29.2	20.5 - 30.8
Bi	3.6	5.0	2.9	5.5	3.7	7.9	2.9 - 6.3
Ms	7.0	2.9	6.3	2.1	1.3	6.3	1.7 - 6.9
And	tr	0.8	0.2	1.0	2.5	-	tr - 1.2
Sill	tr	0.3	-	0.7	0.3	tr	-
Cd	-	0.3	-	0.7	0.3	-	- 0.5
Others	0.3	0.5	0.1	0.1	0.4	0.5	0.1 - 0.7

Cd = pseudomorphics on cordierite; *others* = Apatite, Zircon, Opaques.

significant textures of these Moravian granites to discuss the magmatic genesis of andalusite, already affirmed for texturally less evident cases (DE ALBUQUERQUE, 1971; CLARKE et al., 1976; CRISCI et al., 1979; CLARKE, 1981; D'AMICO et al., 1981; D'AMICO-ROTTURA, 1981), and its relationship with muscovite in peraluminous granites.

Petrographic and geochemical data

The samples were gathered near Telč in the Mrákotín (n. 1-5) and Řásná (n. 6-7) quarries, and near Melechov in the Lipnice quarry (n. 8).

They are medium-fine-grained heterogranular leucocratic monzogranites. Their modal composition and classification are shown in table 1 and in fig. 1.

The texture is subhipidiomorphic: reddish-brown biotite (with apatite and zircon inclusions, the latter surrounded by pleochroic haloes) and plagioclases (about An_{20}, slightly zoned) are for the main part idiomorphic to subidiomorphic; quartz, microclinperthite and muscovite are mainly — but not always — anhedral. The andalusite, rarely zoned with a pink core, is almost always euhedral; the cordierite (pseudomorphics) is both euhedral and anhedral; the sillimanite is in very small fibrolitic clusters or tiny needles included in muscovite and quartz.

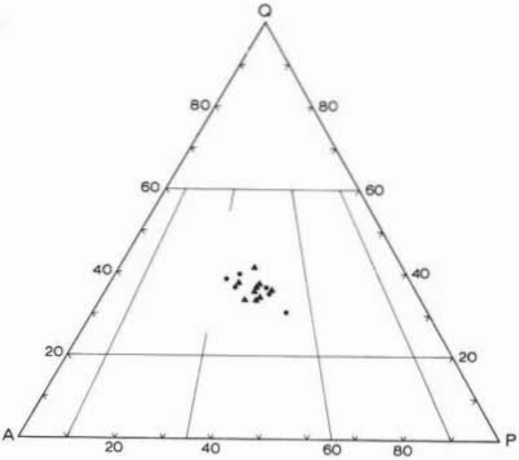

Fig. 1. — *Q-A-P* modal classification of Eisgarn type peraluminous granites. *Dots* = this work; *triangles* = DUDEK et al. (1962).

The geochemical data (1) are shown in

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(1) The whole rock chemical analyses were carried out with X-ray fluorescence, with a control of the standards, except for the following: FeO, determined by titration with $KMnO_4$; Na_2O and K_2O, by flame spectrophotometry; MgO by means of AA. and H_2O by calcination. The mineral analyses were carried out using the electron microprobe at the Istituto di Mineralogia e Petrologia of Modena University.

TABLE 2

Chemical analyses of peraluminous granites from Moravia

	Mrákotín			Řásná		Lipnice	Dudek et al. (1962)	
Sample	2	3	4	6	7	8	$\bar{X}$ (9 samples)	SD
Wt %								
SiO_2	72.66	72.84	72.48	72.96	72.14	69.36	72.69	0.68
TiO_2	0.21	0.21	0.21	0.20	0.22	0.51	0.16	0.06
Al_2O_3	14.58	14.78	14.36	14.26	14.43	14.96	14.24	0.23
Fe_2O_3	0.46	0.58	0.44	0.42	0.52	0.88	0.83	0.34
FeO	0.84	0.74	0.85	0.80	0.90	1.86	1.02	0.25
MnO	0.02	0.02	0.02	0.02	0.02	0.03	0.01	0.005
MgO	0.34	0.34	0.34	0.29	0.35	0.78	0.38	0.09
CaO	0.78	0.84	0.77	0.77	0.80	2.01	1.19	0.15
Na_2O	3.33	3.28	3.39	2.77	3.39	2.75	2.94	0.16
K_2O	5.33	5.21	5.23	5.75	5.32	5.39	5.30	0.32
P_2O_5	0.25	0.25	0.24	0.23	0.27	0.31	0.19	0.01
L.O.I	1.20	0.91	1.68	1.53	1.65	1.16	-	-
Na_2O/K_2O	0.62	0.63	0.65	0.48	0.64	0.51	0.55	
C	2.51	2.82	2.30	2.63	2.29	1.69	1.95	
ppm								
Ce	36	37	32	21	39	83		
La	20	11	12	10	13	41		
Ba	335	346	333	295	342	703		
Sr	91	92	89	92	83	131		
Rb	305	325	308	315	311	321		
Li	88	88	78	77	85	77		
Y	18	15	15	16	18	21		
Nb	16	15	11	13	13	13		
Zr	99	100	92	92	100	215		

$\bar{x}$ = average; *SD* = standard deviation; *C* = CIPW normative corundum.

table 2. The peraluminous, leucogranitic typology is evident and the population is very homogeneous, except for sample 8 which is less leucocratic. C.I.P.W. normative corundum between 1.6 and 2.6, K > Na (*k* of NIGGLI between 0.51 and 0.57) and high P_2O_5 are characteristic of these rocks.

The trace elements are all within the common values for these types of granites (ref. HINE et al., 1978; MUECKE-CLARKE, 1981; STRONG-HAMMER, 1981; D'AMICO et al., 1981); there is, however, a wide dispersion range in the data found in literature which has not yet critically analysed in its complexity.

TABLE 3

Mean chemical analyses of biotites

Sample	CS 3	CS 6	CS 7
n.grains	6	1	1
n.analyses	21	4	4
SiO_2	35.08	34.67	34.87
TiO_2	2.74	2.32	2.91
Al_2O_3	19.12	19.59	19.42
FeO tot	21.02	21.27	20.87
MnO	0.18	0.22	0.17
MgO	6.00	6.12	5.66
CaO	0.01	-	-
Na_2O	0.14	0.16	0.22
K_2O	9.54	9.36	9.26
Cr_2O_3	0.02	-	0.06
NiO	-	-	0.02
Anhydrous total	93.85	93.71	93.46
Number of ions on the basis of 22(O)			
Si	5.473	5.423	5.453
Al^{IV}	2.527	2.577	2.547
Σ	8.00	8.00	8.00
Al^{VI}	0.989	1.034	1.032
Ti	0.322	0.273	0.342
Mg	1.396	1.427	1.319
◉Fe^{2+}	2.743	2.782	2.729
Mn	0.024	0.029	0.023
Cr	0.003	-	0.007
Ni	-	-	0.003
Σ	5.477	5.545	5.455
Ca	0.002	-	-
Na	0.042	0.049	0.067
K	1.899	1.867	1.847
Σ	1.943	1.916	1.914

◉ Total iron calculated as Fe^{2+}.

Peraluminous minerals

Biotite

Some of the biotites were analyzed by the electron microprobe (table 3). They showed the normal characteristics of peraluminous granites. The biotites were intermediate members, with a limited siderophyllitic tendency, and lie on the border of the biotite field coexisting with peraluminous silicates (figs. 2, 3), according to the data gathered by CLARKE (1981) and DE ALBUQUERQUE (1973).

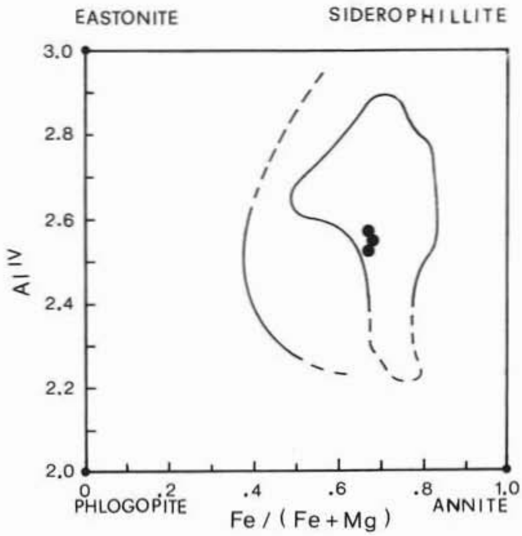

Fig. 2. — Biotite compositions of peraluminous granites from Moravia. The analyzed samples plotted in the biotite field (contoured) coexisting with peraluminous silicates. External limit of the biotite field in absence of Al-silicates (after CLARKE, 1981, fig. 2, modified).

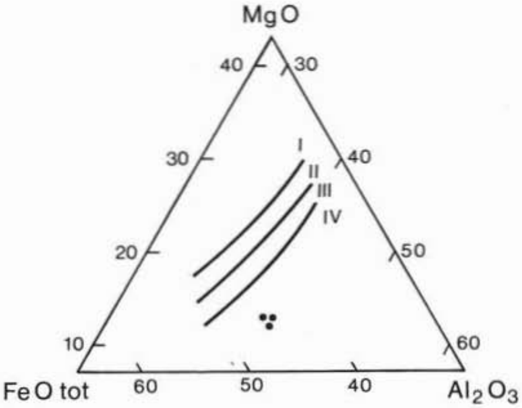

Fig. 3. — Diagram Al_2O_3-FeOtot-MgO of the biotites of the peraluminous granites from Moravia. I - Field of biotites coexisting with amphibole. II - Field of biotites unaccompanied by other ferromagnesian minerals. III - Field of biotites coexisting with muscovite. IV - Field of biotites coexisting which aluminosilicates (after de ALBUQUERQUE, 1973, fig. 3).

Andalusite

Andalusite is present in small quantities, up to 2.5 % (table 1). It is distributed homogeneously in the texture, as isolated euhedral grains, or gathered in small cumulates.

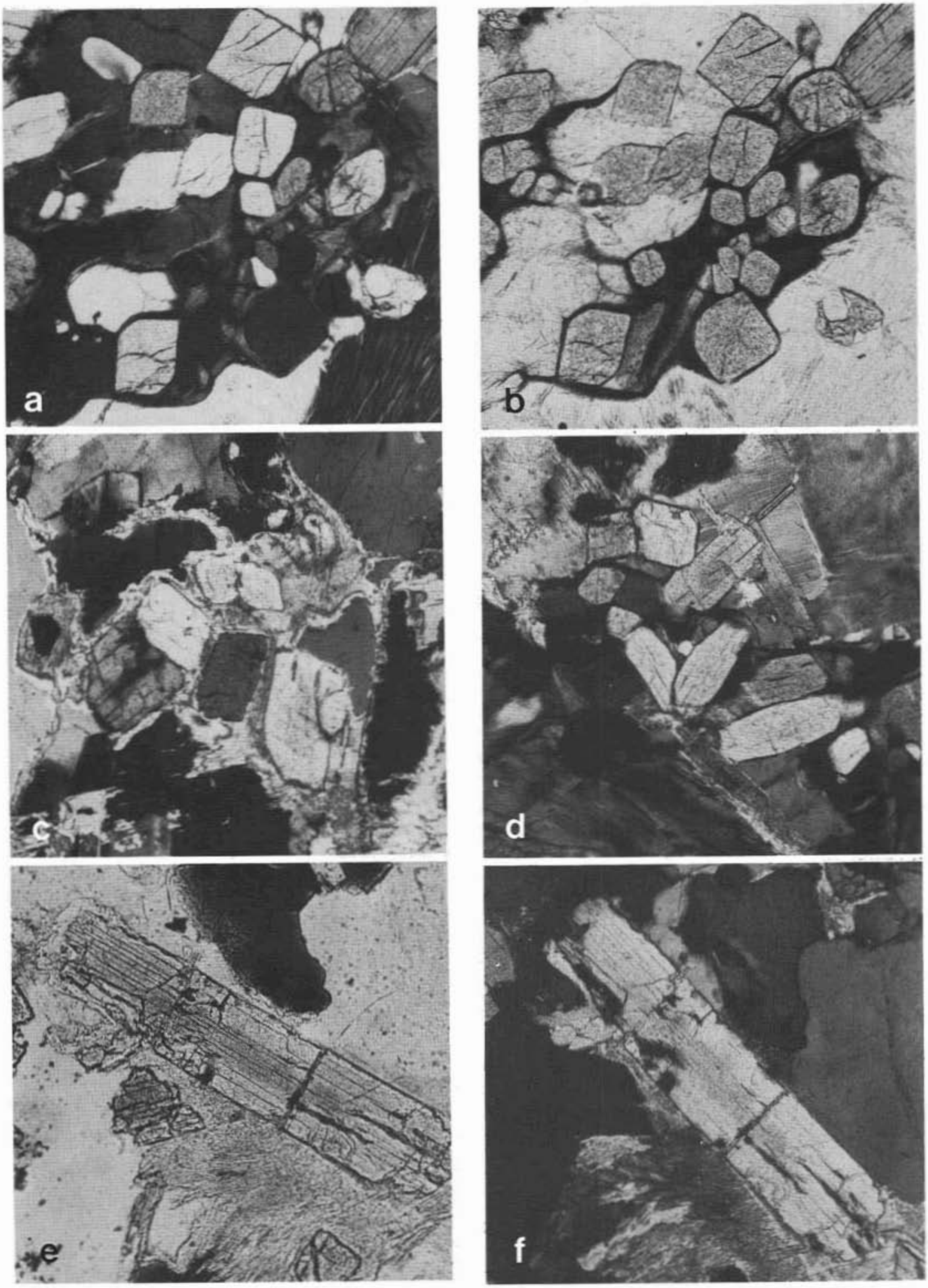

Fig. 4. — (*a, b, c, d*) Clusters of andalusite near quartz-fibrolitic relics (*a, b*) and rimmed by muscovite (*c, d*); (*a, d*) crossed polars, 48 x; (*b*) one polar, 42 x; (*c*) crossed polars, 63 x; (*e, f*) idiomorphic andalusite, with a pinkish core, enveloped by muscovite; one polar and crossed polars respectively, 15 x.

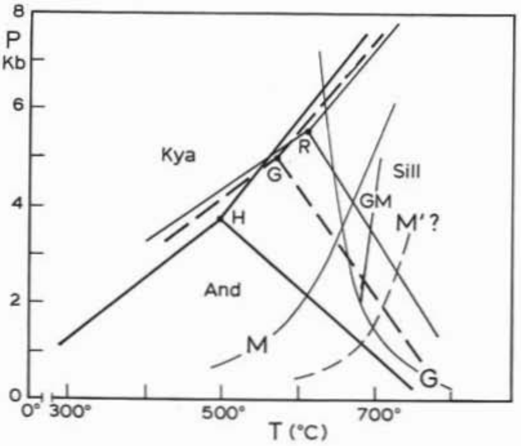

Fig. 5. — Al_2SiO_5 phase relations according to HOLDAWAY (1971, *H*), GREENWOOD (1976, *G*) and RICHARDSON et al. (1969 *R*). *G* = wet granite solidus; *GM* = example of H_2O-undersaturated granite solidus; *M* = muscovite + quartz experimental reaction curve (EVANS, 1965); *M'* = empirical curve of muscovite + quartz stability in H_2O undersaturated conditions, according to petrographic and geologic data (see text).

TABLE 4
Mean chemical analyses of andalusites

Sample	CS 3	CS 6	CS 7
n.grains	2	2	2
n.analyses	6	5	6
SiO_2	37.00	37.08	37.24
Al_2O_3	61.93	61.92	61.44
FeO tot	0.24	0.46	0.50
MgO	0.01	0.02	0.04
CaO	tr	tr	-
Na_2O	0.02	-	-
SrO	-	0.02	0.03
BaO	0.13	0.36	0.38
Total	99.33	99.86	99.63
Number of ions on the basis of 20(O)			
Si	4.027	4.026	4.053
Al	7.944	7.924	7.882
Fe^{2+}	0.022	0.042	0.045
Mg	0.002	0.003	0.006
Na	0.004	-	-
Sr	-	0.001	0.002
Ba	0.005	0.015	0.010

Frequently the andalusite has a thin rim of muscovite, but it always clearly maintains its original form. It is never reduced to a few relics within the muscovite as in most of the other cases described (DE ALBUQUERQUE, 1971; CLARKE et al., 1976; LORENZONI et al., 1978; CRISCI et al., 1979; D'AMICO et al., 1981; D'AMICO-ROTTURA, 1981).

This state of the andalusite makes the S-granites of Mrákotín and Řásná exceptional for the clarity of the textural relations (fig. 4). The euhedrality, the homogeneous distribution in the texture, the independence of the small internal metamorphic relics, as well as of the country metamorphic rocks, are all decisive petrographic constraints for the interpretation of andalusite as of magmatic genesis. These same textures exclude, of themselves, a metamorphic nature, relic or xenolithic, of the andalusite.

The andalusite has a very pure composition (table 4). It crystallized early from the granitic magma, as is demonstrated by the textural relationships (fig. 4). The small and rare cumulates usually occur near, or within, small quartz-fibrolite relics (fig. 4 *a*-4 *d*); the latter probably produced a hyperaluminous micro-environment, which favoured a locally rich nucleation of andalusite from the magma.

The textural evidence strongly confirms the interpretation of a magmatic genesis of the andalusite given by same previous authors (op. cit. above).

On other hand, the theoretical possibility of the crystallization of the aluminum silicates from a peraluminous melt is demonstrated by the analysis of the pelitic model-systems of THOMPSON-ALGOR (1977) and THOMPSON-TRACY (1979); the latter expressely mention the possibility of magmatic andalusite (pag. 433). A magmatic crystallization of the aluminum silicates is also easily deduced from the simple system SiO_2-K_2O-Al_2O_3 (LAMBERT et al., 1969). So, the nucleation and growth of andalusite in peraluminous granitic melt under $P/T/aH_2O$ conditions, which are compatible with the stability of this mineral, would present no theoretical difficulties.

If the andalusite contained in peralumi-

TABLE 5
Mean chemical analyses of muscovites

Sample	CS 3	CS 6	CS 7
n.grains	3	1	1
n.analyses	10	3	2
SiO_2	45.82	46.09	45.22
TiO_2	0.66	0.01	0.02
Al_2O_3	34.08	33.84	35.32
FeO tot	1.26	1.58	0.87
MnO	-	-	0.07
MgO	0.70	0.90	0.26
Na_2O	0.65	0.65	0.63
K_2O	10.58	10.58	10.05
BaO	0.11	-	-
Anhydrous total	93.86	93.75	92.44
Number of ions on the basis of 22(O)			
Si	6.207	6.257	6.175
Al^{IV}	1.793	1.743	1.825
Σ	8.00	8.00	8.00
Al^{VI}	3.648	3.671	3.860
Ti	0.067	0.001	0.002
Mg	0.141	0.182	0.053
Fe^{2+}	0.143	0.179	0.099
Mn	-	-	0.008
Σ	3.999	4.033	4.022
Na	0.171	0.171	0.167
K	1.828	1.832	1.751
Ba	0.006	-	-
Σ	2.005	2.003	1.918

nous granites is magmatic, as we have shown, then some experimental results of the Al_2SiO_5 polymorphic system must be re-examined. In fact, as shown in fig. 5, the curves on the polymorphic system Al_2SiO_5, according to ALTHAUS (1967, 1969) and HOLDAWAY (1971), are incompatible with the coexistence of andalusite and granitic melt. The reaction curves proposed by RICHARDSON et al. (1969) are, on the contrary, compatible with this coexistence. Similar considerations may be found in CURRIE-PAJARI (1981).

GREENWOOD (1976), in considering the thermodynamic and kinetic difficulties of the Al-silicates polymorphic system — although from a metamorphic point of view — found himself obliged to propose, on a petrographic basis, an empirical system as a compromise between the HOLDAWAY curves and those of RICHARDSON et al.. Fig. 5 shows that the Greenwood compromise allows space for a magmatic genesis of andalusite. However, in the case of water undersaturation, which is a constraint for a melt rising in the crust, curves similar to that of RICHARDSON et al. would appear to be more favourable to an early crystallization of andalusite.

Muscovite

Muscovite is found on the rim of the andalusite; but it is mainly found as flakes: distributed in the fabric, within some euhedral plagioclases, intergrown with biotite and in irregular fractures within feldspars.

It is not always easy to texturally distinguish the magmatic from the subsolidus muscovite (see also CLARKE, 1981). The isolated anhedral flakes and those associated with biotite are all homogeneously distributed in the texture and are better interpreted as magmatic; the more irregular muscovite in veins within the feldspars are to be interpreted as subsolidus; that surrounding the andalusite may be either subsolidus — muscovite with a « uralitic » aspects — or magmatic — complete flakes of muscovite — (see D'AMICO-ROTTURA, 1981 for the discussion).

The crystallization of muscovite from a granitic melt is commonly accepted (e.g. LUTH, 1976; THOMPSON-ALGOR, 1977; WYLLIE, 1977; THOMPSON-TRACY, 1979; MILLER et al., 1981 etc.) and it is clearly demonstrated by the textures of the granites under examination, as in most of the S-granites.

The generally accepted intersection of the granite solidus curve with the experimental curves for the reaction Ms + Qtz ⇆ Kf + As (EVANS, 1965; ALTHAUS et al., 1970; HUANG-WYLLIE, 1974) would suggest a depth of crystallization of at least 13-15 km (3.5-4 kb). A similar interpretation is also given by some other authorities (e.g. LUTH, 1976; BURNHAM, 1979 etc.).

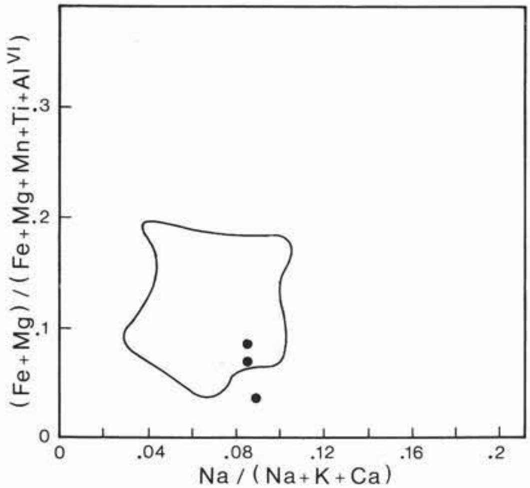

Fig. 6. — Peraluminous granite muscovite composition from Moravia. The contoured field is that of muscovite composition from peraluminous granitoids (after CLARKE, 1981, fig. 3, modified).

However, the use of the above experimental data, in order to deduce the crystallization depth of the granitic magmas, is in strong contradiction with many geological data. SYLVESTER et al. (1978), SWANSON (1978), MILLER et al. (1981), ANDERSON-ROWLEY (1981), D'AMICO-ROTTURA (1981), not to mention others, have described granitoids bearing magmatic muscovite, whose petrographic and geological characteristics give strong evidence of crystallization at depths much less than 13-15 km. The data of D'AMICO-ROTTURA (1981) are particularly strong evidences with regards to this.

The Eisgarn type Moldanubikum granites, discussed here, are also considered, on a geological basis, to be high-level intrusions (about 1 km, according to DUDEK-SUK, 1965).

It is ironic that the natural, petrographic and geological data find a better compatibility with the Ms + Qtz stability fields given by YODER and EUGSTER (1955), SEGNIT and KENNEDY (1961), SHARIKOV et al. (1969) — as reported by ALTHAUS et al. (1970) — considered of small validity by most authors.

We feel that the *natural applicability* of the Ms-out reaction in presence of silica excess must be reexamined, and that the muscovite field ought to be extended towards lower pressures and higher temperatures.

A tentative interpretation was proposed by MILLER et al. (1981) and ANDERSON-ROWLEY (1981), who suggested that the discrepancy between the experimental data and the natural observations may be caused by the deviation of the muscovite from the ideal formula: the complexity of the isomorphic solution would enlarge the muscovite stability field towards higher *T* and lower *P*, up to possible values of 2 kb. The data are still scarse and relatively unhomogeneous, so that a clear synthesis of this aspect of the problem is still not possible; also the theoretical base of this interpretation is still rather feeble.

Some chemical analyses by the electron microprobe (table 5, figs. 6, 7) show that our muscovite crystals display a small deviation from the ideal formula: the celadonite component is very low, TiO_2 is low and variable and Na is relatively high. It is not yet possible to give a significance to the compositional heterogeneity of muscovite within a pluton or between different plutons (figs. 6, 7). This field of research is still open.

A second interpretation can be found in WYLLIE'S (1977) experimental and theoretical data for the sistem K_2O-Al_2O_3-SiO_2-H_2O. Vapour absent or water undersatured

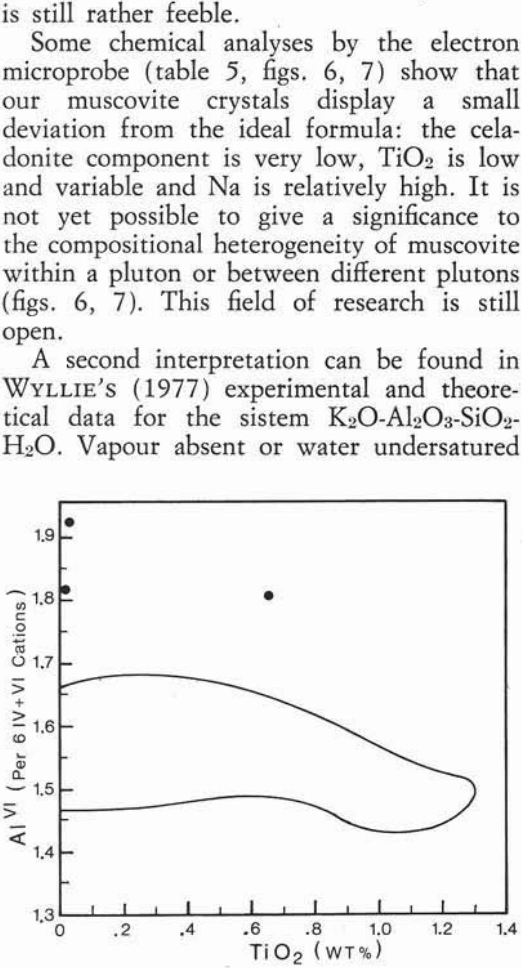

Fig. 7. — Peraluminous granite muscovite composition from Moravia in terms of octahedral Al and wt. % TiO_2. The contoured field is that of muscovite compositions from Whipple Mountain (California) peraluminous granitoids (after ANDERSON-ROWLEY, 1981, fig. 4, modified).

conditions seem to favour the muscovite stability at higher temperatures than those inferred from the water saturated systems. So the same requirement for the rising of the magma into the crust, that is the water undersaturation, appears to be able to extend, towards higher temperatures, the muscovite stability in the melt (provided there is enough water to construct muscovite).

In the fig. 9 *a*, by WYLLIE (1977), the muscovite-out curve is interrupted at 3 kb; but it seems implicit in the discussion that its continuation can be predicted up to pressure between 1 and 1.5 kb.

Tentatively we would like to propose, on the basis of the arguments above, an *empirical* extension of the muscovite stability field in water undersaturated peraluminous granitic melts up to the *M′* curve in fig. 5. This curve is very closed to the curves of YODER-EUGSTER, SEGNIT-KENNEDY and SHARIKOV et al. up to 2 kb and to the WYLLIE curve (1977, fig. 9 *a*) above 3 kb. The *M′* curve seems to be compatible with the natural situations described.

Andalusite-muscovite relationships

Fig. 8 show evidence of an inverse correlation between andalusite and muscovite, demonstrating that these two minerals are alternatives in the crystallization. The dominant factor is clearly the water activity. It can be deduced, for example, from the cases examined here (table 1) that the crystallization in the granites of Rásná had a low $a\mathrm{H_2O}$, those of Mrákotín a major one and those of Lipnice an even higher $a\mathrm{H_2O}$.

In andalusite-muscovite relationships there is a constant temporal succession: early andalusite and later muscovite. It is probably due to the diminishing temperature during the solidification, but, also much more likely, to an increase in $a\mathrm{H_2O}$ in the melt as crystallization proceeds. The reciprocal quantity of andalusite and muscovite depends on the $a\mathrm{H_2O}$ at the start and on the rhythm of its increase in the melt during crystallization. When the conditions for the muscovite stability have achieved, the discontinuous reaction develops:

$$\mathrm{And} + \mathrm{Kf}_{[l]} + \mathrm{H_2O} \rightarrow \mathrm{Ms} + \mathrm{Qtz}_{[l,s]} .$$

A similar sequence was also theoretically predicted by THOMPSON-ALGOR (1977, p. 263) for $\mathrm{H_2O}$ saturation conditions.

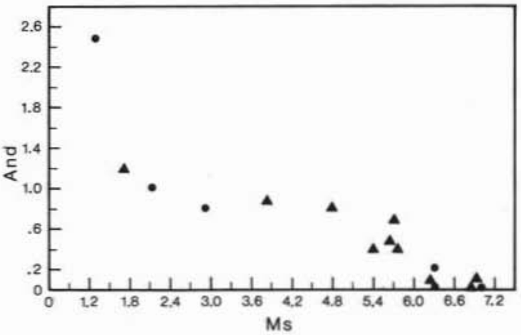

Fig. 8. — Muscovite/andalusite correlation. *Dots* = this work; *triangles* = DUDEK et al. (1962).

Obviously, the possibility remains of having a subsolidus muscovitization, rare in the granites examined here, but abundant in other case (e.g. D'AMICO-ROTTURA, 1981).

Some muscovite lamellae, which seem to be primary, are sometimes enclosed within subhedral, magmatic plagioclases. This problem was more widely discussed by D'AMICO et al. (1981). With regard to this problem, in the case under examination, similar muscovite flakes occurred only in granites lacking andalusite (e.g. n. 8 of table 1). This seems to suggest that muscovite may crystallize early in the peraluminous magma instead of andalusite, probably in relation to a higher $a\mathrm{H_2O}$.

Conclusions

The Eisgarn type S-granites give important indications for the general petrology of peraluminous granites, discussed above, on the following points:

1) The texture (fig. 4) gives clear indications of a magmatic nucleation and growth of andalusite, at an early stage of the crystallization of the magma. This places a limit to the applicability of the different experimental results of the $\mathrm{Al_2SiO_5}$ system. The applicability of the HOLDAWAY and ALTHAUS curves to the natural petrological systems should be excluded while the curves of RICHARDSON et al. and GREENWOOD appear to be more realistic.

2) The magmatic crystallization of muscovite is partly alternative to that of andalusite. This fact is interpreted as due

to the influence of variable aH_2O conditions during the solidification in different masses or different positions of the same mass. In any case, as solidification proceeds, aH_2O obviously increases in the melt, until it provokes a discontinuous reaction between andalusite and muscovite.

3) Muscovite is the only peraluminous mineral which nucleates and grows in the main and in the final stages of crystallization, following the early crystallization of the andalusite.

If aH_2O is sufficiently high from the beginning, then muscovite can crystallize early, instead of andalusite.

4) Muscovite crystallizes under geological conditions which are not consistent with the 3.5-4 kb inferred by the more usual (e.g. Evans, 1965; Althaus et al., 1970) experimental systems. This ascertainment throws doubts upon the quantitative applicability of the experimental curves of the simple $Ms + Qtz \leftrightarrows Kf + AS$ system to the complex natural systems, where there is also a variable aH_2O in play. The moderate deviation of the muscovite from the ideal formula, and, still more, the crystallization under aH_2O conditions lower than 1 (sufficient, however, for the hydration of the muscovite), appear to be the main causes of the enlargement of the muscovite stability field towards higher T and lower P.

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