Geol. vjesnik	Vol. 41	str. 145—157	Zagreb 1988.

UDC 552.43:549.6 *Izvorni znanstveni rad*

Andalusite-bearing Schists from the Southwestern Parts of Papuk Mt. in Slavonija (Northern Croatia)

Jakob J. PAMIĆ[1], Gyöngyi LELKES-FELVARI[2] and Petar RAFFAELLI[3]

[1]*Geološki zavod, Sachsova 2, YU — 41000 Zagreb*
[2]*Magyar Allami Földtani Intezet, Nepstadion 14, H — 1442 Budapest*
[3]*INA-Naftaplin, Šubićeva 29, YU — 41000 Zagreb*

U kristalastim škriljavcima jugozapadnih obronaka Papuka utvrđeno je novijim istraživanjima prisustvo andaluzita. On se javlja zajedno sa staurolitom i almandinom u tinjčevim škriljavcima i gnajsevima viših dijelova progresivno metamorfozirane sekvencije koji su nastali u PT-uvjetima amfibolitskog facijesa za vrijeme hercinske orogeneze. U radu su prikazane mineralne parageneze, kemizam nekih karakterističnih minerala i mikrostrukturne karakteristike stijena progresivno metamorfozirane sekvencije. Na kraju su data i neka petrogenetska razmatranja.

Andalusite-bearing schists have recently been identified in the southwestern parts of Papuk Mt. Andalusite is found with staurolite and almandine in mica schists and gneisses of a progressivelly metamorphosed sequence which was formed under PT-conditions of amphibolite facies during the Hercyinian orogeny. Mineral paragenesis, its microprobe chemical composition, and microtextural features of the progressivelly metamorphosed sequence are presented and, at the end, some petrogenetic considerations are given.

INTRODUCTION

Metamorphic rocks of the Slavonian Mountains Psunj, Papuk, and Krndija have been studied by numerous authors. Kišpatić (1891, 1892, 1910 and 1910a) was the first to describe garnet, staurolite, sillimanite, kyanite and chloritoid bearing schists giving the basis for metamorphic petrology of metamorphic complexes of Slavonian Mountains. Raffaelli (1965) presented a prograde metamorphic sequence from Ravna Gora in Papuk Mt. and Vragović (1965) described migmatites and associated anatectic granites from Papuk Mt. Recently Jamičić (1983) separated in the Slavonian Mountains: (1) the Psunj (or Kutjevo) complex made up of gneiss, mica schist, and amphibolite with granitoids; (2) the Papuk (or Jankovac) complex made up of the same schists accompanied by migmatites and anatectic granites, and (3) the Radlovac complex consisting of slate, phyllite, and schistose metasandstone invaded by metadiabase and ophitic metagabbro (Pamić and Jamičić, 1986).

Pamić (1986) emphasized in his review that metamorphic rocks from the Slavonian Mountains have some characteristics of a Barrovian-type prograde metamorphic sequence which occurs both in the Psunj and Papuk complexes, separated by Jamičić (1983). Most recently, Pamić (1987) described the occurrence of andalusite in Psunj Mt., and this was the first record of this mineral in metamorphic complexes of Slavonian Mountains.

Afterwards other occurrences of andalusite have been identified in metamorphic rocks of Papuk Mt. The aim of this paper is to present first data on andalusite-bearing schists from this area. Our data indicate that andalusite-bearing schists are not uncommon in the metamorphic complex of the largest Slavonian Mountain Papuk.

Basic Data on Progresive Metamorphic Sequences of The Slavoniam Mountains

All available petrographic data (Kišpatić, 1891, 1892 and 1910; Raffaelli, 1965; Vragović, 1965; Tajder, 1969; Marci, 1973 and 1979; Jamičić, 1983 and others) show that the metamorphic complexes of the Slavonian Mountains associated with granitoids consist of gneiss, mica schist, amphibolite, greenschist, phyllite, quartzite and marble. Raffaelli (1965) was the first to discover the existence of a progressivelly metamorphosed sequence in Ravna Gora in the southwestern parts of Papuk Mt. which shows a distinct zonation: chlorite—biotite—garnet—staurolite—sillimanite. The prograde sequence originated under PT-conditions of greenschist and amphibolite facies and its highest grade parts grade into migmatites associated with anatectic granitoids. Recently, Slovenec (1982 and 1984) analyzed garnet and biotite from paragneisses and mica schists from the progressivelly metamorphosed sequence in Koturić potok in Ravna Gora and, using Perčuk's garnet-biotite geothermometre, he concluded that these two minerals were formed at a temperature of about 550—590 °C.

Raffaelli (1965) has not found kyanite in the sequence but he pointed out its occurrence in heavy fraction of recent sediments of the surrounding rivers. However, kyanite was found many years ago by Kišpatić (1910) and recently, Jamičić (1983) emphasized its common presence in the amphibolite facies rocks in the eastern parts of Papuk Mt. and in Krndija Mt. Kyanite occurs in the same mica schists and gneisses which stretch from Krndija Mt. to the southwestern parts of Papuk Mt. where it is most probably absent.

The prograde metamorphic sequence grades into migmatites only in the western parts of Papuk Mt. In other parts of the Slavonian Mountains (Psunj, Krndija and eastern parts of Papuk) it is invaded by I-granitoids which are characteristically cataclastic and in some places associated with quartz diorite, monzodiorite and gabbro (Marci, 1973; Pamić, 1987a; Pamić et al., 1984).

High-grade metamorphic rocks from central parts of the Slavonian Mountains have been for a long time considered as Archaean as distinguished from adjacent lower-grade metamorphic rocks of presumed Paleozoic (mostly Carboniferous) age (Gorjanović-Kramberger, 1897; Koch, 1919; Poljak, 1952). Raffaelli (1965) and Tajder (1969) presumed that the whole prograde metamorphic sequence and migmatites originated from Paleozoic low-grade rocks during the Hercynian orogeny. Disregarding published radiometric data, Jamičić (1983) assumed on the basis of his structural analysis that the Psunj complex, i. e. the prograde metamorphic sequence with I-granitoids belongs to the Baikalian orogeny, whereas the Papuk complex, i. e. the prograde metamorphic sequence grading into migmatites he included within the Caledonian orogeny.

Deleon (1969) presented radiometric data for migmatites from Papuk Mt. which gave 279 to 285 Ma (Late Permian to Early Carboniferous). Recent K-Ar and Rb-Sr determinations of a research still in progress point mostly to the Hercynian age of the prograde metamorphic sequence regardless of being migmatized, invaded by I-granitoids or even without any granitoids (Pamić, 1987a).

PROGRADE METAMORPHIC SEQUENCE IN THE SOUTHWESTERN PARTS OF PAPUK MT.

Field Data

Systematic and detailed sampling was carried out along the Koturić, Mijači and Samanovica Creeks in the area of Ravna Gora, in southwestern parts of Papuk Mt. (Figure 1) where Raffaelli (1965) found the above mentioned progressive metamorphic sequence with a distinct zonation from chlorite up to sillimanite.

The area under investigation is rather monotonous in lithology and consists of rocks of semipelitic-pelitic and psammitic origin which are represented by quartz phyllite and albite-muscovite-chlorite-quartz schist in lower-grade part, and mostly by mica schists and gneisses in the higher-grade part of the sequence. These schists are isoclinally folded with distinct southern vergence. Their dip direction is mostly in the range of N20W to N5W; they are steeply inclined between 60 to 70^0. Metamorphic grade increases from the south to the north as it has been recognized by Raffaelli (1965).

The characteristic minerals can be recognized by naked eye so that chlorite, biotite, garnet, staurolite and sillimanite zones can be easily mapped in the field. The lowermost parts of the progressive sequence are covered by Neogene sediments (Figure 1) and the boundary between lower and higher grade rocks is not sharp so that they repeatedly occur in southern parts of the sampled cross-section in Koturić Creak (points 4 to 6 in Figure 2).

Petrological Data

The structure of rocks of the prograde metamorphic sequence is displayed by compositional, modal and granulometric banding. The thickness of individual bands varies from 0.5—1 mm up to 5—10 mm. Continuous and crenulation cleavage alternate determined by quartz poor and quartz enriched layers. Separate layers are mostly granolepidoblastic and lepidoblastic in microtexture. Differences in the size of grains of individual layers can be recognized in lower-grade rocks together with microaugen texture.

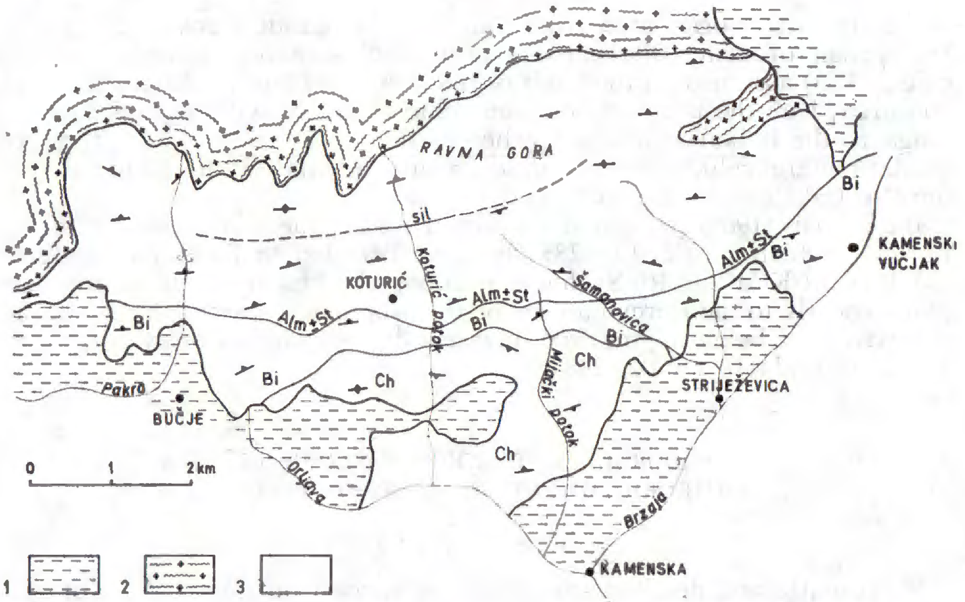

Fig. 1. Schematic geological map of the area of Ravna Gora in Papuk Mt. (R a f f a e l l i, 1965).

Sl. 1. Shematizirana geološka karta područja Ravne gore na Papuku (R a f a e l l i, 1965).
1 — Neogene (neogen), 2 — migmatitic complex of Papuk Mt. (papučki migmatitski kompleks), 3 — progressivelly metamorphosed sequence (progresivno metamorfozirana sekvencija);
Ch — chlorite zone (kloritna zona), Bi — biotite zone (biotitna zona), Alm ± St — almandine-staurolite zone (almandinsko-staurolitna zona), Sil — sillimanite zone (silimanitska zona)

Mineral assemblages display a distinct increasing grade:

quartz + albite + muscovite + chlorite ± epidote

quartz + albite + muscovite + chlorite + biotite

quartz + albite + muscovite + biotite + garnet

quartz + oligoclase + muscovite + biotite + garnet + staurolite

quartz + oligoclase + muscovite + biotite + garnet + staurolite + andalusite

quartz + oligoclase + biotite + garnet + andalusite + sillimanite ± muscovite

Accessory minerals are apatite, zircon, tourmaline, ilmenite, magnetite and graphite.

Mineral assemblages are listed in Table 1. For a better correlation, locations of samples are marked on the enclosed cross-section along Koturić Creek (Figure 2).

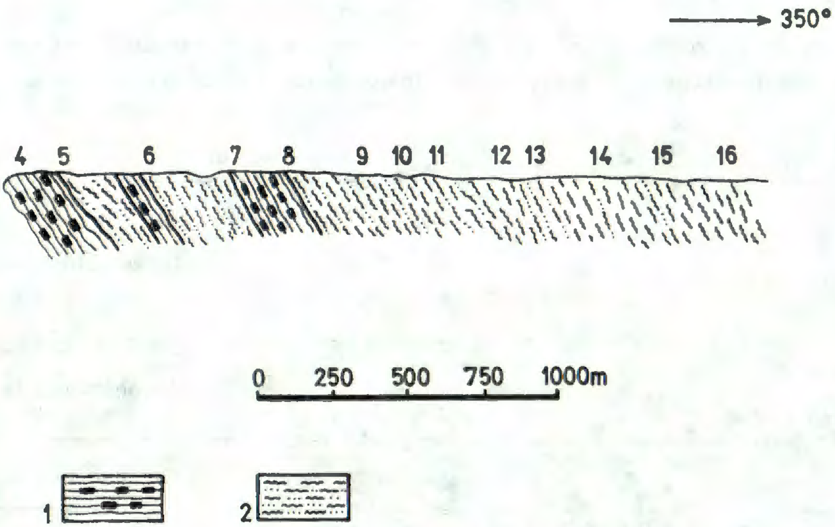

Fig. 2. Cross-section in progressivelly metamorphosed sequence along Koturić Creek.

Sl. 2. Profil u progresivno metamorfoziranoj sekvenciji u Koturić potoku.

1 — lower grade rocks of greenschist facies (niže metamorfozirane stijene grinšistnog facijesa), 2 — higher grade rocks of amphibolite facies (više metamorfozirane stijene amfibolitskog facijesa).

Microprobe chemical composition of biotite, garnet, and staurolite is presented in Table 2.

In *lower-grade rocks* quartz is fine-grained, xenoblastic or forms polycrystalline monomineralic microaugens or the bimineralic ones together with albite. It crystallized as a coarser-grained mosaic in the pressure shadows of the microaugens.

Albite makes up a granoblastic, fine-grained mosaic with quartz or sericitized microaugens. Chessboard albite has been rarely found. Its composition varies and in the chlorite zone it averages An_5 and with the occurrence of biotite it changes up to An_{15} (Raffaelli, 1965).

Muscovite, commonly as a fine-grained sericite aggregate forms very thin laminae around microaugens containing some coarser flakes. With increasing grade it grows larger marking the schistosity.

Biotite is much more common and it appears at first in tiny flakes in the pressure shadows of microaugens. With increasing grade it becomes more abundant and larger like muscovite, making up well crystallized layers poor in quartz, or is clustered in quartz rich layers. A coarser-grained biotite of a second generation indicates the direction of the second (axial-plane) schistosity (Plate I, photo 1).

Chlorite is associated with muscovite and biotite. Its quantity decreases as the grade increases, and it disappears entirely in the garnet zone.

Garnet occurs in low-grade rocks in pelitic microlayers where it is commonly broken and chloritized to various degrees.

Table — Tabela 1.

Mineral assemblages in prograde metamorphic sequence in Koturić Creek

Mineralne parageneze u progresivno metamorfoziranoj sekvenciji Koturić potoka

Sample numbers	Qz	Ab	Ch_1	Ch_2	Ms	Bi_1	Bi_2	Gr	And	St	Sil	
4—1 to 4—3	+	+	+		+							
4—4 to 4—8	+	+	+		+	+						
4—9	+	+	+		+	+		+				Greenschist facies
4—10	+	+	+		+	+						
4—11	+	+			+	+		+				
5—1	+	+		+	+	+		+		+		
5—2	+	+		+	+	+		+	+	+		Amphibolite facies
5—3 to 5—4	+	+			+	+		+		+		
5—5	+	+	+		+	+		+				Greenschist facies
6—1	+	+				+		+				
6—2	+	+		+	+	+		+		+		
6—3	+	+		+	+	+	+	+		+		
6—4	+	+			+	+		+		+		
6—5	+	+		+	+							Amphibolite facies
6—6	+	+		+		+		+				
6—7	+	+		+	+	+		+				
6—8 to 6—10	+	+			+	+		+		+		
7—1	+	+	+		+	+						Greenschist facies
7—2 to 7—3	+	+			+	+		+				
7—4	+	+			+	+		+				
8—1	+	+		+	+	+		+				
8—2 to 8—6	+	+		+	+	+		+		+		
9	+	+		+	+	+		+		+		
10—1 to 10—2	+	+		+	+	+		+		+		
11—1	+	+		+	+	+		+		+		
11—2	+	+		+	+	+		+	+	+		Amphibolite facies
12—1 to 12—3	+	+			+	+		+		+		
13	+	+			+	+		+		+	+	
14	+	+			+	+		+			+	
14—1	+	+			+	+						
15	+	+			+	+			+		+	
15—1	+	+			+	+		+	+		+	
16	+	+		+	+	+		+			+	
16—1	+	+			+	+		+			+	

Qz — quartz, Ab — albite, Ch_1 — first generation chlorite, Ch_2 — second generation chlorite, Ms — muscovite, B_1 — first generation biotite, Bi_2 — second generation biotite, Gr — garnet, And — andalusite, St — staurolite, Sil — sillimanite.

Table — Tabela 2.

Biotite, staurolite and garnet microprobe chemical composition

Kemijski sastav biotita, staurolita i granata dobiven mikrosondom

	Biotite						Staurolite							Garnet			
	16	16	16	16	16	16	11—1	11—1	11—1	11—1	11—3	11—3	11—3	11—2	11—2	11—2	11—2
SiO_2	34,96	35,06	34,74	36,05	35,73	35,07	28,23	28,55	28,25	27,64	28,47	28,12	27,46	34,61	34,37	35,36	34,10
TiO_2	1,78	1,59	1,91	1,95	1,85	1,70	0,58	0,39	0,62	0,36	0,70	0,45	0,34	0,00	0,10	0,00	0,00
Al_2O_3	19,19	18,50	18,48	18,66	18,62	18,92	55,80	55,22	56,66	56,63	57,55	56,22	55,50	21,04	20,35	20,38	20,75
FeO*	19,73	19,79	20,85	19,77	20.46	19,82	13,17	12,90	12,72	12,30	12,58	12,22	12,07	35,57	34,86	34,36	35,00
MnO	0,14	0,15	0,13	0,19	0,11	0,11	0,26	0,38	0,24	0,34	0,28	0,26	0,29	4,37	4,47	4,51	4,58
MgO	10,30	10,58	10,27	10,32	10,21	10,29	0,88	1,04	0,92	0,99	1,12	1,04	1,08	3,16	3,09	2,86	3,30
CaO	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	0,09	0,00	0,10	0,00	0,00	0,01	0,00	1,31	2,04	2,78	1,30
Na_2O	0,12	0,45	0,00	0,41	0,25	0,53	0,00	0,07	0,03	0,11	0,06	0,04	0,20	n. d.	n. d.	n. d.	n. d.
K_2O	8,50	8,16	7,55	7,70	8,14	8,46	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.

* Total iron as FeO

	Cations per unit cell normalized to 22 O						Structural formulas based on 47 O							Molecular proportion				
Si	5,341	5,381	5,356	5,454	5,420	5,356	7,869	7,985	7,812	7,729	7,769	7,849	7,789					
Al^{IV}	2,660	2,619	2,644	2,546	2,580	2,644	0,131	0,015	0,188	0,271	0,231	0,151	0,211	75,2	73,4	72,2	74,1	Alm
Al^{VI}	0,795	0,728	0,713	0,781	0,749	0,761	18,200	18,189	18,280	18,389	18,280	18,348	18,345	11,9	11,6	10,7	12,5	Py
Ti	0,204	0,183	0,222	0,221	0,211	0,195	0,121	0,083	0,128	0,076	0,145	0,094	0,072	9,4	9,5	9,6	9,8	Sp
Fe	2,521	2,541	2,687	2,501	2,596	2,532	3,070	3,016	2,943	2,876	2,871	2,854	2,863	3,5	5,5	7,5	3,6	Gr
Mn	0,018	0,019	0,017	0,024	0,014	0,014	0,061	0,080	0,057	0,079	0,065	0,062	0,068					
Mg	2,344	2,422	2,359	2,327	2,309	2,342	0,364	0,433	0,380	0,412	0,464	0,433	0,457					
Ca	—	—	—	—	—	—	0,026	—	0,029	—	—	0,003	—					
Na	0,038	0,135	—	0,122	0,073	0,156	—	0,039	0,118	0,057	0,029	0,023	0,107					
K	1,655	1,598	1,486	1,487	1,575	1,648	—	—	—	—	—	—	—					

11—1, 11—2, 11—3 and 16 — number of samples (see Table 1 and Figure 2), Alm — almandine, Py — pyrope, Sp — spessartite, Gr — grossulare

Medium-grade rocks are characterized by better organized texture due to more perfect preferred orientation and recrystallization. Distinct signes of polyphase deformations are visible in these rocks as well.

In lower part of this grade garnet forms postkinematic idioblasts with small quartz inclusions ($s_i = s_e$). It shows only in some thin sections postcrystalline fragmentation. Rocks from higher parts of the grade contain garnets with a more complex history. They have sigmoidal inclusion-rich synkinematic core and inclusion-free postkinematic rim (Plate I, photo 2). Microprobe chemical composition (Table 2) indicates that the garnet is enriched in almandine with subordinate quantities of spessartite, pyrope and grossulare. Chemical composition of the synkinematic core of a garnet crystal from amphibolite facies rocks with almandine content in the range 70 to 80 per cent points to its formation under PT-conditions of upper greenschist facies. In some garnets straight s_i is oblique to s_e and the matrix shows flattening effects around them. Coarser-grained pressure shadows composed of quartz and biotite fill up these areas.

Biotite of medium-grade zone shows an intense brown-reddish pleochroism. Its is illustrated by data of chemical analyses (Table 2) which also indicate that it belongs to Fe = Mg biotite represented mostly by 1M polytype (Slovenec, 1982 and 1984).

Plagioclase, containing up to 25 per cent of An, occurs commonly in hypidioblastic twinned grains in quartz enriched layers. It replaces albite beginning with the occurrence of staurolite.

Staurolite is almost as frequent as garnet and the former makes up large postkinematic poikiloblasts in the lower part of amphibolite facies rocks (Plate II, photo 3) or small idioblasts or xenoblastic inclusions in andalusite poikiloblasts in the higher parts of the same facies (Plate II, photo 4). Its crystallization can be interpreted in some thin sections as postkinematic with respect to the development of matrix schistosity and as prekinematic with respect to its deformation (slight flattening and folding of the matrix around them). Microprobe chemical composition of staurolite is presented in Table 2. It fits with the composition of staurolite in common aphibolite facies rocks (Deer et al., 1962).

Andalusite is much more subordinate than staurolite. The former can be found as long poikiloblast in deformed quartz segregations or as big poikiloblasts oblique to the schistosity containing quartz, muscovite, biotite and staurolite inclusions (Plate III, photo 5). Because of the first record of andalusite in the western parts of Papuk Mt., its presence was checked both by optics and X-ray.

Sillimanite is much more frequent than andalusite. The sillimanite is associated manly with biotite forming small straight, or big long and crenulated fibrolites whose deformation is stronger than that of the surrounding biotite-rich domain. Stout single sillimanite prisms surrounded by fibrolite could be observed only in some thin sections (Plate III, photo 6). Only in one sample andalusite and sillimanite were found together but they had no mutual contact. Andalusite-bearing mica rich layer was surrounded by fibrolitic sillimanite.

Big postkinematic muscovite poikiloblasts with sillimanite or andalusite inclusions can be observed in medium-grade rocks.

Effects of retrogradation are shown mostly in chloritization of biotite and garnet and in sericitization of staurolite and sillimanite. Chloritization of biotite is accompanied by separation of acicular rutile (sagenite). Crystalization of small chlorite flakes in big pseudomorphs after staurolite is scarce.

DISCUSSION

On the basis of microtextural analysis the crystallization history of the progressively metamorphosed sequence from the southwestern parts of Papuk Mt. can be interpreted as follows! In the lower-grade rocks synkinematic crystallization of quartz + albite + muscovite + chlorite + biotite make up the first schistosity (s_1) which was crenulated. An axial-plane schistosity (s_2) is enhanced by crystallization of a second generation biotite.

In the medium-grade rocks recrystallization of former textures is almost complete and earlier schistosity directions can be traced by the preferred orinetation of small inclusions in poikiloblasts. The principal schistosity is displayed by synkinematic quartz + plagioclase + muscovite + biotite crystals. Garnet formed partly during and partly after the main crystallization, i.e., schistosity. Staurolite and andalusite originated after the deformation which produced the principal schistosity but before its crenulation. Andalusite is later than staurolite but earlier than sillimanite.

According to mineral assemblages and microtextural observations, rocks from the investigated sections represent a progressively metamorphosed sequence beginning with the lower part of greenschist and grading up to the upper part of amphibolite facies as it has been proposed by Raffaelli (1965). The distance between the rocks of the chlorite zone and the rocks of the sillimanite zone on the cross-section in Koturić Creek is maximally about 1 200 — 1 300 metres in less disturbed parts of the prograde sequence.

The characteristic Al_2SiO_5 polymorphs of the sequence are andalusite and sillimanite. In addition, almandine-rich garnet and staurolite are widespread in these rocks.

The presence of andalusite and the rapid succession of the mineral zones can be related to a metamorphic event characterized by a comparatively high thermal gradient (Sassi et al., 1979). Preliminary isotopic data indicate that it probably took place during the Hercynian orogeny.

The prograde metamorphic sequence of the southwestern parts of Mt. Papuk exhibits some pecularities which distinguishes it from both the well known Abukuma and Barrovian-type sequences. According to Miyashiro (1961), the prograde sequence from the southwestern parts of Papuk Mt. is a facies series which falls in the low pressure-intermediate group, and according to Carmichael (1978) it can be included within his bathozones 1, 2 and 3.

The findings of andalusite in the Mts. Papuk and Psunj make the problem of the metamorphic sequences of the Slavonian mountains more complex. It is quite evident that kyanite also occurs in some areas of the

Slavonian metamorphic terrenes (Kišpatić, 1910 and Jamičić, 1983) and its presence points to medium thermal gradient conditions. By contrast, the new findings of andalusite suggest high thermal gradient conditions.

As so far we have not found these two Al_2SiO_5 polymorphs in the same rock, we have no data if we are dealing with two distinct metamorphic events (or phases) characterized by contrasting thermal gradients, or we have a special geothermal regime with a thermal gradient around 40 °C/km.

The fact is that our kyanite bearing metamorphic rocks show more complicated deformational history and are strongly retrogressed and thus indicate that they might belong to an older stage. This would imply a high thermal overprint on an earlier intermediate thermal gradient metamorphism.

The data so far available do not make possible to give a definite conclusion. Additional field work, petrologic and radiometric investigations are in progress to resolve this problem.

Received: 28. 12. 1987.

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Andaluzitski škriljavci iz jugozapadnih dijelova Papuka u Slavoniji

J. Pamić, Gy. Lelkes-Felvari i P. Raffaelli

Metamorfni kompleks slavonskih planina, kojeg su proučavali brojni autori (K i š p a t i ć, 1891, 1892 i 1910; R a f f a e l l i, 1965; V r a g o v i ć, 1965; T a j d e r, 1969; M a r c i, 1973 i 1979; J a m i č i ć, 1983 i dr.), izgrađen je od gnajseva, mikašista, amfibolita, zelenih škriljavaca, filita, kvarcita i mramora. U njemu je R a f f a e l l i (1965) prvi utvrdio na Ravnoj gori progresivno metamorfoziranu sekvenciju s jasnom zonalnošću: klorit—biotit—granat—staurolit—silimanit, koja je kasnije zapažena i na drugim lokalitetima (J a m i č i ć, 1983), i to mjestimice s kijanitom kojeg je K i š p a t i ć (1910) već davno zapazio. Ova progresivna sekvenca, koja bi po navedenoj zonalnosti i prisustvu kijanita, mogla odgovarati barovijenskoj, u zapadnim dijelovima Papuka postupno prelazi u migmatite. No, u većem dijelu slavonskih planina (Psunj, istočni dio Papuka i Krdija) ona je isprobijana s I-granitima, koji su pretežno kataklazirani i na nekim mjestima udruženi s intermedijarnim i mafitskim intruzivnim stijenama (M a r c i, 1973; P a m i ć, 1987a; P a m i ć et al., 1984).

Različiti autori pripisivali su različitu starost metamorfnom kompleksu slavonskih planina: arhajsku (G o r j a n o v i ć - K r a m b e r g e r, 1897; K o c h, 1919; P o l j a k, 1952), hercinsku (R a f f a e l l i, 1965; V r a g o v i ć, 1965; T a j d e r, 1969) i bajkalsku i kaledonsku (J a m i č i ć, 1983). Izotopna određivanja D e l e o n a (1969) pokazuju da su papučki migmatiti nastali u hercinskoj orogenezi, a vjerojatno su iste starosti, prema preliminarnim radiometrijskim određivanjima, i stijene progresivno metamorfozirane sekvencije u širem području slavonskih planina (P a m i ć, 1897a).

Andaluzit i kordijerit su nedavno po prvi puta određeni u stijenama metamorfnog kompleksa Psunja (P a m i ć, 1987). Kasnije je andaluzit otkriven u istom metamorfnom kompleksu i u drugim dijelovima slavonskih planina, i cilj je ovog rada da se dade petrološki prikaz metamorfnih stijena s andaluzitom iz jugozapadnih dijelova Papuka.

Progresivno metamorfozirani kompleks sjeverozapadnih dijelova Papuka

Sistematsko je uzorkovanje obavljeno u potocima Koturić, Mijači i Šamanovica (sl. 1), u području gdje je Raffaelli (1965) zapazio navedenu zonalnost. Ono je dosta monotonog litološkog sastava i izgrađeno od kvarcnih filita, grinšista, paragnajseva i mikašista. Oni su izoklino borani s jasnom južnom vergencijom i sa različitim indeksima boranja (sl. 2).

Stijene progresivno metamorfozirane sekvencije imaju jasne kompoziciono i modalno vrpčaste teksture i granolepidoblastičnu i lepidoblastičnu, nekad i okcastu strukturu. Mineralna parageneza pokazuje jasan progresivan karakter idući od juga ka sjeveru (tabela 1). Kemijski sastav nekih petrogenih minerala, dobiven mikrosondom, prikazan je na tabeli 2.

Stijene nižeg stupnja metamorfizma, koje su sitnozrnije, sadržavaju kvarc, često u vidu mikrookcastih nakupina, klorit, albit, muskovit, biotit i granat. Zapažene su dvije generacije biotita; krupni postkinematski biotit definira drugu fazu uškriljavanja (tabla I, sl. 1). Količina se klorita postupno s povećanjem metamorfnog stupnja smanjuje, tako da on potpuno nestaje u granatnoj zoni.

Stijene višeg metamorfnog stupnja jače su rekristalizirane, krupnozrnije s izraženijom paralelnom teksturom i jasnim znakovima polifaznih deformacija. U donjim dijelovima se almandinom bogati granat javlja kao postkinematski idioblast s uklopcima kvarca, dok u stijenama iz viših dijelova ima sigmoidalno sinkinematsku jezgru bogatu inkluzijama i postkinematsku ovojnicu bez inkluzija (tabla I, sl. 2). Bazični oligoklas, namjesto albita, počinje se javljati zajedno sa staurolitom koji dolazi kao krupni pojkiloblast ili pak kao sitni idioblast ili uklopak u pojkiloblastima andaluzita (tabla II, sl. 3 i 4), tako da je on nastajao i u postkinematskoj i u prekinematskoj fazi.

Andaluzit, čije je prisustvo dokazano optičkom i rentgenskom metodom, javlja se kao izduženi porfiroblast i kao krupan pojkiloblast (okomit na škriljavost) s uklopcima kvarca, muskovita, biotita i staurolita (tabla III, sl. 5). Silimanit je većinom asociran s biotitom kao izduženi i krenulirani fibrolit, rijetko u jasnim prizmatskim kristalima (tabla III, sl. 6).

Efekti retrogradnih promjena izraženi su u kloritizaciji biotita i granata, te u sericitizaciji staurolita i silimanita. Rijetko se javlja krupan muskovit s inkluzijama silimanita i andaluzita, kao i klorit po staurolitu.

Diskusija

U stijenama nižeg metamorfnog stupnja sinkinematski kvarc + muskovit + albit + klorit + biotit tvore prvu škriljavost (s_1) koja je krenulacijom dala drugu škriljavost (s_2) markiranu drugom generacijom biotita. U stijenama amfibolitskog facijesa primarna škriljavost se zbog rekristalizacije može pratiti samo preko orijentacije uklopaka u pojkiloblastima. Glavnu škriljavost markiraju sinkinematski kvarc, feldspat, muskovit i biotit, te granat nastao djelomice u drugoj fazi. Staurolit i andaluzit formirani su nakon boranja i glavnog metamorfnog događaja koji je dao glavnu škriljavost, no prije njezinog krenuliranja. Andaluzit je kasniji od staurolita no mlađi od silimanita.

Mineralne parageneze progresivno metamorfnog kompleksa nastale su u PT-uvjetima grinšistnog i amfibolitskog facijesa (Raffaelli, 1965). Udaljenosti između stijena kloritne i silimanitne zone iznose na obrađenim profilima do 1.2000—1.300 m u neporemećenim dijelovima sekvencija. Prisustvo andaluzita i dosta brze izmjene pojedinih mineralnih zona ukazuju da je pri metamorfizmu morao biti relativno visok geotermijski gradijent.

Progresivno metamorfozirana sekvencija jugozapadnih dijelova Papuka ima specifične karakteristike koje je odvajaju od sekvencija Abukuma i Barroviena. Po Miyashiru (1961) ona bi odgovarala facijelnoj seriji intermedijarne grupe amfibolitskog facijesa, dok bi po Carmichaelu (1978) padala u njegove batozone 1, 2 i 3.

Nalasci andaluzita na Papuku i Psunju usložnjavaju problematiku progresivno metamorfoziranih sekvencija slavonskih planina. Sasvim je sigurno, i to se već davno zna, da se u njima na nekim mjestima pojavljuje disten (Kišpatić, 1910 i Jamičić, 1983) čije prisustvo ukazuje na uvjete umjerenih geotermalnih gradijenata.

Budući da mi nismo uspjeli naći disten i andaluzit zajedno u istoj stijeni, to mi zasad ne možemo biti sigurni da li se u našem konkretnom slučaju radi o dva jasno odvojena metamorfna događaja (faze) s kontrastnim geotermalnim gradijentima ili pak o nekom specifičnom geotermalnom režimu s geotermalnim gradijentima oko 40 °C.

Činjenica je da su naše metamorfne stijene s distenom jače deformirane i znatno retrogradirane što ukazuje na mogućnost da su mogle nestati u nekoj starijoj fazi. To bi onda govorilo da su visoki temperaturni gradijenti (andaluzit) utisnuti na raniji metamorfizam (disten) umjerenih geotermalnih gradijenata. Današnja raspoloživa faktografija ne pruža mogućnost povlačenja definitivnog zaključka. Taj se problem treba riješiti dodatnim terenskim radovima i petrološkim i radiometrijskim ispitivanjima koja su u toku.

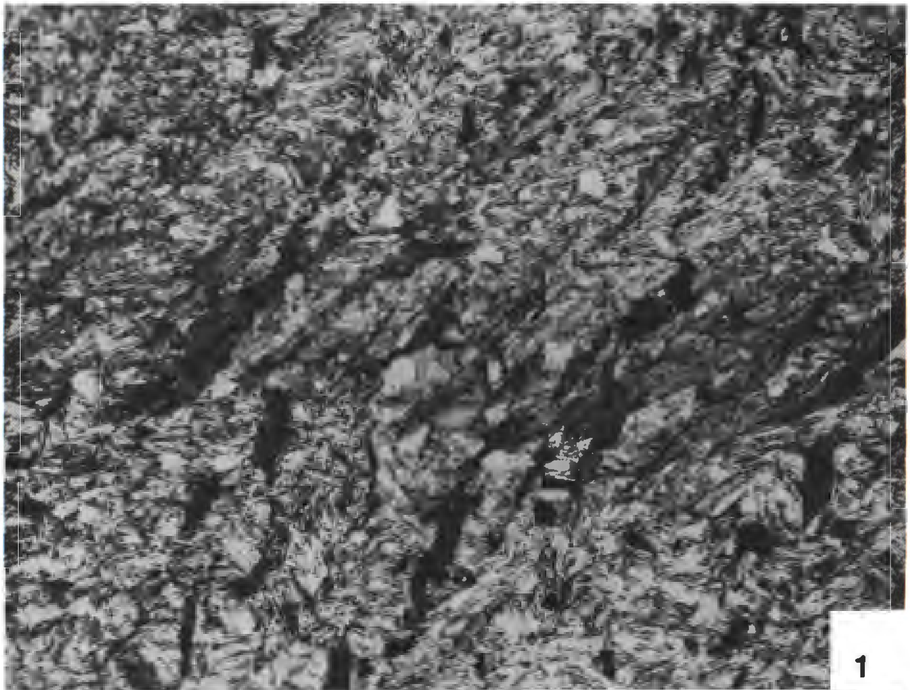
PLATE — TABLA I

1. Coarser biotite of a second generation marking the second (axial plane) schistosity. Magnif. 100 ×.

1. Krupni biotit druge generacije koji definira sekundarnu škriljavost duž aksijalne površine. Poveć. 100 ×.

2. Garnet porphyroblast with sigmoidal inclusion-rich synkinematic core and inclusion-free postkinematic rim. Magnif. 100 ×.

2. Granatni porfiroblast sa sinkinematskom jezgrom obogaćenim inkluzijama i postkinematskim ovojem bez inkluzija. Poveć. 100 ×.



1

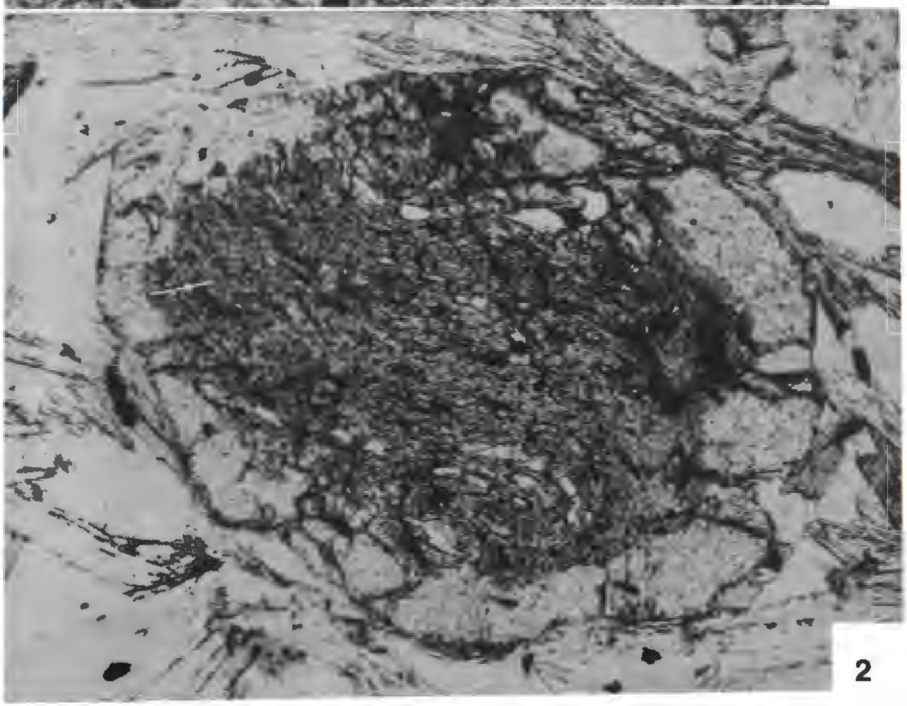


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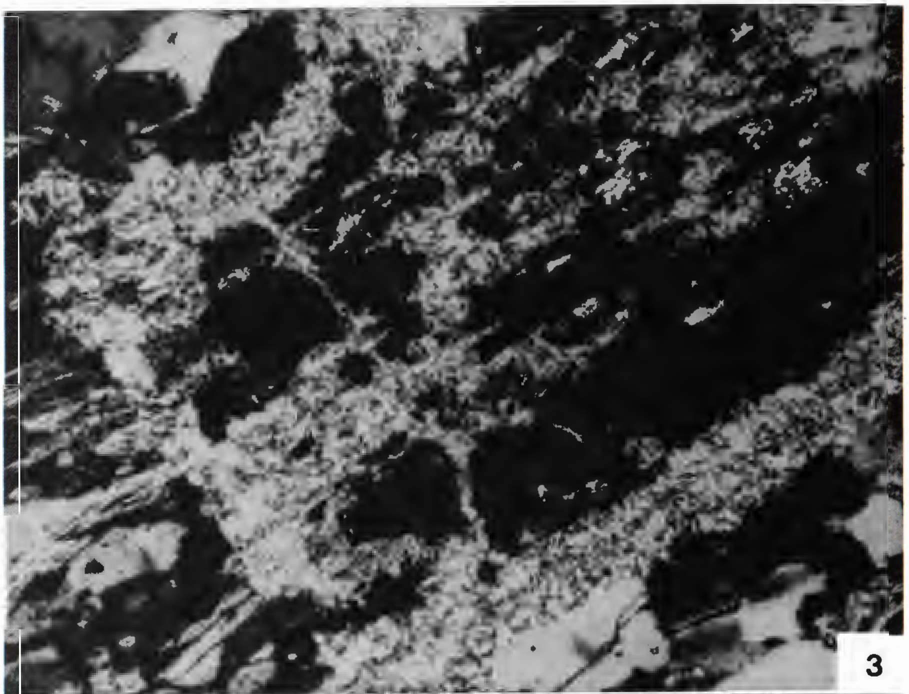
PLATE — TABLA II

3. Sericitized postkinematic poikiloblast of staurolite. Magnif. 100 ×.

3. Sericitizirani postkinematski pojkiloblast staurolita. Pov. 100 ×.

4. Xenoblastic inclusions of staurolite in andalusite poikiloblast. Magnif. 100 ×.

4. Ksenoblastne inkluzije staurolita u andaluzitnom pojkiloblastu. Poveć. 100 ×.



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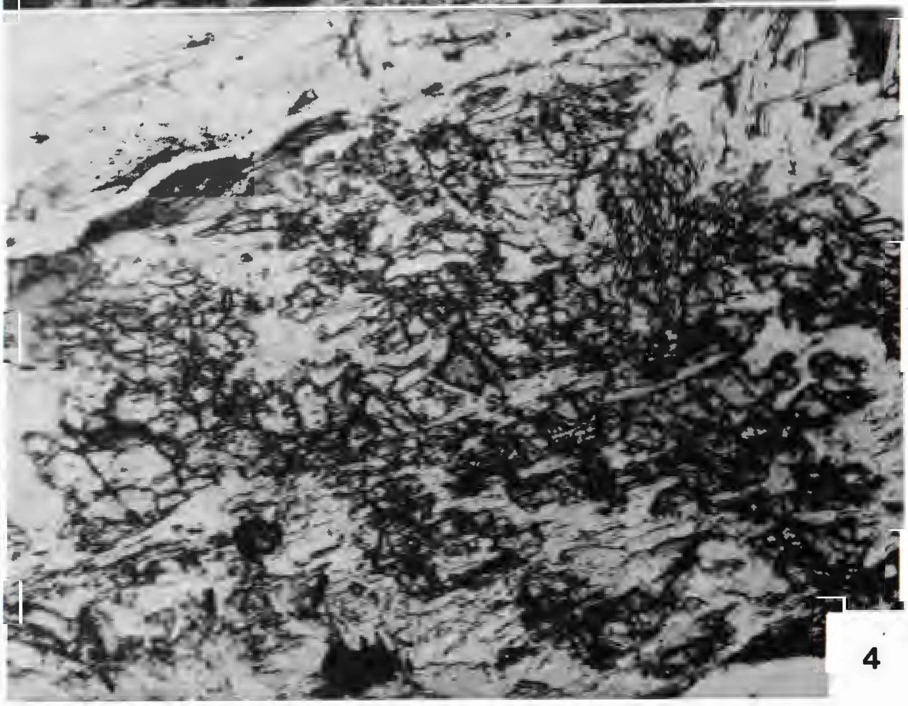

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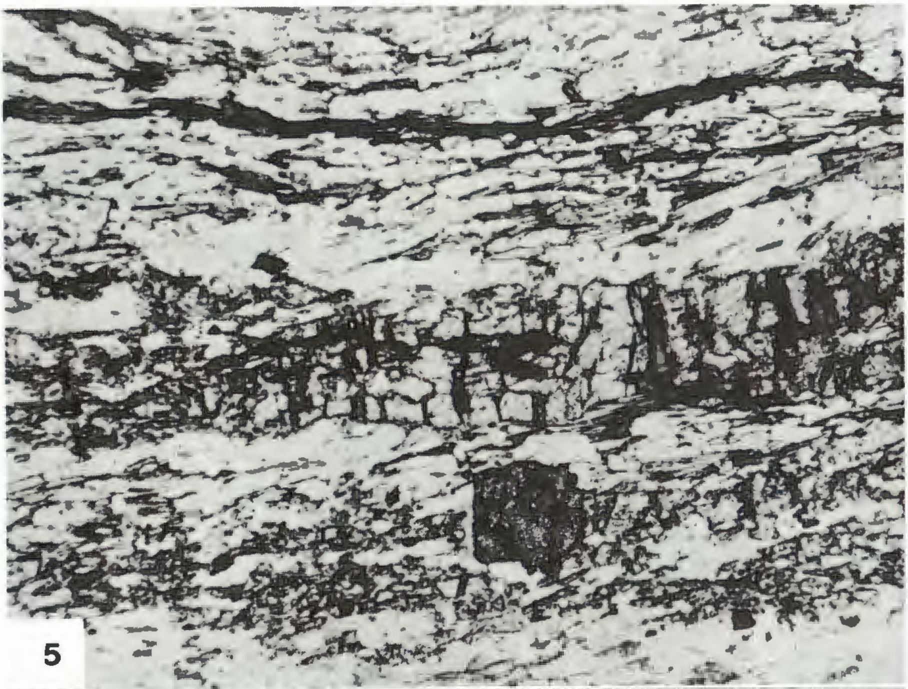
PLATE — TABLA III

5. Long andalusite poikiloblast in deformed quartz segregations. Magnif. 32 ×.
5. Izdužen porfiroblast andaluzita u deformiranoj kvarcnoj vrpci. Poveć. 32 ×.

6. Stout single sillimanite prisms surrounded by fibrolite. Magnif. 200 ×.
6. Pojedinačni prizmatski kristali silimanita u fibrolitu. Poveć. 200 ×.



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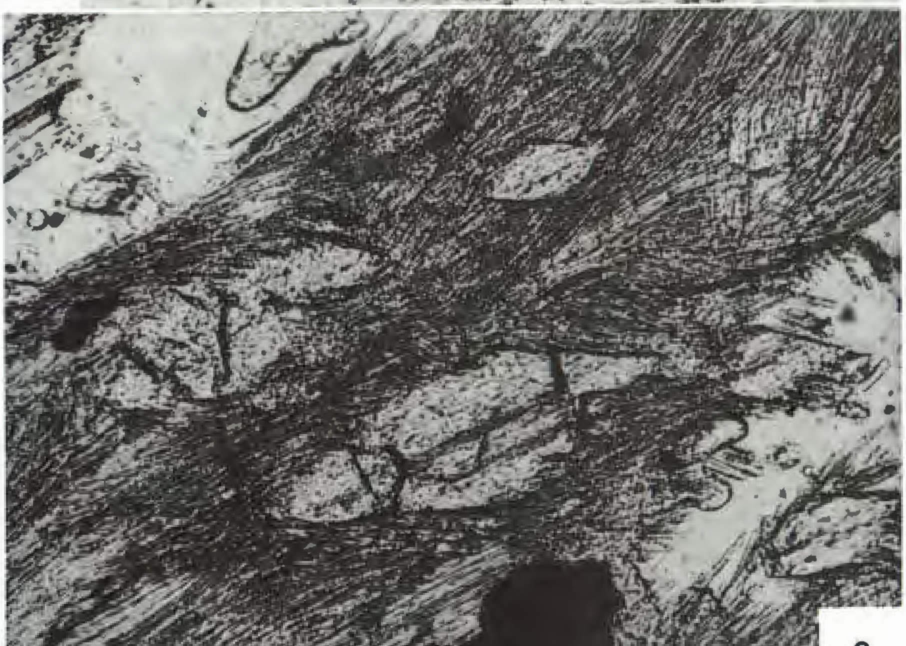

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