2 | The evolution of the northeastern part of the Dinarides

2.1 The Dinarides: Regional overview of the geodynamics

In recent years much attention has been paid to this part of the Mediterranean, which has resulted in a wealth of publications. The following segment of this chapter is meant to give an overview of relevant regional geology and geodynamic evolution that is fundamental for the research of this thesis. Special focus was set on the pre-Tertiary evolution, considering the fact that our research includes more recent phases of regional development. This is followed by the sub-chapters in which we provide new inferences on the age and affinity of major crustal blocks in the NE Dinarides, including meta-sedimentary sequences, lithostratigraphic units, and magmatic intrusions. These new findings have direct implications on interpretation of thermochronology data obtained in this study.

The Dinarides comprise parts of the Adria micro-plate paleogeographic realm situated at the convergent boundary with

---

Chapter 2

Tisza and Dacia mega-units, which have a complete or partial European paleogeographic affinity (Figure 2.1a). Following the Middle Triassic onset of the opening of the Vardar/Neotethys ocean, this area recorded a late Jurassic obduction event that affected both European and Dinarides continental margins (e.g., Dimitrijević, 1997). The West Vardar (or Dinaridic, External Vardar Sub-zone) ophiolites, with a dominant MORB-type geochemistry, represent parts of the Neotethys that opened during Triassic-Jurassic times and were obducted during Late Jurassic times over the internal Dinaridic units (Figure 2.2a, Dimitrijević, 1997; Robertson and Karamata, 1994). The obducted ophiolites and the tectonic units that structurally underlie them were together involved in the subsequent deformations in the Dinarides. Therefore, these units represent composite tectonic units composed of continental parts of the distal Adriatic passive continental margin, overlain by obducted ophiolites and subsequently involved in shortening. Starting in Late Jurassic times, one other large sheet of oceanic crust containing supra-subduction ophiolites, grouped under the name East Vardar Ophiolites, was obducted onto the Dacia continental unit (Figure 2.2a, Schmid et al., 2008; the equivalent of the Central Vardar Sub-zone of Dimitrijević, 1997). These ophiolitic units presently crop out in the Apuseni Mountains, the East Carpathians, the central-southern Serbia and are buried by Neogene sediments in the SE part of the Pannonian Basin (e.g. Čanović and Kemenci, 1988; Robertson et al., 2009; Schmid et al., 2008; Matenco and Radivojević, 2012). The Dacia unit (Fig. 2.1b) is a piece of European continent that broke off during latest Middle to
The evolution of the northeastern part of the Dinarides

Figure 2.1: a – Tectonic map of the Alps–Carpathians–Dinarides System (simplified after Schmid et al., 2008). The grey rectangle is the location of Figure 2.1b. The thick blue line is the locations of the cross-section in Figure 2.1c. b – Detailed tectonic map of the connection between the Dinarides, South Carpathians and Pannonian Basin (modified from Schmid et al., 2008). The white line is the distribution of the Miocene sediments of the Pannonian Basin. c – Cross section across the Dinarides and the Serbian part of the Carpatho–Balkanides (from Schmid et al. 2008). The legend is the same as for Figure 2.1b.
Late Jurassic times and was gradually sutured backwards during the Middle Cretaceous to Miocene closure of the Ceahlău–Severin ocean and its eastern Miocene remnant located at the exterior of the Carpathians (i.e. the Carpathians embayment, Săndulescu, 1988; Matenco et al., 2010). The Dacia unit consists of a thick-skinned nappe stack that formed during late Early to Late Cretaceous times, particularly well-studied in the South Carpathians (e.g., Iancu et al., 2005 and references therein). The Tisza Unit, which displays mixed European and Adriatic affinities, has experienced significant amounts of translations and rotations during Mid-Jurassic separation from Europe, subsequent movement to a position close to Adria, and Cretaceous re-alignment with the European blocks (e.g., Csontos and Vörös, 2004; Schmid et al., 2008). The suturing between Dacia and Tisza continental units took place gradually during Cretaceous times, closing the intervening East Vardar segment of the Neotethys ocean (or the Transylvanides of Săndulescu, 1988) (Figure 2.2b). The Cretaceous docking between Tisza and Dacia was followed by the progressive closure of the Neotethys/Vardar oceanic segment situated between Europe- and Adriatic-derived units (Schmid et al., 2008). Early to Middle Cretaceous tectonic setting in the Dinarides is marked by orogen-wide compressional deformation events (Tomljenović et al., 2008), which were accommodated by northward propagation of nappes and metamorphic overprint in the Dinaridic units (Arkai et al., 1995; Milovanović, 1984). The accretionary trenches and deposition of syn-kinematic sediments composed of variable proportions of ophiolitic, continental and carbonate detritus in the
The evolution of the northeastern part of the Dinarides

a) Latest Jurassic

b) Late Early Cretaceous

c) Late Cretaceous

Figure 2.2: Schematic sketches depicting the tectonic evolution of the Europe–Adria plate boundary in pre-Cenozoic times (after Schmid et al., 2008).
Central Dinarides (e.g., Vranduk and Pogari formations; Mikes et al., 2008, and references therein). The nappe propagation has resulted in gradual migration of syn-kinematic sedimentation towards the more distal Adria plate in the early Late Cretaceous (Lužar-Oberiter, 2009). Adriatic (i.e. Dinarides) and European (i.e. Tisza and Dacia) margins were juxtaposed during the late Cretaceous formation of the Sava suture zone from a Neotethys remnant that was presumably subducted by the onset of collision during Maastrichtian times (Figure 2.2c, Schmid et al., 2008; Ustaszewski et al., 2009). The NE-oriented Late Cretaceous subduction was followed by calc-alkaline volcanism and formation of large volcano-plutonic complexes (i.e. ‘Banatites’; von Quadt et al., 2005). The subduction of the Sava Zone was also associated with the Late Cretaceous to Paleogene greenschist to amphibolite-grade metamorphism, and deposition of turbiditic ‘flysch-type’ facies sediments (Ustaszewski et al., 2010). The subsequent Paleogene structural evolution of the Dinarides was dominated by transpressive tectonic regime, associated with the large-scale Eocene shortening in the Budva-Pindos pelagic realm of the Dinarides and Hellenides (Schmid et al., 2008; van Hinsbergen et al., 2005). The contractual deformation was characterized by an overall propagation of deformation towards the foreland (Tari, 2002). This is marked by the deposition of other elongated belts of turbidites spanning into the Eocene times that were located at the thrusting contact between the different units in the External Dinarides. The Neogene tectonic setting in the Dinarides is characterized by post-orogenic extension. The onset of extensional regime is generally
The evolution of the northeastern part of the Dinarides

interpreted as being related to the subduction processes taking place at the exterior of the Carpathian chain. The retreat of the Carpathian slab coupled with a lateral escape of continental material from the Eastern Alps collision have created the large Pannonian continental back-arc basin (Horváth et al., 2006). The latest Miocene–Pliocene stage of inversion of the Pannonian Basin is, generally, interpreted as an effect of indentation and counter-clockwise rotation of Adria (Marović et al., 2002, 2007a; Bada et al., 2007).

2.1.1 Main unites of the Dinarides

From the southwest to the northeast, the main tectonic units of the Dinarides are (Schmid et al., 2008): External Dinaridic Platform; Internal Dinaridic Platform; East Bosnian–Durmitor Unit; Drina–Ivanjica Unit; and Jadar–Kopaonik Unit.

The External Dinaridic Platform is occupying the proximal part of the Adriatic margin (Figure 2.1b). It is consisting of the more external Dalmatian Zone and the more internal High Karst Unit, two Mesozoic carbonate platforms that are separated by the deep water basin of the Budva–Cukali nappe. The Budva–Cukali nappe, and its lateral prolongation in the Hellenides in the Pindos zone, is a narrow and highly deformed unit, that was floored during its Triassic–Jurassic opening by a crust of uncertain composition (thinned continental and/or oceanic). It contains a record of Triassic deep water facies rocks, covered by Paleogene flysch sediments. The Budva–Cukali nappe wedges out near Dubrovnik, hence the thrusting of the High Karst Unit over the Dalmatian Zone can be
traced further north up to the area of Split where it runs offshore, interfering with the Split-Karlovac transpressive zone (Schmid et al., 2008). Thrusting between the two units most probably occurred during Eocene times (Figures 2.1c, 2.3, Tari-Kovačić and Mrinjek, 1994).

The Internal Dinaridic Platform is comprised of Pre-Karst Unit and the Bosnian Flysch Unit (or the Sarajevo sigmoid of Dimitrijević, 1997) that are thrusted over the High Karst Unit of the external Dinarides during the Late Cretaceous to Paleogene time (Figures 2.1c, 2.3). The Paleozoic of the Pre-Karst Unit is exposing a very low grade Variscian metamorphism, with a Cretaceous to Paleogene low-grade metamorphic overprint (Pamić et al., 2004). The external parts of the unit are characterized by transitional platform-slope carbonate facies sedimentation in the Mesozoic, while the more internal parts contain a transition towards deeper water facies carbonate sedimentation in the Jurassic. The Bosnian Flysch Unit is composed of various types of latest Jurassic (Tithonian) to Paleogene flysch deposits. In eastern Bosnia and Montenegro, other Senonian flysch deposits, which overlie the Bosnian Flysch, belong to the so-called ‘Durmitor Flysch’.

The East Bosnian-Durmitor Unit was emplaced on top of the Bosnian Flysch Unit and its lateral Durmitor flysch equivalent, during the Late Cretaceous to Paleogene top-to-SW oriented thrusting (Figures 2.1c, 2.3). Stratigraphically, it contains Triassic-Jurassic platform carbonates that cover a Paleozoic basement made up by low-grade metasediments (i.e., the Lim Unit,
The evolution of the northeastern part of the Dinarides
Chapter 2

Dimitrijević, 1997). Triassic–Jurassic carbonates are covered by Middle to Late Jurassic radiolarite successions (Vishnevskaya and Đerić, 2005), which probably lie in the base of the Late Jurassic ophiolitic tectonic melange (‘diabase-chert formation’ of Dimitrijević, 1997). The upper part of the unit consists of the Western Vardar ophiolites that were obducted in the Late Jurassic times. The thrusting which most probably occurred in the late Early Cretaceous juxtaposed the East Bosnian–Durmitor Unit against the more internal Drina–Ivanjica (Figures 2.1c, 2.3).

The Drina–Ivanjica Unit contains more distal parts of the Adriatic passive margin when compared to the East Bosnian–Durmitor Unit (Figure 2.1b). It is a composite tectonic unit since it also carries the large portions of previously obducted Western Vardar ophiolites (e.g. the Zlatibor and Maljen Massifs; Chiari et al., 2011). The basement of Drina–Ivanjica consists of low-grade Paleozoic metamorphics (Milovanović, 1984). Triassic sedimentation is represented by deep water carbonates that indicate deposition in the more distal parts of the Adriatic continental passive margin (i.e. the Grivska formation of Dimitrijević, 1997 and overlying radiolarites). The sequences of Lower–Middle Jurassic radiolarites are tectonically overlain by the ophiolitic melange containing also exotic blocks of other Upper Triassic radiolarites (Đerić et al., 2007) and by ophiolites in an upper tectonic position. These are uncomformably overlain by Cretaceous sediments, rudist limestones and clastics followed by a Maastrichtian–Paleocene? flysch sequence. On a regional scale, the tectonic position of the Drina–Ivanjica can be
The evolution of the northeastern part of the Dinarides correlated with the Korab element in Albania, or the Pelagonides in Macedonia and Greece (Schmid et al., 2008).

The Jadar–Kopaonik Unit is the next tectonically higher and more internal unit of the Dinarides that is derived from the most distal parts of Adriatic passive margin (Figure 2.1b). The present-day tectonic contact between the Drina–Ivanjica and Jadar–Kopaonik units is marked by a major transpressional structure (i.e. the Zvornik "suture", Figure 2.1c, Gerzina and Csontos, 2003). The contact zone is characterized by a long belt of Cretaceous turbidite sediments (the Kosovska Mitrovica flysch, Dimitrijević and Dimitrijević, 2009), deposited in the immediate footwall over the Drina–Ivanjica basement. The Jadar block (or Jadar Paleozoicum) represents a unit consisting of a Paleozoic sub-greenschists facies metamorphic basement which is covered by a Triassic–Jurassic carbonatic succession and deep water radiolarites (Robertson et al., 2009). Carbonate succession of the Jadar–Kopaonik can be very well correlated with the one of the Drina–Ivanjica unit, evidencing deposition in the distal parts of Adriatic margin (Dimitrijević, 1997). Along the strike of the Dinarides and along the Mid-Hungarian Shear Zone (Horváth et al., 2006), sequence of the Jadar block is correlated with the NW Sana–Una Unit and parautochthonous Paleozoic unit of the Bukk Mountains of the NE Hungary (Karamata, 2000; Dimitrijević et al., 2003; Csontos and Vörös, 2004). The Jadar block has also been laterally correlated with similar type of rocks that outcrop in the SE-located Kopaonik and Studenica tectonic windows (Figure 2.1b, Schefer, 2010). Together (including the overlying Late
Jurassic obducted ophiolites), they define the Jadar–Kopaonik composite unit (Schmid et al., 2008), which represents the most distal Adriatic block involved in the Cretaceous–Paleogene subduction of the Neotethys ocean and collision with Tisza and Dacia units. Widespread occurrences of Late Cretaceous (Turonian–Paleogene) flysch unconformably cover continental units along the eastern margin of the Jadar–Kopaonik block. This flysch belt (the external Vardar sub-zone of Dimitrijević, 2001) is interpreted to mark the suture between the Dinarides and Carpatho–Balkanides, as the southern segment of the Sava Zone (Figure 2.1c, Schmid et al., 2008).

2.1.2 The Fruška Gora, Cer, and Bukulja Mountains of the NE Dinarides

Three isolated inselbergs situated along the NE Dinarides border, i.e. the Fruška Gora, Cer, and Bukulja Mountains of western and central Serbia show structural, petrological, and stratigraphic indications of a complex evolution related to the late Jurassic obduction, the Cretaceous–Paleogene Europe–Adria collision, the Miocene Pannonian extension, and the subsequent Adria inversion.

The Fruška Gora Mountains is an E-W oriented inselberg surrounded by Miocene–Quaternary sediments of the Pannonian Basin, which is situated in the proximity of its southern contact with the Dinarides, at ~60 km NW of Belgrade (Figure 2.1b). The mountains expose a suite of metamorphosed basement, located in the central and southwestern part, and a Lower Triassic to Paleogene clastic-carbonate sedimentary cover with intercalated ophiolites,
The evolution of the northeastern part of the Dinarides

ophiolitic mélange and volcanics (Figure 2.4). These rocks are buried along the flanks and lateral terminations of the antiform underneath Miocene–Quaternary sediments of the Pannonian Basin.

The Cer Mountains are an isolated topographic feature situated near the contact area of the Dinarides with the Pannonian Basin, on the right bank of Drina River in western Serbia (Figure 2.1b). The mountains are made up by a composite pluton intruded at the northern margin of the Jadar block, a unit consisting of Paleozoic siliciclastic sediments (Filipović et al., 2003; Krstić et al., 2005), which have been affected by a Variscan sub-greenschists to lower greenschists metamorphic conditions (Robertson et al., 2009). The Jadar Paleozoic metamorphic basement is covered by Middle Permian to Mesozoic clastic-carbonate sedimentary sequence, overlain by Middle–Upper Miocene marine to brackish sediments and Pliocene–Quaternary continental deposits of the Pannonian Basin (Figure 2.5).

The Bukulja Mountains are comprised of an S-type pluton intruded near the easternmost limit of the Jadar block, some 60 km south of Belgrade (Figures 2.1b, 2.6). Metamorphic series of the Jadar block (Karamata et al., 2003) are here made up of clastics alternating with basic volcanics and volcaniclastics metamorphosed to greenschists facies conditions, or retromorphosed from an initial higher amphibolites facies (the Drina Formation of Trivić et al., 2010). Further westwards, the dominant metamorphic conditions decrease to greenschists or sub-greenschists facies that is typical for the main
Figure 2.4: Geological map of the Fruška Gora mountains, based on the Geological Map of Yugoslavia (1:100.000), sheet Novi Sad (Čičulić and Rakić, 1976), modified with observations and interpretations presented in study of Toljić et al (2013). Coordinates are in kilometers, system of projection MGI Balkan zone 7. Abbreviations: SD - Srem Dislocation, VF - Vrdnik Fault, FGD - Fruška Gora Detachment. Legend: 1 – Quaternary; 2 – Pliocene; 3 – Upper Miocene; 4 – Middle Miocene; 5 – Lower Miocene; 6 – Eocene-Oligocene latites; 7 – Eocene-Oligocene trachy-andesites; 8 – Uppermost Cretaceous–Paleogene “Sava flysch”; 9 – Upper Cretaceous–Paleogene; 10 – Serpentinites; 11 – Ophiolitic melange; 12 – Diabase; 13 – Peridotite; 14 – Middle Triassic; 15 – Lower Triassic; 16 – Marbles; 17 – Sericite schist.
The evolution of the northeastern part of the Dinarides

Figure 2.5: Geological Map of the Cer Mountains, based on the Basic Geological Map of Yugoslavia (1:100,000) sheets Zvornik (Majšek et al., 1975) and Vladimirin (Filipović et al., 1971) with newly obtained high-precision U-Pb zircon ages, modified with observations and interpretations presented in study of Matenco et al (2014). Coordinates are in kilometers, system of projection MGI Balkan zone 6.

Figure 2.6: Geological Map of the Bukulja Mountains, based on the Basic Geological Map of Yugoslavia (1:100,000) sheets Obrenovac (Filipović et al., 1979), Smederevca (Parčević et al., 1979), Ćurmić Milanovac (Filipović et al., 1976) and Kragujevac (Brkić et al., 1979) with newly obtained high-precision U-Pb zircon ages and modified with observations and interpretations presented in study of Matenco et al (2014). Coordinates are in kilometers, system of projection MGI Balkan zone 7.
part of the Jadra block (see also Filipović et al., 2003; Marović et al., 2007c). Mesozoic non-metamorphosed cover of the Bukulja Mountains is represented by Lower Cretaceous shallow water to shelf deposits and Late Cretaceous–Paleogene turbiditic (flysch-type) deposits, with intercalated ophiolites (Figure 2.6, Dimitrijević, 1997). The Miocene Pannonian Basin sedimentation starts with conglomerates and other coarse clastic deposits, being followed by marine clastic-carbonatic sediments (Marović et al., 2007c).

2.2 Correlation of Mesozoic meta-sedimentary sequences in the NE Dinarides

The metamorphic core of the Fruška Gora Mountains has been described extensively in Toljić et al. (2013). According to these authors this core is predominantly made up by chlorite and chlorite-sericite schists with local variations along a large number of lenticular intercalations (Figure 2.4). These intercalations are made up of marbles, carbonate schists, quartz-sericite and muscovite-chlorite schist, quartzites, retro-morphosed gneisses, epidote-chlorite, albite-chlorite and albite-chlorite-epidote schists, meta-volcanics (keratophyres, basalts and tuffs) and highly altered remnants derived from ophiolitic material (Figure 2.10). Petrological analyses points to a quartz-albite-muscovite-chlorite association in greenschists facies that indicates temperatures in the order of 300–450 °C. The degree of metamorphism is variable, higher temperatures of the mentioned interval being observed in the center and northern part of the
The evolution of the northeastern part of the Dinarides

metamorphic core, gradually decreasing towards its margins elsewhere. Outside the metamorphic core, sericite and sericite–chlorite schists are locally outcropping beneath the overlying Upper Cretaceous sediments in the central-northern part of Fruška Gora (Figure 2.4). One other isolated patch of metamorphics is outcropping in the north-eastern part of the mountains. It contains a high-pressure mineral assemblage dated by K-Ar method at 123±5 Ma that formed in epidote-blueschist subfacies or high-T epidote-bearing segment of blueschist facies. It infers an Early Cretaceous stage of subduction and high-pressure metamorphism (the “crossite schists” of Milovanović et al., 1995).

Biostratigraphic dating provides evidence that a part of the Fruška Gora metamorphic core contains a protolith of Upper Triassic age. Carbonate schists and meta-sandstones containing Carnian conodonts were mapped in the SW part of the metamorphic core, whilst Norian–(Rhaetian?) conodonts were obtained in meta-clastics, carbonate schists and white marbles located in its central part (Toljić et al., 2013). Furthermore, the meta-radiolarites in the metamorphic series near Ležimir contain preserved radiolarians of Late Triassic age (Figure 2.4). The area where the Late Triassic age has been obtained around Ležimir displays a diagnostic lithological sequence in metamorphosed rocks that can be well correlated with the Triassic-Lower Jurassic non-metamorphosed sediments observed elsewhere in the Dinarides (Figure 2.7, Dimitrijević, 1997). In the lower part, the quartzitic schists are metamorphosed Lower Triassic continental to shallow water arkose sandstones, greywacke,
continental red sandstones and shales, the upper part of which resembles the typical Bundsandstein sequence of Western Europe. Overlying black and white marbles are metamorphosed equivalents of black and white limestones with pelecypods, cephalopods and gastropods fauna of upper Lower-Middle Triassic age (“Guttenstein” and “Steinalm”, see also Dimitrijević, 1997). The overlying metamorphosed nodular limestones and carbonate schists are the metamorphosed equivalents of the Middle–Upper Triassic (~Lower Jurassic?) siliceous distal carbonates of the Grivska Formation (Dimitrijević and Dimitrijević, 1991). This formation is represented by black, bituminous limestones, grey and brown crystalline massive and white massive dolomites, calcarenites and dolomitic limestones. It displays a wide transition in space and time from distal carbonate shelf, slope deposition to basal carbonate turbidites overlain by Lower–Middle Jurassic radiolarites, representing a typical marker that testifies the gradual deepening of the Adriatic carbonate platform. The intercalated meta-volcanic and volcani-clastic material is an equivalent of the Anisian–Ladinian break-up volcanism that took place during the opening of the Neotethys/Vardar ocean (Pamić, 1984). The upper meta-radiolarites are metamorphosed equivalents of the Upper Triassic–Middle Jurassic distal oceanic pelagic sediments and radiolarites well known in the internal Dinaridic units (e.g., Đerić et al., 2007 and references therein). This typical Middle Triassic–Middle Jurassic facies can only be assigned to the distal Adriatic continental margin and its adjacent oceanic domain by correlation with the similar metamorphosed and
Figure 2.7: Correlation between meta-sedimentary sequences of the Fruška Gora Mountains, Bukulja Mountains, and similar sedimentary and metamorphosed facies observed elsewhere in the Drina–Ivanjica and Jadar–Kopaonik units of the Dinarides (Dimitrijević, 1997; Schefer et al., 2010).
non-metamorphosed facies observed in the Drina–Ivanjica and Jadar–Kopaonik units of the Dinarides (Figure 2.7, Dimitrijević, 1997). By comparison, the Middle–Upper Triassic facies of the European-derived passive continental margin (Dacia and Tisza) is significantly different, being made up mostly by shallow water carbonates with numerous unconformities (e.g. Haas and Péró, 2004). Furthermore, the Triassic–Jurassic metamorphic facies of the Fruška Gora is similar in composition and age with the metamorphosed sediments of the distal Adriatic margin observed in the Kopaonik area such as the calcareous schists of the Kopaonik Formation (Schefer et al., 2010) or the Central Kopaonik series (Sudar, 1986). Therefore, the metamorphic core must be largely attributed to the Jadar–Kopaonik unit of the internal Dinarides, given its spatial position and metamorphic facies. The sericite schists, phyllites and some of the meta-carbonates that form the older, underlying metamorphic stratigraphy of the metamorphic core are the equivalent of the Jadar Paleozoic in a higher metamorphic facies. This facies is similar to the metamorphosed Paleozoic observed in the southward located Kopaonik window (Figure 2.7, Schefer, 2010). Furthermore, Upper Cretaceous–Paleogene palynomorphs (spores and pollen grains) have been described in the calcareous schists of the central northern part of the Fruška Gora metamorphic core (Pantić and Ercegovac in Đurđanović et al., 1971). The protholits of these calcareous schists have been ascribed to the distal turbidites of the Sava flysch. The non-metamorphosed equivalent of this calcareous distal facies is found at the eastern margin of the Kopaonik unit (“Scaglia Rossa”, Schefer,
The evolution of the northeastern part of the Dinarides 2010). It is also the distal equivalent of Upper Cretaceous–Paleogene more proximal turbidites largely exposed in Fruška Gora outside the metamorphic core (Figure 2.4).

On its western flank, the Bukulja Mountains granite is intruded into the Paleozoic age greenschist facies metamorphic series of the Jadar block (the Drina Formation of Trivić et al., 2010). However, regionally metamorphosed rocks of the eastern flank of the Bukulja pluton (Figure 2.6, the Bukulja–Venčac crystalline of Marović et al., 2007c; or the Birač formation of Trivić et al., 2010), which are generally interpreted as Paleozoic in age, display a rock composition that is significantly different when compared with the normal Paleozoic protoliths that can be studied elsewhere in the Jadar block. Our field observations along the eastern flank indicate a Mesozoic metamorphosed sequence overlying the normal phyllites, sericitic schists and retromorphosed gneises that can be found on the western flank of Bukulja pluton. These observations are in accordance with the findings published in the study of Marović et al. (2005). This metamorphic sequence is composed of (gradually younger) quartzites, grey dolomites and black marbles, thick white marbles with local meta-basic volcanic intercalations, calcareous schists with quartzites, meta-cherts intercalations, local meta-radiolarites and other contrasting types of metamorphic rocks (Figure 2.10). These types of mixtures are diagnostic for a metamorphosed ophiolitic mélangé (i.e., a metamorphosed diabase-chert formation of Dimitrijević, 1997). These are unconformably overlain by fine calcareous-sericitic schists with intercalation of quartzites and meta-
ophiolitic material. Except for the calcareous-sericitic ultramylonitic schists, the protolith of the entire succession is very similar to the standard non metamorphosed Triassic–Middle Jurassic succession found elsewhere in the distal parts of the Drina–Ivanjica and/or Jadar–Kopaonik composite unit (Figure 2.7). This succession is generally made up by Lower–Middle Triassic continental Bundsandstein, Muschelkalk, partly dolomitised Guttestein (black shallow-water limestones), Steinalm (white shallow-water limestones), Upper Anisian Neotethys rift break-up volcanics, Upper Triassic (~Lower Jurassic?) Grivska formation (deep water nodular and slope limestones) and Lower–Middle Jurassic radiolarites. This succession is overlain by the Late Jurassic ophiolitic mélange and sequence of the obducted Western Vardar ophiolites (see Dimitrijević, 1997; Schmid et al., 2008 for further details). The same complete succession has been demonstrated to be metamorphosed to greenschist facies in the Studenica and Kopaonik windows, which are located southward, in along-strike southward prolongation of the Bukulja mountains (Figure 2.1b; Egli, 2008; Schefer et al., 2010). The similarity of the Bukulja succession in its entirety with the metamorphosed and non-metamorphosed rocks found elsewhere in similar structural position points directly to a Triassic–Jurassic Adriatic distal passive continental margin and its transition to an oceanic domain that was subducted and metamorphosed during the Late Cretaceous–Paleogene continental collision recorded in the Sava suture zone of the Dinarides (Schmid et al., 2008; Ustaszewski et al., 2010). The protolith of the uppermost calcareous sericitic
The evolution of the northeastern part of the Dinarides ultramylonitic schists with quartzitic–ophiolitic detritus is interpreted as the Uppermost Cretaceous–Paleogene sediments of the Sava zone (Figure 2.10), based on microfloral association found in these rocks and lithological similarities with its non-metamorphosed counterpart (Marović et al., 2005; Marović et al., 2007c; Schefer et al., 2010).

2.3 Cretaceous–Paleogene syn-kinematic turbidites (i.e. flysch) deposited along the NE Dinarides margin

The one of the diagnostic characteristics of the Internal Dinarides units that are exposed in the NE part of the Dinarides is that they all contain in an upper structural position ophiolites and genetically associated ophiolitic melanges that were obducted in late Jurassic times. The subsequent Cretaceous–Eocene shortening has affected the continental units and overlying ophiolites, creating the Internal Dinaridic nappe stack that is composed, from bottom to top, of the East Bosnian–Durmitor, Drina–Ivanjica and Jadar–Kopaonik composite units. This contractional evolution is associated with the widespread occurrence of various syn-kinematic turbiditic (i.e. flysch) sequences, deposited in local foredeep troughs that often mark the transition zones between individual nappes with distinctive structural and lithological features.

The thrusting of the more internal Jadar–Kopaonik over the Drina–Ivanjica unit was associated with a gradual sedimentary transgression over the Drina–Ivanjica metamorphic basement that started with Turonian continental deposits and shallow-water
limestones gradually passing to Maastrichtian syn-kinematic deposition of what is usually known as the Kosovska Mitrovica flysch sequence, a long suture that can be followed along almost the entire Dinarides (Figure 2.3). Late Cretaceous (Senonian)–Paleogene siliciclastic deposits with turbiditic characteristics unconformably cover continental units along the eastern boundary of the Jadar–Kopaonik block (Dimitrijević, 1997). This flysch sedimentation comprises parts of the Sava Zone in Serbia that presently defines the late Cretaceous to Paleogene suture between Adria-derived units of the Dinarides (more specifically the Jadar Kopaonik unit) and the European-derived Tisza and Dacia Mega-unit of the Carpatho–Balkanides (Figure 2.1c, Schmid et al., 2008). Extending SE-ward from Zagreb to Belgrade, the Sava Zone represents a long belt of flysch sediments containing often ophiolitic detritus, intruded locally by magmatic bodies such as the Motajica granitoid, and found locally in structural or unconformable contact with post-Variscan greenschist to amphibolite facies metamorphic rocks (Ustaszewski et al., 2010). East of the Fruška Gora Mountains in Serbia, Sava Zone bends into the N-S trend, extending through central and southern Serbia and S-wards to Greece as a belt of Uppermost Cretaceous to Paleogene turbidites. In this area, the Sava Zone separates the most distal parts of Adriatic margin from the upper plate Serbo-Macedonian unit with an European affinity. This contact can be observed in the areas of the Bukulja, Cer, Jastrebec, and Kopaonik Mountains in central Serbia, where, in a number of places, greenschist facies metamorphosed sediments of the Sava Zone and
The evolution of the northeastern part of the Dinarides

its underlying basement are exposed by the Miocene extension and in tectonic omission contact with their non-metamorphosed equivalents (Marović et al., 2007b, 2007c; Schefer, 2010). Following the late Jurassic obduction of the East Vardar ophiolites, the Serbo-Macedonian margin adjacent to the Sava Zone was affected by localized subsidence and the deposition of a clastic and carbonatic sequence deposited generally in shallow-water conditions. The basal part of the unit exposes coarse-grained, very badly sorted breccia-type sediments that indicate a rapid transgression over the margin of the European overriding plate. The base is composed of a clastic alternation between sandstones and siltstones most likely deposited in shallow-water conditions (the “paraflysch”, i.e. flysch-looking, of Dimitrijević, 1997). Two mega sequences are overlying this unit and are composed of a lower clastic and upper clastic-carbonate member that includes an upper Lower Cretaceous Urgonian shallow-water carbonatic facies. Paleontological record in the two mega-sequences indicates ongoing sedimentation throughout Lower Cretaceous (between Lower Valangian and Albian-Cenomanian).

In the study area, Upper Cretaceous–Paleogene turbidites outcrop on the slopes of the Fruška Gora Mts, separated by a stripe of previously obducted Jurassic West Vardar ophiolites (Figure 2.4). As described in the study of Toljić et al. (2013), these sediments have a geometry and composition that strongly resembles the Gosau-type of clastic-carbonate deposition (sensu Wagreich and Faupl, 1994; Willingshofer et al., 1999) widely observed in the Alps, neighboring Carpathians and Apuseni Mountains. In the western part of the
mountains, these deposits are transgressive over older Mesozoic metamorphic basement, Triassic marly limestones with scarce Anisian fauna, and Jurassic ophiolites. The sedimentation starts with heterogeneous breccia and conglomerates that contain elements from the underlying metamorphic basement (Figure 2.8a). These are overlain by sandstones, sandy limestones, shales, siltstones, marly limestones and massive reef limestones, which contain abundant Maastichtian fauna of rudists and corals, and globotruncanids (Čičulić and Rakić, 1977). This deposition ends with marls and marly limestones. In the northeastern part of the mountains the sedimentation starts with Maastichtian rudist limestones; red marls and limestones with globotruncanidas; red sandstones; and siltstones with belemnites and brachiopods that are interpreted as the base of flysch (Figure 2.8b). More than 2000 meters thick turbiditic sequence is composed of cycles of coarse-grained sandstones and pebbles, shales, siltstones, and carbonate sandstones. This succession is generally interpreted as a flysch sequence that was deposited during the final moments of collision in the Dinarides (Schmid et al., 2008). The lower parts of flysch sequence are composed of coarse-grained thick-bedded lithic conglomerates and arkose sandstones that contain fragments of basic magmatic rocks, metamorphics, sandstones, and altered volcanics, with large quartz and feldspar grains. Coarse-grained arkose sandstones grade into the medium and fine-grained sandstones, siltstones and shales. These deposits display deformations along S-vergent overturned folds and, less frequently,
Figure 2.8: Stratigraphic columns of Mesozoic to Paleogene sedimentary sequences of the Frutška Gora (Figs. 2.8a, b) and Bukulja Mountains (Fig. 2.8c).
along E-W oriented symmetrical folds. The folding occurred during a regional N-S contractional event that affected the NE Dinarides margin (Toljić et al., 2013). Fruška Gora Mountains flysch sedimentary sequence has been deposited over the units with Adriatic affinity. North of the mountains an E-W oriented zone of ophiolites is buried beneath the Miocene and locally Cretaceous clastic-carbonate and turbidites cover (Čanović and Kemenci, 1988), and it represents lateral equivalent of the Biharia nappe of the Apuseni Mountains that experienced a medium- to high-grade Middle Jurassic-Early Cretaceous metamorphic overprint (Figure 2.1b; Matenco and Radivojević, 2012). Since the entire ophiolitic zone is in a structurally higher position with respect to the Biharia unit with European affinity, these ophiolites are inferred to be part of East Vardar ophiolites (Toljić et al., 2013). This implies that the contact between Europe- and Adriatic-derived units is located immediately north of the Fruška Gora (Figure 2.1b).

Coarse-grained siliciclastic turbidites along the eastern margin of the Cer Mountains (Figure 2.5) are considered to be part of flysch sequence deposited in the Jadad trough starting from the Middle Devonian (Filipović et al., 1971). According to Filipović (2003), these turbidites represent lateral equivalent of the Lower Carboniferous ‘Culm flysch’, which comprises the youngest part of the Drina-Ivanjica Paleozoic Unit (the equivalent of the Birač Formation in the Bukulja Mountains, see Trivić et al., 2010). However, our field and microscopic observations indicate that these sediments are very similar to the siliciclastic turbidites sequence found in
The evolution of the northeastern part of the Dinarides neighboring Croatia and Bosnia. The Motajica, Prosara, and Kozara Mountains of northern Bosnia (Figure 2.1b) share strong lithological and structural similarities with the Cer Mountains. In these areas, non-metamorphic succession of coarse-grained conglomerates, arkoses, lithic sandstones, and shales of Maastrichtian to possibly Paleogene age is overlying magmatics, metasediments and the obducted western Vardar ophiolites (Ustaszewski et al., 2010). Similar with other areas, these turbidites are here interpreted as syn-kinematic sediments deposited on the Adriatic plate during the moments of collision between Adria and European-derived Tisza unit (i.e. the Uppermost Cretaceous flysch of the Sava suture zone, Ustaszewski et al., 2010).

Turbiditic sediments in the area surrounding the Bukulja Mountains have been deposited in the northern part of the former NW-SE elongated flysch trough, extending some 60 kilometers across central Serbia (i.e. “the Rudnik flysch”; Obradović, 1987). The entire area is affected by dense brittle faults and the sediments, which only partly show turbiditic characteristics, have been affected by WNW vergent folds. These sediments have been deposited over the Jurassic radiolarites, and East Vardar ophiolites obducted in Late Jurassic times. Interestingly, these Sava Zone turbidites also cover the Lower Cretaceous shallow-water to shelf deposits of the European-derived Serbo-Macedonian Massif (e.g. Urgonian facies and the “para-flysch”). The Serbo-Macedonian Massif is characterized here by a medium to high-degree metamorphic sequence comprised of gneisses, granodiorites, and amphibolites (e.g. Dimitrijević, 1997).
This unit can be correlated with the Biharia nappe, together defining structurally highest parts of the Dacia mega-unit of the European margin (Matenco and Radivojević, 2012). In the Bukulja area, the Upper Cretaceous flysch starts with basal conglomerates that consist of pebbles composed of chert, dolomite, limestone, serpentinite, amphibolite, magmatic and volcanic rocks (Figure 2.8c). Pyrite and chromite are dominant in the heavy mineral fraction that also contains frequent zircon, turmaline, and rutile, whereas apatite and epidote are less frequent. The basal conglomerates are followed by carbonate series comprised of limestones and marls, with scarce globotruncananas and globigerinas fauna. These are followed by a sandy-carbonate lithofacies, containing the thin-bedded greywacke in alterations with siltstones, marls and shales. The upper sandy part starts with coarse-grained monomictic microconglomerates, composed of quartzite pebbles and quartz grains. These are followed by thin-bedded grey sandstones occurring in alterations with shales and rare occurrences of biomicrite with globotruncananas. The turbiditic character of this set is clearly expressed in its upper sandy part that contains numerous sedimentary structures.

2.4 Oligocene–Miocene magmatism in the Cer and Bukulja Mountains

The Cer intrusion, located in the core of the mountains, is a composite pluton that comprises a predominantly I-type quartz–monzodiorite (QMZD), subsequently intruded by an S-type two-
mica granite (TMG) that is occurring as a large body in the central-western part and as meter-thick dykes in its eastern part. The main intrusion is separated from an intrusion of granodiorites that occurs at ~7 km distance towards NW (the granodiorite of Stražanica area – GDS, Fig. 2.5, Cvetković et al., 2001; Koroneos et al., 2011). The metaluminous quartz monzonite to quartz–monzodiorite (QMZD) rocks compose the central parts of the Cer Mts constituting ~60 vol.% of the whole pluton (Koroneos et al., 2011). Quartz–monzodiorites are massive, grey to dark grey rocks. The texture is allotriomorphic granular, with subordinate occurrences of porphyritic varieties with large grains of K-feldspar. These rocks are mainly composed of xenomorphic and undulose quartz, K-feldspar, plagioclase, biotite, and hornblende. Titanite, allanite, magmatic epidote, zircon, apatite, rutile, magnetite and ilmenite are present as accessory minerals. Furthermore, enclaves with variable chemical compositions and the mineralogical assemblage dominated by mafic minerals (> 80 vol. %) are found exclusively in QMZD (Koroneos et al., 2011). Stražanica granodiorites to quartz monzonites (GDS) are, likewise, predominantly metaluminous I-type rocks. They represent light-grey rocks, with a uniform hypidiomorphic medium-grained texture. They are composed of quartz, plagioclase, K-feldspar, and biotite, whereas zircon, allanite, apatite, muscovite, epidote, and titanite comprise accessory phases. Two-mica granites (TMG) are fine- to medium-grained, white-grey in color with hypidiomorphic granular texture and massive structure. They consist of quartz, K-feldspar, plagioclase, muscovite, and biotite, together with accessory garnet,
tourmaline, apatite, rutile and zircon. Petrographic characteristics indicate that the Cer Mts TMG are S-type rocks with dominant peraluminous character, which infers important role of upper levels of continental crust in their origin (Koroneos et al., 2011). These rocks are very similar, regarding their mineral chemistry and major and trace element geochemistry, to the two-mica granites from the Bukulja Mountains, situated ~80 km further to the southeast (Figure 2.1b). This fact is suggesting that their origin and evolution are related to the same tectono-magmatic event (Cvetković et al., 2001; Koroneos et al., 2011). Geochemical characterisation of the Cer Mts composite pluton suggests that the combination of different types of magmas reflects a mantle source for the I-type rocks and an upper crustal source for the S-type granites, which originated due to melting of different types of crustal materials in response to the uprising of isotherms. The interference of magmas belonging to the different sources has generated a bimodal granitoid magmatism, which can also be observed elsewhere near the northern margin of the Dinarides (e.g. Karamata et al., 1992; Cvetković et al., 2007 and references therein). The I-type magmatism has been explained as being related to the Adriatic slab delamination during the late stages of collision recorded in the Sava Zone near the Eocene–Oligocene transition (Schefer et al., 2011), while the S-type is related to the Miocene extension of the Pannonian Basin (Koroneos et al., 2011). The onset of emplacement of main QMZD and GDS mass occurred during the lowermost Oligocene, as inferred from the high-precision single grain U-Pb zircon ages of ~32 Ma (Fig. 2.5; Matenco et al.,
The evolution of the northeastern part of the Dinarides (2014), whereas the emplacement of the S-type TMG occurred not later than ~16 Ma, as inferred from K-Ar dating (Koroneos et al., 2011).

The Bukulja Mountains pluton is predominantly composed of slightly peraluminous two-mica granite (TMG) with a couple of small-sized bodies of metaluminous hornblende-biotite and biotite-bearing granites (Cvetković et al., 2007). Furthermore, near the western margin of the two-mica granite, a lamprophyric dyke was found to cut the adjacent marbles (Cvetković et al., 2004). The main mass of intrusion consists of a medium-grained to slightly porphyritic two-mica granite (TMG), showing gradual transitions to coarse grained and porphyritic varieties with large K-feldspar crystals in the central and southern parts (Figure 2.6, Cvetković et al., 2007). These rocks are composed of quartz, K-feldspar, plagioclase, biotite, and muscovite as main constituents, accompanied by titanite, allanite, apatite, zircon, and ilmenite as accessories. The available petrological and geochemical data (Cvetković et al., 2007) infer that the Bukulja TMG parental magma originated by melting substantial amounts of the intermediate-lower continental crust. Similarly with other S-type Miocene plutons distributed in the Dinarides (such as Polumir or the TMG phase of Cer, Schefer et al., 2011; Vukov and Milovanović, 2001), the Bukulja intrusion is interpreted to have derived from magmas generated by partial melting of the continental crust during decompression and dehydration of hydrous phases accompanying intensive crustal thinning associated with the extension of the Pannonian Basin (Cvetković et al., 2007). Newly obtained results of high-precision single grain U-Pb dating of zircons indicate that the
onset of magmatic emplacement of the Bukulja Mountains TMG occurred at ~23 Ma (Fig. 2.6; Matenco et al., 2014).

2.5 Miocene–Quaternary sedimentation in the southeastern Pannonian Basin

The extension in the southeastern Pannonian Basin and its prolongation along the Morava river (the Peri-Pannonian domain of Marović et al., 2007a, Figure 2.1b) is associated with the sedimentation of the upper Lower Miocene continental-lacustrine and alluvial sediments, a marine Middle Miocene clastic-carbonatic succession deposited during the main phase of rifting, and an Upper Miocene marine to brackish succession. The exact age of Lower Miocene sediments is not well constrained, hence, an upper Ottnangian–Karpatian age (~17.8–16.0 Ma, Central Paratethys endemic time scale) has been suggested by lithological correlations with other Lower Miocene continental-lacustrine and alluvial sediments predating the main syn-rift phase of the Pannonian Basin (Figure 2.9; Piller et al., 2007). After a hiatus located at the Karpatian/Badenian (Burdigalian/Langhian at ~16 Ma, Piller et al., 2007) that was caused possibly by a significant global sea level drop (Hardenbol et al., 1998), an overall transgression led to the deposition of the overlying marine Badenian sediments that are biostratigraphically well-constrained and show large lithological varieties. The Lower Badenian sequence is characterized by shallow-marine facies along structural highs and deep-water sedimentation in the center of extensional grabens.
The evolution of the northeastern part of the Dinarides (Matenco and Radivojević, 2012). The age of these sediments is interpreted to be between ~16.0-15.0 Ma and it can be correlated with the early Langhian of the standard Tethys time scale (Rögl et al., 2002). These are followed by lithologically variable Middle–Upper Badenian deposits, which locally overlie Lower Badenian sediments (the Middle/Upper Badenian Paratethys boundary is roughly the Langhian/Serravallian boundary at ~13.5 Ma, Foresi et al., 2002). The Sarmatian marine to brackish sediments generally have reduced thicknesses below 50m, or are completely eroded. The Badenian/Sarmatian boundary is generally marked by an erosional unconformity in the Central Paratethys (Harzhauser and Piller 2004) and constrained at 12.7 Ma (Figure 2.9; Abreu and Haddad, 1998). The gradual closure of the Central Paratethys gateways during Middle Miocene times (Magyar et al., 1999) has led to an increasingly endemic deposition until the end of the Sarmatian when the Pannonian lake was closed (Sarmatian/Pannonian boundary at 11.3-11.6 Ma, ter Borgh et al., 2013). The subsequent sedimentation took place in a prograding lacustrine – deltaic - alluvial depositional environment and it testifies the gradual regressive fill pattern in this part of the Pannonian Basin (sensu Magyar et al., 1999, 2013). This is followed by the widespread deposition of Pliocene continental Paludina beds and alluvial sediments (e.g. Nenadić et al., 2011).

In the studied area, the Neogene succession of the Fruška Gora starts with Lower Miocene shallow-water lacustrine deposits that outcrop along the northern margin of mountains and in their central part, near the locality of Vrdnik (Fig. 2.4). The sedimentation
Chapter 2

is represented by poorly cemented basal conglomerates and breccias, coarse grained-sands, siltstones, shales and marls. A precise biostratigraphic dating of these deposits is missing due to the scarcity of fossils, therefore their upper Lower Miocene (Ottnangian–Karpatian) age has been inferred by spatial relationships with overlying Middle Miocene sediments and underlying Paleogene volcanics (Čičulić and Rakić, 1977). The early Badenian sedimentation in Fruška Gora Mountains is represented by basal conglomerates and the course-grained sandstones, with intercalated tuffs generated by the onset of Middle Miocene explosive volcanism in the intra-Carpathian region (e.g., Pécskay et al., 2006; Seghedi et al., 1998). These are followed by early to middle Badenian sandstones, shallow water fossiliferous limestones, marls, and clays. The upper Badenian sedimentation is characterized by fine-grained sands and clays. Thin Sarmatian sedimentation in Fruška Gora is represented by a wide variety of siliciclastic deposits, such as conglomerates, coarse-grained sandstones, fine-grained sandstones, siltstones and clays. A gradually regressive stage of basin fill during Pannonian times was characterized by dominantly SE directed prograding deposits, the facies changing laterally from deeper water marls to basal slope turbidites, slope deposits and coarser deltaic topsets located along the margins or the prograding system (e.g., Magyar and Sztanó, 2008). Thick and coarse Pliocene-Quaternary sediments are observed along the northern and southern flanks of Fruška Gora deposited by an active fluviatile system (Sremska series of Čičulić and Rakić, 1977). This system created km-scale alluvial fans, in particular well
The evolution of the northeastern part of the Dinarides

Figure 2.9: Oligocene–Miocene chronostratigraphy of the Central Paratethys and its correlation to the Mediterranean area (from Piller et al., 2007). Geochronology, geomagnetic polarity chronos, biozonations of planktonic foraminifera and calcareous nannoplankton (all after Lourens et al., 2004), sequence stratigraphy and sea level curve (after Hardenbol et al., 1998), and oxygen isotope stratigraphy (after Abreu and Haddad, 1998) partly recalibrated and correlated to regional chronostratigraphy of the Central Paratethys.
developed in the south. This is associated with the formation of large-scale denudational surfaces that accommodate the active tectonic exhumation of the Fruška Gora (Toljić et al., 2013). The overall sedimentation ends with Upper Pleistocene loess deposition and a Holocene alluvial system with reduced thicknesses.

The southern flank of Cer Mountains is affected by a large scale E-W striking Lešnica fault, which is associated with a large negative gravimetric anomaly corresponding to depocenter of Middle Miocene sediments that reach ~800 m in thickness in the northern part of Jadar Basin (Figure 2.5). The sedimentation is represented by coarse clastic conglomerates that contain blocks of reworked magmatics and metamorphics, overlain by sands, sandy marls, clays, and platy and sandy limestones. The Middle Miocene marine to brackish sediments outcrop locally around the Cer Mountains, being overlain by the Pliocene-Quaternary continental alluvial sediments of the Pannonian Basin (Mojsilović et al., 1975).

Neogene-Quaternary cover of the Bukulja Mountains is represented by loosely bound coarse-grained conglomerates, sands, and sandy-clay deposits (Figure 2.6). The Early to Middle Miocene syn-kinematic sedimentation starts with basal conglomerates and other coarse clastic deposits, stratigraphically poorly constrained due to the lack of faunal material (Marović et al., 2007c). These are followed by sandstones and clays, with intercalated volcanioclastics, overlain by another stratigraphically higher level of conglomerates that contain pieces of magmatics and metamorphic rocks. The
The evolution of the northeastern part of the Dinarides

Miocene sedimentation ends up with massive limestones, sands, and sandy clays. South of the Bukulja Mountains (Figure 2.6), the Neogene sedimentation is made up by coarse-grained conglomerates and sandstones; and volcaniclastics series comprised of volcanic breccias, and tuffs, which are overlain by fine-grained sands, clays, and marls (Filipović et al., 1976).
Figure 2.10: a – Sericite schists, Fruska Gora Mountains; b – Diabase clasts in ophiolitic melange matrix, Fruska Gora Mountains; c – Marbles, Bukulja Mountains; d – Meta-volcanics, Bukulja Mountains; e – Calc-schists, Bukulja Mountains; f – Metamorphosed “scaglia rossa”, Bukulja Mountains.