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Geološki odsjek

Universitất Salzburg
Abteilung Mineralogie und
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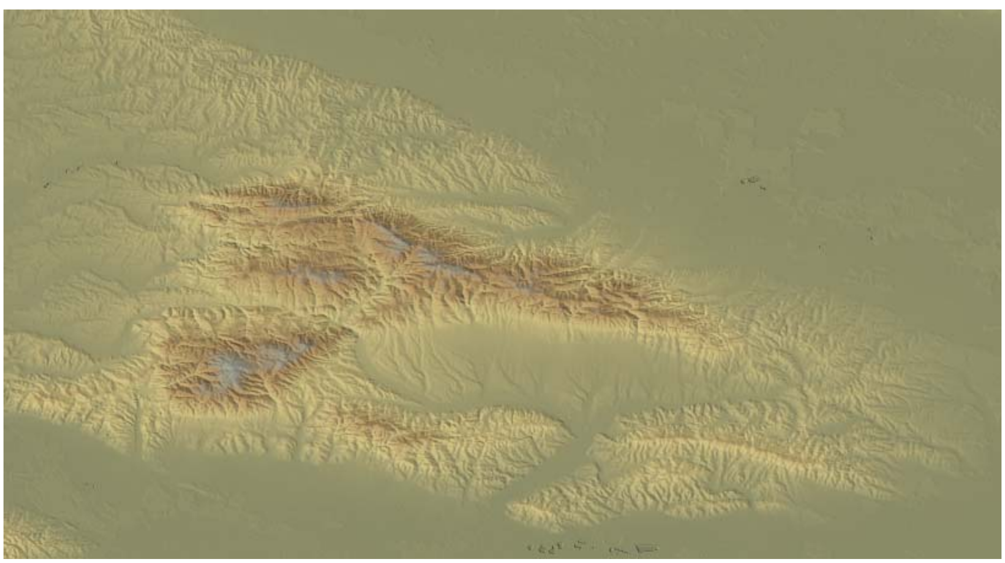
# Croatian – Austrian Student Excursion in Mineralogy and Petrology



## Slavonian Mts. Area

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Compiled by:

Dražen Balen[1] *and* Bruno Tomljenović[2]
[1] Mineraloško-petrografski zavod, Geološki odsjek, Prirodoslovno-matematički fakultet
[2] Zavod za geologiju i geološko inženjerstvo, Rudarsko-geološko-naftni fakultet

Contents



## *Introduction*

Slavonian Mts. comprise four up to 1000 m high hills of Psunj, Ravna Gora, Papuk and Krndija located along the southern edge of the Pannonian Basin (PB) in the northeastern Croatia (Fig. 1). In the course of the Neogene to recent tectonic history these hills are seen as a structural assemblage of the pre-Neogene tectonic units, composing a complex WNW-ESE trending positive flower structure formed within a transpressive corridor between the Drava and Sava dextral strike-slip faults (*Jamičić*, 1995). In their central parts they expose metamorphic and igneous pre-Alpine rocks considered to build up the crystalline basement of the southern part of Tisia Unit (e.g. *Csontos*, 1995; *Pamić* and *Jurković*, 2002; *Pamić* et al., 2002). This crystalline basement was firstly covered by Permian-Mesozoic sediments, recently only locally preserved in cores of map-scale synclines, and then by Neogene-Quaternary fill of the Pannonian Basin (*Jamičić* and *Brkić*, 1987; *Jamičić*, 1989). Later inversions, however, obliterated original contacts, which are largely overprinted by younger faults of reverse, normal and strike-slip character (Fig. 1).

Separation of the major tectonic units of the crystalline pre-Alpine basement of the Slavonian Mts. and particularly the timing of their metamorphic-deformational history are still controversial. According to the subdivision of *Jamičić* (1983, 1988) this basement comprises the following tectonic and metamorphic units (Fig. 1): (1) the Psunj metamorphic complex (also named as the Kutjevo metamorphic series) originated from a progressive metamorphism during the Baikalian orogeny, later overprinted and retrogressed by younger metamorphic events; (2) the Papuk metamorphic complex (also named as the Jankovac metamorphic series) originated from progressive metamorphism and migmatitization during the Caledonian orogeny, and (3) the Radlovac metamorphic complex originated from a very low-grade metamorphism during the Variscan orogeny. The Psunj metamorphic complex consists of (a) low-grade (greenschist facies) metamorphic sequences composed of metapelites, chlorite schists and micaschists, and (b) medium-grade (amphibolite facies) metamorphic sequences composed of paragneisses, garnetiferous micaschists, amphibolites, metagabbros and marbles, locally intruded by discordant granodiorites and plagiogranites (i.e. I-type granites according to *Pamić*, 1986; *Pamić et al*., 1988a; *Pamić* and *Lanphere*, 1991).

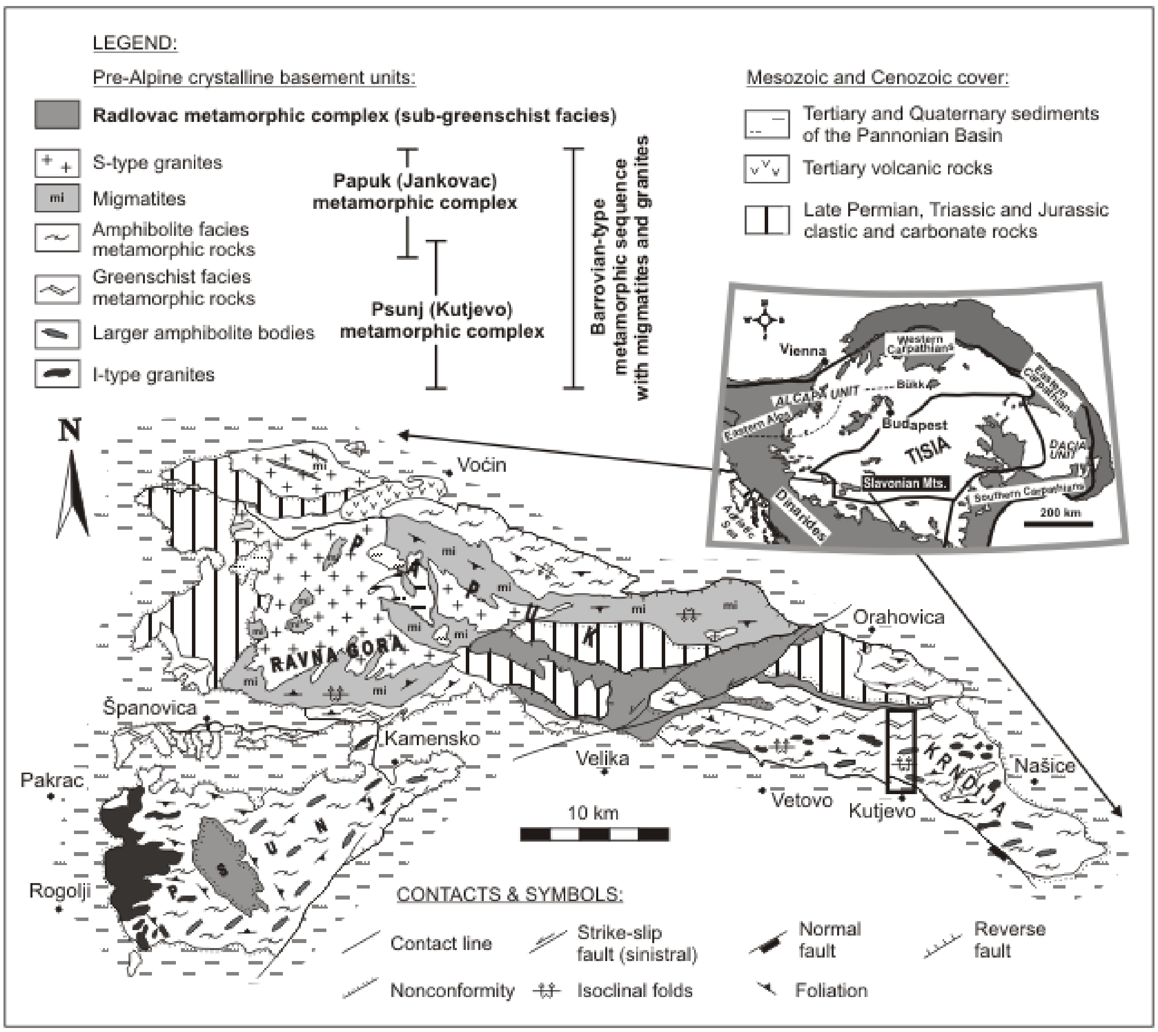


Fig. 1. Simplified geological map of the Slavonian Mts. (after *Jamičić* et al. 1986; *Jamičić and Brkić,* 1987; *Jamičić*, 1988; *Pamić and Lanphere*, 1991; modified and partly reinterpreted) with index-map showing position of the Tisia Unit inside the Pannonian Basin. Black-box shows the approximate position of the Kutjevo River (Kutjevačka rijeka) transect through progressive metamorphic complex.

The Papuk metamorphic complex largely consists of (a) granites (S-type granites according to *Pamić*, 1986; *Pamić et al*., 1988a; *Pamić* and *Lanphere*, 1991) surrounded by (b) migmatites and migmatitic gneisses that grade into (c) medium-grade (amphibolite facies) metamorphic sequences composed of garnetiferous amphibolites, paragneisses and micaschists. The Radlovac metamorphic complex consists of very low-grade (sub-greenschist facies) metamorphic sequences largely composed of slates, metagreywackes, metaconglomerates and subordinate phyllites, locally invaded by metadiabases and metagabbros (*Pamić* and *Jamičić*, 1986). According to *Jamičić* (1983, 1988) and *Jamičić* and *Brkić* (1987) this complex occupies the highest position in the pre-Alpine structural assemblage of the Slavonian Mts., originally representing a sedimentary cover of the Late Silurian to Early Permian age (*Brkić et al*., 1974; *Jerinić et al*., 1994) over the Psunj (Kutjevo) metamorphic complex (Fig. 1). In turn, it is nonconformably covered by a clastic-carbonate succession of Late Permian and Triassic age, not affected by the Alpine metamorphism (Figs. 1 and 2; *Jamičić* and *Brkić*, 1987).

Based on extensive petrological analysis combined with radiometric age determinations of plutonic and metamorphic rocks of the Slavonian Mts. *Pamić* and *Lanphere* (1991) put forward an alternative subdivision of major tectonic units and timing of major metamorphic events (Fig. 1) (see also *Pamić* and *Jurković*, 2002 and references therein). They proposed that the Psunj (Kutjevo) and the Papuk (Jankovac) complexes defined by *Jamičić* (1983, 1988) compose one plutonic and metamorphic complex comprising the E-W trending Barrovian-type metamorphic sequences, which following a roughly N-S oriented sections grade into migmatites and granitoids. These sequences are characterized by zoned distribution of index-minerals of chlorite-biotite-almandine-staurolite–sillimanite (*Raffaelli*, 1965), ± kyanite (*Jamičić*, 1983) or andalusite (*Pamić et al*., 1988b). This uniform complex is interpreted as a part of a low-pressure/high temperature metamorphic belt of Variscan age inferred from geochronological results which include (*Pamić* and *Jurković*, 2002 and references therein): (1) a 333 ± 1.7 to 324.7 ± 1.5 Ma $^{40}Ar/^{39}Ar$ plateau ages for muscovite concentrates from paragneisses and micaschists; (2) a 376.4 ± 11.5 to 352.6 ± 8.5 Ma K-Ar ages for hornblende concentrates from orthoamphibolites; (3) a 314 ± 16 to 317 ± 17 Ma Rb/Sr-isochrone ages for whole-rock samples of S-type granites and migmatites (Pamić et al. 1996), and (4) a 423.7 ± 12.9 to 336.3 ± 8.4 Ma K-Ar ages for muscovite concentrates from I-type granites (*Pamić et al*., 1988a). Besides these, however, *Pamić et al*. (1996) reported older K-Ar and Ar-Ar ages grouped around 430 Ma obtained on muscovite concentrates from micaschists of the same complex, which possibly imply a presence of some relict pre-Variscan mineral parageneses observed by *Jamičić* (1983, 1988). In accordance with subdivision of *Jamičić* (1983, 1988), they also separated the semimetamorphic complex with metadiabases and metagabbros, i.e. the Radlovac complex, which they interpreted as to originate from a very low-grade metamorphism of Variscan age, too.

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For additional overviews on geology of Slavonian Mts. see:

*Pamić* and *Jurković* (2002), *Pamić* (1998), *Tomljenović* (1998), *Pamić* and *Tomljenović* (2000), *Jamičić* (2003), *Pamić* et al. (2003).

Table 1. Age and thermobarometry data for South Tisia (*Pamić* and *Jurković*, 2002)

| Rock unit | P–T conditions | Applied methods | Age (Ma) | References |
|---|---|---|---|---|
| Barrovian-type metamorphic sequences, Slavonian Mts. | 550–670 °C<br>5–7 kbar | Rb–Sr amphibolite whole rock sample<br>K–Ar hornblende<br>K–Ar hornblende<br>K–Ar hornblende with very low K content<br>K–Ar muscovite<br>K–Ar muscovite<br>K–Ar biotite<br>Ar–Ar muscovite<br>Ar–Ar biotite<br>Ar–Ar muscovite | 317±17<br>262.3±6.3 to 219.7±7<br>376.4±11.5 to 352.6±8.5<br>568.0±20 to 421.7±10<br>337±4.3 to 326.5±1.5<br>430±2.0<br>264.0±6.3<br>333±1.7 to 324.7±1.5<br>264.0±1.5<br>430±2.0 | Pamić et al. (1988), 1996; Pamić and Lanphere (1991) |
| Two-stage metamorphic sequences, Mt. Moslavačka Gora | 550–820 °C<br>5.2–9.6 kbar<br>550–650 °C<br>2.5–4 kbar | K–Ar hornblende<br>K–Ar hornblende<br>K–Ar biotite | 88.0±3<br>48.5±2.4 to 43.2±2.0<br>38.5±4.0 to 27.0±2.0 | Pamić (1990); Lanphere and Pamić (1992); Garašić (1993); Balen (1999); Balen and Pamić (2001) |
| S-type granites and migmatites, Slavonian Mts. | | Rb–Sr whole rock isochron<br>K–Ar hornblende<br>K–Ar muscovite<br>K–Ar biotite | 314±16 to 317±17<br>336.8±8.4 to 335.1±7.8<br>336.3±8 to 324.6±8.3<br>300.2±7 to 277.1±5.0 | Pamić et al. (1996) |
| S-type granites and migmatites, Mt. Moslavačka Gora | | Rb–Sr whole rock model age<br>$^{87}Sr/^{86}Sr=0.7430$<br>K–Ar biotite<br>K–Ar muscovite | 90±5 to 62.0±4<br>Pre-Alpine<br>70±2.2 to 57.0±2<br>70.5±2 | Lanphere and Pamić (1992) |
| I-type granitoids with diorite, gabbro and ultramafics, Slavonian Mts. | | K–Ar muscovite<br>K–Ar hornblende<br>K–Ar biotite<br>K–Ar hornblende with very low K content | 423.7±12.9 to 336.3±8.4<br>338.9±8.5<br>321.5±8 to 223.3±5.3<br>527.3 to 506.3±10.2 | Pamić et al. (1988) |
| Very low grade Radlovac Formation Slavonian Mts. | $b_0$=9002 pyrophyllite, paragonite, albite, pumpellyite, chlorite | K–Ar whole rock slate<br>K–Ar clinopyroxene | 203.9±6.9<br>416.0±9 to 318.6±12.2 | Pamić et al. (1988); Pamić (1998) |

## *Potential stops*

## *#1 Vrtlinska (Moslavačka Gora area)*

*Quartz sands of Moslavina and Slavonia*

Vrtlinska (Moslavačka Gora) quartz sand deposits

The Neogene formations of the marginal parts of the Pannonian Basin in Croatia include numerous quartz sand deposits like in: Vrtlinska (Moslavačka Gora), Jagma (Psunj), Vranić, Španovica and Branešci (Papuk)). During the initial evolution of PB (early Miocene) weathering conditions led to erosion of exposed granites, transportation of terrigenous material and deposition of quartz ± feldspar psammitic fractions. The deposition of quartz resistates during the Miocene and Pliocene was cyclic. Cyclicity was induced by the regional tectonic events and repeated transgressions and regressions accompanied by intense weathering of exposed rocks under moderately warm and humid climatic conditions.

High quality quartz sands are included in *Rhomboidea* deposits (Late Pontian). Purity of that sand is due to intensive process of feldspar alteration. Heavy mineral content comprise garnet, zircon, epidote, amphibole, tourmaline, etc.
General characteristics of sand deposits at Vrtlinska locality: reserves are estimated to 10.500.000 t, $SiO_2$ 93-97 wt.%, grain size 0.063 mm - up to 8 mm, use in the glass and chemical industry, constructions, water filtering, etc. (*Krkalo*, 1998; *Šuprina*, 2000).

## #2 Podvrško

*Shoreline cross-bedded biocalcarenites of Middle Miocene age*
The extensively distributed bioclastic sedimentary bodies in the Podvrško-Šnjegavić Area, Mt. Psunj (Požega Subdepression, Eastern Croatia) are mostly composed of fragments of bryozoans, echinoids, lamellibranchs and corallinaceans. Apart from this, a relatively compositionally uniform, but granulometrically variable bioclastic detritus occurs, which also contains a smaller proportion (5-30%) of siliciclastic grains of medium to coarse sand, as well as sporadic pebbles up to 60 mm in diameter. These sediments are characterized by remarkably large-scale cross-bedding with erosional surfaces clearly delimiting cross-bedded sets. These sets are interpreted as shallow-marine shoreface dunes, sand bars and barriers formed on the nearshore - mainly shoreface area during the Late Badenian (Middle Miocene) in a high-energy depositional cycle with strong synsedimentary tectonics (*Velić* et al., 2000).

Velić et al. (2000)

## #3 Poljanska

*Tuff deposits with zeolites (analcime)*
Near the village of Poljanska there is a small quarry where tuff is excavated. It is used as correction component and additive for the cement industry (Našice). Analcime bearing deposits in Poljanska (Mt. Papuk) are interstratified with Ottnangian - Karpatian and Badenian (Helvetian, i.e. Miocene) saline sediments. They are developed in two horizons and have a hybrid composition, due to the mixture of carbonate sediments (dolomite), pyroclastic and volcanoclastic material and terrigenous detritus derived from older crystalline rocks. Among different sedimentary members one could determine penecontemporaneous dolomicrites, shales, marls, tuffs, tuffites and tuffaceous sandstones - all containing analcime as important component, either dispersed or concentrated in aggregates. Frequently, monomineral layers or lamina of analcime are formed and interstratified among different sedimentary members. Analcime was formed by alteration of volcanic glass, in the shallow water of an unsheltered saline alcaline lake, under conditions of increased aridity and closure of the lake. These “marginal lakes” of salina-type existed only locally within the Pannonian Basin, in which silty sediments associated with some coarse-grained clastics and pyroclastics were deposited during the Miocene (*Šćavničar* et al., 1983; Pavelić, 2001).

## *#4 Zvečevo*

*S-type granites*

S-type granites and associated intermediate rocks occur as large or small bodies within the migmatitic complex. Texture of S-type granites is commonly xenomorphic, medium- (1-3 mm) to coarse-grained (5-6 mm); porphyroid varieties are subordinate. Structure is mostly massive whereas foliated varieties are rare. Mineral composition comprises quartz and plagioclase, biotite as the most common mafic mineral, with muscovite, hornblende and accessory minerals (apatite, zircon). Biotite and secondary muscovite are commonly found in nest-like aggregates which are similar to lensoid mica agglomeration in migmatites. Classification based on modes shows that most of these rocks are monzogranites and granodiorites. *Pamić* and *Lanphere* (1991) interpreted that both the migmatites and the S-type granites occurred simultaneously and are related to the Variscan orogeny (Fig. 2).

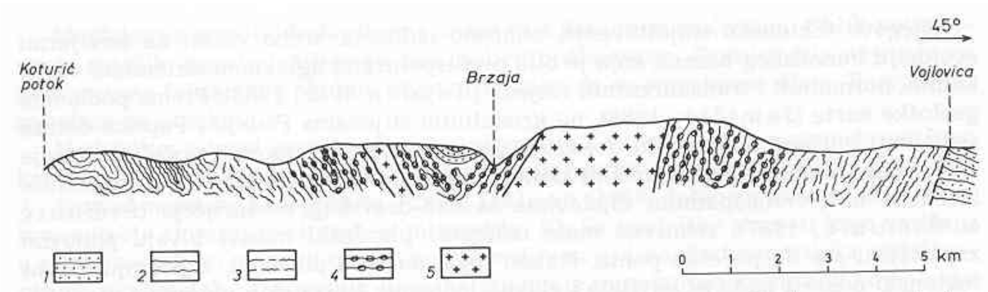



Fig. 2. Sketch cross-section Koturić potok – Brzaja – Vojlovica based on geological map of *Jamičić* (1988); 1 Neogene sediments; 2 low-grade metamorphic rocks; 3 medium-grade metamorphic rocks; 4 migmatites; 5 S-type granites (from *Pamić* and *Lanphere*, 1991)

## *#5 Djedovica (Trešnjevo brdo)*

*Migmatites intruded by basalt dikes*

Up to 1 m thick basalt dike intruded in migmatites.

Detail shows migmatite xenolith and chilled margins at basalt - migmatite contact.

The mineral assemblage of migmatites (Variscan in age, mostly 336-324 Ma - *Pamić* and *Lanphere*, 1991) comprises quartz and feldspar, as the predominant leucosome minerals, micas (biotite) with subordinate hornblende and garnet as melanosome constituents, and various secondary and accessory minerals. Melanosomes characteristically contain greater quantities of accessory minerals (garnet, titanite, zircon, apatite) and some of them approach the abundance of major minerals. Most of the migmatites fall into the fields of granodiorites and monzogranites.

In the basalts near Voćin, plagioclase phenocrysts are zoned; average composition $An_{74-61}$, while in groundmass plagioclase is more sodic $An_{57}$, clinopyroxene is augite. The K-Ar ages of basalts are in range 72-62 Ma (Pamić et al., 2000). However, authors of geological map interpreted volcanic rocks as Miocene in age (ca. 16 Ma) - *Jamičić* and *Brkić* (1987).

## #6 Rupnica

*Columnar jointing in volcanic rocks*


Rupnica locality is situated in the valley of Djedovica creek, a few km SW from Voćin. This is one amongst the very few protected geological monuments in Croatia (protected since 1948) where columnar jointing and folding of volcanic rock columns are visible. Characteristically, the joints are shrinkage cracks formed by cooling of volcanic rock and form 4-6 sided polygons and columns.

These rocks are part of heterogeneous volcanic body composed of different varieties of basalt, andesite, rhyolite, tuff and pyroclastic agglomerate.

## #7 Veličanka, Velika, Tisica

Middle and Late Triassic sediments ($T_2$ and $T_3$) in the Veličanka quarry are represented by dolomites, dolomitic limestones and limestones.

In the valley of Dubočanka, in the vicinity of mountain hut Lapjak and the old castle (Velički grad) a recently renovated spa center is located. It is fed by thermal water (26 ºC) from the spring formed in faulted Triassic dolomites surrounded by less permeable Paleozoic rocks.

Further to the north, there is a small quarry at Tisica (Radiša) locality, which is placed in rocks of Radlovac formation (see stop description at #14 Radlovac).

### #8 Jankovac

This locality exposes tufa barrier at the 40 m high Skakavac waterfall. In the surrounding area, numerous springs formed along the contact between carbonate and less permeable Paleozoic crystalline rocks are present.
One of the most beautiful is the spring of Jankovac creek.

### #9 Slatinski Drenovac

*Migmatite on the road from Jankovac to Slatinski Drenovac*

The mineral assemblage of migmatites comprises quartz and feldspar, as the predominant leucosome minerals, micas (biotite) with subordinate hornblende and garnet as melanosome constituents, and various secondary and accessory minerals. Most of the migmatites fall into the fields of granodiorites and monzogranites (*Pamić* and *Lanphere*, 1991).

### #10 Vetovo

*Psunj (Kutjevo) met. complex, gneiss, amphibolite, sulphide mineralization, goethite*

The Psunj (Kutjevo) metamorphic complex is formed under the P-T conditions of greenschists and amphibolite facies. Higher grade, amphibolite facies rocks are paragneisses and mica schists commonly interlayered together with amphibolites and subordinate marbles. The lower-grade, greenschist facies rocks are mostly phyllites, quartz schists and greenschists.

Paragneiss, the most common rock type, shows lepidogranoblastic and lepidoblastic, rarely porphyroblastic texture. Modal, compositional and granulometric layering is common, together with internal foliation and microfolding. Mineral composition comprises biotite, quartz, subordinate muscovite, plagioclase, garnet, hornblende.

Amphibolites occur as few decimeter thick interlayers in paragneisses and also as larger bodies. Textures are fine-grained nematogranoblastic, lepidogranoblastic and relic ophitic. Foliation and lineation are strongly developed. Mineral assemblage includes predominately hornblende and plagioclase with garnet, quartz, biotite. Geochemical data suggest that amphibolites originate from tholeiitic basalts (Pamić and Marci, 1990; Pamić et al, 2002).

In the huge Vetovo quarry occurrences of sulfide and goethite mineralization in the veins and along fault planes are quite common.

Pamić et al. (2002)

## #11 Kutjevo

*Prograde metamorphic sequence along the Kutjevačka Rijeka transect*

Beside the N-S striking transect in the central part of the Slavonian Mts. where *Raffaelli* (1965) firstly described a zoned distribution of index minerals within the prograde metamorphic sequence, a parallel, more to the east located transect along the Kutjevačka Rijeka valley is another section where the same unit can be studied in great detail (Figs. 1 and 3). Along this transect heading north, the prograde metamorphic sequence is firstly represented by its medium-grade (amphibolite facies) part largely composed of garnet-bearing micaschists and paragneisses with subordinate orthoamphibolite intercalations and granitoid intrusions (Fig. 3). Further north, this grades into greenschists facies schists comprising the low-grade part (chlorite zone) of the prograde metamorphic sequence, which is firstly covered by sub-greenschist facies rocks of the Radlovac metamorphic complex and then by a clastic-carbonate succession of Permian and Triassic age. Mesoscopic observations in the prograde metamorphic sequence reveal evidence of two foliations that predate Alpine deformation. An older ($S_1$) foliation is only locally recognized within $F_2$ fold closures where it is folded around $F_2$ fold axes (see structural cross-section of Fig. 3). Here, $S_1$ is marked by a metamorphic layering characterized by a cm-scale alternation of micaschist, paragneiss and amphibolite, all containing mm-scale garnet trails parallel to the metamorphic layering. This relationship indicates that amphibolite facies conditions took place during formation of $S_1$ foliation. By passing from $F_2$ fold hinges into strongly attenuated limbs $S_1$ becomes sub-parallel and parallel to a younger ($S_2$) planar fabric, which is the most evident mesoscopic foliation in these rocks. This foliation is either parallel or show consistent geometrical relationship with the axial planes of predominantly E-W trending, isoclinal $F_2$ folds. Hence, it is interpreted as to represent an axial plane cleavage of $F_2$ folds related to D2 deformational event, which resulted in greenschist facies retrogression of the prograde metamorphic sequence. Sporadically along the transect, $S_2$ is found to dip in opposite directions, which is interpreted as a result of a subsequent post-$D_2$ folding event attributed to Alpine deformation (Fig. 3).

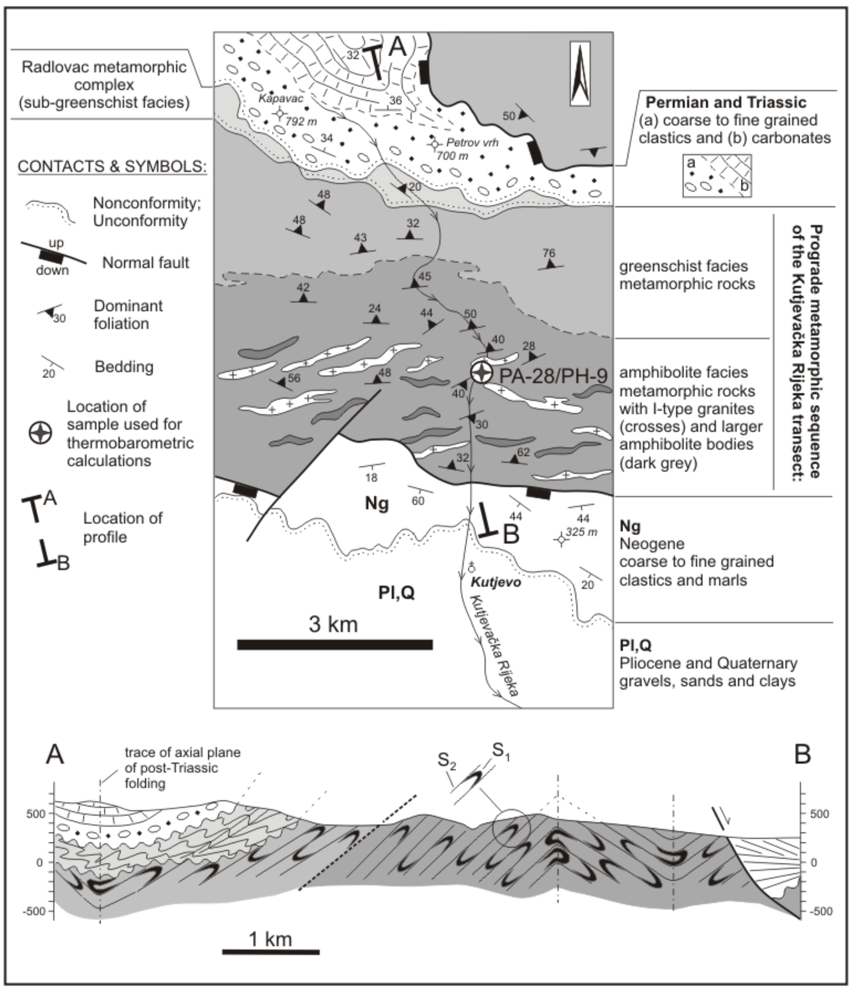



Fig. 3. Geological map in the area of the Kutjevačka Rijeka transect (based on data from *Jamičić and Brkić* (1987), partly modified and reinterpreted).

M*icaschists* have a well preserved metamorphic fabric ($S_1$) with a peak metamorphic assemblage of garnet, biotite, muscovite, plagioclase and quartz corresponding to amphibolite facies conditions. This foliation is predominantly marked by preferentially oriented biotite, muscovite and abundant garnet trails. Plagioclase is elongated and together with quartz occurs in layers parallel to $S_1$ foliation. Garnets are hypidioblastic and partly fractured, and typically surrounded by asymmetric pressure shadows filled with chlorite, biotite, muscovite, epidote and quartz. Regarding the grain size garnets form two distinct groups comprising relatively larger- and smaller-sized population, respectively. Large-sized garnet population clearly preserves a complex growth history.

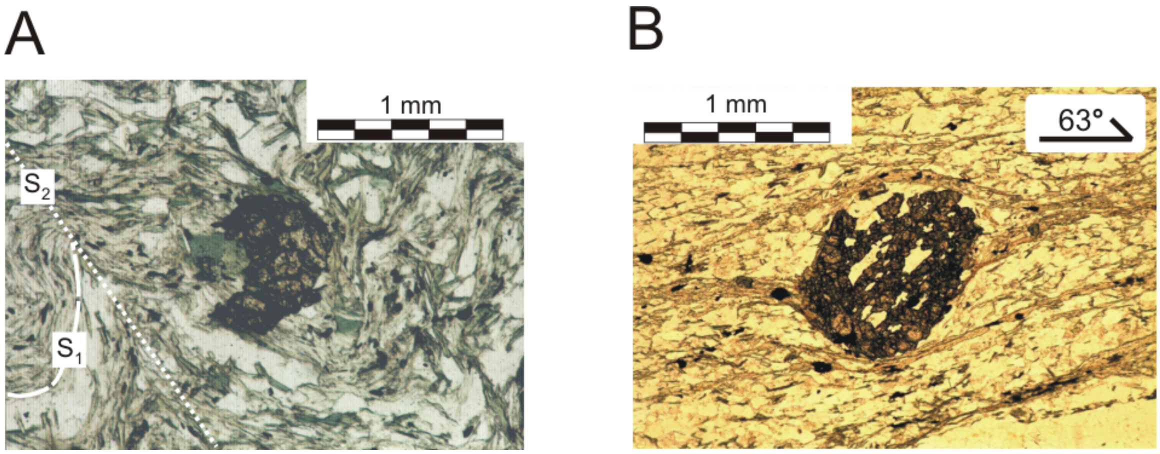



Fig. 4. Microstructural relations in garnet-bearing micaschists from the Kutjevačka Rijeka transect, PPL, N-. A Microscale isoclinal folding of older foliation (S1) overprinted by a younger S2 foliation. B mylonitic microstructure around garnet grain.

Paragneiss assemblage comprises garnets with slightly different core and rim composition, suggesting prograde character. Peak assemblage includes biotite, amphibole, plagioclase (~28 %An) and quartz. Apatite, ilmenite, zircon, amphibole and quartz are inclusions in garnets.

Amphibolites also contain garnets with slightly different core and rim compositon. Cation distribution suggests prograde character. Peak assemblage also includes amphibole, plagioclase (20-30 %An) and quartz, with minor ilmenite, apatite, titanite, epidote-clinozoisite.

A detailed investigation of compositional variation in garnet combined with monazite dating of the medium grade metamorphic rocks exposed along the Kutjevačka Rijeka transect in the Slavonian Mts. (NE Croatia) has been undertaken in order to decipher the metamorphic history of the crystalline basement of the southern part of Tisia Unit. Microstructural observations, together with the interpretation of preserved garnet chemistry, point to a complex metamorphic history reaching amphibolite facies peak conditions of ca. 600-650 °C and 8-11 kbar. Compositional variation in garnet from micaschists is interpreted as a change in reaction assemblage involving breakdown of calcium-rich phase during a prograde P-T path. Th, U, Pb contents of yttrium-rich accessory monazites indicate a pre-Variscan, i.e. Silurian (428±25 and 444±19 Ma) age for the medium-grade metamorphism of garnet-bearing micaschists exposed along the Kutjevačka Rijeka transect.

*Greenschist* facies rocks comprise greenschists (s. str.), as the most common, composed of quartz, chlorite and muscovite with subordinate feldspar (commonly albite) and clinozoisite, and in the higher garde parts with epidote, garnet and biotite.
Phyllites alternate with greenschists. In many places they show microfolding. Quartz and "white mica" (most commonly muscovite) predominate, with subordinate feldspar and chlorite and opaques and zircon as accessories.


Chloritoid schists comprise metapelites and metapsammites which contain chloritoid as a major or subordinate mineral. As a rule, these rocks occur along the contact zone between anchimetamorphic complex and the lower-grade parts of the progressively metamorphosed complex. However, the exact relations are not clearly defined yet. Chloritoid phyllites and schistose chloritoid metasandstones are the most common rocks

I-type granites occur within the progressively metamorphosed complex. These are mostly small, up to few hundreds or km long bodies. The largest one is known as Omanovac granitic body (Psunj Mt.). Mineral assemblage comprises quartz, feldspar, biotite, muscovite, hornblende, garnet. Primary texture is xenomorphic. Majority of rocks are classified as tonalite, granodiorite, and monzogranite. Garnet-bearing tonalite varieties are common in granitic bodies of Krndija Mt. (*Pamić* and Lanphere, 1991)

*Sedimentary rocks at Kutjevo River transect*

The oldest Mesozioc units are represented by Permo-Triassic rocks. These are coarse- to medium grained terrigeneous clastics, i.e. conglomerates and sandstones that unconformably overlie the metamorphic complex. Composition of detrital components indicates magmatic and metamorphic rocks as the near by source region. Permo-Triassic rocks crop out as elongate narrow zones dividing crystalline complex from the Triassic, predominately carbonate rocks.

"Phyllitic conglomerates" pinky to violet colored, poorly sorted, composed of granite derived pebbles grade into more fine-grained violet sandstones. Quartz sandstones (arkose and subarkose) concordantly overlie coarse-grained rocks and are considered as a transition to Lower Triassic clastic sequence represented by sandstones and siltstones. Middle Triassic is represented by carbonate rocks (dolomite and subordinate limestone) - *Jamičić* and *Brkić* (1987), *Tomljenović* (1998).

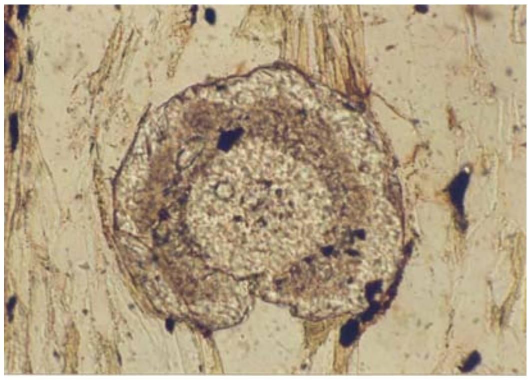
*Panoramic view of Drava River Valley (Pannonian Basin). In the case of clear weather visible are Mecsek and Villány hills in Hungary.*

## #12 Krndija quarry (in vicinity of village Gradište)

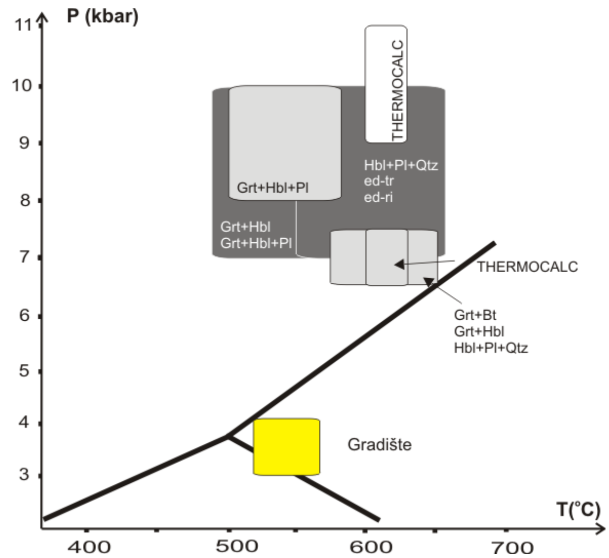
*Psunj (Kutjevo) metamorphic complex, micaschist, amphibolite, metagabbro*

Domino or bookshelf structure in metagabbro (amphibolite) layer embedded in micaschist

Micaschist mineral assemblage comprises biotite, muscovite, quartz, plagioclase ($An_{16-23}$), garnet ± staurolite ± andalusite. Calculated P-T is in range 520-570 ºC and 3-4 kbar.



Zonal garnet from micaschist, Krndija quarry (Geadište), PPL, N-, garnet size ca. 1mm




Peak metamorphic P-T values for micaschist (white box), gneiss (light gray box) and amphibolite (dark gray box) from Kutjevačka Rijeka and Gradište micaschists (yellow) area (*Balen* and *Horváth*, 2003; *Horváth* and *Balen*, 2003).

## #13 Lončarski Vis, Torine, Gradac

*Miocene trachyandesites (shoshonite)*

In the South Pannonian Basin, adjacent to the North Dinarides, rocks of Tertiary postorogenic shoshonite association are known from Mt. Krndija. They are predominantly trachyandesites with subordinate basaltic trachyandesites. On the $SiO_2$ versus $K_2O$ diagram (*Peccerillo* and *Taylor*, 1976) analyzed samples can be classified as members of the shoshonite volcanic series. Ages of the volcanic suite are constrained by concordant geological and radiometric K-Ar dates. The age of the volcanic occurrences is Karpatian (~17 Ma). Geochemical data suggest that volcanic rocks originated from melts generated by a partial melting of the metasomatized pargasite peridotite of upper mantle wedge were slightly modified by fractional crystallization. Magma was also affected by slight and, to a lesser extent, by moderate crustal contamination. In geochemical aspects magmatism can be genetically related to the postorogenic evolution of the Dinarides and explained by a slab-breakoff model related to underplating of Apulia (Africa) below Tisia (Eurasia).

The trachyandesites are porphyritic (pilotaxitic), rarely aphyric in texture with massive, amygdaloidal and fluidal structure. Mineral content comprises phenocrysts of plagioclase and sanidine, pyroxene (diopside and augite, hypersthene), olivine, phlogopite and accessories (mostly apatite) which also are present in the groundmass. Plagioclase phenocrysts show inverse ($An_{38-52}$) and normal ($An_{45-29}$) zonation. Sanidine is nearly of the same composition in the groundmass and in the phenocrysts. Phlogopite and augite are characterized by high Mg/Fe ratios, and hypersthene is the subordinate mafic phase. Amygdales are filled by zeolites and rarely quartz. The quartz is commonly surrounded by a very fine-grained clinopyroxene wreath, suggesting that it may be partly xenocrystic (*Pamić* and *Balen,* 2001; *Balen* and *Pamić*, 2001).

## *#14 Radlovac*

On the way of our excursion, outcrops of the Radlovac metamorphic complex (also known as the Radlovac formation) can be found in a broad region of the Papuk Mt. (see Fig. 1), and on the type locality along the Radlovačka Rijeka valley. Good outcrops also exist in the Tisica quarry near the village of Velika and along the Kutjevačka Rijeka transect.

Age constraints: Based on the field relations this anchimetamorphic complex unconformably overlying the prograde metamorphic sequences (*Jamičić,* 1983; 1988) and contains Westphalian microflora (*Brkić* et al., 1974) which documents Carboniferous age of protolith. On the other hand, K-Ar dating on "clinopyroxene" monomineralic concentrate (comment D.B. - probably on amphibole) from ophitic metagabbro, which intrudes the complex, gave age of 416-318 Ma (*Pamić* and *Jamičić*, 1986; *Pamić* et al., 1988a; *Pamić* and *Lanphere*, 1991). Furthermore, *Jerinić* et al. (1994) found preserved palynomorph associations which indicate a Silurian, Devonian to (?) Early Carboniferous age. That widely set age constraints support the idea about Radlovac metamorphic complex as the potential protolith of the Barrovian-type metamorphic sequence and caused vivid debate between two groups of authors.

Bearing in mind a new Silurian monazite age for Kutjevo River micaschists (unpublished data, see #11) idea of Radlovac metamorphic complex as a potential protolith for the prograde Barrovian-type metamorphic sequence should be questioned.

Very low grade (VLG) metamorphic rocks are mostly *slates* and schistose *metasandstones* with subordinate *phyllites*, *quartzites* and schistose *metaconglomerates*. The complex is intruded by sills (?) of *metadiabase* and ophitic *metagabbro* up to 100 m thick (Fig. 5). Slates are grey, green or violet to red colored, showing distinct cleavage and foliation. The mineral composition is quartz, white mica (mostly illite) with subordinate chlorite and sodic plagioclase. Accessories are opaque(s), zircon and hematite (in the red colored slate). Phyllites have the same mineral composition and are characterized by modal and compositional layering, microfolding and kink-bending. Schistose metapsammites are represented mostly by grey to green foliated metagreywackes. Metaconglomerates contain well rounded pebbles of quartz and subordinate granites and schists. Metabasic igneous rocks occurs as sills, a few meter to hundred meter thick, showing ophitic texture and grains up to 3 mm (metadiabase) or up to 10 mm (ophitic metagabbro) in size. Beside relics of primary clinopyroxene and plagioclase the mineral composition comprises alteration products as fine-grained aggregates of muscovite and clinozoisite with uralite, chlorite and epidote.

A metadiabase body, about 20 m thick, is roofed and floored by slates; in its marginal parts chilled margins are developed, which grade into schistose metadiabase (Tisica quarry, Velika, Mt. Papuk).

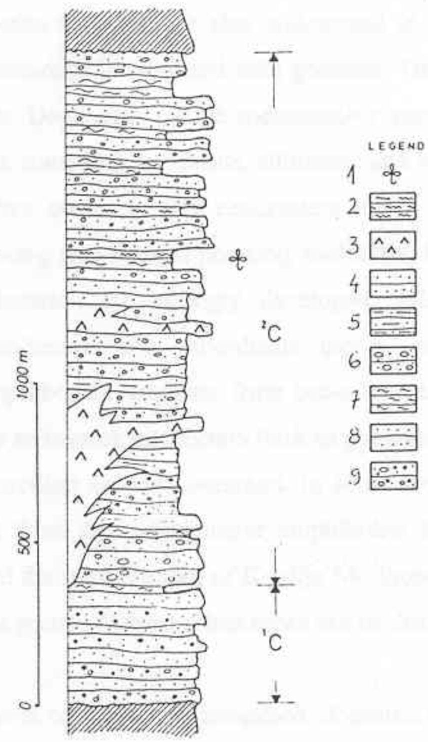



Fig. 5.: Schematic geological column of the Radlovac metamorphic complex (*Jamičić*, 1988). Legend: 1-Westphalian microflora; 2-schists; 3-spilites; 4-silts; 5-tuffitic sandstones; 6-conglomerates and metagreywackes; 7-schists; 8-metasandstones; 9-graphitic metagreywackes

Recent research confirms in more detail that the rocks were affected mainly by a VLG metamorphism and, to a lesser extent, by the lowermost rank of the low-grade metamorphism. This is indicated by the occurrence of pyrophillyte together with paragonite in the metasediments as well as by $b_0$- values of “white mica” separated from some slates and phyllites (*Pamić* and *Lanphere*, 1991). Thermal alterations were recently studied by illite (IC) and chlorite (ChC) “crystallinity” (Kübler and Árkai indices, respectively) and vitrinite reflection for assessing the level of the organic matter thermal maturity. IC and ChC data are in good correlation with vitrinite reflection measurements and show that thermal alterations of metapelites are in temperature range from the upper anchizone (approx. 250 ºC) to the low temperature part of epizone (300 ºC) - (*Biševac*, pers. comm.).

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## ***General info for students***

The field trip stops are meant to illustrate the type localities or key points for understanding the geology of the Slavonian Mts. At each stop we will perform a short overview of geology, than divide ourselves to subgroups. Each subgroup will take on one task per outcrop. The goal is to consider these outcrops in different contexts (mineralogy, petrology, textural and structural relations, tectonics, etc.). Use all equipment that you have, hammering a lot (*Mente et maleo*), make your own notes and support your ideas with detail sketches – and do not hesitate to ask questions! Every kind of question is welcome and warmly encouraged. We will bring some additional "heavy artillery" and geological maps.

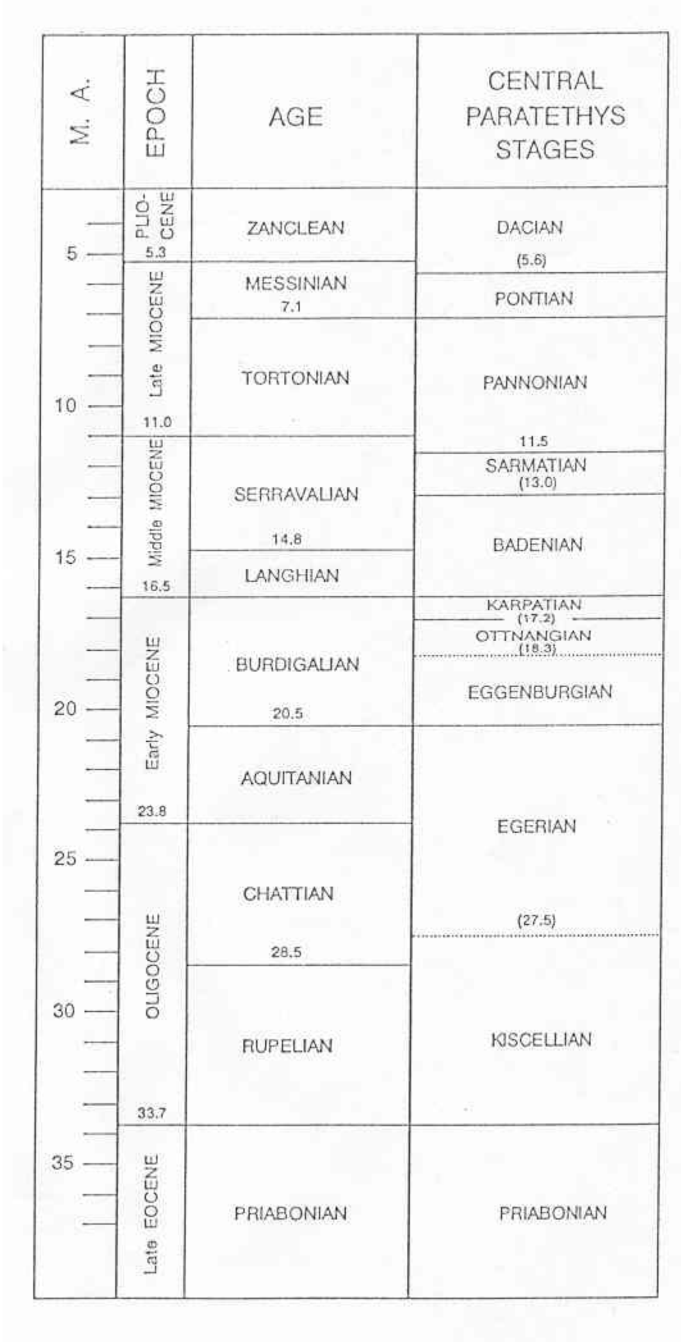
With a hand lens it is possible to see most of the tiny mineralogical features including garnet trails. From tiny detail we can have a clearer understanding of the larger picture. We will have subgroup discussions and the whole group discussions at the end of work on outcrop and possible at the end of the day.

*Nota bene*! <u>In some parts of our excursion there are still visible relics of last decade war activities. You can not go free everywhere because of land mines. For your safety - do not leave the group and the leaders!</u>

## *Time-scale*

International Stratigraphic Chart

Cronostratigraphic correlation of the Mediterranean and Central Paratethys stages



### *Accommodation place ("SchönBlick" Vetovo)*

For Ladies and Gentlemen …

… and for mortal combatants!

Some of the bungalows will be open during all evenings and through the night in order that you can take a quick shower and use toilets. Camping here is improvisation so, please, be tolerant to your colleagues. On the left hand side of tents is the restaurant where we will have morning and evening meals (picture is taken on 2003. excursion through the Alps and the Dinarides http://www.strukturgeologie.uni-bonn.de/en/html/alpen.html).

### *Požega*

Park prirode Papuk (Nature park Papuk)
http://www.pp-papuk.hr/1english/index.html
Grad Požega (City of Požega)
http://www.pozega.hr/
7 Day Weather Forecast (clicks on 7-day forecast, Croatia, Požega)
http://prognoza.hr/prognoze_en.html

## *Road map with approximate position of stops*