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Jurassic Evolution of the Tectonostratigraphic Units of the Circum-Pannonian Region

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Piemont-Penninic Ocean
Pannonian Basin
Carpathians
Stratigraphy
Dinarides
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Jurassic
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Jura-Tektonostratigraphie im Circum-Pannonischen Raum

Zusammenfassung

Die Jura-Sedimentation in den verschiedenen tektonischen Einheiten im Circum-Pannonischen Raum (Alpen-Karpaten-Pannonien-Dinariden) ist geprägt durch bedeutende plattentektonische Veränderungen. Im Norden bzw. Nordwesten öffnet sich der zum Atlantik-System gehörenden Piemont-Pennin Ozean, während sich gleichzeitig der zum tethyalen System gehörende westliche Teil des Neotethys Oceans im Osten bzw. Südosten schließt. Ziel der vorliegenden Arbeit ist es, die Jura-Entwicklungen der verschiedenen Einheiten kurzgefasst darzustellen, ihre fazielle und lithostratigraphische Entwicklung zu dokumentieren und die jeweils beschriebenen Fazies-Affinitäten für die Diskussion der ursprünglichen Jura-Paläogeographie heranzuziehen.
Neben der textlichen Darstellung erfolgt eine bildliche Klarstellung in Form von vergleichenden stratigraphischen Entwicklungsschemen. Darüber hinaus wird eine kurze Übersicht zur Jura-Gesamtentwicklung im dargestellten Raum angeschlossen.

Abstract

In the Jurassic due to important plate tectonic processes remarkable changes took place in the setting of the tectonostratigraphic units in the Circum-Pannonian (Alpine-Carpathian-Pannonian-Dinaridic) domain. These changes were mostly controlled by coeval closure of the westernmost part of the Neotethys Ocean in the eastern Mediterranean region and the opening of the Piemont-Penninic Ocean as an eastern continuation of the early Atlantic Ocean in the western Mediterranean area. The aim of the present paper is to briefly summarize the main characteristics of the Jurassic successions of the tectonostratigraphic units, referring to the recognized affinities and relationships among the units. Demonstration of the stratigraphy and basic facies pattern is facilitated by simplified lithofacies columns for the units defined. This review may provide a base for an interpretation of the Jurassic evolutionary history of the studied domain and for better paleogeographic reconstructions. A brief summary of the evolutionary history is given.

Introduction

Coeval closure of the westernmost part of the Neotethys Ocean in the eastern Mediterranean region and opening of the Piemont-Penninic Ocean as an eastern continuation of the early Atlantic Ocean in the western Mediterranean area resulted in a new plate configuration in the Circum-Pannonian (Alpine-Carpathian-Pannonian-Dinaridic) domain in the Jurassic, discussed controversially (STAMPFLI et al., 1991; DERCOURT et al., 1993; PLAŠIENKA, 2000; STAMPFLI & BOREL, 2002; CSONTOS & VÖRÖS, 2004; HAAS & PÉRÓ, 2004). Spreading of the Piemont-Penninic Ocean (“Alpine Tethys”; e.g. STAMPFLI et al., 2001; BILL et al., 2002; SCHMID et al., 2004; “Alpine Atlantic”; MISSONI & GAWLICK, 2010) with formation of oceanic crust since the late Early Jurassic (e.g. RATSCHBACHER et al., 2004) and early Middle Jurassic (e.g. BILL et al., 2002) led to the separation of the Austroalpine-Western Carpathian and the Tisza Megaunits (e.g. GÉCZY, 1973; KOVÁCS, 1984; HAAS & PÉRÓ, 2004) from other parts of the European plate. In the late Early Jurassic to Middle Jurassic subduction initiated in the Neotethys realm (e.g. GAWLICK et al., 2008) that resulted in the formation of accretionary complexes in the Vardar Zone, the Dinaridic Ophiolite Belt / Mirdita Ophiolite Zone (e.g. DIMITRIJEVIĆ, 1997; DIMITRIJEVIĆ et al., 2003; KARAMATA, 2006; GAWLICK et al., 2008) and the Meliata-Hallstatt Zone (GAWLICK et al., 1999) in the Middle to Late Jurassic. The accretionary complex and the out-of-sequence nappes in the more proximal part of the former continental margin are locally covered by platform carbonates of Kimmeridgian to Berriasian age.

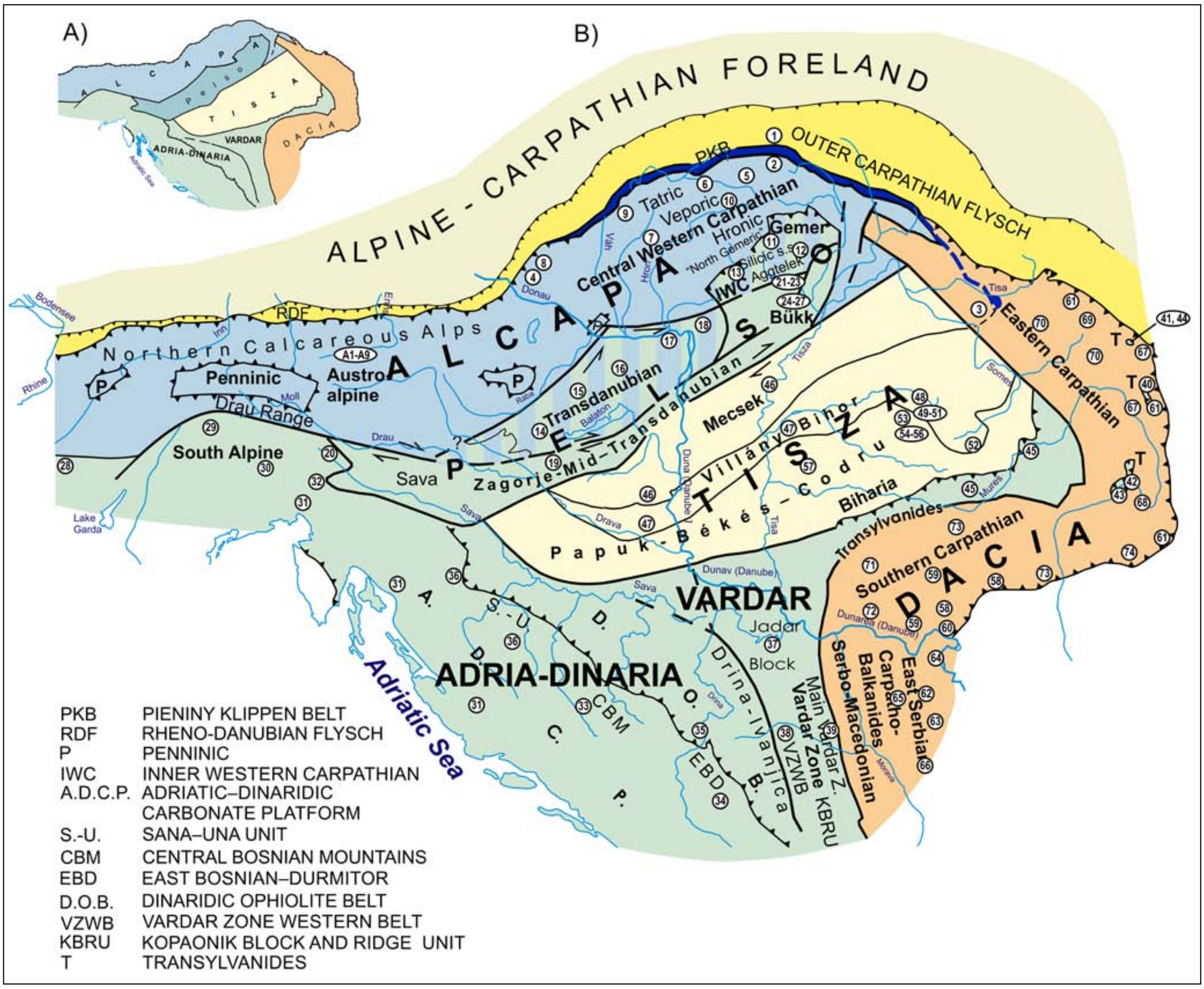
Due to further tectonic shortening after the closure of the westernmost Neotethys and the Piemont-Penninic oceanic basins since Late Cretaceous and lateral displacements of plate fragments during the Cretaceous and Tertiary, the Jurassic formations moved partly relatively far from their original position leading to significant changes in their relationships and paleogeographic setting (e.g. SĂNDULESCU, 1984; BALLA, 1987; ROYDEN & BÁLDI, 1988; RATSCHBACHER et al., 1991; CSONTOS, 1995; KOVÁČ et al., 1998; FODOR et al., 1999; NEUBAUER et al., 1999; HAAS & KOVÁCS, 2001; CSONTOS & VÖRÖS, 2004; FRANK & SCHLAGER, 2006; SCHMID et al., 2008). Essential characteristics of the Jurassic formations of the tectonostratigraphic units are presented below, thus providing the basis for the reconstruction of the provenance of the tectonostratigraphic units that will be briefly summarized in the last part of the present paper. Setting and names of the structural units referred to in the text and locations of the lithofacies columns are presented in Text-Fig. 1.

Jurassic Stratigraphy and Evolution of Tectonostratigraphic Units

ALCAPA MEGAUNIT

Penninic Unit

The Jurassic sedimentary successions of the Penninic Unit represent the distal continuation of the Lower Austroalpine successions towards the newly formed Penninic Ocean, but finer-grained. Accordingly, the sedimentary evolution of this unit is more or less the same as that of the Lower Austroalpine passive continental margin. The sedimentary successions generally are highly deformed and metamorphosed (e.g. Engadin and Tauern Windows), form different nappes and lack mostly in determinable fossils (details in TOLLMANN, 1977). In the Early Jurassic, quartzites, arkoses and phyllites (Hochstegenquarzit, Schwarzkopfquarzit) dominate in both windows beside conglomerates and Bündner schists. First ophiolites (Pl. 1, Fig. 1) occur in the upper part of the Early Jurassic (RATSCHBACHER et al., 2004). In the Middle Jurassic the fine-grained Bündner schists are dominating (Pl. 1, Fig. 2) beside sandstones (Idalp sandstone). Rare radiolarites (e.g. in the Idalp region) may be contemporaneous with the radiolarites in the Swiss or French Alps (Bathonian to Oxfordian; BILL et al., 2001). In the Late Jurassic the sedimentation changed from shaly/siliceous sediments to more carbonatic ones: Hochstegen limestone/-dolomite and Klammkalk in the Tauern and Rechnitz windows (Oxfordian to Tithonian), Falknis and Sulzfluh limestone in the Engadin window (Oxfordian to Tithonian) (TOLLMANN, 1977; PILLER et al., 2004).



Text-Fig. 1.
Megaunits (A) and lower-rank structural units (B) in the Circum-Pannonian region, with location of the lithofacies columns.

Austroalpine-Western Carpathian Units

Eastern Alps (Austroalpine Unit)

For a detailed description of the Jurassic evolution of the Austroalpine with definition and revision of all formations see GAWLICK et al. (2009a).

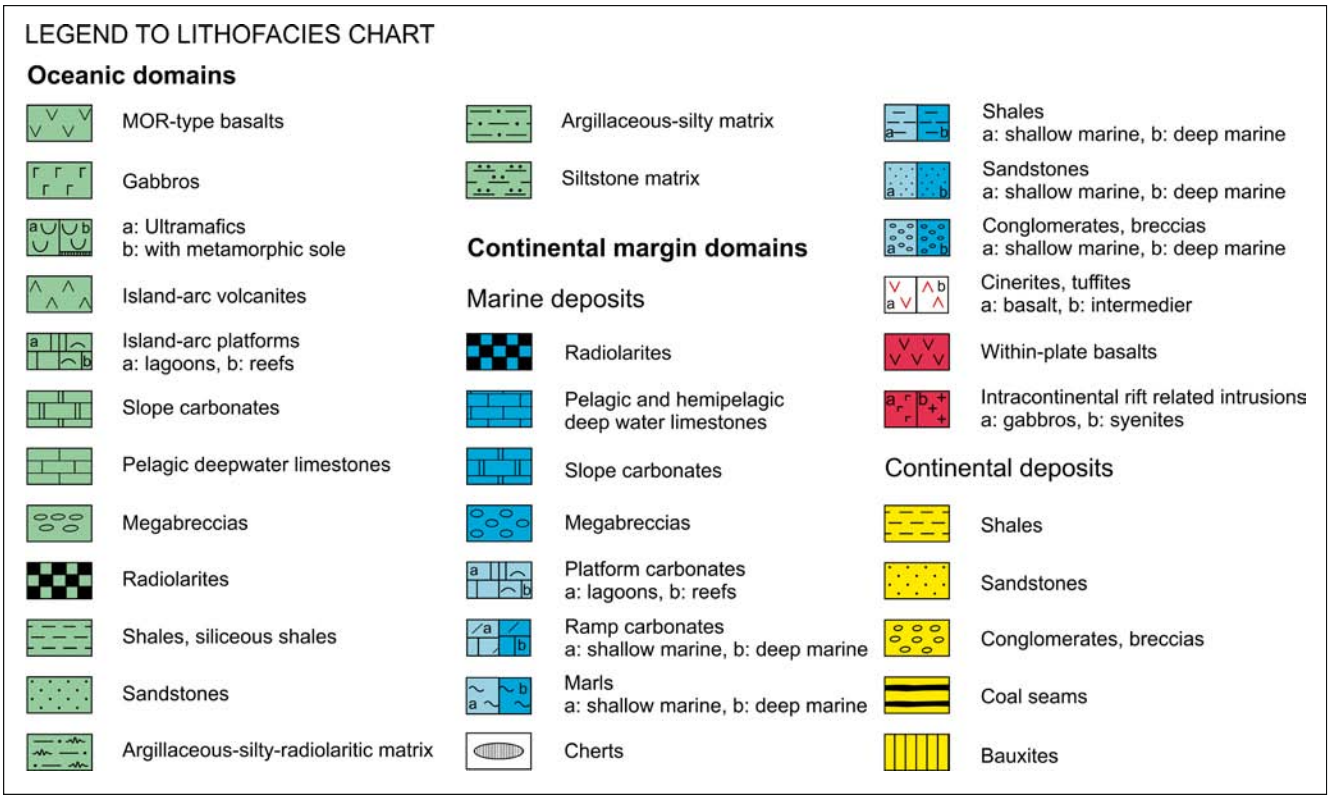
Lower Austroalpine Units and p.p. Central Alpine Mesozoic Units (Text-Fig. 3, col. A1)

The Lower Austroalpine Units formed in Jurassic times the passive continental margin facing the Penninic-Piemont Ocean to the northwest. Breccia formation due to extensional tectonics started above siliciclastic influenced carbonates in the Late Hettangian and should prevail until the end of the Early Jurassic or early Middle Jurassic (e.g. ENZENBERG, 1967; HÄUSLER, 1988; CONTI et al., 1994), but metamorphism and deformation prevent exact dating of the successions in the Lower Austroalpine units (TOLLMANN, 1977). Exact dating of the equivalent breccias in the Engadin shows that breccia formation decreased in the Sinemurian to Early Pliensbachian (e.g. EBERLI, 1988; CONTI et al., 1994). This Late Hettangian to Early Pliensbachian breccias are related to the first extensional pulse. A second pulse may start in the Late Toarcian to Aalenian and could be related to the final break-up of the Penninic Ocean (RATSCHBACHER et al., 2004).

The Early Jurassic breccias occur in deep-water marly and cherty limestones and derive from nearby escarpments (Text-Fig. 3). Radiolarite deposition may start in the late Middle Jurassic, contemporaneous with the deposition of the radiolarian cherts in the Penninic-Piemont oceanic domain (O'DOGHERTY et al., 2006). In Late Jurassic times, after the deposition of the radiolarites, calcareous sedimentation becomes important, but again breccias occur (e.g. GRUNER, 1981; HÄUSLER, 1988). Whereas in the Lower Austroalpine Units the Jurassic successions seems to be more or less completely prevailed, they are rare (mostly eroded) in the Central Alpine Mesozoic Units. Where prevailed these successions show the same evolution as in the Lower Austroalpine Units but with less tectonic influence (compare TOLLMANN, 1977).

Northern Calcareous Alps

At the Triassic/Jurassic boundary carbonate production significantly decreased in connection with the environmental crisis leading to a mass extinction accompanied by a sea-level drop. Therefore earliest Jurassic sedi-

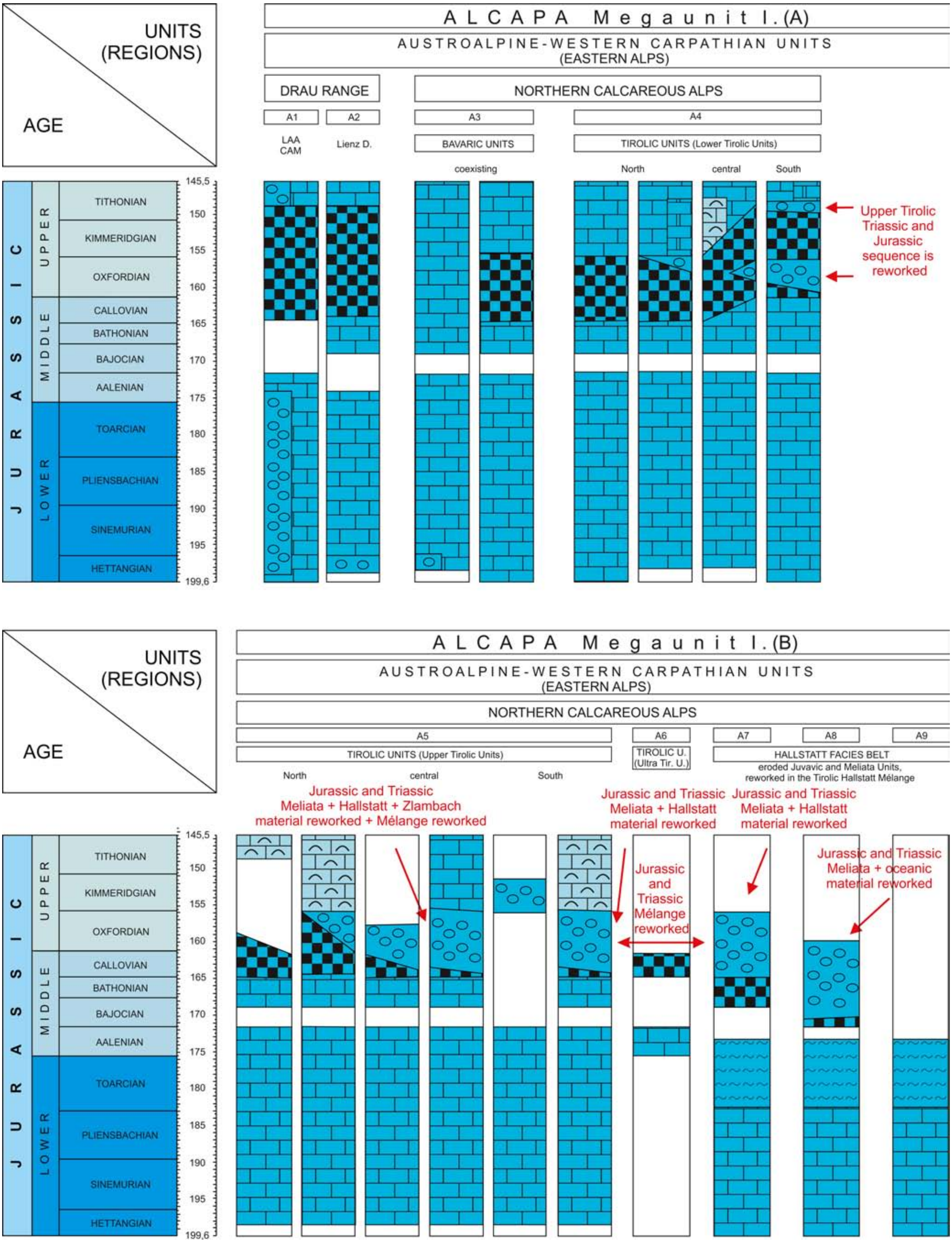


Text-Fig. 2.
Legend to lithofacies charts (Text-Figs. 3–16).

ments are missing on top of the morphologic highs (former Hauptdolomit/Dachstein Carbonate Platform). Only in basinal areas sedimentation was continuous (Hillebrandt & Krystyn, 2009). Lack of sufficient sediment supply led to drowning of the Hauptdolomit/Dachstein Carbonate Platform in Late Hettangian times due to a sea-level rise. Later on, a horst and graben morphology developed (Bernoulli & Jenkyns, 1974; Eberli, 1988; Krainer et al., 1994) and triggered breccia formation (Text-Figs. 1, 2 and 3) along submarine slopes and escarpments, mainly in Pliensbachian to Early Toarcian times (Böhm et al., 1995). An increasing pelagic influence was manifested in the Early to Middle Jurassic sediments of the Northern Calcareous Alps (NCA) (Garrison & Fischer, 1969; Böhm, 1992). Breccia formation in late Early Jurassic times was mostly interpreted as a result of the opening of the Penninic Ocean (e.g. Bernoulli & Jenkyns, 1974; Eberli, 1988; Krainer et al., 1994). Whereas the lower part of the Early Jurassic sequences of the Lower Austroalpine shows the typical features of a rifted margin (e.g. Eberli, 1988); the Bavaric and Tirolic Units were only slightly influenced by these rifting processes. In contrast, late Early Jurassic tectonic movements affected mainly the Tirolic Unit and resulted in a completely new paleogeographic setting, whereas the Bavaric to Lower Austroalpine Units show only mild or no influence of these tectonic processes. This change in the late Early Jurassic (Late Pliensbachian to Early Toarcian) was interpreted by many authors also as a result of the opening of the Penninic Ocean (e.g. Eberli, 1988; Krainer et al., 1994). In contrast, Frisch & Gawlick (2003) and Missoni & Gawlick (2011) attributed this “event” to the onset of subduction of the Neotethys Ocean.

Due to the subduction processes in the Neotethys realm and the contemporaneous out-of-sequence thrusting towards the continent (Juvavic and Tirolic Nappes), the sedimentation pattern in the Northern Calcareous Alps changed dramatically in the Middle Jurassic (Gawlick & Frisch, 2003), and not in the Oxfordian as formerly assumed (Tollmann, 1985). Significant sedimentation resumed with the deposition of the Ruhpolding Radiolarite Group, which documented the change from condensed carbonates to almost purely siliceous sediments. In the Middle Jurassic, the sedimentary evolution in the southern part of the Tirolic Unit (Upper Tirolic Nappe with Bajocian to Oxfordian Hallstatt Mélange) clearly differed from the one in the northern part (Lower Tirolic Nappe with Oxfordian Tauglboden Mélange). The main difference of the Hallstatt and Tauglboden Mélanges was the earlier onset and the different composition of huge mass-flows in the Hallstatt Mélange basins. The mélanges are interpreted as carbonate-clastic-radiolaritic trench fills formed in sequence due to the closure of parts of the Neotethys Ocean.

The Plassen Carbonate Platform (PCP, Kimmeridgian to Early Berriasian; Gawlick & Schlagintweit, 2006) developed during tectonically active periods in a convergent regime (Gawlick et al., 2009a). In the Late Kimmeridgian to Early Berriasian huge masses of shallow-water carbonates were formed. The platform carbonates are covered by calpionellid-radiolaria wackestones to packstones of Late Berriasian age. A siliciclastic influenced drowning sequence sealed the highly differentiated PCP (Schrambach Formation). The onset, evolution and drowning of the PCP took place in a tectonic active regime. The tectonic evolution of the Northern Calcareous Alps during Kimmeridgian to Berriasian times and the final drowning of the PCP



Text-Fig. 3.
Lithofacies chart of the Eastern Alpine Units (A1–A9) (ALCAPA I).

Abbreviations:
LAA = Lower Austroalpine, CAM = Central Alpine Mesozoic,
Lienz D. = Lienz Dolomites, Ultra Tir. U. = Ultra-Tirolic Unit.

can be interpreted as a result of further tectonic shortening and uplift of the accretionary prism after the closure of parts of the Neotethys Ocean. This led to the erosion of siliciclastic material, which reached at this time the inner parts of the NCA.

Bavaric Unit (Text-Fig. 3, col. A3)

In the Early Jurassic the sedimentation was mainly controlled by the Late Triassic topography (Böhm, 2003; Gawlick & Frisch, 2003). Block tilting was mild in this area. The Rhaetian shallow-water carbonates were overlain by red and grey crinoidal limestones in the Late Hettangian to Sinemurian with a gap (Ebli, 1997). On top of the Rhaetian Kössen Formation cherty and marly bedded limestones were deposited (Kirchstein Formation). These sediments progressed gradually to the hemipelagic Allgäu Formation (Sinemurian to ?Bathonian). In the depositional areas of the Adnet Formation condensed sedimentation prevailed partly until the late Middle Jurassic (Adnet Formation: Sinemurian to Toarcian; Klaus Formation: Bathonian to Callovian), and condensed red limestones were formed subsequently (Steinmühl Formation – Kimmeridgian to Tithonian) (Krystyn, 1971, 1972). In the Upper Bavaric Nappe, i.e. in the basinal transitional areas to the Lower Tirolic Unit only the deposition of the organic rich Sachrang Member indicates a slight tectonic influence in the Early Toarcian, in contrast to the stronger tectonic influence which occurred in the Tirolic Units. In the Callovian to Oxfordian these depositional areas deepened which resulted in the deposition of cherty limestones, cherty marls, and radiolarites. In basinal areas on top of the Allgäu Formation dark grey cherty marls and cherty limestones were deposited, formerly interpreted as early to late Middle Jurassic Allgäu Formation (Ebli, 1997; Piller et al., 2004), being in fact time equivalents of the Ruhpolding Radiolarite Group in the sense of Gawlick & Frisch (2003). On the Early to Middle Jurassic topographic highs red condensed limestones or condensed radiolarites were deposited (Callovian to Kimmeridgian). In the Kimmeridgian the siliceous sedimentation passed gradually to marly sedimentation, which is characteristic for the Kimmeridgian to Early Berriasian (Ammergau Formation, Aptychus beds). Typical Aptychus beds beside Biancone were deposited in the Late Tithonian. These sediments may reflect tectonic movements in the Tirolic Units and an enormous amount of fine-grained carbonate export from the PCP to the Penninic realm. This time synchronity suggests that coeval tectonic subsidence and shedding of huge amounts of carbonate material from the platform areas of the PCP may have been responsible for the great thickness of the Oberalm Formation/Aptychus beds (Gawlick & Schlagintweit, 2006) rather than enhanced nannoplankton productivity in the whole Tethys realm (e.g. Colacicchi & Bigozzi, 1995).

Tirolic Unit (Text-Fig. 3, col. A4-A6)

In the Early Jurassic the sedimentation was controlled by the topography of the Late Triassic Hauptdolomit/Dachstein Carbonate Platform (Böhm, 2003; Gawlick & Frisch, 2003). On top of the Rhaetian shallow-water carbonates red condensed limestones of the Adnet Group (Late Hettangian to Toarcian; Böhm, 1992, 2003) were deposited, partly above a gap. On top of the Rhaetian Kössen Formation cherty and marly bedded limestones (Scheibelberg Formation: Sinemurian to Toarcian – Pl. 1, Fig. 3; Kendlbach Formation: Hettangian; Böhm, 1992, 2003; Ebli, 1997; Krainer & Mostler, 1997), whereas in the transitional areas to the Rhaetian Kössen Basin crinoidal or sponge spicule rich limestones of the Enzesfeld Formation were deposited (Hettangian to Sinemurian; Böhm, 1992). In the Late Pliensbachian and Early Toarcian a horst and graben morphology developed (Bernoulli & Jenkyns, 1974; Krainer et al., 1994) and triggered breccia formation along submarine slopes and escarpments (Pl. 1, Fig. 4; Böhm et al., 1995). On the horsts the Toarcian and most of the Middle Jurassic is characterized by starving sedimentation and ferro-manganese crusts or there is a hiatus, whereas the grabens were filled with deep-water carbonates and breccias, which were formed at near fault scarps. Neptunian dykes developed in various places. In these newly formed basinal areas grey bedded limestones of the Scheibelberg Formation were deposited, whereas the topographic highs were covered by condensed red limestones of the Klaus Formation (e.g. Krystyn, 1972).

This sedimentation pattern changed dramatically in the late Middle Jurassic (Gawlick & Frisch, 2003) when radiolarian cherts and radiolarian rich marls and limestones of the Ruhpolding Radiolarite Group start to deposit (Diersche, 1980) (Pl. 2, Fig. 1).

In the Bajocian the sedimentary evolution in the southern part of the Tirolic Unit (= Upper Tirolic Unit) differed from that in the northern part (= Lower Tirolic nappe group; recently subdivided by Gawlick et al. (2011) in a Lower Tirolic nappe and a Lowermost Tirolic nappe, separated by the Brunnwinkl Rise in central position). Deep-water trenches were formed in front of advancing nappes. The southern parts of the Northern Calcareous Alps (= Upper Tirolic nappe) received mass-flow deposits and large slides derived from the Hallstatt zone (Gawlick & Frisch, 2003; Pl. 2, Fig. 3). The thickness of the basin fills may reach 2000 m (Gawlick, 1996; Gawlick et al., 2007). The Tauglboden trench in the north (= Upper Tirolic nappe) was subjected to high subsidence and sedimentation rates in the Oxfordian (Schlager & Schlager, 1973; Gawlick & Frisch, 2003). A rise (= nappe front of the Upper Tirolic units; northern part) was eroded and supplied the Tauglboden trench to its north with mass-flow deposits and slides (Pl. 1, Fig. 5). These two groups differ significantly, since the Hallstatt Mélange trenches formed earlier and exhibited a different composition of its huge mass-flows. However, both basins formed syntectonically suggesting a substantial relief between the basin axis and the source area. The third type of radiolarite basin, the Sillenkopf Basin (Missoni et al., 2001), remained a starved basin in the Kimmeridgian in the southern NCA. This basin contains the earliest ophiolitic detritus deriving from the accreted and or obducted Neotethys ocean floor (Missoni, 2003; Missoni & Gawlick, 2011).

Gawlick et al. (1999) interpreted all these patterns of sedimentation as a reflection of nappe movements in the today eroded southernmost Northern Calcareous Alps (= eroded Juvavic nappe pile) in late Middle to Late Jurassic times and related it to the Kimmeridgian orogeny according to earlier authors (see “Jurassic gravitational tectonics”; Plöchinger, 1976; Tollmann, 1981, 1985, 1987; Mandl, 1982). This orogenic event (e.g. Lein, 1985, 1987a) was related to the closure of parts of the Neotethys Ocean.

According to other authors (e.g. Wächter, 1987; Channell et al., 1992; Frank & Schlager, 2006) these Late Jurassic coarse clastic sediments should be related to strike-slip faulting (compare Schmid et al., 2008; Gawlick et al., 2008).

The Hallstatt Mélange as erosional product of the today eroded Juvavic nappes was formed in the late Early to early Late Jurassic interval as a result of a successive shortening of the Triassic to Early Jurassic distal shelf area (Hallstatt Zone). In front of advancing and rising nappes, trenches were formed and filled up by various deposits. These trenches were overthrusted and incorporated into the accretionary prism subsequently (Gawlick et al., 2009a).

In the Tirolic Units of the Northern Calcareous Alps establishment of the shallow-water PCP started on the frontal parts of the rising and advancing nappes (Gawlick et al., 1999, 2005). From there these platforms prograded towards the adjacent radiolarite basins (Gawlick & Frisch, 2003; Gawlick et al., 2005). This resulted in a complex basin and rise topography with shallow-water and deep-water areas with different types of sediments (Gawlick & Schlagintweit, 2006). In the Kimmeridgian a huge carbonate platform was formed in the southern and northern parts of the Upper Tirolic Unit (Pl. 2, Fig. 4), whereas in the Lower Tirolic Unit the formation of Kimmeridgian shallow-water carbonates was restricted to its central part (Gawlick et al., 2007), i.e. the rise separating the Lower and Lowermost Tirolic nappe (Gawlick et al., 2011). The whole PCP cycle lasted from the Kimmeridgian till the Early Berriasian platform drowning, but drowning resp. uplift of the platform was not contemporaneous (Gawlick & Schlagintweit, 2010). From the Late Tithonian onwards due to the break up of rises a large amount of carbonate debris was shed into the adjacent basins, and further to the Bavaric Units and to the Lower Austroalpine realm forming there the Oberalm Formation (resp. Aptychus beds). The “Barmstein Limestones” consists of proximal reef debris and in parts with allochthonous components (Plöchinger, 1976; Steiger, 1981; Gawlick et al., 2005) and represent mass-flows and turbiditic layers in a basinal succession (Oberalm Formation) with components deriving mostly from the adjacent autochthonous PCP (Pl. 2, Fig. 2), although older clasts also occur (Schlagintweit & Gawlick, 2007).

Hallstatt Facies Belt (reworked Jurassic Hallstatt Mélange)

In the area of the Northern Calcareous Alps, the eroded Juvavicum represents the Jurassic accretionary prism (Frisch & Gawlick, 2003). Remnants of this nappe complex are only present in the Middle to Late Jurassic radiolaritic trenches respectively on top of them where all sedimentary rock types of the Hallstatt facies belt from the transitional area to the Triassic platform and to the Meliata Facies Zone occur (for details: Missoni & Gawlick, 2011).

Zlambach/Pötschen Facies Zone (Text-Fig. 3, col. A7)

The Rhaetian marly Zlambach Formation progresses gradually to the Early Jurassic Dürrnberg Formation (Gawlick et al., 2001) that is made up of marly sediments in its basal part (Hettangian) that gradually progress into cherty limestones (Sinemurian), cherty marls and radiolarites (Pliensbachian) (O’Dogherty & Gawlick, 2008). The Toarcian is represented by dark grey marly limestones and grey marls (Missoni, 2003; Gawlick et al., 2009b). In the Middle Jurassic the Zlambach/Pötschen Facies Zone was incorporated into an accretionary prism.

Hallstatt Limestone Facies Zone (Text-Fig. 3, col. A8)

The Zlambach Marl (Rhaetian) progresses gradually into the Early Jurassic Dürrnberg Formation (for small variations and transitional successions in this typical sedimentary sequence see Krystyn, 1970, 1987; Tollmann, 1985; Lein, 1987b; Gawlick, 1998). The Dürrnberg Formation passes also gradually from marly sediments (Hettangian) to cherty limestones (Sinemurian) and cherty marls to radiolarites (Pliensbachian) (O’Dogherty & Gawlick, 2008). Toarcian sediments are dark grey marly limestones and grey marls (Missoni, 2003; Gawlick et al., 2009a). In the Middle Jurassic the Hallstatt Facies Zone was incorporated into an accretionary prism. Resedimented remnants of these early trenches formed in this area occur in the Florianikogel Formation (Piller et al., 2004) and the Sandlingalm Formation (Gawlick et al., 2007).

Meliata Facies Zone (Text-Fig. 3, col. A9)

The Meliata facies zone represents the most distal part of the shelf area and the continental slope as well as the transition to the Neotethys Ocean. Rare remnants of these facies belt are described from the eastern (Kozur & Mostler, 1992; Mandl & Ondrejičková, 1993) and central part of the Northern Calcareous Alps (Gawlick, 1993). These remnants occur partly as metamorphosed isolated slides (Florianikogel area) or as breccia components in the Hallstatt Mélange (Gawlick, 1993). The Meliata facies zone should have been the first, which was incorporated into the accretionary prism.

Drau Range

Lienz Dolomites and Gailtal Alps (Text-Fig. 3, col. A2)

In the Lienz Dolomites Jurassic sediments are only preserved on top of the Oberrhätkalk. In contrast to the Bavaric and the Tirolic Units of the Northern Calcareous Alps the shallow-water Oberrhätkalk drowned partly, and was overlain by the Allgäu Formation (partly with breccias) or the Adnet Formation. Contemporaneously the Lavant Breccia was formed (Hettangian to Sinemurian; Schlager, 1963; Blau & Schmidt, 1988) in contrast to similar but younger breccias in the Tirolic Units. This clearly shows that the Lienz Dolomites represent a transitional area between the Bavaric Units and the Lower Austroalpine, where parts of the Türkenkogel and Tarntaler breccias started to form at that time (Tollmann, 1977; Häusler, 1988). These breccias are overlain by the Pliensbachian Adnet and the Klaus Formations (Tollmann, 1977; Blau & Schmidt, 1988). The overlying sequences are not very well investigated (Tollmann, 1977), the correlation with other Middle to Late Jurassic sequences is poorly constrained (Piller et al., 2004). The radiolarian-rich red cherty limestones may correlate with the cherty sediments of the Ruhpoldinger Radiolarite Group and the red nodular crinoid-rich limestones may correlate with the Late Jurassic Steinmühl Formation. The following *Calpionella*-rich reddish-greyish limestones progress into the Early Cretaceous and can be correlated with the Oberalm Formation or Aptychus beds respectively Biancone.

Northern Karavanks

The Jurassic sedimentation (TELLER, 1888; TOLLMANN, 1977) started with deposition of red limestones of the Adnet Group which progress into red condensed limestones of the Klaus Formation. The radiolarian-rich red cherty limestone may correlate with the cherty sediments of the Ruhpoldinger Radiolarite Group, and the red nodular crinoid-rich limestone may correlate with the Late Jurassic Steinmühl Formation. The following *Calpionella*-rich, reddish-greyish limestones progress into the Early Cretaceous and can be correlated with the Oberalm Formation or Aptychus beds (SUETTE, 1978; BAUER et al., 1983).

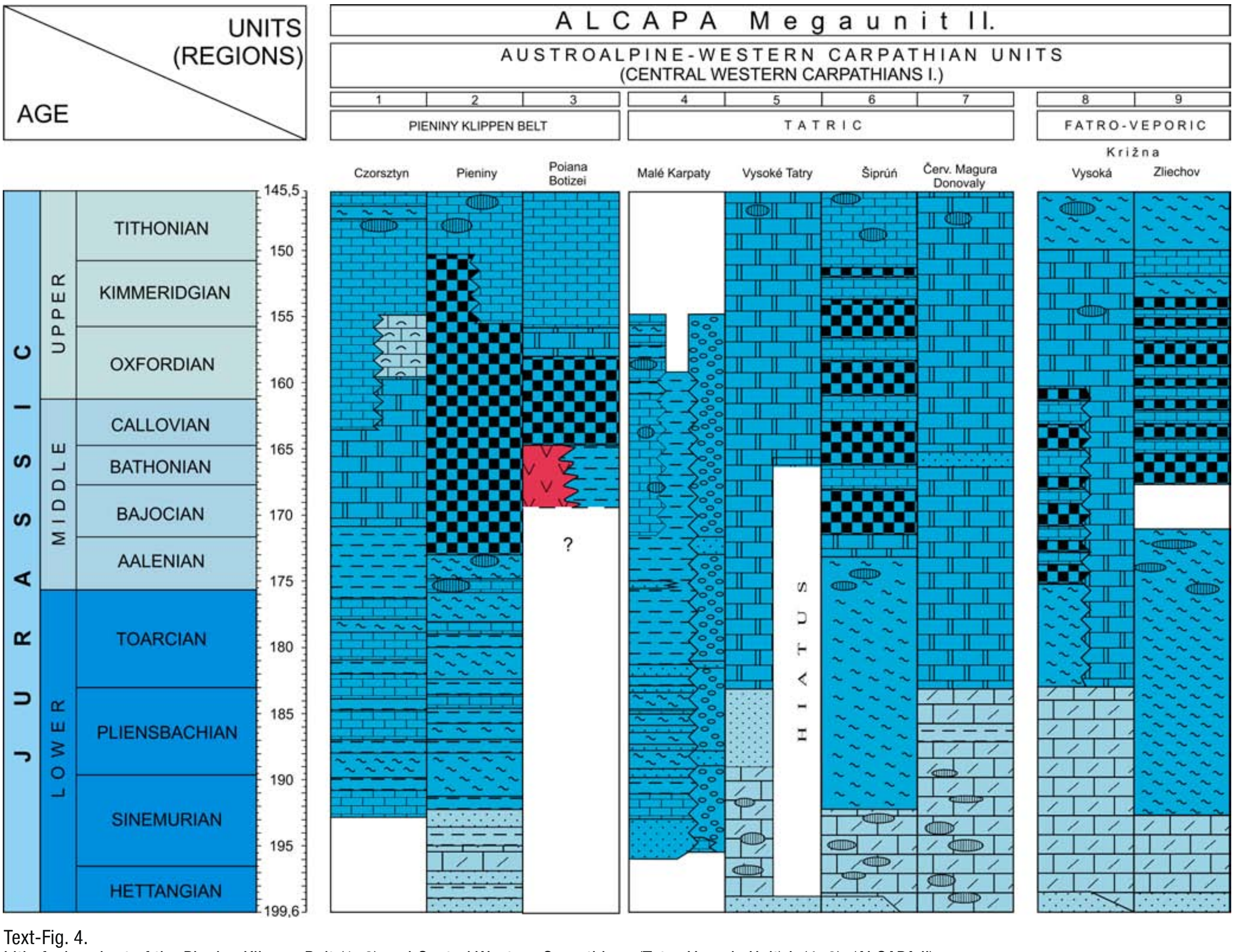
Central Western Carpathian (Tatro-Veporic) Unit

Pieniny Klippen Belt (Text-Fig. 4, col. 1–3)

The Pieniny Klippen belt is the most complicated unit of the Western Carpathians, Slovakia and Poland that continues eastward in the North-Eastern Carpathians, Ukraine and in the Eastern Carpathians, Romania. Two markedly different sequences are present: the deep-water **Pieniny** (-Kysuca) sequence and the shallower **Czorsztyn** sequence (ANDRUSOV, 1968; BIRKENMAJER, 1977, 1998; GOLONKA & KROBICKI, 2004) (Text-Figs. 1, 2 and 4); however, there are transitional sequences too.

Hettangian sediments occur only in the Pieniny(-Kysuca), Drietoma and Klape sequences, but continuous successions are not exposed. The Kopienec Formation is similar to the Gresten facies. Similar rock types occur in the Sinemurian to Pliensbachian in the Manín and Haligovce sequences, with increasing amount of coarse bioclastic material. In the Czorsztyn sequence and Drietoma transitional sequence the Sinemurian to Toarcian is represented by deep-water dark-grey, mottled, marly limestones similar to the Allgäu facies. In the Pieniny(-Kysuca) sequence black shales reflecting euxinic environment also occur (Zázrivá beds). Deepening took place in the late Pliensbachian to Toarcian when variegated marly limestones (Kozince beds) were formed, which progress into Adnet-type red nodular limestones. The Aalenian is represented by sandy limestones, calcareous sandstones (ANDRUSOV, 1968) with intercalations of the Posidonia beds (Szlachtowa Formation).

The Upper Bathonian to Oxfordian is represented in the Pieniny(-Kysuca), Drietoma and Manín sequences by variegated radiolarian limestones and radiolarites. The Kimmeridgian is characterized in almost all sequences by red, nodular, Saccocoma limestones (Czorsztyn Limestone, Vršatec Limestone) that is overlain by Ti-



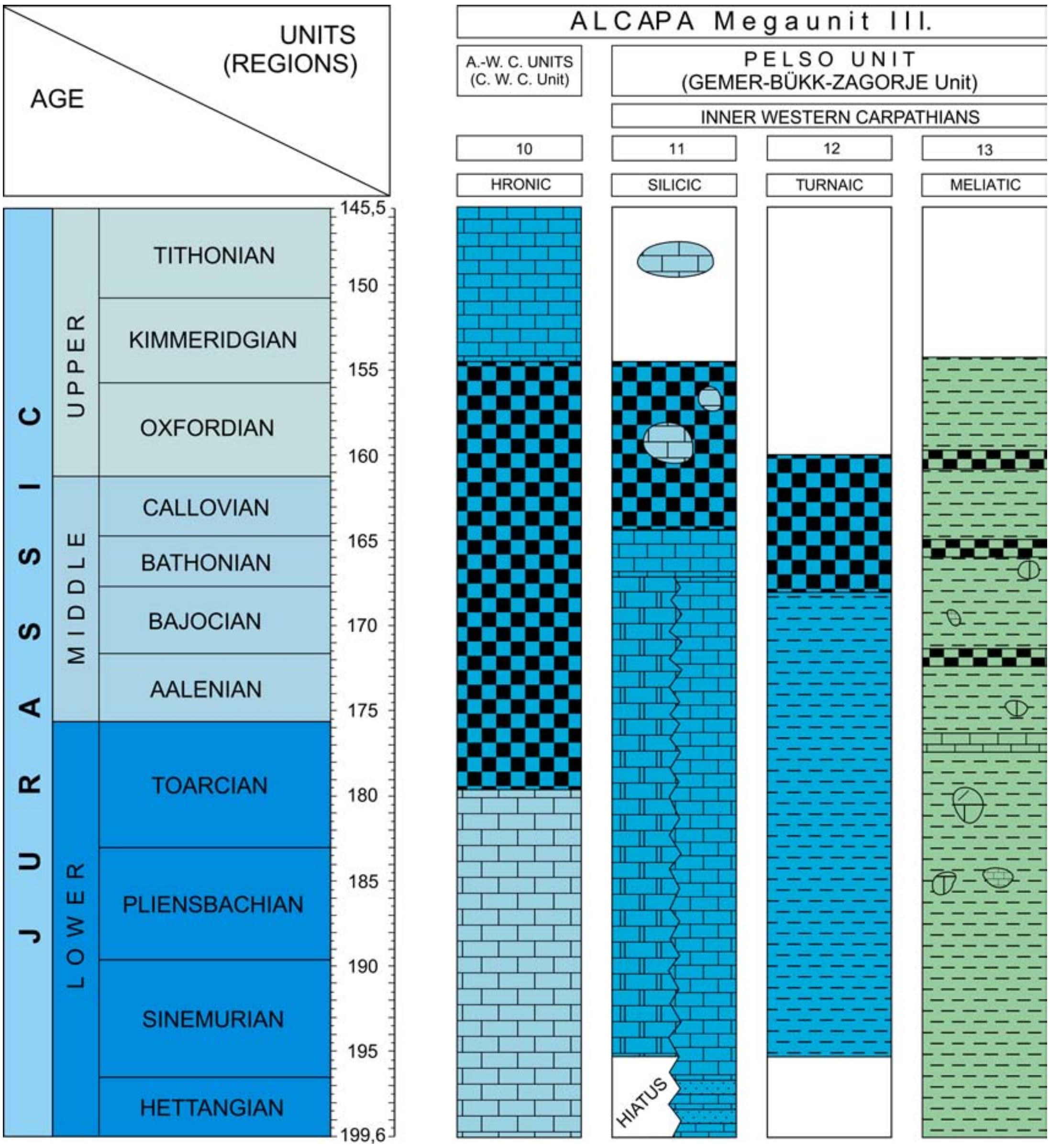
Text-Fig. 4.
Lithofacies chart of the Pieniny Klippen Belt (1–3) and Central Western Carpathians (Tatro-Veporic Unit) I. (4–9). (ALCAPA II).
Abbreviation:
Červ. Magura = Červená Magura.

thonian to Valanginian marly, cherty pelagic limestones (Pieniny Formation). In the Pieniny sequence the whole Bathonian to Tithonian interval is represented by radiolarian cherts.

In the Pienides in the Transcarpathian Flysch Zone of the Eastern Carpathians, Pieniny-type klippens containing pelagic Jurassic to Cretaceous and ?Paleocene sequences occur only in the frontal scales of the *Botiza* Nappe (i.e. in the **Poiana Botizei** region) (SĂNDULESCU, 1984). The Jurassic succession includes in ascending stratigraphic order: basic cinerites with a basal breccia of variolitic basalts and hyalobasalts of ?Callovian age, radiolarites (Callovian–Oxfordian), detrital limestones with fragments of basic rocks (Oxfordian – ?Lower Kimmeridgian) and Aptychus beds (Kimmeridgian – ?Berriasian; SĂNDULESCU et al., 1982; BOMBIȚĂ et al., 1992).

Tatric Unit (Text-Fig. 4, col. 4-7)

The sedimentation area of the different Tatric units was most probably the continuation of the Lower Austroalpine units of the Eastern Alps (PUTIŠ et al., 2008). Differentiation of the Tatric sedimentation area commenced in the latest Triassic to earliest Jurassic. Intense extensional tectonics led to the development of the **Šiprúň** Trough in the Middle to Late Liassic (PLAŠIENKA, 1998). The sedimentary record in the eastern segment of the northern Tatric Ridge in the High Tatra (**Vysoké Tatry**) is reflected in the presence of the continental Rhaetian Tomanová Formation, and Pisany Sandstone that is followed by crinoidal and sandy limestones. The western segment of the northern Tatric Ridge controlled the sedimentation record of the **Malé Karpaty** Mts (PLAŠIENKA, 1991, 1995). In the Early Liassic the South Tatric Ridge emerged at the southern part of the Šiprúň area (**Červená Magura** sequence, **Donovaly** sequence). This paleogeographic setting is reflected in the sedimentological features of the Upper Liassic siliciclastic rocks, crinoidal and Hierlatz-type limestones and also of the Dogger crinoidal and sandy limestones. During the Pliensbachian to Toarcian an intensive extension took place and characteristic Allgäu facies developed. In the Bathonian to Oxfordian radiolarian limestones and radiolarites were formed. The deep-water sedimentation continued in the Early Cretaceous with deposition of pelagic limestones (Lúčivná Formation).



Text-Fig. 5.
Lithofacies chart of the Central Western Carpathians II (10) and Inner Western Carpathians (11–13). (ALCAPA III).
Abbreviations:
A.-W.C. UNITS = Austroalpine-Western Carpathian Units,
C.W.C. Unit = Central Western Carpathian Unit

In the Tatric Unit an intense segmentation took place in the latest Triassic which resulted in erosion and non-deposition over a predominant part of the area. Rudimentary occurrences are present only in the western part of the unit. During the Early Liassic differentiation of the sedimentary basin continued; longitudinal basins (troughs) separated by rigdes were formed. The sedimentation was controlled by extensional tectonics until the Pliensbachian, when the Šiprúň Basin developed.

The Hettangian to Sinemurian sequences of the Tatric Unit are characterized by slope facies of crinoidal and sandy-crinoidal limestones with a different abundance of siliciclastic components. In the eastern part of the unit Hettangian to Sinemurian sequences are missing. In the central part of the unit mottled Hierlatz-type limestones were formed during the Sinemurian and partly in the Pliensbachian. In the Pliensbachian deepening took place in the Šiprúň Basin which was reflected in the deposition of 100–250 m "Fleckenmergel" (Allgäu facies), which continued in the Toarcian and Aalenian. In the Bathonian to Oxfordian radiolarian limestones, claystones and radiolarites were formed up to 30 m in thickness (POLÁK et al., 1998).

In the other, relatively elevated parts of the Tatric sedimentation area the contribution of terrestrial siliciclastic material was remarkable. Variegated, crinoidal and crinoidal-sandy limestones were formed in ventilated, strongly agitated environments.

The sedimentation conditions became more and more uniform during the Late Jurassic. Deep-water sedimentation prevailed during the Kimmeridgian to Middle Tithonian, when mottled, up to 10 m thick nodular Saccocoma limestones were formed. The Upper Tithonian is represented in the whole Tatric area by light marly, cherty Calpionella limestones that belong to the Lúčivná Formation (Upper Tithonian to Lower Aptian).

The geological setting is significantly different in the area of the **Malé Karpaty** Mts that is characterized by the *Borinka* sequence (PLAŠIENKA, 1987). Shallow-water, biodetritic and sandy limestones to sandstones (Prepadlé Formation of the Borinka sequence) were deposited during the Sinemurian to Pliensbachian. The upper part of the Borinka sequence is made up mostly by carbonate breccia. The lateral equivalent of the Prepadlé Formation is the Korenec Formation, which is composed of turbiditic claystones, marlstones, sandstones and sandy limestones. The most characteristic formation in the Borinka sequence is the Marianka Formation, which consists of black shales indicating anoxic conditions with intercalations of crinoidal-sandy limestones, breccias and manganiferous beds. The age of this formation is Toarcian to Kimmeridgian(?). The uppermost part of the Borinka sequence (Somár Formation; Toarcian to Tithonian?) is made up of polymictic breccias composed of various rock-types (granitic and metamorphic rocks, carbonates, siliciclasts).

Fatro-Veporic Unit (Text-Fig. 4, col. 8-9)

The **Krížna** Nappe of the Fatricum is characterized by a continuous sedimentary succession from the Upper Paleozoic to the Upper Cretaceous (Cenomanian). According to the lithofacies subdivision of the Krížna Nappe sensu MAHEĽ (1964), the **Zliechov** sequence was deposited from the Early Jurassic to the Albian and is characterized by shallow-marine Hettangian to Sinemurian deeper-water shales and carbonates in the Pliensbachian–Toarcian; deep-water radiolarian limestones, radiolarites in the Middle to early Late Jurassic; hemipelagic limestones and marly limestones in the Kimmeridgian to the early part of the Early Cretaceous. MAHEĽ (1964) and MAHEĽ & BUDAY (1968) distinguished the shallow-water Belianska and **Vysoká** sequences of the Krížna Nappe.

In the **Vysoká** sequence the Late Triassic sedimentation progressed continuously into the Jurassic. The Fatra Formation is overlain by the Hettangian to Sinemurian Kopieniec Formation of slope facies. It consists of 100–150 m thick dark-grey calcareous sandstones, sandy shales and crinoidal limestones rich in quartz sand. At the end of the Pliensbachian the sedimentation area differentiated.

In the **Zliechov** sequence the Pliensbachian is represented by Allgäu facies up to 150 m thick (ANDRUSOV, 1964, 1965). Pink to red Adnet-type nodular limestones formed in the Toarcian. The Upper Toarcian to Aalenian is made up of dark-grey, spotted, cherty limestones with intercalations of black shales (MIŠÍK, 1964; SOTÁK & PLAŠIENKA, 1996). In the shallower-water sequences the Sinemurian to Pliensbachian is made up of crinoidal limestones. Its uppermost part consists of pink, pinkish-grey crinoidal limestones containing irregular nodules of pink biomicritic limestones (Prístodolok Limestone). Condensed Ammonitico Rosso facies with hardgrounds were formed in the Toarcian to Bajocian.

The Bathonian to Lower Kimmeridgian is characterized by deep-water facies (Ždiar Formation) over the whole Veporic area. This succession is composed of radiolarian limestones up to 50 m thick, claystones and radiolarites (POLÁK & ONDREJIČKOVÁ, 1993; POLÁK et al., 1998). It is overlain by Kimmeridgian to Lower Tithonian Saccocoma limestones, which is composed of red, pink, brownish-grey nodular and tabular limestones with common intercalations of shale beds. The Upper Tithonian to Lower Berriasian is represented by Calpionella limestones (Osnica Formation).

Hronic Unit (Text-Fig. 5, col. 10)

Hettangian rocks occur only in the Nízke Tatry Mts. This sequence consists of grey to black, mostly well-stratified limestones. Crinoidal limestones occur is some levels. Grey, black or brownish chert nodules or even chert layers are common. Slope facies of the mottled thick-crinoidal Hierlatz-type limestones represent the Sinemurian to Toarcian. The uppermost part of the Toarcian to Aalenian is a condensed sequence composed of red limestones with hardgrounds and rich ammonite faunas (MAHEĽ, 1985). This is overlain by radiolarian limestones and variegated radiolarites. The age of this formation is Late Toarcian to Oxfordian (POLÁK & OŽVOLDOVÁ, 2001). During the Late Oxfordian to Kimmeridgian red, nodular Saccocoma limestones were formed. The sedimentation of Biancone-type pink, light grey, marly limestones started in the Tithonian and continued until the Hauterivian.

Pelso Unit

Transdanubian Range Unit (Text-Fig. 6, col. 14-18)

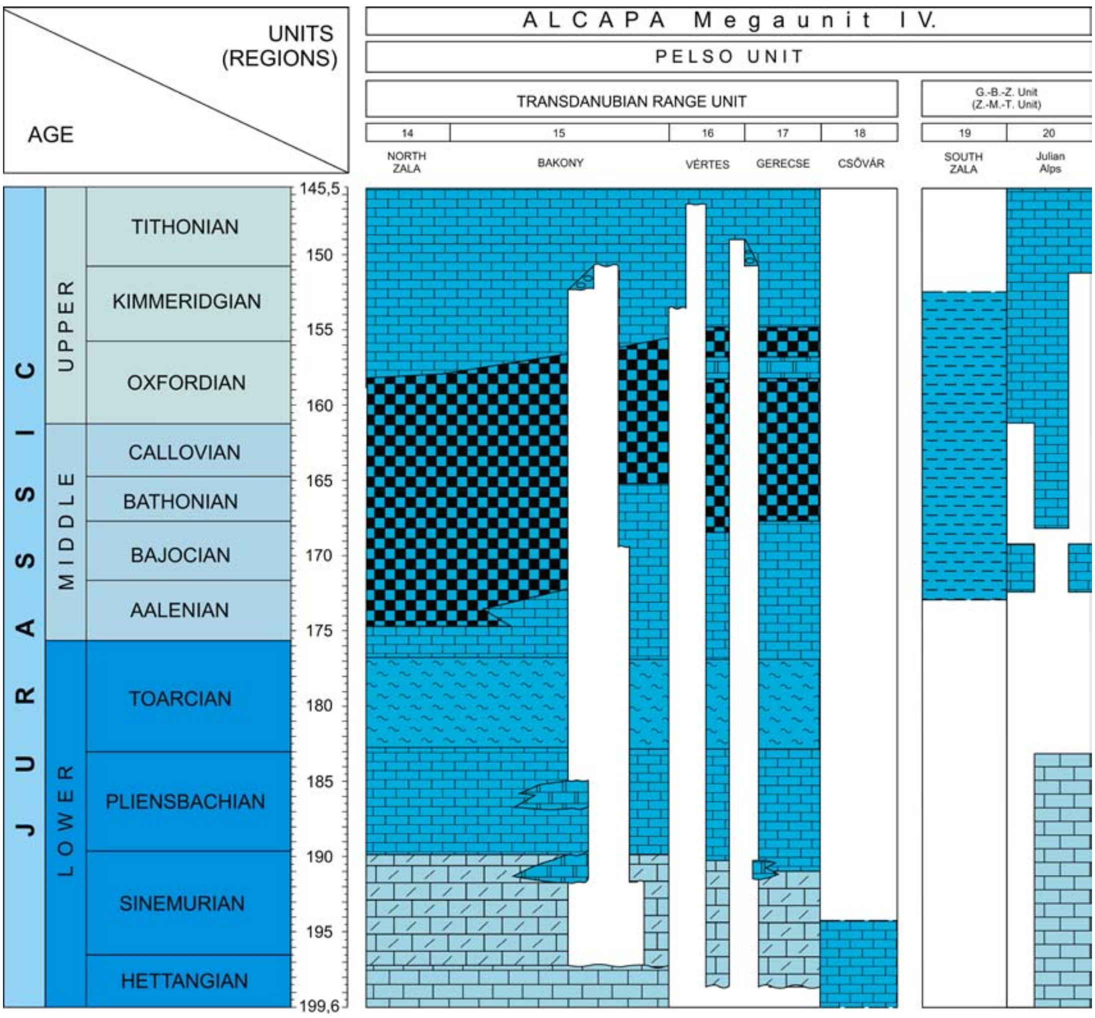
The process of segmentation and unequal subsidence of the carbonate platforms was initiated around the Triassic/Jurassic boundary. In the **Bakony** Mts. and the basement of the **Norh Zala** Basin the shallow-marine carbonate deposition continued in the Hettangian; 100–150 m thick, oolitic-oncoidal limestones were formed (For setting of localities see Text-Fig. 1). In contrast, in the **Gerecse** and **Vértes** Mts., the topmost part of the Triassic and the lower part of the Hettangian are missing; the Dachstein Limestone is overlain by pinkish limestones with brachiopods, and ammonites (Pl. 3, Figs. 1 and 2). In the **Csővár** (East of Danube), deposition of pelagic grey cherty limestones continued in the Early Jurassic (PÁLFY et al., 2001, 2007).

In the Sinemurian intense extensional tectonic movements initiated forming a substantial relief (GALÁCZ & VÖRÖS, 1972; GALÁCZ, 1988; CSÁSZÁR et al., 1998, VÖRÖS & GALÁCZ, 1998). In the Bakony area (GÉCZY, 1971) a variable facies pattern developed in the Early Sinemurian: light red, nodular limestones, grey, cherty limestones with sponge spicules, or crinoidal, brachiopodal grainstones (Hierlatz Limestone) were deposited. Neptunian dykes of generally Sinemurian to Pliensbachian age are common (Pl. 2, Fig. 5). An Ammonitico Rosso-type facies is characteristic in the troughs. Condensed sequences with gaps and hardgrounds are typical on the top of the paleo-highs, whereas lithoclastic, crinoidal-brachiopodal grainstones characterize the fault-controlled, steplike slopes.

In the Toarcian an anoxic event caused the formation of black shales and manganese ores in some restricted subbasins (JENKYNS et al., 1991; VÖRÖS & GALÁCZ, 1998). In the Toarcian to Aalenian interval pelagic argillaceous carbonate sedimentation prevailed in the basins. Bositra/radiolaria limestones and red nodular limestones are characteristic. In the sequences of the paleo-highs this stratigraphic interval is represented by a gap or condensed carbonate layers only a few m thick.

A new phase of tectonic mobility began in the Bajocian manifested in the formation of a new generation of neptunian dykes, the accumulation of synsedimentary breccia and redeposited mostly crinoidal calcarenites (GALÁCZ, 1988). In the basins the deposition of Ammonitico Rosso-type limestones continued, whereas in the deepest parts of the basins radiolarites began forming.

In the Bathonian to Oxfordian deposition of radiolarites extended over the top of the paleo-highs (VÖRÖS & GALÁCZ, 1998). The thickness of radiolarites in the southwestern part of the Transdanubian Range exceeds 150 m, in the Bakony not more than 5–50 m, and in the Gerecse usually only a few m (Pl. 3, Fig. 3). In the Late Oxfordian the deposition of radiolarites ended. At the same time, due to resuming tectonic mobility, facies types of highs, basins and slopes similar to those in the Early Jurassic were re-established; Ammonitico Rosso-type basin facies, crinoidal calcarenite slope facies, locally also megabreccias were formed and new neptunian dykes were opened (Pl. 3, Fig. 4). The Kimmeridgian to Middle Tithonian interval is characterized by pelagic red nodular Saccocoma limestone, 5–15 m thick. The Upper Tithonian to Valangin-



Text-Fig. 6.
Lithofacies chart of the Transdanubian Range Unit (14–18) and Zagorje-Mid-Transdanubian Unit (19–20) (ALCAPA IV).
Abbreviations:
G.-B.-Z. = Gemer-Bükk-Zagorje,
Z.-M.-T. = Zagorje-Mid-Transdanubian

ian is represented by white cherty limestones of Biancone facies in the SW part of the area progressing NE-wards into more condensed white, pinkish or reddish Calpionella limestones (Fülöp, 1964).

In the Gerecse Mts clasts of Tithonian platform carbonates appear in a breccia horizon in the Berriasian.

Jurassic sedimentation and tectonics of the Transdanubian Range Unit show an intermediate charactacter between the South Alpine and the NCA reflecting its paleogeographic setting. The thickness pattern of the radiolarites at its western side may have been in close connection with the Piemont-Penninic oceanic domain. Appearance of clasts of Tithonian platform carbonates and detritus of ophiolitic origin in the Lower Cretaceous deposits in the Gerecse Mts suggests close relationship to the Lower Tirolic in the NCA (Haas & Császár, 1987; Pober & Faupl, 1988; Faupl & Wagreich, 1992; Császár & Bagoly-Árgyelán, 1994).

Gemer-Bükk-Zagorje Unit

Inner Western Carpathian (Gemeric s.l.) Unit

Meliatic, Turnaic, Silicic Units (Text-Fig. 5, col. 11–13)

In the Meliatic, Turnaic and Silicic Units pelagic sedimentation prevailed in the Jurassic.

The **Meliatic** Unit is made up mostly of dark shales with turbiditic sandstones, claystones, radiolarite intercalations and olistostrome beds. This is a trench fill mélange complex of Middle Jurassic age containing blocks of various types of Triassic limestones, marbles, red radiolarites, cherty limestones, basic volcanics and serpentinites (Kozur & Mock, 1985; Mock et al., 1998; Rakús et al., 1998; Aubrecht et al., 2010).

From the **Turnaic** Unit Jurassic dark shales, radiolarites and olistostromes are reported (Mello et al., 1997).

In the **Silicic** area the carbonate platforms drowned at the Triassic/Jurassic boundary. The Jurassic sedimentation began with deposition of variegated breccias, Hierlatz and Adnet limestones and continued with deposition of the Allgäu Formation in the Lower Jurassic. Bathonian–Oxfordian radiolarites with olistostromes are the youngest Jurassic formation.

Bódva Unit (Text-Fig. 7, col. 21)

Jurassic formations of the Bódva Unit are exposed in the Rudabánya Hills.

There are three units containing Jurassic formations of different development, namely the Telekesvölgy, the Telekesoldal and the Csipkéshegy Units.

In the ***Telekesvölgy Unit*** there are two Jurassic lithofacies units. One of them consists of grey, bioturbated marls to marly limestones, alternating with shales and allodapical crinoidal calcareous turbidite beds, the latter being partly chertified. Based on lithological analogies it is considered a variant of the Liassic “spotty marl” (“Fleckenmergel”) (Grill, 1988). The other lithofacies is made up of dark grey to black, manganiferous siliceous mudstones and shales, containing large amounts of sponge spicules and radiolarians. Based on radiolarians, the age of the formation extends from Bajocian to Bathonian (Kövér et al., 2009).

The ***Telekesoldal Unit*** is made up of a lower, shaly mudstone or shale-siliceous marl unit and of an upper, turbiditic-olistostromal unit (Grill, 1988). The lower unit consists of grey to dark grey, partly siliceous shaly mudstones and shales, and grey siliceous marls, in its higher part with black chert intercalations and rhyolite bodies. Based on radiolarian and dinoflagellate data the Bajocian–Bathonian age of this segment of the formation was proved (Dosztály, 1994; Kövér et al., 2009).

The upper unit is characterized by sandstone turbidites and (intraformational) olistoliths in its lower part, and by limestone-rhyolite olistostromes with very rare basalt clasts (Kovács, 1988) and limestone olistoliths in its middle and upper part, in a dark grey shale matrix. Based on dinoflagellates this unit is Callovian in age (Kövér et al., 2009).

This group represents a fragment of a Middle to Late Jurassic Neotethyan accretionary complex with acidic subvolcanic bodies and/or olistoliths, probably of Jurassic age (Harangi et al., 1996).

The Telekesoldal Group shows some similarity with the Mónosbél Unit of the Bükk Unit s.l., the latter also contains olistostromes with rhyolite fragments. Similarities to the Meliata Unit of SE Slovakia can be recognized as well.

The *Csipkéshegy Unit* is characterized by a dark grey shale matrix with debrites (“microolistostromes”) clasts of the Triassic of the Bódva Unit (especially Bódvalenke-type limestone and red chert clasts) and Jurassic platform-derived carbonate turbidites (Kövér et al., 2009). The latter are common in the Mónosbél Unit of the Bükk Unit s.l. (Haas et al., 2006) as well.

Tornakápolna Unit (Text-Fig. 7, col. 22)

Serpentinite slices are known in the evaporitic sole of the Aggtelek–Silica nappe system. In a borehole (Tornakápolna 3) dark grey to black siliceous shales and silicified sandstones were found between two large serpentinite slices showing a marked lithological similarity with Jurassic formations exposed in cores in the Darnó Unit. The serpentinite blocks probably emplaced in the Jurassic (compare with the description of the Dinaridic Ophiolite Belt and Vardar Zone). The serpentinites are of lherzolitic origin (Réti, 1985).

Martonyi (Torna) Unit (Text-Fig. 7, col. 23)

Strongly sheared, schistose “spotty marl” (exposed in a small quarry near Tornaszentjakab) might correspond to formations of similar lithology in the Telekes Valley sections and can be tentatively assigned to the Liassic(?).

Bükk Unit s.l.

Bükk Unit s.s. (Text-Fig. 7, col. 24)

Following the disintegration and drowning of the Triassic carbonate platforms, variegated (pinkish, yellowish) micritic limestones with red cherts and purple crinoidal limestones were deposited in some places. It is likely that the deposition of these pelagic limestones continued during the Early and Middle Jurassic; however, biostratigraphic evidences for this are still lacking.

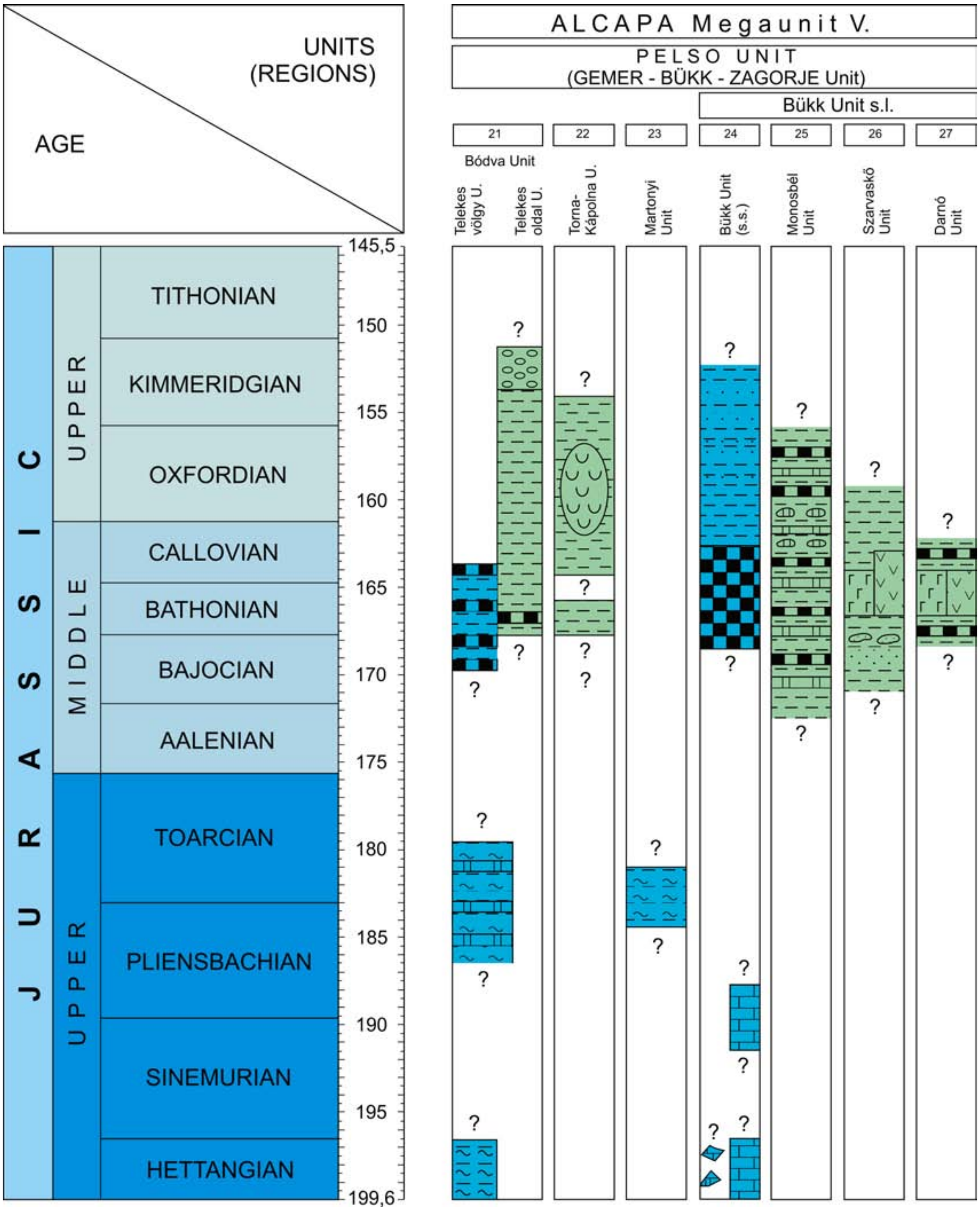
Variegated radiolarites (red, brown or green) uniformly cover all former depositional settings: the variegated limestones, the Upper Triassic grey, cherty limestones, or they even rest directly on platform carbonates. Slump structures and slide blocks of purple crinoidal limestones and of Upper Triassic reef limestones are common within the radiolarite. The poorly preserved radiolarian fauna allowed only a wide age range from the Bathonian to Oxfordian of the radiolarite (CSONTOS et al., 1991; PELIKÁN et al., 2005; HAAS et al., in press). The radiolarites are overlain by a dark grey shale sequence of distal turbiditic character, a few 100 m thick.

Mónosbél Unit (Text-Fig. 7, col. 25)

This unit was originally recognized in the SW Bükk Mts (CSONTOS, 1988, 1999), but recent investigations have proven also its presence beneath the Darnó Unit s.s. (HAAS & KOVÁCS, 2001; DOSZTÁLY et al., 2002; KOVÁCS et al., 2008) and above the Bükk Unit s.s. It consists of dark grey to black shales and bluish grey siliceous shales, which can be considered as a matrix, and two types of redeposited carbonates intercalated into them: platform-derived bioclastic, oolitic limestones (HAAS et al., 2006), and grey, marly, cherty peloidal micritic limestones. Gravity flows (olistostromes) are also common with cm-sized micaceous sandstone clasts, rich in granitic and rhyolitic rock fragments (ÁRGYELÁN & GULÁCSI, 1997); their age has not yet been determined.

In the Szarvaskő area, western part of the Bükk Mts, the Mónosbél Unit occurs beneath the Szarvaskő Unit and above the Bükk Unit s.s. It consists of dark grey or black shales, black radiolarites containing Bathonian to Oxfordian radiolarians, and olistostromes with limestone, radiolarite and basalt clasts (DOSZTÁLY et al., 1998; HAAS et al., 2006).

In the SW Bükk Mts the Mónosbél Unit is made up of sandstones, dark shales and radiolarites and peloidal micritic limestones (Oldalvölgy Limestone) that is overlain by



Text-Fig. 7.
Lithofacies chart of the Bódva, Tornakápolna, Martonyi Units (21–23) and Bükk (s.l.) Unit (24–27) (Gemer-Bükk-Zagorje Unit). (ALCAPA V).

olistostromes with Triassic and Jurassic limestone, radiolarite, sandstone, siltstone, phyllite, rhyolite, andesite and basalt components (PELIKÁN et al., 2005; Pl. 4, Figs. 1 and 2). Platform-derived redeposited oolites containing Bajocian to Bathonian foraminifera (BÉRCZI-MAKK, 1999; HAAS et al., 2006) characterize the upper part of the succession (Bükkzsérc Limestone; Pl. 4, Fig. 3) being usually present in the form of components of debris flows or large slid blocks (PELIKÁN & DOSZTÁLY, 2000; HAAS et al., 2006; Pl. 3, Fig 5).

Szarvaskő Unit (Text-Fig. 7, col. 26)

The Szarvaskő Unit occurs in an uppermost structural position in the Szarvaskő area, on top of the Mónosbél Unit and is made up of siliciclastic rocks (shales, sandstones) and mafic effusive (pillow basalts; Pl. 4, Fig. 4) and intrusive rocks (massive basalts, dolerites, gabbros). Limestone turbidites are missing. The lower part of its reconstructed sequence (DOSZTÁLY et al., 1998) is made up by shales and turbiditic sandstones and higher up by olistostromes containig sandstone olistoliths. This sequence is intruded by mafic magmatic rocks. The upper part of the sequence is made up of shales and 300–600 m thick pillow basalt. Another olistostrome horizon occurs here, with radiolarite blocks, which yielded both Triassic and Jurassic (Callovian to Oxfordian) ages. Around 165 Ma of K/Ar age was measured on basalts, and 168 ±8 Ma on gabbros (ÁRVA-SÓS et al., 1987).

Darnó Unit (Text-Fig. 7, col. 27)

This unit is made up by a Jurassic accretionary complex, in which both Triassic and Jurassic magmatites and deep-sea sediments occur. Basalt bodies predominate, which are separated by abyssal sediments. Red radiolarites and pelagic mudstones yielded either Triassic (Ladinian to Carnian) or Jurassic (Bathonian to Callovian) radiolarian fauna. Bluish grey siliceous shales, similar to that in the underlying Mónosbél Unit are thought to be of Jurassic age. Greenish basalts, macroscopically similar to those in the Szarvaskő Unit are probably Jurassic in age (JÓZSA et al., 1996; KOVÁCS et al., 2008; Pl. 4, Fig. 5). Gabbros yielded Middle Jurassic ages (175 Ma; DOSZTÁLY & JÓZSA, 1992). Blocks of Upper Permian black, algal limestones akin to those in the Bükk Unit s.s. were encountered in this unit (KISS, 1958; FÜLÖP, 1994) and also in the underlying Mónosbél Unit.

Zagorje-Mid-Transdanubian Unit

Julian-Savinja Unit

Sheared and dislocated eastern continuation of the South Karavanks and Julian and Savinja Alps and Internal Dinarides occur in this composite unit that is usually covered by Tertiary formations in the Pannonian Basin.

In the *Ivanšćica Mts* that can be assigned to the Julian-Savinja Unit, the Upper Triassic or locally Lower Jurassic shallow-marine formations are unconformably overlain by deep-water carbonates, graded siliciclastics and shales with radiolarites and tuffaceous interlayers, Tithonian to Turonian in age (ŠIMUNIĆ & ŠIMUNIĆ, 1992).

No Jurassic formations have been encountered so far in the subsurface part either of the South Karavanks or the Julian-Savinja Units.

In the **Julian Alps** (Text-Fig. 6, col. 20) the Upper Triassic platform carbonates are overlain by shallow-marine Lower Jurassic deposits. At the contact red emersion breccias occur locally (BABIĆ, 1981). The Liassic succession is made up of an alternation of biosparitic, oolitic, and micritic limestones, subordinately also by stromatolitic and loferitic beds. The Julian Carbonate Platform was broken into several variously subsided blocks in the Late Liassic. On them, condensed pelagic sedimentation took place (BUSER, 1986; JURKOVŠEK et al., 1990; ŠMUC, 2005). At many localities Ammonitico Rosso-type limestones deposited with Fe-Mn nodules. Dogger and Malm red and brownish micritic limestones with chert nodules, a few tens of m in thickness overlay the manganese horizon that is followed by Biancone-type limestones in the Berriasian.

South Zala, Medvednica, and Kalnik Units (Text-Fig. 6, col. 19)

South to the Julian-Savinja Unit slightly metamorphosed Jurassic formations, of deep-sea slope and basin facies were encountered in Transdanubia, Hungary that were assigned to the **South Zala** Unit. Middle to Upper Jurassic radiolarians were found in dark gray radiolarite in one of the wells (RÁLISCH-FELGENHAUER, 1998).

Remnants of a Jurassic accretionary complex of the Neotethys are known in the Medvednica and Kalnik Mts in Croatia that was assigned to the *Kalnik Unit* (PAMIĆ et al., 2002; HALAMIĆ et al., 2005). Along with basalts Triassic and Jurassic radiolarian chert and Calpionella limestone were reported from the Medvednica Mts. The ophiolitic mélange that is similar to that in the Darnó Unit probably continues in the Pannonian Basin in a narrow zone within the Zagorje-Mid-Transdanubian Unit along the Mid-Hungarian Lineament (HAAS & KOVÁCS, 2001).

ADRIA – DINARIA MEGAUNIT

South Alpine Unit (Text-Fig. 8, col. 28-30)

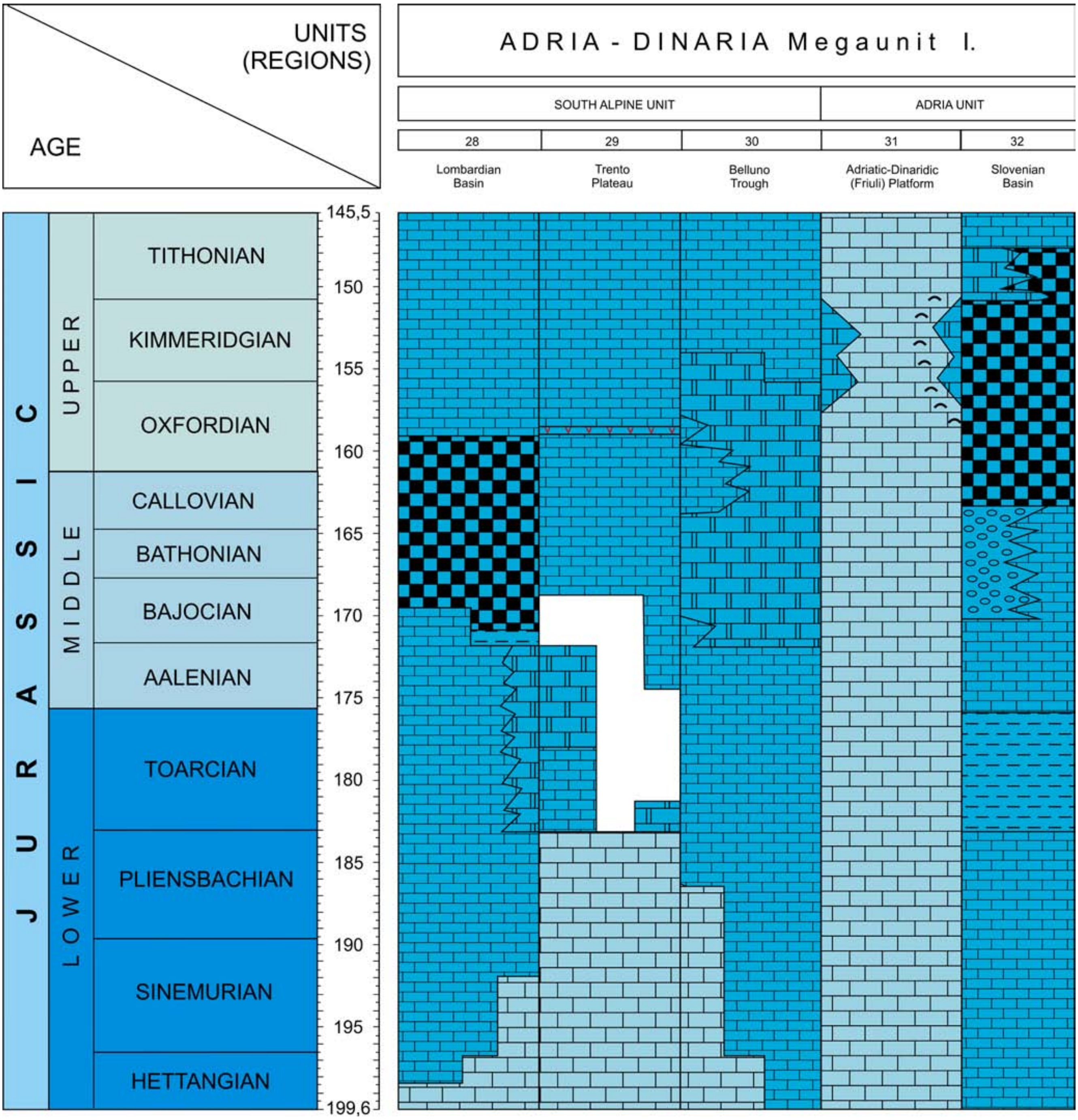
In spite of significant Alpine shortening since the Middle Jurassic the original facies relationships are usually visible, providing a suitable base for reconstruction of the paleogeographic setting, as a rule. Based on thickness and development of the Jurassic succession the following basic facies units can be distinguished within the South Alpine domain: Lombardian Basin in the west which was located in the neighbourhood of the Ligurian-Piemont Ocean; Trento Plateau; Belluno Trough in the east. Further east, the Friuli Platform belongs to the Adriatic-Dinaridic Carbonate Platform (Text-Fig. 1).

In the Hettangian to Pliensbachian dark grey well-bedded cherty (spongiolithic) limestones (Moltrasio Formation) and Adnet-type limestones were deposited. Development of north-south trending major listric faults led to the formation of asymmetric sub-basins (BERNOULLI, 1964). East of the Lugano-Monte Grona fault, nearly 4 km thick hemipelagic siliceous limestones, carbonate turbidites and olistoliths were deposited in the Generoso Basin during the Hettangian to Sinemurian (BERNOULLI, 1964; BAUMGARTNER et al., 2001). In contrast, west of the major fault zone on the Lugano High, only a 100 m thick succession was formed in the Rhaetian to Liassic interval, shallow-water limestones in the Rhaetian and pelagic limestone in the Pliensbachian. The extensional tectonics are constrained here by multigeneration neptunian dykes (BAUMGARTNER et al., 2001; Pl. 5, Fig. 1).

The **Lombardian Basin** was separated from the Trento Plateau by the Garda fault. On the Trento Plateau deposition of shallow-water carbonates continued in the Early Jurassic till the end of the Pliensbachian. The Dolomia Principale is overlain by massive to thick-bedded shallow-water limestones predominantly oolitic, oncoidal grainstones (Calcari Grigi), interrupted at the end of the Pliensbachian leading to a regional unconformity (SARTI et al., 1992). In the **Belluno Trough** deposition of cherty limestones (Soverzene Formation) prevailed in the Hettangian to Pliensbachian (WINTERER & BOSELLINI, 1981).

The Tethys-wide Toarcian anoxic event is reflected in the deposition of organic-rich shales ("fish shale") in the Lombardian Basin and dark siliceous limestones (Misone and Tenno Formation) on the Trento Plateau. In the Belluno Trough thin-bedded cherty limestones (Igne Formation) were formed coevally (WINTERER & BOSELLINI, 1981).

The Toarcian to Lower Cretaceous in the Lombardian Basin is characterized by deep-water sediments (CHIARI et al., 2007). Condensed red nodular limestones (Rosso Ammonitico Lombardo) and cherty limestones (Sogno Formation) were deposited in the Toarcian to Aalenian and radiolarites in the Bajocian to Early Oxfordian (BAUMGARTNER et al., 1995). The Upper Oxfordian to Lower Tithonian is char-



Text-Fig. 8.
Lithofacies chart of the South Alpine Units (28–30), Adriatic-Dinaridic Carbonate Platform (31) and Slovenian Basin (32). (ADRIA-DINARIA I).

acterized by red nodular, cherty limestones (Rosso ad Aptici; Pl. 5, Fig. 2). The Upper Tithonian to the lower part of the Lower Cretaceous is made up of white cherty Calpionella limestones (Maiolica or Biancone facies).

On the **Trento Plateau** the shallow-water conditions in the Toarcian to Aalenian led to deposition of more than 100 m thick cross-bedded oolites (Vigilio Oolite). Drowning of the platform happened at the beginning of the Bajocian coeval with the onset of radiolarite deposition in the Lombardian Basin (BAUMGARTNER et al., 1995). The oolites were covered by condensed pelagic limestones (Rosso Ammonitico Inferiore – Upper Bajocian to Lower Callovian). It is overlain by cherty radiolarian limestones with bentonite interlayers (Upper Callovian to Oxfordian), red nodular limestones (Rosso Ammonitico Superiore – Kimmeridgian to Lower Tithonian) and white cherty Calpionella limestones (Biancone – Upper Tithonian to Lower Aptian).

In the **Belluno Trough** limestones consisting predominantly of redeposited shallow-marine carbonate grains, mostly oolites were formed in the Bajocian to Bathonian. The thickness of the redeposited carbonates (Vajont Limestone) may reach 600 m (BOSELLINI et al., 1981). The Friuli Platform was the source area of the Vajont Limestone (CLARI & MASETTI, 2002) which is overlain by Ammonitico Rosso and Biancone facies.

Adria Unit

Adriatic-Dinaridic Carbonate Platform (Text-Fig. 8, col. 31)

In the Adriatic (Apulian) the domain development of the tropical carbonate platforms continued after the Triassic until the late Early Jurassic, when extensional tectonics led to the formation of the Adriatic basin that separated the Adriatic (AdCP) and the Apulian Carbonate Platforms. On the AdCP shallow-marine conditions prolonged more or less for the Jurassic and also for the Cretaceous. An extremely thick platform carbonate succession was formed that extends over a very large area from Italy (Friuli Platform) through Slovenia, Croatia, Bosnia, Herzegovina, and Montenegro to North Albania (VLAHOVIĆ et al., 2005).

The Upper Triassic peritidal dolomites (Main Dolomite) progress gradually into Lower Jurassic dolomites, still formed in peritidal environments (OGORELEC & ROTHE, 1993). In the marginal part of the platform (Herzegovina, Montenegro, western Slovenia) where the Rhaetian is represented by Dachstein Limestone (DRAGIČEVIĆ & VELIĆ, 2002), limestones occur also in the lower part of the Lower Liassic sequence. In places, up to some tens of m thick breccia occurs at the contact, which indicates short emersion periods and development of paleokarstic surfaces (BUSER, 1978; OGORELEC & ROTHE, 1993).

In the Sinemurian to Toarcian Lithiotis limestones occur widely in the AdCP (BUSER & DEBELJAK, 1996; MEÇO & ALIAJ, 2000; VLAHOVIĆ et al., 2005), e.g. in Slovenia, Croatia (Velebit) to the Albanian Alps. Rare coral buildups and crinoid biostromes occur (TURNŠEK, 1997). In the late Early Jurassic dark grey bio- and pelmicritic limestone deposited in the more quiet parts of the shelf, and in smaller lagoons reductive conditions prevailed (VLAHOVIĆ et al., 2005). Along the NE margin of the platform, oolitic limestones were typically formed under high-energy conditions (DRAGIČEVIĆ & VELIĆ, 2002).

During the Pliensbachian to Toarcian various depositional environments characterized the shallow carbonate shelf. In the Middle Jurassic large areas became subaerially exposed along the NE margin of the platform. Ooid shoal facies are typical in the outer platform and peritidal to shallow subtidal facies in the inner platform (VLAHOVIĆ et al., 2005).

In the Kimmeridgian synsedimentary tectonics caused significant facies differentiation. Some parts of the platform emerged and bauxite deposited on the karstified surface (W Istria). Coevally in the area of Velika Kapela Mt a shallow intraplatform basin developed where dark cherty limestones with tuff interlayers were deposited (VELIĆ et al., 2002).

In the Late Jurassic large areas of the AdCP (Slovenia, Croatia, Montenegro, Albania) were characterized by the deposition of algal-foraminiferal carbonates formed in an inner platform environment. A coral-stromatoporid reef complex developed in the platform margin zone in a thickness of 500 m at most (Oxfordian–Kimmeridgian) (TURNŠEK et al., 1981; TURNŠEK, 1997). The Kimmeridgian to Tithonian succession is also characterized locally by oolitic limestones.

Slovenian Basin and Bosnian Zone (Text-Fig. 8, col. 32)

Pelagic deposits of Jurassic age can be found at the foothills of the Julian Alps (ŠMUC, 2005; ŠMUC & GORIČAN, 2005) (Tolmin Nappe according to KRYSTYN et al., 1999) and in the western part of the South Karavanke Mts (Koschuta and Hahnkogel Units according to KRYSTYN et al., 1994). To some extent they also occur in the eastern Sava Folds. Sedimentation took place under deep water conditions.

The Hettangian to Pliensbachian is represented by platy limestones 300 m thick at most with chert nodules that are intercalated by thin layers of muddy marlstone. It is overlain by Toarcian black shale (Perbla Formation) that progresses upwards into siliceous limestones (Aalenian) and a thick succession of limestone breccias and graded oolitic limestones (Tolmin Formation) of Early Bajocian to Early Callovian age which were deposited along the trough margins at the toe-of-slopes via gravity flows (ROŽIČ & POPIT, 2006). The Upper Callovian to Lower Tithonian sequence consists of clayey shales with chert intercalations, radiolarites and cherty limestones in a thickness of tens of m (BUSER, 1979; OGORELEC & DOZET, 1997). The Tithonian–Berriasian is characterized by 50 m thick light coloured micritic Calpionella limestones with chert nodules.

Middle to Upper Jurassic carbonate lithoclastic slope deposits and redeposited oolitic limestones very similar to that in the Slovenian Basin were reported from Croatia (DRAGIČEVIĆ & VELIĆ, 2002; BUCKOVIĆ et al., 2004; BUCKOVIĆ, 2006). In the Pre-Karst and Bosnian Zone in the territory of Herzegovina and Montenegro platform derived sediments of slope and toe-of-slope facies were accumulated during the Late Triassic(?) to earliest Cretaceous (Berriasian) interval (PAMIĆ, 1993; PAMIĆ et al., 1998; DRAGIČEVIĆ & VELIĆ, 2002). The succession (Vranduk Group; OLUJIĆ, 1978) is made up of turbiditic series consisting of graded calcarenites (mostly oolites), graded arenites alternating with argillaceous micritic limestones and pelagic carbonates, shales and intercalating radiolarites.

Dinaridic Unit

Central Bosnian Mountains Unit (Text-Fig. 9, col. 33)

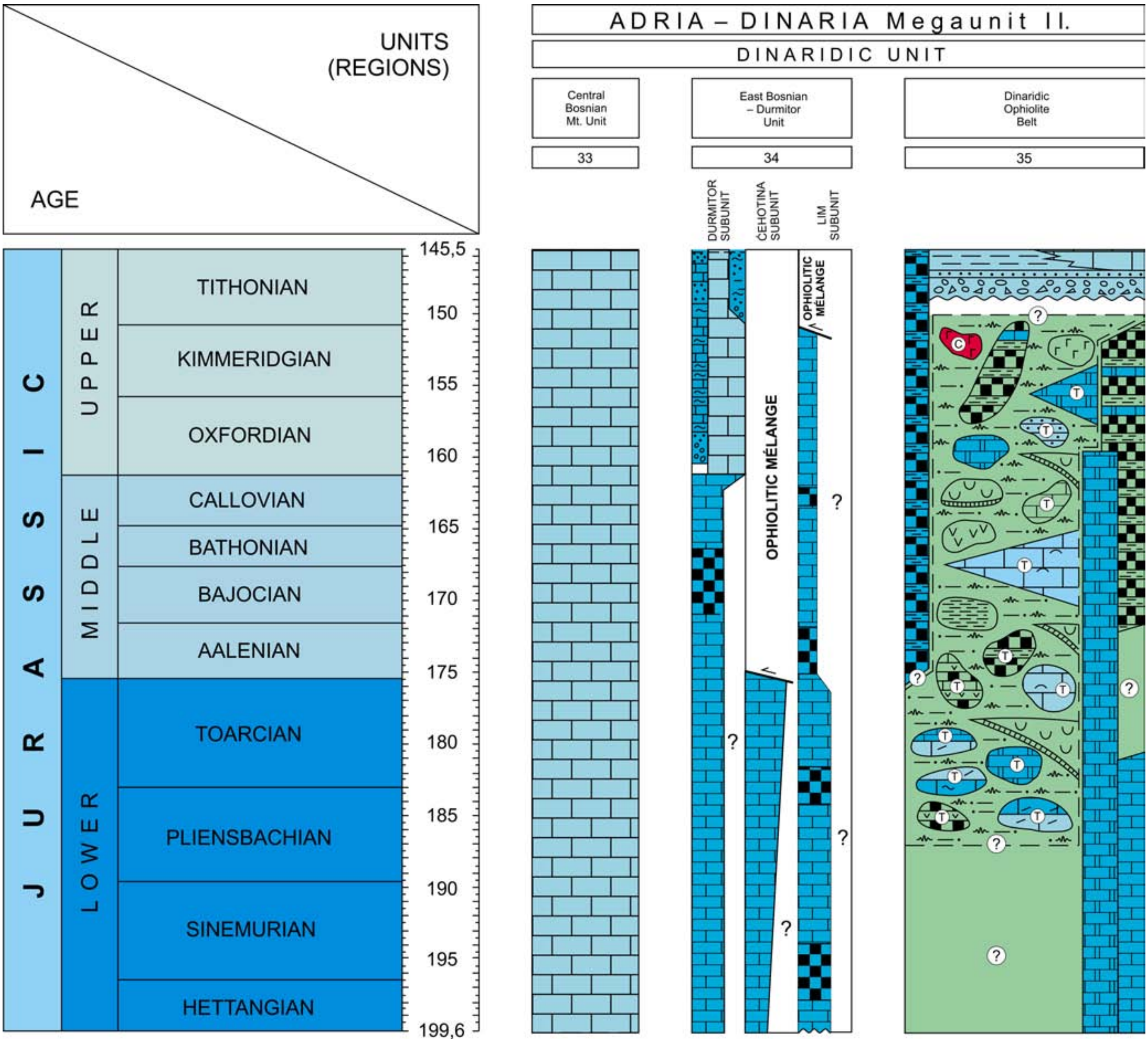
As in the Upper Triassic the whole Jurassic of this unit is represented by limestones and dolomites of the shallow-water carbonate platform sedimentation (Pl. 5, Fig. 3). In this very monotonous carbonate sequence only Lower to Upper Jurassic (to Valanginian) is sporadically proven (KARAMATA et al., 1997; HRVATOVIĆ, 1999).

East Bosnian-Durmitor Unit (Text-Fig. 9, col. 34)

Durmitor Subunit

Triassic deposition continued without break in the Jurassic in the western part of the subunit. The Lower Jurassic begins with platy limestones with thin-shelled pelecypods and foraminifera. These are overlain by deeper marine marly limestones interbedded with red marlstones. The upward transition into grey or grey-green marly biomicrites reflects a gradual deepening. The overlying Middle Jurassic limestones are red, brecciated and the sequence terminates with varicoloured interlayers of platy cherty marlstones and detrital limestones with foraminifera and radiolarians. The entire Lower–Middle Jurassic succession is only 40–60 m thick (DIMITRIJEVIĆ, 1997).

In the Upper Jurassic reef and near-reef facies sediments contain gastropods, pelecypods, hydrozoans and algae (Pl. 5, Fig. 4). In the Tithonian two flysch troughs developed along the margins of this platform (DIMITRIJEVIĆ, 1997). The Suha Flysch occurs along the front of the Durmitor Nappe. There is a gap on the top of the Middle Jurassic marly limestones, locally. It is overlain by a few m of limestone breccia, with chert nodules. It was followed by deposition of marly and sandy limestones alternating with varicoloured marlstones. These rocks contain Late Tithonian and possibly also Valanginian pelagic microfossils. They are overlain by a flysch sequence that is made up



Text-Fig. 9.
Lithofacies chart of the Dinaridic Unit (33–35). (ADRIA-DINARIA II).
Abbreviations: C = Carboniferous, T = Triassic

of graded calcareous microrudites, sandstones displaying graded bedding and cross lamination, marly limestones with Calpionellids, and marlstones.

Near to the margin of the Ćehotina Subunit the around 100 m thick Lever Tara flysch trough developed in the Tithonian to Berriasian. The sedimentary succession shows a fining upward trend with basal calcareous rudites and microconglomerates, which progress gradually upsection into siltstones, and finally marlstones upsection. It is significant that rudites and sandstones contain numerous mafic rock fragments and chert detritus derived from the ophiolite mélange. Limestone fragments in rudites contain algae.

Ćehotina Subunit

The principal difference between the Jurassic of the Durmitor and Ćehotina Subunits is that in the latter the Lower Jurassic basin facies is overthrusted by ophiolitic mélange from the Dinaridic Ophiolite Belt (Dimitrijević, 1997).

Lim Subunit

After the Late Triassic hiatus, the deposition resumed during the Early and Middle Jurassic only in the western part of the subunit. The Hettangian–Sinemurian is represented by silicified limestones with chert interbeds and nodules. The estimated thickness of the whole Lower Jurassic strata is more than 100 m. The 250 m thick Middle Jurassic sequence shows similar features. Marly limestones with chert intercalations and nodules are characteristic for the Oxfordian to Kimmeridgian deposits. Thick-bedded oolitic limestones and biosparites with laminated bituminous biomicrosparite intercalations are typical. The greatest preserved thickness is 550 m, although these strata are missing over large areas.

According to Dimitrijević (1997) the overthrusted Oxfordian to Kimmeridgian ophiolitic mélange from the Dinaridic Ophiolite Belt is made up of a marlstone-siltstone matrix with clasts and blocks of sandstones, cherts and magmatites (syenite, spilite, diabase, serpentinite). The greatest estimated thickness of the olistostrome/mélange is 350 m.

Dinaridic Ophiolite Belt (Text-Fig. 9, col. 35)

During the Early to Middle Jurassic, the marginal oceanic basin formed in the Middle–Late Triassic, evolved into the wide Dinaridic Ophiolite Belt (DOB) basin (Karamata, 2006) and its southward continuation, after a transform fault covered in the Metohija depression, to Albania (Mirdita Belt; Pl. 5, Fig. 5; Shallo, 1994) and Northern Greece (Jones & Robertson, 1991).

The DOB is primarily characterized by the ophiolitic mélange, i.e. “Diabase-Chert Formation” in former Yugoslavian geological literature. It was considered a volcano-sedimentary series, formed by normal “bed-to-bed” deposition; a concept, which persisted up to recent times. However, the chaotic fabric of these rocks of different age and provenance suggests that it can not be regarded as a “normal formation”. These chaotic associations of different sedimentary rocks and rocks of ophiolite affinity (magmatics and ultramafics) represent olistostrome/mélange deposits of sedimentary origin (in the sense of Dimitrijević et al., 2003, etc.), or oceanic trench assemblages (in the sense of Karamata et al., 1999, etc.). Jurassic deposits and fragments of the continental slope and the oceanic crust are preserved in the complex of olistostrome/mélange only as blocks or olistoliths varying in size and with chaotic composition (Dimitrijević et al., 2003). The ophiolitic assemblages are always dismembered, two or three rock-types occur together mainly in very large bodies (Karamata et al., 1999, etc.).

The Jurassic carbonate successions of the DOB consist, besides the cherty limestones of the Jurassic part of the Grivska Formation (compare Missoni et al., 2011), of Lower Jurassic pelagic limestones of the Ammonitico Rosso facies, which were formed on a drowned platform. In the Middle (?Upper) Jurassic bioclastic, rarely ooidal carbonate turbidites deriving from a platform margin occur in deep-water radiolarites.

In the wider regions of the Zlatar Mt several types of the Jurassic siliceous rocks are present. According to preliminary studies some of them deposited probably on the deeper part of the continental slope. The others are the products of the deposition from the oceanic basin or eventually from the margin of the abyssal plain. The former type is made up of more or less folded red, green or black cherts and radiolarites with one to two beds of calcarenites (calcrudites) mainly in the upper part of the sequence which are of ?Late Aalenian to Callovian age (Obradović & Goričan, 1988, etc.), but they reach the Kimmeridgian or Early Tithonian, locally (Djerić & Vishnevskaya, 2006) (Pl. 6, Fig. 1).

During the late Early Jurassic subduction started in the provenance area of the Dinaridic ophiolites. The inversion from a previous extensional regime to a compressional one is indicated by the obduction of ultramafic/ophiolitic units over parts of the oceanic crust located along the oceanic ridge, or over the previously accreted oceanic trench complex.

The km to tens of km sized ultramafic massifs are particularly important in the DOB. The largest of them are the massifs of Zlatibor Mt (Pl. 6, Fig. 5) and the Konjuh-Krivaja, together with Ozren, Brezovica-Kodža Balkan and others. These mostly plate-shaped bodies are composed of lherzolite with subordinate harzburgite and rare dunite, strongly serpentinized on the margins. They were introduced as hot masses, producing conspicuous metamorphic (amphibolite to greenschist) soles. The age of metamorphism of the amphibolites in the basement of the obducted ultramafic slices in this belt (from Central Bosnia to Northwest Greece) was determined as 181–157 Ma by the K/Ar and 174–162 Ma by the Ar/Ar method (Lanphere et al., 1975; Karamata & Lovrić, 1978; Okrush et al., 1978; Dimo-Lahitte et al., 2001, etc.); both methods yielded very similar results. Therefore the metamorphic soles in the DOB and further in Albania and Greece, originated in a time interval 181–157 Ma (= late Early Jurassic to Middle Jurassic).

The most characteristic constituents of the olistostrome/mélange of DOB are as follows:

a) small blocks (up to a few m to tens of m), mostly sandstones-subgreywackes (= ophiolitic sandstones), rarely limestones, which slid into the trench probably from the adjacent Drina-Ivanjica Unit

b) small blocks (up to a few tens of m) of rocks derived from the oceanic crust which were scratched off by subduction, e.g. Triassic and Jurassic radiolarites, ophiolitic magmatic rocks: basalts or spilites, less frequently diabases and gabbros, Triassic deep-water carbonates, rare blocks of a sheeted dyke complex

c) exotic blocks, m to tens of m in size of albite granite and other kind of granite, conglomerates of unusual composition, hydrothermally altered ultramafic rocks, etc.

d) large plate-shaped bodies, i.e. "massifs" of ultramafites, but many smaller blocks occur, too and

e) different types of limestones:

e_1) plate- to lense-shaped Triassic shallow-marine limestone bodies slid into or over the trench assemblage (Pl. 6, Fig. 2)

e_2) rather monotonous thin-bedded pelagic, basinal limestones with cherty interlayers, lenses and nodules, and with rare intercalations of calcarenite of latest Ladinian to Middle (? Late) Jurassic age (Pl. 6, Figs. 3 and 4), or

e_3) Upper Triassic Hallstatt and Lower Jurassic pelagic grey and reddish Ammonitico Rosso-type limestones.

The mentioned bodies and components of the ophiolitic-radiolaritic mélange are in argillaceous/sandy-silty to partly radiolaritic matrix which until now, were dated only in central DOB as Middle Jurassic (GAWLICK et al., 2009b).

In the *Dalmatian-Herzegovian Unit* and *Central Bosnian Mountains Unit* a unique sequence of Lower to Upper Jurassic (Lower Cretaceous) hemipelagic sediments was deposited (KARAMATA et al., 2004, etc.). This unit, earlier regarded as Triassic–Jurassic in age, is a sequence of bedded cherts and radiolarites with rare interlayers and blocks (?olistoliths) of siliceous limestones, and extremly rare turbidite beds consisting of terrigenous material. Geographically, this chert unit up to hundred km long and up to a few km wide (or thick respectively), are exposed in NW and central Bosnia, but similar rocks occur locally, also further at southeast. Up to now, from this bedded chert formation radiolarians of Aalenian – Early Bajocian, Late Bajocian – Bathonian and Callovian–Kimmeridgian age were documented (VISHNEVSKAYA & DJERIĆ, 2006). This unit is overlain by Tithonian-Valanginian-Hauterivian siliceous limestones alternating with spongiolith-radiolarites, spongioliths and other continental slope deposits (VISHNEVSKAYA & DJERIĆ, 2006).

Subsequent to the Late Jurassic closure of the DOB in their eastern and central parts the olistostrome/mélange complex was covered by uppermost Tithonian–Valanginian shallow-water transgressive deposits, about 1000 m thick (i.e. "Pogari Series"). These sequences are composed mostly of coarse and unsorted siliciclastics, containing pebbles of all rocks from the ophiolitic mélange; they grade into sandstone with subordinate marly shale, that laterally interfinger with platform limestones.

VARDAR MEGAUNIT

Jadar Block, Sana-Una and Banija-Kordun Units
(Text-Fig. 10, col. 36-37)

The Upper Triassic rocks of the Lelić Formation occur only in a few places in the area of the Jadar Block Unit and pass gradually into red and grey coloured, thick-bedded lowermost Lower Jurassic limestones with foraminifera (FILIPOVIĆ et al., 2003) (Text-Figs. 1, 2 and 10).

In the Sanski Most area, south to the Blaha river (Sana-Una and Banija-Kordun Unit) Upper Jurassic (Oxfordian to Tithonian) shallow-water deposits occur (HRVATOVIĆ, 1999) (Text-Fig. 10).

Vardar Zone Western Belt (Text-Fig. 10, col. 38)

The Late Triassic opening was followed by spreading of the VZWB which continued during the whole Jurassic and the basin became the main oceanic realm of the Vardar Ocean (i.e. Neotethys) (KARAMATA et al., 2005; KARAMATA, 2006). In the direction of the subduction large masses of trench deposits (i.e. olistostrome/mélange with argillaceous-silty matrix and gravity slides from the oceanic crust and the continental margin) accumulated in this basin (Pl. 6, Fig. 6). From the oceanic area (a) blocks of basalts (pillow or rarely compact lavas), of MORB or IA type, altered by low-grade ocean-floor metamorphism, (b) bedded green and reddish radiolarite/cherts, with documented Carnian to Norian, Middle Jurassic (Late Bajocian – Early Callovian) and Late Jurassic radiolarians, (c) gabbro, rare as small-rounded fragments, and (d) ultramafics, sometimes silicified, as very small-rounded fragments or as huge masses, as well as associated metamorphic rocks in their base were transported. From the margins of the oceanic realm arrived: (a) sandstones, coarse to fine-grained greywackes, mostly as rounded or ellipsoidal blocks, up to a few m in diameter, which dominate in many parts of the belt, and (b) limestones of Middle–Late Triassic, Late Jurassic and Late Cretaceous age; some are as large lense or plate-like limestone slabs slid into the basin. Large olistoplakas of sedimentary rocks are absent in the olistostrome/mélanges of both belts of the Vardar Zone.

According to the age of metamorphic soles beneath the ultramafics the closing of this basin began 157–146 Ma ago (KARAMATA & POPEVIĆ, pers. comm.). The youngest basaltic rocks, members of the ophiolite complex of this unit include Campanian limestone blocks (FILIPOVIĆ, pers. comm.); also basaltic pillow lavas are interlayered with Upper Campanian – Lower Maastrichtian sandy limestones (KARAMATA et al., 2005). The diabase of the sheeted dyke unit below these basalts is dated (K/Ar age) at 80 Ma. The first sequences that cover the trench deposits of the VZWB are rudist limestones grading into Upper Maastrichtian to Eocene flysch. Accordingly, the western oceanic basin of the Vardar Ocean (Neotethys) was closed by the end of the Maastrichtian (KARAMATA, 2006).

Along the western flank of the Kopaonik Block and Ridge Unit the Jurassic is represented by the olistostrome/mélange of the VZWB. Along the eastern flank of the same unit the Jurassic deposits are represented only locally as olistostrome/mélange which were thrusted together with ultramafics onto older formations in the Maastrichtian to the Late Oligocene interval.

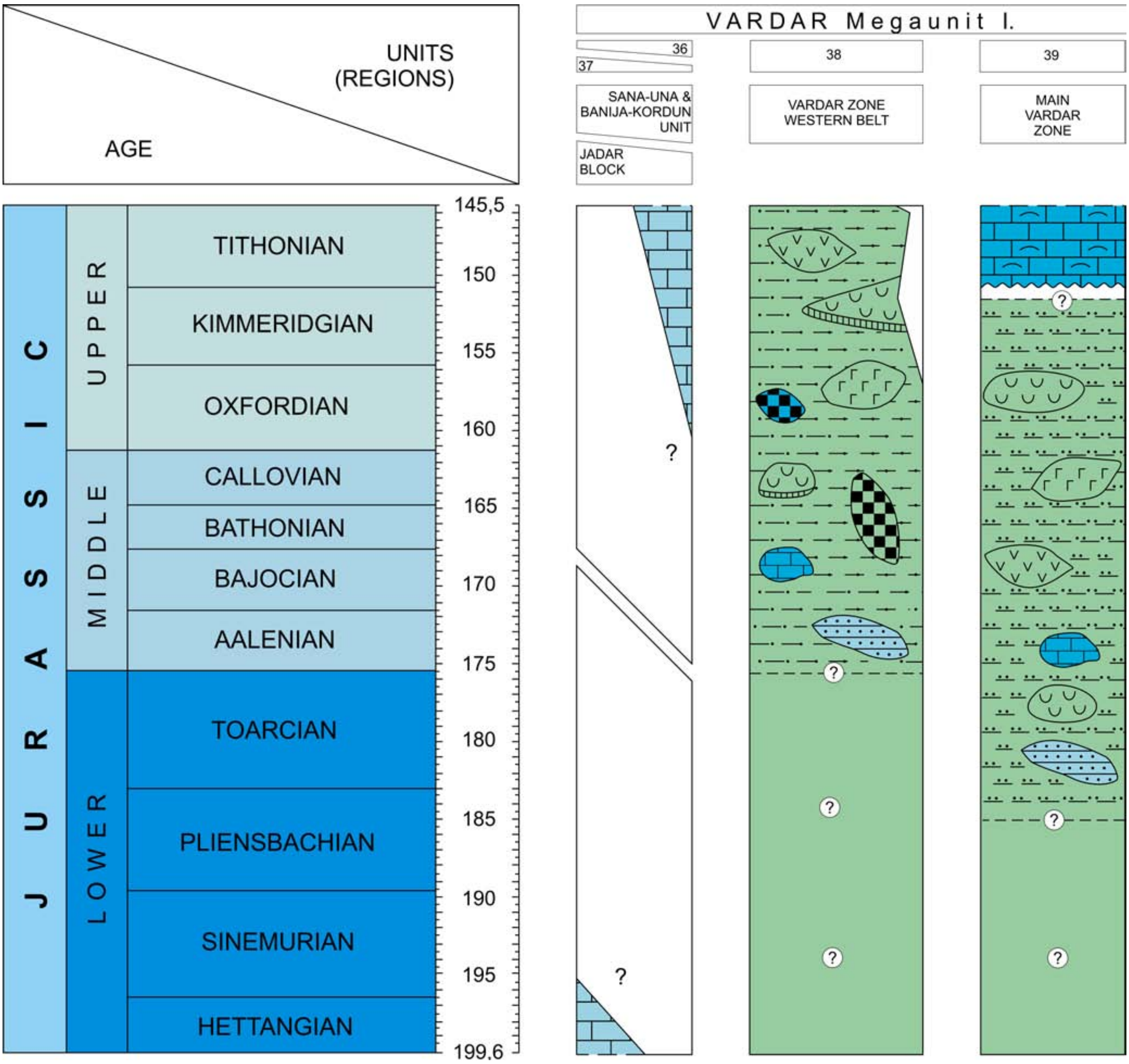
Main Vardar Zone (Text-Fig. 10, col. 39)

The units of this eastern branch, i.e. the present-day Main Vardar Zone, are represented by trench deposits and ophiolitic rocks, together with metamorphics at its margin formed during the closing of the Vardar Ocean. In the Late Jurassic this basin became probably completely closed and was subject to strong erosion. The initiation of the final closure can be dated at around 185 Ma (182–187, according to the age of amphibolites; KARAMATA, pers. comm.).

The Middle–Upper Jurassic olistostrome/mélange of this unit consists of a very fine-grained siltstone matrix with clasts and olistoliths. They represent the relics of ophiolitic rocks (ultramafics lenses with very rare metamorphic sole, gabbros, basalts of IA type, diabases) of this belt occurring at its eastern and western borders (Pl. 7, Figs. 1, 2 and 3). Ophiolitic rock-assemblage is of tholeiitic affinity, but calc-alkaline granitoids and dioritoids indicate the existence of an intraoceanic island arc environment (RESIMIĆ-ŠARIĆ et al., 2000). Also, in the trench deposits the relics of the continental margin and of oceanic crust are present: mainly greywackes and rare cherts/radiolarites, dark or white silicified limestones (of unknown age) and Upper Jurassic limestones. This chaotic rock association is transgressively overlain by Tithonian reef limestones, exposed in the southern part of this area (Pl. 7, Fig. 5). In a synform, between the above-mentioned ophiolitic associations in Central Serbia, a basin succession ("paraflysch") was formed in the Early Cretaceous (DIMITRIJEVIĆ, 1997). This belt, i.e. the relics of the main basin of the Vardar Ocean can be traced from Central Serbia northward up to the important transcurrent fault running along the southern margin of Tisza Megaunit (below the Neogene deposits) and further, after eastward displacement in the Southern Apuseni Mountains (Mureş Zone; Transylvanides), as well as southward to Macedonia and Greece.

Transylvanides

The Transylvanides (Transylvanian Dacides; SĂNDULESCU, 1984) are the highest overthrust units both in the Eastern Carpathians, and in the Southern Apuseni Mts. They are typical obducted nappes or nappe outliers with oceanic



Text-Fig. 10.
Lithofacies chart of the Vardar Megaunit (36–39). (VARDAR I).

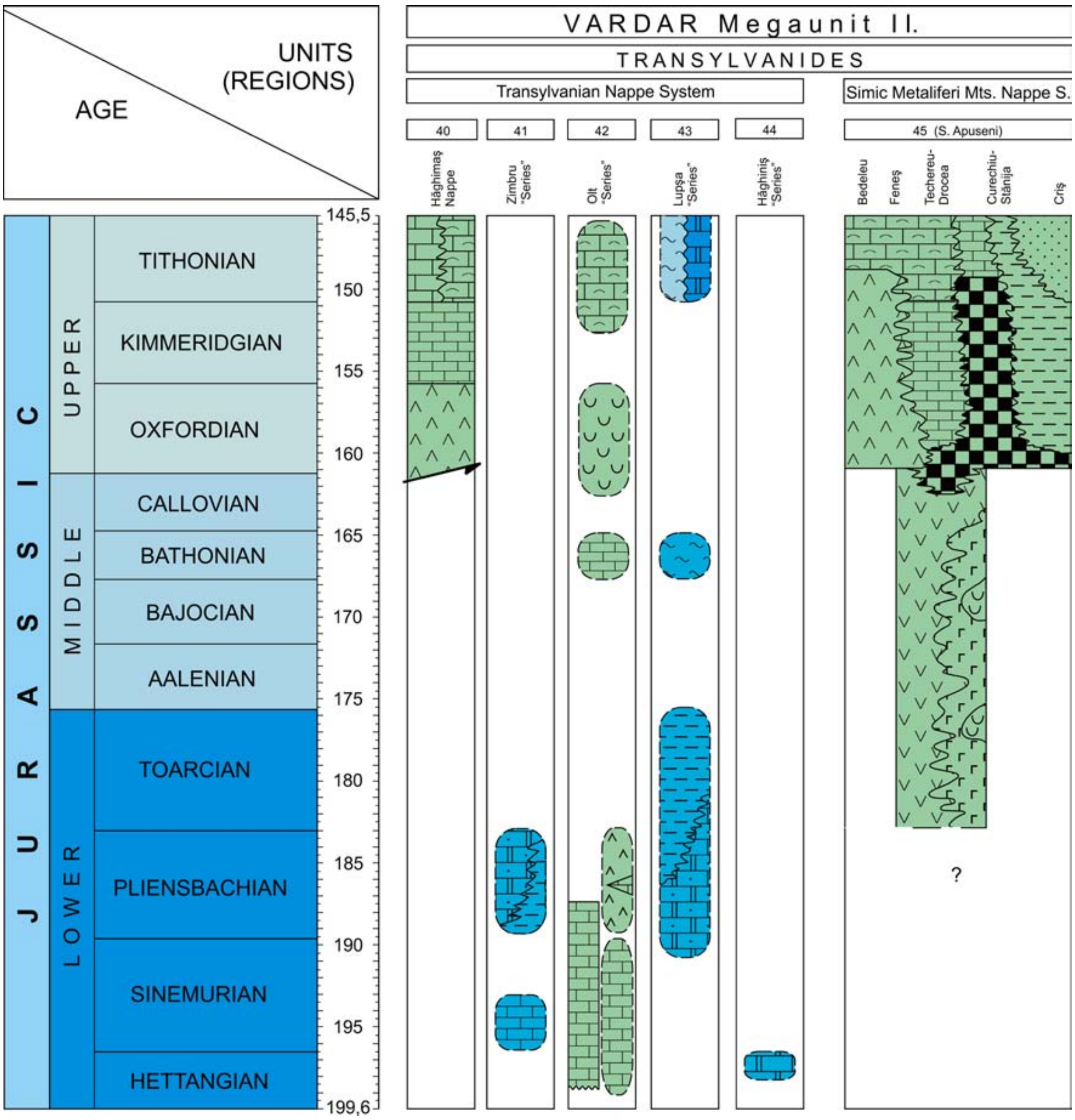
crust and/or Mesozoic deposits (Patrulius et al., 1966, 1972; Patrulius, 1971a; Săndulescu, 1975a, b, 1984, 1994; Hoeck et al., 2009). The Transylvanides include two distinct groups of units, i.e. the **Simic Metaliferi Mts Nappe System** located in the Southern Apuseni Mts, and the unrooted **Transylvanian Nappe System** from the inner zones of the Eastern Carpathians (Săndulescu & Dimitrescu, 2004).

Simic Metaliferi Mts Nappe System
(Southern Apuseni Mts) (Text-Fig. 11, col. 45)

The Southern Apuseni ophiolitic suture zone (or Mureş Zone) can be followed eastward in the basement of the Transylvanian Basin (Rădulescu et al., 1976; Săndulescu & Visarion, 1978; Ionescu et al., 2009). Farther to the west the continuation of the ophiolitic suture zone, although dissected by the huge South Transylvanian (Mureş) dextral strike-slip zone (Săndulescu, 1975b, 1984, 1988; Balla, 1984; Ratschbacher et al., 1993) is structurally connected to the Vardar Zone.

The Southern Apuseni ophiolitic suture zone represents a complex tectonic collage of mainly obducted nappes (Simic Metaliferi Mts Nappe System; Săndulescu, 1984), which are made up of sedimentary Jurassic and Cretaceous formations, at the base of which magmatic complexes of ophiolitic or island arc character were conserved (Ianovici et al., 1976; Bleahu et al., 1981; Lupu, 1983; Săndulescu, 1984; Săndulescu & Dimitrescu, 2004).

The ophiolites of the Southern Apusenides include (1) a gabbroic intrusive section, (2) a sheeted dyke complex showing transition to (3) a volcano-sedimentary cover. Mantle rocks are absent, and thus these ophiolites represent only the upper oceanic crust (Savu et al., 1981; Savu, 1983). Small, discontinuous gabbroic bodies occur in the **Techereu-Drocea** Nappe, show both layered and isotropic textures, and include scarce ultramafic cumulates, melagabbros, gabbros, and rare gabbronorites associated with ferrogabbros. The sheeted dyke complex is formed by basaltic and subordinate basaltic-andesitic dykes. The volcano-sedimentary cover is by far the most abundant portion in the ophiolitic sequence and includes massive and pillow-lava basalts (Pl. 8, Fig. 2), with pillow breccias and related arenites occurring between several of the different lava flows. The entire ophiolite sequence



Text-Fig. 11.
Lithofacies chart of the Transylvanides of the Eastern Carpathians (40–44) and of the Southern Apuseni Mts (45) (VARDAR II).
Abbreviation:
S. Apuseni = Southern Apuseni

displays MORB patterns suggesting a mid-ocean ridge setting.

In the **Criş** Nappe the basic volcano-sedimentary succession includes basaltic lava flows, tuffites, volcanic sands and agglomerates, violaceous argillites and sandstones, violaceous and green radiolarian cherts, and rare intercalations of marly limestones. The radiolarian assemblages suggest ages from Callovian to Tithonian (LUPU et al., 1993). Similar basic volcano-sedimentary successions, dated by radiolarians (BLEAHU et al., 1981; CIOFLICĂ et al., 1981), are also found in the higher nappes, i.e. in the **Techereu-Docea** and **Curechiu-Stănija** Nappes. In the last unit the sequence of the Curechiu Formation continues with greenish-grey micritic limestones with interbedded red argillaceous shales of Tithonian – ?Neocomian age.

Several K/Ar datings on the ophiolites are provided by NICOLAE et al. (1992), falling between 138.9 ± 6.0 and 167.8 ± 5.0 Ma. The oldest radiometric age is in agreement with the Callovian age of the oldest radiolarian assemblages identified in the basic volcano-sedimentary series. Consequently, Middle Jurassic age is generally accepted for the lower sections of ophiolites in the Southern Apusenides, while the upper basic volcano-sedimentary series has a comprehensive age from Callovian till Tithonian (LUPU et al., 1993, 1995).

In the **Techereu**-**Drocea**, **Curechiu** and **Feneş** Nappes, and also in the Trascău Mts, the ophiolites are overlain by island arc calc-alkaline rocks ranging from basalts through basaltic andesites, andesites, and dacites to rhyolites. Some granitoid intrusions with calc-alkaline affinity are located in the southern and western areas of the Southern Apuseni Mts, consisting of granites to granodiorites as well as diorites at the margins of the intrusions (SAVU et al., 1986, 1996). The age of the Săvârşin Granite, measured on zircon is 155 Ma (PANĂ, 1998). For the calc-alkaline island-arc volcanics, the complex relations with sedimentary formations confine their age mainly to the Middle to Late Jurassic (Pl. 8, Fig. 3; Pl. 9, Fig. 1).

The Upper Jurassic and Lower Cretaceous sedimentary series associated with the calc-alkaline volcanics show deep-water and carbonate platform facies, in close connections with different depositional settings in the Transylvanian Ocean. They have the most important development in the Trascău Mts, where several isolated carbonate platforms separated by back arc-type deep-water basins were identified (SĂSĂRAN, 2006; SĂSĂRAN & BUCUR, 2006).

In the **Bedeleu** Nappe of the Trascău Mts (BALINTONI & IANCU, 1986) the Upper Jurassic to Lower Cretaceous interval is represented by shallow-water Stramberg-type limestones (Pl. 8, Figs. 3 and 4; Pl. 9, Fig. 1). The carbonate platforms are underlain either by island-arc volcanics or mixed, oceanic/continental basement. The platform carbonates are made up of three distinct depositional units separated by regional unconformities. In the region of the Trascău Mts there are also numerous olistoliths with Upper Jurassic – Lower Cretaceous shallow-water carbonate deposits, which are included in the Upper Cretaceous wildflysh (BORDEA et al., 1968; BUCUR et al., 1993).

The Upper Jurassic – Lower Cretaceous basin succession is represented by the “Aptychus beds” s.l. (SĂSĂRAN, 2006) which includes (1) slope apron carbonates and mass-flow deposits with reworked material from both carbonate platform and their magmatic/metamorphic basement, and (2) basin floor-pelagic and hemipelagic deposits with deep-sea fans of calcareous or siliciclastic turbidites (Pl. 8, Fig. 5). They are included in the Valea Muntelui and Izvoarele Nappes (BALINTONI & IANCU, 1986).

Outside the Trascău Mts, extended Upper Jurassic – Lower Cretaceous platform carbonate deposits are also found in the south part of the **Techereu-Drocea** Nappe where they cover also a volcanic island arc (SAVU, 1983). The Jurassic sequence is made up of radiolarites and cherty limestones (Upper Callovian) followed by pelagic, Saccocoma limestones (Oxfordian – Lower Kimmeridgian) and carbonate platform reef-limestones (Upper Kimmeridgian – Tithonian) (DRAGASTAN, 1997). The Jurassic of the Ardeu Nappe (MANTEA & TOMESCU, 1986) and the Vulcan outlier (BORDEA, 1972) includes Ammonitico Rosso-type limestones (Oxfordian–Kimmeridgian) and Stramberg-type limestones (Tithonian–Berriasian).

Transylvanian Nappe System

(Perşani, Olt and Hăghimaş Nappes in the Eastern Carpathians)
(Text-Fig. 11, col. 40–44)

The main units of the unrooted Transylvanian Nappe System in the Eastern Carpathians, which were obducted during the Meso-Cretaceous tectogenesis, are the Perșani, Olt and Hăghimaș Nappes (SĂNDULESCU, 1984). They have distinct lithostratigraphic successions and ages of the ophiolitic complexes from the basal part of the nappes, except the Perșani Nappe whithout ophiolitic complex. The Triassic age of the ophiolitic rocks in the Olt Nappe and in many olistoliths is well constrained by their close relationship with the Triassic sedimentary rocks. The only ophiolitic rocks of Jurassic age are represented by the pillowed basalts from Lacu Roșu in the sole of the Hăghimaș Nappe, which are assigned to the Callovian–Oxfordian (SĂNDULESCU, 1984), and also by the serpentinites in the Rarău Mts. Alongside the Jurassic sedimentary rocks included in the successions of the above-mentioned nappes, there are also numerous olistoliths of Jurassic rocks included in the Bucovinian Lower Cretaceous wildflysch that fills the Hăghimaș and Rarău synclines, and also found in the Perșani Mts.

The **Hăghimaș Nappe**, having the most internal paleogeographic position in the Transylvanian realm, is made up of a continuous sequence from the Upper Jurassic to Lower Cretaceous (SĂNDULESCU, 1975a). In the Hăghimaș Mts, the Ammonitico Rosso-type limestones (Upper Oxfordian – Middle Kimmeridgian; Pl. 7, Fig. 6), capping Callovian–Oxfordian pillowed basalts, are followed by a siliciclastic sequence made up of siltstones and marly shales (Upper Kimmeridgian – Lower Tithonian), and thick, massive Stramberg-type limestones (GRASU, 1971; DRAGASTAN, 1975; GRIGORE, 2000; GRASU et al., 2010) (Pl. 7, Fig. 4; Pl. 8, Fig. 1). Kimmeridgian stromatactis mud-mound buildups with abundant rhynchonellid brachiopod assemblages (*Lacunosella* and *Septaliphoria*) develop locally (LAZĂR et al., 2011).

The outliers made up by Stramberg limestones from the Merești region in the northern part of the Perșani Mts are also assigned to the Hăghimaș Nappe (SĂNDULESCU, 1984; PATRULIUS et al., 1996).

The *Perșani* and *Olt Nappes*, which are found only in the Perșani Mts, are made mainly of Triassic sedimentary rocks to which only Lower to ?lower Middle Jurassic rocks are subordinately added.

Based on the facies characteristics of the Transylvanian Triassic and Lower Jurassic formations, from both the olistoplakae and olistoliths embedded in the Bucovinian Lower Cretaceous wildflysch, PATRULIUS (1996) defined several independent sedimentary "series". They are as follows: the Zimbru "Series" (lower olistoplaka of the Rarău Mt), the Olt "Series" (Olt Nappe, incl. the lower olistoplaka of the Perşani Mts), the Lupşa "Series" (Perşani Nappe s.s., incl. the upper olistoplaka of the Perşani Mts) and the Hăghiniş "Series" (Hăghiniş Nappe, incl. the upper olistoplaka of the Rarău Mt).

In the Rarău Mt, the **Zimbru "Series"** includes Lower Sinemurian massive argillaceous, dark limestones (TURCULEŢ, 1971), Pliensbachian sandy limestones and silty marly shales (STĂNOIU, 1967a), which are olistoliths within the Bucovinian Lower Cretaceous wildflysch.

In the **Olt "Series"** of the Olt Nappe the Middle Hettangian to Lowermost Pliensbachian Adnet Limestone unconformably overlies Upper Triassic Hallstatt-type limestones (PATRULIUS, 1996; TOMAS & PÁLFY, 2007). In the central Perşani Mts, also in the Rarău and Hăghimaş Mts, there are olistoliths of Adnet-type Lower Jurassic red limestones assumed to be akin to the Olt "Series" (PATRULIUS et al., 1996; TURCULEŢ & ŢIBULEAC, 2002; GRASU et al., 2010).

In the **Lupşa "Series"** of the Perşani Nappe the Middle Triassic Schreyeralm-type limestone is unconformably overlain by the Gresten-type Racila Formation, around 300 m thick. Its lowest member consists of coarse-grained limy sandstones and crinoidal sandy limestones (Upper Sinemurian? to Pliensbachian); the upper one is composed of grey marls and limestones with interbeds of violet sandy siltstone and oolitic limestone (Toarcian–?Aalenian) (PATRULIUS et al., 1996).

In the **Hăghiniş "Series"** the Middle Triassic limestones in the Rarău Mt are overlain by thin Upper Hettangian red, argillaceous-sandy encrinitic or oolitic to pisolitic limestones, which also fill narrow neptunian dykes in the Steinalm Limestone (PATRULIUS, 1996). On the Norian massive limestones of the Piatra Şoimului outlier Lower Jurassic red-violet argillaceous diasporic bauxites occur locally (PATRULIUS, unpubl.).

Olistoliths made up by varied Lower and Middle Jurassic lithologies, that are not properly ascribed to one of the above-mentioned "series", were also found in the Bucovinian Lower Cretaceous wildflysch. In the *Rarău Syncline*, olistoliths are described, made up by Toarcian dark sandy limestones, grey-yellowish marlstones and siltstones, fine-grained limy sandstones and marly siltstones, by Aalenian grey marls with concretions of marlstones and oolitic limestones, by Bajocian dark limy sandstones and sandy limestones, bioclastic limestones and marls, or by Bathonian silty-oolitic limestones, sandy limestones and limy sandstones (POPESCU & PATRULIUS, 1964; STĂNOIU, 1967a; MUTIHAC, 1968; TURCULEŢ, 2004). In the *Hăghimaş Syncline* olistoliths are reported that are made up by Pliensbachian sandy limestones and argillaceous sandstones, by Toarcian black limestones or sandy limestones, or by Middle Jurassic limy sandstones and encrinitic limestones (NĂSTSEANU & SOLCANU, 1963; GRASU, 1971; SĂNDULESCU, 1975a; PREDA, 1976; GRASU et al., 2010).

From among the allochthonous deposits the Callovian–Hauterivian Carhaga Formation is of special importance. It is made up of several sheet-olistoliths (PATRULIUS et al., 1976, 1996). The sequence includes the following members:

1) Callovian grey, reddish ammonite-bearing limestones with angular pebbles of crystalline shists;

2) Callovian and/or Oxfordian red radiolarites and limestones with radiolaria;

3) Upper Jurassic light-grey, pink and red marls and marly limestones with spongiolithic cherts and interbedded conglomerate or breccia with pebbles of crystalline schists, thin layers of bentonite;

4) Tithonian light-grey or pink marls with small lenses of calcarenite and bedded white allodapic calcarenites with brown cherts;

5) Uppermost Tithonian – Berriasian grey-bluish marls with some glauconite and light-grey to almost white ammonite-rich limestones with calpionellids and radiolaria;

6) Valanginian and Hauterivian ammonite-rich soft marls.

According to SĂNDULESCU (1984), the olistoliths of the Carhaga Formation are presumably derived from a swell or they could be linked to the Olt or Perşani Nappes.

TISZA MEGAUNIT

Mecsek Unit (Text-Fig. 12, col. 46)

Thin coal interlayers already appear in the fluvial succession in the latest Rhaetian. At the beginning of the Liassic, fluvial-lacustrine-palustrine sedimentation continued but paralic coal-swamp deposits became predominant in the sedimentary record (Mecsek Coal Formation) (Text-Figs. 1, 2 and 12).

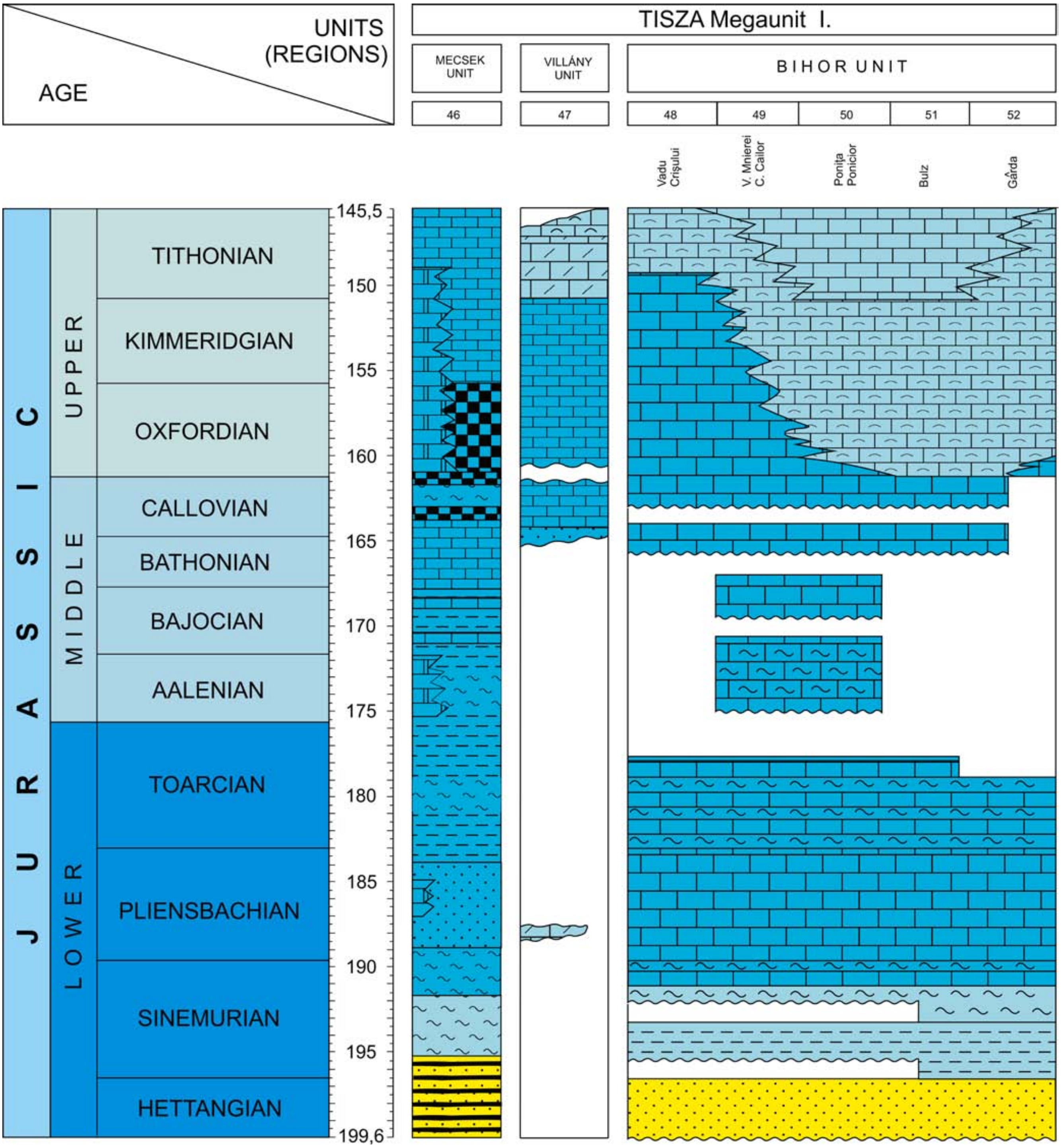
The formation is made up of a cyclic alternation of arkosic sandstone, siltstone, claystone and coal layers (Gresten facies; Pl. 9, Fig. 2). The thickness of the coal-bearing series is usually 150–300 m; in the southern part of the Mecsek Mts, however, it may reach 1200 m. This asymmetric thickening was the consequence of the formation of an extensional half-graben (NAGY, 1969, 1971).

The basal (partially Rhaetian) part of the Mecsek Coal was formed predominantly in lacustrine as well as lacustrine/deltaic facies. The Hettangian middle member of the formation is mainly fluvial with channel, flood plain and swamp facies; however, passing upward, coquinas of brackish-water molluscs appear in increasing frequency. The Lower Sinemurian upper member of the Mecsek Coal may have been deposited in a tidal flat marsh environment. In the middle member of the Mecsek Coal thin (0.5–1.5 m) rhyolitic tuffite interlayers occur (NÉMEDI-VARGA, 1983). In some layers of the upper member remnants of crinoids also appear, indicating a temporary establishment of normal salinity conditions.

The coal formation is overlain by fine-grained sandstone and dark grey shale with upward-thinning sandstone interlayers showing a deepening upward trend. The thickness of the formation in the Mecsek Mts is 250–500 m.

During the later part of the Sinemurian water depth continued to increase. Coevally the continental source area moved even farther away from the site of deposition. In accordance with this paleogeographic setting an open marine deep basin had been the site of deposition until the middle part of the Jurassic. In this basin fine-grained terrigenous material and pelagic biogenic ooze were deposited together; however, their ratio continuously changed. This heavily bioturbated marl sequence is similar to the "Fleckenmergel" (Allgäu facies). In the rapidly subsiding southern zone of the Mecsek half-graben its total thickness may attain 2000 m, whereas in the northern part of this structural unit, as well as in the subsurface parts of the Mecsek Zone (i.e. in the basement of the Transdanubian area and the Great Plain), it generally reaches only 150–300 m (BÉRCZI-MAKK, 1998).

In the Mecsek Mts in the upper part of the Sinemurian, grey, slightly bioturbated marl and calcareous marl become characteristic. This formation was deposited under open marine conditions in the deeper zone of the open shelf. In the Pliensbachian, grey, fine to medium-grained sandstone punctuated by thin shale interbeds was depos-



Text-Fig. 12.
Lithofacies chart of the Mecsek (46), Villány (47) and Bihor Units (48–52). (TISZA I).
Abbreviations:
V. Mnierei = Valea Mnierei,
C. Cailor = Coasta Cailor.

ited. Chert nodules and grey, bituminous limestone and crinoidal limestone interbeds are common. In the rapidly subsiding southern zone of the Mecsek Mts area the thickness of the formation may attain 1000 m, and only 70 m in its northern zone. The depositional environment may have been a relatively deep, pelagic basin.

Upsection, silty marl becomes predominant again and the share of sandstone decreases. This approximately 150 m thick formation represents the Lower and Middle Toarcian. In the Lower Toarcian a 10 m thick, black shale intercalation with thin sandstone and crinoidal limestone interlayers as well as thin-shelled pelagic bivalves and fish remnants can be found suggesting anoxic bottom-water conditions (DULAI et al., 1992).

Above the black shale intercalation the typical "Fleckenmergel" facies resumes. The Upper Toarcian to Middle Bajocian is characterized by a rather monotonous, 200–500 m thick sequence consisting of grey, strongly bioturbated marl, calcareous marl, and silty marl (Pl. 9, Fig. 3). It contains predominantly pelagic fossil elements (VADÁSZ, 1935). In the southern and northern margins of the "Mecsek Basin" grey and red crinoidal-brachiopodal limestone has been encountered.

At the end of the Bajocian the sedimentation character fundamentally changed: the amount of terrigenous material and the sedimentation rate significantly decreased; continuous and probably accelerated subsidence led to increased water depth. A significant change took place also in the fossil assemblage that is manifested in the appearance and then prevalence of Mediterranean elements (GÉCZY, 1973; VÖRÖS, 1993). Reflecting the changes in the depositional regime the spotty marl ("Fleckenmergel") facies is overlain by greenish-yellowish-reddish marl, then by red calcareous marl and finally by nodular, argillaceous limestone rich in poorly-preserved ammonoids and pelagic microfossils. This 10–20 m thick formation of Bathonian age (GALÁCZ, 1995) may have been deposited in a deep, pelagic, starved basin. The changes in the sedimentary pattern and fossil assemblages at the end of the Bajocian can be related to the separation of the Tisza Megaunit from the European plate (HAAS & PÉRÓ, 2004).

The next unit consists of deep-water brownish- and greenish-grey, thin-bedded, siliceous calcareous marl of Callovian and probably Early Oxfordian age. It also contains altered pyroclastics but only a few. The thickness of this formation does not exceed 10–20 m. The calcareous marl passes upward into Oxfordian siliceous limestone (NAGY, 1986). In the basal part of the formation brownish-greenish, highly silicified radiolarite occurs. Above it, the 30–120 m thick formation is made up of thin-bedded, yellowish-grey, reddish, and greenish cherty limestone.

The Kimmeridgian to Lower Tithonian interval is represented by 10 to 50 m thick red, nodular, locally cherty Saccocoma limestones with ammonoids and aptychi with features of the Mediterranean Ammonitico Rosso facies.

The red nodular limestone passes upward into Upper Tithonian – Berriasian greyish- or yellowish-white, thin-bedded limestone and argillaceous limestone, locally with intraclasts and chert nodules, similar to the Mediterranean Biancone (Maiolica) facies. Its thickness may attain 100 m. The site of deposition may have been a deep pelagic basin. Intrabreccia intercalations in the pelagic sequences and the chronostratigraphically mixed microfossil assemblage indicate a significant gravity mass flow activity resulting in the redeposition of the unconsolidated and semiconsolidated sediments (NAGY, 1986). In the upper part of the formation, in addition to the redeposited carbonate grains, fine pyroclastics and volcanic bombs appear in the layers, indicating the intensification of volcanic activity in the Berriasian (NAGY, 1986).

Villány-Bihor Unit (Text-Fig. 12, col. 47-52)

The Jurassic sequence of the Villány-Bihor Zone is known mainly from the Villány Hills in Hungary, and in the Bihor Parautochthon in the Northern Apuseni Mountains in Romania. Core data are only available for the Malm formations in the Pannonian Basin. In the Villány Hills, unconformably overlying the Upper Triassic rocks, the Jurassic series of the **Villány Unit** begins with quartzarenite beds, grading upward into shallow-marine, sandy, crinoidal limestone with conglomerate interlayers. In the conglomerate, quartzite and dolomite components are recognized, indicating the proximity of a continental hinterland. The sandy, pebbly layers are overlain by yellowish-grey limestone, followed by grey, strongly bioturbated, thick-bedded, cherty, crinoidal limestone. Only a 8–10 m thick limestone formation can be assigned to the Pliensbachian (VÖRÖS, 1989). Above a hiatus a thin, yellow, sandy limestone bed, rich in Bathonian ammonites, occurs. It is overlain by an extremely condensed limestone layer (GÉCZY, 1982; Pl. 9, Fig. 4). Most of the ammonites are characteristic of the European province; a smaller part of the assemblage, however, is Mediterranean (GÉCZY, 1973).

The ammonite-bearing limestone is overlain by 300 m of thick-bedded, grey, brownish- or yellowish-grey limestone. It is characterized by a peloidal and oolitic-oncoidal texture. In the lower part of the formation pelagic elements prevail in the microfossil assemblage. In the upper part, however, a typical shallow-marine biofacies appears and the pelagic elements disappear. The age of the formation is Oxfordian–Tithonian and its upper member may extend into the Berriasian (BODROGI et al., 1993).

In the **Bihor Unit**, Jurassic deposits are found in the Pădurea Craiului and Bihor Mts (PREDA, 1962, 1971; PATRULIUS et al., 1972; IANOVICI et al., 1976; PATRULIUS, 1976a; PATRULIUS et al., 1976; POPA, 1981; MANTEA, 1985; POPA et al., 1985; DRAGASTAN et al., 1986).

In the *Pădurea Craiului* (Text-Fig. 12, col. 48-50) and *Bihor Mts* (Text-Fig. 12, col. 51-52), the Lower Jurassic succession, around 250 m thick, unconformably overlies the Ladinian Wetterstein-type limestone. A continental sequence (100–180 m) occurs at the base of the succession consisting of red argillaceous-silty shales locally including breccia with boulders of Triassic limestones. Upsection there is another development that is similar to the Gresten Sandstone. It is composed of micaceous quartzitic sandstones with interbeds of refractory clays in the lower part (Pl. 9, Fig. 5), with quartzitic conglomerates at the top (Hettangian), with vegetal remains. The continental series is followed by a marine sequence. It starts with a basal member (40–60 m) consisting of micaceous and fine-grained quartzitic sandstones, locally with marly-argillaceous micaceous siltstones (?Upper Hettangian – Lower Sinemurian). It is overlain by massive or thick-bedded Gryphaea limestones (5–35 m) with crinoidal layers (Upper Sinemurian – Lower Pliensbachian), and an upper succession (3–40 m) of spongiolithic cherty limestones, silty or marly with brachiopods and ammonites (Upper Pliensbachian) and a third member (5–15 m) of grey-blackish condensed marls and marly/silty limestones with phosphate concretions, with abundant belemnites and ammonites, Gresten-type (celto-suab) fauna (Toarcian).

The Middle Jurassic, which is strongly condensed in the *Pădurea Craiului Mts*, rarely more than 10 m in thickness, with several breaks in sedimentation in the area of **Valea Mnierei**, **Coasta Cailor**, **Poniţa** and **Ponicior** (Text-Fig. 12, col. 49-50), includes the following carbonate units:

1) blackish, sometimes spotted marls ("Fleckenmergel") and marly/silty limestones, less than 2 m thick (Lower Aalenian);

2) blackish spotted marly limestones ("Fleckenkalk"), with phosphate ooids and nodules, 0.8–3 m (Upper Aalenian);

3) red-violaceous ferruginous oolitic/silty limestones and marls of minette-type (Lower Bajocian);

4) Entolium limestones (Middle Bajocian – Middle Bathonian), and nodular limestones (0.2–0.5 m) with an abundant polyzonal ammonite fauna (Upper Bathonian – Lower Callovian);

5) reddish to grey-greenish marly or silty limestones (Middle and Upper Callovian).

During the Upper Jurassic, a carbonate platform was established in the territory of the Bihor Unit. In the area of the *Pădurea Craiului* and *Bihor Mts*, the carbonate deposits, 100–300 m thick, show two distinct facies zones with a passage zone:

1) a NW zone in **Vadu Crişului** area (Text-Fig. 12, col. 48); basinal dark-grey cherty limestones progress into pelagic Saccocoma limestones (Vad and Gălăşeni Limestone, Oxfordian – lower Tithonian) followed by massive Stramberg-type limestones (Cornet Limestone, Tithonian) or oolitic limestones (Aştileu Limestone, Tithonian);

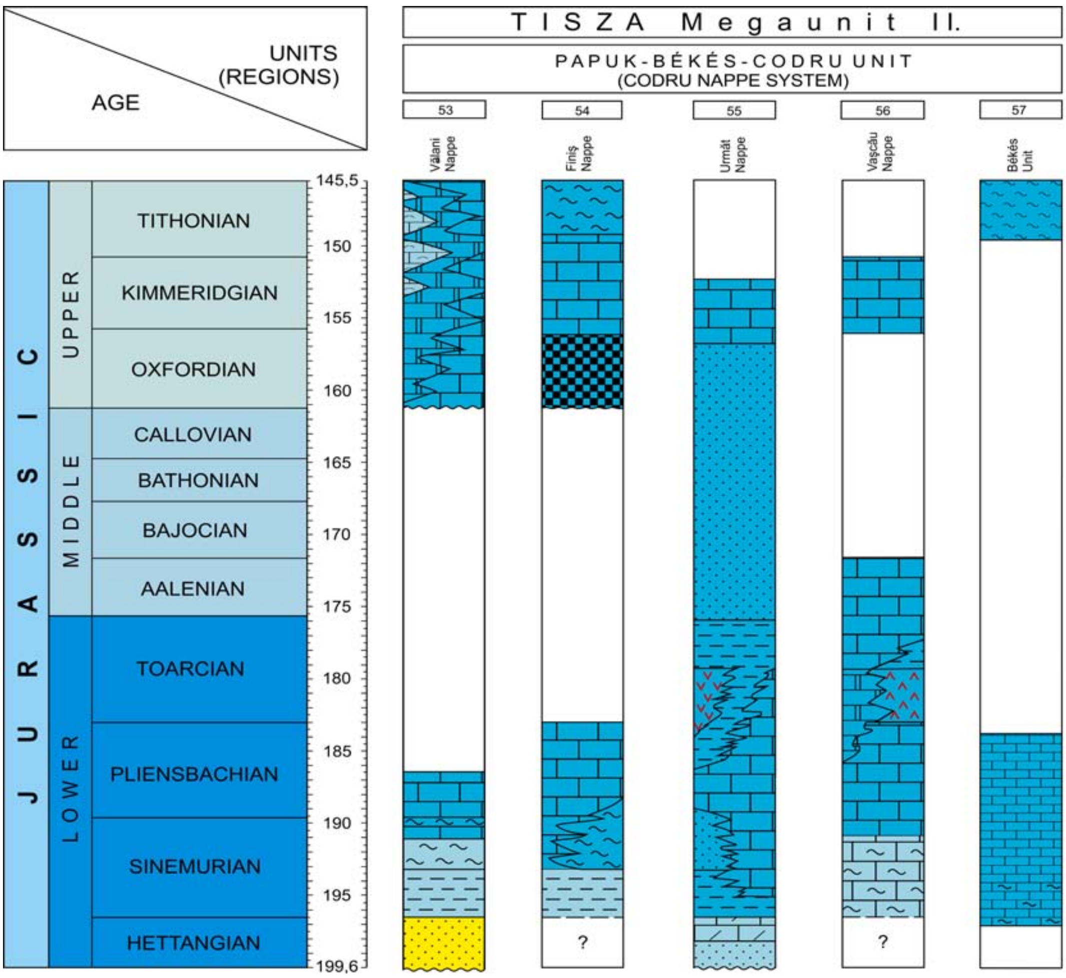
2) a SW zone in **Poniţa**, **Ponicior**, **Bulz** and **Gârda** area (Text-Fig. 12, col. 50-52) with massive, whitish limestones with corals and hydrozoans (Farcu Limestone, Oxfordian – lower Tithonian; Pl. 10, Fig. 1) followed by grey, bedded micritic/oncolitic limestones of lagoonal facies (Albioara Limestone, Tithonian);

3) a passage zone in the area of **Valea Mnierei** and **Coasta Cailor** where all carbonate facies are found in ascending order (Text-Fig. 12, col. 49).

Papuk-Békés-Codru Unit (Text-Fig. 13, col. 53-57)

The Jurassic deposits are cropping out in the **Codru Nappe System** in the Northern Apuseni Mts (classed together with the Bihor Unit as Inner Dacides by Săndulescu, 1984) and in the Papuk Mts, Croatia. Jurassic sequences explored in the basement of the Békés Basin, Hungary can also be assigned to this unit.

In the Apuseni Mts, Jurassic formations are known in the Codru-Moma, Pădurea Craiului and Bihor Mts (Patrulius, 1976a; Ianovici et al., 1976; Bleahu et al., 1981).



Text-Fig. 13.
Lithofacies chart of the Papuk-Békés-Codru Unit (53–57). (TISZA II).

The Jurassic succession in the **Vălani Nappe**, *Bihor Mts* (PATRULIUS, 1971b) includes: disconformable massive or thick-bedded quartzitic-micaceous sandstones, 100 m thick, locally with basal conglomerates (Hettangian); a sequence, only a few m thick, of dark shales (?Hettangian – Lower Sinemurian) and blackish bioclastic limestones (?Upper Sinemurian – Pliensbachian); after a significant stratigraphic gap (Toarcian and the Middle Jurassic) the sedimentation resumed in the Late Jurassic with bedded Saccocoma and Calpionella limestones interfingering with massive limestones of platform-edge and reef talus (Farcu and Cornet Limestones).

The Jurassic succession of the **Finiş Nappe** is the most complete in the Codru Nappe System. In the Şeasa Valley, in the central area of the Codru Mts, a Rhaetian Kössen-type formation is overlain by 150 m thick silty shales (Lower Sinemurian), succeeded by a 75 m thick calcareous formation, with grey silty limestones in the lower, and red, sometimes nodular limestones in the upper part (Upper Sinemurian – Pliensbachian). In the Moneasa (SW Codru) area, the succession begins with a 200 m thick black sandstone unit with shales grading upwards to black encrinitic limestones (Black Moneasa Limestone) (?Hettangian – Lower Sinemurian). It is overlain by encrinitic, thick-bedded nodular and breccious red limestones about 80 m thick (Red Moneasa Limestone, Upper Sinemurian – Pliensbachian) showing lithofacies comparable with the Adnet Limestone, but it has a Gresten-type (celto-suab) fauna (Pl. 10, Fig. 4). The Lower Jurassic formations are overlain by pelagic, light grey micritic and cherty calcarenitic limestones (Oxfordian–Kimmeridgian) followed by the Valea Mare Formation (PATRULIUS et al., 1976), around 1000 m thick, including a pre-flysch facies of marls and marly limestones with *Aptychus* and calpionellids on the base (Tithonian–Berriasian).

The **Următ Nappe** outlier in the Bihor Mts includes the Lower Sinemurian – Pliensbachian Următ beds. This sequence starts with grey sandstone, succeeded by encrinitic-micritic limestones with basical volcanic detritus, *Gryphaea* and brachiopods. This is followed by a siliciclastic turbiditic sequence with olistoliths and slumps, without fossils. The Următ beds are overlain by Kimmeridgian Saccocoma limestones (BORDEA et al., 1975; TOMESCU & BORDEA, 1976).

In the uppermost units of the Codru Nappe System only Lower – lower Middle Jurassic deposits are present. In the **Vaşcău Nappe** (Codru-Moma Mts) (PANIN et al., 1974) the Jurassic succession unconformably overlies Norian–Rhaetian basinal limestones and includes:

1) a lower sequence, 80 m thick, of pink-greenish micritic/crinoidal limestones associated with greenish marly limestones and limy sandstones (Sinemurian);

2) a detrital sequence, transgressive upon the lower sequence and the Upper Triassic limestones, with limy sandstones, Holzschiefer-like black argillites with sideritic concretions, greenish cinerites, lenses of black encrinitic limestones, platy black limestones with layered cherts (Toarcian–?Aalenian).

In the *Coleşti Nappe* (Codru-Moma Mts) (PANIN et al., 1974), the Upper Triassic Dachstein Limestone has Lower to Middle Jurassic neptunian dykes (Pl. 10, Fig. 2).

In the basement of the **Békés** Basin, southeastern Hungary, Lower Jurassic red limestone was encountered in a few wells; it was identified as the Moneasa Limestone of the Finiş Nappe (BÉRCZI-MAKK, 1998).

In a number of wells in the Békés Basin, Upper Jurassic to Lower Cretaceous formations were found. The several hundred m thick series consists of grey and red clayey marl, marl, calcareous marl and limestone layers with sandstone intercalations in the upper part of the formation (BÉRCZI-MAKK, 1986).

In the *Papuk Mts*, Jurassic formations (overlying the Upper Triassic Kössen Formation) are known only at the western edge of the mountains, near Daruvar (ŠIKIĆ et al., 1975). It is a condensed succession (max. 100 m thick).

The Lower–Middle Liassic is represented by grey-pinkish, crinoidal limestones, sometimes with chert nodules. The pelagic fossils (*Bositra*) appear in Upper Liassic micritic limestones. The thickness of the Lower Jurassic is 25 m. The Middle Jurassic – Oxfordian (40 m) is characterized by grey, pinkish, brownish-red Bositra limestones. Red and grey radiolarian chert beds are common. The Kimmeridgian – Middle Tithonian is represented by thick-bedded grey limestone (10 m) with radiolarian chert beds, which are overlain by Tithonian–Berriasian thin-bedded, micritic cherty *Calpionella*-bearing limestones (20 m).

DACIA MEGAUNIT

Danubian-Vrška Čuka-Stara Planina (Prebalkan) Unit

Southern Carpathians

The Danubian-Stara Planina-Vrška Čuka (-Prebalkan) Unit in Romania corresponds to the Marginal Dacides in the sense of SĂNDULESCU (1984). This unit, together with the neighbouring Moesia, represents a segment of the European–?Asian margin, located outside the „external" Severin-Ceahlău ocean basin, which separated them from the Getic microcontinent. This unit can be subdivided north of the Danube into a Lower (External), and an Upper (Internal) group of Alpine nappes (STĂNOIU, 1973; BERZA, 1998; IANCU et al., 2005).
North to the Danube, the Jurassic – Lower Cretaceous sedimentary series overlie Variscan crystallines, remnants of a Variscan oceanic basement and Upper Paleozoic molasse deposits with sharp disconformity.

Lower Danubian Units (Text-Fig. 14, col. 58)

Two distinct Mesozoic sedimentary zones were formerly defined in the External Danubian realm, the Cerna and Coşuştea Zones (CODARCEA, 1940; NĂSTĂSEANU, 1979). The **Cerna** Zone (= Mehedinți-Retezat Zone; STĂNOIU, 1973) is the equivalent of the Lower Danubian of BERZA et al. (1983). Two Alpine tectonic units are recognized in the Lower Danubian, i.e. the Lainici Unit, in the upper position, and the Schela Unit, below (BERZA, 1998). The sedimentary series of the Coşuştea Zone is assigned to a distinct tectonic unit, i.e. the Coşuştea Nappe (STĂNOIU, 1996).

In the External Danubian realm, the Jurassic successions are incomplete and discontinuous. The Lower Jurassic is represented by Gresten-type deposits in all areas (Text-Figs. 1, 2 and 14). In the Mehedinți Mts, the 50–350 m thick Balta de Aramă Formation yielded a rich flora (DRĂGHICI et al., 1964; BĂDĂLUȚĂ et al., 1988). In the **Schela Unit**, the strongly deformed and metamorphosed Lower Jurassic Schela Formation starts with very coarse-grained metaconglomerates succeeded by quartzitic and arkosic metasandstones, graphitic phyllites, in places with chloritoid, and pyrophyllitic schists with anthracite lenses (Manolescu, 1932; Semaka, 1965). The Middle Jurassic marks the onset of the marine sedimentation. It is represented by fossiliferous limy sandstones and gritty limestones, 20 m in thickness (Stănoiu, 1973).

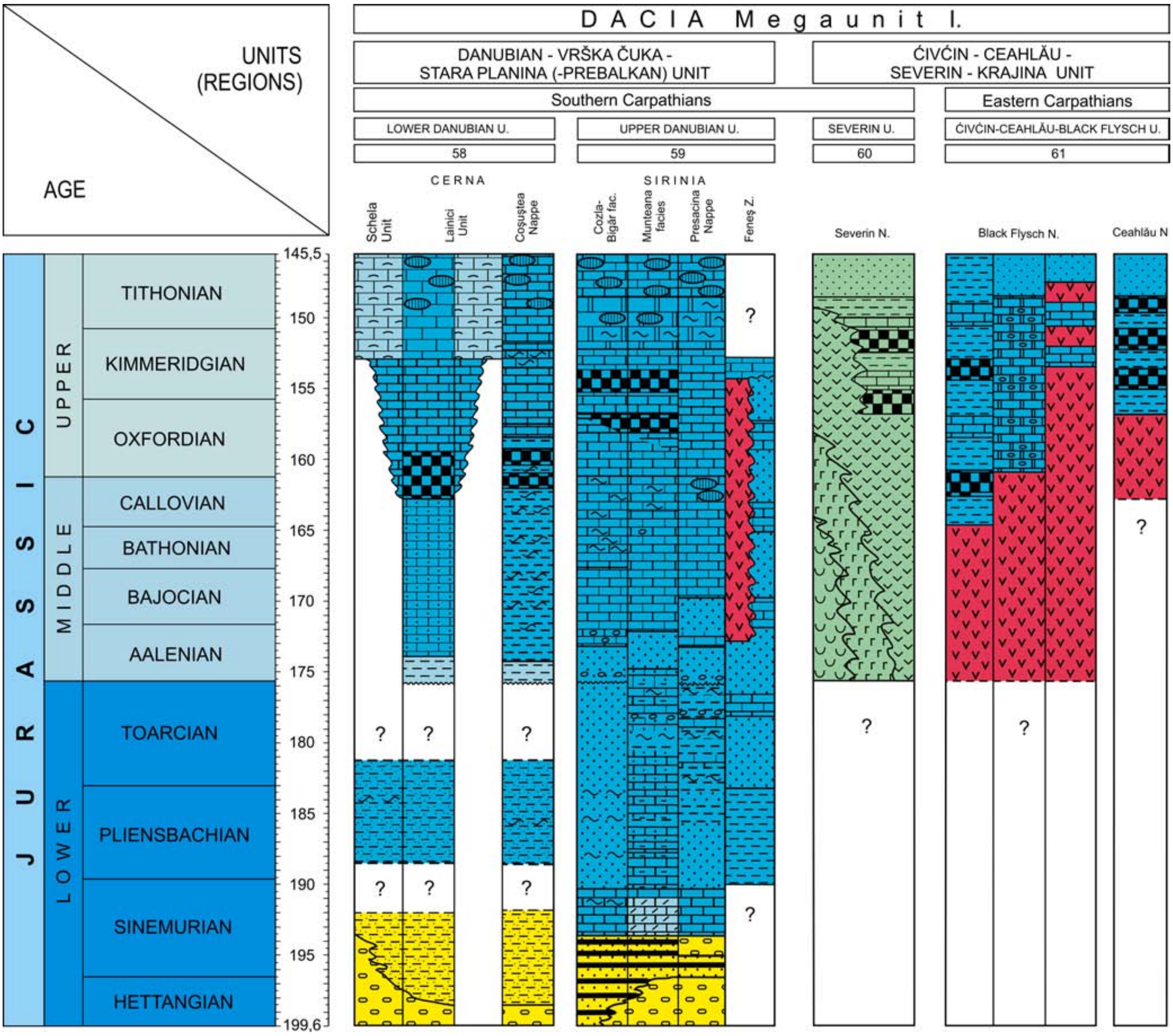
The calcareous sedimentation started in the Middle Callovian and lasted for most of the Early Cretaceous and characterized the **Cerna** Basin which covered the whole area of the Lower Danubian (Stănoiu, 2000). Subsequent to the Middle Callovian transgression, uniform pelagic sequences were settled all over the Cerna Basin. By the end of Kimmeridgian the paleogeographic pattern significantly changed; a central deep-water basin bordered by two carbonate platforms developed. The central basin is typified by a continuous succession:

(1) the Middle Callovian to Lower Kimmeridgian Cerna Vârf Formation (150–200 m thick) that is made up of stratified, blackish micritic limestones, with chert in the lower part;

2) the Upper Kimmeridgian to Neocomian Ponicova Formation (200–300 m thick) consisting of greyish limestones with *Saccocoma* in the lower part and calpionellids in the upper part.

The two marginal carbonate platforms are characterized by a shallow-water carbonate facies in the Upper Kimmeridgian – Tithonian. Emersion at the Jurassic/Cretaceous boundary led to subaerial alteration and accumulation of ferrolithic deposits. In the Mehedinți Mts and SW the Vâlcan Mts, the sedimentation resumed with the uppermost Tithonian? – Lower Berriasian Sohodol Formation, a mixed siliciclastic-carbonate sequence with alluvial terrigenous deposits and lenticular intercalations of paludal or brackish micritic limestones.

In the NE Godeanu Mts, the **Lainici Unit** includes the Lower–Middle Jurassic Albele Sandstone and the Upper Jurassic – Lower Cretaceous Stănuleți Limestone (Gherasi



Text-Fig. 14.
Lithofacies chart of the Danubian Units (in Romania, 58–59) and Ćivćin-Ceahlău-Severin Unit (60–61). (DACIA I).

et al., 1986), which corresponds to the deep-water basin facies of the Cerna Basin (STĂNOIU, 2000).

The **Coşuştea Nappe** is mainly occurring in the Mehedinţi Plateau, and includes also the Jurassic – Lower Cretaceous allochthonous occurrences from the Topleţ-Cazane Zone. The Jurassic to Lower Cretaceous has a continuous basinal succession:

1) a 500 m thick Lower Jurassic Gresten-type sequence consisting of siltstone, grey-blackish micaceous argillites with spherosiderites and grey or blackish quartz-feldspar sandstones;

2) a 30–50 m thick Middle Jurassic siltic-argillitic deep-water sequence;

3) a 20–50 m thick Middle Callovian – Lower Oxfordian deep-water sequence of argillites and grey siltstone grading to thin-bedded micritic limestones or marly limestones to its top;

4) a 10–30 m thick Upper Oxfordian – Kimmeridgian sequence of cherty micritic limestones with clay intercalations at the top;

5) a 20–50 m thick Upper Kimmeridgian – Upper Tithonian – ?Neocomian pelagic limestone sequence (Pl. 11, Fig. 1).

Upper Danubian Units (Text-Fig. 14, col. 59)

The facies of the Jurassic to Lower Cretaceous sedimentary series (RĂILEANU, 1960; RUSU, 1970; POPA et al., 1977; NĂSTĂSEANU, 1979; AVRAM, 1984; STĂNOIU, 1997; POP, 1998; GRIGORE, 2000) demonstrate a complex paleogeography of the Internal Danubian realm. The most part of the Upper Danubian Units are exposed in the western part of the Danubian tectonic window (IANCU et al., 2005). Three major zones of Jurassic deposition existed in the western Upper Danubian in the eastern Banat area, namely Sirinia, Presacina and Feneş Zones.

In the **Sirinia** Zone the onlapping Gresten-type Hettangian? to Lower Sinemurian deposits (50–450 m thick) start with coarse conglomerates succeeded by sandstones and shales with coal seams (SEMAKA, 1970). The marine deposition started in the Late Sinemurian with two distinct facies:

1) the Cozla-Bigăr sandy-marly facies, and

2) the Munteana sandy-calcareous facies.

The **Cozla-Bigăr facies** succession includes: Upper Sinemurian calcareous and marly sandstones; Pliensbachian limy or quartzose sandstones, siltstones and marly shales; Toarcian thick-bedded whitish quartzose sandstones, around 100 m thick, with levels of black silty clays grading upwards to black fine-grained calcareous sandstones with intercalations of argillaceous siltstones, 150 m thick; Aalenian massive, coarse-grained sandstones, locally microconglomerates, grading upwards to limy sandstones, 200 m thick.

The **Munteana facies** (Pl. 11, Fig. 3) is a condensed calcareous-siliciclastic succession rich in ammonites (POPA et al., 1977; POPA & PATRULIUS, 1996; CALLOMON & GRĂDINARU, 2005). The lower sequence (~60 m thick) consists of Upper Sinemurian to Pliensbachian sandy bioclastic-Fe-oolitic limestones sandstones and siltstones, silty crinoidal limestones. The upper sequence (~20 m thick) is made up of Toarcian to ?Aalenian bedded sandy limestones and marly siltstones grading upwards to sandstones.

In the Sirinia Zone the Bajocian is made up of carbonates, 5 to 20 m in thickness. The Bathonian – Lower Callovian is represented by two facies:

1) the Bigăr facies containing marls and nodular limestones, 200 m thick;

2) extremely condensed (0.40 m thick) Fe-oolitic limestones rich in ammonites (RĂILEANU, 1960; PATRULIUS & POPA, 1971; GALÁCZ, 1994).

From the Middle Callovian the pelagic carbonate sedimentation became uniform in the Sviniţa (=Sirinia) Zone (Pl. 11, Fig. 3). The Middle to Upper Callovian red nodular limestones are followed by Oxfordian to Lower Kimmeridgian radiolaritic marly limestones and calciturbidites, with banded and nodular radiolarian cherts (25 m thick; Pl. 11, Fig. 2). The Upper Kimmeridgian to Middle Tithonian is represented by reddish or grey-greenish clayey nodular limestone with debris flow intercalations and coarse-grained calciturbidites succeeded by thin-bedded greenish pelagic limestones with rare intercalations of fine-grained calciturbidites (Greben Formation; Pl. 11, Fig. 5). It is followed from the Upper Tithonian by Maiolica-type, light grey, cherty Calpionella limestones (NĂSTĂSEANU, 1979; AVRAM, 1984).

The Jurassic succession in the **Presacina Nappe** corresponds to the Presacina facies of NĂSTĂSEANU (1979) and NĂSTĂSEANU et al. (1981). The Gresten-type Lower Jurassic is represented by a fining-upward terrigenous sequence, 800 to 1100 m thick, starting with Hettangian–Sinemurian conglomerates and sandstones, and continuing with Pliensbachian–Toarcian grey-blackish sandstones grading upwards to black clays. The siliciclastic sequence ends with Aalenian thick-bedded sandstones (100 to 250 m thick). The open-marine carbonate sedimentation started in the Early Bajocian with deposition of calcareous sandstones (10 m thick). It was followed by a condensed sequence (1.5 m thick) of dark grey ammonite-rich, commonly oolitic limestones in the Late Bajocian – Early Bathonian (NĂSTĂSEANU & BĂDĂLUŢĂ, 1984). The remaining Middle Jurassic succession (around 15 m thick) consists of cherty limestones. The Upper Jurassic succession (less than 150 m thick) is pelagic, with bedded or massive, cherty radiolarian limestones (Oxfordian – Lower Kimmeridgian), nodular Saccocoma limestones (Upper Kimmeridgian – Lower Tithonian) and cherty Calpionella limestones and marlstones (Upper Tithonian – Berriasian).

The Jurassic succession of the **Feneş** facies as described by NĂSTĂSEANU (1979) is made up of two distinct Jurassic successions which are allocated to different tectonic units (BERZA et al., 1994). The Arjana Nappe includes exclusively a volcano-sedimentary sequence, 200 to 500 m thick, assigned to the Middle and Upper Jurassic (up to Oxfordian). Pelagic carbonate deposits are intercalated with alkaline bimodal volcanic rocks (GHERASI & HANN, 1990; RUSSO-SĂNDULESCU et al., 1996).

East Serbian Carpatho-Balkanides

South to the Danube, Jurassic sediments of the Danubian-Vrška Čuka-Stara Planina (-Prebalkan) Unit are present in the Vrška Čuka-Miroč (Lower Danubian) and Stara Planina-Poreč (Upper Danubian) Units (KARAMATA et al., 1997).

Vrška Čuka-Miroč Unit (Lower Danubian) (Text-Fig. 15, col. 62)

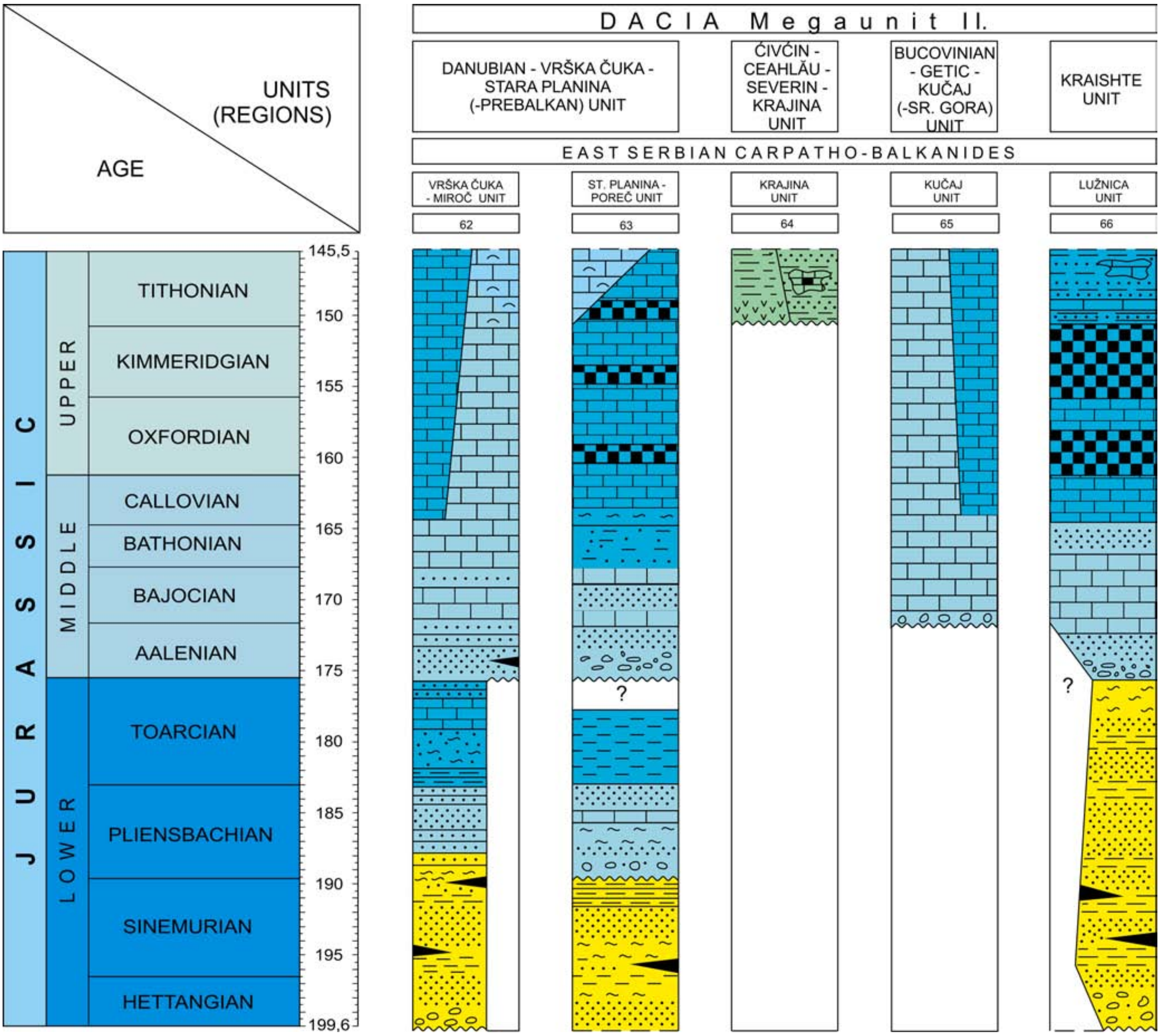
After the Late Carboniferous and Permian the area of this unit was a dry land until the Early Jurassic. In the Hettangian–Sinemurian shallow depressions were filled by basal clastics and later by estuarine-lagoonal coal-bearing facies with sandstones, shales and semi-anthracite beds. The Pliensbachian strata correspond to the shallow-water Gresten facies of the Eastern Alps. In the Toarcian deep-water black shales and carbonate layers are present. The Lower Jurassic unit may reach 300 m in thickness.

The whole area was submerged during the Middle Jurassic. Prevailingly up to 50 m thick neritic sediments (sandstones passing upward into sandy carbonates) were deposited.

The Upper Jurassic sequence is 240 m thick in the northwest but only 100 m in the southeast. It consists of the shallow-marine Oxfordian and Kimmeridgian carbonate rocks, followed by typical Tithonian reef and near-reef facies. In these regions the Callovian–Kimmeridgian is made of hemipelagic nodular limestones with chert. They are overlain by Tithonian to Berriasian deep-water limestones (DIMITRIJEVIĆ, 1997).

Stara Planina-Poreč Unit (Upper Danubian) (Text-Fig. 15, col. 63)

After the deposition of continental clastic sediments from Rhaetian to Lower Jurassic a new depositional cycle began with the deposition of terrigenous-carbonate successions in depressions. They are composed of marine conglomerates, sandstones, and shales including phosphorite concretions, oolitic iron ores. These deposits are followed by Pliensbachian formations after a short break. They have a variable thickness from 10 to 250 m and are conformably overlain by some 50 m of almost black Toarcian shales followed by a hiatus.



Text-Fig. 15.
Lithofacies chart of the East Serbian Carpatho-Balkanides Unit (62–66). (DACIA II).
Abbreviations:
Sr. Gora = Sredno Gora,
St. Planina = Stara Planina.

The transgressive Middle Jurassic is composed of quartz conglomerates and sandstones, later calcareous sandstones (20–250 m), which are followed by Bathonian sandstones and shales (15–20 m) and deeper marine Callovian limestones and marlstones. This sequence is overlain by grey and reddish Oxfordian and Kimmeridgian cherty limestones, marly limestones and radiolarites (50 m thick at the most). It is followed by Tithonian pelagic nodular limestones with cherts (~250 m thick). Reef facies also occur in the Tithonian, locally (DIMITRIEJVIĆ, 1997).

Ćivćin-Ceahlău-Severin-Krajina Unit

This unit, corresponding to the Outer Dacides (SĂNDULESCU, 1984), can be divided into the following segments: Eastern Carpathians (Ćivćin-Ceahlău-Black Flysch Units), Southern Carpathians (Severin Unit), and East Serbian Carpatho-Balkanides (Krajina Unit).

Eastern Carpathians

Ćivćin-Ceahlău-Black Flysch Unit (Text-Fig. 14, col. 61)

These units originate from a Jurassic to Cretaceous (para) oceanic trench/trough, which was situated along the European margin (Severin-Ceahlău Ocean) (SĂNDULESCU, 1980, 1994). They are built up of a basic magmatic basement that is covered by pelagic and flysch sediments. The greatest part of Jurassic formations can be found in the innermost Black Flysch Nappe, while the main Ceahlău Nappe is made up predominantly of Lower Cretaceous flysch (SĂNDULESCU, 1984, 1990).

The mafic complex of the **Black Flysch Nappe** is older than the sedimentary formations. The within-plate continental mafic complex is made up of submarine basalt flows and cineritic basic rocks (redeposited basalts, limestone breccias, schalstein is known as well; Pl. 10, Fig. 3), and are intruded by doleritic dykes and sills (RUSSO-SĂNDULESCU et al., 1998). The oldest dated sedimentary rocks are pelagic limestones with *Saccocoma* of Kimmeridgian or with calpionellids of Tithonian age. Thus, a Middle Jurassic (or perhaps Lower Jurassic) age of the lowermost part of the mafic complex is assumed, while Tithonian age of its uppermost part is proved. In the external scales, the mafic complex is covered by Black Flysch (Tithonian–Neocomian). It is preceded by the Mihailec-Vârtop Formation (basal Malm) that consists of calcareous breccias and allodapic limestones.

The Sinaia beds are the most characteristic and widespread formation of the **Ceahlău Nappe** (Pl. 11, Fig. 4). Its oldest member, 100 to 200 m thick, has a preflysch character. It is made up of grey-greenish marly shales, with scattered intercalations of micaceous sandstone and calcareous breccias (Tithonian). Dismembered slices or lenses (boudins) up to a km in size are squeezed into the lower and middle parts of the Sinaia beds. In these boudins red and green cherts and shales are genetically linked to pillowed basalts (Azuga beds, Upper Jurassic, up to the Tithonian; ŞTEFĂNESCU et al., 1979).

Southern Carpathians

Severin Unit (Text-Fig. 14, col. 60)

In the Southern Carpathians the **Severin Nappe** corresponds to the Ceahlău Nappe in the Eastern Carpathians. The Severin Nappe of CODARCEA (1940) is a tectonic mélange including Jurassic oceanic crust rocks and Tithonian – Early Cretaceous turbidites (STĂNOIU, 1997).

The ophiolitic complex is made of peridotites (serpentinites), gabbros, dolerites, basalts and tuffs (MĂRUNŢIU, 1983; SAVU, 1985). It is overlain by red, green or grey shales, interbedded with basic tuffites and basalts, red and green radiolarites, cherty or marly limestone, and sandstones of the Azuga beds (Upper Jurassic, up to the Tithonian). The deposition of the thick Sinaia beds, with distal turbidites and *Calpionella*-bearing limestones, began at the end of the Jurassic (Late Tithonian) and continued in the Neocomian (STĂNOIU, 1978).

East Serbian Carpatho-Balkanides

Krajina Unit (Text-Fig. 15, col. 64)

In the East Serbian Carpatho-Balkanides the Krajina Unit (GRUBIĆ, 1983; DIMITRIJEVIĆ, 1997; KARAMATA et al., 1999; KRÄUTNER & KRSTIĆ, 2003) corresponds to the Severin Unit of the Southern Carpathians in Romania.

The lowermost series is the pelagic “Azuga beds” that is made up of grey and pink siltstones, dark shales and sandstones with red cherts, basalts. They are overlain by Upper Tithonian – Berriasian flysch-type sediments: Sinaia Flysch (dark grey calcarenite, olistostrome breccia conglomerate and mica breccia) and its lateral equivalents, “quasi-Sinaia beds” which are more pelagic in character.

The Kiloma tectonic window with Tithonian–Neocomian basic metavolcanics, black shales and quartzites of the Kiloma Metadiabase Formation belongs also to this unit and may be equivalent to the Eastern Carpathian Black Flysch Nappe.

Bucovinian-Getic-Kučaj (-Sredno Gora) Unit

This unit, which corresponds to the Median Dacides of SĂNDULESCU (1984), can be subdivided into the following regions: Eastern Carpathians (Central Eastern Carpathian Nappe System), Southern Carpathians (Getic Unit) and East Serbian Carpatho-Balkanides (Kučaj Unit).

Eastern Carpathians

Bucovinian, Subbucovinian and Infrabucovinian Units (Text-Fig. 16, col. 67–70)

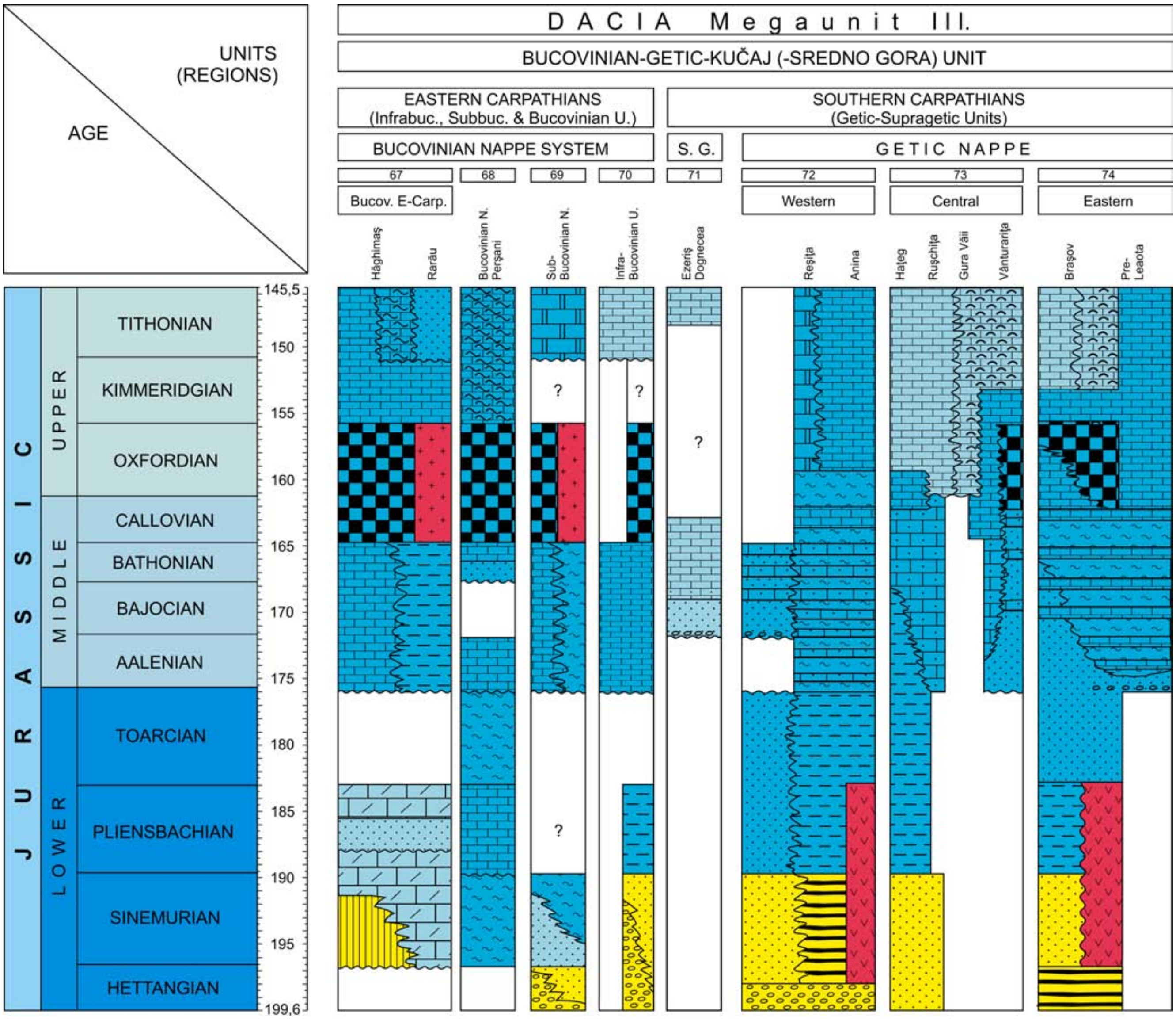
The Bucovinian, Subbucovinian and Infrabucovinian Units form a Mid-Cretaceous nappe stack, assigned to the Central Eastern Carpathian Nappe System (SĂNDULESCU, 1984). After a Late Triassic continental period, in the Early Jurassic condensed shelf sediments, punctuated by erosional gaps, were formed. The Early and Middle Jurassic sedimentation suggests a swell-type regime for the entire area, while during the Late Jurassic it was drowned and pelagic deposits and flysch sequences began forming (MUTIHAC, 1968; PATRULIUS et al., 1968, 1972; GRASU, 1971; TURCULEŢ, 1971, 2004; SĂNDULESCU, 1973, 1974, 1975a, 1976, 1984; POP, 1987). The Jurassic successions are typified by frequent unconformities that are overlain by transgressive sequences. The thickness of the formations significantly decreases from the internal Bucovinian zone to the most external Infrabucovinian zone.

The **Bucovinian** Jurassic succession is the most representative and complete, infilling two large synclines in the Hăghimaş and Rarău Mts (Text-Fig. 16, col. 67). In the **Hăghimaş** Syncline the succession starts with bauxites deposited on karstic surfaces of Middle Triassic carbonatic rocks, locally. Red oolitic or encrinitic limestones and reddish platy limestones (5 to 10 m thick) occur in the basal part of the marine sequence, which are assigned to the Sinemurian and Lower Pliensbachian (Patrulius, 1964; Grasu, 1971; Săndulescu, 1975a; Grasu et al., 2010). These are unconformably overlain by a Middle–Upper Pliensbachian Gresten-type sequence starting with basal conglomerates succeeded by dark-coloured sandy limestones, calcareous sandstones and fine-grained clayey sandstones. The Toarcian–Bathonian sequence, 20 to 270 m thick, is made up of grey-bluish sandy limestones with spongiolithic cherts succeeded by micaceous, silty marls and fine-grained sandstones. Blackish micaceous sandy limestones and argillaceous-silty sequences with *Bositra* occur in the southern regions (Dinu, 1971; Grasu & Turculeţ, 1978; Grasu et al., 2010).

In the **Rarău** Syncline, Lower Jurassic deposits are absent and the Middle Jurassic deposits are unconformably overlying the Middle Triassic carbonate rocks. They start with a 40 m thick breccia sequence, followed by reddish sandy, micritic or oolitic limestones (Stănoiu, 1967b).

In the **Subbucovinian Nappe** and **Infrabucovinian Units**, the Lower and Middle Jurassic deposits are poorly developed or absent (Text-Fig. 16, col. 69-70).

Ferruginous quartzitic conglomerates succeeded by a sandy-argillaceous sequence, made up of blackish silty clays and limonitized calcareous sandstones, of supposed Lower Jurassic age, and Middle Jurassic blackish calcareous sequences with *Bositra* occur in the Subbucovinic domain (Săndulescu, 1974).



Text-Fig. 16.
Lithofacies chart of the Bucovinian Unit (67–70) and Getic (s.l.) Unit (71–74) (in Romania). (DACIA III).
Abbreviations:
Infrabuc. = Infrabucovinian, Subbuc. = Subbucovinian,
Bucov. = Bucovinian, E-Carp. = Eastern Carpathians,
S. G. = Supragetic.

Lower Jurassic Gresten-type deposits, represented by metamorphosed black siltstones and argillites with thin-bedded sandstones are known only in the most external Infrabucovinian Units (i.e. in the Vaser Unit), while Middle Jurassic sandy limestones occur in the Iacobeni Unit (SĂNDULESCU, 1976).

During the Callovian and Oxfordian the whole Bucovinian and Subbucovinian domains and partially the Infrabucovinian domain were affected by a major transgression. Variegated radiolarites with intercalations of shales, siltstones, sometimes with tuffites and basic cinerites, are well developed in the Bucovinian, and locally in the Subbucovinian and Infrabucovinian series (STĂNOIU, 1967b; TURCULEȚ, 1978; DUMITRICĂ, 1995).

In the eastern zone of the Hăghimaş Syncline, the ?Callovian–?Oxfordian is represented by the Antaluc Formation (PATRULIUS et al., 1976). It is a dark-coloured, homogenous silty-argillaceous sequence (max. 120 m thick) with fine-grained micaceous sandstones, calcarenites and sideritic marly limestone intercalations.

In the **Perşani** Mts, the **Bucovinian** sedimentary series has a thin Jurassic succession with frequent gaps (Text-Fig. 16, col. 68). A lower sequence (~25 m thick) starts with transgressive Upper Pliensbachian reddish-yellowish sandy oolitic limestones, upsection with Lower Toarcian grey-blackish silty marls and marly limestones, and Upper Toarcian to Aalenian ferruginous oolitic and sandy ammonitic limestones (PATRULIUS, 1996; POPA & PATRULIUS, 1996). The Bathonian sequence (70 m thick) consists of whitish pseudo-oolitic or bioclastic limestones, and quartzose sandstones which unconformably overlay older formations. The Callovian to Oxfordian sequence is composed of reddish argillites and radiolarites, with grey sandstone, cherty limestone interlayers and thin intercalations of bentonites, and a Kimmeridgian–Tithonian *Aptychus*-bearing greenish marly-sandy-limy sequence (350 m thick) (TURCULEȚ & GRASU, 1973; PATRULIUS et al., 1976).

During the Tithonian the sedimentation became more diversified in the Bucovinian domain. Along its external part a flysch trough developed, site of deposition of the Tithonian–Berriasian Pojorâta beds (200–300 m thick) (SĂNDULESCU, 1973), whereas in the more external Tarnița tectonic scale, the Tithonian?–Neocomian Clifele beds are made up of polymictic sandstones and silty-shaly sequences with polymictic breccias (SĂNDULESCU, 1981). The inner zone was the sedimentation area of the Tithonian – Lower Valanginian Aptychus beds, 50–100 m thick, with a lower sandy-marly sequence succeeded by a limy-marly sequence (TURCULEȚ, 1971; SĂNDULESCU, 1973, 1976; POP, 1987). In the external zones of the Hăghimaş Syncline, the Tithonian–Neocomian is represented by the Lunca Formation (700 m thick at the most) that is composed of Aptychus marls with intercalations of sandstones, calcarenites and cherts (PATRULIUS et al., 1969; GRASU, 1971; GRASU & TURCULEȚ, 1973; SĂNDULESCU, 1975a; GRASU et al., 2010).

In the Perşani Mts, the Stejaru Flysch (Tithonian–Neocomian) is made up of two members:

1) limy sandstones, marlstones and marls, with calpionellids, and

2) a gritty-limy flysch above it (ŞTEFĂNESCU & ŞTEFĂNESCU, 1981).

Contemporaneously, in the Subbucovinian Nappe polymictic breccia with Calpionella limestones and marly sequences were formed, whereas in the Infrabucovinian Units shallow-water *Clypeina*-bearing carbonates were deposited (SĂNDULESCU, 1973, 1976).

A Callovian–Oxfordian (160 Ma) nepheline-syenite intrusion (Ditrău) and dykes of Jurassic age are known in the Bucovinian and Subbucovinian Nappes (KRÄUTNER & BINDEA, 1998).

Southern Carpathians

Getic-Supragetic Units (Text-Fig. 16, col. 71–74)

The Jurassic formations have the widest distribution in the Getic Nappe while in the Supragetic Units there are only scarce and very incomplete successions.

Although there are similar facies in various areas and time intervals, the different zones show distinct sedimentary features, which suggest complexity of the Jurassic paleogeography in the Getic Domain (CODARCEA & POP, 1970; PATRULIUS et al., 1972; DRAGASTAN, 2010).

In the Getic domain, after a Late Triassic uplift, the sedimentation started in the early part of the Early Jurassic with Gresten-type deposits overlain by hemipelagic Toarcian deposits. From the Late Callovian onward, troughs formed which were characterized by a continuous sedimentation leading to the deposition of thick successions with hemipelagic to pelagic sediments. In contrast, thin sequences with many gaps were formed on swells. In the central and eastern areas of the Getic domain carbonate platforms began to form in the latest Jurassic.

Complete successions occur in the **western**, **Reşița-Anina** region of the Getic domain (Text-Fig. 16, col. 72) (RĂILEANU et al., 1964; BĂDĂLUȚĂ, 1976; NĂSTĂSEANU et al., 1981; BUCUR, 1997). Coarse clastics occur at the base of the Gresten-type sequence, they are followed by sandstones, siltstones and clays containing coal seams and vegetal remains (Steierdorf Formation; Pl. 12, Fig. 2) of Hettangian to Sinemurian age (SEMAKA, 1965; GIVULESCU, 1998; POPA & VAN KONIJNENBURG-VAN CITTERT, 2006). Pliensbachian black bituminous shales containing spherosiderites and coal lenses (~200 m thick) are overlain by a Toarcian silty argillaceous ammonitic sequence (10 to 15 m thick) (MUTIHAC, 1959). In the Middle Liassic, alkaline trachyte and basalt volcanism took place. In the central area there is a 90 m thick continuous succession from Aalenian to Lower Callovian, with hemipelagic *Bositra* spotty marls and marly limestones. In the eastern marginal area, a transgression took place during the Middle Jurassic that resulted in the deposition of basal coarse-grained sandstones and later on, in the Bathonian to Early Callovian sandstones and marly limestones (BOLDUR et al., 1964).

The Middle Callovian consists of sandy limestones with cherts (15 to 20 m thick). In the eastern marginal area crinoidal limestones or glauconite-bearing sandy limestones developed coevally (RĂILEANU & NĂSTĂSEANU, 1965). They grade upwards into Upper Callovian – Lower Oxfordian medium-bedded, dark grey marls (80 to 100 m thick). The occurrence of *Kosmoceras* in this formation demonstrates close connection of this unit to the Boreal realm (PATRULIUS & POPA, 1971; BĂDĂLUȚĂ, 1976).

The Upper Oxfordian to Lower Berriasian interval was characterized by pelagic and allodapic limestones, banded or nodular cherts (250 to 300 m thick; Upper Oxfordian – Lower Kimmeridgian), Ammonitico Rosso-type Saccocoma limestones (50 to 100 m thick; Upper Kimmeridgian – Lower Tithonian), Maiolica-type limestones (100 to 200 m thick; Upper Tithonian – Middle Berriasian).

In the **Reşiţa** and *Sasca-Gornjak* Nappes the Bajocian? to Callovian formations lie transgressively either on Permian or Middle Triassic rocks with basal microconglomerates, sandstones, bioclastic and cherty nodular limestones (BUCUR et al., 1997). In the the western Supragetic domain, i.e. in the **Ezeriş-Dognecea** region, a carbonate platform rimmed by oolithic shoals developed in the Middle Jurassic (BUCUR, 1997). It is capped by Upper Tithonian-Barremian platform carbonates (POP, 1976) (Text-Fig. 16, col. 71).

In the **central** part of the Getic domain, including **Haţeg**, **Ruşchiţa**, **Gura Văii** and **Vânturariţa** regions (Text-Fig. 16, col. 73) the Jurassic succession starts also with a Lower Jurassic Gresten-type formation (100 to 125 m thick). It grades upwards to a Middle Jurassic mixed siliciclastic-carbonate sequence, around 100 m thick. The Oxfordian – Lower Kimmeridgian is represented by marly and cherty-calcareous successions which are overlain by Stramberg-type massive reefal limestones (STILLA, 1985). In other areas the Jurassic transgression started in different times, and in some places the pre-Jurassic basement is directly covered by Stramberg-type limestones.

In the **eastern** part of the Getic domain (Text-Fig. 16, col. 74), the Jurassic is typified by various facies and complex stratigraphic relationships (SĂNDULESCU, 1964, 1984; PATRULIUS et al., 1968, 1976; PATRULIUS, 1969, 1976b; SĂNDULESCU et al., 1986). In the **Braşov** Unit, i.e. in the *Cristian* and *Holbav* regions, the Lower Jurassic is represented by Gresten-type deposits, reaching 250 m in thickness. The coal-bearing succession with refractory clays occurs in the Hettangian–Sinemurian interval (SEMAKA, 1965; PHILIPPE et al., 2006) although in the Holbav region the coal accumulation lasted till the Lower Toarcian (ANTONESCU, 1973). In the Cristian region the marine influences initiated in the earliest Sinemurian, while in the Pliensbachian–Toarcian the marine sedimentation became general, leading to the deposition of micaceous hemipelagic sandstones. Alkaline volcanic rocks (rhyolitic ignimbrites, basalts and trachytes) are common (SĂNDULESCU et al., 1986).

The Middle Jurassic is transgressive and shows different facies in the eastern Getic domain (PATRULIUS, 1969; LAZĂR, 2006) (Pl. 12, Figs. 1 and 3). In some parts of this domain, i.e. in the Bucegi Mts, the Bajocian is typified by shallow-water fossiliferous mixed siliciclastic-carbonate deposits, of variable thickness, from 3 to 55 m. They directly overlay the crystalline basement. The Bathonian – Lower Callovian interval is condensed, less than 1.5 m thick. It consists of ammonitic limestones with ferruginous ooids and nodules, capped by a polyphase hardground (PATRULIUS, 1969; LAZĂR, 2006). The following starved sedimentation and planktonic foraminifera demonstrate the onset of marked deepening of the region starting with the Middle Callovian (NEAGU, 1996). In other parts of the domain, i.e. in the Braşov Mts, quartzose conglomerates and sandstones transgressively onlap the Toarcian micaceous sandstones. The Lower Bathonian silty clays and marls are followed by Upper Bathonian – Lower Callovian marly-silty and limy deposits with *Bositra* (more than 100 m thick). Locally, on elevated areas of the crystalline basement, a transgressive carbonate sequence occurs. It starts with a basal breccia and continues upwards with alternating Middle to Late Callovian reddish micritic limestones and brown-yellowish bioclastic-sandy limestones (SIMIONESCU, 1899).

A deep-water sedimentary sequence with cherty limestones and variegated radiolarites (less than 1.5 m thick) occasionally with basic volcaniclastics, characterizes the Middle Callovian to Oxfordian interval (BECCARO & LAZĂR, 2007). In some places the Callovian radiolarites are unconformably overlain by pelagic limestones and marls of Late Oxfordian to Neocomian age (**Pre-Leaota** Group; less than 100 m thick). Lower Kimmeridgian Ammonitico Rosso-type limestones (less than 10 m thick) occur only locally. The Late Kimmeridgian to Early Valanginian interval is represented by a thick succession (up to 900 m) of Stramberg-type limestones (Pl. 12, Fig. 1).

In contrast to the eastern Getic Nappe where a mostly complete Jurassic to Lower Cretaceous sequence is present, the Jurassic to Lower Cretaceous deposits are almost absent in the eastern Supragetic Units, suggesting a swell-type regime of the Supragetic domain (SĂNDULESCU, 1966). Locally the Middle Triassic rocks are unconformably overlain by a thin sequence with Lower Jurassic coal-bearing deposits and marine encrinitic limy sandstones (GRĂDINARU, unpubl.).

East Serbian Carpatho-Balkanides

Kučaj Unit (Getic) (Text-Fig. 15, col. 65)

In the Bajocian, basal clastics and oolitic limestones were formed transgressively above a Middle Triassic to Carnian basement. After that, in the largest, eastern part of the unit the platform carbonates were developed up to the Aptian. In the western regions of the unit Callovian–Tithonian deep-water deposits occur.

Kraishte Unit

East Serbian Carpatho-Balkanides

The Kraishte Unit is located in the territory of Bulgaria; the Lužnica Unit of the East Serbian Carpatho-Balkanides is considered as prolongation of the west Kraishte. It is characterized mainly by thick flysch deposits in the Upper Jurassic (Ruj flysch) and specific basement rocks (e.g. Diabase-Phyllitoid and other units).

Lužnica Unit (West Kraishte) (Text-Fig. 15, col. 66)

The Lower Triassic deposits are covered by Lower Jurassic quartz conglomerates, micaceous sandstones (with coal deposits) and shales. This sequence is conformably overlain by Middle Jurassic coarse grained sandstones and sandy limestones sporadically with oolitic iron ores (20 m). Then 50–100 m thick Oxfordian–Kimmeridgian limestones follow with chert nodules, and subordinately dolomitic limestones and dolomites.

The Ruj flysch principally characterizes the unit (DIMITRIJEVIĆ, 1997). The sedimentation is initiated by ?Middle Jurassic pre-flysch followed by sandstones, olistostromes and calcarenites. Reef limestones and cherty limestones were formed during the Tithonian. Discontinuous bodies of black non-flysch shales and olistoliths of Upper Jurassic limestones of various shape and size (up to 1000 m^3) are also characteristic. The total thickness of the formation is more than 1700 m in the proximal part.

History of Evolution and Notes for Paleogeographic Interpretation

In the Late Triassic to Early Jurassic spreading in the Neotethys realm still continued. The closure of the western Neotethys realm started in the late Early to Middle Jurassic (GAWLICK et al., 2008; compare SCHMID et al., 2008) and it was usually completed by the Late Jurassic although the latest oceanic basins still existed until the latest Cretaceous – earliest Paleogene, locally (USTASZEWSKI at al., 2009). However, in connection with the opening of the central Atlantic Ocean a new oceanic branch started to open through continental rifting from the Late Triassic and progressed to ocean opening from the late Early Jurassic onward (Piemont-Penninic Ocean respectively "Alpine Atlantic" or "Alpine Tethys"; FRISCH, 1979; DERCOURT et al., 1986, 2000; STAMPFLI et al., 1991; FRISCH et al., 1998; PLAŠIENKA, 2002; STAMPFLI & BOREL, 2002; CSONTOS & VÖRÖS, 2004; GOLONKA, 2004; GOLONKA & KROBICKI, 2004; HAAS & PÉRÓ, 2004; MISSONI & GAWLICK, 2010). This resulted in the dismembering of some parts of the Eurasian Plate and the reorganisation of the plate fragments between the Eurasian and Gondwana plates. So, coeval development of the two ocean systems controlled basically the Jurassic evolution of the Circum-Pannonian region.

During Early to Middle Jurassic the ocean basin which separated Eurasia (with attached units) and Gondwana (Adria/Apulia) was still large, in spite of narrowing because of the subduction that took place along an intraoceanic subduction zone (e.g. NICOLAS & BOUDIER, 1999; DILEK & FLOWER, 2003; KARAMATA, 2006; KOLLER at al., 2006). On the margin of the Adria/Apulia, evolution of huge carbonate platforms continued during the entire Jurassic (and even during the Cretaceous) exporting a large amounts of carbonate mud and grain to the newly formed trenches; some of them became part of the Neotethyan accretionary complex in the course of the subduction and ophiolite obduction. This process was accompanied by intense gravity mass movements that resulted in the formation of deep-water chaotic deposits (GAWLICK et al., 1999; DIMITRIJEVIĆ et al., 2003) in the trenches. In the Late Jurassic, closure of this basin was mostly completed and it was followed by strong erosion. The nappe stacks as well as the ophiolites were covered by platform limestones during the Kimmeridgian to Berriasian.

Large parts of the huge Late Triassic carbonate platforms developed all around the Neotethys margin drowned at the Triassic/Jurassic boundary. In the early part of the Early Liassic the western Penninic-Piemont related part of Apulia/Adria (the western part of the South Alps and the Transdanubian Range) was subject to intense rifting that resulted in the formation of rift-related basins. Coevally large extensional basins came into existence along the European margin (Helvetic, Pieniny, Mecsek, Getic-Kučaj Units) – site of deposition of fluvial, deltaic, and paralic coal swamp facies (Gresten facies) in the Rhaetian to Early Sinemurian interval. This process can be considered as an incipient stage of evolution of the Piemont-Penninic Ocean. The continental to shallow-marine siliciclastic sedimentation was followed by deposition of bioturbated shale in an upward deepening basin from the Late Sinemurian to the Bathonian. Both the Tatric Unit of the Western Carpathians and the Villány-Bihor Unit of the later Tisza Megaunit preserved their swell position and large parts of these areas were subaerially exposed for shorter or longer time.

The double effect of ongoing Neotethys rifting and incipient rifting (sinistral transtension) of the Piemont-Penninic Ocean (FRISCH, 1979; RATSCHBACHER et al., 2004) resulted in a step-by-step disruption and drowning of the still existing platforms between the two oceanic basins during the Early Jurassic (PLAŠIENKA, 1998; GAWLICK et al., 1999; HAAS, 2002). In the Pliensbachian/Toarcian most of the still existing carbonate platforms were subject to drowning in the studied region with exception of the huge Adriatic Carbonate Platform that survived during the entire Jurassic and even during the Cretaceous (DRAGIČEVIĆ & VELIĆ, 2002).

In connection with the opening of the Atlantic Ocean, the spreading of the Piemont-Penninic Ocean led to the separation of the Austroalpine-Central Western Carpathian and the Tisza Megaunits from other parts of the European plate (FAUPL & WAGREICH, 2000; GOLONKA & KROBICKI, 2004; HAAS & PÉRÓ, 2004). However, according to the relevant paleomagnetic data, prior to the Hauterivian the Tisza Megaunit moved together with the European plate and its real dismembering and remarkable rotation began only at that time (MÁRTON, 2000).

The Penninic Ocean continued eastward in the supposed "Vahicum" (Penninic-Vahic trough), although remnants of the oceanic basement are missing (PLAŠIENKA, 1998, 2000). Further eastward in the Krichevo-Ceahlău-Severin zone the rifting processes began in the Early Jurassic along the European margin and led to the separation of a continental sliver corresponding to the Bucovinian-Getic-Kučaj Unit of the Eastern and Southern Carpathians and East Serbian Carpatho-Balkanides (SĂNDULESCU, 1984, 1988). It was accompanied with the formation of volcano-sedimentary sequences and intrusions. The oceanic basin reached its maximum extension at the end of the Middle Jurassic coeval with the onset of the subduction. A significant crustal shortening took place in the latest Tithonian to earliest Cretaceous.

In the late Early Jurassic to Middle Jurassic, parallel to the opening of the Piemont-Penninic Ocean, subduction of the Neotethys initiated, which resulted in the formation of accretionary wedges in the Middle to early Late Jurassic (MELLO et al., 1998; HALAMIĆ et al., 2005; KARAMATA et al., 2005; GAWLICK et al., 2008). More of less displaced remnants of them are preserved in the Vardar Zone, Dinaridic Ophiolite Belt, Mureş Ophiolite Zone, Darnó-Szarvaskő Units and Meliata-Hallstatt Zone.

During the late Middle to Late Jurassic period deep-sea conditions prevailed over a predominant part of the ALCAPA, Tisza and Dacia Megaunits. However, at the beginning of the Callovian a significant change took place in the sedimentation pattern, the deposition of condensed pelagic carbonates was usually followed by the deposition of radiolarites.

At the same time gravity mass-flow deposition initiated in the southern part of the NCA/Western Carpathians as well as in the Dinarides/Albanides/Hellenides and somewhat later in the Oxfordian in the northern part, indicating the closure of the Neotethys in this region. The mass-flow deposits were covered by platform carbonates (Plassen Carbonate Platform and equivalents) of

Kimmeridgian to Early Berriasian age (GAWLICK & SCHLAGINTWEIT, 2006). Similarly, in the Main Vardar Zone the accretionary complex was transgressively overlain by Tithonian reef limestones (KARAMATA et al., 2000) as well as the Mirdita ophiolites as southward continuation of the DOB (SCHLAGINTWEIT et al., 2008). The Pogari series (North Bosnia) also contains blocks of Tithonian platform carbonates. Extended Late Jurassic to earliest Early Cretaceous carbonate platforms covered the island volcanic arcs in the Mureş Zone, feeding with debris the oceanic basins where pelagic sediments (Aptychus beds) were deposited (SĂSĂRAN, 2006; SĂSĂRAN & BUCUR, 2006).

In the pelagic basins the radiolarian rich deposits were usually overlain by red and grey Saccocoma limestones in the Kimmeridgian to Early Tithonian and Biancone-type Calpionella limestones in the Late Tithonian to Early Cretaceous.

The Tatric and Fatro-Veporic Units of the Austroalpine-Central Western Carpathian Megaunit (PLAŠIENKA, 1998) as well as the Villány-Bihor Unit in the Tisza Megaunit and also the Bucovinian-Getic-Kučaj Unit (Median Dacides) (SĂNDULESCU, 1984) that were located relatively far from both the Penninic and the Neotethys realms still preserved their relatively elevated (swell) position.

In the Getic and Lower Danubian Units in the Southern Carpathians, the Oxfordian to Early Kimmeridgian pelagic deposits were covered by Late Kimmeridgian to Tithonian Stramberg-type platform carbonates with reef deposits. Tithonian reef limestones were formed in the Stara Planina-Poreč and Vrška Čuka-Miroč Units of the East Serbian Carpatho-Balkanides.

Conclusions

During the Jurassic, as a consequence of the opening of the Atlantic-related Piemont-Penninic Ocean near to the western end of the still developing Neotethys, a peculiar geodynamic situation came into existence in the Circum-Pannonian region.

In the earliest Jurassic, the paleo-position of the structural units did not change significantly compared to their Middle to Late Triassic setting. The basic geodynamic changes began in the late Early to Middle Jurassic when the opening of the Piemont-Penninic(-Vahic), and Ceahlău-Severin Oceans resulted in the dismembering of parts of the Eurasian plate margin leading to the formation of several continental plate fragments (Austroalpine-Central Western Carpathian, Tisza, Bucovinian-Getic-Kučaj) which played an important role in the subsequent history.

The next main evolutionary stage was the subduction in the Neotethys realm during the latest Early Jurassic to early Late Jurassic period. Radiometric age data for amphibolite facies metamorphic soles (for data see in the description of the Dinaridic Ophiolite Belt and Vardar Zone; KARAMATA, 2006) beneath large ultramafic bodies constrain Jurassic oceanic thrusting. The middle to early Late Jurassic obduction was directed onto the Adriatic/Apulian margin (GAWLICK et al., 2008; SCHMID et al., 2008). It was post-dated by overlying latest Jurassic platform carbonates. These processes resulted in the formation of ophiolite nappes and accretionary complexes with a complicated internal structure and complicated history of development. In the course of this process (i.e. the “Eohellenic phase”; JAKOBSHAGEN, 1986) the oceanic sediments were subject to strong deformation, the attenuated continental crust crushed and nappe-stacks were formed, accompanied by metamorphism of the deepest nappe. Basins developed in connection with the nappe stacking were filled up by reworked material of the nappes.

The suture zone of the Neotethys can be continuously followed in the Serbian-Bosnian sector of the Dinarides-Vardar Zone, although it was subject to multistage nappe stacking and multiple redeposition of the components of the ophiolite mélange after the Jurassic.

In the Transylvanides, representing also a segment of the Neotethys, remnants of the oceanic basin (island arc and back-arc complexes and flysch) occur in nappes that were emplaced onto the SE margin of the Tisza Megaunit (Metaliferi Mts, Southern Apuseni) in the Late Cretaceous. Displaced remnants of the oceanic basement also appear in the Eastern Carpathians, Dacia Megaunit in the Mid-Cretaceous obducted Transylvanian Nappe System, and in smaller or larger blocks in the Lower Cretaceous Bucovinian wildflysch.

The deformations and nappe stackings due to the closure of the Neotethys (Jurassic to Cretaceous/Paleogene) and the various Jurassic–Cretaceous oceanic basins of the Penninic-Piemont-Ligurian realm (Late Cretaceous to Neogene) and corresponding interactions among the microcontinental blocks led to significant displacements/rotations. However, real terrane disruption and large scale dispersion of the northwestern Neotethys remnants took place mainly in the Tertiary with a northeastward movement of the Gemer-Bükk-Zagorje Unit between the Periadriatic and the Mid-Hungarian lineaments, in the Mid-Hungarian shear zone (CSONTOS & NAGYMAROSY, 1998). That is why displaced parts of the Kalnik Unit, that is the northwesternmost remnant of the Neotethys suture zone of the Adria-Dinaria Megaunit, can be found in the territory of NE Hungary (Bükk-Darnó area).

On two sides of the Mid-Hungarian shear zone (Gemer-Bükk-Zagorje Unit) exotic terranes construct the basement of the Pannonian Basin: the Transdanubian Range Unit representing a dislocated fragment of the Adria and the Tisza Megaunits which belonged to the European margin until the Middle Jurassic. Differences in the paleogeographic setting of these units are reflected in their significantly different development in the Devonian to Jurassic interval.

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Plate 1

Fig. 1: Massive serpentinite, Penninic, Rechnitz Unit, Bernstein tectonic window.
Bernstein N quarry, Rechnitz Mts (photo: Cs. Péró).

Fig. 2: Folded Late Jurassic – Lower Cretaceous "Kalkglimmerschiefer" from the "Bündner Schist Series", Penninic Units, Glockner Nappe, Fuscher-Kar-Kopf, Glocknergruppe, Hohe Tauern Mts (photo: Cs. Péró).

Fig. 3: Bedded grey cherty limestones of the Early Jurassic Scheibelberg Formation (Allgäu Group) in the Wimbach valley south of the village Berchtesgaden (Berchtesgaden Calcareous Alps) (photo: H.-J. Gawlick).

Fig. 4: Sinemurian to Toarcian Adnet Formation from the type locality Adnet village (Adnet quarries).
The lower, bedded nodular limestones belong to the Lienbach Member overlain by the Scheck Member, which consist of Late Pliensbachian to Early Toarcian mass flow deposits (Salzburg Calcareous Alps) (photo: H.-J. Gawlick).

Fig. 5: Well-bedded Early Oxfordian red and grey radiolarite with intercalated mass flow deposits, which consist of reworked lagoonal Dachstein Limestone and overlying sediments of the Tauglboden Formation.
Type locality Taugl Valley East of the village Kuchl (Salzburg Calcareous Alps) (photo: H.-J. Gawlick).


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Plate 2

Fig. 1: Well-bedded Early Oxfordian reddish to black radiolarite on top of Callovian Klaus Formation.
Fludergraben valley north of the village Altaussee (Salzkammergut area) (photo: H.-J. Gawlick).

Fig. 2: Type locality of the Late Tithonian Oberalm Formation with intercalated Barmstein Limestone (thick bed on top of the well-bedded grey cherty limestones), which consists of reworked shallow-water reefal carbonates from the Plassen Carbonate Platform. Adnet Riedel northwest of the village Adnet (Salzburg Calcareous Alps) (photo: H.-J. Gawlick).

Fig. 3: Polymictic mass flow of the Callovian to Oxfordian Strubberg Formation with components of the Triassic Pötschen Formation. Mount Rauhes Sommereck south of the village Scheffau (Salzburg Calcareous Alps) (photo: H.-J. Gawlick).

Fig. 4: Type locality of the Kimmeridgian to Berriasian Plassen Formation.
Mount Plassen west of the village Hallstatt (Salzkammergut area) (photo: H.-J. Gawlick).

Fig. 5: Neptunian dyke in the Dachstein Limestone filled by Lower Jurassic marine sediments and fragments of the host rock and previous fissure fills.
Transdanubian Range Unit, Tata (photo: J. Haas).

Plate 3

Fig. 1: Triassic Dachstein Limestone is overlained by pinkish deeper water Lower Jurassic limestones.
There is a gap at the boundary; the Lower Hettangian is missing. Transdanubian Range Unit, Tata (photo: J. Haas).

Fig. 2: Condensed but complete Jurassic succession from the topmost bed of the Dachstein Limestone to the Upper Jurassic deep sea deposits.
Transdanubian Range Unit, Pisznice, Gerecse Mts (photo: J. Haas).

Fig. 3: Radiolaritic chert beds, Bathonian–Callovian, Transdanubian Range Unit, Tata (photo: J. Haas).

Fig. 4: Hardground in Kimmeridgian red nodular limestones, rich in ammonites.
The neptunian dykes are filled with Tithonian limestones.
Transdanubian Range Unit, Tata (photo: J. Haas).

Fig. 5: Steeply dipping radiolarite and olistostrome beds with large “Bükkzsérc-type” limestone olistoliths, Mónosbél Unit, Tardos quarry, Bükk Unit s.l., Mónosbél, Bükk Mts (photo: J. Haas).

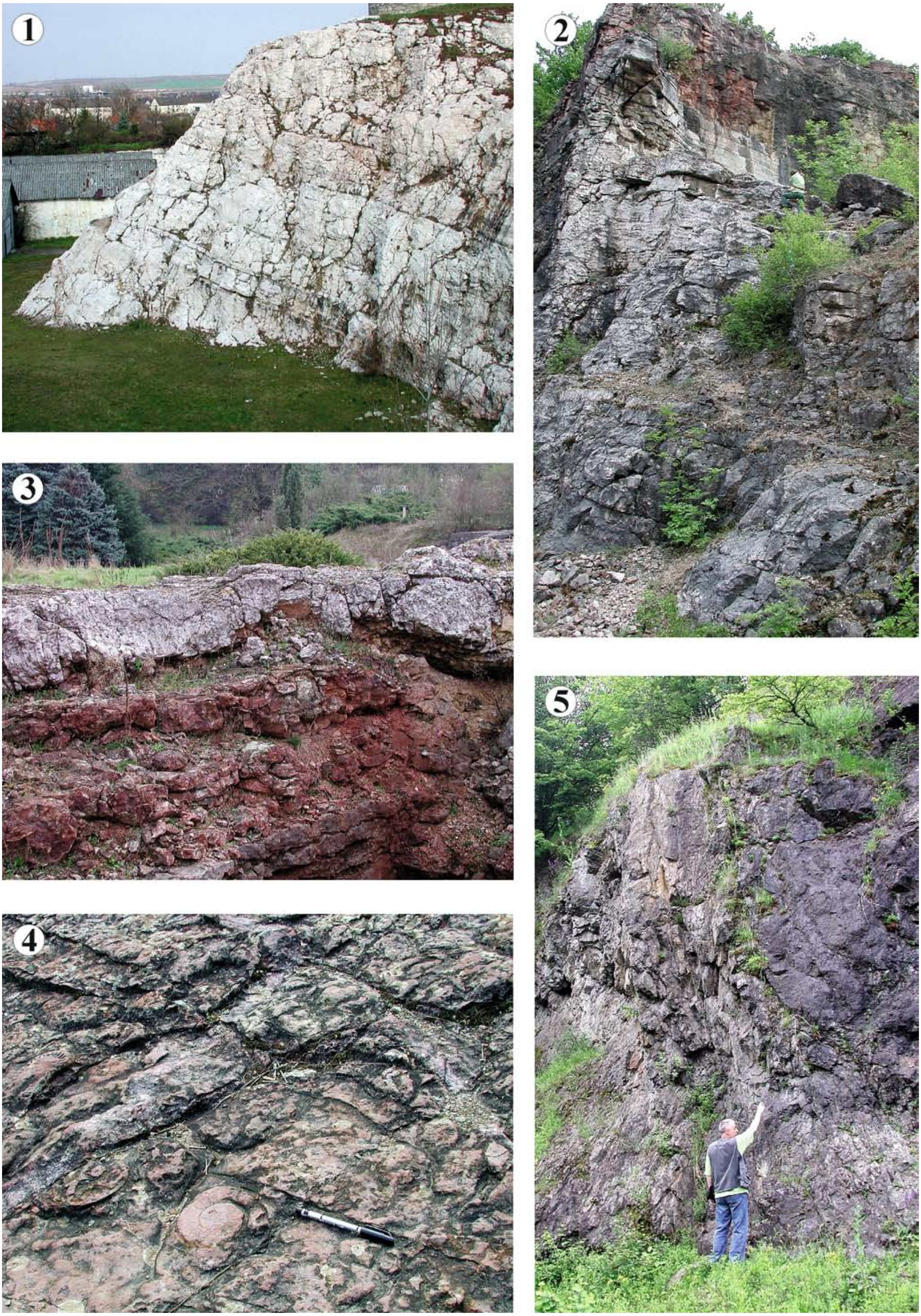

Plate 4

Fig. 1: A larger carbonate olistolith in an olistostrome (debrite) bed, Bükk Unit s.l., Mónosbél Unit, Bátor, Bükk Mts (photo: J. Haas).

Fig. 2: Olistostrome (debrite) containing mostly carbonate clasts. Bükk Unit s.l., Mónosbél Unit, Core Rm-118, Recsk, Mátra Mts (photo: J. Haas).

Fig. 3: Oolite turbidite beds. Bajocian.
Bükk Unit s.l., Mónosbél Unit, Bükkzsérc, Bükk Mts (photo: J. Haas).

Fig. 4: Middle Jurassic pillow basalts in overturned position.
Bükk Unit s.l., Szarvaskő Nappe, Szarvaskő Gorge, Bükk Mts (photo: Cs. Péró).

Fig. 5: Pillow basalts, Bükk Unit s.l., Darnó Unit, Nagy-Rézoldal, Darnó Hill, Recsk, Mátra Mts (photo: J. Haas).

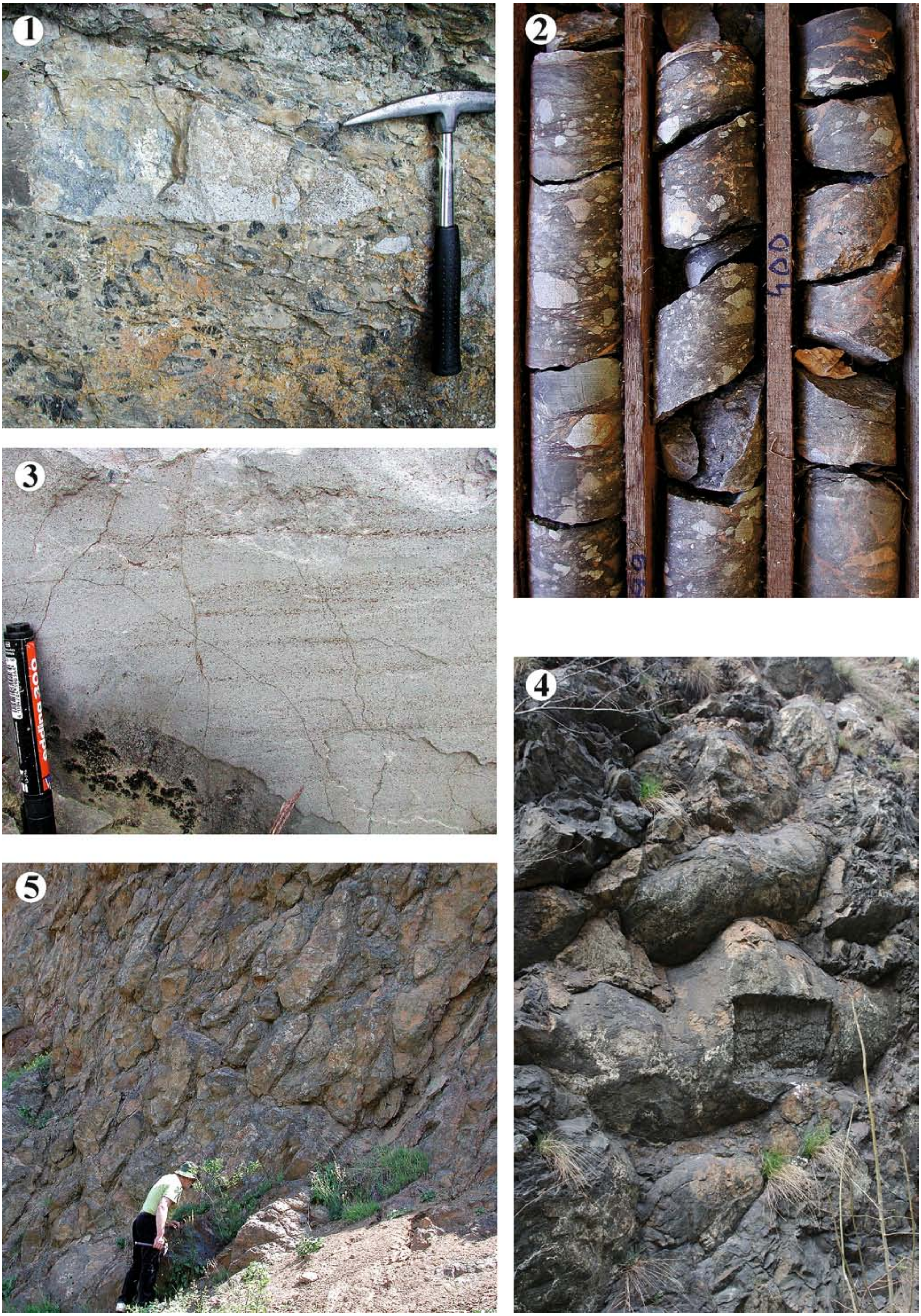
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Plate 5

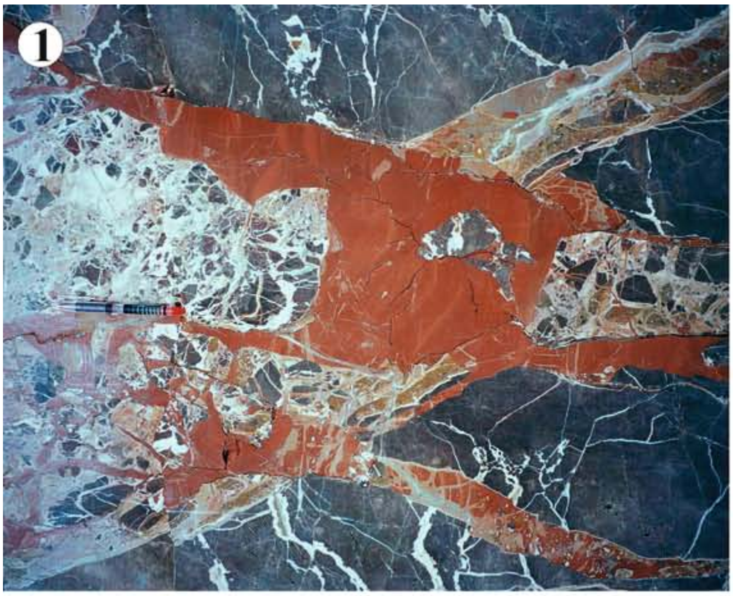
Fig. 1: Lower Liassic unstratified, varycolored micritic and skeletal limestones cut by neptunian dykes with Pliensbachian red crinoideal and micritic pelagic limestone infillings.
South Alpine Unit, Lombardian Basin, Arzo, Switzerland (photo: J. Haas).

Fig. 2: Red radiolaritic cherty limestone of Rosso ad Aptici Mb. (Upper Oxfordian – Middle Tithonian, and overlying white coccolith limestones Maiolica Fm. (here Berriasian–Barremian).
South Alpine Unit, Lombardian Basin, Breggia Gorge, Morbio Superiore, Switzerland (photo: J. Haas).

Fig. 3: Lower Jurassic Lithiotis beds, and overlying thick, monotonous Middle Jurassic – Lower Cretaceous carbonate platform.
Central Bosnian Mt Unit, Mrtvica Canyon, Mrtvo Duboko locality, Maganik Mts (photo: Cs. Péró).

Fig. 4: Upper Jurassic platform carbonates (East Bosnian – Durmitor Unit, Durmitor Subunit) overthrust on Maastrichtian limy Durmitor Flysch Formation (Central Bosnian Mt Unit).
Bobotov Kuk peak over Samar Pass, Durmitor Mts (photo: Cs. Péró).

Fig. 5: Serpentinites of Mirdita ophiolites, Mirdita/Dinaridic Ophiolite Belt.
Gomsiquës Gorge, W of Korthpulë locality, Dukadzin Mts (photo: Cs. Péró).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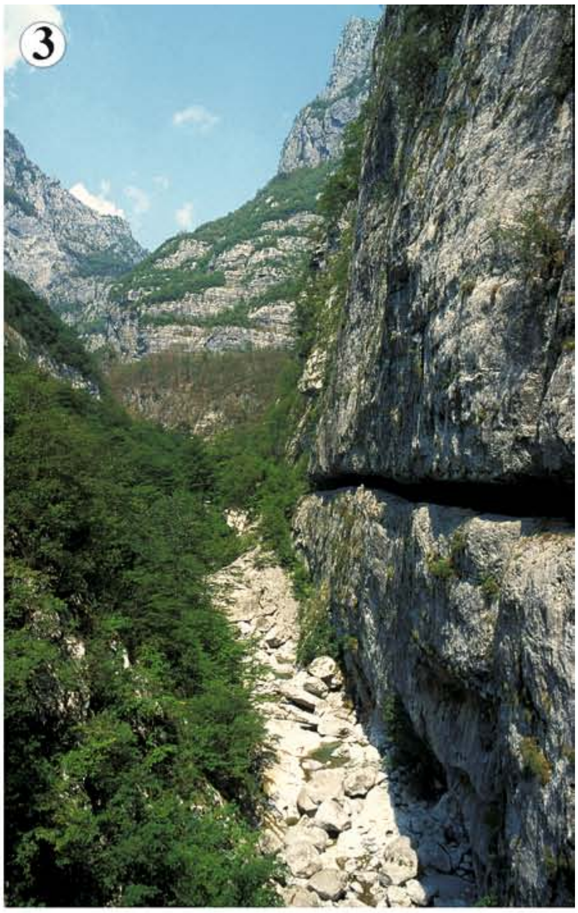
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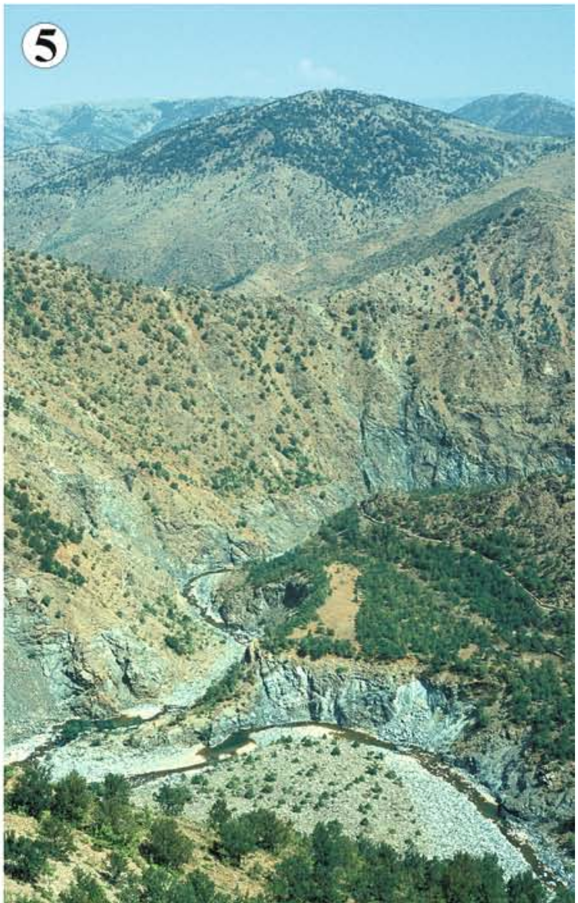
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Plate 6

Fig. 1: Deformed Middle – Upper Jurassic red, green and black platy cherts and radiolarites intercalated with few thin carbonate turbidite beds of shallow-water origin.
Dinaridic Ophiolite Belt, road Nova Varoš – Bistrica, Zlatar Mt (photo: Cs. Péró).

Fig. 2: Coarse limestone olistostrome block resedimented in red Jurassic radiolaritic shales.
Dinaridic Ophiolite Belt, Bela Reka, Ljubiş, Zlatar Mt (photo: J. Haas).

Fig. 3: Calciturbiditic lenses with coarse calcarenite and radiolarite detritus on the base of a channel in red Upper Doggerian – Malmian radiolarites and shales.
Dinaridic Ophiolite Belt, Kriš Gradac, Zlatar Mt (photo: J. Haas).

Fig. 4: Debrite on the base of an ooidic calcarenite bed with limestone, volcanite and bioclastic clasts.
Dinaridic Ophiolite Belt, Stremenica, Zlatar Mt (photo: J. Haas).

Fig. 5: Zlatibor ultramafic massif of the Dinaridic Ophiolite Belt.
Lherzolites, road Vode – Vodice, Zlatibor Mt (photo: S. Kovács).

Fig. 6: Maljen ultramafic massif of the Vardar Zone Western Belt.
Serpentinized peridotites (left) over ophiolitic mélange (right) made of blocks of pillow lavas, cherts, rare limestones, etc. in silty-shaly matrix.
Road Kaona – Mionica, over Divčibare before Kraljevski Sto peak (photo: D. Milovanović).


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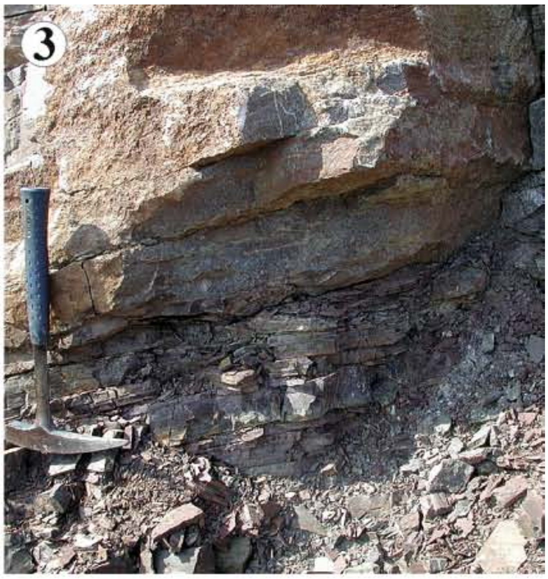
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Plate 7

Fig. 1: Sheeted diabase dyke complex. Main Vardar Zone, Ždraljica locality, Kragujevac (photo: K. Šarić).

Fig. 2: Basaltic pillow lavas in the olistostrome/mélange deposits of the Main Vardar Zone.
Road Kuršumlija – Žuč (photo: K. Šarić).

Fig. 3: Basaltic pillow lavas and dyke (in the left, with S. Karamata).
Sheeted dyke complex in olistostrome/mélange deposits of the Main Vardar Zone, NW from Kuršumlija (photo: Cs. Péró).

Fig. 4: Small nappe outlier of massive Stramberg-type limestone (Tithonian), with Ammonitico Rosso (Kimmeridgian) in the base (covered), overthrust to the top of the Bucovinian Wildflysch (Barremian – Lower Albian).
Transylvanides, Hăghimaş Nappe, Mt. Piatra Singuratică, near Bălan locality, Hăghimaş Mts (photo: Cs. Péró).

Fig. 5: Olistostrome/mélange deposits overlain by Upper Jurassic carbonate platform.
Main Vardar Zone, Taorska klissura (Taor Gorge) near Vetersko locality (photo: Cs. Péró).

Fig. 6: Burial stone from the Armenian Catholic churchyard in Gheorgheni.
Upper Oxfordian – Middle Kimmeridgian Ammonitico Rosso from the base of the Hăghimaş Nappe, Transylvanides, Hăghimaş Mts (photo: Cs. Péró).

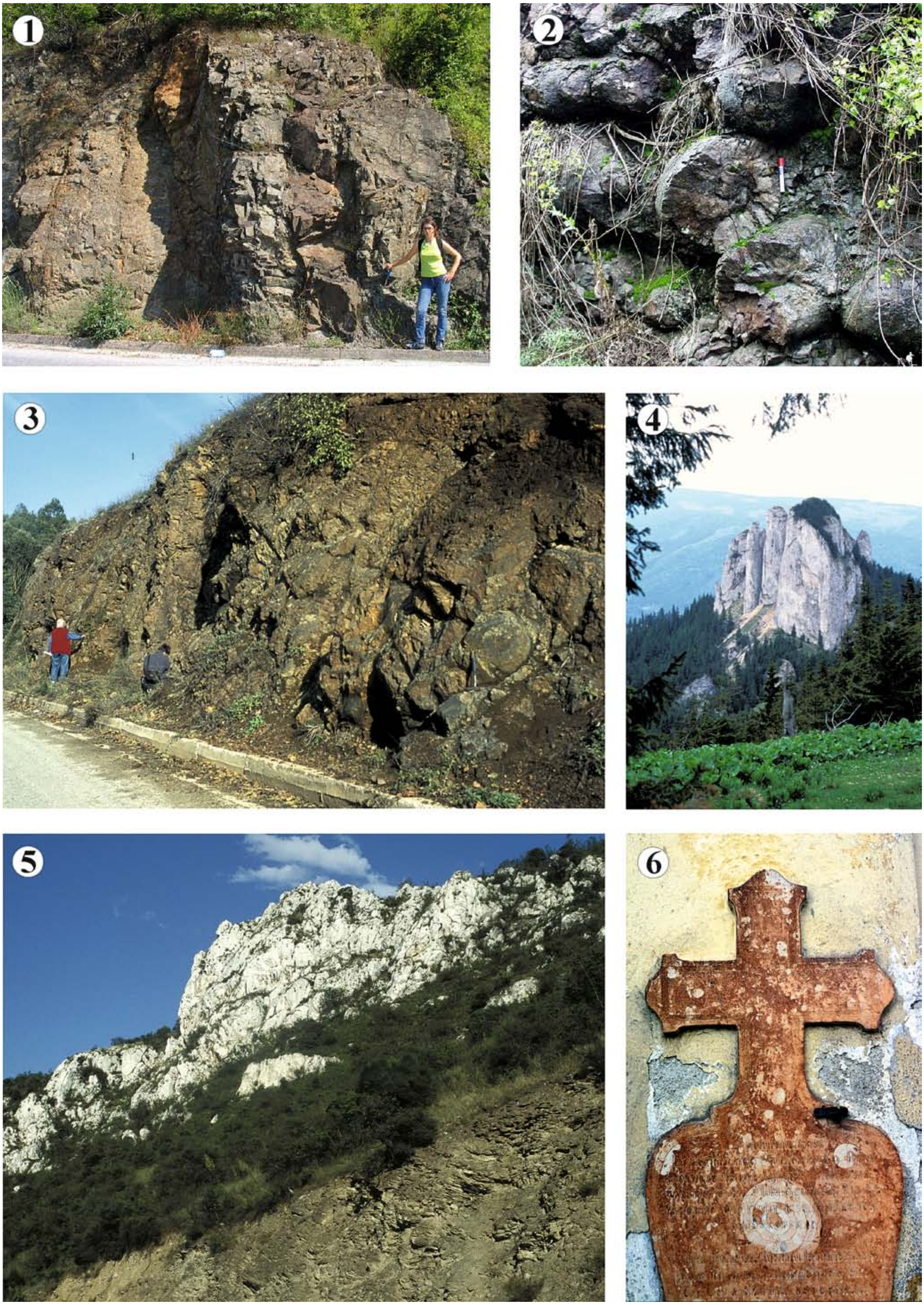
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Plate 8

Fig. 1: Outlier of massive Stramberg-like and Urgonian-like limestones.
Transylvanides, Hăghimaş Nappe, in the area of the Lacu Roşu (Red Lake), Hăghimaş Mts (photo: S. Baciu).

Fig. 2: Tholeiitic pillow basalt, Middle Jurassic. Transylvanides, South Apuseni, Techereu-Drocea Nappe, Zam locality, Quarry, Metaliferi Mts (photo: Cs. Péró).

Fig. 3: Slightly overthrust Kimmeridgian–Tithonian Stramberg-type massive limestones over Oxfordian?–Kimmeridgian–Tithonian well-bedded turbiditic cherty limestones (in the middle) and Oxfordian island arc andesites (downside).
Transylvanides, South Apuseni, Bedeleu Nappe, Râmeți locality, Trascăului Mts (photo: Cs. Péró).

Fig. 4: Channels (Upper Oxfordian?) filled with reef-detritus and volcanic gravels in the base of the Stramberg-type prograding reef (Kimmeridgian – Lower Tithonian).
Transylvanides, South Apuseni, Bedeleu Nappe, E entrance of Turda Canyon near Turda locality, Trascăului Mts (photo: Cs. Péró).

Fig. 5: Folded Oxfordian?– Kimmeridgian–Tithonian well-bedded turbiditic cherty limestones.
Transylvanides, South Apuseni, Izvoarele Nappe, Râmeți locality, E entrance of Râmeți Canyon, Trascăului Mts (photo: Cs. Péró).


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Ghilcoş Mt.
1406 m
Hãghimaş Nappe
Red Lake
Bucovinian Nappe

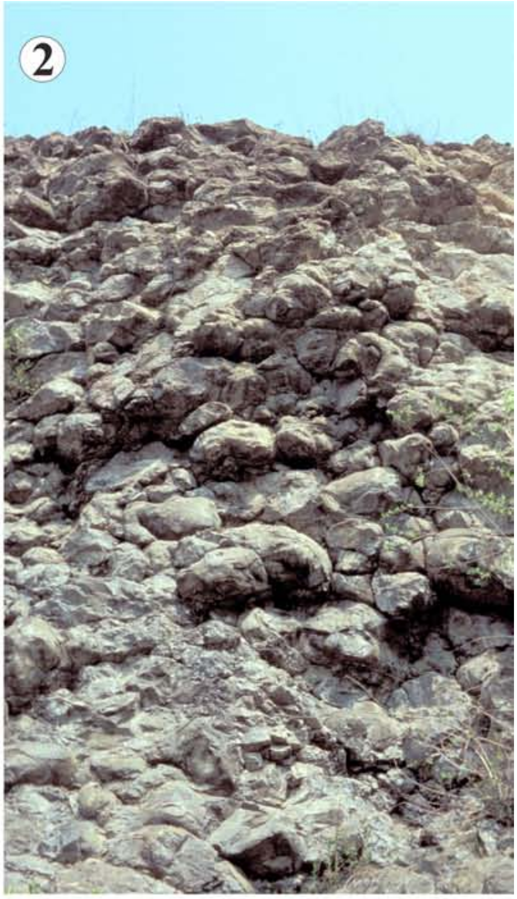
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Plate 9

Fig. 1: Oxfordian calc-alkaline island arc andesites with prograding ?Upper Oxfordian – Kimmeridgian – Lower Tithonian Stramberg-type massive reef limestones on the top.
Transylvanides, South Apuseni, Bedeleu Nappe, Piatra Secuiului over Rimetea locality, Trascăului Mts (photo: Cs. Péró).

Fig. 2: Cyclic alternation of white arcose and black coaly clay beds in Hettangian Gresten-type sequence.
Mecsek Unit, Vasas open pit coal mine, Pécs-Vasas, Mecsek Mts (photo: J. Haas).

Fig. 3: Spotted marl ("Fleckenmergel"), Upper Toarcian – Middle Bajocian, Mecsek Unit, Óbánya Valley, near Óbánya locality, Mecsek Mts (photo: Cs. Péró).

Fig. 4: Highly condensed Callovian ammonitic bed, Villány Unit.
Templom Hill, Villány locality, Villány Hills (photo: J. Haas).

Fig. 5: Red sandstone with refractory clay bed in the Gresten-type sandstone (Hettangian).
Bihor Unit, Dumbrăva Hill open pit mine, locality Şuncuiuş, Pădurea Craiului Mts (photo: Cs. Péró).

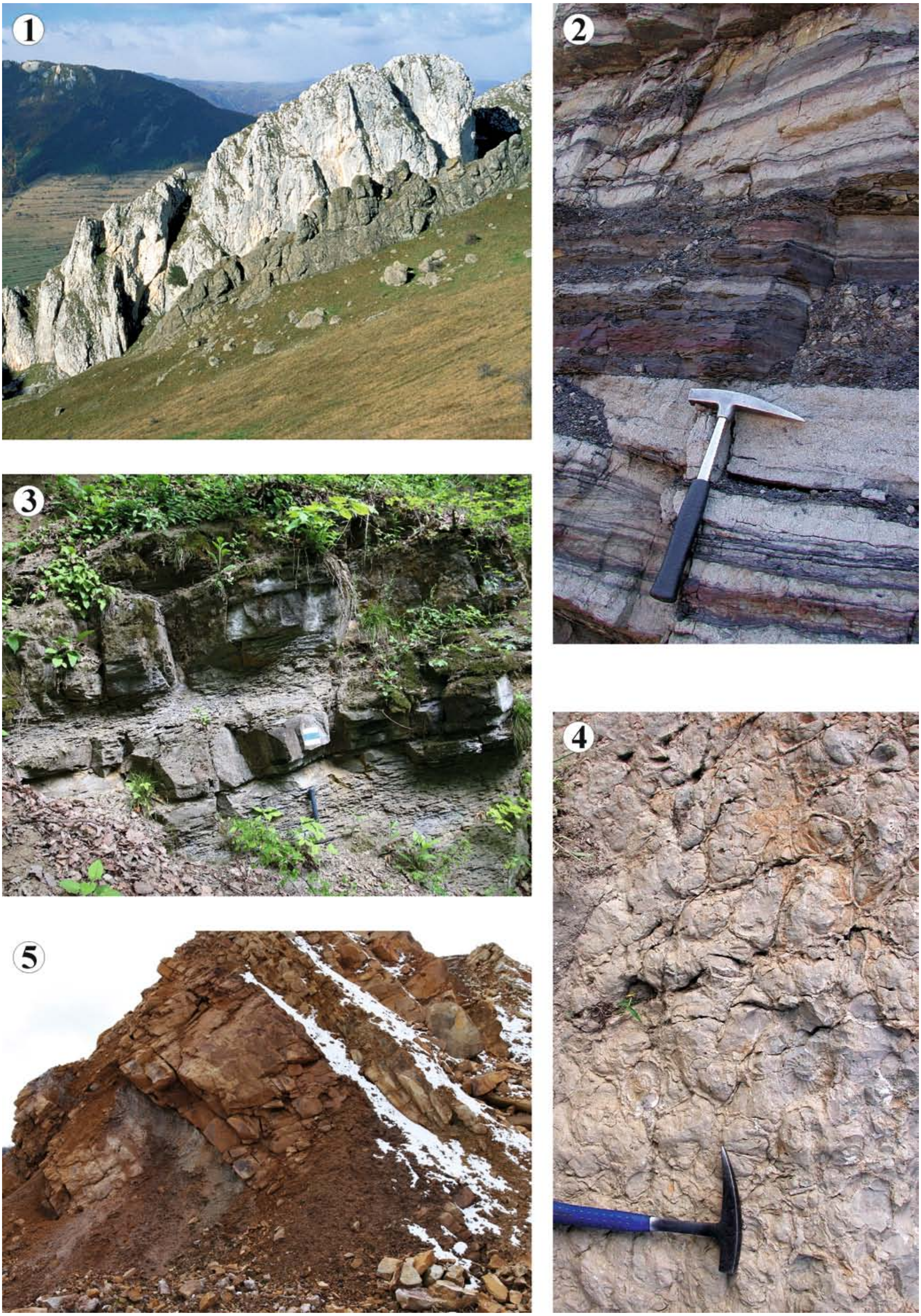
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Plate 10

Fig. 1: Coral reef in the Upper Jurassic Farcu Limestone bedrock in the open pit bauxite mine Rujetu Hill.
Bihor Unit, locality Zece Hotare, Pădurea Craiului Mts (photo: Cs. Péró).

Fig. 2: Neptunian dyke filled with red encrinitic limestones and marls (Aalenian) in the Dachstein reefal limestone.
North Apuseni, Codru Nappe System, Coleşti Nappe, Coleşti locality, Vaşcău Plateau, Codru-Moma Mts (photo: Cs. Péró).

Fig. 3: Coeval strained, redeposited limestone clasts in basaltic cinerites in the Upper Jurassic part of the within-plate mafic complex.
Outer Dacides, Obnuj Scale of the Black Flysch Nappe, Repedea Valley near Repedea locality, Mt Fărcău, Maramureş Mts (photo: Cs. Péró).

Fig. 4: Micritic Ammonitico Rosso-type sediments with encrinitic turbidites, with Gresten-type (celto-suab) brachiopod fauna.
Moneasa Limestone (Upper Sinemurian – Pliensbachian), North Apuseni, Codru Nappe System, Finiş Nappe, Moneasa locality, Codru Mts (photo: Cs. Péró).

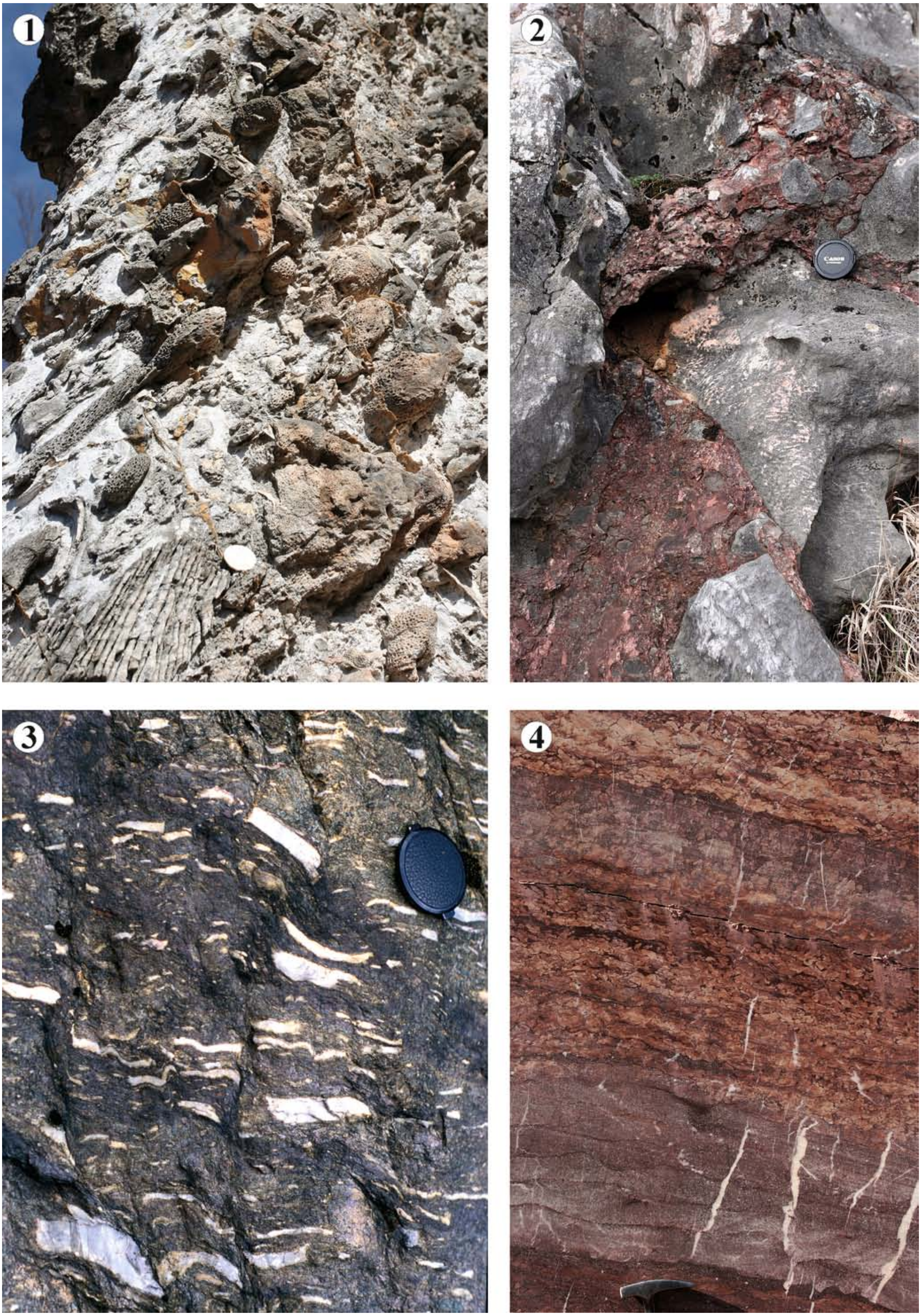
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Plate 11

Fig. 1: Basinal limestones (Upper Kimmeridgian – Neocomian) topped by Urgonian-like limestones (Barremian–Aptian).
Lower Danubian Units, Cazanele Mari viewed from Ciucaru Mare Peak on Romanian side Danube Gorge (photo: C. Panaiotu).

Fig. 2: Bedded radiolaritic cherts (Oxfordian–Kimmeridgian 1) in between "lower" (Callovian 2-3) and "upper" (Kimmeridgian 2 – Tithonian 2) Ammonitico Rosso from Sirinia zone.
Upper Danubian Units, Munteana Hill, Danube Gorge, Almăj Mts (photo: Cs. Péró).

Fig. 3: East vergent folded Jurassic sequence from Sirinia zone, Munteana facies (base: P3, top: Berriasian).
Upper Danubian Units, Munteana Hill, Danube Gorge, Almăj Mts (photo: Cs. Péró).

Fig. 4: Strongly folded calcareous turbidites of the Sinaia Flysch Formation (Tithonian – Lower Barremian).
Outer Dacides, Ceahlău Nappe, Bicaz Valley at Bicaz-Chei locality, Ceahlău Mts (photo: Cs. Péró).

Fig. 5: Slump in the Upper Kimmeridgian – Middle Tithonian Ammonitico Rosso/coarse-grained calciturbiditic limestones of Greben Formation.
Upper Danubian Units, Poreč Unit, near Lepenski Vir locality, Danube Gorge (photo: Cs. Péró).


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Plate 12

Fig. 1: Upper Jurassic – lowermost Cretaceous carbonate platform in the eastern region of the Getic domain.
Getic Nappe, Piatra Craiului Mts, western slope viewed from Păpuşa Mt (photo: A. Munteanu).

Fig. 2: Open pit coal mine in the Gresten-type deposits (Hettangian–Sinemurian).
Getic Nappe, Resița-Moldova Nouă zone, Doman locality, Anina Mts (photo: Cs. Péró).

Fig. 3: Well-bedded Middle Jurassic calcareous sandstones (encircled person as scale), followed by Upper Callovian – Oxfordian radiolarites (covered), topped by massive Kimmeridgian limestones.
Getic Nappe, Strunga Pass, Bucegi Mts (photo: I. Lazăr).


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