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## PIEMONITE AND ASSOCIATED MINERALS FROM SUDETEN MOUNTAINS (POLAND) AND EUBOEA ISLAND (GREECE)

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**A b s t r a c t.** Peculiar parageneses of piemontite with Mn-rich minerals such as tourmaline, titanhematite and/or ferriphengite, garnet have been found in pegmatoidal segregations in gneiss-amphibolite complex (Marcinków, Sudeten Mts.) and in epizonal crystalline schists (Treppes, Euboea Isl.), respectively. Associated minerals list embraces besides: epidote, Mg-chlorite, titanite, apatite, phlogopite, quartz and alkali feldspars. The succession of the most significant minerals was established as follows: tourmaline, epidote, piemontite,  $\pm$  phlogopite,  $\pm$  alurrite,  $\pm$ spessartinic garnet, titanhematite and Mg-chlorite. Postmagmatic waters contaminated by the products of oxidation reactions during metamorphism of country rocks were the chief factors of piemontite-bearing parageneses origin.

### INTRODUCTION

Piemontite was firstly reported from Sudeten Mts. by Traube (1888) as a component of quartz veins transsecting granite on the right Nysa riverside in Zgorzelec. Second occurrence in Poland, here discussed and primarily announced by Gęgotek (1956), is connected with pegmatoidal segregations in gneiss-amphibolite complex near Marcinków (SE of Kłodzko). Besides, piemontite was found in abundance by the present author in manganese-enriched crystalline schists at Treppes (southern part of Euboea Isl.), where the oxidation cap is mined for manganese oxide ore.

The two last mentioned localities will be discussed in detail from the petrological and mineralogical point of view. Confrontation with the questions regarding provenance of piemontite-bearing metamorphites is made, as well as, a proposed elucidation of this problem.

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Indisputable is the fact, that piemontite is a metamorphic mineral, as well as, a full agreement prevails what concerns hydrothermal origin of this mineral. This statement is confirmed by a lot of reports in the literature, embracing examples of occurrences in phyllites, metacherts, greenschists, blueschists (glaucophane s.), mica schists or even gneisses. From the other side, piemontite was recorded from felsic till intermediate volcanites and their wall rocks (e.g., Guild, 1935) or in deep-seated igneous rocks, as nepheline syenites (e.g., Lyashkevich, 1958) and pegmatites (e.g., Bilgrami, 1956). The secretional filling of cavities and fissures with quartz and calcite on the first occasion and metasomatic replacement (with prehnite) of nepheline in the second are sufficient evidences implying postmagmatic waters as responsible factors of transformation.

Much more striking than the mentioned country rocks are the mineral parageneses containing piemontite and the succession of minerals forming these assemblages.

Cooper (1971) described quartz-muscovite-piemontite schists from Central Otago (New Zealand), rocks similar to the ones found in the Haast Schist Group by Hutton, Turner, Mason, a.o. The piemontite schists are interbedded here with greenschists, spessartine metacherts (formerly *Radiolaria* oozes rich in Mn ?) and rare ultrabasic schists, all indicating eugeosynclinal environment of formation in the pre-metamorphic stage. Mineralogical assemblages comprise the following components: quartz-albite-muscovite-phlogopite-piemontite-tourmaline, with: hematite-apatite-spessartine (1, 2) or spessartine-chlorite-hematite-titanite (3) or spessartine-tremolite-apatite-titanite (4). The last, highest grade piemontite schist from the uppermost part of the garnet zone, was treated in detail. Very significant is a remark concerning the succession of minerals: ... „the habit of some garnet suggests a formation at a late metamorphic stage, since it poikiloblastically encloses piemontite and hematite“. It should be pointed out that the accompanying chlorite is Mg-rich and the tourmaline has an elbaitic character.

Genetically similar and belonging to the same blue- and greenschist facies are piemontite-quartz schists (metacherts) of Japan. Their mineral parageneses were specially commented by Iwasaki (1960) and Ernst (1964). It should be noted that the piemontite-quartz schists are accompanied by the graphite schist and sometimes by calcite (probably both of algal origin, see Wieser, 1963). Piemontite is known to coexist with many minerals, such as: epidote, spessartine-type garnet, Mg-chlorite, tourmaline, tremolite-actinolite, Mg-glaucophane, magnesioriebeckite, jadeitic and diopsidic aegirine, rutile, titanite, rarely braunite. The observations indicating, that completely colourless Mg-rich chlorite always assists piemontite but not epidote, as well as, epidote (sometimes with piemontite cores) coexists with almost colourless Mg-rich glaucophane (with magnesioriebeckite rims) induced Iwasaki to express these relations by a chemical equation:  $2 \text{ colourless glaucophane} + 3 \text{ piemontite} + 2,5 \text{ hematite} + 3 \text{ quartz} = \text{magnesioriebeckite} + 3 \text{ epidote} + \text{spessartine} + 3/4 \text{ O}_2$ . Moreover, Iwasaki distinguished two stages of recrystallization, namely: — earlier formation of Mg-rich glaucophane and piemon-

ite with Mg-chlorite under oxidizing conditions and later formation of magnesioriebeckite, epidote, garnet and  $\text{Fe}^{2+}$ -rich chlorite with reduction of Mn and Fe. The reduction was possibly caused by increasing temperature. This is a reversed sequence in comparison with almost all other occurrences judging from the presence of piemontite with epidote cores.

From a great number of metamorphic reactions postulated by Ernst (1964) for the same (from Japan) material two are especially significant for the current discussion. These are:  $1/2 \text{ muscovite} + 1 \text{ ferriclinochlore} = 1/2 \text{ ferrimuscovite} + \text{clinochlore} (1)$ ;  $1/2 \text{ muscovite} + 1/3 \text{ ferriepidote} = 1/2 \text{ ferrimuscovite} + 1/3 \text{ clinozoisite} (2)$ .

From the above demonstrated examples differ apparently the occurrences recorded by Voznesenski (1961) from western Tuva (Soviet-Union) or by Smith and Albee (1967) from California and Stensrud (1973) from New Mexico.

In the first instance the country rocks are represented by albite schists, sericite-chlorite schists and sericite quartzites. These mineral assemblages indicate phyllite grade of metamorphism. In addition to mentioned minerals abundant spessartine (in spessartine-piemontite rocks!) and accessory apatite, titanite, green tourmaline, rutile, hematite  $\pm$  magnetite were reported.

Opposed to these epizonal assemblages, Californian and New Mexican occurrences display parageneses which after mentioned writers are typical for amphibolite facies. The piemontite or epidote gneiss cropping out in the southern foothills of the San Bernardino Mts., California, consists in 75—80% of quartz, plagioclase ( $\text{An}_{29-63}$ ), and microcline; the remainder being distributed between piemontite (or epidote), phlogopite (or biotite in epidote gneiss),  $\pm$  amphibole,  $\pm$  pyroxene,  $\pm$  spessartine, hematite and titanite. In another occurrence, near the Whitewater River, muscovite (phengite) is the commonest mineral with K-feldspar and quartz, whereas phlogopite, plagioclase, piemontite, hematite, titanite persist only in subordinate amounts. Phlogopite was not observed in contact with garnet and assemblage: amphibole—pyroxene—garnet in a single layer. The epidote, usually rimmed by piemontite, may contain more manganese than does piemontite but in divalent form and restricted to X (Ca) position.

In the Las Tablas area of the San Juan Mts. (New Mexico) appear extensive piemontite- and epidote-bearing schists (up to 150 m thick) with typical associations of adjacent rocks consisting of quartz—microcline—muscovite—epidote  $\pm$  plagioclase  $\pm$  biotite in quartz-feldspathic schists and hornblende—andesine  $\pm$  epidote in metabasalts. Examined samples rarely contained both piemontite and garnet (uncommon mineral in New Mexico); the remainder being microcline, red muscovite (with  $\text{Mn}^{3+}$ ), phlogopite and hematite.

As might be expected, numerous lensoid bodies of piemontite metacherts are scattered in California within chlorite zone, biotite zone of the greenschist facies and a few demonstrate the adherence to the amphibolite facies. Characteristically they are connected with major fault zones (e. g. San Andreas) and blastocataclastic textures are peculiar features (Allen, 1957, a.o.). Short (1933) determined the order of deposition in a shear zone in schistose volcanic rocks, as follows: piemontite, tremolite,

vein quartz and spessartine-type garnet. The majority of the piemontite crystals have their *a* and *b* axes in the plane of schistosity. It was also shown by Mayo (1932) and the neighbouring occurrence, that biotite may be replaced by piemontite, simultaneously being overgrown upon by a rim of small epidote crystals. On the other hand, in another exposure „sericite replaces nearly every piemontite grain to a slight extent, but is never enclosed by the latter; hence this mica would seem to be restricted to a narrow time interval, near the close of crystallization of the piemontite, and perhaps for a time thereafter”. The apatite was found to be earlier than sericite. An interesting phenomenon was also revealed by Webb (1939) who reports that some of the alurgite flakes are surrounded by rims of hematite.

In view of the preceding discussion the two occurrences of piemontite and associated minerals examined by present author will help to clarify some undissolved problems.

The piemontite-bearing pegmatoidal segregations in gneisses found in Sudeten Mts. become very instructive in this respect. In the village Marcinków (about 20 km to SE of Kłodzko) they crop out in association of amphibolites containing intermediate plagioclase and common hornblende indicative for mesozonal amphibolite facies. Another sign is the Marcinków fault (see Oberc, 1972) with SE—NW strike, dropping down and cutting gneisses from the north — east.

The pegmatoidal segregations are in 80—90% composed from microcline, less common quartz, rarer albite; the remainder being piemontite, tourmaline, hematite, phengite, chlorite, titanite and apatite. The content of phengite and chlorite increases towards peripheries of segregations. The quantitative proportions of constituents appear to be very variable and no attempt was done to establish the extension of shear zone with pegmatoidal segregations owing to absence of exposures.

It is noteworthy, that relics of epidote are still discernable though the replacement by piemontite is usually well advanced. On the other hand, the piemontite is intricately veined by hematite (Fig. 1c). Chlorite, phengite (without pinkish hue, that is,  $Mn^{3+}$ ) and quartz of second generation (first produces relict graphic intergrowths in microcline) represent the later products of deposition too. This might be deduced from fillings of interstices between broken and displaced epidote-piemontite grains. Formation of titanite seems to be contemporaneous with epidote and accumulations of titanite grains correspond to Scheumann's restites. Tourmaline crystals are in comparison with piemontite ones more deformed and crushed and after replacement examples of tourmaline by piemontite one can state that piemontite is somewhat later growing mineral.

Second, here reported, occurrence is also attached to a shear zone, this time, in epizonal metamorphic complex of southern Euboea. This complex presents a compositional part of Palagonian Massif, built by metamorphosed calcareous, ophiolitic and typical Flysch deposits of Palaeozoic-Mezozoic (excluding Upper Cretaceous) age (see Marinos, 1957). In the studied area phyllites-mica schists and marbles, sometimes with blueschists are best developed (Teller, 1880; Aubouin, Guernet, 1963, a.o.). Piemontite-bearing schists, structurally hornfelsic or schistose, locally

blastocataclastic, are distinguished by manganese oxide-rich weathering zones (e.g. Treppes mine) and peculiar mineral assemblages. The resemblance of the last mentioned to the recorded from Japan and New Zealand is easily evident. The dominant types of schists oscillate in quantitative mineral proportions between Mn-rich ferriphengite and albite-rich varieties (tab. 1).

Table 1

Planimetric data of mineral composition (in per cents)

Sample	Microcline	Albite	Clouded, acid plagioclase	Quartz	Phlogopite	Chlorite
2T	17,8	14,2	1,3	16,5	1,3	—
3T	20,2	31,3	18,5	10,0	0,1	0,5
Sample	Ferri- phengite	Piemontite	Garnet	Hematite	Apatite	Titanite
2T	38,9	4,6	0,7	3,4	0,5	0,8
3T	0,3	14,5	0,3	1,9	0,5	1,9

Certain thin sections reveal conspicuous dependence between accumulation of piemontite crystals and close neighbourhood of microcline + quartz segregations (Fig. 1b). The transitional zones are enriched in rather large chlorite flakes. The quartz-rich layers are accompanied in the near proximity by microporphroblastic albite and piemontite with holoblastic phlogopite, hematite and local garnet. Incorporated in dominantly phengitic aggregate some of the listed minerals show stretching haloes behind rotating blasts (Fig. 1a). Most distinct are those appertaining to the piemontite crystals while stretching haloes belonging to albite and hematite grains are least developed or absent. These relations may serve as an indications for the succession of growth. In the stretching haloes behind piemontite blasts excluding quartz may appear albite, phlogopite and garnet. Titanite seems to be contemporaneous with piemontite or epidote if primarily present.

Some samples demonstrate feldspar and piemontite-hematite segregations originated after synkinematic brecciation. Paleosoms are impregnated from borders by piemontite (secondary after epidote) and hematite aggregates. Feldspar segregations are almost entirely composed of microcline and surrounded by albitized (clouded) plagioclase and bordered by hematite. Sporadic tourmaline is overgrown upon by piemontite, therefore, may be considered as older in order of crystallization.

Another sample of pegmatoidal aggregate with tourmaline is composed in similar proportions from tourmaline, alkali feldspars (mainly microcline) and quartz. Phengite, leucoxenized titanite, hematite and apatite are much less abundant, while piemontite is lacking. Graphic intergrowths of microcline and quartz are only rarely visible, while perthitic ones disappear completely.

## MORPHOLOGIC AND CRYSTALLOOPTIC PROPERTIES

Nearly all studied minerals with exception of typical accessory minerals are well discernible with naked eye or under hand lens. The piemontite, of course, and some minerals characteristic for the piemontite-bearing assemblages have been selected for determination of morphologic and crystallooptic features.

**Piemontite.** This mineral is known to possess a wide range of morphologic and crystallooptic properties as a consequence of quite great variability in chemical composition. This is marked not only in the same locality but even in a single grain.

The piemontite derived from the Marcinków (Sudeten Mts.) locality forms subhedral and euhedral prisms up to 12 mm in length. These crystals elongated according to  $b(Y)$  axis and flattened parallel to basal pinacoid are rather poor in crystallographic faces. The frequency of faces is visualized in Figure 2, which was obtained basing on the measurements of interfacial angles on separated minerals with the goniometer and spindle-stage methods. Individuals with more isometric habit are restricted to epidote pseudomorphs. Simple twins with (100) as compositional plane are rather common.

The optic features of Marcinków piemontites though changeable all are included in variation range of normal piemontites. These are: distinct pleochroism with  $\alpha$  — lemon-yellow,  $\beta$  — faintly lilac pink,  $\gamma$  — pink with



Fig. 1. Sketches after photomicrographs of thin sections  
 a — schist from Treppes with piemontite (thick outlines), titanite (dark areas), hematite (thin outlines), ferriphosphate (dotted outlines). Note stretching haloes connected with rotating piemontite. Magn. 23 X.  
 b — contact of schist with microcline-rich segregations. Some piemontite grains exhibit relict epidote cores. In upper part two flakes of chlorite and small titanite grains are well distinguishable. Treppes. Magn. 20 X.  
 c — replacement of piemontite by hematite in the shape of veinlets following cleavage surfaces. Dotted areas in piemontite belong to epidote. Above two grains of quartz (clear areas) and below — a microcline. Marcinków. Magn. 21 X

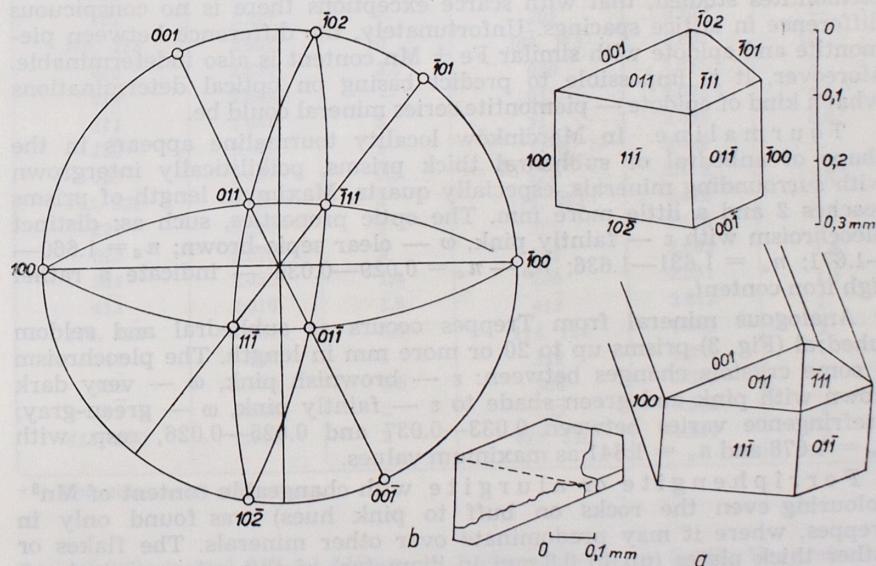


Fig. 2. Stereographic and clinographic projections of piemontite crystals from Marcinków

Terminal faces of individual b can be indexed as:  $011$ ,  $0\bar{1}\bar{1}$ ,  $1\bar{1}\bar{1}$

Table 2

Spacings and relative intensities of reflections in hematite and piemontite X-ray diffractograms: CuK $\alpha$  radiation; Ni filter. The indices listed after Harcourt and Cooper, respectively

Locality (hkl)	Treppes		Locality (hkl)	Marcinków	
	d(Å)	I/I <sub>0</sub>		d(Å)	I/I <sub>0</sub>
<b>Hematite</b>					
101	3.69	3	101	3.69	3
112	2.702	10	112	2.706	10
101	2.517	8	101	2.521	8
102	2.208	2	102	2.212	2
202	1.842	3	202	1.844	3
123	1.695	4	123	1.699	3,5
233, 112̄β	1.600	0,5	233, 112̄β	1.603	1
<b>Piemontite</b>					
100	8.01	1,5	100	8.04	1,5
102	5.03	2,5	102	5.03	3
110, 111	4.625	1	110, 111	4.625	1
200	4.023	2	200	3.998	4
211	3.498	5,5	211	3.497	5
102	3.430	2	102	3.412	2
201	3.20 *	—	201	3.20 *	—
302, 113	2.907	10	302, 113	2.905	10
020	2.836	3,5	020	2.835	3
013	2.689 *	—	013	2.683 *	4,5
311	2.601	5	311	2.605	6,5
122	2.463	1	122	2.468	1
022	2.407	2,5	022	2.413	4,5
113, 222	2.295	3	113, 222	2.306	2
221	2.118	3	221	2.118	2,5
023	2.075	2	023	2.082	1,5
203	2.050	1,5	203	2.051	1,5
413	2.016	1,5	413	2.012	1
114, 124	1.881	2,5	114, 124	1.880	2
312	1.860	1	312	1.859	1
306	1.670	0,5	306	1.669	1
505	1.588	2	505	1.588	2
412, 510	1.541	2	412, 510	1.541	2

\* Coincidence of reflections.

$n_{\gamma} = 1.621$ ;  $n_{\beta} = 1.617-1.618$ ;  $n_a = 1.579$ ;  $n_{\gamma} - n_a = 0.043$ . Very similar are characteristics for Mn-arm phengites (?) in other samples: weak pleochroism with  $\gamma$ ,  $\beta$  — faintly yellowish brown,  $a$  — faintly yellowish, almost colourless;  $2V_a = 28-29^\circ$ ;  $r > v$ ;  $n_{\gamma} - n_a = 0.043$ . Such a mica is probably identical to one occurring in Marcinków, judging from fol-

violet shade to crimson or purple; absorption scheme —  $\gamma > a \geq \beta$ , extinction angles —  $X/\gamma = 30.5-31.5^\circ$  and  $Z/a = -5$  to  $-6^\circ$ : optic axes angle  $2V_{\gamma} = 91-99^\circ$ ; dispersion weak with  $r < v$ ;  $n_{\gamma} = 1.790-1.807$ ;  $n_{\beta} = 1.777-1.785$ ;  $n_a = 1.764-1.763$ ; birefringence,  $n_{\gamma} - n_a = 0.026-0.044$ . The first values of refractive indices and birefringence correspond to variety originated by replacement of epidote (judging from relicts in cores of grains) in which the birefringence may drop to 0.017-0.018, while  $2V_{\gamma}$  increases simultaneously to  $106-108^\circ$ .

The piemontite found in Treppes (Euboea) is distinguished by the absence of euhedral grains and by undistinctly prismatic habit. The piemontite grains, sometimes true porphyroblasts up to 2 mm in diameter were disintegrated and displaced during rotation with  $b(Y)$  axis parallel to  $B$  petrofabric axis. Simple twins, including lamellae, after (100) are not infrequent, as are the examples of zoning showing weaker absorption on margins or of occasional epidote with poikilitic structure in cores. The pleochroism is more intense than in the previously described examples:  $\alpha$  — orange-yellow,  $\beta$  — amethystine,  $\gamma$  — deep pink to vine-red or carmine. Other properties are as follows:  $X/\gamma = 29-32^\circ$ ;  $2V_{\gamma} = 81-89^\circ$ , rarely to  $93^\circ$ ; weak dispersion with  $v > r$  or  $r > v$ ;  $n_{\gamma} = 1.781$ , max. 1.804;  $n_{\beta} = 1.760-1.784$ ;  $n_a = 1.739-1.760$ ;  $n_{\gamma} - n_a = 0.042-0.044$ ; in the epidote-piemontite core: —  $n_{\gamma} = 1.781$ ;  $n_{\beta} = 1.760$ ;  $n_a = 1.745$ ;  $n_{\gamma} - n_a = 0.029$ ;  $2V_{\gamma} = 99^\circ$ ;  $r > v$ . These optic values are variable and representative to only a fraction of crystals.

It may be inferred from the X-ray diffractometer data (Tab. 2) of both piemontites studied, that with scarce exceptions there is no conspicuous difference in lattice spacings. Unfortunately, the difference between piemontite and epidote with similar Fe + Mn content is also indeterminable. Moreover, it is impossible to predict basing on optical determinations what a kind of epidote — piemontite series mineral could be.

Tourmaline. In Marcinków locality tourmaline appears in the shape of anhedral or subhedral thick prisms, poikilitically intergrown with surrounding minerals, especially quartz. Maximum length of prisms reaches 2 and a little more mm. The optic properties, such as: distinct pleochroism with  $\epsilon$  — faintly pink,  $\omega$  — clear sepia-brown;  $n_{\epsilon} = 1.660-1.671$ ;  $n_{\omega} = 1.631-1.636$ ;  $n_{\omega} - n_{\epsilon} = 0.029-0.035$  — indicate a rather high iron content.

Analogous mineral from Treppes occurs as subhedral and seldom euhedral (Fig. 3) prisms up to 20 or more mm in length. The pleochroism in some crystals changes between:  $\epsilon$  — brownish pink,  $\omega$  — very dark brown with pink and green shade to  $\epsilon$  — faintly pink,  $\omega$  — green-gray; birefringence varies between 0.033-0.037 and 0.025-0.026, resp. with  $n_{\omega} = 1.678$  and  $n_{\epsilon} = 1.641$  as maximum values.

Ferriphengite or alurgite with changeable content of Mn<sup>3+</sup> (colouring even the rocks on buff to pink hues) was found only in Treppes, where it may predominate over other minerals. The flakes or rather thick plates (up to 0.8 mm in diameter) of this mica mineral are fully xenoblastic and much deformed. Beneath microscope the absorption and pleochroism though weak are readily distinguishables. The measurements gave:  $\gamma > \beta$  = buff to faintly brownish pink,  $a$  — almost colourless;  $Z/a = 1^\circ$ ;  $2V_a = 27-30^\circ$ , mean  $29-29.5^\circ$ ; weak dispersion,  $r > v$ ;

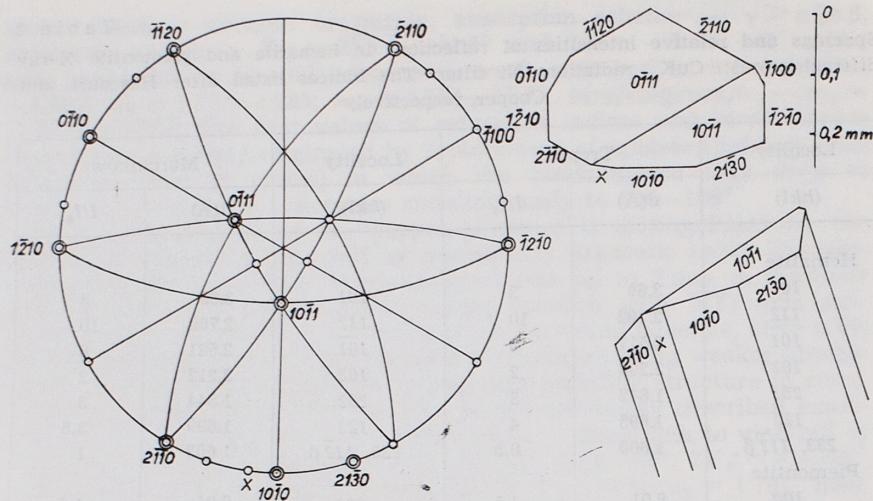


Fig. 3. Stereographic and clinographic projections of tourmaline crystal from Treppes. Double-ringed poles symbolize most frequent crystallographic faces. A vicinal face was marked by X.

l owing data:  $2V_a = 27-28^\circ$ ;  $r > v$ ;  $n_y - n_a = 0.042$ ;  $n_y = 1.592$ ;  $n \parallel = 1.590$ ;  $n_a = 1.550$ . In both cases phengite possibly transforms lightly in chlorite with peculiar optic features. The optic properties of ferriphengite (alurgite) correspond well to the members of probable isomorphous series between picrophengite (phengite s. stricto) and ferrimuscovite projecting on the one side of the Winchell's triangular diagram.

**P h l o g o p i t e.** This is only trioctahedral mica known exclusively from Treppes locality. It occurs there in small plates (up to 0.35 mm) in association with garnet though not in direct contact. The pleochroism is more intensive than in ferriphengite:  $\gamma = \beta$  — orange-yellow to reddish brown,  $a$  — faintly yellowish. Other data are:  $Z/a = 2^\circ$ ;  $2V_a = 37^\circ$ ; weak dispersion with  $r < v$ ;  $n_y - n_a = 0.048$ ;  $n_y = 1.623$ ;  $n_\beta = 1.619$ ;  $n_a = 1.575$ .

**C h l o r i t e.** In samples from Marcinków and Treppes two kinds of chlorite might be determined. Both were frequently observed in close association with phengite, possibly representing product of phengite alteration. Chlorite from Treppes, optically positive, possesses a weak pleochroism:  $\gamma, \beta$  — faintly grass-green,  $a$  — yellowish, almost colourless, and rather strong birefringence:  $n_y - n_a = 0.007$  with  $n_{y, \beta} = 1.588$ . Mean diameter of flakes equals 0.5 mm, decreasing in hornfelsic schists to 0.12 mm.

Chlorite from Marcinków is optically negative, with identical absorption colours but with weaker birefringence:  $n_y - n_a = 0.004$ . The index of refraction for  $n_y = n_\beta = 1.588-1.595$  is also rather small, emphasizing a high content of magnesia.

**G a r n e t** found in Treppes exhibits anhedral or subhedral outlines of usually deformed rhombic dodecahedron with maximum 0.2 mm in diameter. Yellowish, in thin section practically colourless. Index of refraction

reaches 1.801 value. Most probably it is a variety rich in spessartine molecule.

**H e m a t i t e.** This persistent mineral appears in all samples as anhedral or subhedral thick plates, sometimes with sieve-structure, and much sutured outlines. Maximum diameter of plates reaches 0.2 mm in schists from Treppes; 0.4 mm in chlorite veins and over 30 mm in pegmatoidal segregations from Marcinków. Sometimes reported supposition of conspicuous substitution of titanium ions in hematite structure (titanhematite), especially from piemontite-bearing assemblages, can argue X-ray diffractometer data. Comparing spacings of reflections (Tab. 2) with those already established for pure hematite (Harrington, Harcourt) and ilmenite (Barth and Posnjak 1934, fiole Deer et al. 1962) e.g.,  $d(112) = 2.702-2.706$ , while in hematite  $d(112) = 2.696-2.694$ , and in ilmenite = 2.74, this is well visible.

**T i t a n i t e** occurs in anhedral, seldom subhedral and euhedral grains up to 0.2 mm in diameter. Rare simple twins with (100) composition plane were noted. Optic axes angle varies between  $29-30^\circ$  in Treppes and  $26^\circ$  in Marcinków samples; strong dispersion  $r > v$ .

Some words are needed to express the peculiar features owned by feldspars. In both occurrences feldspars are represented by albite, albitized (clouded) plagioclase and microcline. Albite in schists of Treppes is distinguished by xenoblastic and microporphroblastic development, characteristic hematite inclusions and simple twinning after albite, rarely Roc Tourné twin laws. Only in feldspar segregations found in Treppes and Marcinków albite may be idioblastic (cleavelandite-type), without inclusions, while simple twinning is complicated by additional lamellae of albite triad law. In the first case optic axes angle  $2V_a = 96-98^\circ$ , and in second  $99-100^\circ$  resembling with extinction angles those characteristic for low-temperature structural state and pure albite composition. This was confirmed by X-ray diffractometer data, as:  $2\Theta(131) = 31^\circ 06'$ ;  $2\Theta(220) = 28^\circ 04'$ ;  $2\Theta(1\bar{3}\bar{1}) = 30^\circ 15'$  and I.I. (intermediacy index) = -1.1.

**M i c r o c l i n e** is regularly xenoblastic with optic data, as:  $2V_a = 62-67.5^\circ$ ;  $X/a = 12-14^\circ$ ;  $\gamma \perp (010) = 13-16^\circ$ ;  $n_y - n_a = 0.0065-0.007$ ; and X-ray data:  $2\Theta(\bar{2}04) = 50^\circ 60'-50^\circ 65'$ ;  $2\Theta(060) = 41^\circ 68'$ ;  $2\Theta(\bar{2}01) = 20^\circ 92'$ , suggesting high ordering (60-70%) and almost pure K-feldspar composition for Treppes specimen. On the other hand, microclines from Marcinków gave following values:  $2V_a = 73-77^\circ$ ;  $X/a = 11-16^\circ$ ;  $\gamma \perp (010) = 12-14^\circ$ ;  $n_y - n_a = 0.007$ ;  $2\Theta(\bar{2}04) = 50^\circ 58'$ ;  $2\Theta(060) = 41^\circ 71'$ ;  $2\Theta(\bar{2}01) = 20^\circ 96'$  — corresponding to a little more ordered („triclinized”) feldspar with ca. 75 per cent order/disorder ratio. It is also almost pure K-feldspar though showing sometimes a certain number of albite stringlets in cores and margins of grains.

## CHEMICAL COMPOSITION

Piemontite presents a rare example of a mineral which was distinguished basing on chemical composition (Mn content) but in practice it is the pleochroism which is now decisive feature in distinction between pie-

Table 3  
Chemical analyses of piemontite, tourmaline, ferriphengite and hematite (in weight percentages)

Component	Piemontite		Tourmaline		Ferri-phengite	Hematite
	Marcinków	Treppes	Marcinków	Treppes	Treppes	Marcinków
SiO <sub>2</sub>	37,39	38,94	37,25	35,86	49,63	1,48
TiO <sub>2</sub>	traces	traces	0,31	0,48	1,05	8,74
Al <sub>2</sub> O <sub>3</sub>	17,70	19,98	27,48	25,02	21,28	0,85
Fe <sub>2</sub> O <sub>3</sub>	14,20	14,49	5,10	9,32	9,36	86,89
FeO	nil	nil	1,89	4,60	nil	nil
Mn <sub>2</sub> O <sub>3</sub>	4,09	2,16	nil	nil	— ?	— ?
MnO	nil	nil	0,57	0,38	1,11	1,10
MgO	0,63	0,74	11,71	7,51	2,80	0,20
CaO	21,91	21,33	1,36	2,54	1,22	0,29
Na <sub>2</sub> O	0,43	0,36	1,81	1,85	0,38	nil
K <sub>2</sub> O	0,65	0,32	0,75	0,36	6,99	nil
H <sub>2</sub> O <sup>+</sup>	2,60	1,89	—	2,69	5,60	nil
H <sub>2</sub> O <sup>-</sup>	0,30	0,30	0,18	0,17	0,58	0,06
B <sub>2</sub> O <sub>3</sub>	—	—	—	9,79	—	—
Total	99,90	100,51	88,41	100,57	100,00	99,61
Spec. gr.	3,39	3,30	3,08	3,17	—	5,31

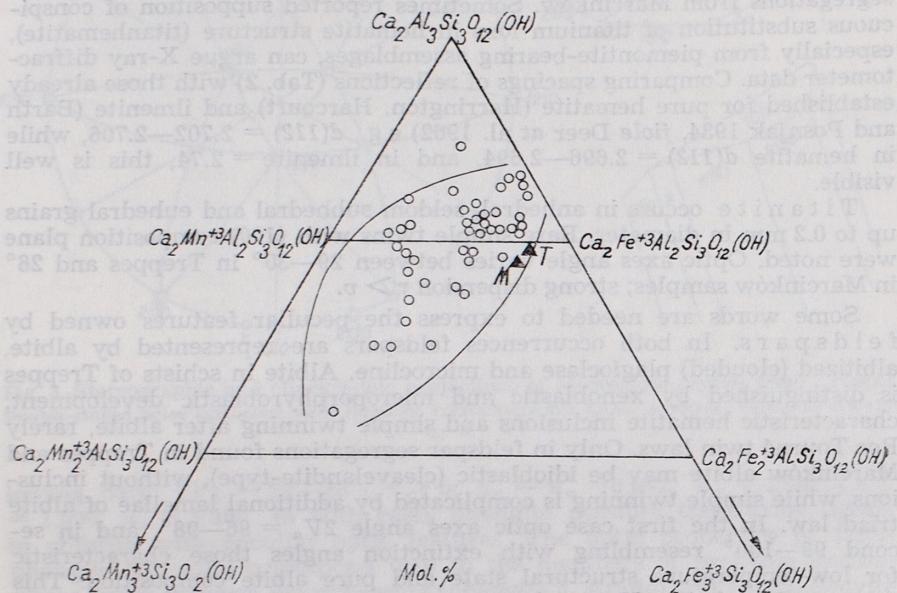


Fig. 4. Triangular diagram showing variation of Al, Fe<sup>3+</sup> and Mn<sup>3+</sup> in piemontites (after Deer et al., 1962)

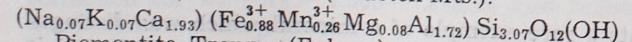
Letter M and T denotes specimen from Marcinków and Treppes, respectively

ped. Some hopes are bounded with the method of electron microprobe wave length scanning as evidenced by Smith and Albee (1967). Mineral (crystallochemical) formulas are also very indicative. When written in the form X<sub>2</sub>Y<sub>3</sub>Si<sub>3</sub>O<sub>12</sub>(OH) the manganese in epidote will be restricted to X(Ca) position (the so-called manganous epidote) while in piemontite it will be found in Y (octahedral) position.

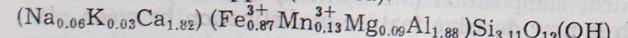
Piemontite grains selected from the crushed rock samples have been undergone a separation in heavy liquids and hand picking under binocular. The results of their chemical analyses are tabulated below (Tab. 3).

The calculation of the crystallochemical (atomic) formulas with theoretical water molecule gave:

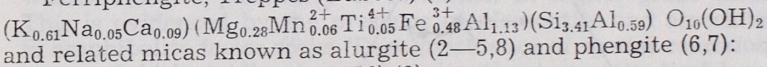
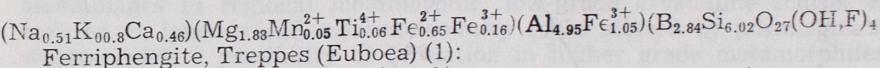
Piemontite, Marcinków (Sudeten Mts.):



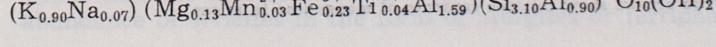
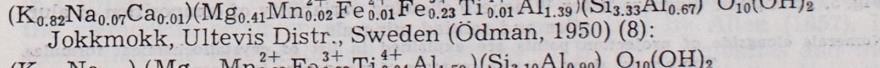
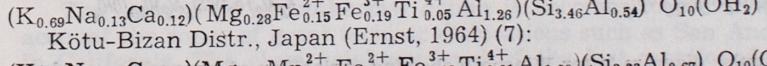
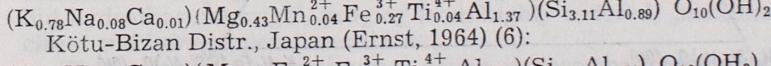
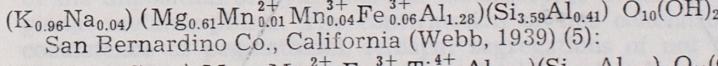
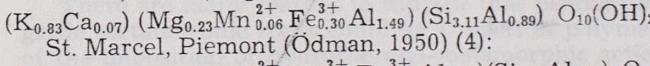
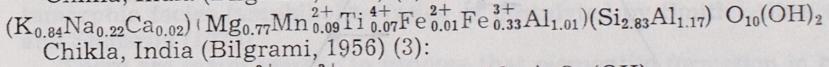
Piemontite, Treppes (Euboea):



#### Tourmaline, Treppes (Euboea):



Chikla, India (Bilgrami, 1956) (2):



Nearly complete compensation of negative valences in octahedral position by all disposable Fe, Mn and Mg cations informs that only possible is the trivalent oxidation state of manganese. No dipositive iron was determined by wet analytical methods. Noteworthy is the full absence of  $TiO_2$  and an excess of silica and alkalis, which may be due to quartz and microcline impurities. This was also shown by rather small specific gravity data.

Chemical analyses of tourmalines (Tab. 3) from both studied occurrences reveal not the elbaitic but mixed, schorl-dravitic character of tourmalines. The recognition of systematic position of tourmaline is still more complex than in piemontite and is hindered by a lack of adequate chemical classification scheme. The low content of  $MnO$  in both localities is very significant and could be ascribed to the early crystallization of tourmaline.

The results of the only analysis of ferriphengite from Treppes (Tab. 3) provided interesting data of wide consequences. Though the usage of term ferriphengite has not been adopted in current literature, it is necessary to express the quite great content of  $Fe_2O_3$  by filling the gap between Winchell's picrophengite (phengite *s. stricto*) and ferrimuscovite. The name alurgite is less convenient as they and the so called sericitic or muscovites from piemontite-bearing schists are not specially rich in Mn (though conspicuously hued), instead being enriched in trivalent iron. In this respect much useful seems to be the presentation of Winchell's triangular diagram having muscovite, ferrimuscovite and picrophengite (phengite)

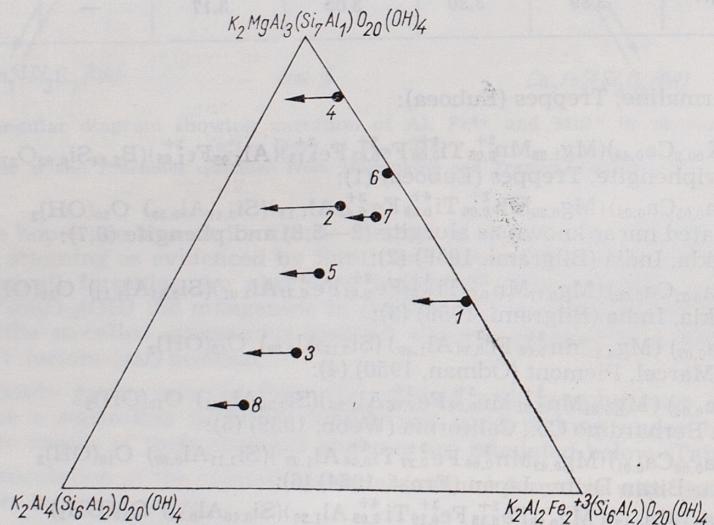


Fig. 5. Triangular diagram (after Winchell) showing variability of composition of alurgites and related minerals  
Numerals alongside of projection points are explained in list of crystallochemical formulas.  
The arrows show relative contents of manganese in micas

as end members, as well as, of all disposable mica compositions from piemontite-bearing assemblages (Fig. 5). The position of projection point of Treppes mica argues the usage of term ferriphengite, proposed by Kanehira and Banno (*fide* Stzunz 1962).

The pink colouration of these relatively Mn-deficient micas might be due to chromophoric effect of  $Mn^{3+}$ -ion-content, as in piemontite. Suggested by Webb (1939) and supported by Ödman (1950) opinion of  $TiO_2$ -content influence on colouration is improbable.

Very instructive proved also to be the only analysis of hematite from Marcinków (Tab. 3). Much striking is here the abnormally high content of titanium dioxide. This content, shown besides in another sample from Marcinków, according to Edwards (1938, *vide* Deer et al., 1962) cannot exceed 10%  $TiO_2$ , without exsolution of ilmenite; Basta (1953, *vide op. cit.*) gives 5% as end limit. Unexpected is also the content of  $Al_2O_3$  (maximum possible 10% after Muan and Gee, 1955, *vide* Deer et al., 1962) taking into account that the only observed impurities belonged to quartz. Instead, the manganese enrichment, expected in these circumstances, is rather low, when the maximum capacity without change of hematite structure equals 17 per cent. The microscopic observations in reflected light disclosed no traces of exsolution in form of rutile or ilmenite inclusions.

## FINAL REMARKS

Observations conducted on the material derived from Polish and Greek occurrences of piemontite-bearing rocks allowed in confrontation with published data to put forward some generalizations.

Except the acknowledged modes of appearance of piemontite-bearing assemblages in regional metamorphic, low-grade crystalline schists, as well as, in igneous and adjacent country rocks altered by postmagmatic waters exists a possibility of formation in higher grade metamorphites. This is evidenced by the presence of piemontite and associated minerals in amphibolite facies rocks. This coincidence of spatial conditions of occurrence might be well only accidental without any genetical bond with metamorphic facies (amphibolite facies as postulated by Smith, Albee (1967) and Stensrud (1973)).

There are many reasons to suppose that piemontite formation in higher grade metamorphic rocks could be a result of polymetamorphism, namely, of the imposition of hydrothermal-metamorphic action on products of regional metamorphism. The confirmation of this conclusion lies in close coexistence of pegmatoidal, feldspar segregations of not true pegmatitic but hydrothermal origin, judging from highly ordered, „maximum” microclines and low-temperature albites.

The sources of hydrothermal action it becomes to search taking into account the zones of great tectonic dislocations such as San Andreas Fault in California. The close neighbourhood of the last mentioned fault with the piemontite occurrences was already emphasized by Allen (1957). It seems that the blastocataclastic structures of B- or R-tectonites and the abundance of sericitic in the form of alurgites or ferriphengites (someti-

mes highly leached from potash as in Treppes) present much significant indications.

It is quite possible that the agents of hydrothermal action represent juvenile postmagmatic waters contaminated by products of metamorphic reactions. It has long been recognized that many metamorphic reactions joined with progressive metamorphism (e.g., pyroxene formation) tend to magnify the oxidation state of minerals, a factor of greatest importance for the piemontite origin. Another sources of oxygene should be looked for, though with probability, in postmagmatic emanations, deeply descending meteoric waters or in metamorphism of iron-oxide-rich rocks (e.g., itabirites). The possibility of the common source of manganese for the piemontite associated with major faults and for a part of Mn-concentrations in abyssal deposits (judging from a great number of major faults in oceanic bottom) is much suggestive.

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#### PIEMONTYT I TOWARZYSZĄCE MU MINERAŁY Z SUDETÓW (POLSKA) I WYSPY EUBEI (GRECJA)

#### Streszczenie

Swoiste paragenezy mineralne tworzy piemontyt i towarzyszące mu minerały w dwu opracowanych występowaniach, w Marcinkowie (Sudety) i Treppes (Eubea). W pierwszym z nich wraz z piemontitem stwierdzono obecność turmalinu, hematytu, fengitu, chlorytu, tytanitu, apatytu oraz kwarcu i skaleni. W drugim znaleziono ponadto ferrifengit, flogopit i granat spessartynowy. Sukcesja krystalizacji była następująca: turmalin, epidot, piemontyt, ±flogopit, ±ferrifengit (alurgit), ±granat spessartynowy, hematyt i chloryt. Turmalin należy do odmiany żelazowo-magnezowej. Epidot występuje jedynie w reliktach, zachowanych w jądrach niektórych ziarn piemontytu. Flogopit i granat spessartynowy występują rzadko i jedynie w łupkach krystalicznych w Treppes. Także i ferrifengit (alurgit) wiąże się wyłącznie z łupkami krystalicznymi, gdzie obok mikroklinu, albantu i kwarcu jest głównym minerałem. Mike tę znamionuje wysoka zawartość  $Fe^{3+}$  i skład pośredni między fengitem i ferrimuskowitem. Niewątpliwą jest również wysoka zawartość  $TiO_2$ ,  $Al_2O_3$  i  $MnO$  w hematycie. Chloryt należy do odmiany bogatej w magnez i w części jest zapewne produktem przeobrażenia fengitu. Tytanit i apatyt są charakterystycznymi minerałami akcesorycznymi. Powstanie paragenes mineralnych z piemontitem najlepiej tłumaczy działalność wód pomagmowych wzbożających w tlen. Ten ostatni jest produktem przemian (np. blasteza piroksenu) związanych z metamorfizmem progresywnym. Rewizji wymagają poglądy o powstawaniu piemontytu w warunkach facji amfibolitowej. Jest on tam zapewne produktem polimetamorfizmu, tj. nałożenia się metamorfizmu hydrotermalnego na regionalny. Godny uwagi jest przy tym częsty związek asocjacji mineralnych z epidotem i piemontitem z wielkimi dyslokacjami tektonicznymi.

#### OBJAŚNIENIA FIGUR

Fig. 1. Szkice z mikrofotografii płytka cienkich

a — łupek z Treppes z piemontitem (grube kontury), ferrifengitem (cienkie kontury), hematytem (ciemne pola), tytanitem (grube kontury w górze), kwarcem i skaleniami (punktowane kontury). Zauważ cienie rozciągania związane z rotującymi mikroporami

Fig. 2. Projekcja stereograficzna i klinograficzna kryształów piemontytu z Marcinkowej

Fig. 2. Projekcja stereograficzna i klinograficzna kryształów piemontytu z Marchi kowa

Ściany terminalne osobnika b należą do: 011, 011, 11

Fig. 3. Projekt stereograficzna i klinograficzna kryształu turmalinu z Treppes Biegun z podwójnymi pierścieniami symbolizują najbardziej rozpowszechnione ściany kryształograficzne. Sciana wycinalna została oznaczona literą x

Fig. 4. Trójkątny diagram zmienności zawartości Al,  $\text{Fe}^{3+}$  i  $\text{Mn}^{3+}$  w piemontytach (według Deera et al. 1962)

Litery M i T oznaczają okazy z Marcinkowa i Treppes, odpowiednio

Fig. 5. Diagram trójkątny (za Winchellem) przedstawiający zmienność składu alufigitów i pokrewnych minerałów  
Cyfry przy punktach projekcyjnych mają objaśnienie w zestawieniu formuł krystalochemicznych. Strzałki odzwierciedlają względną zawartość manganu w mikach

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## ПЬЕМОНТИТ И СОПУТСТВУЮЩИЕ МИНЕРАЛЫ В СУДЕТАХ (ПОЛЬША) И НА О. ЭВБЕЯ (ГРЕЦИЯ)

## РЕЗЮМЕ

В исследованных рудопроявлениях Марцинкув (Судеты) и Треппес (о. Эвбей) пьемонтит и сопровождающие его минералы образуют своеобразные минеральные парагенезисы. В первом из этих месторождений вместе с пьемонтитом встречаются турмалин, гематит, фенгит, хлорит, титанит, апатит, а также кварц и полевые шпаты. Во втором, кроме перечисленных минералов, распространены феррифенит, флогопит и спессартиновый гранат. Последовательность кристаллизации была следующая: турмалин, эпидот, пьемонтит,  $\pm$  феррифенит (алургит),  $\pm$  спессартиновый гранат, гематит и хлорит. Турмалин относится к железисто-магниевой разновидности. Эпидот встречается единственно в виде реликтов, сохранившихся в ядрах некоторых зерен пьемонтита. Флогопит и спессартиновый гранат встречаются редко и лишь в кристаллических сланцах месторождения в Треппес. Феррифенит (алургит) тоже связан с кристаллическими сланцами, в которых наряду с микроклином, альбитом и кварцем принадлежит к главным минералам. Эта слюда отличается высоким содержанием  $Fe^{3+}$  и характеризуется промежуточным составом между фенгитом и ферримусковитом. Исключительно высокое содержание  $TiO_2$ ,  $Al_2O_3$  и  $MnO$  отмечено в гематите. Хлорит представлен разновидностью богатой магнием и частично является, по-вероятности, продуктом преобразования фенгита. Титанит и апатит представляют типичные акцессорные минералы. Образование минеральных парагенезисов с пьемонтитом лучше всего объясняется деятельностью постмагматических вод, обогащенных кислородом. Пьемонтит

является продуктом преобразования (например, бластез пироксена), связанного с прогрессивным метаморфизмом. Пересмотрения требуют взгляды об образовании пьемонтита в условиях амфиболитовой фации. В этих условиях он представляет, очевидно, продукт полиметаморфизма, т.е. наложения гидротермального метаморфизма на региональный. Внимания заслуживает часто наблюдающаяся связь минеральных ассоциаций с эпидотом и пьемонтитом с крупными тектоническими дислокациями.

## ОБЪЯСНЕНИЯ К ФИГУРАМ

Фиг. 1. Схематические зарисовки по микрофотоснимкам шлифов  
 а — сланец из Треппес с пьемонитом (жирные контуры), феррифенитом (тонкие контуры), гематитом (темное поле), титанитом (жирные контуры вверху), кварцем и полевыми шпатами (пунктирные контуры). Видны тени растяжения, связанные с обращением микропорфиробластов пьемонита. Увел. 23×, б — контакт сланца с выделениями богатыми микроклином. В некоторых зернах пьемонита наблюдаются реликтовые ядра эпиллита. Вверху две чешуйки хлорита и маленькие зерна титанита, выраженные отчетливо. Треппес, увел. 20×. в — замещение пьемонита гематитом, в виде прожилков, использующих трещинки сланцеватости. Участки в пьемоните, отмеченные пунктиром, представляют эпиллит. Вверху два зерна кварца (чистые поля), внизу — микроклин. Марцинкун, увел. 21×

Фиг. 2. Стереографическая и клинографическая проекции кристаллов пьемонита из месторождения Марцинкув  
Термические грани юнипика представлена:  $011$ ,  $0\bar{1}\bar{1}$ ,  $\bar{1}11$

Фиг. 3. Стереографическая и клинографическая проекции кристалла турмалина из месторождения в Треппес  
Полюса с двойными кольцами обозначают самые распространенные кристаллографические

Фиг. 4. Треугольная диаграмма колебаний содержания  $\text{Al}$ ,  $\text{Fe}^{3+}$  и  $\text{Mn}^{3+}$  в пьемонтитах (по Дирк и пр., 1962)

Фиг. 5. Треугольная диаграмма (по Винчеллу), представляющая переменный состав аулургитов и близких минералов. Числа вблизи точек проекции объяснены в сопоставлении кристаллохимических формул. Стрелками показано относительное содержание марганца в слюдах.