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Stratigraphic Definition and Correlation of Middle Triassic Volcaniclastic Facies in the External Dinarides: Croatia and Bosnia and Herzegovina

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ABSTRACT: Middle Triassic volcaniclastic depositsin the External Dinarides of Croatia and Bosnia and Herzegovina are related to the rifting of the Tethyan Ocean. Three localities in the External Dinarides: Donje Pazarište, Bosansko Grahovo and Zelovo were biostratigraphically analysed in this study. The Middle Triassic carbonate deposits with volcaniclastic interlayers in Donje Pazarište were defined by means of conodonts. Rare ammonoid specimens were collected.Recovered conodont and ammonoid taxa suggest these sections are of Early Illyrian to Early Fassanian Age. The section studied in Bosansko Grahovo is dominantly composed of volcanic and volcaniclastic rocks. Limestone peperites were collected for conodont analysis. Two conodont zones were defined, suggesting volcanic activity in the same, from Lower Illyrian to Fassanian, time interval. The Zelovo Section was biostratigraphically investigated by several authors. The *pietra verde* deposits from Zelovo are referred as late Fassanian to Early Longobardian Age. Biostratigraphic correlation from mentioned three localities imply that the magmatic activity in the External Dinarides, and formation of different volcaniclastic facies lasted from Illyrian to Longobardian, similar as in the surrounding western Tethyan territories.

KEY WORDS: External Dinarides, biostratigraphy, Middle Triassic, volcaniclastic deposits, western Tethys.

0 INTRODUCTION

In the Middle Triassic, Dinaridic area was located in the western Tethys. After the tectonically stable periodin the Early Triassic, the Dinaridic area underwent severe tectonic processes related to the opening of the Tethyan Ocean. Stable epeiric ramp dominated by mixed clastic-carbonate sediments at theend of Early Triassic (Aljinović et al., this issue) was disintegrated mainly by wrench faulting and block tectonics. Due to rift-type tectonics, some areas were uplifted and subaerially exposed (with bauxite formation), some remained shallow marine, dominated by carbonate sediments, while others subsided and developedas pelagic or deeper marine realms (flysch-like deposits, pelagic limestones, volcaniclastic turbidites) and volcanics. The volcanic activity following block tectonics was not clearly stratigraphically documented in the External Dinarides. The main volcanic activity in the External Dinaridic area, as well as in the surrounding western Tethys took place in the Middle Triassic (Mundil et al., 1996; Castellarin et al., 1988; Pamić, 1984; Bechstädt et al., 1978). Most of the authors refer to it as Ladinian but the precise age of this activity was not defined. Since the definition of the Anisian-Ladinian boundary (Brack et al., 2005), their stratigraphic definition should be reconsidered. In the area of the External Dinarides, the Middle Triassic volcanic and volcaniclastic rocks crop outat several localities. Volcanics are presented by occurrences of small-scale basaltic and andesitic bodies. Volcaniclastic deposits are present by crystaloclastic and vitriclastic tuffs of andesitic to rhyolitic composition (Smirčić et al., in preparation), peperitic rocks formed by mixing of magma and unconsolidated water saturated sediments (Smirčić et al., in prep; Smirčić et al., 2016) and gravity flow resedimented pyroclastic material (Belak, 2000; Marjanac, 2000). Volcaniclastic deposits in the investigated localities occur as meter-scale layers of pyroclastic deposits and thick hyaloclastic deposits of tens of meters in contact with different types of sedimentary rocks. Three localities with occurrences of Middle Triassic volcaniclastic rock were investigated (Fig. 1): Donje Pazarište on Velebit Mts., Bosansko Grahovo in the Southwest Bosnia and Herzegovina, and Zelovo on Mt. Svilaja.

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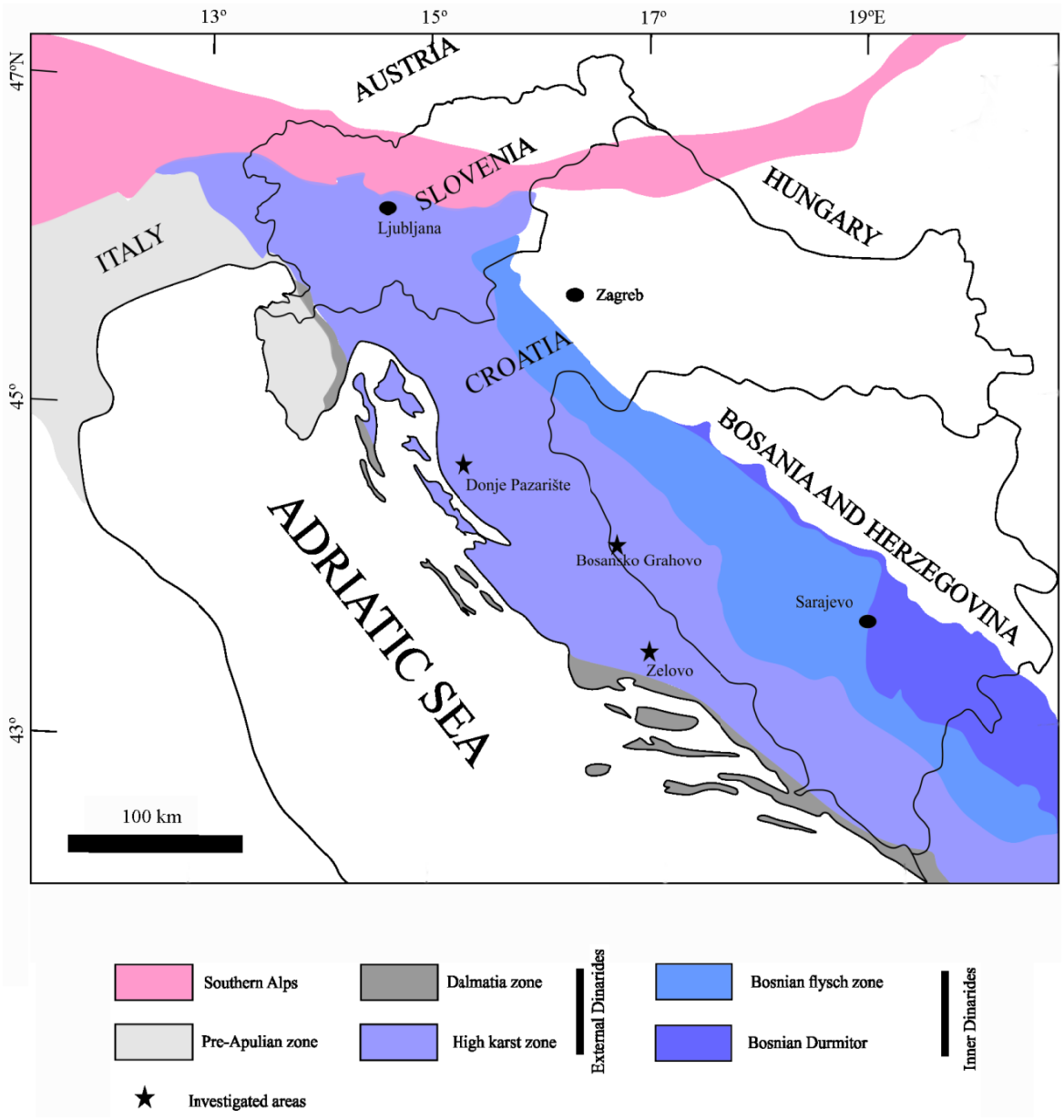

Figure 1. Simplified map of the External Dinarides and surrounding tectonic units according to Schmidt et al., 2008. Black stars mark the investigated areas of Donje Pazarište, Bosansko Grahovo and Zelovo.

1 GEOLOGICAL SETTING

The Dinarides are a part of Alpine orogenetic belt striking from Slovenia in the northwest to Albania in the southeast. The belt of high mountain area along the coast of the Adriatic Sea is termed External Dinarides, while the north-eastern part is termed the Internal Dinarides. The External Dinaridic subunit consists mainly of carbonate sediments from Jurassic to Cretaceous deposited on the Adriatic carbonate platform (ACP) (Vlahović et al., 2005).

All investigated localities belong to the High Karst zone of the External Dinarides (according to Schmidt et al., 2008). The northernmost investigated locality of Donje Pazarište is located in the Velebit Mts. in the central part of the External Dinarides (Fig. 1). Velebit Mts. represent a dominant tectonic structure in this area of the External Dinarides and consist of several overthrusted zones with Carboniferous to Eocene strata. The investigated area is located on north-eastern slope of Velebit Mts., near the Donje Pazarište Village (Fig. 1). In the area of Donje Pazarište the volcaniclastic deposits described in the Basic geological map sheet Gospić were divided into four units (Sokač et al., 1976). These deposits are determined as Ladinian by the presence of the ammonoid *Haliculites haugi*, *Dinarites* (*Velebites*) *dinaricus*, *Ptychites* sp., and *Arcestes* sp. (Salopek, 1918; Sokač et al., 1976).

Bosansko Grahovo (Fig. 1) locality belongs to a tectonic subunit comprised of Lower Triassic to Middle Jurassic overthrusted strata and a typical Dinaridic (NW-SE striking). This tectonic unit is bordered by faults on the south, bringing it in contact with Jurassic deposits, with Cretaceous deposits in the east and north, and with Triassic strata on the west. The investigated area is located in the south-eastern part of the tectonic unit composed of Middle Triassic deposits. Volcaniclastic

deposits in the area of Bosansko Grahovo in the basic geological map sheet Knin (Grimani et al., 1972) are determined as "volcano sedimentary" unit and are included in the clastic sediments of the Ladinian. The age was determined by the presence of *Daonella lommeli* and *Halobia* sp. as well as the various ammonoids of *Popinites*, *Ceratites*, *Proarcestes*, *Pinacoceras*, *Gymmnites* and *Ptychites* sp. (Salopek, 1914).

The third, southern most investigated locality (Zelovo, Fig. 1) is situated on the flanks of Svilaja Mts. The tectonic unit is composed of a complete sedimentary succession from the Lower Triassic to Upper Cretaceous deposits, with a transgressional unconformity between the Middle Triassic and Lower Jurassic deposits. The strata have an east-west orientation, and a general dip towards the North. The section of the Middle Triassic deposits on Mt. Svilaja was investigated by several authors (Halamski et al., 2015; Goričan et al., 2015; Hrvatović et al., 2011; Aljinović et al., 2010; Balini et al., 2006; Kolar-Jurkovšek et al., 2006; Jelaska et al., 2003; Belak, 2000; Marjanac, 2000; Šćavničar et al., 1984). Šćavničar et al. (1984) presented an overview of the Triassic deposits of the area. They stated that two basaltic effusive bodies occur in the area and two tuff horizons are associated with them. The first one is lithoclastic tuff comprised of basalt lithoclasts, and the second one is the characteristic "*pietra verde*" type tuff (Šćavničar et al. 1984). They assumed the age of the tuffs as Upper Anisian for the first horizon, and Ladinian for the second one.

2 METHODS

Sedimentary sections were recorded in the investigated localities (Figs. 2–4). Different facies were micropetrographically determined (Smirčić et al., in prep). Three sections were recorded in the area of Donje Pazarište on the Velebit Mts. (Donje Pazarište 1, Donje Pazarište 2 and Donje Pazarište 3). All three studied sections in the area of Donje Pazarište are situated in the road-cut that extends from the Donje Pazarište Village to the local altitude rise. The coordinates of the beginning of Donje Pazarište 1 Section is 44º37'39.75"N, 15º08'54.25"E. In the carbonate shale facies of the Donje Pazarište 1 Section, ammonoid fauna was collected 12 meters below the first volcaniclastic deposits (Fig. 2). The ammonoid specimens have a well preserved suture lines. The specimens were determined by L. Krystyn, Institute for Palaeontology and Stratigraphy, University of Vienna. The samples of the platy limestone facies from Donje Pazarište 1 and Donje Pazarište 2 sections (beginning of the section is marked by coordinates 44º37'58.43"N, 15º08'46.37"E) as well asthe samples from the facies of limestones, pyroclastics and cherts with slump textures from the Donje Pazarište 3 Section (beginning of the section 44º37'42.76"N, 15º08'44.39"E) were collected for conodont analysis.

A section in the area of Bosansko Grahovo was recorded along the road leading from Strmica (Croatia) to the Bosansko Grahovo village (Bosnia and Herzegovina), with coordinates of the beginning of the section at 44°30'43.20"N and 15º15'30.27"E. The recorded section is 79 m thick. The lower part consists of limestone fluidal peperites passing upward into completely volcaniclastic facies rocks. The limestone part of the peperites is biomicritic consisting of thin-shelled bivalves and radiolarians, sometimes heavily silicified. Limestone parts of the peperites were collected for conodont analysis.

The section recorded in the Zelovo locality on Svilaja Mt. is situated in the abandoned quarry (43º42'4.24"N, 16º32'43.42"E) eastward from the main road that leads to Zelovo Village. The section is 14 m thick and comprises of silicified bioclast rich limestonesand dolostones, green crystallovitric tuffs and pale green to white unconsolidated claytuffs. The stratigraphic position of these volcaniclastic horizons is provided by means of conodonts in Jelaska et al. (2003) and Kolar-Jurkovšek et al. (2006) and according to ammonoid assemblages in Balini et al. (2006).

Collected conodont samples from all investigated localities weighted between 3 and 7 kg. The samples were prepared by the standard conodont technique at the Geological Survey of Slovenia, Ljubljana and partly in the LaGeMA (Laboratory for Analysis of Geological Materials) of the Department of Mineralogy, petrology and mineral resources (Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb).

3 OCCURRENCE OF VOLCANICLASTICS IN RELATION TO OTHER SEDIMENTARY ROCKS

Donje Pazarište 1, 2 and 3 sections consist of various sedimentary facies that can be organized to an almost continuous vertical succession according to the conodont biostratigraphy (Fig. 2). The volcaniclastic deposits are represented as crystaloclastic and vitroclastic tuffs of andesitic composition (Fig. 5a) in the lower part of the section, and dacitic to rhyolitic in the upper part. These volcaniclastic deposits are interlayered with filament-rich biomicritic limestones, and intra-biosparitic limestones of allodapic origin, as well as the rocks originated and deposited by debris-flow—limestone breccias (Smirčić et al., in prep).

Donje Pazarište 1 Section begins with flysch like deposits of volcanogenic sandstones, interlayered with dark, sometimes nodular shales, overlain by carbonate shales, volcaniclastics and finally by platy limestones containing pyroclastic material (Fig. 5b). Donje Pazarište 2 Section has the same vertical organisation of facies except that in the upper part of the section debris flow limestone breccias are intercalated with pyroclast rich platy limestones (Fig. 2). Pyroclastic rocks in these two sections are of andesitic compositions. The last recorded section, Donje Pazarište 3, consists of limestones, pyroclastic deposits and chert layers with the notable slump structures (Fig. 2). Compositions of the pyroclastic deposits from the Donje Pazarište 3 Section correspond to rhyolitic to dacitic composition (Fig. 5c).

Bosansko Grahovo Section comprises various volcaniclastic facies (Smirčić et al., 2016). The beginning of the section is characterised by fluidal limestone peperites (Fig. 5d). The following deposits are composed of pyroclastic grain flow deposits of trachytic to basaltic composition and *in situ* to resedimented basaltic-andesitic to basaltic volcaniclastic rocks (Smirčić et al., in press). The top of the section is composed of petromictic paraconglomerates with the volcanic matrix. Products of volcanic activity predominate through the entire (Fig. 3).

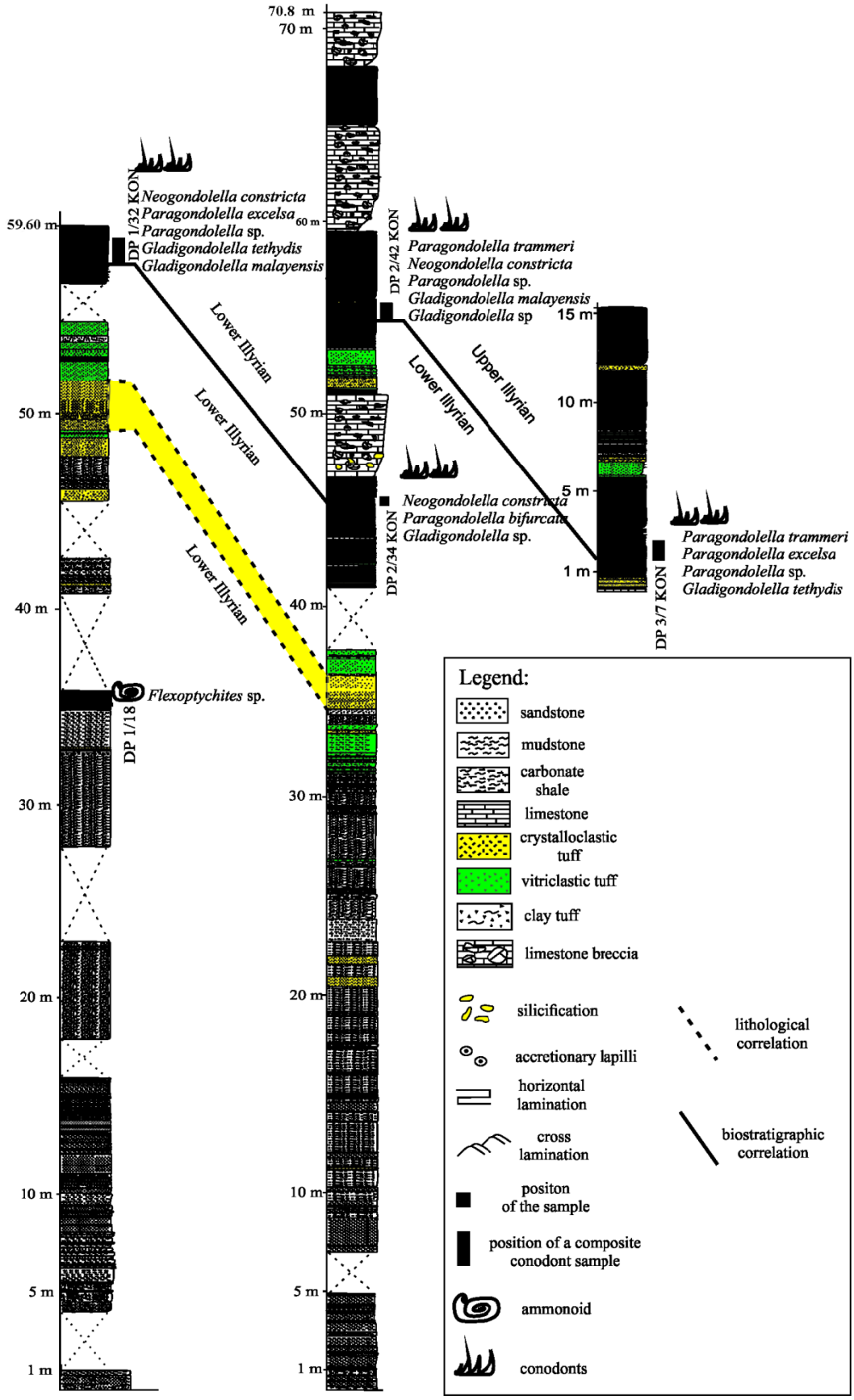

Figure 2. Recorded Donje Pazarište 1, 2 and 3 sections with lithology and position of conodont and ammonoid samples. Dashed line is used to correlate the significant yellow crystaloclastic tuff layers with horizontal and cross lamination in sections Donje Pazarište 1 and 2. Heavy lines are used for biostratigraphic correlation based on conodont and ammonoid occurrences.

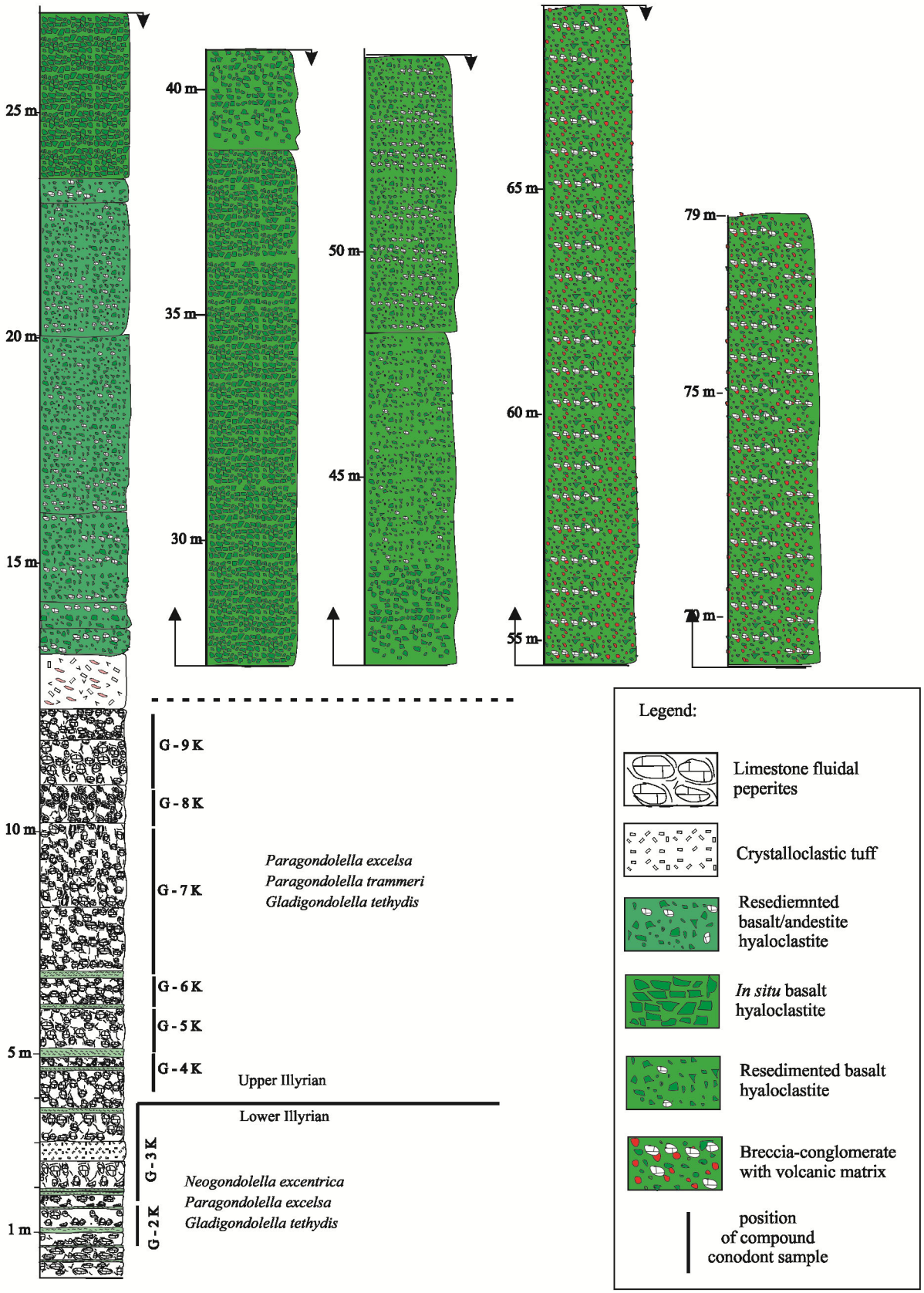

Figure 3. Section Bosansko Grahovo composed entirely of volcaniclastic facies rocks. Conodont samples collected from the limestone part of the peperitic interval in the beginning of the section. The whole peperitic interval is 12.5 m thick. Lowermost 5.9 m contains Lower Illyrian Age, while the upper part (6.6 m thick) has an Upper Illyrian conodonts assemblage.

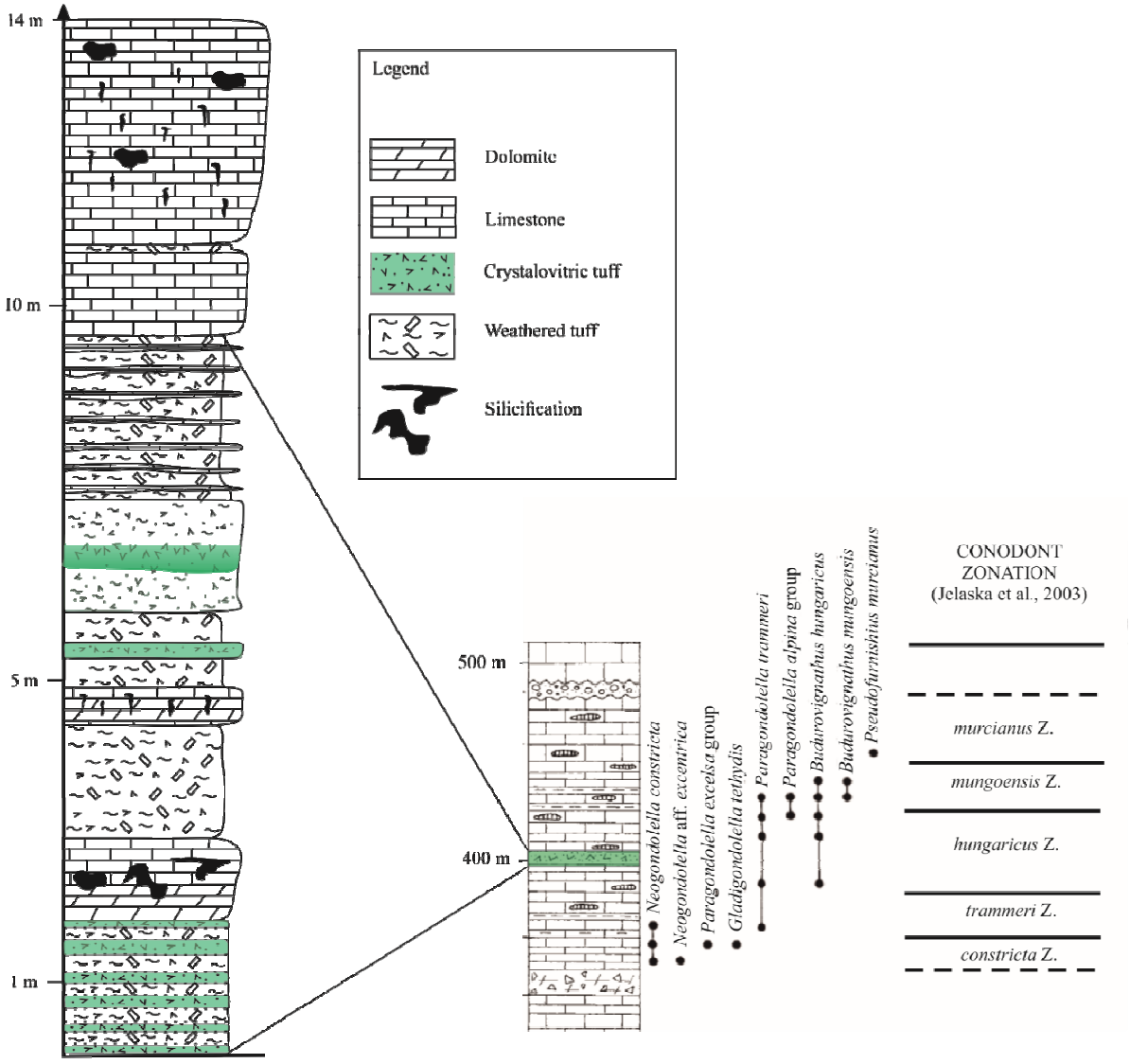

Figure 4. Zelovo Section with green crystallovitric tuffs and cherty limestones/dolostones. On the right the general section of Lower to Upper Triassic with conodont zonation from Jelaska et al. (2003) suggests the age of the "*pietra verde*" tuffs on Svilaja Mt..

Zelovo Section, on Mt. Svilaja, consists of the well-known "*pietra verde"* deposits interlayered with strongly silicified and dolomitized bioclast-rich limestones and allodapic limestones (Fig. 5e). These deposits of the Middle Triassic "*pietra verde*" tuffs were biostratigraphically, paleontologically and sedimentologically investigated by several authors (e.g., Halamski et al., 2015; Goričan et al., 2015; Hrvatović et al., 2011; Aljinović et al., 2010; Balini et al., 2006; Kolar-Jurkovšek et al., 2006; Jelaska et al., 2003; Belak, 2000; Marjanac, 2000; Šćavničar et al., 1984).

The thickness of the pyroclastic layers varies from 0.2 to 1.5 m. Carbonates are strongly silicified and dolomitized. Silicification is irregular, rarely nodular. Dolomites are micro- to macro-crystalline, sometimes totally obliterating the primary carbonate composition (Fig. 4). Pyroclastic deposits have the characteristics of resedimentation by gravity (possibly turbidity) flows of pyroclastic grains (Belak, 2000; Marjanac, 2000).

4 AMMONOID BIOSTRATIGRAPHY

Ammonoid specimens found in the carbonate shale from the Donje Pazarište 1 (Sample DP-1/18), 12 m below the first volcaniclastic deposits, are determined as *Flexoptychites* sp. (L. Krystyn, personal communication).Due to poor preservation it was not possible to determine the specimens at a species level. Species of this ammonoid genus are characteristic for the Upper Anisian (Illyrian substage). This ammonoid genus was reported earlier in the area of External Dinarides in the Illyrian part of*Paraceratites trinodosus* zone and through the whole *Kellnerites felsoeoersensis* ammonoid zone (Japundžić, 2011; Petek, 1998; Prlj and Murđanović, 1988) (Fig. 6).

5 CONODONT BIOSTRATIGRAPHY

Almost all analysed conodont samples wereproved to be positive. The samples from Donje Pazarište sections (Fig. 2) are DP-1/32, DP-2/34, DP-2/42 and DP-3/7. The Sample DP-1/32, from the Donje Pazarište 1 Section, and the Sample DP-2/34 yield following conodonts: *Gladigondolella malayensis*, *G.*

tethydis, *Gladigondolella* sp., *Neogondolella constricta*, *Paragondolella bifurcata*, *P. excelsa*, and *Paragondolella* sp. suggesting lowermost Illyrian Age.

Sample DP-2/42 from the Donje Pazarište 2 Section, and Sample DP-3/7 from the slumped limestones of the Donje Pazarište 3 Section are marked by presence of *P. trammeri*,in association with *G. malayensis*, *G. tethydis*, *Gladigondolella* sp., *N. constricta*, *Neogondolella* sp., *P. excelsa*, and *Paragondolella* sp.. This conodont assemblage is characteristic for late Illyrian to Early Fassanian Age.

In the Bosansko Grahovo Section, from the limestone parts of the peperites two conodont assemblages were determined. Samples G2, G3 contain the following species: *G. tethydis*, *N. excentrica*, and *P. excelsa* suggestingthe Early Illyrian Age of these strata. The samples G4, G5, G6, G7, G8, G9 and G9/2K are characterized by the presence of *P. trammeri*

Figure 5. Plate of volcaniclastic rocks from the investigated localities. (a) Field photograph of andesitic crystaloclastic tuffs from the locality Donje Pazarište, the correlative marker between sections Donje Pazarište 1 and Donje Pazarište 2. (b) Field photograph of the platy limestones with pyroclastics from sections Donje Pazarište 1 and Donje Pazarište 2 collected for conodont samples. (c) Field photograph of limestones, pyroclastics and cherts from Donje Pazarište 3 Section. Notice the mixing of limestone and pyroclastic material in the thick bed and completely vitroclastic rhyolitic tuff on top. (d) Limestone peperites from the Bosansko Grahovo Section from which the limestone parts were collected for conodont analysis. (e) Field photograph of the Zelovo Section with a distinctive green and blue green "*pietra verde*" type pyroclastics.

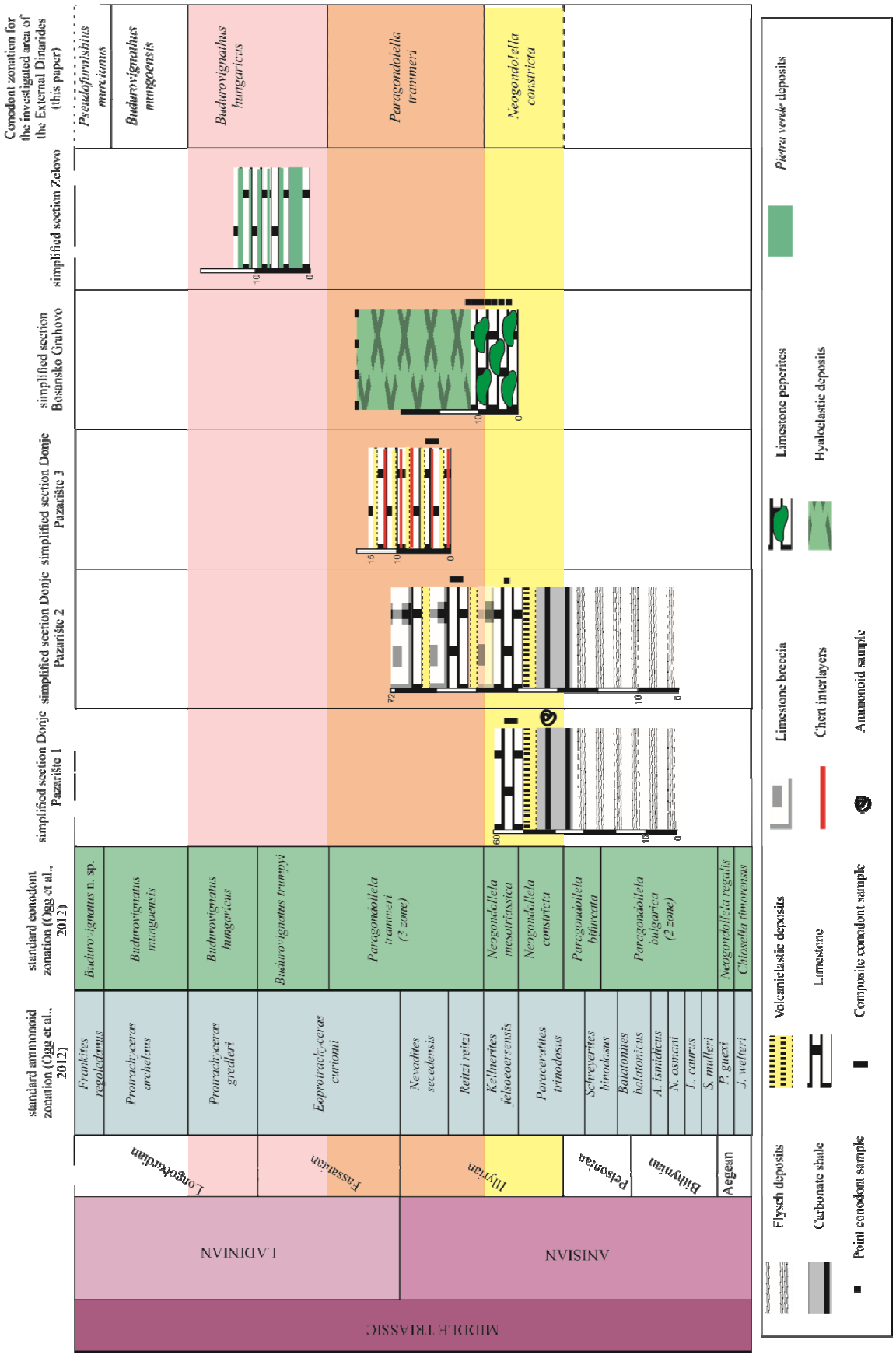

Figure 6. Middle Triassic stratigraphic chart. Standard ammonoid and conodont zonation are presented in columns 1 and 2. Columns 3, 4, 5, 6 and 7 represent the recorded sections with found conodont assemblages and ammonoid species from collected samples with their stratigraphic positions. Column 8 presents the conodont zonation after Jelaska et al. (2003) used as a standard for the area of the External Dinarides modified after Brack et al. (2005).

in association with *Gladigondolella tethydis* and *P. excelsa* indicating Late Illyrian to Early Fassanian Age.

In the investigated area of Zelovo, earlier investigations carried out by Jelaska et al. (2003), Balini et al. (2006), Kolar-Jurkovšek et al. (2006), Goričan et al. (2015), Halamski et al. (2015) defined the stratigraphic age of this main volcaniclastic deposits. Jelaska et al., 2003, presented the results of conodont biostratigraphy Triassic strata of the Svilaja Mt.. According to their results, the main tuff zone comprising the "*pietra verde*" deposits is ranged to the *Budurovighnatus hungaricus* assemblage zone and is of Late Fassanian to Early Longobardian Age (Fig. 6).

6 DISCUSSION

The occurrence of the ammonoid genus *Flexoptychites*in the Dinaridic area is reported by Prlj and Murđanović (1988), Petek (1998) and Japundžić (2011). All these authors suggest that this ammonoid genus occurs in the strata spanning from the Illyrian part of *Paraceratites trinodusus* and its occurrence persists throughout theentire *Kellnerites felsoeoersensis* zone (Ogg et al., 2012) (Fig. 6). Therefore the finding of *Flexoptychites* in the carbonate shales, in the lower part of the Donje Pazarište 1 Section suggests Early Illyrian Age.

The conodont data suggests the continuation of the three recorded sections in Donje Pazarište area (Donje Pazarište 1, Donje Pazarište 2 and Donje Pazarište 3; Fig. 2). The first occurring conodonts in the samples DP-1/32 (from Donje Pazarište 1 Section) and DP-2/34 (from Donje Pazarište 2 Section) imply Early Illyrian Age. In both sections (Donje Pazarište 1 and Donje Pazarište 2) mentioned conodont samples (DP-1/32 and DP-2/34) are collected from the platy limestones conformably overlying the distinctive meter-scale yellow crystaloclastic tuffs with horizontal and cross lamination (Fig. 2). This distinctive bed and the determined conodont taxaof the samples DP-1/32 and DP-2/34 served as a correlative marker for the Illyrian strata in the two sections (Donje Pazarište 1 and Donje Pazarište 2). The following conodont samples (DP-2/42 from Donje Pazarište 2, and DP-3/7 from Donje Pazarište 3) are correlated, based on the presence of *P. trammeri* indicating the Late Illyrian to Early Fassanian Age.

Based on the conodont data from the three sections in Donje Pazarište an almost continuous and complete sequence ranging from Early Illyrian to Early Fassanian Age can be concluded.

In the area of Donje Pazarište, Marci et al. (1991) investigated the occurrence of accretionary lapilli—a specific pyroclastic grain type formed by accretion of volcanic ash in the pyroclastic cloud. They determined the age of the deposits with the accretionary lapilli as Upper Ladinian to Carnian, based on the appearance of the foraminifera *Gauydrina triadica* Kristan-Tollmann (Đurđanović, 1986 in Marci et al., 1990). The mentioned foraminifer species was found in the Carpathians in the strata spanning from the Ladinian to the Rhaetian (Salaj et al., 1983). There is no evidence that Marci et al. (1991) investigated the same strata as in the Donje Pazarište 2 Section, as for this study the examined lapilli-rich strata from Donje Pazarište 2 Section is determined as Illyrian (Fig. 2). If not, it is possible to consider it as the evidence for the continuation of the volcanic activity throughout the entire Ladinian. If the accretionary lapilli investigated by Marci et al. (1991) represented the same strata as the accretionary lapilli-rich strata recorded in the Donje Pazarište 2 Section, we may consider them as Late Illyrian Age. In this case, foraminifer fauna should be also studied in detail.

In the 79 m thick Bosansko Grahovo Section, two zones are determined. In the first 5.9 m of the section, the strata belong to the *N. constricta* Zone of the Early Illyrian, and the following 6.6 m belongto the *P. trammeri* Zone that ranges from the Late Illyrian to Early Fassanian. The volcaniclastic deposits in the upper part of the section were not stratigraphically constrained, since no limestones were present in the entirely volcaniclastic facies rocks. Nevertheless, the underlying peperitic rocks with conodonts of the Early and Late Illyrian represent the evidence that the magmatic activity in the External Dinarides started at least in the Early Illyrian.

In the Middle Triassic of the Svilaja Mt., Jelaska et al. (2003) determined four consecutive zones: *constricta*, *trammeri*, *hungaricus* and *mungoensis* zones, and the succeeding Late Ladinian—Early Carnian *murcianus* Zone. The Middle Triassic strata in the Svilaja Mt. area begin with the dolomite, the so-called "Otarnik breccia" unconformably overlaying the Early Triassic deposits. Limestones conformably deposited over the "Otarnik breccia" present the deposits of the *constricta* Zone pointing to Early Illyrian Age. Since Early Anisian strata are missing from this locality, a long lasting hiatus in the area is assumed. According to Jelaska et al. (2003) the main "*pietra verde*" tuff zone belongs to the *hungaricus* Zone that defines its Late Fassanian to Early Longobardian Age (Kolar-Jurkovšek et al., 2006). In the investigation by Balini et al. (2006, Fig. 2) two tuff zones were presented, similar as earlier documented by Šćavničar et al. (1984). The first tuff horizon (lithoclastic *sensu* Šćavničar et al., 1984) is a part of the Upper Anisian strata, while the second one (crystallovitric "*pietra verde*" *sensu* Šćavničar et al., 1984) is of the Ladinian. Balini et al. (2006) studied the ammonoid fauna collected just above the main "*pietra verde*" horizon. The authors introduced three new ammonoid taxa *Alkaites dinaricus*, *Detoniceras svilajanus* and *Argolites trinodosus* comprising their age with the *Gredleri* and *Archelaus* ammonoid zones. Following this the determinations of Šćavničar et al. (1984), Belak (2000), Jelaska et al. (2003), Kolar-Jurkovšek et al. (2006) and Balini et al. (2006) all agree that the main tuff zones with "*pietra verde*" tuffs is of Ladinian Age (Fig. 6).

7 CORRELATION OF VOLCANICLASTIC FACIES IN THE EXTERNAL DINARIDES

Following the obtained biostratigraphic data, the correlation of the investigated sections is presented (Fig. 7). The three recorded sections in the area of Donje Pazarište represent a continuous deposition from the Lower Illyrian to Lower Fassanian.

The fluidal limestone peperites from the Bosansko Grahovo Section are stratigraphically divided into two zones. The *Neogondolella constricta* Zone is Early Illyrian Age and thus can be correlated with the Donje Pazarište 1, and the lower part of the Donje Pazarište 2 Section. The upper interval of the fluidal limestone peperites from the Bosansko Grahovo Section is defined as the *Paragondolella trammeri* Zone of Late Illyrian to Early Fassanian interval, thus can be correlated with the

younger deposits of the Donje Pazarište 2 and the Donje Pazarište 3 sections. Thus, we interpret the Donje Pazarište and the Bosansko Grahovo sections as being of the same age, and possibly related to the same volcanic events in the External Dinaridic area (Fig. 7).

The volcaniclastic deposits from the Svilaja Mt. Section are stratigraphically determined as Fassanian to Longobardian in age, according to Jelaska et al. (2003), as well as other

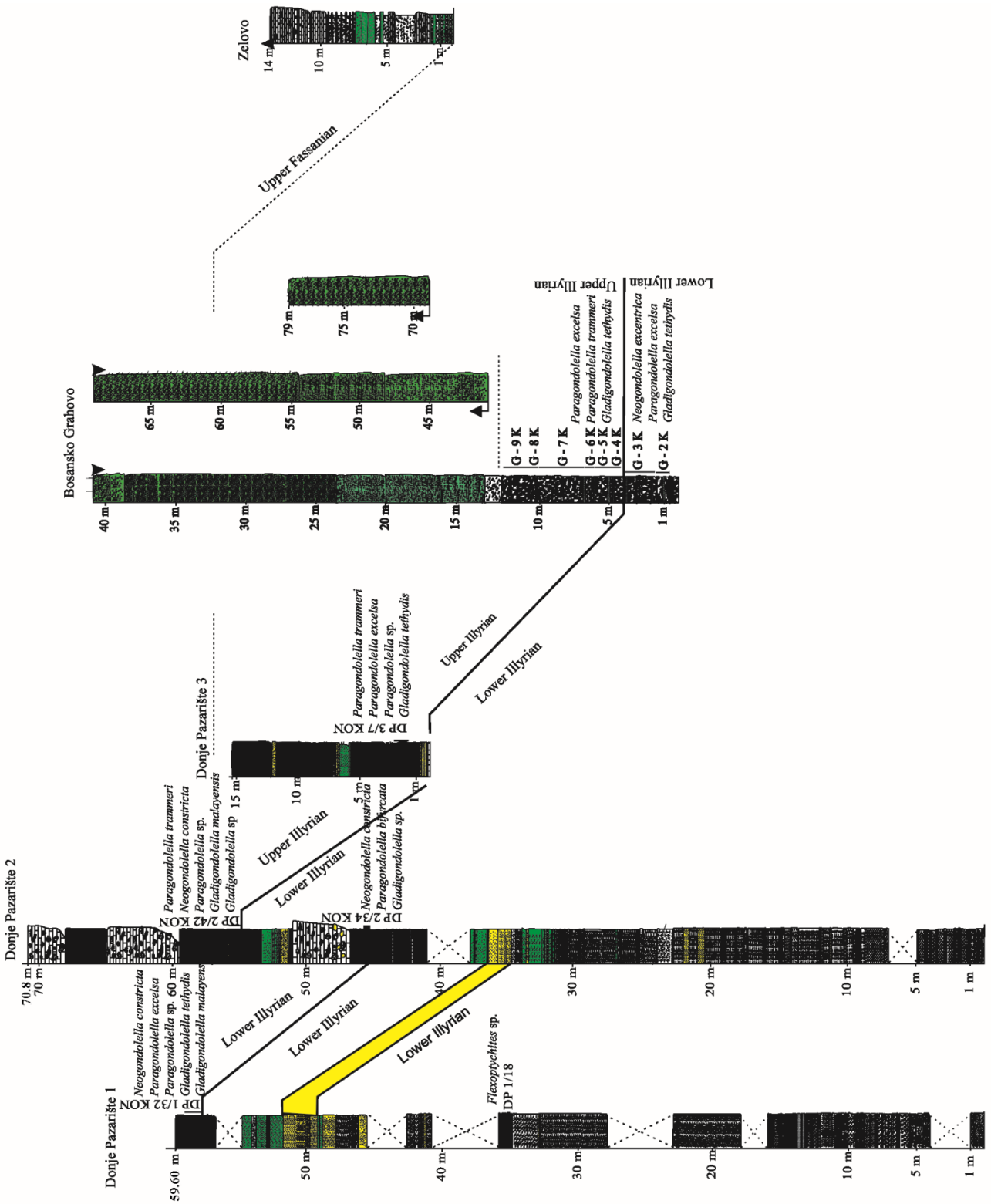

Figure 7. The correlation of the three investigated areas. Donje Pazarište areas with Donje Pazarište 1, 2 and 3 sections; Bosansko Grahovo Section and Zelovo Section. The dashed line from Zelovo Section represents a supposed correlation with Donje Pazarište 3 and Bosansko Grahovo sections, because no strata of the *hungaricus* Zone were determined in these areas.

authors (Halamski et al. 2015; Balini et al., 2006, Kolar-Jurkovšek et al., 2006; Jelaska et al., 2003; Belak, 2000; Šćavničar et al., 1984). These volcaniclastic deposits represent the product of a somewhat younger volcanic activity and confirm that the volcanism persisted throughout the Middle Triassic in the investigated area. The lithoclastic tuffs mentioned by Šćavničar et al. (1984) could represent the products of the older volcanic activity in this area, and could possibly be correlated with the sections of Donje Pazarište area and Bosansko Grahovo. However, the first tuff zone, composed of lithoclastic tuffsand suggested as Upper Anisian, was not analysed in the frame of this investigation. Biostratigraphic results, based on conodont analysisin carbonates intercalated with volcaniclastic deposits, indicatethat the volcanic activity in the External Dinarides lasted from Lower Illyrian to Lower Longobardian.

8 EVIDENCE OF VOLCANIC ACTIVITY IN THE AREA OF THE WESTERN TETHYS

After the formation of Pangea in the Permian, External Dinarides were situated on the western coast of the Palaeotethyan Ocean (Schmidt et al., 2008; Csontos and Vörös, 2004; Stampfli and Borel, 2003, 2002; Scotese, 2002; Haas et al., 1995). As mentioned, the Middle Triassic was characterized by the intensive tectonic movements related to the opening of the Tethyan Ocean accompanied by the magmatic activity.

The development of the southern and northern shelf of the western Tethys differs in the occurrences of the magmatic activity. Clear evidences of the Middle Triassic magmatic activity in form of volcanic and volcaniclastic rocks are found only in the southern shelf of the western Tethys (Southern Alps, Dinarides, Transdanubian range, Bükk Mts.) while the northern western Tethyan shelf was characterized by a noticeable sea-level rise and drowning of the existing carbonate platforms. This event in the northern shelf of the western Tethys is termed the "rifling event" (Schlager and Schollnberger, 1975) and was caused by the thinning of the crust and subsidence of the terrain (Lein et al, 2012; Krystyn, 2008; Gallet et al., 1998; Lein, 1987; Brandner, 1972).

Some authors declared that the evidences of volcanic activity in the External Dinaridic area in form of tuff layers were recorded in the Permian *Gröden type sandstones* (Hinterlacher-Ravnik, 1965) and in the Upper Permian evaporates (Šćavničar, 1984). These occurrences of volcaniclastic deposits could represent the product of the initial stage of the Tethyan Ocean rifting (Pamić and Balen, 2005). Surly the peak of the volcanic activity in the External Dinarides can be correlated with the formation of the Middle Triassic basalts, andesites (Trubelja et al., 2004; Dimitrijević, 1997; Pamić, 1984, 1982; Lugović and Majer, 1983) and more evolved effusive rocks in the southern part of the Dinarides (Dimitrijević, 1997). At the same time occurrences of the intrusive bodies were also reported (Trubelja et al., 2004; Pamić, 2000, 1984; Marić, 1976; Golub and Vragović, 1975).

Early Triassic epeiric platform/epeiric ramp environment (Aljinović et al., 2018; Vlahović et al., 2005) in the External Dinarides was disintegrated in the Middle Triassic and transformed into a terrain composed of subsided blocks forming deeper marine basins and uplifted blocks with, shallow marine sediments, and subaerially exposed blocks prone to weathering and erosion. The deeper marine environments were filled with different types of sedimentary (cherts, shales, flysch deposits, nodular limestones), volcaniclastic and volcanic rocks (Kovács et al., 2011; Balini et al., 2006; Dimitrijević, 1997; Sakač, 1992; Sokač et al., 1976). *Graben*, *half graben* or *simple graben* structures were formed in the External Dinaridic area (Goričan et al., 2015; Celarc et al., 2013; Belak, 2000) that can be compared to the surrounding areas in the western Tethys: southern Alps (Gianolla et al., 1998; Bechstädt et al., 1978); northern Calcareous Alps (Kovács et al., 2011; Krystyn, 2008; Missoni et al., 2001; Krystyn and Lein, 1996), and in Hungary in the Transdanubian Range (Budai and Vörös, 2006; Haas and Budai, 1995), Bükk Mts. (Velledits, 2006), and in Aggtelek Mts. (Péró et al., 2015; Velledits et al., 2011).

In Slovenia, the Upper Anisian, Illyrian strata consists of nodular limestones and marls with siltstones, sandstones and conglomerates (Petek, 1998; Kolar-Jurkovšek, 1983), whereas the Ladinian strata are dominantly volcanic and volcaniclastic rocks, breccias and marls. For the Slovenian part of the External Dinarides a conodont zonation for the Middle and Upper Triassic has been introduced by Kolar-Jurkovšek (1990).

In the area of the western dolomites Early Triassic deposits are found in contact with the Richthoflen conglomerates (Brandner and Bechstädt, 1970), which can be the lithostratigraphic counterpart of the "*Uggowitza breccias*" in Slovenia (Celarc et al., 2013) and "*Otarnik breccias*" in the External Dinarides. The sedimentation of the pelagic facies rocks (nodular limestones with cherts and volcaniclastics, marls with filaments of bivalves and radiolarians) of the Buchenstein or Livinallongo Formation (De Zanche et al., 1993; Cros and Houel, 1983; Brusca et al., 1982) continued throughout the Upper Anisian and Lower Ladinian.

In the Late Ladinian of the Southern Alps, probably due to the decrease of the magmatic activity, and the reduction of the accommodation space, the deeper marine sediments changed into the deposition of marls, micritic limestones and oolithic calcturbidites in a relatively shallower environment (Bernardi et al., 2011; Keim and Neri, 2005; Broglio-Loriga, 1967).

The evidence of magmatic activity in the Hungary is presented as the prominent volcanic, magmatic and sedimentary complex of the Upper Anisian (Illyrian) to Ladinian Age (Harangi et al., 1996; Szoldán, 1990). The unit is composed of effusive volcanic agglomerates, tuffs, ignimbrites and volcaniclastics of the Szentistvanhagy metaandesite formation in the Bükk Mts., while the Transdanubian range is characterized by the deposition of the volcaniclastics from the distant volcanic centers (Feist-Burkhardt et al., 2008). The pelagic environments in Bükk Mts. were filled with marls, tuffs, feldspar sandstones, resedimented volcaniclastics, radiolarite, and cherty limestones until the Rhaetian (Velledits, 2006, 2004, 2000). It is also found that in the Hungarian terrains the magmatic activity significantly reactivated at the end of the Middle Triassic, in Upper Ladinian (Szoldán, 1990; Harangi et al., 1996).

Coeval to the uplift and formation of the clastic units" in the southern part of western Tethys (Richthoflen conglomerate, "*Uggowitza breccia*" and "*Otarnik breccias*), in the northern part deep marine basinal environments were formed due to the "rifling event" (Schlager and Schollnberger, 1975). Basinal

sediments on the northern Tethyan area are presented by reddish to dark limestones with chert, while the volcanic material is present only in form of thin intercalations or is completely absent. The only influence of the Tethyan Ocean opening is evidenced by the sea level rise in the northern Tethyan shelf due to rapid subsidence of the crust (Lein et al, 2012; Krystyn, 2008; Gallet et al., 1998; Lein, 1987; Brandner, 1972).

9 WESTERN TETHYAN TRENDS

Western Tethyan realm presented a vast shallow marine environment in the Early Triassic dominated by mixed clastic-carbonate sedimentary rocks. By the beginning of Middle Triassic, the tectonic events had severely differentiated the area causing differences in development in the southern and northern shelf areas of the western Tethys (Velledits et al., 2017; Péró et al., 2015; Sudar et al., 2013; Kovács et al., 2011; Velledits, 2006; Lein, 1987).

In the entire area of the western Tethys, some global events can be traced. The beginning of the Middle Triassic is accompanied by the global sea level rise that caused the drowning of the western Tethyan carbonate platforms in the northern shelf (Celarc et al., 2013; Kovács et al., 2011; Krystyn, 2008; Budai and Vörös, 2006; Missoni et al., 2001; Gianolla et al., 1998; Krystyn and Lein, 1996; Haas and Budai, 1995; Bechstädt et al., 1978).

The sea level rise in the north part of western Tethys was probably triggered by the intensive tectonics and subsidence and thinning of the continental crust (Velledits et al., 2017; Lein, 1987; Krystyn and Schöllnberger, 1972), while in the southern western Tethyan area the beginning of main volcanic phase took place. These events (drowning in the north and volcanic activity in the south) in the western Tethys were related to the opening of the Tethyan Ocean (formerly considered as opening of Neotethys). The rift-like (graben, half-graben or simple graben) morphology occurred with the pronounced uplifting or subsiding of blocks. The evidence of uplifting is noticeable only on the southern shelf of the western Tethys and is recorded by the local presence of the clastic deposits ("*Otarnik breccias*", "*Uggowitza breccias*", Richthoflen conglomerates) (Celarc et al., 2013; Vozár et al., 2010; Jelaska et al., 2003; Belak, 2000; Marjanac, 2000; Šćavničar et al., 1984; Brandner and Bechstädt, 1970), suggesting severe tectonic movements at the beginning of the Middle Triassic in the southern area of the western Tethys. At the same time, local subsidence occurred forming deeper marine environments filled with different sediments. The differences in the basinal/pelagic lithologies in the Anisian times depend on several factors: vicinity of continent, possibility of communication with the open ocean areas and differences in bathymetric and palaeorelief characteristics (Goričan et al., 2015; Stockar et al., 2013; Sudar et al., 2013; Gawlick et al., 2012; Missoni et al., 2012; Schefer et al., 2010; Sudar and Kovács, 2006; Jelaska et al., 2003; Belak, 2000; Brack and Muttoni, 2000; Anđelković and Sudar, 1990; Sokač et al., 1976).

The first occurrence of the magmatic activity in the western Tethys was recorded at the beginning of the Middle Triassic, while its peak started in the Upper Anisian and persisted into the Ladinian (Velledits et al, 2017; Crisci et al., 1984; Velledits, 2009, 2006, 2004; Dimitrijević, 1997; Harangi et al., 1996; Mundil et al., 1996; Castellarin and Rossi, 1981; Obenholzner, 1991; Castellarin et al., 1988; Pamić, 1984). After the peak, magmatic activity gradually abated, as only thin layers of pyroclastic deposits were found in the Upper Ladinian of the western Tethys.

The occurrence of "*pietra verde*" tuffs (Du Riche Preller, 1916) in the area of the Dinarides and the southern Alps indicate a severe pyroclastic eruption in the area, which took place in the Upper Anisian and Lower Ladinian. Deposition of the Buchenstein type limestones with cherts and volcaniclastics can be considered a widespread facies, indicating global deep marine Middle Triassic conditions on the southern shelf of the western Tethys, and ranging in age from Middle Anisian throughout the Ladinian. As the volcanic activity and related intensive tectonic ceased, the pelagic sediments were overlain by the shallow marine carbonates of the Wetterstein- or Schlern-type platforms, prograding towards the filled basinal areas (Celarc et al., 2013; Lein et al., 2012; Manfrin et al., 2005).

10 CONCLUSION

Based on the analysis of the conodont assemblages and the rare occurrence of ammonoids, the time span of the deposition of volcaniclasticsand related volcanic activity was determined in the External Dinarides. The main Middle Triassic magmatic phase in the External Dinarides is defined as Upper Anisian, Illyrian, to Upper Ladinian, Longobardian. Three investigated localities, all consisting of different volcaniclastic facies, were a product of the magma originated in the same geotectonic suiterelated to the beginning of Tethyan rifting (Smirčić et al., in press). In the investigated area of Donje Pazarište on Velebit Mts., three sections were recorded and stratigraphically defined as Early Illyrian to Early Fassanian. The Bosansko Grahovo Section is stratigraphically divided into two zones, *Neogondolella constricta*—Early Illyrian, and *Paragondolella trammeri*—Late Illyrian to Early Fassanian. According to this, the section in Donje Pazarište area, and Bosansko Grahovo can be very well correlated, as they possibly represent the volcanic activity of the sametime interval (Early Illyrian to Early Fassanian). The different sedimentary and volcaniclastic facies recorded reflect the different positions in the diversified marine environments related to the rift tectonic.

The section including the characteristic "*pietra verde*" tuffs recorded on Mt. Svilaja, at Zelovo locality has already been stratigraphically determined byJelaska et al. (2003), Balini et al. (2006), Kolar-Jurkovšek et al. (2006). The investigations constrain the "*pietra verde*" horizons to *Budurovignatus hungaricus* zone of the Late Fassanian to Early Longobardian Age. According to this, the Zelovo Section with "*pietra verde*" tuffs is younger than the investigated Donje Pazarište and Bosansko Grahovo sections, and suggests thecontinuation of the volcanic activity until the Upper Ladinian. In this work, as a standard for the investigated part of the External Dinaridic area, the conodont zonation proposed by Jelaska et al. (2003) and Kolar-Jurkovšek et al. (2006), in which the GSSP of the Ladinian Stage (Brack et al., 2005), is taken into account.

The comparison of the western Tethys areas shows that some regional events can be correlated in all of the areas. Events related to the opening of the Tethyan Ocean (Neotethys)

had the consequence of sea-level rise and termination of the carbonate platform growth in the shallow marine areason the Northern Tethyan shelf, and contemporary development of the deep marine areas and uplifted subaerially exposed areas, filled with various sedimentary, volcaniclastic and volcanic rockswith significant thickness only in the southern shelf of the western Tethys. The differences in deep marine areas were controlled by local factors. The main volcanic phase in the western Tethys is recorded in the Upper Anisian to Lower Ladinian. The only difference is shown in the Internal Dinarides, where the intrusive bodies, volcanics and volcaniclastics locally occur at the beginning of the Anisian (Dimitrijević, 1997). Also, the lack of significant amount of volcanics and volcaniclasticsin areas of the northern Calcareous Alps and Aggtalek Mts. in Hungary (Velledits et al., 2017) can be interpreted due to their position distant from the Tethyan rift. The beginning of the volcanic activity in the External Dinarides, southern Alps, the Transdanubian range, and Bükk Mts. in Hungary fits almost perfectly, although to different extents (the volume of volcanics and volcaniclastics). The duration of the Middle Triassic magmatic and volcanic activity varies in the western Tethyan area as some volcanic systems ceased to exist in the Ladinian (External Dinarides and southern Alps) while others (Transdanubian Range in Hungary) persisted into the Jurassic and the full formation of the Tethyan Ocean.

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