*Jacek PUZIEWICZ**

ANDALUSITE—TOURMALINE APLITE FROM LISIEC HILL NEAR STRZEGOM

Abstract. A dyke of peraluminous granitic aplite (quartz, feldspars, accessory tourmaline, biotite, garnet and andalusite, mole ratio $Al_2O_3(Na_2O + K_2O + CaO = 1.4)$, in which the sequence of crystallization of minerals had been established, served as a basis for the study of crystallization processes in a peraluminous granitic magma. Low water pressure ($PH_2O < Ptot.$) and the great excess of alumina over alkalies determined the mechanism of water solubility in the magma, made possible the coexistence of biotite and garnet, and favoured the crystallization of andalusite. The presence of boron promoted the decomposition of earlier formed biotite and the crystallization of tourmaline.

INTRODUCTION

Peraluminous aplite dykes occur among the amphibolites belonging to the south-western cover of the Strzegom — Sobótka granitic massif (Majerowicz 1972), on the Lisiec hill situated 2 km south of Strzegom. They have been mentioned (Teisseyre *et al.* 1957) but never described in detail in the recent geological literature. The geologic situation indicates that they lie at a short distance, presumably not more than some hundred metres, from the roof of granite. The contacts of dykes with the enclosing amphibolites are sharp, showing no evidence of the chemical interaction between the two rocks.

One of these dykes, 1.5 m thick, served as a basis for the study of some phenomena occurring during the crystallization of a peraluminous granitic magma. The dyke contains a characteristic assemblage of accesory minerals, consisting of biotite, almandine-spessartine garnet, tourmaline and andalusite. Worth noting is the presence of andalusite which crystallized from a magma. The occurrences of andalusite or sillimanite in igneous rocks have been reported from many localities (Hills 1938), but they are very uncommon in the Sudetes. The only known occurrences of this mineral in this area are granites with andalusite in the Strzelin granitic massif (Bereś 1961) and pegmatites with andalusite in the cover of the Karkonosze granitic massif (Żaba 1979).

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PETROGRAPHY

The amphibolite enclosing the aplite dyke in question is made up of quartz, plagioclase (An₄₃), actinolitic hornblende and subordinate sphene. Within a short distance (3 – 5 m) from the dyke there appear varicoloured quartz-clay lenses (quartz + kaolinite, montmorillonite, sometimes hydromicas), varying from a few to a dozen or so cm in size. The contact of aplite with amphibolite is sharp and runs along large, flat surfaces. The changes observed in the amphibolite have been presumably induced by the thermal action of the aplite dyke. On the other hand, there is no evidence of the chemical interaction between the two rocks (Table 1).

The aplite dyke is made up of aplites of two generations and subordinate coarse-grained pegmatite intercalations. The bulk of the dyke is made up of older aplite (on the average 37 Qz, 12 Pl An₇₋₁₀, 48 Alk Fsp, 2.5 Tourm., 0.5 Bi + Ga + + And) which is intruded by veins of younger aplite (on the average 31 Qz, 14 Pl An₇₋₁₀, 54 Alk Fsp, 1 Ga + And), 3 – 20 cm in thickness. The two rocks differ

essentially neither in mineralogical nor chemical composition (Table 1). Younger aplite is almost completely free from tourmaline, which is present in older aplite, but contains nests of subhedral andalusite crystals. These crystals attain a length of 2 mm and are settled in the quartz-feldspar matrix.

A feature characteristic of the younger aplite is the presence of garnet-tourmaline schlieren of a thickness of 2 – 3 mm, extending within the range of 1 m. The directional orientation of tourmaline poles in the schlieren suggests the fluidal movement of the magma.

Both rocks have the same porphyritic texture: large anhedral crystals of alkali feldspar up to 4 – 5 mm in diameter and smaller subhedral plagioclase crystals are settled in the fine-grained quartz-feldspar matrix of an average grain-size less than 0.5 – 0.1 mm. The size of tourmaline poles varies from very small to large, 3 mm in length.

Alkali feldspar present in the rock is intensely corrodive to the crystals of plagioclase and, in a less degree, of quartz, causing the rounding of the latter. Alkali feldspar grains contain commonly relics of plagioclase and quartz. The shape and size of albite intergrowths are diversified (perthites of the flame, flake and sometimes patchy type are present), their size being generally small. Triclinicity of potassium phase is 0.50, and the poor separation of X-ray reflections from the 060 planes of potassium and sodium phases suggests that significant amounts of albite are present in alkali feldspar as cryptoperthitic intergrowths (Parsons 1978).

As appears from optical feature and unit cell parameters, tourmaline is a schorl with a small admixture of dravite (a = 16.00 Å, c = 7.18 Å, which corresponds to a 75% content of shorl and 25% of dravite). It shows pleochroism varying from pale yellow for ε to olive-brown for ω. Its prismatic crystals are anhedral on the contact with quartz grains. Quartz also appears in the form of poikilitic inclusions that sometimes attain a substantial volume relative to that of the host tourmaline. A part of larger tourmaline crystals exhibits zonal structure in sections normal to the Z-axis. No direct contact of tourmaline with biotite has been noted. The morphology of tourmaline crystals corresponds to that described by Němec (1978) in aplite from the Říčany massif in Bohemia.

Biotite is rare in the rock, sometimes being absent altogether. It appears in the form of shreds and flakes ranging from 0.01 to 0.7 mm in size. Its pleochroism varies from pale yellow for α to cinnamon for γ. It is, as a rule, intensely corroded by alkali feldspar.

Euhedral garnet (50% almandine + 50% spessartine) shows no evidence of decomposition; only in garnet-tourmaline schlieren in younger aplite it is partly replaced by biotite which is presumably the product of post-magmatic alteration. Garnet grains are not more than 0.5 mm in diameter.

Andalusite with barely discernible pleochroism of the colours varying from whitish to pale pink forms crystals from 0.2 to 2 mm in size. Its grains are, as a rule, coated with a narrow rim of fine-flake muscovite which presumably owes its origin to the action of post-magmatic solutions on andalusite grains.

As appears from the petrographic studies, the sequence of crystallization of minerals, identical in the two varieties of aplite, seems to be as follow:
1. Garnet, biotite and phenocrysts of acid plagioclase.
2. Fine-grained quartz-feldspar mush that presumably formed after the intrusion of the magma to its present position, which expedited the crystallization rate.
3. Alkali feldspar, tourmaline and quartz of the younger generation.
4. Andalusite.

Table 1

Bulk rock analysis (in weight %)

Component	1	2	3	4	5	6
SiO₂	74.65	72.70	73.53	72.07	74.61	47.97
Al₂O₃	14.76	16.18	15.10	14.95	14.39	13.48
TiO₂	0.16	0.15	0.14	0.18	0.17	3.68
FeO	0.79	0.66	1.36	1.10	1.14	8.32
Fe₂O₃	0.57	1.09	0.55	1.95	0.67	5.57
MnO	0.05	0.07	0.16	0.06	0.19	0.12
CaO	0.67	0.81	0.65	0.79	0.68	12.54
MgO	0.44	0.65	0.49	0.71	0.99	4.92
Na₂O	3.29	3.37	3.49	2.90	3.54	1.74
K₂O	3.76	4.27	3.66	3.92	3.25	0.24
P₂O₅	–	–	–	–	–	0.85
H₂O⁺	0.21	0.23	0.26	0.33	0.22	0.83
H₂O⁻	0.05	0.04	0.14	0.04	0.09	0.48
B₂O₃	0.56	0.36	0.01	1.22	0.01	10⁻³
F (ppm)	337	309	100	1094	480	1092
Total	99.96	100.58	99.54	100.20	99.95	100.74
CIPW norms						
Q	38.64	34.24	36.16	37.21	37.73	
or	22.24	25.02	21.68	23.35	19.46	
ab	27.77	28.30	29.34	24.63	29.87	
an	3.34	3.89	3.34	3.89	3.34	
C	4.07	4.68	4.18	4.47	3.78	
hy	2.02	1.88	3.32	1.92	4.18	
mt	0.86	1.60	0.76	2.83	0.95	

1, 2 – the older aplite, *3* – the younger aplite, *4* – the pegmatitic intercalation, *5* – another aplitic dyke from Lisiec hill. *6* – amphibolite. 3 m below the aplitic dyke described
Analyst: H. Siagło

5. Post-magmatic minerals.

The small coarse-grained pegmatitic intercalations, consisting of quartz, feldspars and tourmaline, differ from aplite in grain size, the grains being about 2 cm in diameter. They have no cavities, nor do they show any other evidence of the separation of volatiles.

PROPERTIES OF APLITIC MAGMA

As appears from the above description of the aplite dyke, it shows no chemical changes associated with components other than those present in the parent magma. Therefore, the chemical constitution of the dyke represents the composition of the magma, which fact encourages considerations concerning some properties of this magma.

Two features seem to be of primary importance for the description of its physico--chemical properties: its peraluminous nature and low water pressure.

Aluminium may play a dual role in silicate melts, depending on the mode of coordination. Aluminium occurring in tetrahedral coordination plays a part of network former while aluminium in octahedral coordination acts as a network modifier. It has been shown experimentally that the appearance of aluminium in tetrahedral coordination is conditioned by the presence of alkalies and alkaline earths that make possible the formation of the M^+AlO_2 or $M^{2+}Al_2O_4$ complexes (Mysen *et al.* 1980a). The mode of coordination of aluminium is also affected by fluorine (Manning et al 1980). In fact, in granitoid magmas aluminium appears as a network former in the three-dimensional lattice of feldspars, so its appearance as a network modifier can be well illustrated by the $Al_2O_3/Na_2O + K_2O + CaO$ mole ratio, which is 1.4 in the rocks in question. This value indicates that significant amounts of aluminium in octahedral coordination were present in the magma from which aplites formed.
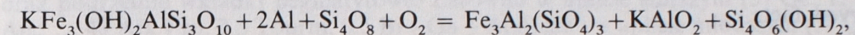
The geologic situation and petrographic data indicate that the low water pressure was a result of low water content in the magma rather than of low total pressure. The total pressure approximated that in the neighbouring granites (there is essentially no difference in the depth of crystallization of aplites and granites), and yet aplites show no evidence of the action of volatiles, so common in granites. Low triclinicity of potassium feldspar indicates that when it was within the microcline stability field, water was not available in sufficient amounts to change the structural state and produce microcline of high triclinicity (Parsons 1978). Large amounts of albite in the form of cryptoperthitic intergrowths in alkali feldspar, as well as the insignificant scale of post magmatic hydrothermal alterations of garnet, andalusite and feldspars, also indicate that only small amounts of water were present in the magma during its crystallization (Parsons 1978). These data suggest that the pressure of water in the rock was lower than the total pressure.

The peraluminous nature of the magma and its undersaturation with water may have affected the water solubility mechanism. It seems that under the conditions of water-undersaturation the excess of alumina over alkalies prevented the formation of complexes of the M^+OH type, as the alkalies cations were utilized to keep aluminium in tetrahedral coordination in the three-dimensional lattice of feldspars. Consequently, all water present in the melt was combined in units of the $Si_4O_{8-x}(OH)_{2x}$ type (Mysen *et al.* 1980b). Such mechanism of water dissolution prevented the alkalization of the magma, which is essential to the formation of tourmaline because in alkaline solutions the BO_3^{3-} anion is replaced by $B(OH)_4^-$, and this precludes the crystallization of tourmaline (Frondel, Colette 1957).
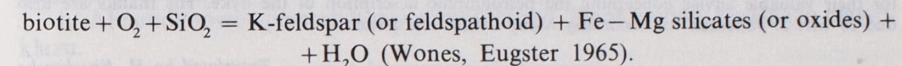
Garnet and biotite were the first phases that crystallized from the magma. Phenocrysts of acid plagioclase are of the same age or somewhat younger. Although described from many granitic rocks, almandine-spessartine garnets have never attracted much attention of petrologists. They are generally treated as an indicator of enrichment of a magma in alumina, and sometimes their presence can be readily accounted for by the contamination phenomena (e.g. Vennum, Meyer 1979).

Since at the discussed stage of crystallization garnet and biotite were the only minerals that incorporated femic elements in their structure, they were probably at equilibrium of the type:

$$KFe_3(OH)_2AlSi_3O_{10} + 2Al + Si_4O_8 + O_2 = Fe_3Al_2(SiO_4)_3 + KAlO_2 + Si_4O_6(OH)_2,$$

which is in accordance with the general equation:

$$biotite + O_2 + SiO_2 = K\text{-feldspar (or feldspathoid)} + Fe - Mg \text{ silicates (or oxides)} + H_2O \text{ (Wones, Eugster 1965)}.$$

This equilibrium can only be maintained under the conditions of an excess of alumina over alkalies and a relatively high oxygen pressure in a magma undersaturated with water.

The next stage of crystallization of the aplitic magma was the formation of the quartz-feldspar complex, involving in its final phase the resorption of plagioclase by alkali feldspar and the crystallization of tourmaline. The crystallization of tourmaline is held to be responsible for the decomposition of biotite (e.g. Němec 1975) which supplies iron and magnesium necessary in this process. Potassium released during the decomposition of biotite presumably takes part in the reaction:

$$NaAlO_2 + K^+ = KAlO_2 + Na^+$$
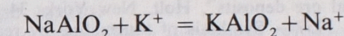
which is in accord with the common resorption of acid plagioclase by alkali feldspar. Sodium is utilized by the crystallizing tourmaline or incorporated in the structure of alkali feldspar.

The last-formed mineral derived from the magma was andalusite. The residual melt from which it crystallized was free from alkalies and belonged to the $Al_2O_3 - SiO_2$ system. It did not contain aluminium in tetrahedral coordination. It is feasible that due to the loss of large amount of silica, which had crystallized earlier as quartz, the melt was more strongly depolymerized. It is worth noting, however, that the crystallization of Al_2SiO_5 polymorphs from a magma is not always associated with the final stages of consolidation of the granitic magma and may also take place at the earlier stages of consolidation (e.g. Anderson *et al.* 1980).

In the schlieren within the younger aplite, which represent a magma of lower viscosity and somewhat enriched in water, garnet is partly replaced by biotite. This presumably reflects the action of post-magmatic solutions produced in small amounts at the final stages of magmatic crystallization.

GENESIS OF APLITIC MAGMA

The characteristic chemical composition of aplites and, consequently, of aplitic magma indicates that it presumably owes its origin to the process of separation of volatiles from the granitic magma due to a pressure drop. Such drop could have

occurred during contraction cracking of the solidified outer carapace of the pluton, where certain amounts of magmatic melt were probably present. The high excess of alumina over alkalies in aplite, which represents a degassed granitic magma, accords well with the experimental evidence which shows that the volatile phase formed as a result of separation of the volatiles from the magma is enriched in alkalies relative to alumina (Burnham 1967; Sakuyama, Kushiro 1979). The presence of boron in the aplitic magma can only be accounted for by its being supplied from an unknown source after the process of degassing. It is feasible that boron was introduced into the magma that gave rise to older aplite during its flow towards the place it occupies at present. Since the presence of boron alone differentiates older aplite from the younger one, this explanation is in agreement with the observed facts.

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Jacek PUZIEWICZ

APLIT TURMALINOWO-ANDALUZYTOWY ZE WZGÓRZA LISIEC KOŁO STRZEGOMIA

Streszczenie

W pracy opisano żyłę peralumniniowego aplitu granitowego, występującego wśród amfibolitów osłony masywu granitowego Strzegom–Sobótka na wzgórzu Lisiec, 2 km na południe od Strzegomia. W żyle występują dwie generacje aplitów oraz podrzędne wkładki pegmatytowe. Zarówno w aplicie starszym (37 Qz, 12 Pl An$_{7-10}$, 48 Alk Fsp, 2.5 Tourm, 0.5 Bi + Ga + And) jak i w aplicie młodszym (31 Qz, 14 Pl An$_{7-10}$, 54 Alk Fsp, 1 Ga + And) stwierdzono identyczną kolejność krystalizacji minerałów:

1. Almandynowo-spessartynowy granat, biotyt, fenokryształy kwaśnego plagioklazu.

2. Drobnoziarnisty agregat kwarcowo-skaleniowy.

3. Skaleń alkaliczny, turmalin, kwarc młodszej generacji.

4. Andaluzyt.

Szereg danych geologicznych i petrograficznych wskazuje, iż magma była niedosycona wodą. Peraluminiowy skład uwarunkował sposób rozpuszczania wody, która była przyłączana do cząsteczek kwarcu, a nie tworzyła połączeń typu M · OH, powstających w wyniku rozpadu skaleniowych kompleksów M · AlO₂.

Specyficzne warunki fizykochemiczne panujące w magmie umożliwiły koegzystencję biotytu i granatu oraz krystalizację andaluzytu. W końcowym etapie zestalania się magmy kosztem biotytu powstał szerlitowo-drawitowy turmalin, główny ciemny minerał starszego aplitu.

Powstanie magmy było związane z procesem odgazowania magmy granitowej. Faza lotna wydzielana w wyniku tego procesu zubożyła magmę w alkalia, co doprowadziło do powstania peraluminiowego składu. Bor został doprowadzony do magmy w okresie późniejszym, przypuszczalnie podczas jej intruzji na obecne miejsce.

Яцек ПУЗЕВИЧ

ТУРМАЛИН – АНДАЛУЗИТОВЫЙ АПЛИТ ВОЗВЫШЕННОСТИ ЛИСЕЦ В РАЙОНЕ СТШЕГОМА

Резюме

В работе описана жила пералюминиевого гранитного аплита, залегающая среди амфиболитов, окружающих гранитный массив Стшегом—Собутка, в 2 км к югу от Стшегома. В жиле наблюдаются две генерации аплитов и небольшие включения пегматитов. Как в более древней генерации аплита (37 Qz, 12 Pl An$_{7-10}$, 48 Alk Fsp, 2,5 Tourm, 0,5 Bi+Ga+And), так и в младшей генерации (31 Qz, 14 Pl An$_{7-10}$, 54 Alk Fsp, 1 Ga+And), проявляются одинаковые последовательности кристаллизации минералов:

1. Альмандин-спессартиновый гранат, биотит, фенокристаллы кислого плагиоклаза.

2. Мелкозернистый кварц-фельдшпатовый агрегат.

3. Щелочной шпат, турмалин, кварц младшей генерации.

4. Андалузит.

Ряд геологических и петрографических признаков свидетельствует о том, что магма не была насыщена водой. Пералюминиевый состав обусловил способ диссоциации воды, которая соединялась с молекулами кварца и не образовала соединений типа $M \cdot OH$, образующихся в результате распада полевошпатовых комплексов $M \cdot AlO_2$.

Специфические физико-химические условия, господствовавшие в магме, позволяли на сосуществование биотита и граната, а также на кристаллизацию андалузита. В заключительной стадии остывания магмы за счет биотита образовался шерлит-дравитовый турмалин — основной темный минерал древнего аплита.

Формирование магмы сопровождалось процессом дегазации, что обусловило обеднение магмы щелочами и образование пералюминиевого состава. Обогащение магмы бором произошло позже, очевидно во время её внедрения в занимаемое ныне место.