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PETROLOGY AND P–T CONDITION OF WHITE MICA–CHLORITE SCHISTS FROM VLASINA SERIES (SURDULICA, SE SERBIA)

by

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This paper reports structural, textural, petrological and metamorphic data from Vlasina Series of greenschsts rocks (as part of the Upper Complex of the Serbo–Macedonian Massif) within which group of white mica–chlorite schist are extensively developed. This group of rocks made the ground of series in which various types of green rocks appear as a lenses and small irregular mass, rarely as dykes. Other features, that characterize these rocks, are the common occurrence of albite and garnet (subordinate) porphyroblasts, as well as development of quartz segregation.

Group of white mica–chlorite schist makes about 75 vol. % of Series. Among them, according to mode and mineral composition, the following schist varieties are distinguished: albite–white mica–chlorite (±garnet), white mica–chlorite (±garnet), albite–white mica, sericite–chlorite (±albite), graphite–sericite as well as phyllites and calcshists. Their metamorphic evolution is characterized by the development of a metamorphic episode during Carboniferous – c. 350–330 Ma (Milovanović et al., 1988) of low to medium P and T. The mineral assemblages of first phase (low PT) is preserved as a very thin S_i=S_1 foliation included in albite porphyroblast or as small polygonal arcs of S_1 in S_2 foliation.

Textural, mineralogical and petrological data indicate that original volcanoclastic–sedimentary series was transformed during three phase of deformation and metamorphism in the temperature range from 320–415°C, locally 450–500°C and pressures 3 to 5 kbar.

Key words: Serbo–Macedonian massif, Upper Complex, Vlasina Series, Surdulica, SE Serbia, fabric, schists, petrology, P–T condition.

У раду су приказане структурне и петролошке кактеристике и PT услови метаморфизма групе мусковит–хлоритских шкриљаца Серије Власине као дела Горњег комплекса Српско–македонског масива. Те стене граде основу серије (око 75 vol. %) у којој се, као сочива или мање неправилне масе или ређе дајкови, јављају различите врсте зелених стена.

Према модалном саставу у групи се разликују следећи варијетети: албит–мусковит–хлоритски и мусковит–хлоритски са или без граната, албит–мусковитски, серицит–хлоритски (± албит) и графит–серицитски шкриљци, затим филити и калкшисти.

Процес метаморфизма одвијао се у току карбона – пре око 350–330 мил. год. (Milovanović et al. 1988). Асоцијације минерала, њихов хемизам, структурне карактеристике стена и израчунати хлоритски геотермометар указују да је примарна вулканокластично–седиментна серија трансформисана у току три

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фазе деформација у температурном интервалу између 320–415°C, локално 450–500°C, при притисцима од 3 до 5 kbara. Реликти прве фазе метаморфизма (ниски PT) сачувани су као S_i=S_1 фолијација у албитским порфиробастима или као мали полигонални лукови S_1 у S_2 фолијацији.

Кључне речи: Српско–македонски масив, Горњи комплекс, Серија Власине, Сурдулица, ЈИ Србија, шкриљци, склоп, петрологија, PT услови

INTRODUCTION

One of the most notable characteristics of a segment of Serbo–Macedonian Upper complex is development of Vlasina Series (Vasković & Tasić, 2000).

Mineralogical assemblages of S_1 foliation are locally well preserved i.e. at the place were they not affected by overprinting which induced the subsequent intermediate P–T evolution and the younger (Tertiary) orogenic intrusion of large Surdulica granitoid.

However, in a few areas presumably affected by low–PT event some assemblages underwent two overprinting and were totally eliminated or, under more favorable circumstances, preserved exclusively as inclusion in porphyroblasts developed during the second phase of deformation. Such is the case of albite–white mica–chlorite schist from the southeast part of Series. The preservation of inclusions in albite, and sometimes in garnet, porphyroblasts, as well as polygonal arcs of S_1 in S_2 foliation, enables us to study the tectonothermal evolution followed by these metavolcanoclastic rocks, by means of detailed determination of their P–T path.

Moreover, this evolution will be one additional example of how precise thermobarometry, based on detailed establishment of textural relationships troughtout the metamorphism, can reveal details of strongly overprinted P–T histories.

GEOLOGICAL SETTING

The investigated area, named Vlasina Series (Vasković & Tasić, 1996, 2000), is situated in southeastern Serbia (Fig. 1). It is a part of the Upper Complex of the Serbo–Macedonian massif, that according to Karamata & Krstić (1996) belongs to Vlasina–Ranovac–Osogovo terrane (Fig. 1). This Ripheo–Cambrian Upper complex of greenschist with subordinate amphibolite facies metavolcanoclastic–sedimentary and metasedimentary (largely psammites and pelites, rarely psefites) rocks was intruded firstly by Ordovician granitoids (Vlajna, Božica, Jarešnik) and later by paleogene Surdulica granitoid as well as underwent to extensive Oligocene–Miocene volcanic activity. According to spatial position, lithology and metamorphic degree the crystalline schists of Upper complex were divided into six regional series: Vlasina (Vasković & Tasić, 1996, 2000), Jarešnik, Vranjska Banja, Božica, Lisina and Stajevac (Babović et al, 1977).

Vlasina Series is separated as a particular lithological unit involving the rocks developed on the northern and eastern margin of Surdulica granitoid (Fig. 2) previously well known as "greenschist" (Petrović, 1969). Occurrences of its small branches on the NE, SE and NW margin of the pluton are result of disruption during the intrusion (Vasković, 1998).

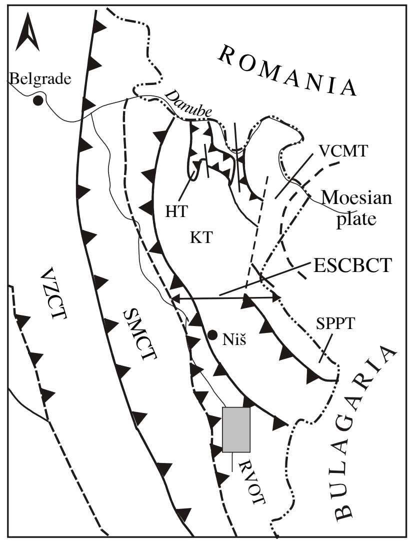

Fig. 1. Position of the studied area on the tectonic sketch Terranes of Serbia (Karamata & Krstić, 1996). ESCBCT– Composite terrane of Carpatho–Balkanides: VCMT– Vrška Čuka–Miroč terrane; SPPT– Stara Planina–Poreč terrane; KT– Kučaj terrane; HT– Homolje terrane; RVOT– Ranovac–Vlasina–Osogovo terrane; SMCT– Serbo–Macedonian composite terrane; VZCT– Vardar zone composite terrane; Fault, observed and covered – solid & dashed line; Overthrust, observed and covered – solid & dashed line with arrows.

Сл. 1. Положај испитиваног подручја у тектонској скици Терани Србије (Karamata & Krstić, 1996). ESCBCT– композитни теран Карпато–балканида: VCMT– теран Вршка Чука–Мироч; SPPT– теран Стара планина–Пореч; KT– теран Кучаја; HT– теран Хомоље; RVOT– теран Рановац–Власина–Осогово; SMCT– Српско–македонски композитни теран; VZCT– композитни теран Вардарске зоне. Пуна и испрекидана линија – расед (посматран и покривен); Линија са стрелицама – навлака, посматрана и покривена.

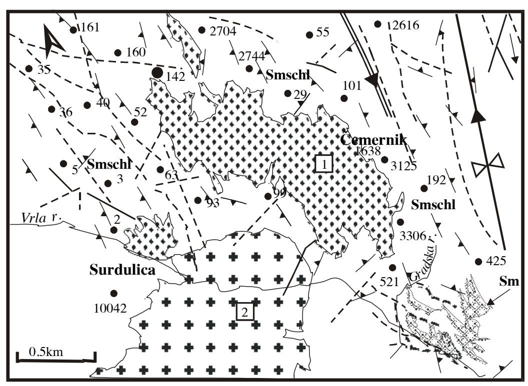

Fig. 2. Simplified geological map of studied area (Vlasina Series). Legend: Smschl– White mica–chlorite schist; Sm– micaschist; 1. Dacite; 2. Surdulica Granitoid; black circle – sample; tectonic labels are presented at Fig. 3; line wit arrow – foliation.

Сл. 2. Упрошћена геолошка карта испитиваног подручја (Серија Власине). Легенда: Smchl– мусковит–хлоритски шкриљац; Sm– микашист; 1. дацит; 2. гранитоид Сурдулице; црни кружићи – узорци; тектонске ознаке приказане су на сл. 3; линија са стрелицом – фолијација.

STRUCTURAL GEOLOGY

The Ripheo–Cambrian Upper Complex of the Serbo–Macedonian massif characterizes a very composite fabric generated during the polyphase folding. According to Dimitrijević (1963) its consolidation corresponds to Variscan events, while the present form was created during Miocene by transversal dislocation and vertical block movements. The main structures in the investigated area are: Čemernik anticlinorium, Vlasina syncline and South Morava synclinorium (Fig. 3).

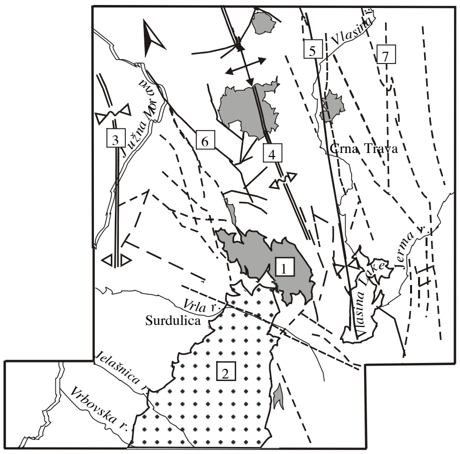

Fig. 3. Tectonic sketch of the eastern part of the Upper Complex of the Serbo–macedonian massif (after, Petrović et al., 1973) i. e. Ranovac–Vlasina–Osogovo terrane (Fig. 2). Legend: 1. Dacites; 2. Surdulica Granitoid; 3. The South Morava sinclinorium; 4. Čemernic anticlinorium with the axes; 5. Vlasina syncline; 6. Fault – observed; 7. Fault – covered.

Сл. 3. Тектонска скица источног дела горњег комплекса Српско–македонског масива (по Петровић et al, 1973) тј. Рановац–Власина–Осогово терана (сл. 2). Легенда: 1. дацити; 2. гранитоид Сурдулице; 3. Јужноморавски синклиноријум; 4. Чемернички антиклиноријум са осама; 5. Власинска синклинала; 6. расед – посматран; 7. расед – покривен.

The rocks of Vlasina Series are the main lithological members of Vlasina syncline, Čemernik anticlinorium and the eastern limb of South Morava synclinorium (Fig. 3).

Čemernik anticlinorium (Fig. 3) builds the central part of the Upper Complex. According to Petrović et al. (1973) the zone of longitudinal dislocation limits its both side, which on the west are normal faults with the west downthrow block. On the east side of the anticlinorium in this zone faults are oblique, nearly subvertical, showing reverse movements to the east. In the hinge of anticlinorium subvolcanic dacites were intruded during Oligocene. This intrusion as well as the intrusion of Surdulica granitoid disrupted schist into a few differently rotated blocks.

Vlasina syncline is continued on the east form Čemernik anticlinorium (Fig. 3). Its southern part has relatively regular form while towards to the north its structure is being more complicated due to the activity of a numbers of longitudinal dislocation (Fig. 3). The northern part of syncline is very tightened and reduced along the longitudinal dislocation. In the area of the Vlasina Lake the syncline is intensely secondary folded and distorted by rupture. Towards the south and southeast from Crna Trava linear folds (m–scale) of high folding degree characterize the syncline. The secondary folds are mostly isoclinal and recumbent to the east.

The South Morava synclinorium has, according to Petrović et al. (1973), very composite structure: its southern shallower part is relatively simple as compared with the deepest northern part (Fig. 3). The axes of northern part of synclinorium slightly deeping to the NNW, while on its southern part to the south. The hinges of synclinorum convexly declined to its core. The following penetrative linear structures show the same characteristic, but in the area of Surdulica they are deviated from regional fabric because of younger tectonic events and intrusion of Tertiary granitoid.

During the long geological evolution the Vlasina series was underwent to numerous phase of formation which done very composite fabric. Unfortunately, the accurate reconstruction of tectonic event is not possible because of very sparse available data. Anyway, the problem being more complicated if we take into consideration the fact that the younger deformation and formation were partly or completely obliterated trails of former folding. However, according to existing data (Petrović, 1969; Babović et al., 1977; Vasković & Tasić, 1996, 2000; Vasković, 1998) it is possible to distinguish three deformational phases:

– During the first phase (D1), due to sinking to deeper level of volcanoclastic–sedimentary basin and compression from the north–east direction as well as shortening, very composite flexure–flow folds (concentric, rarely disharmonic) with statistically parallel axes and numbers of secondary folds were formed. Principally, they preserved in dm–scale and often recumbent. Folds are linear with axis softly deeping to NNW. Deviations from this direction are minor and mostly local.

– The second phase (D2) characterized continuation of compression in the hinges of flexure–flow folds (F1) and developing of axial plane cleavage along which shear folding is produced by differential movement – frictional folds of mm–m scale were formed (second folds generation – F2). Along the regional longitudinal fault they are disharmonicaly folded. The axes of frictional folds are parallel each other and gently dipped at first to the west, and later were rotated mostly at a steep angle to the southwest. Against the axial plane cleavage new foliation is developed (S_2) and takes major role in further formation of terrene. Continuation of compression along the cleavage plane result in refolding – transposition movements caused at first parallel arrangement of hinges, and after those permutation movements their disruption.

– The S_3–planes (subnormal or oblique to the axial plane of former folds) take major role in formation of terrene during the third phase (D3). The accordion folds of cm–dm scale are developed by combination of flexure and disruption. This phase (D3) probably partly was caused by intrusion and ascending of Tertiary Surdulica Granitoid.

The investigated group of schist is the main lithological member of the southern part of Čemernik anticlinorium, the central part of Vlasina synclines, and the eastern limb of South Morava synclinorium.

PETROLOGY

Group of white mica–chlorite schist builds c. 75 vol.% of Vlasina Series (Fig. 2). It is characterized by the presence of numbers varieties separated according to modal composition of white mica and chlorite (Table 1).

Albite–white mica–chlorite schist is the most widespread (Fig. 2). Its schistosity is emphasized by bands, lenses or exudes of quartz which thickness varies from 1 mm to 20 cm. They are porphyroblastic and lepidoblastic texture. In some part this rocks preserved the oldest microstructure generated during the first phase of deformation (D1). The existence of S_1 is indicated by inclusion–trails in albite or garnet porphyroblasts or by quartz lenses and bands generated at first during D1 and later folded, refolded and partly transposed during D2 and locally fractured during D3. The range of mineral mode composition is listed in Table 1.

Table 1. Varieties schists according modal composition of albite, white mica and chlorite.
Табела 1. Варијетети шкриљаца издвојени на основу модалног садржаја албита, мусковита и хлорита.

Varieties (варијетети стена)	Ab* (vol. %)	WM* (vol. %)	Chl* (vol. %)	Qtz* (vol. %)	Grt* (vol. %)
Albite–white mica–chlorite schist (албит–мусковит–хлоритски шкриљац)	30–50	15–30	10–20	2–15	1.5–15
White mica–chlorite schist (мусковит–хлоритски шкриљац)	< 5	25–40	15–30	15–35	1–10
Albite–white mica schist (албит–мусковитски шкриљац)	20–35	15–25	< 5	15–45	1–3
Sericite–chlorite schist (серицит–хлоритски шкриљац)		Ser* + Chl = 55–75 vol. %; 15–25 vol. % Qtz and 5–10 vol % Ab			
Phylite (филит)		Ser + Chl > 90 vol. %			
Graphite schist (графитски шкриљац)		15–25 vol. % Graph*; 10–35 vol. % Ser, 20–45 vol. % Qtz; < 10 vol. % albite			
Calcschist (калкшист)		Cal*=25–55 vol. %. WM=15–25 vol. %; Chl = 10–15 vol. %; Ab=10–25 vol. %			

* Ab – albite (албит); Chl– chlorite (хлорит); WM– white mica (мусковит); Cal– calcite (калцит); Ser– Sericite (серицит); Qtz – quartz (кварц); Grt – garnet (гранат); Graph – graphite (графит)

White mica–chlorite schist is widespread in the western part of Series or occurred as thin elongated bodies, intercalation or "bands" in albite–white mica–chlorite schist – among them gradual transition often exist. Within white mica–chlorite schist quartz lenses (1–10 cm thick and 5–50 cm long) or bands (0.5–5 cm thick) are common and show the same features as in albite–white mica–chlorite schists. The rocks are lepidoblastic texture, rarely porphyroblastic. The range of mineral mode composition is listed in Table 1.

Albite–white mica schist occurs as lenses (5 to 20 m, rarely 100 m long and 1 to 20 thick) within albite–white mica–chlorite and white mica–chlorite schists on the north of Vrla river as well as in the area southern of Surdulica (Fig. 2). They are crenulated and of lepidoblastic, porphyroblastic and fine–grained granoblastic texture. The range of mineral mode composition is listed in Table 1.

Sericite–chlorite schist appears as intercalations within albite–white mica–chlorite schists (Fig. 2). Among them gradual transition exist. However, these rocks made lateral transition to albite–sericite–chlorite schist. They are mm–cm folded or crenulated with locally well–developed axial–plane cleavage. Within dislocation zone they are broken and foliated. Texture is lepidoblastic and/or porphyroblastic. The range of mineral mode composition is listed in Table 1.

Phyllite occurred on the northeastern part of investigated area as intercalations (2 to 10 m thick) within group of white mica–chlorite schist. They are mm–cm folded or crenulated (pleated) with well–developed axial–plane cleavage. The range of mineral mode composition is listed in Table 1.

Graphite schist is rare. These rocks appear as a very thin intercalation or lenses within white mica–chlorite and sericite–chlorite schists or in phyllites. They are mm folded or crenulated (pleated) with well developing of the axial–plane cleavage. Some of these rocks are banded; there is an alternation of quartz– or quartz–graphite – rich bands by mica–rich. The range of mineral mode composition is listed in Table 1.

Calcshist is relatively rare and appears as intercalation or lenses of a few to 50 m thick and 250 to 500 m long within white mica–chlorite schist on the western hinge of Čemernik anticlinorium and central, southern and western parts of Vlasina syncline. They usually alternate by phyllites or albite–white mica–chlorite schist. Its texture is heteroblastic, lepidoblastic and porphyroblastic, sometimes blastopsammitic. The range of mineral mode composition is listed in Table 1.

MODE OF OCCURRENCES AND CHEMISTRY OF MINERALS

Table 2 lists the mineral assemblages of all varieties from group of white mica–chlorite schists. The localities of the samples are referred in Fig. 2.

Table 2. Mineral assemblages within group of white mica–chlorite schists.
Табела 2. Асоцијације минерала у стенама из групе мусковит–хлоритских шкриљаца.

Rocks varieties (варијетети стена)	Mineral assemblages (асоцијације минерала)
Albite–white mica–chlorite schist (албит–мусковит–хлоритски шкриљац)	Ab+Chl+WM+Ep*±Grt±Bt*+Qtz±Mt*+Ilm/Lx*+Tour*+Ap*+Zr*
White mica–chlorite schist (мусковит–хлоритски шкриљац)	Chl+WM+Ep±Grt+Qtz±Ab±Mt+Ilm/Lx+Tour+Ap+Zr
Albite– white mica schist (албит–мусковитски шкриљац)	Ab+WM±Grt±Bt+Qtz+Ilm/Lx±Ep
Sericite–chlorite schist (серицит–хлоритски шкриљац)	Ser+Chl+Qtz±Ab±Graph±Ilm/Lx±Tour
Phyllte (филит)	Ser±Chl±Qtz±Ab±Graph
Graphite schists (графитски шкриљци)	Graph+sericite+Qtz±Ab±Tour
Calcshist (калкшист)	Cal+WM+Chl+Ab+Ep+Grt+Graph+Ilm/Lx

* Ep – Epidote (епидот); Bt– biotite (биотит); Ilm/Lx– ilmenit/leucoxene (илменит/леукоксен); Mt– magnetite (магнетит); Zr– Zircone (циркон); Ap– apatite (апатит); Tour– Tourmaline (турмалин)

The 25th samples were collected in study area and examined petrographycally. According this study detailed mineralogical analyses of white mica–chlorite schist group was undertaken using a CAMECA electron–probe microanalyzer at the University of Hamburg. Operating conditions were 20 kV, acceleration voltage 10μA absorbed sample current, 10–sec counting time. Natural and synthetic oxide and minerals were used as standard. Representative analyses of albite, white mica, chlorite, biotite, garnet and epidote are given at Tables 3 to 7. Systematic compositional zoning was found in all coexisting phase.

Albite

Albite occurs usually as isometric to elongated lensoidal or spindle porphyroblasts of 0.5×0.35 to 1.5×3 mm in size or as blasts from 0.06×0.1 to 0.25×0.35 mm in size which are homogenous or twined. It builds amygduls or irregular accumulations (1.25×0.5 to 2.5×5 mm in size) arranged as linear sets parallel to main schistosity (S_2) or appear in single grains in white mica–chlorite–rich matrix or bands or in quartz–rich zones. Albite along with quartz makes fine–grained matrix of the albite–white mica schists.

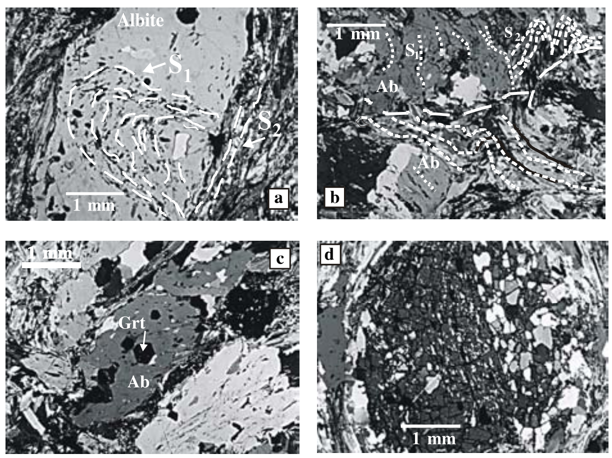

Fig. 4. Photomicrographs showing the principal stuctural characteristic in group of white mica–chlorite schist of Vlasina Series: a) S_1 included in albite porphyroblast and surrounded by S_2; b) S_1 included in albite porphyroblast, and development of S_2; c) Inclusion of garnet (Grt_1) in albite porphyroblast; d) inclusion trails of quartz and opaques in garnet porphyroblast.

Сл. 4. Микроструктурне карактеристике стена из групе мусковит–хлоритских шкриљаца серије Власине: а) однос сачуване S_1 фолијација уклопљене у албитском порфиробласту и S_2 фолијације; b) однос сачуване S_1 фолијације уклопљене у албитском порфиробласту и S_2 фолијације; c) Инклузије граната прве генерације (Grt_1) у порфиробласту албита; d) Инклузије кварца и опаких минерала у гранатском порфиробласту.

The porphyroblasts commonly contain inclusions of quartz, opaque minerals (Ilm/Lx, Mt), epidote, minute garnets (Grt_1, Fig. 4c)[*], fine dusty graphite grains and rarely micas (WM, Chl). Included grains occupy 10 to 60 volume of porphyroblast. Moreover, very common are clear albite grains as well as grains intergrowth by quartz.

The internal schistosity (S_i) included in albite porphyroblasts and its relationships to external schistosity (S_e[**]) suggest two phase of crystallization: pre–kinematic and syn–kinematic. The inclusion–trails (S_i) within pre–kinematic porphyroblasts made linear–sets perpendicular to S_e. The S_i within syn–kinematic porphyroblasts can be spiral or sigmoidal ("S"), commonly it is S_1 which lies at a market angle to the enclosing schistosity, S_e, (Fig. 4a). Some of these porphyroblasts contain inclusion–trails of fan–form, and

[*] Grt_1– Garnet of first generation
[**] S_e=S_2

within some they are radomnly oriented. Furthermore, within marginal zone of many albitic porphyroblasts droplets quartz is present.

The microprobe analyses was made on three type of albite porphyroblasts (Table 3):

- I–type: homogenous and twined grains without inclusions (79, 80, 81)
- II– type: grains with inclusions of epidote and opaque minerals (45, 46)
- III–type: grains which marginal zone contains droplets quartz (47, 62)

The mineral chemistry of these albitic porphyroblasts from albite–white–mica–chlorite, white mica–chlorite and garnet–white mica–chlorite schists are shown in Table 3.

Table 3. Chemical composition of albite.
Табела 3. Хемијски састав албита.

Sample (узорак)	Albite–white mica–chlorite (албит–хлорит–мусковитски шкриљац) schist (шкриљац) T. 425				White mica–chlorite (мусковит–хлоритски шкриљац) schist (шкриљац) T. 2			Garnet–white mica–chlorite (гранат–мусковит–хлоритски шкриљац) schist (шкриљац) – T. 2a		
No.	45	46	47c	47p	62c	62p	65	79	80	81
SiO_2	67.29	68.22	66.12	63.92	66.35	63.22	68.25	67.51	67.92	67.83
Al_2O_3	20.97	20.63	21.38	24.05	21.92	23.10	20.42	20.74	20.31	21.08
FeO	0.03	0.01	0.05	0.03	0.01	0.04	0.01	–	–	–
CaO	0.98	1.11	1.53	2.32	1.82	3.05	0.69	0.32	0.41	0.60
Na_2O	10.35	10.35	10.12	9.32	10.02	10.01	11.28	11.22	11.20	10.81
K_2O	0.03	0.02	0.03	0.03	0.01	0.01	0.03	0.01	0.03	0.03
$\sum$	99.65	100.34	100.04	99.67	100.13	99.43	100.68	99.80	99.87	100.35
8 (O)										
Si	11.780	11.854	11.604	11.243	11.593	11.220	11.850	11.810	11.872	11.792
Al	4.323	4.221	4.419	4.982	4.511	4.828	4.175	4.273	4.181	4.316
Fe	0.004	0.001	0.007	0.004	0.009	0.006	0.009	–	–	–
Ca	0.184	0.207	0.288	0.437	0.341	0.580	0.128	0.060	0.077	0.112
Na	3.351	3.487	3.716	3.179	3.395	3.445	3.797	3.806	3.796	3.644
K	0.007	0.004	0.009	0.007	0.002	0.002	0.007	0.002	0.007	0.007
Ab	94.80	94.30	92.60	87.70	90.80	85.50	96.60	98.40	97.80	96.80
An	5.00	5.60	7.20	12.10	9.10	14.40	3.20	1.60	2.00	3.00
Or	0.20	0.10	0.20	0.20	0.10	0.10	0.20	0.10	0.20	0.20

The I–type is practically pure albite (An $\leq$ 3%), the II–type contains from 5 to 5.60% An, and the III–type shows zonal composition with albitic core (7.20 to 9.10% An) and oligoclase rim (12.10 to 14.40% An). The increase of anothite component can be explained by increasing of temperature: (1) during the end of first metamorphic phase synchronous to D1 (which characterized at first by higher P and lower T), and (2) at the beginning or during the second phase of metamorphism (synchronous to D2) when calcium–rich phases (epidote) were gradually breakdown.

White mica

White mica makes bands (0.5 to 5 mm thick), irregular accumulation or linear sets commonly microfolded (Fig. 4b) in association with albite, chlorite and subordinate quartz, garnet and biotite. It also makes elongated lenticular monomineral accumulation in quartz–rich matrix. The grains are 0.1 to 2 mm long and always deformed, sometimes kinked. The pre–kinematic flakes are deformed, commonly coarser, and subnormal or at angle to main schistosity (S_2), while the post–kinematic are undeformed. Some coarser flakes contain inclusions of minute garnet (Grt_1).

Chemical analyses of pre–kinematic and syn–kinematic white mica are presented in Table 4.

Table 4. Chemical composition of white mica.
Табела 4. Хемијски састав мусковита.

Sample (узорак)	T. 2		T.425					T. 2a		
	Pre–kinematic (пре–кинематски)			Syn–kinematic (син–кинематски)						
No.	41	42	59	55	56	57	58	50	51	52
SiO_2	49.38	49.32	49.98	48.54	46.32	48.56	46.81	47.01	46.97	49.01
TiO_2	0.35	0.31	0.20	0.38	0.40	0.21	0.48	0.35	0.40	0.23
Al_2O_3	28.72	29.21	28.02	30.21	32.82	30.01	34.43	35.03	34.62	30.02
FeO	328	2.65	3.98	3.29	1.95	3.17	1.92	1.21	1.03	4.52
MnO	0.01	0.03	0.00	0.03	0.02	0.01	0.00	0.01	0.01	0.00
MgO	2.02	2.92	1.46	1.98	2.27	2.11	1.03	1.23	1.03	1.38
CaO	0.01	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00
Na_2O	1.21	0.62	0.32	0.93	0.82	0.72	1.38	1.22	1.42	0.29
K_2O	10.42	9.57	10.83	9.31	10.17	10.19	9.35	9.11	9.38	10.52
$\sum$	95.40	94.63	94.79	94.68	94.28	94.98	95.41	95.17	94.86	95.97
					22 (O)					
Si	6.638	6.614	6.765	6.525	6.245	6.534	6.216	6.218	6.243	6.563
Al^{IV}	1.362	1.386	1.235	1.475	1.755	1.466	1.784	1.782	1.757	1.437
Al^{VI}	3.184	3.227	3.232	3.308	3.456	3.289	3.600	3.674	3.662	3.298
Ti	0.035	0.031	0.020	0.038	0.041	0.021	0.048	0.035	0.040	0.023
Fe^{2+}	0.369	0.297	0.451	0.370	0.163	0.357	0.213	0.134	0.114	0.506
Mn	0.001	0.003	0.000	0.003	0.002	0.001	0.000	0.001	0.001	0.000
Mg	0.405	0.584	0.295	0.397	0.456	0.423	0.204	0.243	0.204	0.276
Ca	0.001	0.000	0.000	0.001	0.001	0.000	0.001	0.000	0.000	0.000
Na	0.315	0.161	0.084	0.242	0.214	0.188	0.355	0.313	0.366	0.075
K	1.787	1.637	1.870	1.597	1.749	1.749	1.584	1.537	1.590	1.797

* Legend: white mica–chlorite schist (T.2) – Vrla river (мусковит–хлоритски шкриљац (T.2) – река Врла); garnet–white mica–chlorite shists (T.2a) – Vrla river (гранат–мусковит–хлоритски шкриљац (T.2a) – река Врла); albite–white mica–chlorite schist (T.425) – Bitvrda (албит–мусковит–хлоритски шкриљац (T.425) – Битврђа).

Pre–kinematic white mica show higher Si and lower Al content than syn–kinematic (Fig. 8). Both characterize a relatively large range of composition (Table 4). Si and Al show negative correlation, due to importance of Tschermak subsitution (Mg,Fe^{2+}), $Si=Al^{IV}$, Al^{VI}, and nearly all analyses plot close to the join Si+0.5Al=9 indicating that the white mica belong to the muscovite–seladonite series, i. e to the phengite and phengitic muscovite (Fig 5), according to Graeser & Niggli (1967).

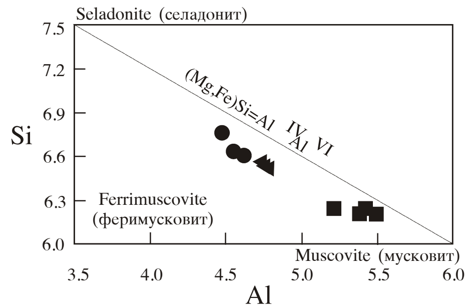

Fig. 5. Al–Si plot of white mica microprobe analyses. Legend: Al=($Al^{IV}+Al^{VI}$); filled circle – pre–kinematic; filled squere and triangle – syn–kinemamatic;

Сл. 5. Однос Al-Si у мусковитима. Легенда: Al=($Al^{IV}+Al^{VI}$); црни квадрати– пре–кинематски; црни квадрати и троуглови – син––кинематски.

Chlorite

Chlorite is pale greenish in colour, 0.1 to 1.5 mm long. Both minerals, white mica and chlorite, make common aggregates (bands or accumulations) in which white mica dominated. Moreover, chlorite itself makes monomineral accumulations (lenticular, or irregular). It occurs in three distinct mode: (1) syn–kinematic – associated with white mica building S_2 and, (2) post–kinematic – single flakes or accumulation at high angle to S_2, and (3) – retrograde chlorite – occurs as pseudomorphs after garnet. Within phyllitic rocks it makes fine–grained matrix with sericite and quartz.

Table 5. Chemical composition of chlorite.
Табела 5. Хемијски састав хлорита.

Type (тип)	White mica–chlorite schist (мусковит–хлоритски шкриљац) T. 2				Garnet–white mica–chlorite schist (гранат–мусковит–хлоритски шкриљац) T. 2a						Albite–white mica–chlorite schist (албит–мусковит–хлоритски шкриљац) T. 425		
No.an (бр. ан.)	43	44	53	54	61	63	64	66	67	68	71	72	73
SiO_2	25.45	25.08	25.31	24.92	25.16	25.55	25.02	24.68	24.28	24.62	25.01	24.12	25.69
TiO_2	0.01	0.01	0.10	0.08	0.09	0.09	0.06	0.07	0.08	0.09	0.08	0.06	0.23
Al_2O_3	22.01	21.11	21.11	22.11	21.78	22.31	21.45	22.15	22.27	21.83	23.81	23.42	23.92
FeO	25.02	25.45	26.50	26.58	25.59	25.31	24.92	24.63	27.01	26.10	28.92	27.51	29.84
MnO	0.42	0.76	1.02	0.92	0.84	0.52	1.01	0.79	0.74	0.74	0.59	0.82	1.09
MgO	15.22	15.19	14.68	14.09	14.03	14.21	14.98	15.03	13.92	14.04	11.23	13.28	11.43
$\sum$	88.13	87.60	89.25	88.70	87.49	87.99	87.44	87.35	88.30	87.42	89.64	85.21	88.48
28 (O)													
Si	5.326	5.317	5.290	5.244	5.337	5.360	5.304	5.223	5.149	5.248	5.239	5.069	5.264
Al^{IV}	2.674	2.683	2.710	2.756	2.663	2.640	2.696	2.777	2.851	2.752	2.761	2.931	2.736
Al^{VI}	2.750	2.587	2.638	2.723	2.778	2.872	2.659	2.743	2.711	2.728	3.113	2.865	3.089
Ti	0.002	0.002	0.002	0.013	0.014	0.014	0.010	0.011	0.013	0.014	0.013	0.009	0.037
Fe^{2+}	4.379	4.512	4.632	4.677	4.540	4.440	4.418	4.359	4.791	4.653	5.066	4.835	5.142
Mn	0.074	0.136	0.181	0.164	0.151	0.092	0.181	0.142	0.133	0.134	0.105	0.146	0.197
Mg	4.748	4.801	4.574	4.420	4.437	4.444	4.734	4.742	4.401	4.461	3.507	4.160	3.315
Cation (катјон)	19.95	20.04	20.03	20.00	19.92	19.86	20.00	20.00	20.04	19.99	19.80	20.01	19.78
X_{Mg}	0.52	0.52	0.50	0.49	0.49	0.50	0.52	0.52	0.48	0.49	0.41	0.46	0.39

Microprobe analyses were made on syn–kinematic chlorites from white mica–chlorite, albite–white mica–chlorite and garnet–white mica–chlorite schist. Chemical composition is presented at Table 5.

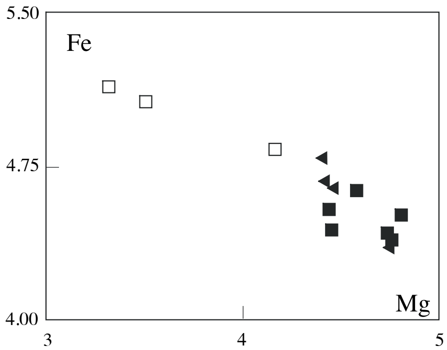

Fig. 6. Fe^{2+} vs. Mg in syn–kinematic chlorites of white mica chlorite schist (■), albite–white mica chlorite schist (□) and garnet white mica chlorite schist (◀).

Сл. 6. Fe^{2+} vs. Mg у син–кинематским хлоритима из мусковит–хлоритских шкриљаца (■), албит–мусковит–хлоритских шкриљаца (□) и гранат–мусковит-хлоритских шкриљаца (◀).

Chorites from all three varieties differ according to content of SiO_2, Al_2O_3, FeO and MgO. The Fe^{2+} vs. Mg (Fig. 6) shows increasing of Mg from garnet–white–mica–chlorite schist to white mica–chlorite schist. According to Hey's classification (1954) they are ripidolites (Fig 7a). Some of chlorites show higher Al^{VI} than Al^{IV} due to Tschermak substitution (Fig. 7b) i. e. increasing of metamorphic grade (Maruyama et al., 1983).

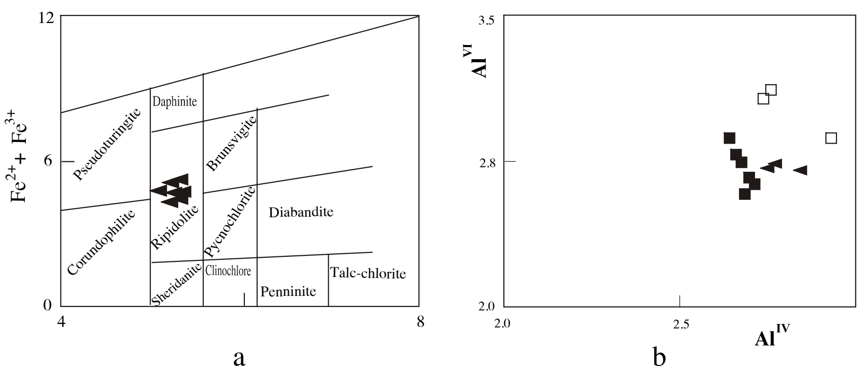

Fig. 7. a). Distribution of chlorite in Si – (Fe^{2+}+Fe^{3+}) classification diagram (after Hey, 1954); b). Al^{IV} vs. Al^{VI} in syn–cinematic chlorites (symbols as in Fig. 6).

Sl. 7. a) Si – (Fe^{2+}+Fe^{3+}) дијаграм класификације хлорита (по Hey, 1954); b) Al^{IV} vs. Al^{VI} код син–кинематских хлорита (симболи као на сл. 6; Псеудотургините = псеудотуринит, Corundophilite = корундофилит, Daphinite = дафинит, Ripidolite = рипидолит, Sheridanite = шериданит, Brunsvigite = брунсвигит, Pycnochlorite = пикнохлорит, Clinochlorite = клинохлорит, Diabandite = дијабандит, Pennite = пенит, Talc-chlorite = талкхлорит).

Garnet

Garnet is not a regular constituent of white mica–chlorite schists group. It is common within albite–white mica–chlorite and white mica chlorite schist from the eastern limb of Čemernik anticlinorium (area of Gradska river), central part of Vlasina syncline (area Vrla river) and the western part of Surdulica (Fig. 2).

Garnet occurs in three forms: (a) large (0.7–5 mm) euhedral to subhedral porphyroblasts (type 1, Fig. 4d), sometimes partially retrograded to chlorite; (b) small (0.1–0.5 mm) – euhedral to subhedral grains in white mica ± chlorite + quartz matrix or quartz accumulations (type 2); (c) tiny (< 0.1 mm) – subhedral to euhedral, usually pristine inclusions in albite porphyroblasts (Fig. 4c), and rarely in coarser flakes of white mica (type 3).

All three garnet types may occur individually or in any combination in the same specimen. These modes of occurrences suggest that garnet be produced during two episodes of growth. The first produced tiny to small garnet grains (type 3, and 2), and the second porphyroblasts (type 1). It seems, from the texture, that some of small grains (type 2) were growth during the second episode – grains situated in coarser recrystallized white mica–chlorite matrix. The grains occur in varying states of preservation ranging from completely fresh or partially altered to the small core remnants surrounded by large crypto– to microcrystalline masses of chlorite. Inclusion trails (commonly quartz, ilmenite/leucoxene, rarely epidote and graphite) in the porphyroblasts are sigmoidal (Fig. 4d) or concentric.

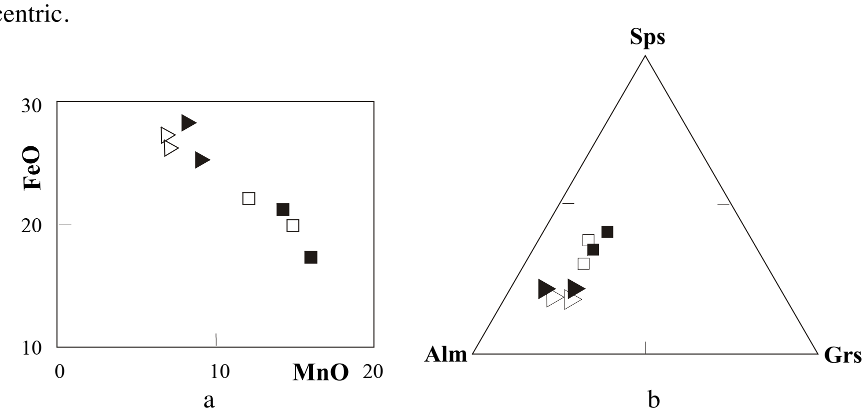

Fig. 8. (a) FeO vs MnO, and (b) Sps–Alm–Grs in garnets of type 1 (triangle: empty– rim, filled – core) and type 2 (squere: empty – rim; filled – core).

Сл. 8. (а) FeO vs. MgO и (b) Sps–Alm–Grs у гранатима типа 1 (троугао: празан – обод зрна; запуњен – центар зрна) и типа 2 (квадрат: празан –обод зрна; запуњен – центар зрна).

According to the fact that each of three before mentioned morphological garnet type may have different composition, even within the same specimen, the chemical composition of type 1 and 2 were determinate by electron microprobe analyses and recalculated after Knowles (1987; Table 6).

The chemical composition clearly exhibits zoning behavior of both garnets type. Moreover, it also defined trends have been recorded in garnet rim composition with increasing grade (Fig. 8a, b). All analyzed grains show increasing of FeO and decreasing of MnO content from core to rim. The bulk grain compositions record almandine–spessartine–grossular end members (Table 6). The garnet of type 1 is spessartine–rich as compared with type 2, which is almandine–rich. The average end member component of type 1 is $Alm_{44}Sps_{33}Grs_{17}Prp_3Adr_3$, and of type 2 is $Alm_{58}Sps_{17}Grs_{15}Prp_4Adr_4$. The higher content of MnO in type 1 is probably due to strong oxidation condition during their growth as experimentally demonstrated Hsu (1968). The same author also pointed out that spessartine–rich garnets nucleate at much lower temperature than almandine–rich. Thus, the garnet of type 1 probably nucleate and growth under higher oxygen fugacity and lower temperature – the condition coincide with the D1. The porphyroblast (type 2), as we saw, are almandine–rich. Its nucleation and growth are consistent with the D2 (higher PT). The slight increasing of CaO from core to rim probably is due to reaction of epidote + quartz = garnet + H_2O as indicated by the present inclusion. Both phases (epidote and quartz) were stable during the garnet porphyroblast growth.

From the preceding discussion it is obvious that, as well as being texturally distinct, two garnet phases from both varieties of white mica–chlorite schist group are also chemically distinct.

Table 6. Chemical composition of garnet.
Табела 6. Хемијски састав граната.

Type (тип)	Albite–white mica–chlorite schist (албит–мусковит–хлоритски шкриљац) Type (тип) 1				White mica–chlorite schist (мусковит–хлоритски шкриљац) Type (тип) 2			
Sample (узорак)	T. 2a		T 2b		T. 2a		T. 2b	
No.	83c	83r	91c	91r	70c	70r	93c	93r
SiO_2	36.52	36.98	38.02	37.22	36.58	36.42	37.30	37.11
TiO_2	0.06	0.08	0.07	0.07	0.06	0.06	0.09	0.08
Al_2O_3	20.11	20.32	21.04	20.83	20.49	20.83	20.61	20.52
FeO	21.16	22.18	17.35	19.93	25.19	26.18	28.22	27.18
MnO	14.31	12.10	16.01	14.89	9.12	7.13	8.23	6.98
MgO	0.75	0.72	0.64	0.61	0.74	0.92	0.91	1.53
CaO	7.05	6.98	6.82	6.11	7.58	7.93	5.15	6.11
$\sum$	99.86	99.34	99.95	99.66	99.76	99.47	100.51	99.51
12 (O)								
Si	2.963	3.009	3.067	3.022	3.005	2.963	3.012	3.005
Al^{IV}	0.037	0.000	0.000	0.000	0.000	0.037	0.000	0.000
Al^{VI}	1.874	1.947	1.999	1.992	1.957	1.917	1.960	1.957
Ti	0.004	0.004	0.004	0.004	0.005	0.004	0.005	0.005
Fe^{3+}	0.072	0.075	0.058	0.068	0.092	0.085	0.095	0.092
Fe^{2+}	1.364	1.434	1.112	1.286	1.748	1.621	1.810	1.748
Mn	0.983	0.834	1.094	1.024	0.479	0.626	0.563	0.479
Mg	0.091	0.087	0.077	0.074	0.185	0.089	0.110	0.185
Ca	0.613	0.609	0.589	0.531	0.530	0.658	0.446	0.530
Alm	44.706	48.381	38.713	44.104	54.144	56.664	61.822	59.433
Sps	32.233	28.139	38.085	35.129	20.899	16.453	19.222	16.272
Grs	16.410	16.813	17.687	14.959	17.725	18.781	10.597	13.542
Prp	2.973	2.947	2.680	2.533	2.985	3.736	3.741	6.278
Adr	3.677	3.720	2.835	3.275	4.247	4.366	4.618	4.476

Biotite

Biotite is not regular constituent of white mica chlorite group of schist. It occurs occasionally within all varieties, except phyllites. The zones with biotite appear in the rocks from northeastern and western part of studied area. The flakes of brownredish colour and pale yellowish polychroism are 0.1 to 1 mm long. They appear in association with mica and garnet. Some small flakes of biotite are included in garnet porphyroblast. It makes < 1 to 5 vol. % (rarely to 8 vol. % – Gradska river). Chemical composition is presented in Table 7.

Table 7. Chemical composition of biotite.
Табела 7. Хемијски састав биотита.

Sample (узорак)	T. 425	T. 2	T. 2a
No. (бр.)	44	69	77
SiO_2	33.25	34.03	34.21
TiO_2	1.73	1.95	1.96
Al_2O_3	20.36	20.69	20.72
FeO	28.65	26.92	27.83
MnO	0.22	0.19	0.20
MgO	4.81	5.52	5.11
Na_2O	0.12	0.14	0.12
K_2O	9.42	9.43	9.58
$\sum$	98.56	98.87	99.72
22 (O)			
Si	5.132	5.176	5.180
Al^{IV}	2.868	2.824	2.820
Al^{VI}	0.833	0.882	0.875
Ti	0.201	0.223	0.222
Fe^{2+}	3.698	3.424	3.524
Mn	0.029	0.024	0.026
Mg	1.107	1.252	1.154
Na	0.036	0.041	0.035
K	1.855	1.830	1.851

Studied biotites show relatively low content of TiO_2 (< 2%). Limited variation of Fe/Fe+Mg (0.73–0.75), Ti and Al suggest very close temperature range of crystallization (Table 7). According to Fe/Fe+Mg vs. Al (Fig. 9) they are siderophilites.

Epidote

Epidote is minor phase in white mica–chlorite group of schist (0.5–3.5 vol. %). Its mode composition increase close to the zone of green rocks (5–15 vol. %). Local enrichment of epidote appears within parts of schists where chlorite is dominated against white mica. The grains are anhedral, mostly elongated or tabular to stubby prismatic from 0.035 to 0.5 mm long. Tiny grains appear as inclusion in albite and garnet, while coarser made itself accumulation or occur among micas.

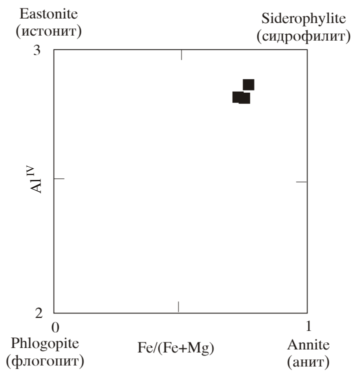

Fig. 9. Fe/Fe+Mg vs. Al^{IV} classification diagram of biotites (after Deer et al., 1966).
Сл. 9. Дијаграм класификације биотита на основу односа Fe/Fe+Mg vs. Al^{IV} (по Deer et al., 1966).

Chemical composition of epidotes from matrix of three, previously mentioned, varieties of white mica–chlorite schist is presented in Table 8.

Table 8. Chemical composition of epidote.
Табела 8. Хемијски састав епидота.

Sample (узорак)	T. 425		T. 2a		T 2		
No. (бр.)	53	54	82	85	86	87p	87c
SiO_2	37.48	36.92	38.62	37.62	37.78	35.62	37.08
TiO_2	0.12	0.10	0.12	0.12	0.18	0.20	0.19
Al_2O_3	25.62	25.02	24.91	24.81	27.21	24.01	23.62
Fe_2O_3	10.11	9.92	11.32	9.96	7.81	8.43	11.92
MnO	0.35	0.42	0.43	0.38	0.45	0.32	0.32
CaO	22.75	21.39	20.13	23.58	26.11	20.01	22.81
Na_2O	0.01	0.01	0.00	0.01	0.00	0.00	0.00
K2O	0.01	0.01	0.00	0.00	0.00	0.00	0.00
$\sum$	96.43	93.77	95.53	96.47	99.54	88.67	95.94
12.5 (O)							
Si	2.969	2.998	3.063	2.988	2.913	3.041	2.974
Al^{IV}	0.031	0.002	0.000	0.012	0.087	0.000	0.026
Al^{VI}	2.359	2.390	2.327	2.309	2.384	2.422	2.205
Ti	0.007	0.006	0.007	0.007	0.010	0.013	0.011
Fe^{3+}	0.669	0.673	0.750	0.661	0.503	0.601	0.798
Mn	0.023	0.029	0.029	0.026	0.029	0.023	0.022
Ca	1.931	1.861	1.711	2.007	2.157	1.830	1.960
Ps	21.87	21.96	24.37	22.17	16.92	19.88	26.34

According to Holdaway classification (1972) the studied epidotes are Al–epidotes with Ps* content in range from 16.92 to 26.34% (Table 8).

* Ps – pistacite component

X_{Fe} in the epidotes from albite–white mica–chlorite and white mica chlorite schists range from 0.22 to 0.24, while in the varieties with garnet its range from 0.17 to 0.26. The coarser grain from last mentioned variety shows zonal composition. Its core is richer in Fe_2O_3 than rim (Table 8). The higher value of X_{Fe} is probably result of increasing substitution $Fe^{3+} \rightarrow Al$ from core to rim (Fig. 10). The higher Ps–value (26.34%) in the core may be a result of higher oxigen fugacity (fO_2) and lower temperature, while the enrichment of Al in the rim suggests decreasing of fO_2 and temperature and pressure increasing as experimentally pointed out by Cho et al. (1986) and Liou et al. (1985).

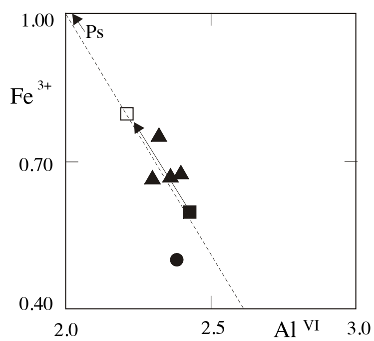

Fig. 10. Al^{VI} vs. Fe^{3+} in epidote. Dotty line represent binary solid–solution of Ps–Zo series. Legend: squere (empty – rim, filled – core); triangle filled – homogeneous grain from rocks with garnet.

Сл. 10. Дијаграм односа Al^{IV} vs. Fe^{3+} у епидоту. Тачкаста линија представља бинарну серију чврстих раствора Ps–Zo. Легенда: квадрат (празан – обод зрна; пун – центар зрна); пун троугао – хомогена зрна из стена са гранатом.

Similar chemical composition of homogenous grains and the core of zonal grain as well as differences among grains from rocks with or without garnets suggest two stage of epidote crystallization: the first happened in the condition of lower T and slightly higher P, and the second in higher P and T.

P–T CONDITION OF METAMORPHISM

White mica–chlorite schist group is associated with greenschist and rare dykes or small masses of metabasitic rocks that have been metamorphosed in chlorite zone of the grenschist facies (Petrović et al., 1973; Milovanović et al, 1988; Vasković & Tasić, 1996). Milovanović et al. (1988) give P–T data for green rocks developed on the north from the studied area (area of Manastiriška river) according to mineral assemblages and chemism of minerals – c. 350–450°C and 4–5 kbar.

During the last ten years experimental studies were shown that minerals of chlorite group, regarding to its large composition range and polytipism, might be used as indicators of metamorphic grade. However, different chlorite thermometers, applying structural and compositional criteria, are available from literature (Cathelineau, 1988; Jowett, 1991; De Caritat et al., 1993). These authors suggested a considerable potential to the applicability of these methods. Furthermore, there is no theoretical explanation for increase of Al^{IV}, and De Caritat et al. (1993) has criticized the use of the calculated Al^{IV} instead of directly measured Si^{IV}. The last three thermometers, previously mentioned, have been applied to white mica–chlorite group of schist i. e. to chlorite analyses (Table 9).

As we see, the calculated temperatures according to Cathelineau (1988) and Jowett (1991) mostly show analogy. The temperature range within rocks free of garnet is 368 to 375°C, and within rocks with garnet 364 to 415°C. The values calculated according to De Caritat et al. (1993) thermometer is the most lower (Table 9).

Table 9. Calculated temperatures according to chlorite thermometry.
Табела 9. Температуре израчунате на основу хлоритског термометра.

No. an (бр. ан.)	Al^{IV}	X_{Fe}	Temperature (температура) °C		
White mica chlorite schist (мусковит–хлоритски шкриљац)			Cathelineau, 1988	Jowett, 1991	De Caritat et al. 1993
43	1.337	0.48	368.5	372.8	301.4
44	1.341	0.48	368.5	374.1	302.3
White mica chlorite schist with garnet (мусковит–хлоритски шкриљац са гранатом)					
68	1.376	0.51	381.1	386.2	309.7
67	1.462	0.52	397.2	402.5	327.9
71	1.381	0.59	382.7	390.4	310.8
72	1.466	0.54	410.1	415.9	328.8
Albite–white mica–chlorite schist (албит–мусковит–хлоритски шкриљац)					
53	1.355	0.50	374.4	379.2	305.3
54	1.378	0.51	381.8	386.8	310.1
Albite–white mica–chlorite schist with garnet (албит–мусковит–хлоритски шкриљац са гранатом)					
63	1.320	0.50	363.1	368.0	297.8
64	1.348	0.48	372.2	376.3	303.8

Determination of metamorphic grade of white mica–chlorite schist from Vlasina Series is based on the experimentally defined stability of chlorite, epidote, garnet, and biotite as well as on their chemical composition.

Mineral assemblages (Table 2), its relationships, structural features and mode of occurrence as well common local alternation of lithological members with gradual transition suggest the existence of one primary volcanoclastic sedimentary basin made of basic rocks and its pyroclastics with intercalations of pelitic, psammitic and carbonaceous rocks.

Field and petrological studies show that the white mica–chlorite schist developed western and southwestern from Vlasina Lake (area of Gradska river), in the area of Čemernik and northern from Surdulica were underwent the strongest metamorphic changes.

The increasing of metamorphic grade indicated by following:

– occurrences of green to umber green biotite in metaclastites (sericite–chlorite schist, Vasković, 1998) eastern from Gradska river, and increasing of vol. % of epidote and its chemistry i.e. content of Ps–component (16.92–26.34 %) in the area between Gradska river and Čemernik (Fig. 2);

– recrystallization of phengite to phengitic muscovite (Fig. 5) and its approach to "ideal" muscovite;

– the first occurrences of reddish to redbrownish biotite in white mica–chlorite schist;

– the first appearance of spessartine–rich garnet ($Alm_{38-48}Sps_{28-38}Grs_{16-18}$) within white–mica–chlorite schist and almandine–rich ($Alm_{43-54}Sps_{17-29}Grs_{20}$ and $Alm_{59-68}Sps_{11-15}Grs_{10-13}$) within albite–white mica–chlorite schists (Table 6, Fig. 8a, b);

The most indicative parameters of metamorphic grade among minerals within white mica–chlorite group of schist are garnet and biotite.

The first appearance of spessartine–rich garnet is probably due to reaction

Fe–Mn–Chl + Qtz = Grt (Sps–rich) + H_2O (after Hsu, 1968)

Regarding that all analyzed chlorites contain small amount of MnO (0.76–1.09 %, Table 3). According to experimental data enter of spessartine–rich garnet in association with Chl ± WM + Qtz ± Ab + Ep+ ilm/Lx would involves temperatures ≤ 370–400°C and pressures of 4–5 kbar (Fig. 11). The presence of MnO in chlorite probably caused it's enter at some lower temperature – may be in the range from 320 to 415°C (Table 9).

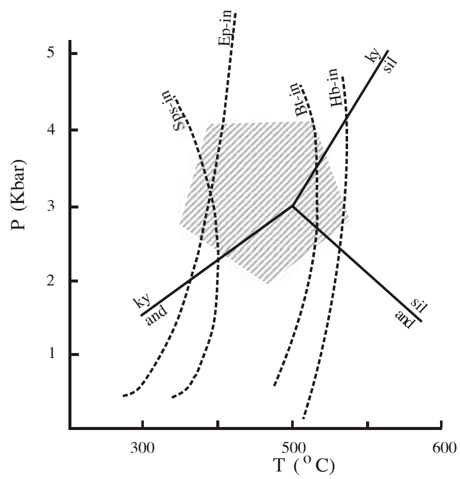

Fig. 11. P–T range of white mica–chlorite schists of the Vlasina Series estimated according to chlorite thermometry. Ky–Sil–And (after Holdaway, 1971).

Сл. 11. Опсег P–T услова метаморфизма мусковит–хлоритских шкриљаца серије Власине процењен на основу хлоритског термометра. Ky–Sil–And (по Holdaway, 1971).

The first appearance of green to umber green biotite is probably due to reaction of sericite and chlorite at the temperature of about 400°C.

The further increase of metamorphism is reflected due to recrystallization of phengite to phengitic muscovite and its reaction with chlorite in red to redbrownish Fe–biotite (Figs 5, 9) as well as by decreasing of pistacite component from 26 to 16% and by appearance of almandine–rich garnet within white mica–chlorite and albite–white mica–chlorite schist due to following reaction:

Fe–Chl + Ep + Qtz = Grt + H_2O + O_2 (after Brown, 1969)

The decreasing of pistacite component in epidote suggest that its first phase was generated in the relatively enriched oxygen condition. The increasing of temperature and reducing of O_2 enable its enrichment by Al. These changes, according to Liou et al. (1985), befall in the temperature range from > 325 to 400°C.

The formation of biotite is continual process as showed by experimental studies. It consumed seladonite component from low–T K–rich mica, which have been transformed to phengitic muscovite. These changes fall in the temperature range from > 400 to 450°C.

Appearance of almandine–rich garnet is caused by local increasing of metamorphic grade in the area of Gradska river and on the north of Surdulica. Its formation falls in the temperature range from 450 to 500°C and pressure 4–5 kbar (Fig. 11).

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РЕЗИМЕ

ПЕТРОЛОГИЈА И P–T УСЛОВИ ФОРМИРАЊА МУСКОВИТ–ХЛОРИТСКИХ ШКРИЉАЦА ВЛАСИНСКЕ СЕРИЈЕ (СУРДУЛИЦА, ЈИ СРБИЈА)

Серију Власине као посебну литолошку јединицу у оквиру Горњег комплекса Српско–македонске масе (сл. 1) издвојили су Vasković & Tasić (1996, 2000). Стене ове серије, познате под називом "зелени шкриљци" (Petrović, 1969), представљају основне литолошке чланове власинске синклинале, чемерничког антиклиноријума и источног крила јужноморавског синклиноријума (сл. 2, 3).

Серија се одликује веома сложеним структурним склопом и током дугог геолошког развоја претрпела је бројне фазе обликовања. Према досадашњим испитивањима (Petrović, 1969; Babović et al., 1977; Vasković & Tasić, 1996, 2000) у њој су издвојене три фазе деформација и обликовања.

На основу теренских и петролошких испитивања констатовано је да се Серија Власине генерално састоји од две групе стена: мусковит–хлоритски шкриљци и зелене стене. У североисточним деловима серије појављују се локално сочива кварцита, метаконгломерата и мање масе серпентинита и талкшиста (Petrović, 1969; Vasković & Tasić, 1996, 2000). Овом приликом детаљно су петролошки обрађене стене из групе мусковит–хлоритских шкриљаца (сл. 2).

Литолошки састав групе мусковит–хлоритских шкриљаца (гради око 75% серије) дефинисан је асоцирањем албит–мусковит–хлоритских и мусковит–хлоритских шкриљаца са прелазима ка серицит–хлоритским шкриљцима и локалним појавама албит–мусковитских и графитичних шкриљаца, филита и калкшиста. То су стене лепидобластичне и порфиробластичне структуре, некад са елементима бластопсамитске, често убране у mm наборе, понекад са добро развијеним кливажом аксијалне површи набора. Изграђене су од фенгита, фенгитског мусковита (сл. 5), хлорита (рипидолит; сл. 6, 7), албита (3–9% An) са прелазима у олигоклас (12–14% An), две генерације граната (спесартинског и алмандинског; сл. 8), две генерације биотита (Fe–биотит; сл. 9), епидота (16 до 26% Ps; сл. 10), и металичних минерала (илменит/леукоксен, ређе магнетит). Асоцијације минерала приказане су у табели 2, а њихов хемијски састав у табелама 3–8.

На основу структурних карактеристика, асоцијације и хемизма минерала, као и уз помоћ хлоритског термометра (табела 9) одређени су P–T услови њиховог метаморфизма.

Према тим карактеристикама стене из групе мусковит–хлоритских шкриљаца метаморфисане су кроз три фазе деформација у температурном интервалу од 320 до 415°C, локално и до 450–500°C при притисцима од 3 до 5 kbara (табела 9, сл. 11).