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Lower Permian Košna conglomerates of the Velebit Mt. (Croatia): modal composition, provenance and depositional environment

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Abstract

The multicoloured 'Košna' conglomerates are investigated in the area of the Košna Voda spring, in the Brušane area of Velebit Mt., Croatia. The studied conglomerates consist of red-coloured matrix and clasts of various lithologies (sandstones, limestones, chert and quartz pebbles) and sizes, suggesting provenance from different areas. Average clast size and their percentage was determined by the Udden-Wentworth classification with estimation of the matrix content. Clasts and matrix lithological and mineralogical characteristics were determined using petrographic, ore microscopy, and X-ray diffraction analysis. Sandstone clasts in the studied conglomerates are classified as lithic arenites, subarkoses and arkoses. Limestone clasts are mostly wackestones to packstones with foraminifera, ostracods, echinoid and bryozoan fragments that derive from late Carboniferous/early Permian shallow-marine limestones. Calcispheres and incipient growth forms of *Microcodium* are also present, suggesting different sediment sources and resedimentation processes. Fragments of fusulinid foraminifera were identified in the matrix of the 'Košna' conglomerates. Based on the analyses performed, and field observations, the 'Košna' conglomerates are described as early Permian (Cisuralian) polymictic clast-supported to matrix-supported conglomerates and breccia-conglomerates that share structural and textural similarities with conglomerates from other areas in the Dinarides, as well as in the Eastern and Southern Alps. The 'Košna' conglomerates are younger than the Sakmarian and are comparable with the Trogkofel limestones of the Carnic Alps and the Karavanke Mts. in Slovenia. We suggest that the studied deposits originated from the uplifted Variscan Mountains during the Variscan and Saalian orogenic movements, and were finally deposited from tractive flows and occasional debris flows in a shallow marine environment of the Palaeo-Tethys, possibly in fan deltas.

Keywords: polymictic conglomerates, Brušane area, Velebit Mt., Variscan orogeny, Cisuralian

1. INTRODUCTION

As one of the most important orogenic events of the late Palaeozoic, the Variscan orogeny had a major influence on the sedimentation and structural configuration of the various tectonostratigraphic units and terranes in the present-day Circum-Pannonian Region. The spatial occurrence of terranes as fault-bounded crustal units comprising rock sequences of regional extent with distinctive geological history (CONEY et al., 1980) does not necessarily reflect their relative position prior to their assembly (CHETTY, 2017). In this respect, the Adria-Dinaria Megaterrane, as one of the megaterranes in the Circum-Pannonian region, belonged to the passive margin of Gondwana and has moved northwards from the late Carboniferous to the present day (KARAMATA, 2006; VOZÁROVÁ et al., 2009). This megaterrane comprises pre-Mesozoic sequences deposited on the passive margin of Gondwana (e.g., RAMOVŠ et al., 1990) and Mesozoic carbonates formed on the Adriatic Carbonate Platform (VLAHOVIĆ et al., 2005), which were later subjected to compression, rotation and transcurrent displacement during the Alpine orogeny (KARAMATA, 2006). The Adria-Dinaria stratigraphic sequences are best exposed in the Dinarides and in the Southern Alps (VOZÁROVÁ et al., 2009).

Upper Palaeozoic rocks in the External Dinarides of southern Croatia are best exposed in the area of Lika and Velebit Mt. (Fig. 1; SREMAC & KOCHANSKY-DEVIDÉ, 1982 and references therein). The core of the Velebit Mt. anticline comprises a succession of clastic and carbonate deposits. These deposits range in age from the Pennsylvanian (Moscovian) until the end of Permian/beginning of the Triassic, with an unconformable or tectonic contact separating Carboniferous from Permian deposits (KOCHANSKY-DEVIDÉ, 1973; ALJINOVIĆ & SREMAC, 1997). They were deposited on the Palaeotethyan shelf area along the northern passive continental margin of Gondwana (RAMOVŠ et al., 1990; SREMAC, 2005).

Geological studies of the Palaeozoic deposits in the area of Lika and Velebit Mt. were initiated by FOETTERLE (1855), HAUER (1868), SCHUBERT (1908, 1910) and KOCH (1909a,b, 1914, 1929a,b), with further research by SALOPEK (1937, 1938, 1939, 1940, 1941, 1942, 1948, 1952). Stratigraphic subdivision of the Permian deposits based on microfossils was presented by KOCHANSKY-DEVIDÉ (1955, 1959, 1965, 1973). Petrological description of the Upper Palaeozoic deposits of the Lika and Velebit Mt. area, as well as their tectonic evolution, was provided by RAFFAELLI and ŠĆAVNIČAR (1968). Biostratigraphic determinations, depositional environments and climatic conditions during deposition of the Palaeozoic deposits in the Velebit Mt. area are presented in papers by TIŠLJAR et al. (1991) and SREMAC (1991, 2005, 2007, 2012). Recent papers by WERNER et al. (2015) and SUDAR et al. (2016) focused on remagnetization phenomena of the lower Permian clastics and the composition and provenance of middle Permian sandstones respectively, in the study area.

Previous research was less focused on the age and depositional environment of clastic deposits, especially the 'Košna' con-

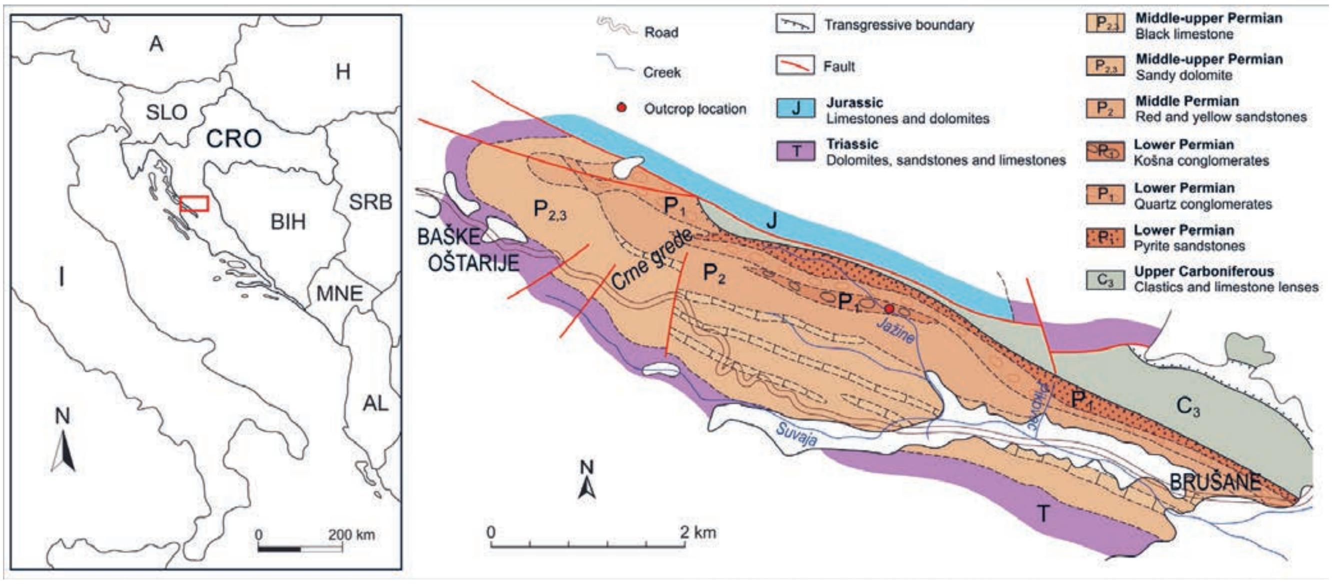


Figure 1. Location and geological map of the studied area (modified after SALOPEK, 1942, 1948).

glomerates, which have been assigned to the Middle Permian by SALOPEK (1942) or early Permian by KOCHANSKY-DEVIDÉ (1973). These conglomerates form part of a 750 m thick succession known as the 'Košna Beds' which were named after the Košna Voda spring in the Brušane area of Velebit Mt. (SALOPEK, 1942). The Košna Beds consist of breccia or green pyritic sandstones in the basal part, and are overlain by quartz conglomerates, 'Košna' conglomerates with limestone and clastic pebbles, and red to yellow 'Košna' sandstones (SALOPEK, 1942, 1948; KOCHANSKY-DEVIDÉ, 1973). The 'Košna Beds' are considered as an equivalent of the Trogkofel beds in Slovenia (KOCHANSKY--DEVIDÉ, 1973) and were petrologically studied by RAFAELLI & ŠĆAVNIČAR (1968), who determined that the occurrence of lithic greywackes and texturally immature sediment was indicative of orogenic movements.

Upper Palaeozoic clastic successions in the area of the Southern Alps were extensively studied and interpreted in terms of depositional environment, stratigraphy and origin (RAMOVŠ & KOCHANSKY-DEVIDÉ, 1965; RAMOVŠ, 1968; KRAINER, 1990, 1993, 2005; CASSINIS et al., 2008; VOZÁROVÁ et al., 2009; SCHAFFHAUSER et al., 2015). In contrast, the upper Palaeozoic clastic deposits in the area of Lika and Gorski Kotar in Croatia have been studied in detail only in terms of their lithological composition (ALJINOVIĆ & SREMAC, 1997), whilst their origin and depositional environment are still not fully understood. Therefore, the aim of this paper is to determine the age, origin, climatic conditions during weathering and the depositional environment of the 'Košna' conglomerates based on the data obtained by field research and qualitative and quantitative analyses. Due to the similar tectono-sedimentary development of the late Palaeozoic successions in the Adria-Dinaria Megaterrane (VOZÁROVÁ et al., 2009), the 'Košna' conglomerates will be compared with similar deposits in Croatia, Slovenia, and the Eastern and Southern Alps.

2. GEOLOGICAL SETTING AND DESCRIPTION OF THE STUDIED AREA

The research area is situated in the central part of the Velebit Mountain, northwest of Brušane village (Lika–Senj County), in the vicinity of the Košna Voda spring (Fig. 1).

The oldest deposits here are upper Carboniferous shales, sandstones and conglomerates, with limestone lenses occurring in the uppermost part of this clastic succession (SALOPEK, 1942; SOKAČ et al., 1976; KOCHANSKY-DEVIDÉ, 1979). This upper Carboniferous succession is considered to be an equivalent of the Auernig Beds (SALOPEK, 1942; SOKAČ et al., 1976; KOCHANSKY-DEVIDÉ, 1973). The end of the Carboniferous and the beginning of the Permian are characterized by Rattendorf limestones with *Schwagerina* and *Pseudoschwagerina* fossils (SREMAC & KOCHANSKY-DEVIDÉ, 1982; CLEAL et al., 2015). The contact between the Auernig Group and the Rattendorf limestones is marked by the occurrence of lithic greywackes and coarse-grained terrigenous clasts, indicating orogenic movements that caused infilling of the sedimentary basin with coarse and immature sediment (RAFFAELLI & ŠĆAVNIČAR, 1968; KOCHANSKY-DEVIDÉ, 1973). The 'Košna' conglomerates in the studied area are locally in either a transgressive contact with the underlying Carboniferous deposits, or intercalated with Permian clastics (SALOPEK, 1942; SOKAČ et al., 1976). The Permian deposits in the area of Brušane – Baške Oštarije can generally be subdivided into the lower, clastic zone (including the 'Košna' conglomerates) and the upper, dolomite zone, with three limestone intervals (SREMAC & KOCHANSKY-DEVIDÉ, 1982). The change in the lithological composition is the result of significant orogenic activity associated with the late stages of the Variscan orogeny in the Middle Permian and at the beginning of the late Permian (SALOPEK, 1942, 1948; RAFFAELLI & ŠĆAVNIČAR, 1968; KOCHANSKY-DEVIDÉ, 1973).

3. METHODS

This research included detailed field investigations in the area of the Košna Voda spring in the Jažine trench (Fig. 1), where conglomerates occur as scattered and discontinuous outcrops. A total of 19 rock samples, which included limestone, chert and sandstone clasts, as well as Košna conglomerate fragments of different size and composition, were randomly selected, sampled and marked with the letter „K“ and numbers 1 to 19. Five well exposed layers were photographed within 60 x 40 cm frames in order to measure the longest (x) and shortest (z) visible clast axes (Fig. 2), determine average clast size and categorize them according to the Udden-Wentworth scale for statistical processing of granulometric data. The matrix percentage was estimated according to TERRY & CHILINGAR (1955).

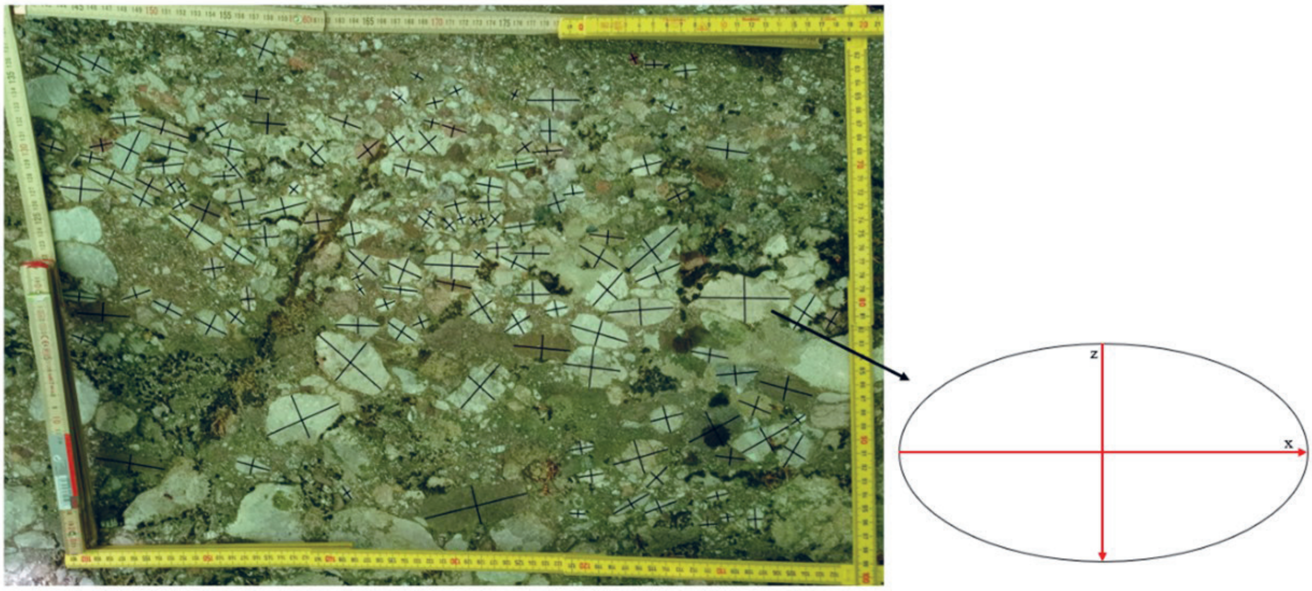


Figure 2. Example of the 60 by 40 cm frame used to measure x and z clast axes.

Petrological analyses of conglomerate clasts and matrix were undertaken at the Department of Geology of the Faculty of Science, University of Zagreb. From the 19 samples, 23 thin-sections were prepared according to the method described in VRKLJAN et al. (2018). Out of these, 17 were thin-sections of sandstones, five of limestones and one of chert. Thin-sections were analyzed using a petrographic polarizing microscope and an ore microscope. From 17 thin-sections and six polished sections of sandstones, representative samples were analyzed using the line counting method, and classified according to PETTIJOHN et al. (1987). Six selected thin-sections of sandstones were stained using a mixture of Alizarin red S and potassium ferricyanide dissolved in a dilute hydrochloric acid solution in order to differentiate the carbonate minerals (DICKSON, 1966; EVAMY, 1969). Identified minerals and lithic fragments in photomicrographs, photographed with and without crossed polars, are annotated with abbreviations according to WHITNEY & EVANS (2010) and SWANSON (1981). To determine the possible provenance of the clastic material, a ternary provenance diagram (modified after DICKINSON et al., 1983) was used together with the weathering index diagram (after WELTJE, 1994; WELTJE et al., 1998), to determine the relief, weathering conditions and origin of the clastic material. Micropalaeontological analyses were conducted on five limestone samples and classified according to FOLK (1959) and DUNHAM (1962).

X-ray powder diffraction analysis was performed on the conglomerate matrix to determine its mineralogical composition and relate it to the specific red colouration. The matrix was extracted from two conglomerate samples and analyzed in a Philips X'Pert Pro diffractometer. The samples were continuously scanned (0,001° 2Θ/s) with the generator set to 40 mA and 40 kV, using a copper anode. Diffractograms were interpreted using the X'Pert Highscore Plus program and the PDF-2 database (ICDD 2004).

4. RESULTS

4.1. Fieldwork

The studied conglomerates crop out as an approximately 2 km wide lens-shaped body, reach a maximum thickness of about 100 m and are fragmented and scattered along the Košna Voda creek (Fig. 3A). They comprise pebble- and cobble-sized clasts of various lithological composition: red, grey and green pyritic sandstones, chert, limestone and quartz. The matrix is composed of mostly red, coarse sand-sized particles. The conglomerates are predominantly clast-supported, massive and poorly sorted, with rounded to subrounded clasts of low sphericity. Pebble imbrication is also common, as well as intervals exhibiting normal grading and crude plane-parallel stratification (Fig. 3B). Subordinate matrix-supported conglomerates contain clasts of different sphericity and roundness. In several places, angular clasts prevail and these deposits can be classified as breccia-conglomerates. Elsewhere, conglomerates intercalate with horizontally laminated sandstones (Fig. 3C).

4.2. Quantitative analysis

From photographs of five selected 60 by 40 cm frames placed on the outcrop (Fig. 2), the length of clast x- and z-axes were measured, for a total of 609 clasts. The length of the longest axis (x) ranges from 0.7 to 10.5 cm with an average of 2.7 cm, while the length of the shortest axis (z) ranges from 0.4 to 7.3 cm with an average of 1.5 cm. Based on the measured diameters, using the Udden-Wentworth grain size classification, clasts are divided into two categories: pebbles (4–64 mm) and cobbles (64–256 mm). The pebbles dominate with 96.40 % (Fig. 4A) and are further divided into three subcategories (Fig. 4B): medium (8–16 mm), coarse (16–32 mm) and very coarse (32–64 mm). Most pebbles are very coarse (54 %), whereas subordinate medium and coarse pebbles are equally represented. The amount of matrix varies from 5 % in clast-supported conglomerates to up to 80 % in matrix-supported conglomerates.

4.3. Petrology of sandstones, provenance and weathering index diagram

Sandstone clasts, determined in 17 out of 23 thin-sections, are lithic arenites, subarkoses and arkoses, with their characteristics described and explained below.

4.3.1. Lithic arenites

Lithic arenites (Fig. 5A to H) are poorly to well-sorted with subangular to sub-rounded grey, yellowish and brownish grains in

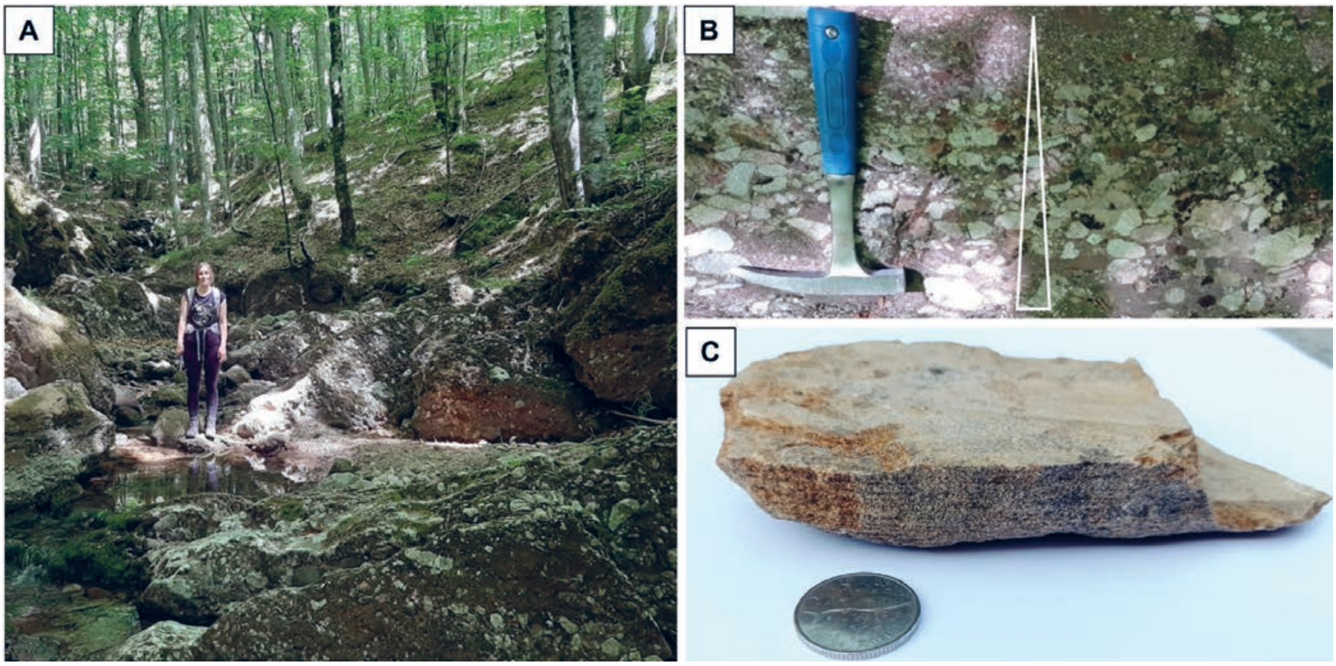


Figure 3. The sedimentary features of the 'Košna' conglomerates. A: Outcrop in the vicinity of the Košna Voda spring, with visible massive matrix-supported conglomerates. Person is 1.70 m tall. B: Close-up photo showing a clast-supported conglomerate with normal grading and crude plane-parallel stratification. Hammer is 30 cm long. C: Horizontally laminated sandstone. Coin for scale is 24.5 mm in diameter.

a dark to reddish matrix (Fig. 5B, D, F) that contains silt-sized brownish to grey particles about 60 µm in size. The rest of the bounding material is cement, composed of ferruginous dolomite. Quartz grains are most common (48–53.5 %; Fig. 5A–F), often interspersed with calcite veins. Lithic fragments make up about 25.7–30 % of the samples, while feldspar grains are present at about 21 % (Fig. 5A, B). Among the lithic fragments, chert is the most common type (Fig. 5A–D), whereas limestone clasts, low-metamorphic rock fragments and unidentifiable fine-grained reddish rock fragments are less common. Besides the main rock-forming minerals, elongated mica grains are also present, as well as small amounts of idiomorphic opaque minerals showing cubic symmetry (Fig. 5G, H). To identify the opaque minerals, two polished sections were made. In reflected light, the colour of these minerals is brassy yellow with a metallic lustre, which is, along with the habitus, characteristic for pyrite (Fig. 5G, H). The X-ray powder diffraction analysis showed the presence of quartz, haematite, muscovite and calcite in sample K-1 (Fig. 6A), whereas sample K-6 additionally shows the presence of clinochlore and feldspar (Fig. 6B).

4.3.2. Subarkoses

Samples of subarkoses (Fig. 7A to F) are moderately- to well-sorted and contain angular to subangular grains. Compositionally, quartz grains prevail (up to 66 %), while feldspars and lithic fragments make up to 22.4 % and 16.8 % of the samples, respectively. The cement is composed of ferruginous dolomite. Lithic fragments comprise chert, limestones, metamorphic rock clasts and microbreccia fragments (Fig. 7A, C). Mica and opaque mineral grains are rare. Chlorite minerals occupy up to 5 % of the samples. Chlorite grains are green and anhedral with an average size of 120 µm (Fig. 7E). The interference colour is lavender-blue to purple (Fig. 7F), which is characteristic for chlorite minerals rich in iron.

4.3.3. Arkose

One sample is classified as a moderately sorted arkose (Fig. 8), with 62.2 % of quartz, 29.5 % of feldspar and 8% of lithic fragments – mostly limestone, rare chert and small amounts of plagioclase and mica (Fig. 8A, B). Cement is present in small amounts and is composed of ferruginous dolomite.

4.3.4. Provenance diagram and weathering index diagram

The ternary provenance diagram by DICKINSON et al. (1983) shows that samples of lithic arenites (K-1, K-6 and K-11) and subarkoses (K-4 and K-12) are all plotted in the area of recycled orogen, while the arkose sample (K-13) plots at the borderline of two areas: recycled orogen and continental block (Fig. 9).

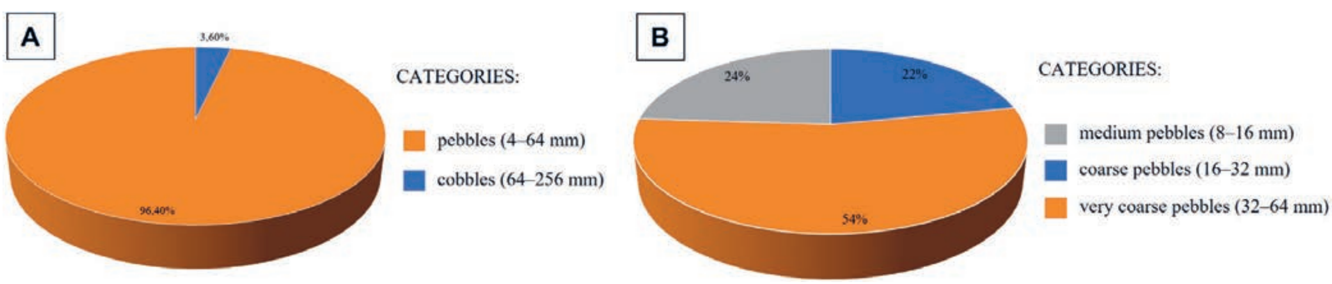


Figure 4. Results of statistical analyses obtained from gravel clast axes measurements of 609 clasts from the 'Košna' conglomerates. A: Pie chart showing the dominance of pebble-sized clasts. B: Pie chart showing the relative proportions of the various pebble categories.

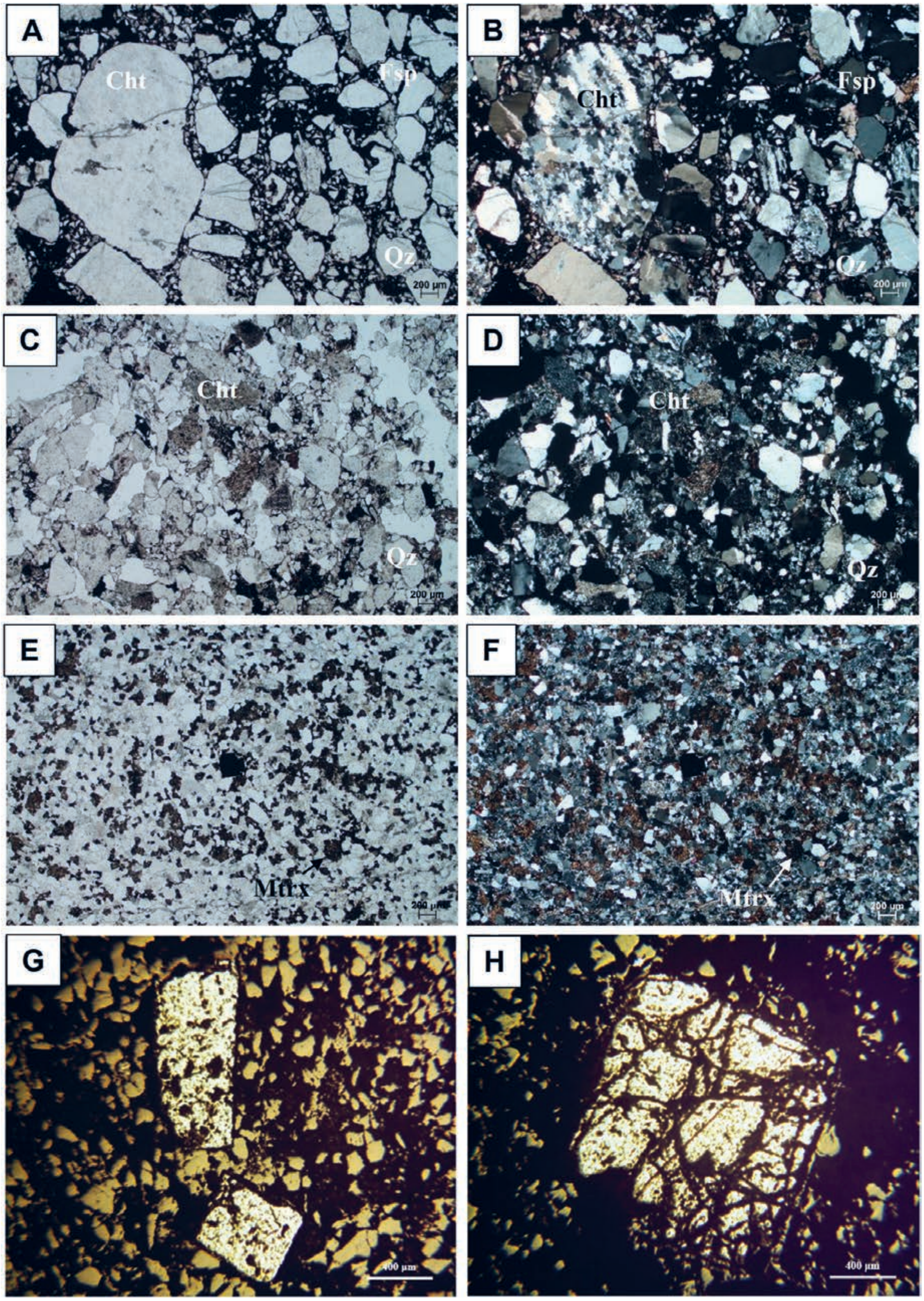


Figure 5. Photomicrographs of lithic arenites from the 'Košna' conglomerates, left under polarized light and right with crossed nicols. Legend: Cht – chert, Qz – quartz, Fsp – feldspar, Mtrx – matrix. A, B: sample K-1. C, D: sample K-6. E, F: Sample K-11, with opaque mineral in the centre. G, H: Close-up of the opaque mineral (most likely pyrite) in sample K-11.

The weathering index diagram (WELTJE, 1994; WELTJE et al., 1998) consists of two areas indicating the origin of the weathered material (metamorphic/sedimentary or plutonic). These areas are divided into four fields, each indicating relief and climate conditions. The natural logarithm of quartz to lithic fragments ratio and the natural logarithm of quartz to feldspar ratio are plotted on the abscissa and ordinate, respectively. Analyzed samples plotted in the plutonic area of the diagram, with

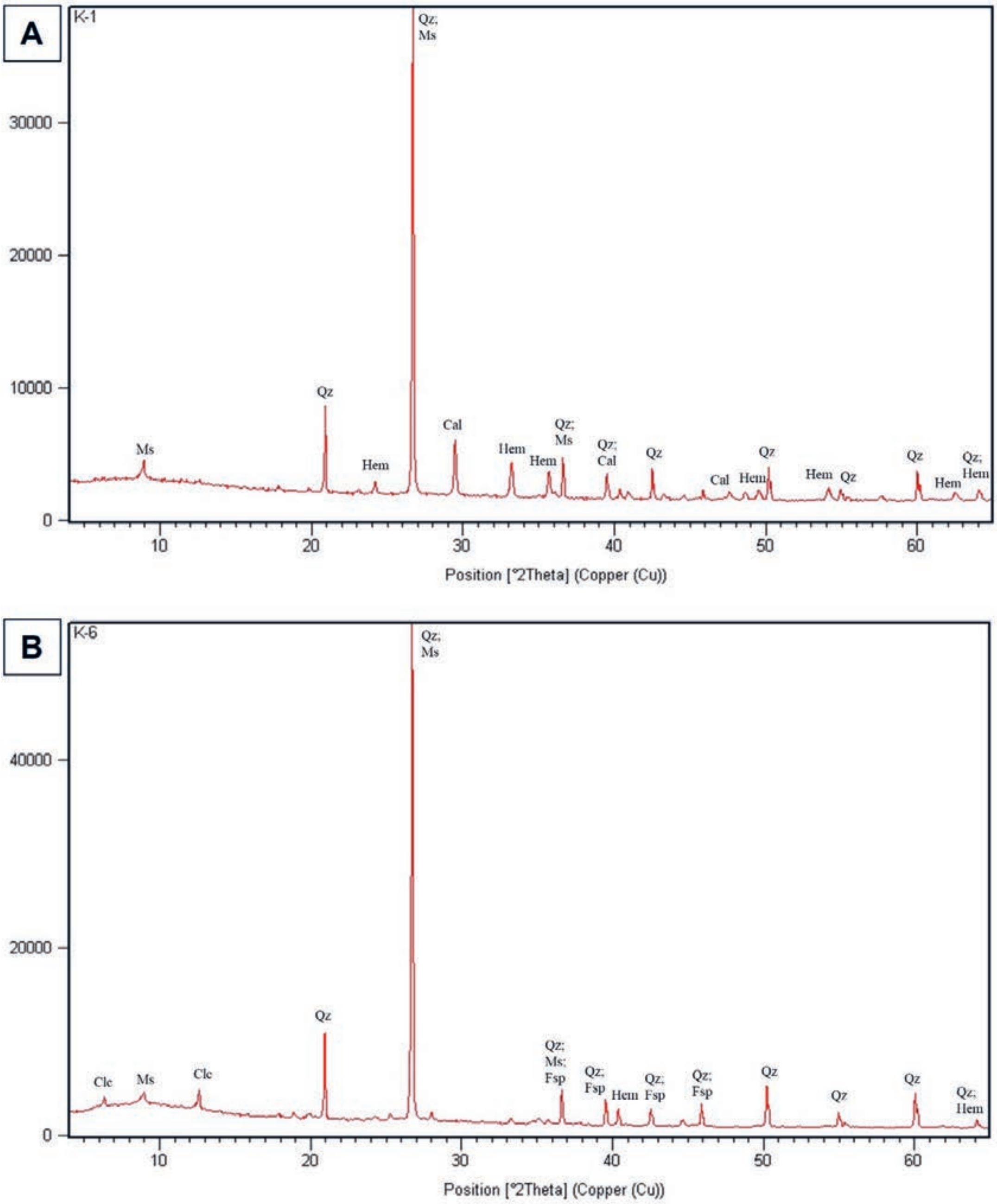


Figure 6. X-ray diffractograms of matrix samples from the 'Košna' conglomerates. Sample K-1 (above) and K-6 (below). Legend: Cal – calcite, Clc – clinochlore, Fsp – feldspar, Hem – hematite, Ms – muscovite, Qz – quartz.

lithic arenites in the area "0" and subarkoses and arkose in the area "1" (Fig. 10).

4.4. Chert petrology

Sample K-5 is a microcrystalline chert with quartz veins (Fig. 11A, B). It contains idiomorphic opaque mineral grains with thin, light-transmitting edges, making their own reddish-brown colour visible. These grains are determined as haematite (Fig. 11C, D). Additionally, polished sections revealed anhedral grains with a brassy-yellow colour in reflected light and a metallic lustre, which are determined as pyrite (Fig. 11E).

4.5. Limestone petrology and microfossil analysis

Limestone clasts within the 'Košna' conglomerates occur mainly as cobbles. Thin-sections from five selected cobbles show that limestones are mostly composed of poorly preserved skeletal fragments and micrite. They are classified as biomicrites (FOLK, 1959). According to DUNHAM (1962), sample K-14 is classified as wackestone (Fig. 12A), samples K-15, K-16 and K-17 as packstones (Fig. 12B), and sample K-18 as wackestone to packstone with sparite-filled cavities.

Fossil content from the analyzed limestones includes ostracods, calcispheres (Fig. 12C), possible radiolarians, echinoid spines, foraminifera, and bryozoans (Fig. 12D). Isodiametric polyhedral elements (crystals/grains), arranged around a hollow central part occur locally and in size and structure, resemble incipient growth forms of *Microcodium* (Fig. 12E–F), i.e. organisms of uncertain systematic position. The features, however, do not show radially elongated calcite grains characteristic of classic *Microcodium* "corncob" and "rosette" morphologies. Determined foraminifera species include: *Diplosphaerina* (previously: *Neotuberitina*) *maljavkini* SULEYMANOV, 1948 (Fig. 12G); *Tu-*

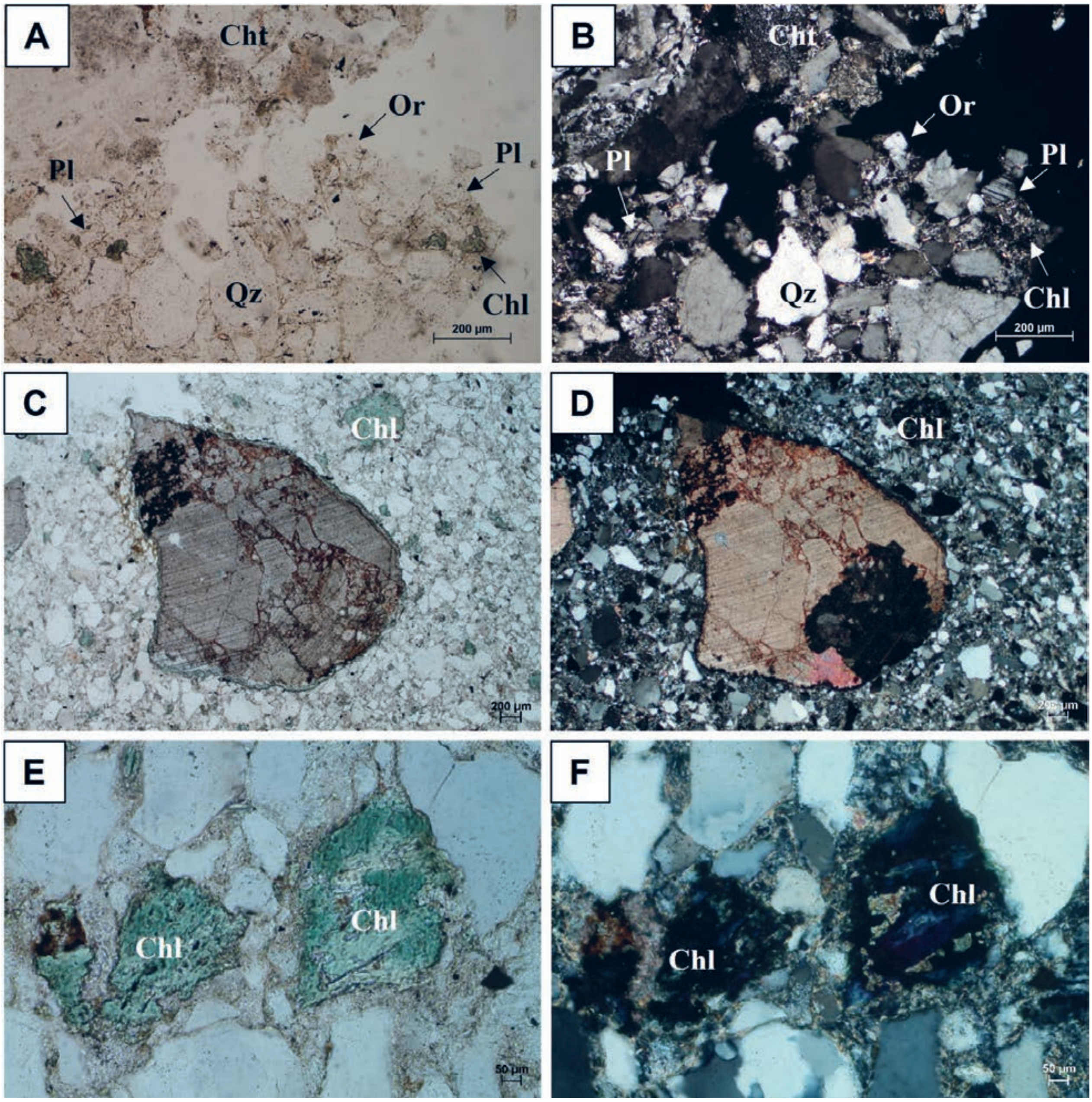


Figure 7. Photomicrographs of subarkose sample K-4 from the 'Košna' conglomerates, left under polarized light and right with crossed nicols. Legend: Cht – chert, Qz – quartz, Chl – chlorite, Pl – plagioclase, Or – orthoclase. A, B: fine-grained subarkose. C, D: microbreccia fragment surrounded by finer grains. E, F: Chlorite minerals.

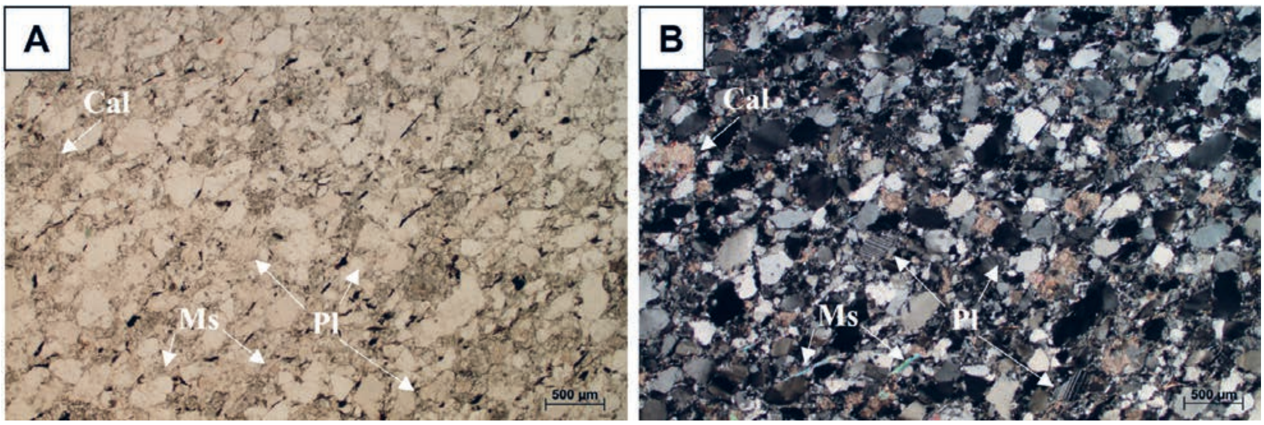


Figure 8. Photomicrographs of arkose sample K-13 from the 'Košna' conglomerates. Legend: Cal – calcite, Ms – muscovite, Pl – plagioclase. A: under polarized light and B: with crossed nicols.

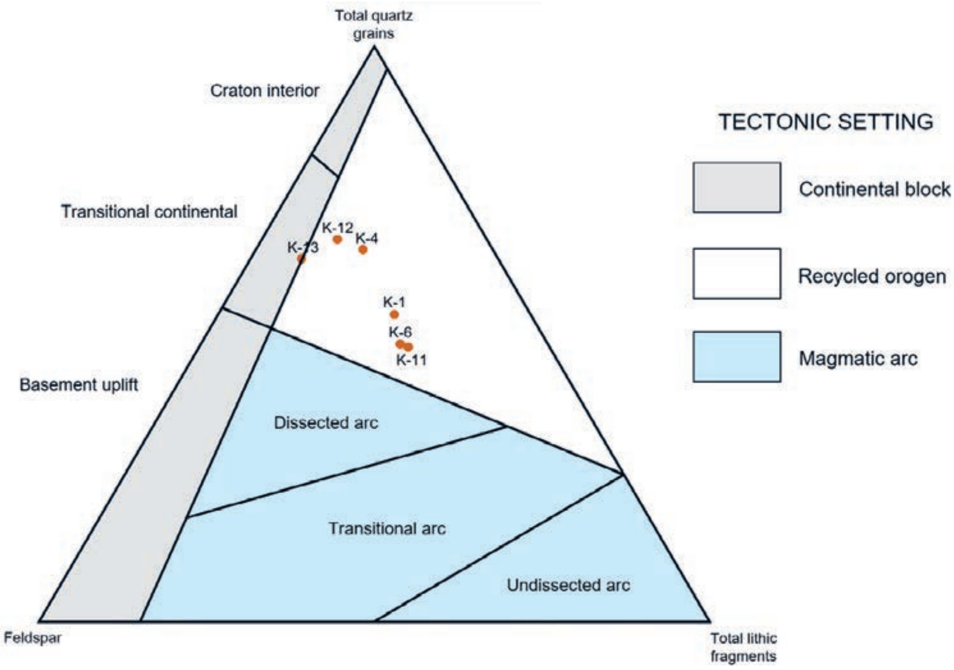
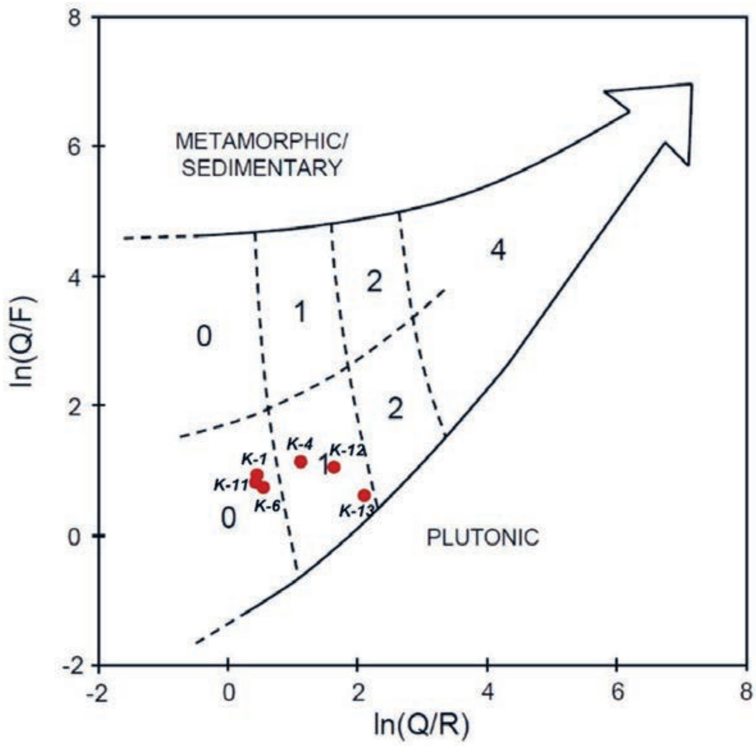


Figure 9. Ternary provenance diagram modified after DICKINSON et al. (1983).



SEMI-QUANTITATIVE WEATHERING INDEX			PHISIOGRAPHY (RELIEF)		
			High (mountains) 0	Moderate (hills) 1	Low (plains) 2
CLIMATE (PRECIPITATION)	(semi)arid and mediterranean	0	0	0	0
	temperate subhumid	1	0	1	2
	tropical humid	2	0	2	4

Figure 10. The weathering index diagram modified after WELTJE (1994) and WELTJE et al. (1998).

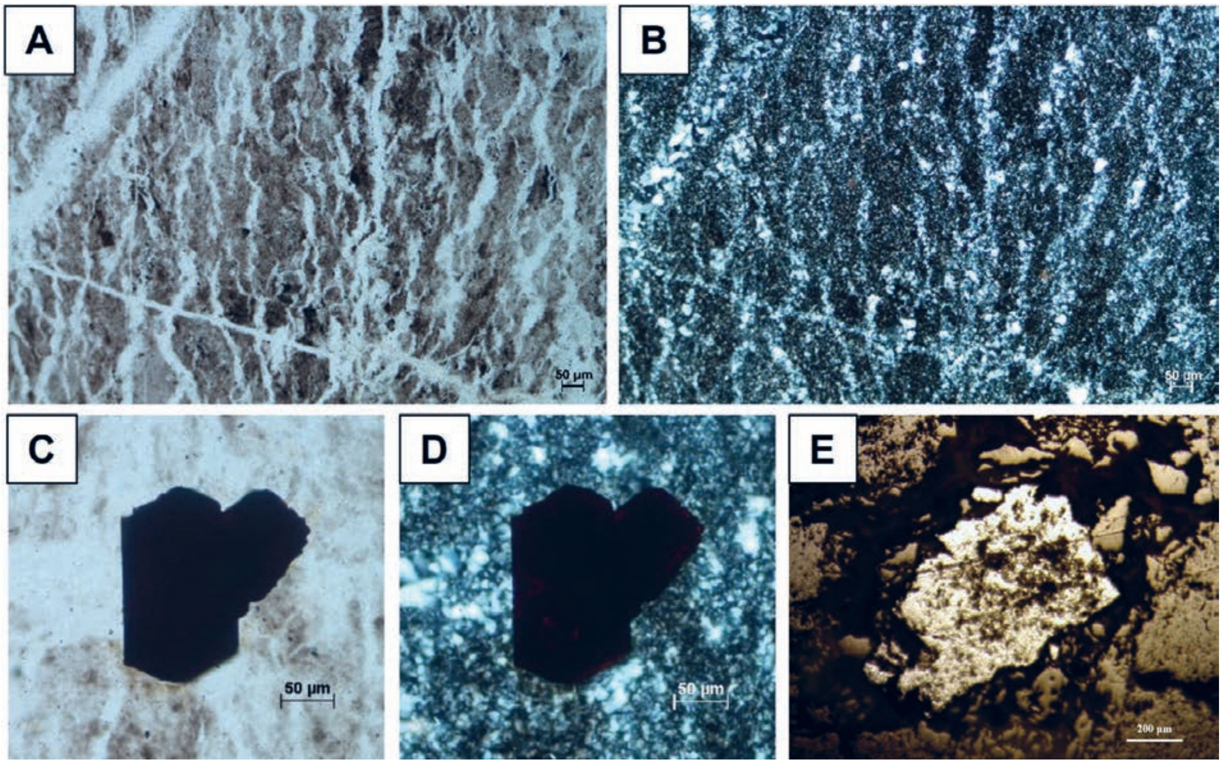


Figure 11. Chert sample K-5. A, B: Photomicrographs under polarized light (A) and under crossed nicols (B). C: Opaque mineral grains under polarized light and (D) under crossed nicols. E: Pyrite grain in polished section under reflected light.

beritina bulbacea GALLOWAY & HARLTON, 1948 (Fig. 12H) and *Turrispiroides* cf. *microsphaerica* K.V. MIKLUKHO-MAKLAY, 1968 (Fig. 12I). It should be noted that fusulinid foraminiferal fragments are observed in limestones, but also within the sandstone matrix (Fig. 12J), together with some unidentified fossil material (Fig. 12K).

5. DISCUSSION

5.1. Sediment source and depositional environment of the 'Košna' conglomerates

The studied deposits in the Košna Voda spring area include mainly massive, poorly sorted clast-supported conglomerates with very large pebbles (32–64 mm), less common matrix-supported conglomerates and rare breccia-conglomerates. The constituent gravel clasts are by composition sandstones (lithic arenites, subarkoses and arkoses), limestones and cherts. The variations in their shape and size result from their different petrological compositions, as well as from transport and weathering conditions prior to their inclusion into the conglomerates. The matrix is composed of coarse-grained sand particles coloured by haematite.

The ternary provenance diagram (DICKINSON et al., 1983) shows that the analyzed sandstone clasts mostly originated from a recycled orogen and a continental block (Fig. 9) and were most likely formed by weathering of a high to moderate relief in a (semi)-arid to partially humid climate, as suggested by the weathering index diagram (Fig. 10). The sedimentary textures and structures observed in the conglomerates (plane-parallel stratification, imbrication and normal grading) are common in sediments deposited by tractive flows in alluvial systems and deltas, as well as from coarse-grained turbidity currents (TIŠLJAR, 1994). Structureless matrix-supported and clast-supported conglomerates may have been deposited from cohesive and cohesionless subaqueous debris flows, respectively (DRAKE, 1990; MULDER & ALEXANDER, 2001). Fragments of fusulinid foraminifera found within the conglomerate matrix suggest deposition in a marine environment. Although not found in the studied samples, the occurrence of chlorite minerals, illite and sericite, as well as pyrite in the conglomerate matrix was reported by RAFFAELLI & ŠĆAVNIČAR (1968), and is considered as another indication of sedimentation in a marine setting. These results reveal that the sediment constituting the 'Košna' conglomerates originated from the erosion of the mountains uplifted during the late phases of the Variscan orogeny and that they were deposited in shallow marine areas, as firstly suggested by RAFFAELLI & ŠĆAVNIČAR (1968). Due to limited outcrop exposure, the precise type of depositional environment is difficult to interpret with certainty, but it is suggested that these shallow-marine conglomerates represent gravelly mouth bars or uppermost slope of fan-deltaic or deltaic systems, sourced either by alluvial fans or braided fluvial systems, respectively (NEMEC & STEEL, 1984).

The limestones – from which the analyzed limestone clasts were derived – most likely formed in a low-energy marine environment, as suggested by the large amount of micrite and presence of ostracods, echinoids and bryozoa (Fig. 12A to D). Determined calcispheres (Fig. 12C) are indicative of deep marine environment; however, in the studied samples they are often found in association with ostracod fragments, suggesting resedimentation processes. The incipient growth forms of *Microcodium* represent a biologically-induced mineralization driven by a saprotrophic microorganism or a microbial association, which is common from the Moscovian to the early Permian, and appears in calcretes and calcareous palaeosols (ESTEBAN, 1972; KOŠIR, 2004; KABANOV et al., 2008). Such types of palaeosols form in subtropical and tropical climatic conditions, with occasional dry periods and well-drained semi-arid soils (KABANOV et al., 2008). These

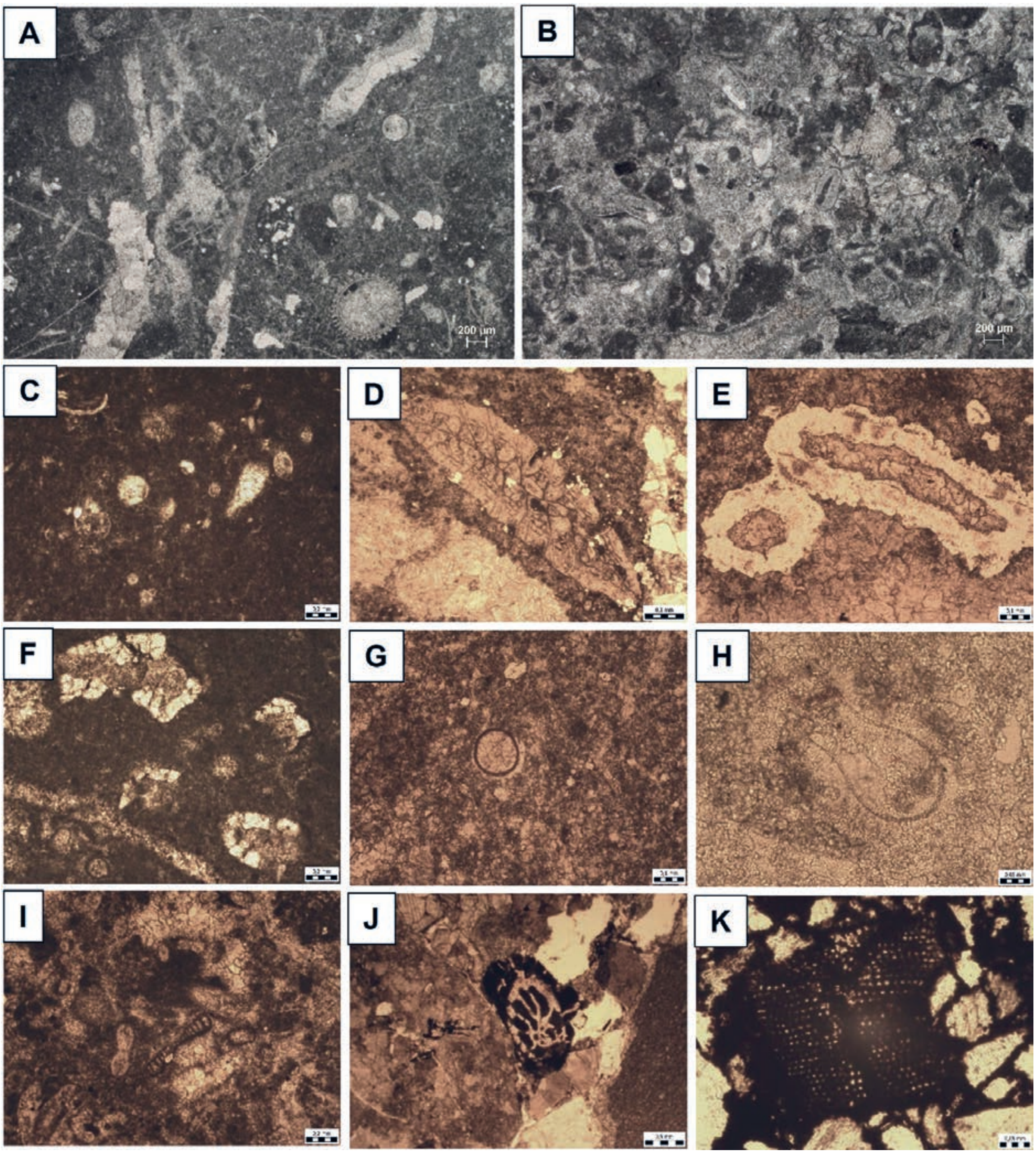


Figure 12. Photomicrographs of limestone and sandstone samples from the 'Košna' conglomerates. A: Wackestone, sample K-14; B: Packstone with various fossil fragments, sample K-16; C: Wackestone with ostracods and calcispheres; D: Wackestone to packstone with bryozoan fragment; E–F: Wackestone to packstone with *Microcodium* sp.; G: Wackestone with *Diplosphaerina* (previously: *Neotuberitina*) *maljavkini* (SULEYMANOV, 1948); H: *Tuberitina bulbacea* GALLOWAY & HARLTON, 1948 surrounded by microsparite; I: Wackestone to packstone with *Turrispiroides* cf. *microsphaerica* K.V. MIKLUKHO-MAKLAY, 1968; J: Fragment of fusulinid foraminifera in the sandstone matrix; K: Unidentified fossil fragment in the sandstone matrix.

observations suggest that limestone clasts in the 'Košna' conglomerates derive from paralic, shallow and deep marine environments, indicating severe tectonic movements (cf. REIJMER et al., 2015). Taking into account the results of the weathering index diagram obtained from the sandstone clasts (Fig. 10; WELTJE, 1994; WELTJE et al., 1998), it transpires that the passive margin of Gondwana was subjected to an overall semi-arid to partially humid climate, which affected the weathering of both carbonate and clastic successions that sourced the diverse gravel clasts found in the 'Košna' conglomerates. Similar climatic conditions continued during the middle Permian, as suggested by the composition and provenance of middle Permian sandstones in the nearby Pikovac Creek valley (Fig. 1; SUDAR et al., 2016).

5.2. Age of the 'Košna' conglomerates

Limestone clasts from the conglomerates near the Košna Voda spring comprise microfossils of late Carboniferous (Gzhelian) to the early Permian (Asselian, Sakmarian) age, suggesting that the conglomerates are younger than the Sakmarian (Fig. 13).

Gzhelian to Sakmarian rocks are not exposed in the vicinity of the Košna Voda spring, but microfossils found in the limestone clasts of the 'Košna' conglomerates are known from the neighbouring regions: e.g. *Tuberitina bulbacea* GALLOWAY & HARLTON, 1928 occurs in the Kasimovian–Gzhelian deposits of the Banovina region (MILANOVIĆ, 1982), early Kasimovian limestones (Auernig Group) of the Carnic Alps in Italy (URL3,

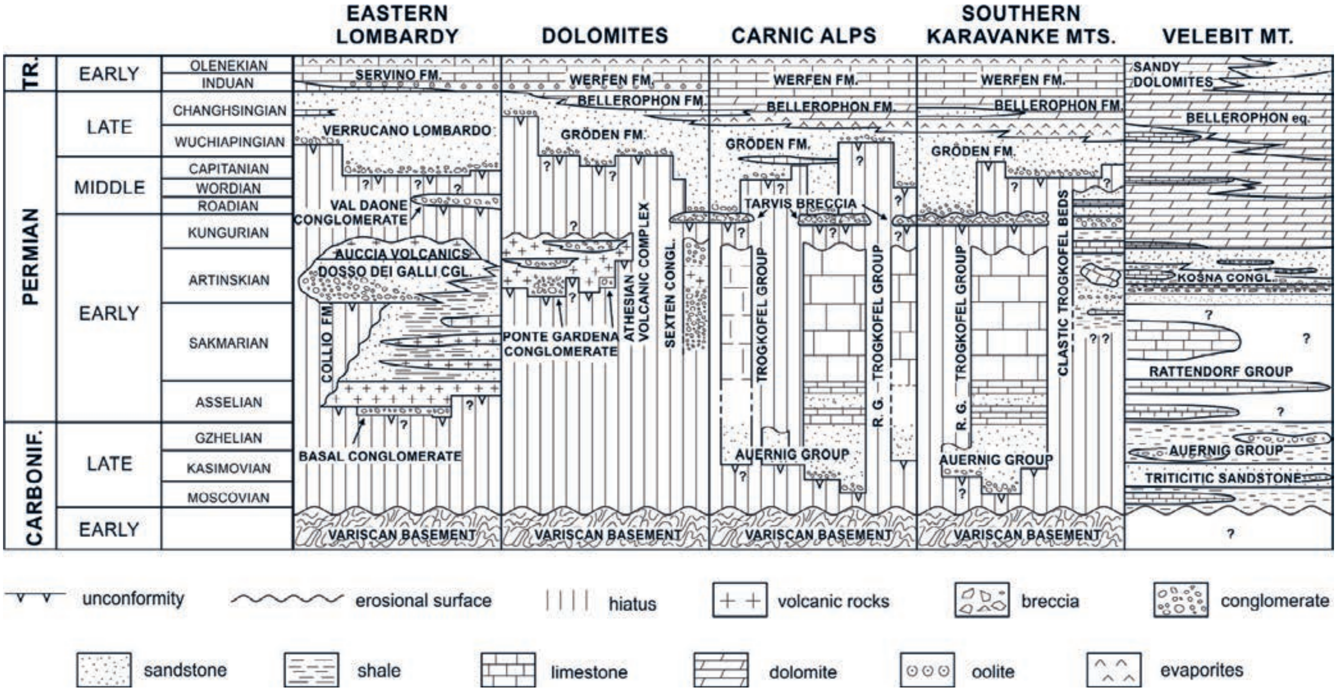


Figure 13. Upper Palaeozoic deposits in the area of the Southern and Eastern Alps, and Velebit Mt. (compiled and modified after KOCHANSKY-DEVIDÉ (1973), RAMOVŠ et al. (1990), KRAINER (1993), MAROCCHI et al. (2008) and CASSINIS et al. (2012)).

URL4), but also in Neoschwagerina Beds of Roadian age in Slovenia (URL5). The foraminifera *Turrispiroides* cf. *microsphaerica* K.V. MIKLUKHO-MAKLAY was not determined in the neighbouring regions, but was reported from the Pennsylvanian to lower Permian deposits of Iran (YARAHMADZAH & VACHARD, 2019).

Limestones discovered at Jajara Hill near Medak (today situated ca. 15 km ESE from the Košna Voda spring), can help in determining the age of the 'Košna' Beds. These limestones overlie ~100 m thick shales and are overlain by ~300 m thick yellow 'Košna' sandstones (KOCHANSKY-DEVIDÉ, 1973), which represent the uppermost part of the 'Košna' Beds (RAFFAELLI & ŠĆAVNIČAR, 1968). The limestones comprise fusulinid taxa *Darvasites* (*Alpites*) ex gr. *contractus* (Schellwien) and *Pseudofusulina* cf. *rakoveci* Ramovš & Kochansky-Devidé, together with *Diplosphaerina* (previously: *Neotuberitina*) *maljavkini* (SULEYMANOV, 1948). According to these fossil findings, KOCHANSKY-DEVIDÉ (1973) suggested that the 'Košna' Beds are contemporaneous with the Trogkofel limestones in Slovenia (Karavanke, Ortnek) and the Carnic Alps, which have been assigned an Artinskian/Kungurian age (Fig. 13; SCHAFFSHAUSER et al., 2015).

5.3. Comparison with similar formations in the neighbouring regions

The Upper Palaeozoic deposits of the Eastern Alps, Southern Alps and Outer Dinarides result from similar tectono-sedimentary evolution and can therefore be compared. The conglomerates were deposited as a result of Variscan and Saalian orogenic movements mostly in alluvial fan environments in Eastern Lombardy and the Dolomites (KRAINER, 1989, 1993), whereas the conglomerates in the Eastern and Southern Alps represent deposition in more distal settings, such as fluvial, lacustrine or deltaic environments (VOZÁROVÁ et al., 2009).

The late- to post-Variscan sequence is divided into two tectono-sedimentary cycles, separated by a major unconformity caused by the Saalian orogenic movements (SCHÖNLAUB, 1982; KRAINER, 1993; CASSINIS et al., 2012), known also as the "Mid-Permian tectonic episode" (DEROIN & BONIN, 2003). Sediments of the lower cycle were deposited in alluvial and lacustrine settings with several volcanoclastic intervals, within intramontane strike-slip and pull-apart basins (e.g., CASSINIS & PEROTTI, 2007) from the late Carboniferous to the Permian (KRAINER, 1993; CASSINIS et al., 2013). Despite the major stratigraphic gap, the middle?/upper Permian to Lower Triassic sediments of the upper cycle conformably overlie the lower Permian sequence of the lower cycle (KRAINER, 1993). The contact between the deposits of the two cycles is in places unexposed, erosional or undetermined. The beginning of the upper cycle is characterized by the deposition of Val Daone conglomerates in the Lombardian Alps, which comprise conglomerates, microconglomerates and sandstones with fragments of quartz and various magmatic rocks, plant debris and coal lenses (Fig. 13; CASSINIS et al., 2008; GRETTER et al., 2013). The conglomerates are multicoloured (white, greyish, reddish, greenish), show clast imbrication and fining-upwards cycles, and are overlain by the laminated Val Gardena sandstone (Grödner Sandstein) (Fig.13; CASSINIS et al., 2008; GRETTER et al., 2013). Such transition is attributed to a shift from alluvial fan to fluvial environments (GRETTER et al., 2013). These conglomerates were deposited at the margins of sedimentary basins along a slope break in response to an extensional tectonic regime (CASSINIS et al., 1995, 2012; GRETTER et al., 2013). Their age was first considered to be late Permian (CASSINIS et al., 1995, 2012), but was later revised to the middle Permian on the basis of palynological data (GRETTER et al., 2013). In general, the middle/late Permian was characterised by clastic sedimentation, followed by carbonate and/or evaporite sedimentation (Fig. 13).

In the western part of the Southern Alps (Dolomites), the lower cycle is represented by the red and greenish-grey Ponte Gardena/Waidbruck conglomerate, overlain by the acidic Athesian Volcanic Group or District (Fig. 13; VISONÀ et al., 2007; MAROCCHI et al., 2008), previously named the Bolzano Volcanic complex (e.g., KRAINER, 1989, 2005; VOZÁROVÁ et al., 2009). This conglomerate represents alluvial-fan sediments deposited under semi-arid climatic conditions (KRAINER, 1989) and is interbedded with volcanic rocks related to the beginning of the Athesian volcanic activity during the middle Artinskian (VISONÀ et al., 2007). In the eastern part of the Southern Alps (the Sexten Dolomites), the lower Permian Sexten breccias and conglomerates occur as an equivalent of the Ponte Gardena conglomerate (Fig. 13; FLÜGEL & KRAUS, 1986; KRAINER, 1993 and references therein). The middle-upper Permian sediments of the upper cycle begin with the Tarvis breccia at the base, which is followed by the Grödner Sandstein (Val Gardena sandstone) and the Bellerophon Formation (Fig. 13; KRAINER, 1993; VOZÁROVÁ et al., 2009). The Sexten breccias and conglomerates and the Tarvis breccia are interpreted to represent deposition from debris flows and stream-channel flows in alluvial fan environments (FLÜGEL & KRAUS, 1986) and are considered as equivalents of the Val Daone conglomerates even though these basal bodies of the second Permian cycle could not necessarily be assessed as quite synchronous (Fig. 13; CASSINIS et al., 2008).

In the Carnic Alps and the Karavanke Mountains, shallow marine clastic and carbonate depositional environments prevailed through most of the Permian (KRAINER, 2005; SHAFFAUSER et al., 2015). The lower Permian lower tectono-sedimentary cycle in this area is represented by the Rattendorf and Trogkofel Groups consisting primarily of limestones (Fig. 13; KRAINER, 1993). In the southern Karavanke Mountains, the Trogkofel Group is represented mostly by clastic deposits intercalated with thin beds of conodont-rich dark limestones (RAMOVŠ, 1963, 1968; KOCHANSKY-DEVIDÉ, 1973). This clastic sequence also includes olistoliths composed of Trogkofel limestone and is considered to represent a deep-marine depositional environment (KOCHANSKY-DEVIDÉ, 1973; KRAINER, 1993). The Mid-Permian hiatus separates the Trogkofel Group from the overlying upper cycle which includes the non-marine Tarvis breccia, the Gröden formation and the Bellerophon formation (Fig. 13; KRAINER, 1993). The Tarvis breccia consists mostly of Trogkofel limestone fragments and subordinate fragments of quartz, magmatic rocks, sandstones, chert and phyllite surrounded by a red to grey clayey matrix (KRAINER, 1993). This breccia is interpreted as a scarpfoot fan deposit and proximal debris flow, possibly deposited in an arid environment or coastal sabkha based on the occurrence of calcareous concretions (FLÜGEL & KRAUS, 1986; KRAINER, 1993). The sedimentary features and occurrence of large Trogkofel limestone clasts in the Tarvis breccia renders it rather similar to the ‘Košna’ conglomerates.

Clastic deposition in the vicinity of Ortnek in Slovenia is attributed to the early to middle Permian, with the lower part consisting of grey to occasionally red quartz conglomerates and quartz sandstones deposited in a shallow marine environment (RAMOVŠ & KOCHANSKY-DEVIDÉ, 1965; RAMOVŠ, 1968). Plant remains and coal intercalations in these deposits suggest their depositional proximity to a vegetated hinterland (RAMOVŠ, 1968). The upper part of the Upper Palaeozoic succession in Slovenia comprises grey shales alternating with organic-rich quartz sandstones (RAMOVŠ, 1968). Limestone lenses, limestone breccias and breccia-conglomerates occur within the shales and are interpreted as small reefs and associated talus produced by reef erosion (RAMOVŠ & KOCHANSKY-DEVIDÉ, 1965; RAMOVŠ, 1968). This Palaeozoic succession corresponds to the clastic Trogkofel beds (ALJINOVIĆ & SREMAC, 1997 and references therein).

In the Gorski Kotar area of Croatia, the Palaeozoic complex of predominantly clastic deposits comprises Carboniferous Triticites sandstones overlain by Permian sandstones, sandstone-shale intercalations, orthoquartzitic and petromictic conglomerates (SALOPEK, 1949a, b, 1960; RAFFAELLI & ŠĆAVNIČAR, 1968; KOCHANSKY-DEVIDÉ, 1973; ALJINOVIĆ, 1997; ALJINOVIĆ & SREMAC, 1997; VOZÁROVÁ et al., 2009). These Permian clastic rocks have an uncertain stratigraphic position in different areas of Gorski Kotar, and have been the subject of many debates (see references in ALJINOVIĆ & SREMAC, 1997; ALJINOVIĆ et al., 2003). Where present, fossiliferous limestone intercalations suggest an early to middle Permian age. SALOPEK (1960) described the aforementioned petromictic conglomerates with clasts of fossiliferous limestones as Gröden-type deposits, attributing them a middle Permian age. However, these findings have later been erroneously cited (see review by ALJINOVIĆ & SREMAC, 1997), which led to the misconception that upper Permian Gröden clastics exist in the area of Gorski Kotar. Nonetheless, sandstone intercalations within this lower–middle Permian clastic series are commonly rich in plant detritus, suggesting their depositional proximity to an uplifted hinterland (ALJINOVIĆ et al., 2003). Despite the debate regarding the stratigraphic attribution, most researchers concur with the notion that this clastic series was most likely deposited in a shallow marine environment, most likely fan deltas that developed in response to early to middle Permian tectonic activity (GRUBIĆ, 1980; ALJINOVIĆ, 1997; ALJINOVIĆ & SREMAC, 1997; ALJINOVIĆ et al., 2003).

Based on the described tectono-stratigraphic development within the Adria-Dinaria Megaterrane, it is evident that the ‘Košna’ conglomerates are comparable with similar lithological units in the neighbouring regions and may be considered as lateral equivalents of the Val Daone conglomerates and the Tarvis breccia in the Alps. Their sedimentological features suggest deposition from coarse-grained tractive flows and occasional debris flows, most likely on mouth bars or the subaqueous slopes of a fan delta or river delta (NEMEC & STEEL, 1984).

6. CONCLUSIONS

1. The ‘Košna’ conglomerates from the Brušane area of the Velebit Mt., Croatia are of lower Permian, most probably Artinskian age, polymict, clast-supported and matrix supported conglomerates, in places breccia-conglomerates with dominantly red coarse-grained matrix, coloured by haematite.
2. The sediment forming the ‘Košna’ conglomerates most likely originates from weathering of the Variscan Mountains in (semi)-arid and partly humid climatic conditions.
3. It is suggested that the material from the Variscan Mountains was reworked and transported by alluvial systems into marine settings where it was deposited most likely on the subaqueous slopes of a fan-delta or river delta.
4. Determined microfossils from the limestone clasts of the ‘Košna’ conglomerates are of late Carboniferous/early Permian age. The identified fauna resemble the biota of the Auernig and Rattendorf Groups.
5. The ‘Košna’ conglomerates show structural and textural similarities with Permian conglomerates from the Eastern and Southern Alps. Their deposition results from Variscan

and Saalian orogenic movements that occurred in different areas at different times. Considering the similar tectono-sedimentary development of the present-day Southern Alps and the Dinarides during the Palaeozoic, the 'Košna' conglomerates can be considered as a lateral equivalent of the Val Daone conglomerates and/or the Tarvis breccia.

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