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Microstructures of the Lim Zone along the contact with Dinaridic Ophiolite nappe

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Abstract. The Lim Zone is a part of the low-grade metamorphic core complex called the Lim Palaeozoic Unit, overlain by detached Triassic sedimentary successions. The Lim Unit is located in the footwall of overriding Dinaridic Ophiolite nappe. In general, three major ductile deformation phases could be observed on the boundary between the Lim Unit and the overriding Dinaridic Ophiolite nappe. In both, the Lim Unit and the Dinaridic ophiolite nappe, the major deformation event was related to the SSW-directed, oblique thrusting along the Dinaridic ophiolite thrust. The same orientation of the stretching lineation in both units is related to the predominant top-to-the-south shear, which suggests, therefore, oblique thrusting during the emplacement of the ophiolites over the Lim Unit. This paper deals with the results of microstructural analysis of Palaeozoic rocks of Lim Zone along the contact with Dinaridic ophiolite nappe.

Key words: microstructure, shear zone, shear bends, transpression, oblique thrusting.

Абстракт. Лимска зона је део ниско-метаморфисаног комплекса званог Лимски палеозоик, који је прекривен тријаским седиментима. Лимски палеозоик се налази у подинском блоку Динарске офиолитске навлаке. Генерално, главна фаза деформација, како у Лимском палеозоику тако и у Динарској офиолитској навлаци је везана а ЈЈЗ-дно навлачење дуж Динарске офиолитске навлаке. Иста оријентација “streaching” линеације у обе јединице је везана за смицање у правцу југа што стугерише косо навлачење офиолита преко Лимске зоне. Овај рад приказује резултате микроструктурне анализе палеозоијских стена Лимске зоне дуж контакта са Динарском офиолитском навлаком.

Кључне речи: микроструктуре, зоне смицања, клизне зоне, C–S склоп, транспресија.

Introduction

The working area is part the East Bosnian–Durmitor Unit of the Central Dinarides in westernmost Serbia and easternmost Montenegro, located in the footwall of overriding Dinaridic Ophiolite nappe (Figs. 1A, B). The Dinaridic Ophiolite nappe is correlated with the Mirdita Zone of Albania (Shallo 1990) and the ophiolites of the Pindos and Subpelagonian Zones of Greece (e.g., Jones & Robertson 1990). The East Bosnian–Durmitor Unit represents a composite pile of nappes (Dimitrijević 1982) and is considered to be the eastern passive continental margin of an Apulian plate (Robertson & Karamata 1994). The outcrops to the south–west of the Dinaridic Ophiolite nappe show mainly Palaeozoic successions, which are overlain by partly detached Triassic sedimentary and sub-volcanic rocks. Within the working area, this is represented by the Lim Zone, part of East Bosnian–Durmitor Unit (“Zone de Lim” of Rampnoux 1970). The Lim Unit was overthrusted by Dinaridic Ophiolite nappe (Figs. 1A, B) during the Late Cretaceous time, associated with low-grade metamorphic conditions. This led to the formation of brittle-ductile and ductile fabrics along the thrust zones (Ilić *et al*. 2003).

Geological and structural settings

The Lim Zone is characterized by molasse-type deposits, including metaconglomerate, metasandstone and

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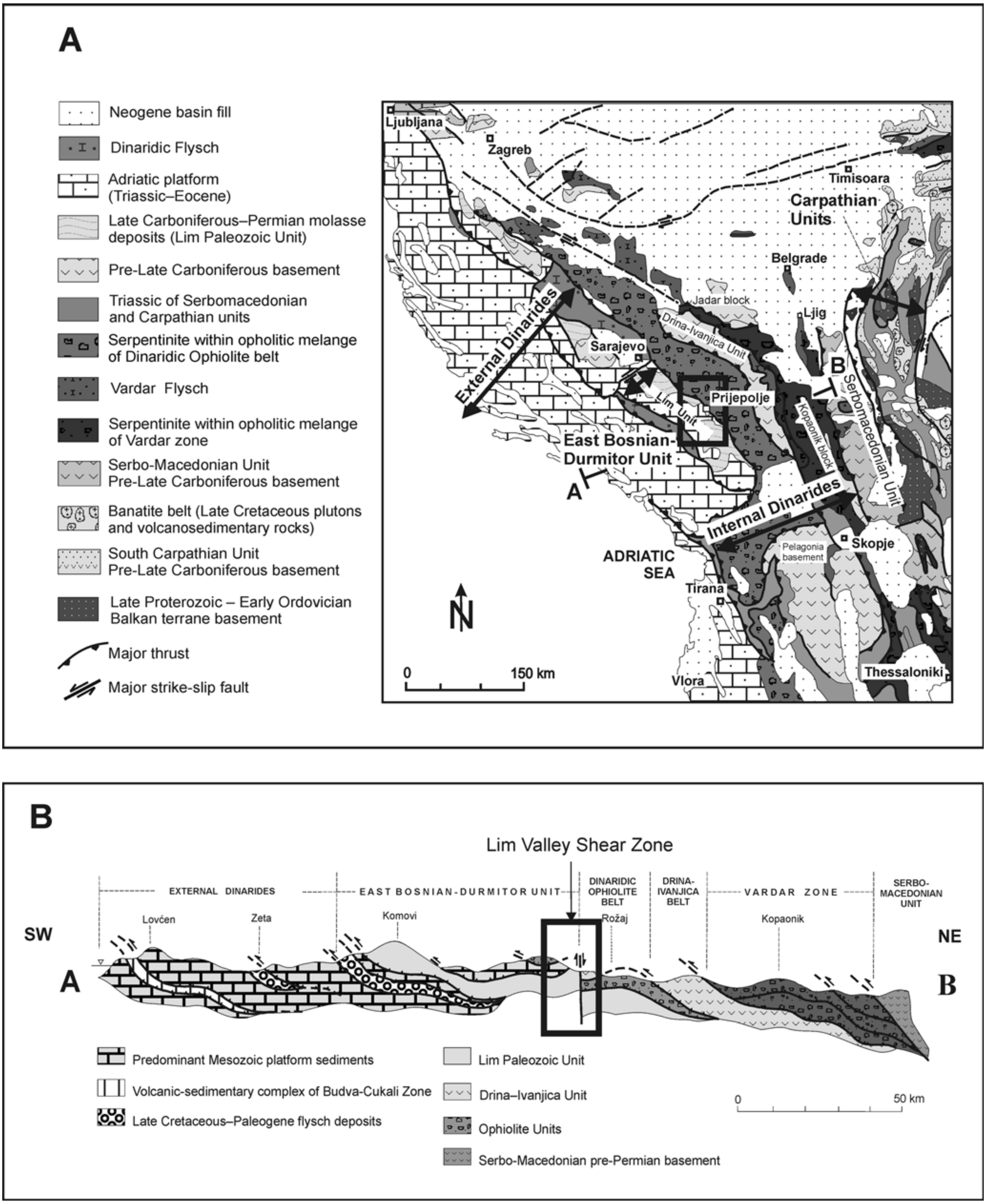

Fig. 1. **A**, Simplified tectonic map of the Dinarides; **B**, Section across the Central Dinarides.

metasiltstone of Early and Late Carboniferous age, which are overlain by Early Triassic clastics, Middle Triassic reef and pelagic carbonate deposits and volcanic successions (PAMIĆ 1984). The north-western part of the Zone ("Paleozoic of Prača" in SE Bosnia) is represented by Early Carboniferous flysch deposits and large, Late Devonian olistostromes (KRSTIĆ *et al*. 1988; EBNER 1991), overlain by Permian and Triassic sequ-

Table 1. Correlation table showing the different ductile deformation phases in the Lim Unit and Dinaridic Ophiolite nappe; DOT, Dinaridic Ophiolite Thrust. (ILIĆ *et al*. 2006).

	Lim Unit	DOT	Dinaridic Ophiolite nappe	Age
D_3	Crenulation, kink bands and kink folds with NW-trending fold axes	?	NW-trending extensional veins in serpentinites Kink bands and SW-vergent kink folds	52–58 Ma (ILIĆ *et al*. 2003)
D_2	Top-to-the west shearing in Triassic cover and EW extension Updoming of Palaeozoic rocks Open folds with strongly developed axial plane foliation and NS trending fold axes	?	EW trending extensional veins	Late Cretaceous
D_1	Formation of metamorphic foliation and N-trending stretching lineation Top-to-the south shearing	SSW-thrusting	Formation of pressure solution foliation and NS stretching lineation Internal W and SW-directed thrust structures	78–80 Ma (ILIĆ *et al*. 2003)

ences. The Central and southern part of the Unit (Prijepolje–Brodarevo area in south-western Serbia, the Bijelo Polje area in north-eastern Montenegro, respectively) consists mainly of low-grade molasse-type sediments with Late Carboniferous fusulinide limestones (ĆIRIĆ 1980), covered in some places in the south with Early to Middle Permian clastic and volcanic rocks (ŽIVALJEVIĆ 1980). The whole complex of Paleozoic rocks is overlain by partly detached slices of very low-grade Early Triassic sandstones and shales, Anisian–Ladinian massive, pelagic limestones, volcanic rocks and massive Ladinian–Carnian carbonates. The Triassic magmatism is represented mainly by intermediate and acid plutonic and volcanic rocks of calc-alkaline affinity (PAMIĆ 1984).

ILIĆ *et al*. (2004) reported Variscan $^{40}Ar/^{39}Ar$ ages of detrital white mica from nearly undeformed sandstones exposed within a higher structural level of the Lim Palaeozoic Subunit. The presence of dominantly Variscan ages of the detrital white mica indicates that Alpine metamorphism was not sufficient to reset these ages, which constrain, therefore, variable Alpine, very low- to low-grade metamorphic overprints (ca. 300–350º C) within these structural levels. There is no evidence for Variscan metamorphic overprints on Carboniferous molasse-type deposits.

The study area, represented by the central part of the Lim Unit, forms a NNW trending structural dome with Palaeozoic rocks in the core and Triassic sequences on the limbs (Fig. 2). An ENE trending zone with Triassic rocks separates the north-western, Prijepolje subdome from the south-eastern, Brodarevo subdome.

In general, three major ductile deformation phases could be observed on the boundary between the Lim Zone and the overriding Dinaridic Ophiolite nappe (ILIĆ *et al*. 2006). In both, the Lim Zone and Dinaridic Ophiolite nappe, the major deformation event was related to the SSW-directed, oblique thrusting (D_1) along the Dinaridic ophiolite thrust (DOT). The same orientation of the stretching lineation in both units (ILIĆ *et al*. 2006) is related to the predominant top-to-the-south shear, which suggests oblique thrusting during the emplacement of the ophiolites over the Lim Zone.

Table 1 presents a correlation of these tectonic phases between the two tectonic units. A more detailed description of the ductile deformation phases is given in ILIĆ *et al*. (2006).

Results of microstructural analysis

The structures were mapped in many stations all over the study area. A relative succession of outcrop-scale deformation structures was established on the basis of overprint criteria. Sets of structures belonging to the same deformation phase were correlated within the study area using their style, geometry and orientation as distinguishing markers (e.g. HANCOCK 1985; PRICE & COSGROVE 1990). Shear sense indicators, such as shear bands, *C–S* fabrics or asymmetric pressure shadows, were employed to obtain information on the kinematics of the deformation phases on the macroscopic as well as the microscopic scale. Thin sections, prepared for kinematic analysis, were cut parallel to the stretching lineation and perpendicular to the foliation plane (*XZ* finite strain plane). This paper deals with the results of microstructural analysis of Palaeozoic rocks of the Lim Zone along the contact with Dinaridic Ophiolite nappe. The terminology follows PASSCHIER & TROUW (1996).

Microfabrics of the Lim Palaeozoic Unit

Based on the compositional types of metamorphic rocks, Palaeozoic rocks of area along the contact with ophiolites can be divided into three main categories:

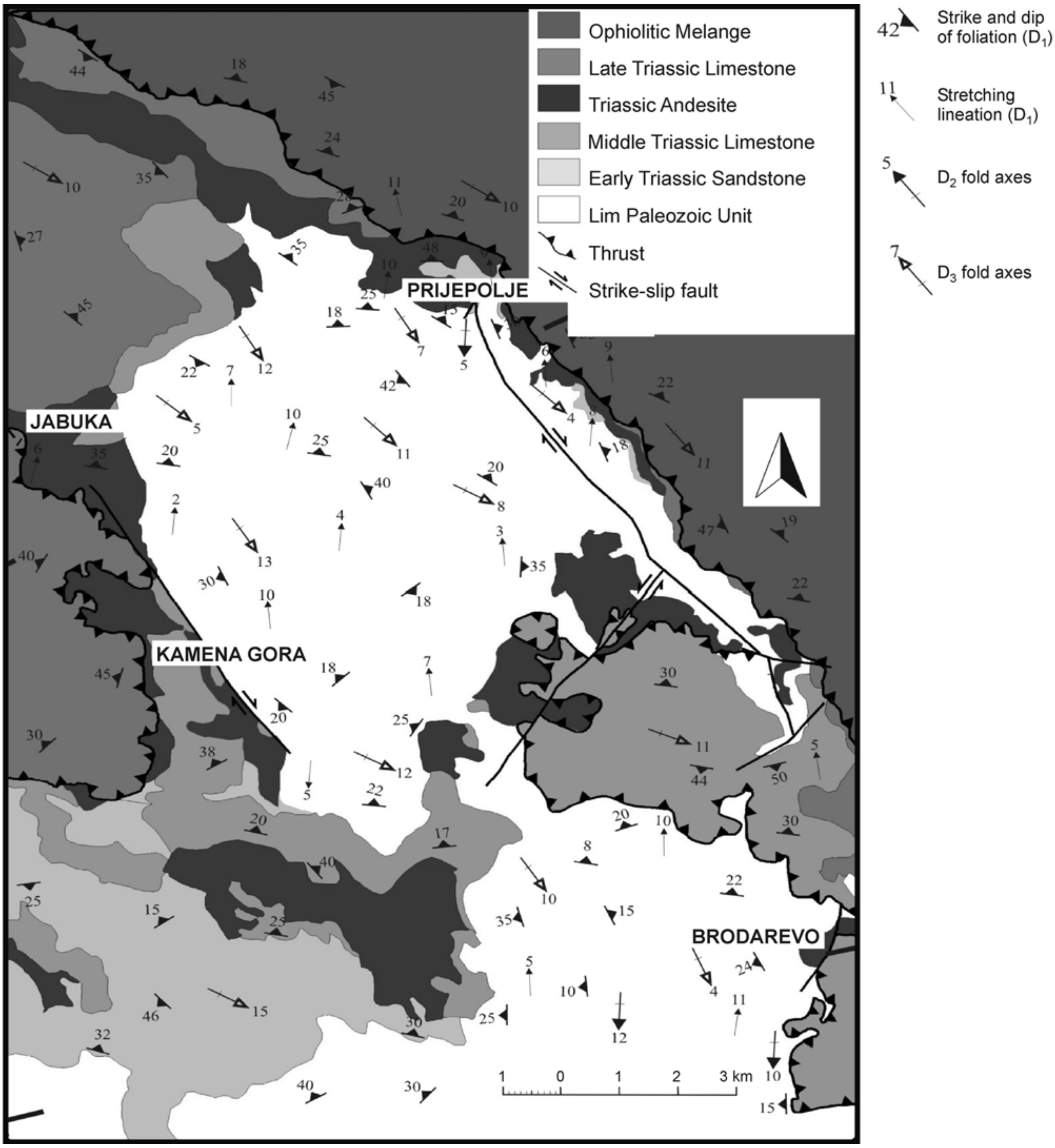

Fig. 2. The central part of the Lim Unit.

– semi-pelitic to pelitic metasediments,

– quartzo-feldspathic-mica rich metasedimentary rocks, and

– metabasites.

Each of thes groups of rocks has its own microfabrics and style of deformation. Semi-pelitic and pelitic metasediments of this area are highly sheared rocks, dominated by phyllosilicates. They show a continuous slaty cleavage (S_1) (after the classification proposed by PASSCHIER & TROUW 1996; Fig. 3A). Quartzo–feldspathic–mica rich metasedimentary rocks are characterised by irregular and often curved quartz and feldspar grain boundaries, while mica aggregates dominate the microstructure; i.e., the quartz grains tend to be elongated parallel to the micas. This is indicative for a higher surface energy system (very small degree of stability; PASSCHIER & TROUW 1996). In low-grade slates and schists, undulose extinction is most common (Fig. 3B). It is frequent in pre- and syn-tectonic minerals, especially in quartz.

The main deformation mechanism in quartzo–feldspathic–mica rich metasediments is pressure in the solu-

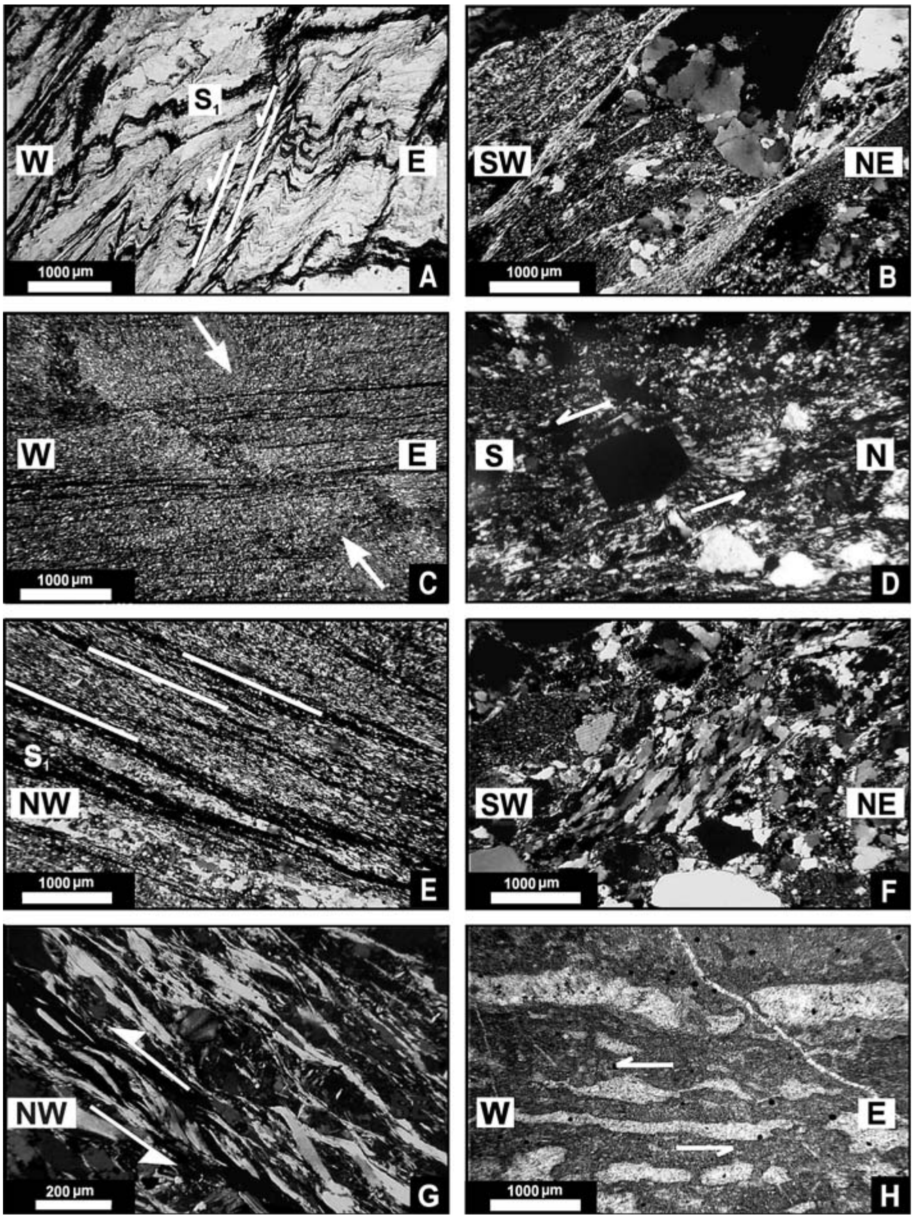

Fig. 3. Microfabrics and shear criteria of the Lim Unit. **A**, Crenulation cleavage developed in phyllonites of the Prijepolje-domain; **B,** Quartzo--feldspathic-mica rich metasandstone; **C,** Apparent slip due to pressure in the solution; **D,** Quartz pressure shadows developed around an euhedral crystals of pyrite in Paleozoic metasandstone; **E,** Continuous slaty cleavage in metabasites; **F,** Grain-scale faults and undulose extinction of Triassic sandstone; **G,** Mica fishes in Paleozoic siltstones; **H,** Calcite grains recrystallised along the boundary and elongated in the east–west direction in Triassic limestones.

tion (Fig. 3B), localized along the grain boundaries, which are at a high angle to the instantaneous shortening direction. Furthermore, a slip along the contact due to the pressure in the solution can be displayed (Fig. 3C).

Pressure fringes around rigid clasts are another characteristic feature of most quartz-feldspar-mica rich metasedimentary rocks of this area. Pressure shadow developed around pre- and syn-tectonic rigid crystals. These pressure shadows are low strain areas where new minerals preferentially crystallised. They result from strain partitioning around rigid porphyroblast or -clast. In this particular case, quartz pressure shadows developed around euhedral crystals of pyrite (Fig. 3D), show the top-south sense of the shear. According to RAMSAY & HUBER (1983) they represent a pyrite-type of strain shadow.

The pyrite-type of strain fringes involve incremental fibre growth of different mineral species at the interface between porphyroblast or porphyroclast and its pressure shadow. Depending on the mode of growth, fibres of pyrite-type shadows can be sub-divided into two categories: (1) displacement-controlled fibres (Fig. 3D) show consistent geometry of progressive growth of the fibres along the displacement path; and (2) face-controlled type fibres exhibit fibre growth normal to the faces of the rigid object, irrespective of the displacement direction. Depending on the P–T conditions, the fibres may also be deformable or rigid. Pressure shadows asymmetry in the X–Z section (deformable-fibre type). The sense of the shear in this particular case is top-to-the-south (Fig. 3G).

Metabasites are found only in the central part of the Prijepolje subdome. They are generally fine-grained rocks, composed of chlorite, albite and quartz. As with the meta-pelites, they are mostly characterised by the presence of a continuous slaty cleavage and quartz, plagioclase, chlorite and white mica grains elongated in the direction parallel to the stretching lineation (Fig. 3E).

Microfabrics of Triassic sandstones and carbonates

Triassic sandstones mainly comprise quartz, feldspar, white mica and some lithic components. These sandstones were deformed under very low-grade metamorphic conditions, probably below 300° C (ILIĆ *et al.* 2004) and are less deformed than rocks of the underlying Lim Palaeozoic Unit. The main deformation mechanisms were brittle fracturing and pressure in the solution. The quartz and feldspar grains display irregular grain boundaries, intercrystalline deformation, including grain-scale micro-faults (Fig. 3F) and undulose extinction. Pressure in the solution was localized at the grain boundaries, where stress in the grains was probably high. Compared to similar rocks of the underlying Paleozoic Unit, the deformation style of these sandstones shows that they were deformed under brittle rather than ductile conditions.

Triassic carbonates are represented by recrystallised micrite-type limestones. The large calcite grains (ca. 2 mm) were recrystallised along the boundary and elongated in the east–west direction (Fig. 3H). Deformation by twinning dominates, indicating very low-grade metamorphic conditions (SCHMID *et al.* 1987). Finer grains of the matrix show the same elongation in ca. the east–west direction.

Discussion and concluding remarks

In both the Lim Unit and Dinaridic Ophiolite nappe, a major deformation event was related to the SSW directed, oblique thrusting along the Dinaridic Ophiolite thrust (DOT) in the Upper Cretaceous times (ILIĆ *et al.* 2006).

This is the time of first ductile deformation phase, D_1, formation of flat-lying milonitic foliation S_1 and the peak metamorphic conditions in the Lim Palaeozoic Unit (ILIĆ *et al.* 2003). The L_1 stretching lineation is marked by elongated quartz grains, preferred orientation of mica flakes and mica-chlorite associations. Consequently, the N–S mineral elongation is seen to be parallel to the direction of the maximum extension due to the major D_1 compressional event.

The previous S_1 foliation is deformed by E–W compression related structures due to updoming of the Lim Palaeozoic Unit in the second phase of ductile deformations (ILIĆ *et al.* 2006). On the thin-section scale, these structures are represented, by crenulation cleavage within semi-pelitic and pelitic metasediments (Fig. 3A). The metamorphic foliation S_1 is folded, sheared and overprinted by close-space crenulation cleavage (Sc). The E–W compressional event was followed by top to the west shearing in the Triassic cover (ILIĆ *et al.* 2006). The structures of this deformation phase are represented by decimetre-scale ductile shear fabrics in Middle Triassic flaser limestones (Fig. 2J).

The third deformation event is probably related to further updoming and it had a brittle-ductile character. In the thin-section, micas deformed by this event are bent without recrystallization in the fold hinges, indicating the brittle-ductile nature of the last deformation event.

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Резиме

Микроструктурна анализа елемената склопа Лимске зоне Динарида

Главне фазе деформација у "Лимској зони" и "Динарској офиолитској навлаци" су везане за југ–југозападно траспресионо навлачење "Динарске офиолитске зоне" преко "Лимског Палеозоика" током горње креде. То је уједно и време прве фазе дуктилних деформација везане за стварање првобитне фолијације S_1.

Предходна S_1 фолијација је деформисана у другој фази дуктилних деформација формирањем набора приближне оријентације север–југ. Набирање првобитне фолијације је праћено формирањем кливажа С и смицањем тријаског покривача у правцу запада.

Трећа фаза деформација је вероватно везана за даље издизање и формирање структурне доме. Она има семи-дуктилни карактер и огледа се у пренабирању мусковита у теменима набора без рекристализације.