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Lithostratigraphy of the Slovenian Part of the Karavanke Road Tunnel

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3 Text-Figures and 4 Plates

Österreichische Karte 1:50 000
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Slovenia
Karavanke Mts.
Road Tunnel
Upper Carboniferous
Permian
Triassic
Microfacies

Contents

Lithostratigraphie der slowenischen Strecke des Karawanken-Straßentunnels

Zusammenfassung

Die slowenische Strecke des Karawanken-Straßentunnels ist 3436 m lang und durchteuft zwölf lithostratigraphische Einheiten, die vom Oberkarbon bis ins Karn reichen. Die Kontakte zwischen den einzelnen Gesteinseinheiten sind meist tektonisch überprägt, was zur Folge hat, daß keine kompletten Schichtfolgen im Straßentunnel vorhanden sind.

Das Oberkarbon und Unterperm zeigt eine klastische Entwicklung mit seltenen linsigen Einschaltungen von Fusulinenkalk. Die mittelpermische Schichtfolge umfaßt die Tarviser Breccie sowie rote und graue Sandsteine der Grödener Schichten. Das Oberperm hingegen besteht aus einer Folge von gebankten Dolomiten. Gefaltete klastische und karbonatische Gesteine der Werfener Schichten bauen fast ein Viertel der Tunnelstrecke auf, wobei rote oolithische Kalksteine und Evaporitgesteine, wie Gips und Anhydrit, lithologisch am auffälligsten sind. Die anisischen Dolomite zeigen zum Teil stromatolithische Ausbildung; sie werden diskordant von der wechselfarbigen Uggowitzer Breccie überlagert. Die obertriassische Schichtfolge besteht aus einem mehrere hundert Meter mächtigen Paket von massigem kristallinem Schlerndolomit und die letzten 200 Tunnelmeter durchteufen auf der slowenischen Seite julisch-tuvalische Kalke und Mergel der Raibler Gruppe.

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Abstract

The Slovenian part of the Karavanke road tunnel is 3436 m long, and comprises 12 stratigraphic units ranging in age from Upper Carboniferous to Carnian. The contacts between formations are dominantly tectonic and for this reason the formations are not entirely incorporated with in the tunnel.

Upper Carboniferous and Lower Permian beds are developed as clastic rocks intercalated with scarce lenses of fusulinid limestone. The Middle Permian succession comprises Tarvis breccia, and red- and gray-coloured sandstones of the Gröden formation. The Upper Permian consists of bedded dolomite. One quarter of the tunnel passes through folded clastic and carbonate rocks of the Werfen formation, which can be recognised lithologically by red oolitic limestone and evaporite occurrences (gypsum and anhydrite). The Anisian dolomite, which is partly developed as stromatolites, is discordantly overlain by the variegated Ukve/Uggowitz breccia. The Upper Triassic succession comprises several hundred a metres thick unit of massive crystalline Schlern dolomite. The final 200 metres of the tunnel pass through limestone and marl of Julian-Tuvalian age (Raibl group).

Litologija in stratigrafija slovenskega dela karavanškega cestnega predora

Povzetek

V 3436 m dolgem slovenskem delu karavanškega cestnega predora se javlja 12 litostratigrafskih enot, ki so zastopane v časovnem razponu od zgornjega karbona do karnija. Večina kontaktov med formacijami je tektonskih, zato so te z raziskavami zajete le delno.

Zgornjekarbonske in spodnjepermske plasti so razvite klastično, z redkimi vmesnimi lečami fusulinskega apnenca. Srednjepermsko zaporedje je zastopano s trbiško brečo in rdečimi ter sivimi klastiti grödenske formacije, zgornji perm pa je zastopan s plastovitim dolomitom. Četrtina predora poteka skozi zgubane klastite in karbonate werfenske formacije, katera je litološko prepoznavna po rdečem oolitnem apnencu in po pojavih evaporitov (sadra in anhidrit). Na anizičnem dolomitu, ki je pogosto razvit stromatolitno, leži diskordantno pisana ukovška breča, zgornjetriasno zaporedje pa sestavlja več sto metrov debel paket masivnega zrnatega dolomita (šlernski dolomit). Zaključnih 200 metrov predora poteka skozi apnenec in lapor julsko-tuvalske starosti (rabeljske plasti).

1. Introduction

Geological observations accompanying excavation of the Slovenian part of the Karavanke road tunnel (Budković, 1999, this volume) also include systematic rock sampling for petrographical and paleontological analyses. In order to obtain a complex image of geological structure of western part of South Karavanke Mts., some surface occurrences were also studied in the tunnel surroundings during the years 1992–1996. Alltogether 204 samples from the tunnel, and 150 from the surface were analysed. The sampling encompass all lithological types of clastic and carbonate rocks ranging in age from Upper Carboniferous (Auernig beds) to Upper Triassic or Lower Jurassic (formations of the Klek/Hahnkogel unit, after Lein et al., 1995). Under intensive tectonic activity in southern (Slovenian) part of the tunnel (Text-Fig. 1), the whole sedimentary sequence, which attains up to 4000 metres, has been reconstructed on the basis of combined data from the tunnel and its surface.

The obtained data are only partial contribution to a better understanding of regional geology in the western part of South Karavanke Mts. Slovenian territory of this geological unit has been mapped during last decades by Ramovš et al. (1964), Buser (1980), Buser & Cajhen (1978) and Jurkovšek (1987a, b) in the framework of Basic Geological Map 1: 100 000, sheets Celovec (Klagenfurt) and Beljak (Villach). Mapping related to the tunnel works has been performed by Bauer et al. (1993), Bäk & Budkovič (1991), Budkovič (1993) and Budkovič et al. (1991). Paleozoic beds of this area were treated biostratigraphically by Kochansky-Devidé (1964, 1965, 1970, 1971), Ramovš (1968, 1980), Kochansky-Devidé & Ramovš (1963, 1966), Buser (1974), Pečar (1985/86) and Buser & Forke (1994/95). Triassic beds were studied by Ramovš (1989, 1992, 1993), Kolar-Jurkovšek (1994), and Kolar-Jurkovšek & Jurkovšek (1995). Hydrogeology of Western Karavanke Mts. has been studied by Brenčič et al. (1995).

In the following contribution, lithology is presented according to the age, irrespectively of the rock position in the tunnel. The location of lithological units in the tunnel is shown in geological cross-section (Text-Fig. 2). Despite relatively short distance (3435 m), 12 lithostratigraphic units were recognised in the tunnel.

2. Lithostratigraphic Units

2.1. Upper Carboniferous-Lower Permian Clastic Rocks with Limestone Lenses

This lithostratigraphic unit encompasses three formations attaining a thickness of over 600 metres. The lower part is composed of Auernig beds, which already belong to Upper Carboniferous (Gshelian). They are followed by Rattendorf beds of the Upper Carboniferous to Lower Permian age, and then by Trogkofel strata, developed as clastic rocks. Auernig beds in the tunnel are mostly developed similar by to their classic locality in Carnic Alps (Heritsch, 1939). The Rattendorf beds, developed as clastics, can not be distinguished from the Auernig beds in the tunnel as they are intensively tectonically destructed. Consequently, their existence can not be proved. In the K-3 borehole, located above the tunnel, Lower Permian age of the limestone lenses has been established (V. Kochansky-Devidé in Drobne et al., 1979). For this reason, they can not be subdivided according to the classical division into Lower Pseudoschwagerina limestone, Grenzland formation and Upper Pseudoschwagerina limestone (Kahler & Kahler, 1937; Forke, 1995). The distinction is possible again in the Central Karavanke Mts. in several localities, i.e. in the vicinity of Tržič (Buser, 1980).

We suppose the primary reason for diverse stratigraphic divisions of both lithological groups (Auernig and Rattendorf beds) in the tunnel is in intensive tectonic activity which destroyed the original succession, and locally also in frequent alternation of both formations along faults.

Outcropping Upper Carboniferous and Lower Permian beds were studied in some samples in Suhi vrh and at Zakamnik, located above the railway tunnel (Text-Fig. 1), in Presušnik and also along the road for Potoška planina under the Mt. Stol.

Altogether 37 rocks sampled from Permian-Carboniferous beds were analysed. Clastic rocks are developed as black clayey shales, siltstones, sandstones and quartzose conglomerate. Sandstone types vary slightly in grain-size, mineral composition and diagenetic alteration. All of them are intensively fractured under tectonic activity.

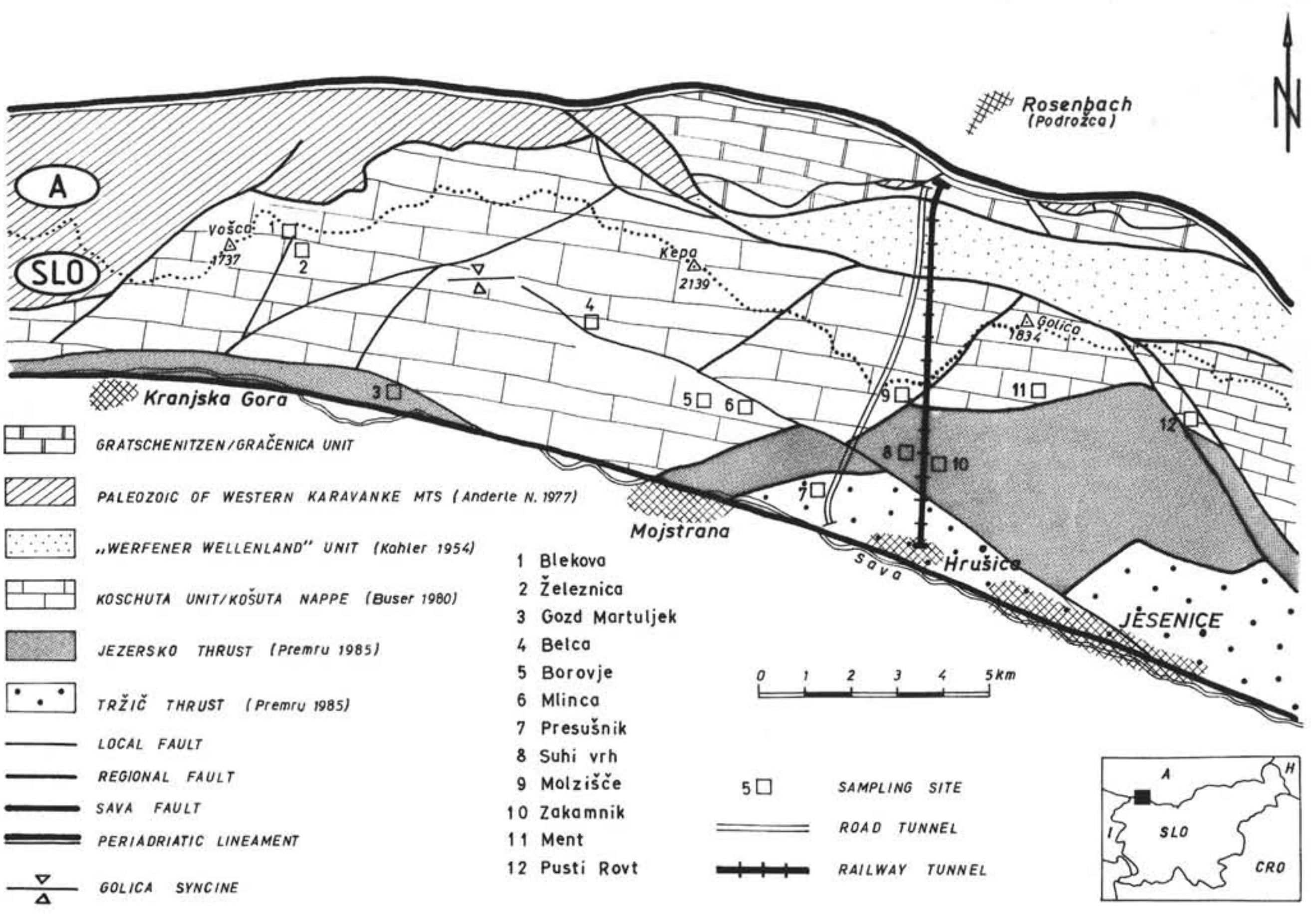
Coarse-grained quartzarenite is composed of quartz and altered feldspars. Dolomite and pyritised organic matter are subordinate constituents. Detrital grains attain up to 2 mm in size. The sandstones underwent incipient metamorphosis, and can be regarded as flexible sandstones. Recrystallisation is related to the action of pressures, and can be seen in longitudinal orientation of quartz grains which commonly show wavy extinction. In general, matrix is of contact type and composed of cryptocrystalline quartz. Dolomite or ankerite is of secondary origin, and replaces sparry calcite.

Fine- to medium-grained sandstone has been subdivided according to degree of silicification, dolomitisation, calcitisation and sericitisation into the following lithological subtypes: quartzarenite with mica and carbonate cement, quartzarenite with mica, quartzarenite-orthoquartzite, and litharenite with volcanic rock fragments. All types are more or less tectonised and schistose. Quartz in monomineral or polymineral form is the most abundant constituent. Potassium feldspars and plagioclases are present too, but they are partially replaced by sericite or dolomite. Lithic fragments are predominantly siliceous in composition, being chert or devitrified glassy matrix of volcanic rocks and their tuffs. Among volcanic lithic fragments, lava fragments and pumice can be recognised, although they are diagenetically extensively altered. Muscovite, chlorite and biotite are present in almost all of the samples.

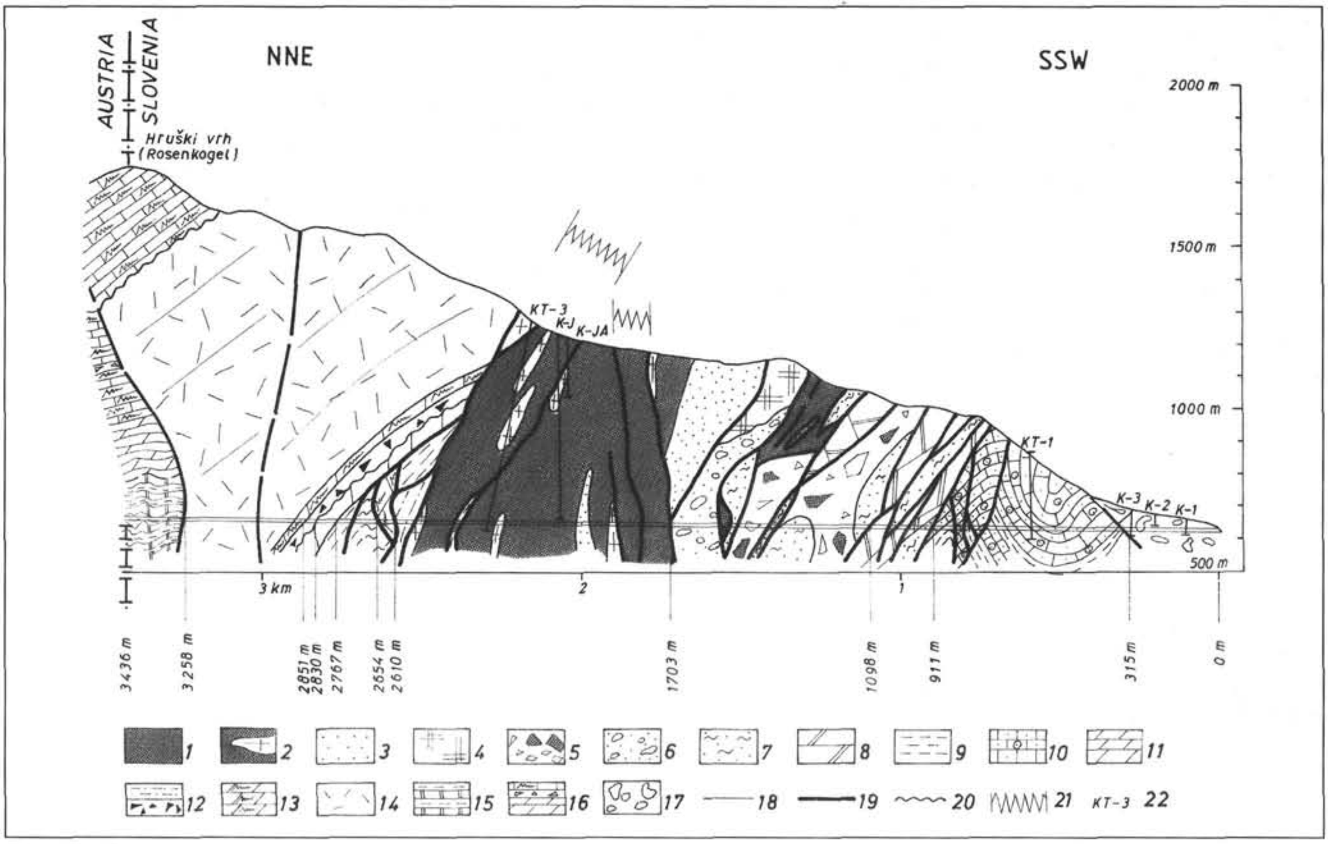
Fine-grained clastic rocks were classified, according to the amount of carbonate, into calcareous shale or calcareous slate (containing up to 15% of carbonate), and into sericite slate without carbonate. Both types commonly contain pyritised or graphitised organic matter. Locally (i.e. at 2581 m), laminated flaser structure can be observed in the rock. Tectonic slide surfaces and abundance of graphitic matter enhance schistosity. X-ray diffraction analysis indicates the presence of clay minerals illite and Na-montmorillonite, and also phyllosilicates chlorite and pyrophillite (DROBNE et al., 1979).

Limestone lenses: Limestone can be encountered within the Carboniferous-Permian clastic complex as a few dm to some ten metres thick and irregularly distributed lenses and beds. We suppose the lenses are a result of intensive tectonical disintegration, and had belonged to a uniform carbonate unit in the time of deposition. In the tunnel, they are present in the following sections: 1824–1902 m, 1910–1930 m, 2030–2040 m, 2270–2300 m, 2370 m, 2440–2450 m, 2460 m, 2490–2500 m and 2510–2550 m.

Research drill-holes K-J and KT-3 (Text-Fig. 2) also penetrated the limestone lenses. Based on the fusulinid fauna, algae and other fossils, V. KOCHANSKY-DEVIDÉ recognised Upper Carboniferous, Gshelian age of the limestone (sections between 90 and 135 m, and 410 and 496 in the K-3 drill-hole). Among fusulinids, *Rugosofusulina alpina* (SCHELLWIEN), *R.* cf. *complicata* (SCHELLWIEN), *Quasifusulina* sp. are present, and among algae *Archeolithophyllum* sp.



Text–Fig. 1.
Tectonic units of the Western Karavanke Mountains (see BUDKOVIČ, 1999; this volume).



Text–Fig. 2.
Cross section of the Slovenian part of the Karavanke road tunnel.
1 - black clayey silt, mudstone and slate, 2 - dark gray to black massive limestone, 3 - gray sandstone (1-3 Upper Carboniferous - Lower Permian clastic rocks with limestone lenses), 4 - massive, pinky to gray limestone (Trogkofel limestone - Lower Permian), 5 - red quartztose-carbonate breccia (Tarvis breccia - Middle Permian), 6 - gray breccia and sandstone, 7 - red sandstone, siltstone and slate (6-7 Gröden formation - Middle Permian), 8 - gray, thick-bedded dolomite (Bellerophon formation - Upper Permian), 9 - red, gray and green dolomitic marl with gypsum lenses, 10 - brown and gray bedded limestone and dolomite, partly oolitic (9-10 Werfen formation - Scythian stage), 11 - gray, thick-bedded dolomite and cellular dolomite (Anisian dolomite), 12 - carbonate breccia, dark gray to red marl and limestone (Ukve/Uggowitz breccia), 13 - platy to bedded dolomite with chert lenses (Buchenstein beds - Ladinian stage), 14 - light gray, massive crystalline dolomite (Schlern dolomite - Cordevolian substage), 15 - dark gray marl and marly limestone (Raibl group), 16 - dark gray dolomite, gray limestone with chert lenses, dark gray marl (Klek/Hahkogel, Bača and Baba/Frauenkogel formations; after Krystin et al., 1994 and Lein et al., 1995 - Julian substage to Liassic), 17 - talus breccia, 18 - normal boundary, 19 - disconformity (superimposed), 20 - fault, 21 - fault zone, 22 - borehole.

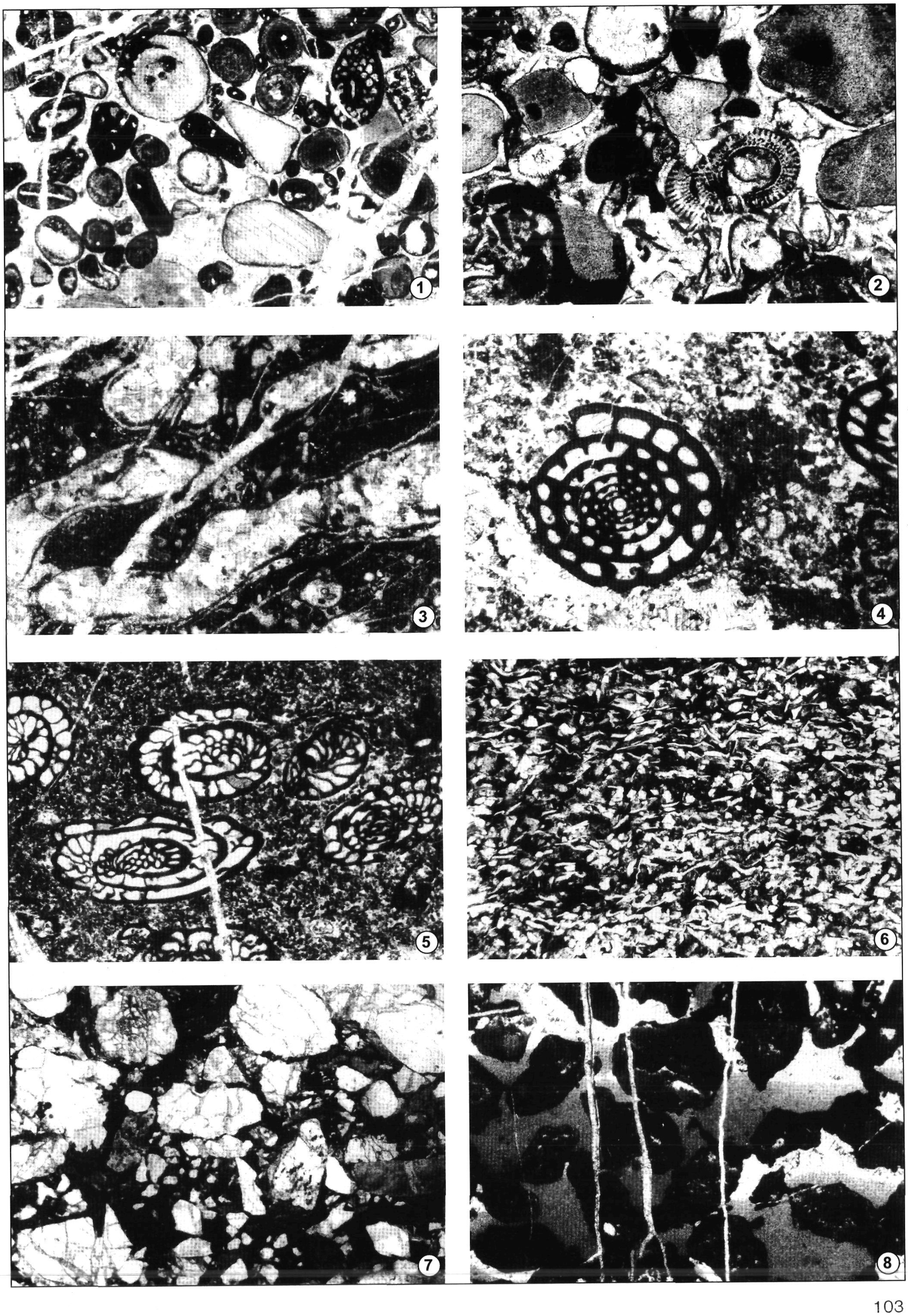
(Johnson). In the dark colored, Lower Permian limestone (sections 0–61 m, and 231–374 m in the drill-hole KT-3) foraminifers *Pseudofusulina* sp., *Tuberitina bulbacea* Gall & Harlt, *Darvasites* sp., *Globivalvulina* sp., *Schubertela* sp., algae *Ortonella morikawai* Endo, *Gyroporella nipponica* Endo & Hashimoto, *Pseudogyroporella mizziaformis* Endo and some others were determined (archive report Drobne et al., 1979).

The limestone is dark-gray to almost black due to abundant pyrite pigment and organic matter. According to the texture, the majority of rocks can be classified as slightly silicified biomicrite or intrabiomicrite (packstone), with more or less abundant calcite veinlets. Among fossils, fusulinid foraminifers are the most common in occurence. For this reason, the rock can be classified as fusulinid limestone. Skeletons of echinoderms are also in great number, while molluscan shells, skeletal algae, mounds of non-skeletal algae and stromatolites are scarce in occurrence. At Dovje, somewhat westerly of the road tunnel, some beds with rock-forming crinoids outcrop. In a few samples (i.e. at 2030 metres of length), recrystallised corallites can be observed. Locally, ooids (Plate 1, Fig. 1) are encountered in the limestone, which is slightly marly and contains stylolites.

Diagenetic alteration of Carboniferous and Lower Permian limestone is reflected in dolomitisation, subordinate silicifica-

Plate 1

Fig. 1: Biosparitic limestone (grainstone) with numerous echinoids and some ooids. Upper Carboniferous. Sample Sv-1, Suhi vrh, 11 x.
Fig. 2: Crinoidal biosparitic limestone (grainstone). Upper Carboniferous. Sample Zav-K5, Potoška planina, 25 x.
Fig. 3: Algal biomicritic limestone with *Neoanchicodium catenoides* ENDO. Lower Permian. Sample Sv-4, Suhi vrh, 11 x.
Fig. 4: Recrystallised biomicritic limestone with fusulina *Paratriticites jesenicensis* Kochansky-Devidé. Trogkofel formation. Sample M-7, Gozd Martuljek, 25 x.
Fig. 5: Fusulinid limestone. Trogkofel formation. Sample M-7, Gozd Martuljek, 11 x.
Fig. 6: Fine grained quartz sandstone with mica. Gröden formation. Tunnel sample 1435 m, 25 x.
Fig. 7: Detail of fine grained breccia. Tarvis breccia, Middle Permian. Tunnel sample 1242 m, 11 x.
Fig. 8: Micritic dolomite (loferite) with internal sediment in shrinkage pores. Bellerophon formation. Sample P-5, Presušnik, 11 x.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tion, and recrystallisation. Quartz is authigenic in origin, and the crystals attain 100 to 200 µm in size. The quartz amount is estimated to 2%. Dolomite of ankerite composition, encountered in up to 100 µm-sized rhomboidal crystals, is late-diagenetic in origin. The ankerite amount ranges from 2 to 5%, but very rarely (i.e. at 1586 m), the original limestone is thoroughly dolomitised.

2.2. Trogkofel Limestone

The upper part of the Lower Permian succession consists of massive light brown, pink, red and gray coloured limestone. It doesn't reach the tunnel level, because it is cut by a fault, but it occurs in some ten metres thick complex above the tunnel (Fig. 2), and also in two kilometre long lense in a tectonic slice at Gozd Martuljek (Text-Fig. 1, Loc. 3).

According to the texture, Trogkofel limestone is fairly recrystallised biomicrite, biosparite or intrasparite (grainstone or packstone). Allochems comprise echinoderm detritus, crinoid articles, and foraminifers which are also abundant in occurrence. Among them, fusulinids predominate (Plate 1, Figs. 4 and 5). The fossils are commonly incrusted with nonskeletal algae and cyanobacteria. Corals and macrofossils (i.e. brachiopods) were not found, although they are commonly mentioned in the literature dealing with Trogkofel limestone. For this reason, we could hardly say that depositional environment in the tunnel area was a coral reef.

Stratigraphic problems related to Trogkofel limestone in the South Karavanke Mts. were recently studied by BUSER & FORKE (1994/1995). Based on the conodont fauna and correlation with fusulinids, they classify the limestone from well known locality of the Dolžanova gorge as Upper Carboniferous, Gshelian, and for the limestone itself the authors also introduce a new name – "Dolžanova soteska limestone member".

2.3. Tarvis Breccia and Gröden Formation

Middle Permian beds in the tunnel area include Tarvis breccia and Gröden sandstones, conglomerates and shales. In western Karavanke Mts., those beds overlay discordantly Trogkofel limestone or Lower Permian clastic beds. Altogether, 25 samples have been investigated. In the tunnel, Tarvis breccia alternates with Gröden clastic rocks, mainly along faults, between 1098 and 1703 metres. Some lithological types can be distinguished according to the colour, grain-size, and mineral composition of pebbles. Reddish-brown to dark red-coloured types dominate in southern part of the section, whereas grayish varieties are more abundant in the vicinity of the contact with Permian-Carboniferous clastic rocks. In the tunnel, a thickness of Tarvis breccia amounts to over 100 metres.

Grain-size of breccia is variable. Some pebbles attain up to 10 cm in diameter. Their roundness is different, and locally, breccia may grade into a mixture of breccia and conglomerate. Among carbonate pebbles, micritic and biomicritic algal and fusulinid limestone occurs, and among pebbles of other composition fragments of mono- and poly-crystalline quartz, chert and calcarenite with quartz and sericite are also encountered. Cement is carbonate, but locally, matrix can also be quartzose sand or limonitised clay. Breccia is usualy tectonised and fissures infilled with calcite.

Gröden Formation: Transition of Tarvis breccia into Gröden clastic rocks is gradual. In the upper parts of the breccia, intercalations of up to 1 m thick reddish shale and sandstone occur, being followed by fine-grained clastic varieties.

Gröden formation is composed of a succession of reddish or violet quartzose sandstone, siltstone, shale, and rarely, fine-grained quartzose conglomerate. In the tunnel, the formation thickness can not be recognised due to intensive folding and many tectonic contacts, but we suppose it amounts to less than 200 m.

Among sandstones, we recognised some types. In the quartzarenite (i.e. at 1623 and 1628 m), feldspars amount to 25% of the rock composition. Another type is fine- to medium-grained quartzarenite, which contains micas and different portions of calcite (under 15%). Very rarely, some beds contain dolomite grains and small calcite concretions. Ferrous hydroxides – mainly hematite, impart reddish colour to the rocks. Shales show lamination and schistosity. Due to intensive tectonics nearby, all Gröden clastic rocks are intersected with calcite and quartz veinlets, and locally, concretions of evaporitic minerals also occur.

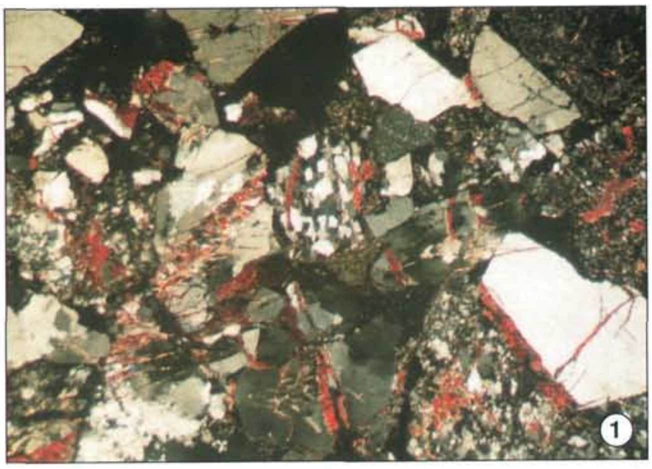
2.4. Bellerophon Formation

In the Karavanke tunnel area, the Gröden beds are followed stratigraphically by a 200 metres thick succession of medium gray, bedded dolomite of the Upper Permian age, in literature known as Bellerophon formation (TELLER, 1914). In the tunnel, it alternates with reddish Gröden sandstone in the form of tectonic slices from the distance of 933 to 1098 m. In both sides it is separated from Werfen and Gröden beds by faults. On the surface it can be followed along the new road, situated immediately above the tunnel at Ment (Text-Fig. 1), in Suhi vrh, at Pusti Rovt and at Molzišče, where it continues into the Werfen carbonate-clastic succession.

Dolomite is commonly monotonously developed as bedded fine-grained sparite or homogenous microsparite; its original texture is obliterated or very weakly preserved. Various types of intrapelmicrite, intrabiosparite (wackestone to packstone) and loferitic dolomite with shrinkage pores can be recognised. The fossils are recrystallised, but nevertheless, gastropods, skeletal algae, stromatolites (locally in the form of oncoids), foraminifers, ostracods and echinoderms can also be recognised. Among foraminifers, *Archeodiscus* sp., *Agathamina* sp.,and *Glomospira* sp. are present, and among algae *Gymnocodium bellerophontis* ROTHPLETZ. This alga can

Plate 2

Fig. 1: Detail of fine grained breccia. Clasts of quartz, feldspars and lithic rocks are transected with calcite veins. Tarvis breccia, Middle Permian. Tunnel sample 1231 m, 15 x, +N.
Fig. 2: Fine grained quartz-feldspar sandstone. Gröden formation. Tunnel sample 1628 m, 15 x, +N.
Fig. 3: *Gymnocodium* algae and vein diagenetically filled by anhydrite in micritic dolomite. Bellerophon formation. Tunnel sample, 911 m, 15 x, +N.
Fig. 4: Gypsum vein in micritic dolomite. Werfen formation. Tunnel sample, 809 m, 15 x, +N.
Fig. 5: Sparitic dolomite with late diagenetic gypsum veins and anhydrite lenses. Werfen formation. Tunnel sample, 2493 m, 15 x, +N.
Fig. 6: Detail of anhydrite sample. Werfen formation. Tunnel sample, 910 m, 15 x, +N.
Fig. 7: Oosparitic limestone with dolomitised ooid cores. Werfen formation. Sample Zpl-18a, Za Planino, 15 x, +N.
Fig. 8: Sparitic dolomite with oolitic structure, preserved due to hematite pigment. Werfen formation. Tunnel sample 523 m, 15 x, +N.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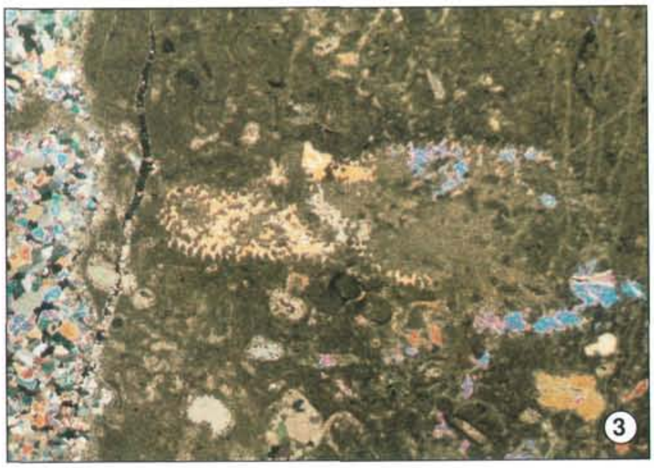
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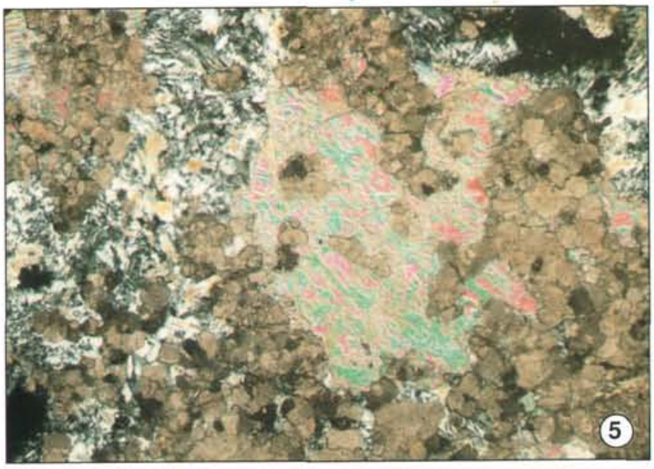
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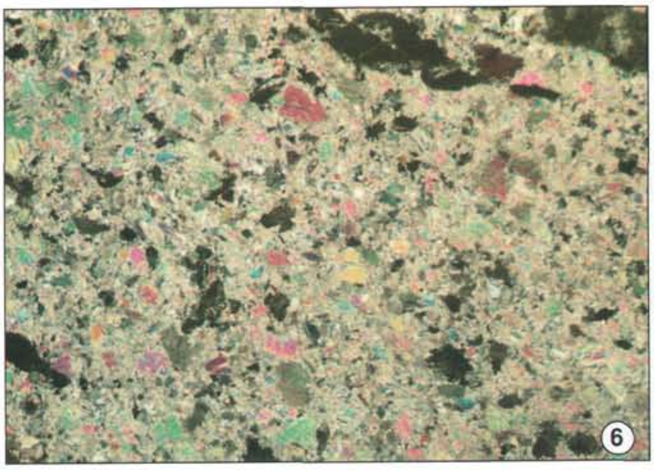
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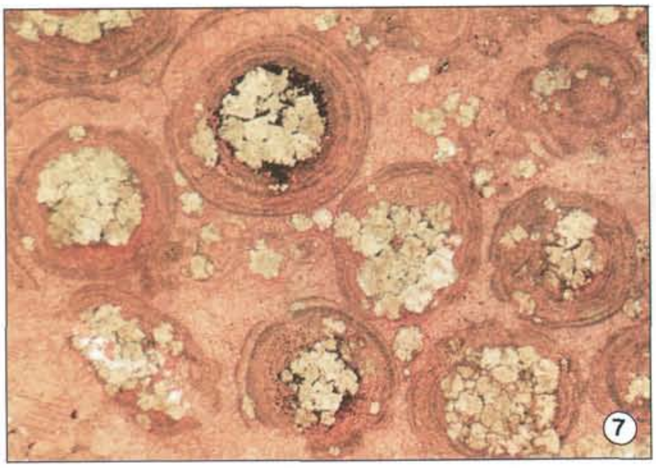
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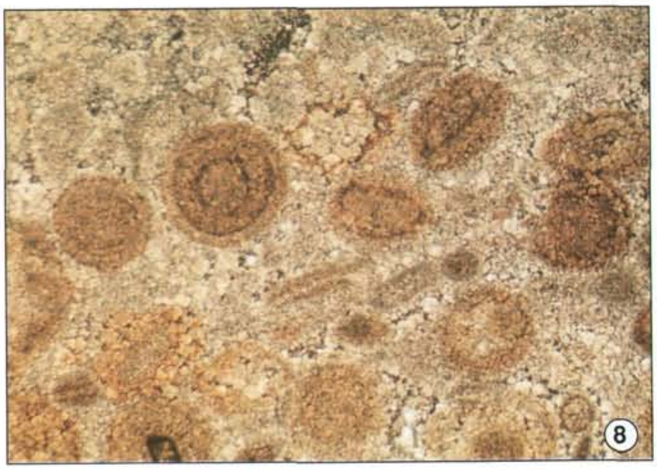
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be observed in a sample taken from the stationary point 911 m. The original skeleton of this algae has been leached, and later-on, the moldic pores were infilled with anhydrite (Plate 2, Fig. 3). In general, small concretions and veinlets of gypsum and anhydrite can be observed in many investigated samples of the Bellerophon formation (Plate 2, Fig. 5).

Shrinkage pores indicate that sedimentation of Upper Permian limestone took place in a restricted shelf environment with littoral and evaporitic conditions. Cellular dolomite (rauchwacke) indicating arid climate, is known in many localities in a broader Karavanke area (BUSER, 1980; BUSER et al. 1989; ANDERLE, 1970, 1977; RAMOVŠ, 1989; DOLENEC et al., 1981), northern Dinarids (ČADEŽ, 1977; GRAD & OGORELEC, 1980), and Carnic Alps (BUGGISCH, 1974; HOLSER & SCHÖNLAUB, 1991; ASSERETO et al., 1972; BOSELLINI & HARDIE, 1973). According to microfacies characteristics, a part of the Bellerophon dolomite already underwent early diagenetic dolomitisation (the beds with characteristics of littoral sedimentation), and it was completely dolomitised during late diagenesis. Many dolomite samples contain traces of authigenic quartz (up to 2% of grains attaining the size up to 200 µm), and pyrite pigment. The dolomite is slightly porous (intergranular pores, up to 5%), and calcite veinlets are locally very abundant.

2.5. Werfen Formation

The Bellerophon formation continuously grades upwards into an up to 300 m thick succession of carbonate and clastic sediments of the Lower Triassic, Scythian age. The formation is well recognisable in the field owing to characteristical reddish colour, and the presence of oolitic limestone or dolomite. They are encountered in the first 500 metre-section in the tunnel, between 388 and 911 metres. They are considerably folded, and along the faults frequently displaced; for this reason they are not encompassed in the whole profile. They are found tectonically sealed between Permian-Carboniferous clastic rocks north of the Hrušenski fault zone, in the sections between 2386 m and 2494 m, and 2654 m and 2767 m. On the surface, they are very well developed in a creek at Molzišče (Text-Fig. 1). Altogether 65 samples were investigated.

Lithological development of the Werfen formation is much alike to that from the Austrian side of the tunnel (ANDERLE, 1970; BAUER, 1985), from the Western Karavanke (JURKOVŠEK, 1987a; RAMOVŠ, 1989), and from the Tržič area in the Central Karavanke (BUSER, 1980; DOLENEC et al., 1981).

The contact between Upper Permian and Scythian dolomite is not obvious, as it can be encountered inside a 20 m thick succession of light yellowish to pinky, bedded and finegrained dolomite with some detrital grains of quartz and mica. This dolomite is followed by approximately 150 m thick succession of reddish to violet coloured sandy marl, siltstone and shale, which are commonly intercalated by up to 0.5 m thick beds of oolitic and biosparitic limestone and dolomite. This succession is equivalent to Seis beds in Northern Alps (MOSTLER & ROSSNER, 1984).

Alternation of limestone and dolomite in the tunnel is very irregular. Between 390 and 605 m, limestone prevails among carbonate rocks, and it is also very common in the section between 715 and 740 m; around a distance of 820 m, it is only a few metres thick; otherwise dolomite occurs between 606 and 702 m, and 767 and 900 m.

Oolitic limestone (Plate 3, Fig. 7) is biosparite (grainstone) according to the texture. Ooids are commonly 0.5–1 mm in size, in some beds they also attain up to 2 mm in diameter. They show radial texture, and their reddish colour is related to the presence of hematite pigment. For this reason, the ooide contures are visible in the sparry dolomite. Many beds of oolitic dolomite underwent late-diagenetic dolomitisation, which amounts to 10%. Dolomite rhombohedra are concentrated predominantly in the ooide cores (Plate 2, Fig. 7). Among fossils occurring in the oolitic limestone, small gastropods of the genus *Holopella gracilior* are the most abundant, along with the plates of echinoids. Non-carbonate components consist of rare detritial quartz and mica. In the tunnel, oolitic limestone is more abundantly encountered in the sections between 440 and 605 m, and as oolitic dolomite, between 623 and 654 metres.

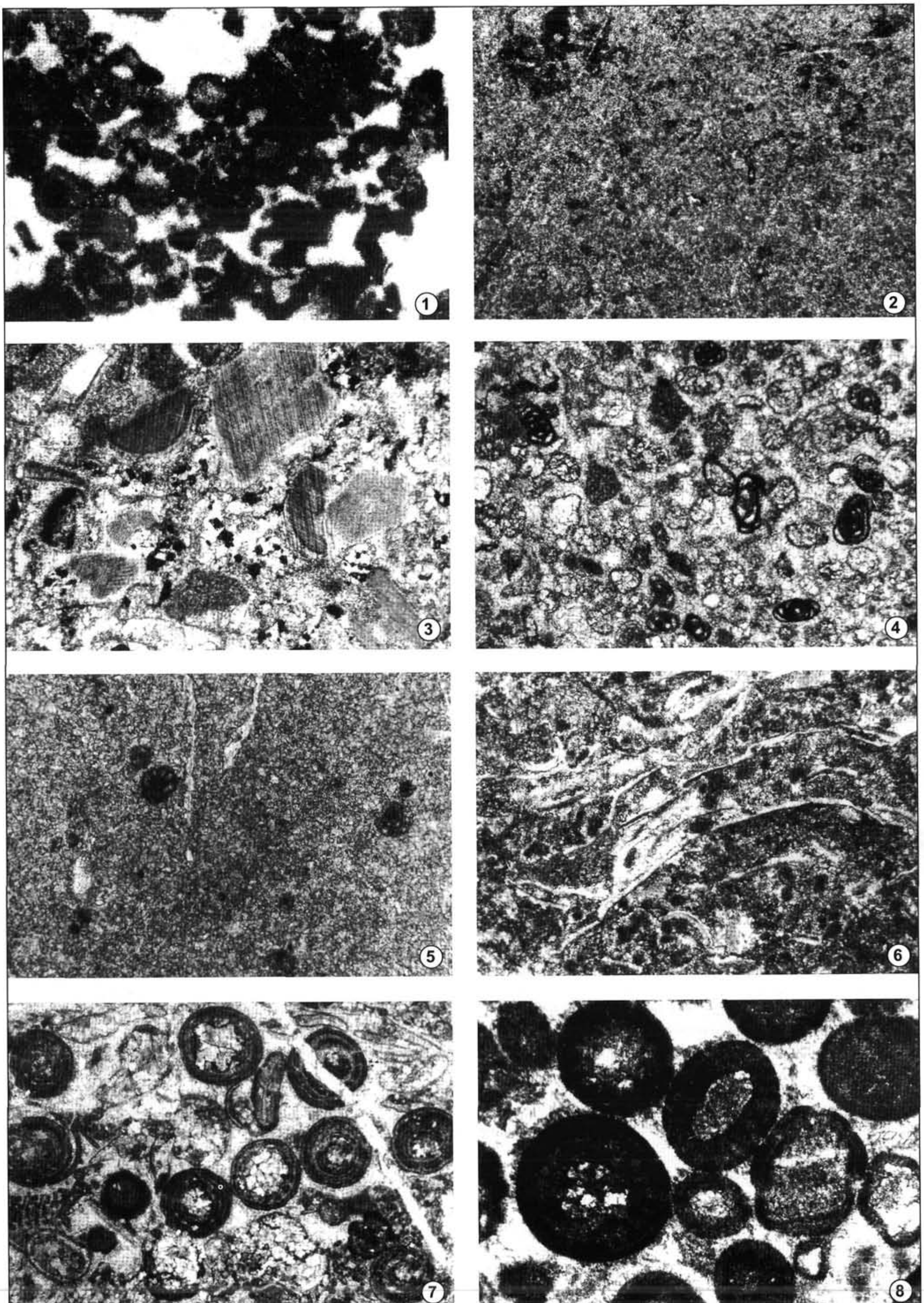
In the upper part of the Werfen formation (Campilian beds), which is up to 300 m thick in western part of Karavanks, dark bedded limestone prevails. Marl, fine-grained sandstone and up to several metres thick units of yellowish sparry dolomite are subordinate in occurrence.

According to the structure, limestone is most commonly dark to black biomicritic mudstone, frequently slightly marly, dolomitised and recrystallised. Dolomite occurs in rhombohedra having up to 200 µm in size, its portion being less than 5%. Pyrite pigment and organic matter impart dark colour to the limestone. Many samples contain traces of quartz, which is detrital or authigenic and occurs in crystals attaining the sizes up to 100 µm. Among fossils, ostracods and moluscan shells are encountered, rarely also foraminifers, echinoderms and gastropods of the genus *Natiria costata*. Scythian age can be determined by the foraminifer *Meandrospira pusilla* (HO), found in recrystallised microsparitic dolomite (Plate 3, Fig. 5). Locally, glomospiras are also present. Some limestone samples from the Blekova did not contain conodont fauna, although Scythian limestone in the Karavanke Mts. is known to be rich in conodonts in many localities, i.e. in Belca at Mojstrana (JURKOVŠEK, 1987a), and near Tržič (KOLAR-JURKOVŠEK & JURKOVŠEK, 1995). Some beds of marly limestone are rich in fucoid structures. In the tunnel and its surroundings, oolitic beds are scarse in the upper part of the Werfen succession.

Lithological pecularity of the Werfen formation in Western Karavanke Mts. is the presence of evaporitic minerals gypsum and anhydrite. Gypsum occurs in two generations – the primary, forming up to one metre thick lenses and beds, is found in the tunnel in a distance from 674 to 705 m, and from 782 to 908 m; the secondary, occurs as veinlets or pore-fil-

Plate 3

Fig. 1: Pelmicritic dolomite with shrinkage pores (loferite). Bellerophon formation. Sample Sv-2, Suhi vrh, 25 x.
Fig. 2: Recrystallised biomicritic dolomite with tube like forms from nonskeletal algae. Lowermost part of Werfen formation. Sample Zpl-1, Za Planino, 25 x.
Fig. 3: Recrystallised crinoidal limestone (packstone). Werfen formation. Sample Zpl-11, Za Planino, 25 x.
Fig. 4: Recrystallised biopelmicritic limestone with *Glomospira* sp. Werfen formation. Sample Zpl-15, Za Planino, 25 x.
Fig. 5: *Meandrospira pusilla* (Ho) in microsparitic limestone. Werfen formation. Sample Zpl-12, Za Planino, 70 x.
Fig. 6: Biopelmicritic limestone with molluscs and ostracods. Werfen formation. Tunnel sample 547 m, 25 x.
Fig. 7: Oosparitic limestone (grainstone) with late dolomitisation of ooid cores. Werfen formation. Sample Zpl-18a, Za Planino, 11 x.
Fig. 8: Detail of oosparitic limestone. Werfen formation. Tunnel sample 577 m, 25 x.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ling in the dolomite (Plate 2, Figs. 4 and 5). Anhydrite is very subordinate in occurrence with respect to gypsum. It is a secondary, diagenetic mineral, formed by dehydration of gypsum and occurs as vein and pore filling in dolomite. Both minerals are more abundant in the tunnel between 650 and 911 metre.

2.6. Anisian Dolomite

Werfen beds pass gradually into the succession of Anisian dolomite. It is of light- to medium-gray, and medium-bedded. In the tunnel, it was studied in 15 samples (from 2767 to 2830 m), and on the surface, in the localities Molzišče and Blekova (Text-Fig.1).

Primary texture of the dolomite is not recognisable any more in almost all of the studied samples. For this reason, the samples were classified as microsparry or sparry dolomite. Only locally the original texture is still preserved in the beds which seem to be deposited in a littoral or very shallow marine environment. This is indicated by the presence of stromatolites, the beds with shrinkage pores (loferite), fine-grained intratidal conglomerates (flat pebble conglomerates), and oncoids. On the weathered surface of dolomite at Blekova, traces of oncoids, having up to 5 cm in diameter, can be observed. The dolomite is a relatively pure carbonate, without any detrital admixtures, but locally it may be dedolomitised. The dedolomitisation is possibly related to reactions between dolomite and gypsum. Gypsum occurs in trace amounts in some of the studied samples.

In the tunnel, Anisian age of the dolomite has not been proved by fossils, but is assumed according to its superposition and facies characteristics. On the surface, the Anisian age of the rock is well documented by foraminifers of genus *Meandrospira dinarica* KOCHANSKY-DEVIDÉ & PANTIĆ.

A relative thinness of Anisian dolomite in the tunnel (some ten metres) indicates variable sedimentary conditions during the Anisian age in the area of western Karavanke, as locally a thickness of dolomite exceeds 600 m (JURKOVŠEK, 1987a). In the tunnel, the presence of erosion, indicated by discordant position of the overlain Ukve/Uggowitz breccia was an additional reason for the recognised thinness of Anisian dolomite.

South of the Sava fault, between Mojstrana and Kranjska gora, massive algal-reef limestone was deposited during Anisian time (RAMOVŠ, 1987).

2.7. Ukve/Uggowitz Breccia

In the tunnel section between 2830 and 2851 m, grayish conglomeratic breccia was deposited discordantly on Anisian dolomite. In literature it is known as Ukve/Uggowitz breccia (BUSER, 1980; JURKOVŠEK, 1987a), named after the village Uggowitz in the Canal valley in Italy. Appreciably thicker layers of Ukve/Uggowitz breccia, attaining over 200 m, occur along the Mlinca creek, above Dovje. The whole succession of the Ukve/Uggowitz breccia does not outcrop in any locality in the Karavanke Mts., and for this reason its whole thickness is unknown.

In the tunnel the Ukve/Uggowitz breccia occurs as a succession of grayish conglomeratic breccia, with composition dominated by dolomite pebbles attaining up to 10 cm in diameter. In Mlinca, two types of conglomeratic breccia occur. The lower part is dominated by red-coloured conglomerate of prevailing limestone composition, interbedded with fine-grained calcareous sandstone. In the upper part, grayish, more dolomitic conglomerate and conglomeratic breccia dominate. Different rock-colour and lithology of pebbles is related to two different carbonate sources. The age of pebbles is Upper Carboniferous to Middle Triassic. Sedimentary structures in sandy beds indicate the Ukve/Uggowitz breccia and conglomerate are fluviatile in origin, deposited as a result of emersion during Anisian and in the beginning of Ladinian time.

Sorting of breccia and conglomerate pebbles is poor to intermediate, and the roundness medium to good. The pebble sizes range from some mm to 5 cm, and only occasionally attain 10 or 15 cm in diameter. Matrix is fine-grained, lithified carbonaceous sand with admixture of detritial quartz and clay, but nevertheless, the rock is relatively compact. Matrix in the gray-coloured conglomerate is mainly calcite. Pebble contacts are frequently stylolitic.

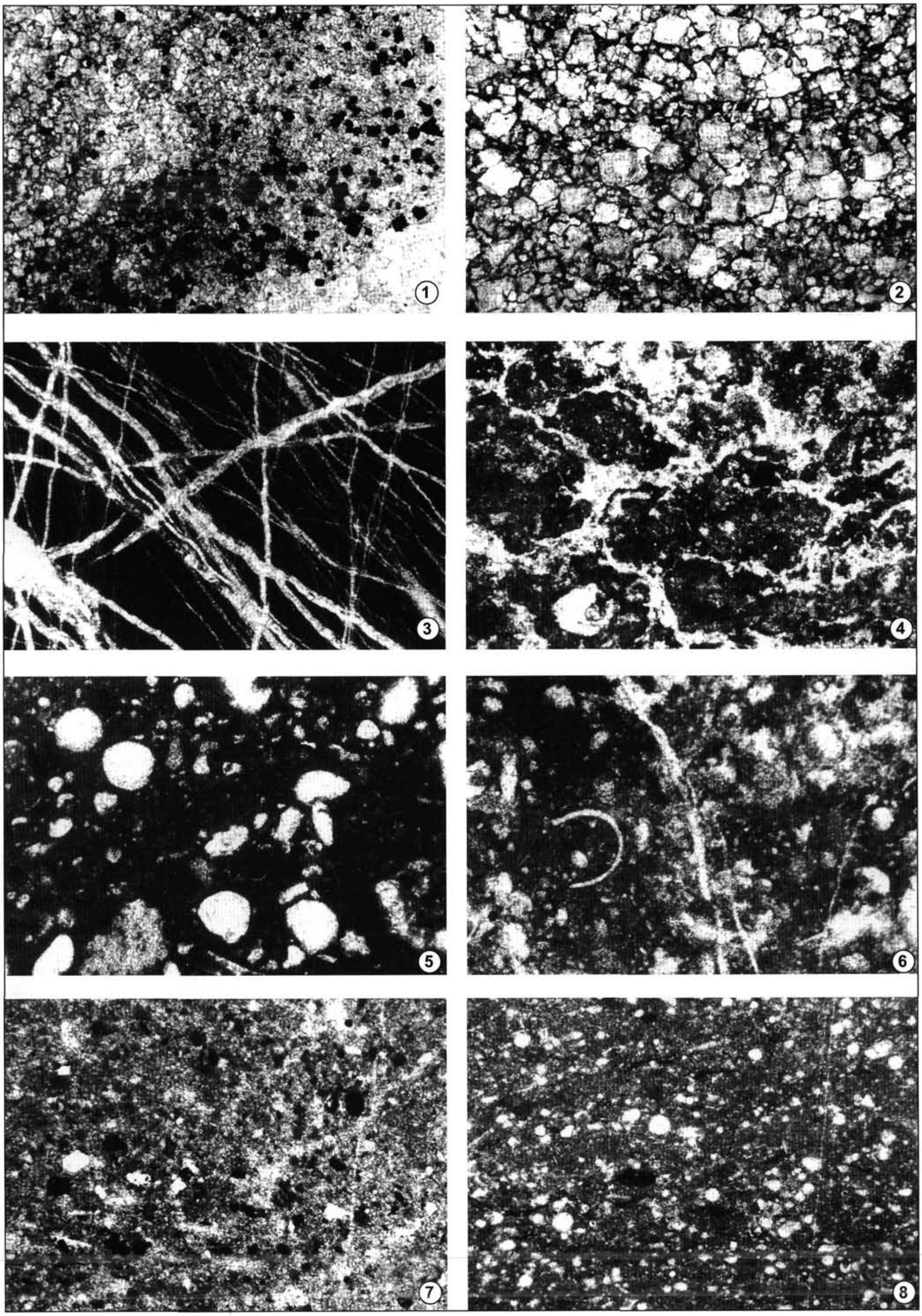
Pebbles in red-coloured Ukve/Uggowitz conglomeratic breccia and conglomerate belong to pinkish and pinkish-gray biomicritic limestone (fossils are echinoderms, fusulinids and non-skeletal algae -Trogkofel limestone), dark-gray biosparitic limestone with fusulinids, red-coloured Gröden sandstone and reddish oolitic limestone (Werfen beds) predominate. In gray dolomitic conglomerate, various types of microsparitic, biomicritic and stromatolitic dolomite (mainly of the Anisian age) occur.

2.8. Schlern Dolomite

At 2851 metre of the tunnel, the Ukve/Uggowitz breccia overlies dark gray dolomite with chert concretions, and locally, it is interstratified with thin layers of siltstone. The thickness of this dolomite complex amounts to about 30 metres, and according to the texture, the dolomite can be classified as biopelmicrite and biomicrite. Fossils are scarce and among them ostracods, molluscan shells, recrystallised foraminifers and calcitised radiolarians are present. Energy index of the rocks is low. We suppose the primary limestone deposited in a pelagic environment. Dolomitisation is late-diagenetic. The age of this complex can not be determined on the basis of fossil remains, but we suppose it is still Ladinian (Buchenstein beds). The same type of dark-coloured dolomite with chert can be encountered in the tunnel in the section between 2610 and 2654 m, where it is found tectonically sealed between the Werfen beds.

Plate 4

Fig. 1: Sparitic dolomite with pyrite mineralization. Werfen formation. Tunnel sample 623 m, 25 x.
Fig. 2: Sparitic dolomite with subhedral structure. Werfen formation. Tunnel sample 616 m, 25 x.
Fig. 3: Micritic limestone with calcitic veins. Werfen formation. Tunnel sample 829 m, 25 x.
Fig. 4: Detail of stromatolitic dolomite. Anisian dolomite. Sample BL-K1, Blekova, 25 x.
Figs. 5, 6: Biomicritic dolomite (wackestone) with some recrystallised foraminifera. Schlern dolomite. Tunnel samples 3060 m (Fig. 5) and 3025 m (Fig. 6), 25 x.
Fig. 7: Recrystallised micritic limestone with some authigenic quartz and pyrite crystals. Raibl beds, Upper Triassic. Tunnel sample 3316 m, 70 x.
Fig. 8: Micritic limestone (mudstone, wackestone) with some calcitised radiolaria. Klek/Hahnkogel formation, Upper Triassic-Liassic. Sample GL-K4, Golica, 25 x.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It is interesting that volcanic rocks haven't been found in the tunnel, although in the Western Karavanks and Julian Alps, they are characteristic of the Ladinian age. Among them, quartz trachyte, alkali liparite and ignimbrite tuff of dacitic and liparitic composition prevail (GRAFENAUER et al., 1981).

Dark dolomite with chert concretions grade upwards into a light-gray to white crystalline dolomite (Schlern dolomite), which is very typical lithological unit in a four hundred metres long section between 2893 and 3258 metre. Locally, lenses of massive to fainty stratified biomicritic limestone or dolomitised limestone also occur in the dolomite. In the whole distance, the dolomite is intensely fractured, mylonitised and porous, and for this reason, it is a good aquifer. The primary limestone texture is fairly obliterated; contours of skeletal algae *(Diplopora?)*, echinoids, and recrystallised foraminifers (Plate 4, Fig. 5 and 6) can locally be observed. The presence of algae *Diplopora annulata* indicates Cordevolian age of the Schlern dolomite. Its thickness amounts to several hundred metres, and locally even up to 1000 m (JURKOVŠEK, 1987a). Between 3020 and 3040 metre, an up to 30 cm thick bed of green pelitic tuff occurs in the dolomite, which is possibly the representative horizon in a monotonously developed dolomite, and could be the only sign of Triassic volcanism in the formations inside the tunnel.

2.9. Raibl Group

The final 200 metres of the Slovenian part of the Karavanke road tunnel (from 3258 to 3436 m) is characterised by alternation of dark-gray to black platy marly limestone and sandy marl. Due to folding of the beds and their low angle of inclination, only some ten metres of Julian-Tuvalian succession have been observed in the above mentioned section. Otherwise, this succession attains from 200 to 400 m on the Slovenian side (JURKOVŠEK, 1987a). In a distance of 3258 metres, the beds are in tectonic contact with Schlern dolomite (Text-Fig. 2).

According to the texture, the marly limestone can be classified as biomicritic mudstone, characterised by black colour due to organic admixtures and pyrite pigment. The fossils are mainly calcitised radiolarians and calcispongia, locally also pelagic pelecypods. They indicate undisturbed sedimentation in a restricted, somewhat deeper environment. Detrital admixture which attains up to 20 % of the bulk rock, is composed of clay minerals and fine-grained quartz. Quartz is subordinate in occurrence (traces up to 1%) and also, authigenic in origin (Plate 4, Fig. 7). In the valley of Belca, between Dovje and Gozd Martuljek, in the same beds are rich macro- and microfauna (JURKOVŠEK, 1987a; RAMOVŠ, 1993).

Raibl beds are more abundantly encountered in the Austrian part of the Karavanke road tunnel, and also on the surface (KRYSTYN et al., 1994; LEIN, et al., 1995).

2.10. Upper Triassic to Liassic Formations of the Klek/Hahnkogel Unit

According to stratigraphy, Upper Triassic to Liassic beds are the youngest in the Karavanke Mts. area. In the Slovenian part, the beds can be encountered only on the surface, between Hruški vrh and Golica in the Klek/Hahnkogel unit (Text-Fig. 1). SCHLAF (in LEIN et al., 1995) subdivided the succession in the Austrian side into some formations, listed according to the stratigraphic position: "Raibl group, Carnitza formation, Bača formation, Frauenkogel formation and Hahnkogel formation".

About 500 metres thick succession of "terrigenous Raibl beds" form the lower part of the Julian-Tuvalian substage, and it is composed of interstratified dark biomicritic limestone, marl and biocalcarenite. In the upper 100 metres, shallow-water, partially laminated dolomite occurs.

Facial characteristics indicate that Norian to Liassic beds, which attain about 500 m too, were also deposited in a deeper environment with pelagic fauna (radiolarians, calcispongia). Chert nodules in the Bača dolomite, as well as chert and turbidites, interstratified with the platy limestone from Baba/Frauenkogel, also suggest deeper sedimentary environment. As mentioned previously, in the Slovenian part of the Karavanke road tunnel, the rocks encountered in the formations younger than Raibl group, do not exist. Norian beds outcropping in Šija north of Tržič in the tectonic unit of Košuta, are dated biostratigraphically on the basis of conodont fauna (KOLAR-JURKOVŠEK, 1994).

The Bača and Baba/Frauenkogel formations are time equivalents of shallow-water Dachstein limestone, which outcrops on the Mt. Kepa. Such lateral changes can be explained with the fact, that the whole Karavanke mountain ridge actually forms a broader fault zone of the Periadriatic lineament, characterised by long distance horizontal displacements.

3. Conclusions

In the years 1986 to 1992 investigations connected to the works on 3436 m long Slovenian part of the Karavanke road tunnel were performed. They incorporate petrographic and stratigraphic characteristics of the rocks from the tunnel and its surrounding (Text-Figs. 1 and 2). Twelve lithostratigraphic units were recognised within the time span from Upper Carboniferous to Upper Triassic (Text-Fig. 3). As contacts between particular formations are mainly fault-bounded, they were not scooped on the whole.

The results can be summed up into the following:

– Upper Carboniferous and Lower Permian beds, which are the equivalent to Auernig and Rattendorf beds in the Carnic Alps, are represented by black slates, sandstone and conglomerates, intercalated by lenses of biomicritic and biosparitic limestone with fusulinid and crinoid fauna. These beds are tectonically totaly destructed.

– Trogkofel limestone occurs in the form of lavger lenses only outside the tunnel. It is recrystallised, of light gray colour and biosparitic by texture. Fossils are fusulinids and nonskeletal algae.

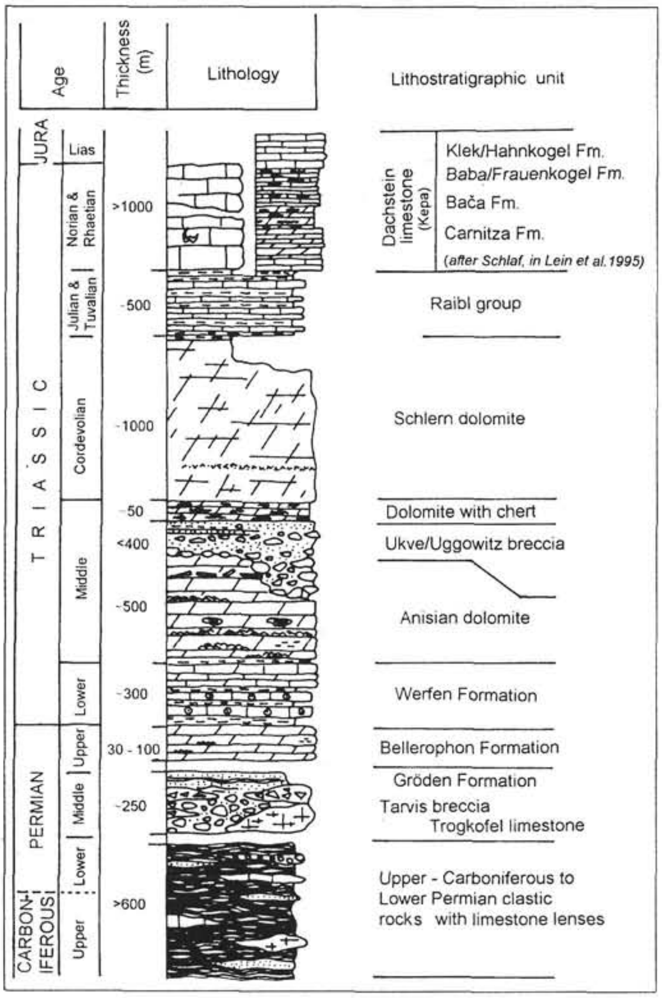
– Tarvis breccia and Gröden formation overlay Trogkofel limestone discordantly. Red or gray quartzarenite sandstone and slate are prevailing.

– Upper Permian beds are represented by bedded dolomite with common stromatolitic and loferitic texture.

– In a distance of about 800 m tunnel is transecting folded beds of Werfen formation. It is characterised by reddish clastic rocks, marl, dolomite and dark biomicritic limestone. Petrographic peculiarity of this formation are oolitic beds and horizons and veins of gypsum and anhydrite.

– Thickness of the Anisian dolomite is relatively variable. In the tunnel, it is exposed only within a few metre thick interval and on the surface in some hundred metres thick succession. In several beds structures indicating littoral sedimentation can be recognised (stromatolites, flat pebble conglomerate).

– Ukve/Uggowitz breccia is a transgresive fluviatile formation, discordantly deposited on the Anisian dolomite. In the tunnel, it also occurs, but only in a 30 metre section. Gray,



Text-Fig. 3.
Schematic lithostratigraphic column of formations, occuring in the Slovenian part of the Karavanke road tunnel.

brecciated conglomerate with dolomitic pebbles prevail.

– Buchenstein beds of Ladinian age occur in the tunnel just as thin beds of darker dolomite with chert. In a broader tunnel area (Mlinca) they are also represented by black limestone and tuff.

– Volcanic rocks and their tuffs outcropping elsewhere in the Western Karavanke Mts., *are not found in the tunnel*. The only exception is one 30 cm thin layer of green pelitic tuff within Schlern dolomite.

– Schlern dolomite of the Cordevolian age is massive and light coloured. Its crystalline texture obscured primary textures to a great extent. It is strongly mylonitised, porous, and for this reason, a good aquifer. In the tunnel its thickness amounts to about 400 m due to tectonic contacts, while on the surface it attains to about 1000 metres.

– Raibl beds of Julian – Tuvalian age in the final 200 metres of the tunnel (at the border with the Austrian part) are represented by dark marl and marly limestone with pelagic fauna. They were deposited at already developed relief of tectonic trenches and horsts on Schlern dolomite.

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