GEOLOGIJA 50/2, 247–268, Ljubljana 2007
https://doi.org/10.5474/geologija.2007.018

Depositional environment of Upper Carboniferous – Lower Permian beds in the Karavanke Mountains (Southern Alps, Slovenia)

Sedimentacijsko okolje zgornjekarbonskih in spodnjepermskih plasti v Karavankah (Južne Alpe, Slovenija)

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Key words: biostratigraphy, sedimentology, facies, platform evolution, Upper Carboniferous, Lower Permian, Karavanke Mts., Slovenia
Ključne besede: biostratigrafija, sedimentologija, facies, razvoj platforme, zgornji karbon, spodnji perm, Karavanke, Slovenija

Abstract

Late Paleozoic rocks were studied in detail in the Dovžanova soteska section. The Upper Carboniferous sedimentary succession, correlated with upper part of Auernig and Schulterkofel Fm. in the Carnic Alps, indicates cyclic clastic-carbonate deposition in a coastal to shallow marine ramp setting with strong influence of coarse-grained fluvial-deltaic siliciclastics from the hinterland, storm dominated regime of nearshore sediments, and offshore algal buildups. The Lower Permian sequence is developed differently from its time equivalent Grenzland Fm. and is subdivided into Dovžanova soteska Fm., Born Fm., and *Rigelj beds*. It is marked by the formation of a reef mound on the platform margin. Open-marine inner platform close to the marginal shoals represented the depositional environment of the mixed carbonate-siliciclastic sediments. Thus, a platform evolution from a ramp into a rimmed shelf is suggested.

Izvleček

Zgornjepaleozojske kamnine so bile detajlno raziskane v profilu Dovžanove soteske. Zgornjekarbonsko sedimentno zaporedje, korelirano z zgornjim delom auerniške in schulterkofelsko formacijo v Karnijskih Alpah, kaže na ciklično klastično-karbonatno sedimentacijo na obalnem in plitvomorskem pasu rampe. Zaznamovana je z močnim dotokom debelozrnatih fluvialno-deltnih klastitov s kopnega zaledja, prevladujoče nevihtnim režimom v priobalnem pasu in z algnimi kopami v odprtomorskem pasu. Spodnjepermsko zaporedje se razlikuje od časovno ekvivalentne grenzland formacije in je razdeljena na dovžanovo-soteško in bornovo formacijo ter *rigeljske plasti*. Zaznamuje jo razvoj grebenske kope na robu platforme. V notranjosti platforme so se v odprtem morju odložili mešani karbonatno-siliciklastični sedimenti. Opisan razvoj kaže na evolucijo platforme iz rampe v šelf z robno bariero.

Introduction

Sections of the Upper Carboniferous and Lower Permian fossiliferous shallow marine deposits in the Karavanke Mts. are commonly exposed in bands or scattered outcrops as a result of strong overprint by Alpine tectonics and thick cover of weathering residue or slope talus. They were historically correlated with better exposed sections in the Carnic Alps (Austria/Italy), where they were subdivided into Auernig, Rattendorf and Trogkofel beds (Geyer, 1895; Heritsch et al., 1934; Selli, 1963; Kahler, F. & Kahler, G., 1937, 1941; Kahler, F., 1939, 1942, 1947). In the Karavanke Mts., Auernig beds, Upper *Pseudoschwagerina* Limestone of the Rattendorf beds and Trogkofel beds were recognised, and within the latter clastic and carbonate units were distinguished (Schellwien, 1898a, b, 1900; Teller, 1903; Heritsch, 1933, 1938, 1939; Ramovš, 1963, 1966, 1968; Kochansky-Devidé, 1965, 1969, 1970, 1971; Kochansky-Devidé & Ramovš, 1966; Buser, 1974, 1980; Jurkovšek, 1987). Earlier works are discussed later in the text.

In this paper a part of the doctoral thesis on the biostratigraphy of Late Paleozoic beds in the Dovžanova soteska (Dovžan's gorge), NE of the town of Tržič, is summarized. In the Dovžanova soteska, the north-south trending valley of the Tržiška Bistrica river cuts deep into the southern slopes of the Karavanke Mountains and exposes the most complete section of marine fossil-rich Late Carboniferous and Permian beds in Slovenia (Fig. 1). The main focus of the paper is on the facies characteristics of the succession, biostratigraphic correlation, and the interpretation of the depositional environment. The interpretation of the Late Paleozoic succession refers also to similar, but better exposed deposits in Carnic Alps, which were studied in detail in the last decades (Venturini, 1990; Schönlaub, 1992; Krainer, 1992; Samankassou, 1997; Forke et al., 1998, 2006; Forke, 2002).

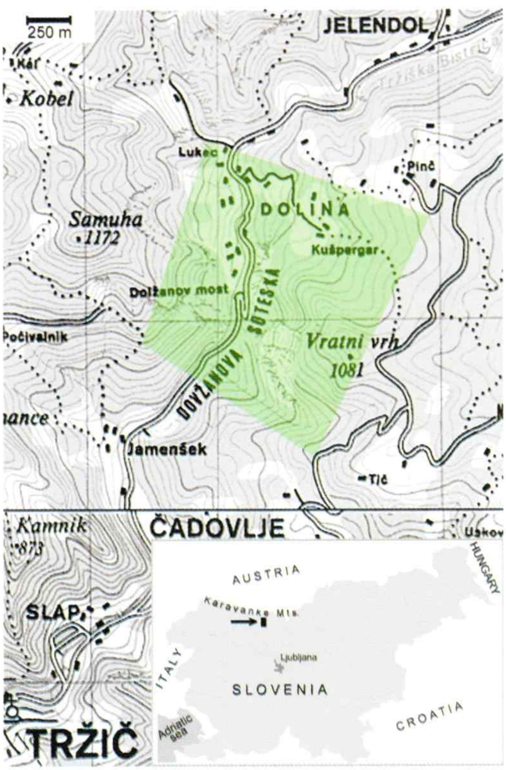


Fig. 1. Location map of the investigated area.

Sl. 1. Lega raziskanega območja.

Biostratigraphy and correlation

Fusulinoideans in the lowermost part of the succession are represented by *Daixina (Daixina) alpina*, *D. (D.) communis*, *Dutkevitchia* aff. *multiseptata*, and *Quasifusulina longissima ultima*. A similar assemblage is known from the lithologically identical Auernig and Carnizza Members (upper part of Auernig Formation) in the Carnic Alps. It can be correlated with the *Daixina sokensis* zone (Gzhelian E) on the Russian Platform (Kahler, F., 1962; Krainer & Davydov, 1998; Leppig et al., 2005; Forke, 2007) (Fig. 2). However, in the upper part of this sequence large inflated forms belonging to the subgenus *Daixina (Bosbytauella)* occur together with *Dutkevitchia expansa*, *Rugosofusulina stabilis*, *Schwageriniformis* sp., and *Ruzhenzevites* aff. *parasolidus*. This assemblage corresponds to the fusulinoidean fauna of the Schulterkofel Formation in Carnic Alps and indicates the *Daixina (B.) bosbytauensis-Daixina (B.) robusta* zone (Gzhelian F) in the Darvaz area (Central Asia) and in the Southern Urals (Kahler, F. & Krainer, 1993; Forke et al., 1998; Krainer & Davydov, 1998; Forke, 2002). The Schulterkofel Formation, formerly known as Lower *Pseudoschwagerina* Limestone (Kahler, F., 1947), has been renamed by Krainer (1995a) after the type section on Mt. Schulterkofel in the Nassfeld area according to the stratigraphic guidelines. In the Dovžanova soteska this assemblage is also present in oolitic limestone, capping the erosional unconformity on the thick quartz conglomerate unit and thus speaks for its uppermost Carboniferous age (Fig. 2) (Novak, 2007).

In the Dovžanova soteska, the Carboniferous/Permian boundary is not exposed due to a tectonic contact. Limestones above the contact were erroneously correlated with the younger Trogkofel Limestone in Carnic Alps for decades. Recently found conodonts *Streptognathodus barskovi*, *Str. simplex*, *Str.* cf. *longissimus*, *Str.* cf. *elongatus*, *Hindeodus*

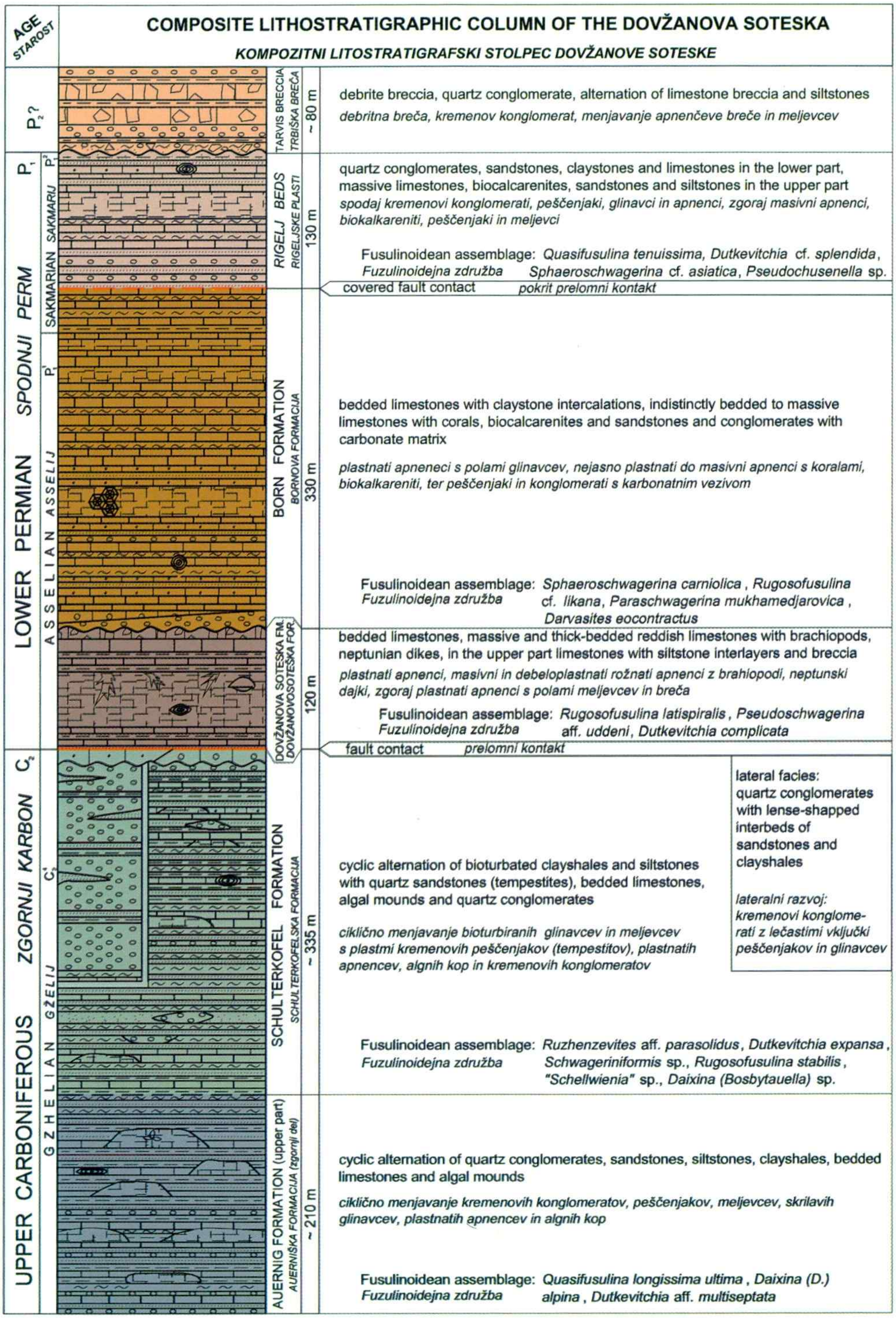


Fig. 2. Composite lithostratigraphic column of the Dovžanova soteska.
Sl. 2. Kompozitni litostratigrafski stolpec Dovžanove soteske.

minutus, and *Diplognathodus* n. sp. together with fusulinoideans *Dutkevitchia complicata*, *Pseudoschwagerina* aff. *uddeni*, *Sphaeroschwagerina citriformis*, and *Sph. carniolica* speak for middle to late Asselian age of these limestones (Buser & Forke, 1996; Forke, 2002; Novak, 2007). Late Asselian fusulinoidean assemblages of *Sphaeroschwagerina carniolica*, *Paraschwageria pseudomira*, *Pseudochusenella pseudopointeli*, *Rugosofusulina latispiralis*, and *R. likana* occur in the overlying clastic-carbonate succession of the Born Formation (Fig. 2). Due to lithologic and faunistic differences these beds can not be correlated with the Zweikofel Formation (Upper *Pseudoschwagerina* Limestone) of the Carnic Alps (as by Kahler, F. & Kahler, G., 1937) neither they can be regarded as clastic Trogkofel beds (as by Buser, 1974, 1980). They probably represent a time-equivalent to predominantly clastic and fossil-barren beds of the Grenzland Formation (Forke, 2002). **Therefore, these fusulinoidean forms have an important role in filling the gaps in the knowledge of the phylogenetic evolution and stratigraphic range of the present genera.**

The uppermost part of the section below the Tarvis breccia is poorly exposed. Fusulinoideans from this interval, informally named *Rigelj beds* (Novak, 2007), indicate early Sakmarian age due to the presence of *Dutkevitchia* cf. *splendida*, *Sphaeroschwagerina* cf. *asiatica*, *Quasifusulina tenuissima*, and *Pseudochusenella* sp. (Fig. 2). A similar faunal assemblage is present in the uppermost Grenzland Formation of the Carnic Alps (Novak & Forke, 2005).

Lithology and facies interpretation

The sedimentary succession in both, the upper part of the **Auernig** and the **Schulterkofel Formation** shows a clear cyclic siliciclastic-carbonate depositional pattern, known as Auernig cyclothems in the Carnic Alps (Austria/Italy) (Kahler, F., 1955; 1962; Buttersack & Boeckelmann, 1984; Boeckelmann, 1985; Massari & Venturini, 1990; Krainer, 1992; Samankassou, 1997, 2003). Because of tectonic deformations and thick cover of weathering residue outcrops are isolated and complete sections are rarely exposed. That makes it impossible to trace cyclothems or even reference horizons over longer distances. However, repeated occurrences of every facies or facies association composing the idealised model of Auernig cyclothem, drawn by Krainer (1992) and Krainer & Davydov (1998) (Fig. 3), can be recognised in the stratigraphic succession.

The base of the typical cyclothem is represented by conglomerates above the diastem. Based on only a few sedimentary structures that can be observed, a fluvial to coarse-grained deltaic or coastal depositional setting can be proposed for these conglomerate sequences. The overlying trough cross-bedded coarse-grained sandstones of the foreshore and upper shoreface settings mark the beginning of the transgressive systems tract (TST). With further sea-level rise the deposition of finer-grained sandstones follows. Hummocky cross-stratification (HCS) is the result of wave or the combination of wave and current oscillation during storms between the fair-weather and storm wave base on the lower shoreface (Tucker, 2001; Flügel, 2004). Upwards gradually bioturbated siltstones with scarce marine fauna prevail, interbedded with HCS storm sandstone beds. However, besides the structures, characteristic of tempestites (sharp basal erosion contact with groove casts, HCS, brachiopod shell lag at the base of event beds, and dwelling burrows of the *Skolithos*-type ichnofacies in the upper part of event beds (Frey, 1990; Pemberton & MacEachern, 1997)), also many typical turbiditic features (Bouma-like sequences, vortex and load structures) and normal water current structures (parallel-laminated sandstones and lense-shaped concentrations of sandstones within bioturbated siltstones) can be observed. The multitude of the described features most probably reflect various depositional mechanisms, complex nature of storm-generated currents and amalgamation of storm beds (Reading, 1996). The peak of the TST is represented by intensely bioturbated siltstones with highly diverse elements of a *Cruziana* ichnofacies suggesting stable conditions in an offshore setting.

The following carbonate complexes mark the maximum relative sea-level. They are represented by algal mounds in which basal, core, flanking and capping beds can be distinguished. Basal beds are usually very rich in fusulinoideans, smaller foraminifera, ostracodes, gastropods, brachiopods, and bryozoans. Almost unbroken thalli of *Anthracoporella spectabilis* and *Archaeolithophyllum missouriense* in growth position

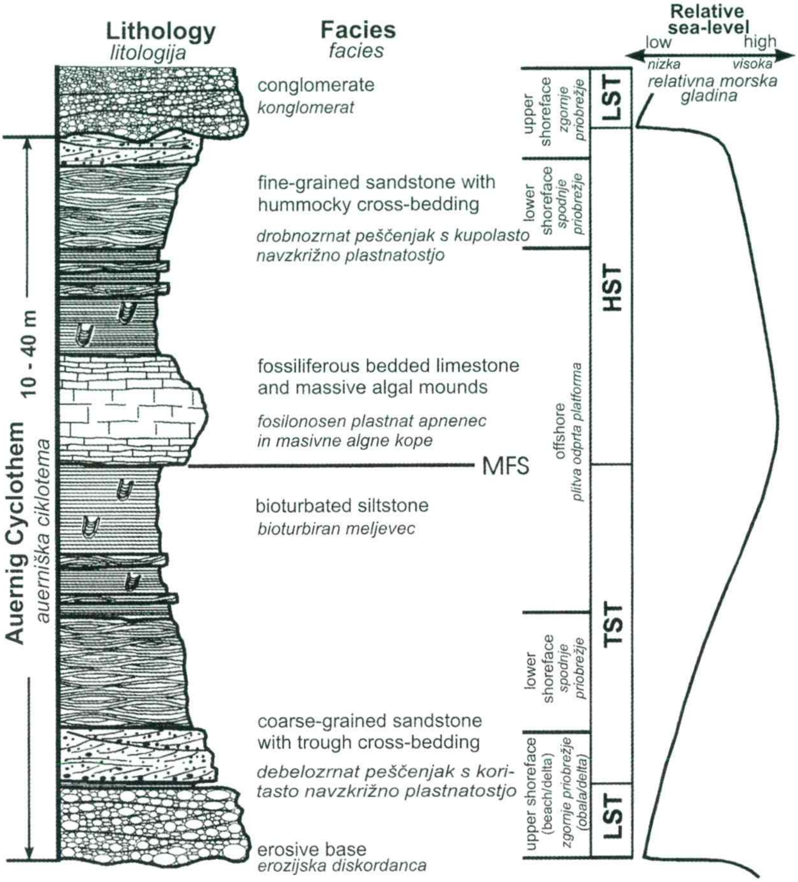


Fig. 3. Idealised Auernig Cyclothem from the upper part of the Auernig Formation in the Carnic Alps (after Krainer & Davydov, 1998).

Sl. 3. Idealiziran model auerniške cikloteme iz zgornjega dela auerniške formacije v Karnijskih Alpah (po Krainer & Davydov, 1998).

build the delicate framework of the massive micritic mound core. In flanking beds, they are accompanied by fragments of phylloid algae *Epimastopora* and *Eugonophyllum*, and binded with *Tubiphytes* or small sessile foraminifera. Capping beds are composed predominantly of crinoid debris.

Optimal conditions for growth of calcareous algae is the upper part of the photic zone, i.e. few tenth of metres. Since their delicate thalli were unable to resist agitated water, they point to restricted environments with moderate current action, most probably just below the storm wave base zone (Toomey et al., 1977). The bedded wacke- to packstones underlying and overlying massive algal mound core were deposited in a shallower zone of higher energy. Predomination of algal biostromes, composed of fragmented algal thalli, over bioherms indicates that most of the buildups grew within the wave action zone. Accumulation of calcareous algae generally started during transgression, while the micritic core facies marks the sea-level highstand. Upwards, in the highstand systems tract (HST), the mirror image of clastic sequences complete the idealised cyclothem (Krainer & Davydov, 1998) (Fig. 3).

The described facies associations and microfacies characteristics suggest that the deposition of Auernig and Schulterkofel Formations took place on a platform of the mixed carbonate-siliciclastic ramp type at the margin of a shallow intracratonic basin (Read, 1985). Similar conclusions were reached by Massari & Venturini (1990) in the Carnic Alps. They pointed out, that the only plausible explanation for substantial shifts of facies belts in relatively short time periods is a flat topography of gently steeping ramp, where even the slightest change of sea-level was causing considerable shifts of the coastal line. However, worldwide recorded Late Paleozoic cyclic deposits exhibit rapid facies changes that reflect both high frequency and high amplitudes of sea-level fluctuations due to glacio-eustatic control associated with Gondwanan glaciation (Soreghan & Giles, 1999; Joachimski et al., 2006).

An up to 200 m thick unit of thick-bedded coarse-grained and poorly-sorted quartz conglomerates most probably represents a lateral fan-deltaic depositional environment within the upper part of the Schulterkofel Formation. A rapid sea-level rise following the deposition of conglomerates resulted in the transgressive lag that caps a flooding surface. It is characterised by high content of bioclastic and quartz pebble components from the eroded surface (Reading, 1996).

The **Dovžanova soteska Formation** also shows clear transgressive-regressive trends. Black wavy to nodular-bedded limestones with marlstone intercalations begin the TST. The following black bioturbated fossil-rich siltstones and claystones pass gradually into the Dovžanova soteska Limestone through increasing carbonate/clay ratio. Since the massive limestone body is grossly built of postmortally segmented skeletal fragments of crinoids, bryozoans, green calcareous algae and brachiopods in a micritic matrix, bounded only with encrusting *Tubiphytes*, algae, bryozoans and small sessile foraminifers, while the true reef-building metazoans play only a subordinate role, we can refer to it as a reef (or skeletal) mound (Flügel, 2004). The bioclastic packstone to microbreccia composed of fragmented allochthonous reef mound derived debris in the upper part of Dovžanova soteska Limestone, corresponds to SMF 5 (sensu Wilson, 1975; Flügel, 1982) of the reef-flank facies. It was deposited in the forereef facies belt and suggests a substantial topographic relief and the rigidity of the reef mound body. Further evidence of this are neptunian dikes and the brecciated horizon in the uppermost part of the complex. Since there is no evidence of regional tectonism at that time, this can not be regarded as the triggering factor of dike formation. Taking into consideration the inherited instability of poorly cemented reef mounds, we can explain fissure opening as a result of high local depositional relief that leads to passive gravitational movements and fracturing (Reading, 1996; Flügel, 2004; Stanton & Pray, 2004). However, seismic events and the loss of hydrostatic support during short-termed relative sea-level falls can not be excluded. Most dikes exhibit multiple phases of fissure opening and filling with marine sediment.

The following horizon, composed of deeper-water calcareous siltstones, marlstones and thin-bedded marly limestones speak for the short-term drowning of the reef complex prior to the deposition of red bedded crinoidal limestones with a rich and diverse shallow-water biotic association. Red stained silty crusts capping almost every limestone bed represent omission surfaces of the hardground type. They were formed during periods in which lowering of the effective wave base reached the sea-floor and there constant water agitation resulted in submarine cementation of calcareous ground and an impregnation with Fe and Mn oxides (Brett, 1998). Similar lithologies have been found in the upper slope sediments of a completely preserved carbonate platform to basin configuration in the Cantabrian Mts. (Bahamonde et al., 2004). The uppermost part of the Dovžanova soteska Formation is marked by a reestablishment of reef growth with strong marine cementation, suggesting a steep slope inclination.

The described development of the Dovžanova soteska Formation with drowning event, restored reefal sedimentation and intermediate tongue of upper-slope facies fits the description of a back-stepping reef with the landwards shift of carbonate production during the episode of relative sea-level rise (Reading, 1996).

Basal quartz conglomerates of the **Born Formation** cut into brecciated uppermost beds of red limestone with erosional unconformity. A clear erosional surface and features like calcareous pisoids and infillings of vadose silt in the topmost limestones of the Dovžanova soteska Formation suggest that the reef sedimentation was terminated as a result of subaerial exposure. During the following transgression, sedimentary depocentre migrated towards the open-marine inner platform. The alternation of black bedded bioclastic grain- to packstones, biocalcarenites, oolites, sandy limestones and quartz sandstones with shallow-water benthos in the lower part of the Born Formation indicates deposition in an open lagoonal setting repeatedly affected by the sedimentary influx from platform-margin oolitic and sand shoals. Some of the mixed carbonate-siliciclastic rocks (e.g. paraconglomerates) have characters of the debris flow deposits (Novak, 2007). One of the rocky pyramids is built of massive light grey micritic limestone with the rugose coral *Carinthiaphyllum kahleri* (Holzer & Ramovš, 1979) forming an isolated patch-reef.

In the upper part of Born Formation often folded beds of dark limestones with clay admixture, concetrated as irregular interbeds prevail. They contain numerous thalli of phylloid algae, many genera of smaller foraminifera, fusulinoideans, and in some places large planispiral euomphalid gastropods. The original depositional structures and textures are modified by the intense burrowing, differential early diagenetic cementation, and the differential solubility of clay-rich and carbonate-rich sediments during late diagenetic processes connected with pressure-solution. Evenly-bedded sediments were transformed into wavy or nodular limestones (McIlreath & James, 1984).

The lower retrogradational succession of the ***Rigelj beds*** indicates gradual shift of the facies belts from high energy coast through open-marine lagoon towards the shallow-marine, and shelf edge. In the transitional coastal belt, conglomerates, sandstones and oolitic limestones were deposited. Sedimentation of black bedded algal limestones with clayshale intercalations took place in the inner-shelf environment. There, in the restricted marine shoals limestones with low diversity algal association were deposited, while in the open lagoon with normal water circulation near to platform edge, sedimentation of limestones with high diversity algal association took place (Flügel, 1977). Reef limestones and limestone breccias mark shelf edge setting. Development of the upper part of *Rigelj beds* suggests a shift of facies belts back into the open-marine lagoon, where black limestones with high-diversity biota and *Osagia*-type oncoids were formed (Flügel, 1977). Substantial content of fine-grained, well-rounded quartz pebbles in several limestone beds indicates periodical terrigenous influx from a distant hinterland. Regressive trend continues with the deposition of sandstones and calcitic siltstones in high-energy shoreface setting.

With the deposition of the **Tarvis breccia**, a new tectono-sedimentary cycle started in Southern Alps in the Middle Permian. It has been interpreted as the deposits of alluvial fans and/or delta fans with periodic lacustrine pans and sabkhas (Rotar, 1999).

Conclusion

Based on facies relationships in the section of Upper Paleozoic rocks in the Dovžanova soteska, a change in platform relief can be suggested. A gently steeping ramp morphology without both, the marginal barrier and the shelf break in the basinward direction evolved into a rimmed shelf with steeper slope as a result of lateral and vertical accretion in response to numerous relative sea-level changes. During periods of sea-level stillstands or slow rises the reef mound on the platform margin rapidly prograded, while as a response to periods of rapid sea-level rises the initial drowning and back-stepping events caused vertical accretion and steeper slope angle (Reading, 1996). Similar platform evolution had been suggested in many sedimentary basins in different geologic periods. However, the closest parallel to the platform evolution in the Dovžanova soteska can be found in the evolution of the Permian Capitan Reef in the Delaware Basin in West Texas (Babcock, 1977; Read, 1985; Tinker, 1998; Pomar, 2001; Stanton & Pray, 2004).

Acknowledgments

I am grateful to my mentors, the late Prof. Stanko Buser and Doc. Dr. Bojan Ogorelec for their help and encouragement. I sincerely thank to Dr. Holger Forke for his "tutorship" in Late Paleozoic biostratigraphy, determination of fusulinoideans and help with microfacies studies. Doc. Dr. Dragomir Skaberne is greatefully acknowledged for his constructive comments and Prof. Jernej Pavšič for improvements by reviewing the manuscript. This study was supported by the young researcher training programme founds of the Slovenian Research Agency (ARRS).

Sedimentacijsko okolje zgornjekarbonskih in spodnjepermskih plasti v Karavankah (Južne Alpe, Slovenija)

V profilih Dovžanove soteske (sl. 1) lahko ločimo pet glavnih fuzulinoidejnih združb, katerih stratigrafski razpon približno sovpada z razponom ugotovljenih formacij (sl. 2). Za zgornji del auerniške formacije je značilna združba *Quasifusulina longissima ultima*, *Daixina (D.) alpina* in *Dutkevitchia* aff. *multiseptata*; za schulterkofelsko formacijo združba *Ruzhenzevites* aff. *parasolidus, Dutkevitchia expansa, Schwageriniformis* sp., *Rugosofusulina stabilis*, *"Schellwienia"* sp. in *Daixina (Bosbytauella)* sp.; za dovžanovosoteško združba *Rugosofusulina latispiralis*, *Pseudoschwagerina* aff. *uddeni* in *Dutkevitchia complicata*; za bornovo združba *Sphaeroschwagerina carniolica*, *Rugosofusulina* cf. *likana*, *Paraschwagerina mukhamedjarovica* in *Darvasites eocontractus*; za *rigeljske plasti* pa združba *Quasifusulina tenuissima*, *Dutkevitchia* cf. *splendida*, *Sphaeroschwagerina* cf. *asiatica* in *Pseudochusenella* sp.

Najstarejše plasti v Dovžanovi soteski lahko koreliramo z zgornjim delom auerniške formacije (auerniškim in carnizza členom), ki obsega cono *Daixina sokensis* Ruske platforme in pripada gželiju E. Najmlajše karbonske plasti schulterkofelske formacije lahko koreliramo s cono *Daixina (B.) bosbytauensis-Daixina robusta* najmlajšega gželija. Pretežno karbonatno razviti dovžanovosoteška in bornova formacija ter *rigeljske plasti* časovno sovpadajo s sr. asselijsko-sp. sakmarijsko, pretežno klastično razvito in s fosili revno grenzland formacijo v Karnijskih Alpah. Fuzulinoidejne združbe v njih tako pomembno izpolnjujejo vrzeli v poznavanju filogenetskega razvoja in stratigrafskega razpona opisanih rodov.

Zaporedje zgornjekarbonskih plasti v Dovžanovi soteski zaznamuje ciklična siliciklastično-karbonatna sedimentacija na položni platformi s konfiguracijo obalne klančine (rampe). Debelejši apnenčevi kompleksi predstavljajo različne oblike algnih kop, ki so nastajale v fotični coni pod bazo učinkovanja nevihtnih valov. V nekoliko globljih delih je bil odložen bioturbiran meljevec, v plitvejšem priobrežnem in obrežnem pasu pa peščenjaki in konglomerati fluvialno-deltnega okolja (sl. 3).

Plate 1 / Tabla 1

Fusulinoidean assemblages of Auernig and Schulterkofel Formations. All figures are 10x magnified.
Fuzulinoidejni združbi auerniške in schulterkofelske formacije. Vse slike so 10x povečane.

Fig. 1. (Sl. 1.) *Quasifusulina longissima ultima* Kanmera, 1958, axial section (osni presek), 852_I_03_a, section (profil) K 4/Schulterkofel Formation (schulterkofelska formacija).

Fig. 2. (Sl. 2.) *Quasifusulina longissima ultima* Kanmera, 1958, saggital section (ekvatorialni presek), 553_02_g, section (profil) ZD 3/Auernig Formation (auerniška formacija).

Fig. 3. (Sl. 3.) *Daixina (Daixina) alpina* (Schellwien, 1898), axial section (osni presek), 550_03_a, section (profil) ZD 3/Auernig Formation (auerniška formacija).

Fig. 4. (Sl. 4.) *Dutkevitchia* aff. *multiseptata* (Schellwien, 1898), tangential section (tangencialni presek), 322_10_b, section (profil) ZD 3/Auernig Formation (auerniška formacija).

Fig. 5. (Sl. 5.) *Daixina (Daixina) communis* (Schellwien, 1898), axial section (osni presek), 852_II_08_a, section (profil) K 4/Schulterkofel Formation (schulterkofelska formacija).

Fig. 6. (Sl. 6.) *Ruzhenzevites* aff. *parasolidus* (Bensh, 1962), axial section (osni presek), 321_09_abcd, section (profil) K 4/Schulterkofel Formation (schulterkofelska formacija).

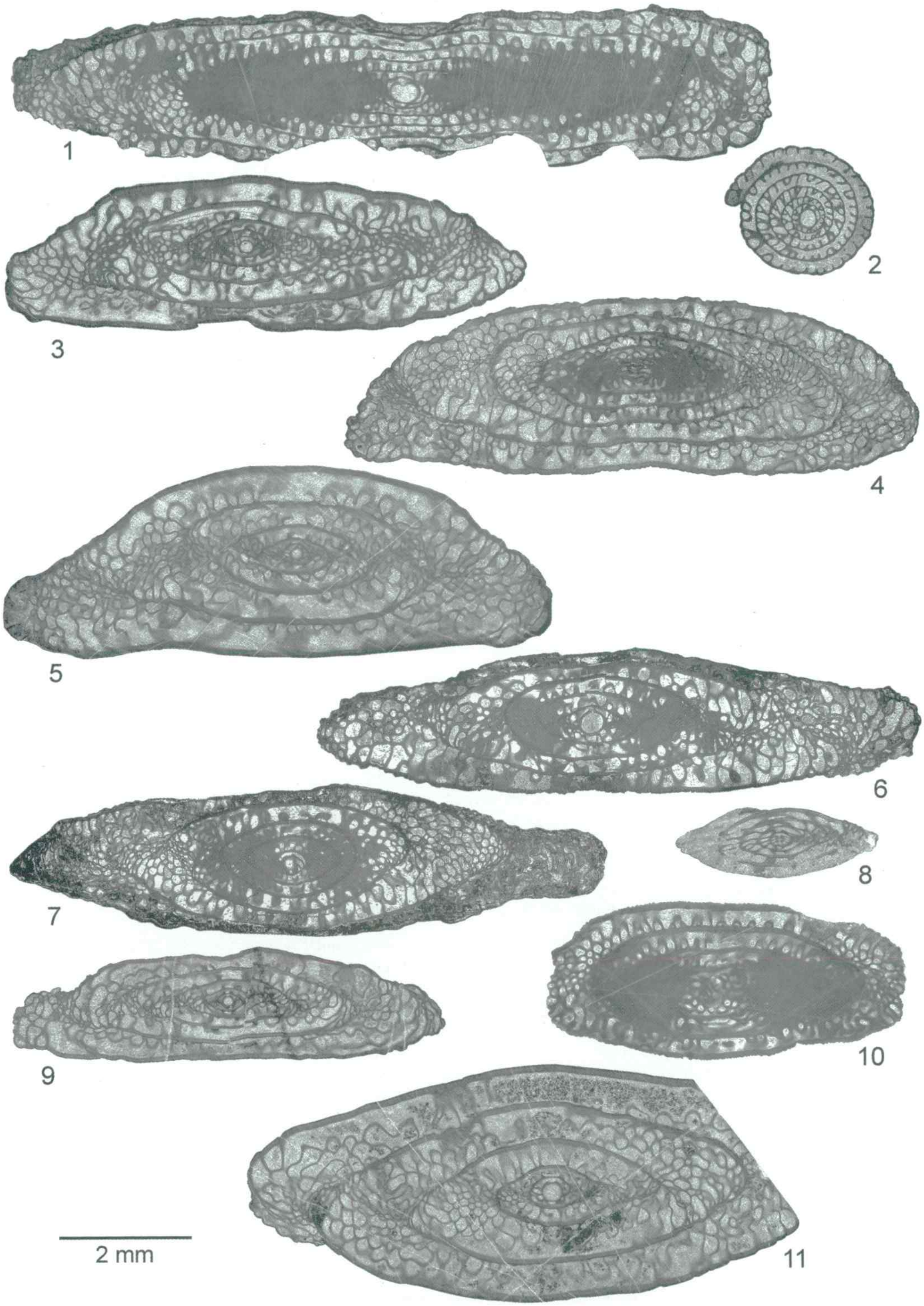
Fig. 7. (Sl. 7.) *Dutkevitchia expansa* (Lee, 1927), axial section (osni presek), 321_04_abcd, section (profil) K 4/Schulterkofel Formation (schulterkofelska formacija).

Fig. 8. (Sl. 8.) *Schwageriniformis* sp., excentric axial section (ekscentrični osni presek), 101_01_s, section (profil) DS 1/Schulterkofel Formation (schulterkofelska formacija).

Fig. 9. (Sl. 9.) *"Schellwienia"* sp., axial section (osni presek), 241_II_05_a1, section (profil) Č 2/Schulterkofel Formation (schulterkofelska formacija).

Fig. 10. (Sl. 10.) *Rugosofusulina stabilis* (Rauzer-Chernousova, 1938), tangential section (tangencialni presek), 852_II_06_d, section (profil) K 4/Schulterkofel Formation (schulterkofelska formacija).

Fig. 11. (Sl. 11.) *Daixina (Bosbytauella)* sp., axial section (osni presek), 241_II_01_b1, section (profil) Č 2/Schulterkofel Formation (schulterkofelska formacija).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Sedimentološke značilnosti v profilih schulterkofelske formacije kažejo močan vpliv nevihtnih dogodkov na sedimentacijo drobnozrnatih peščenjakov in meljevcev v spodnjem priobrežnem pasu. V zgornjem priobrežnem pasu so nastajali plastnati apnenci z vložki meljevcev, bogati z gastropodno favno. Večji del schulterkofelske formacije je nastajal v nekoliko globljem morskem okolju kot auerniška formacija, v zgornjem delu pa so se lateralno sedimentirali vršajno-deltni debelozrnati konglomerati (sl. 2).

Kontakt zgornjekarbonskih plasti z zgoraj ležečo spodnjepermsko dovžanovosoteško formacijo je tektonski, tako da karbonsko/permska meja ni vidna. To formacijo zaznamujejo jasni transgresijsko-regresijski cikli z nastankom, potopitvijo, ponovno rastjo in končno okopnitvijo obsežnejše grebenske kope.

Konfiguracija klančine se je s progradacijo platformnega roba postopno spreminjala v šelf z robno bariero. V odprti laguni so nastali plastnati apnenci in mešane karbonatno siliciklastične kamnine bornove formacije s horizonti prodnatih apnencev, sedimentiranih z debritnimi tokovi.

Najvišji del spodnjepermskega zaporedja predstavljajo kamnine novo izdvojene litostratigrafske enote, ki je zaradi nepopolnega profila in težke sledljivosti na terenu, poimenovana z neformalnim imenom *rigeljske plasti* (sl. 2). Zaznamujejo jih svetli grebenski in temni onkoidni apnenci, odloženi na robu karbonatne platforme.

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Plate 2 / Tabla 2

Fusulinoidean assemblages of Dovžanova soteska and Born Formations. All figures are 10x magnified.

Fuzulinoidejni združbi dovžanovosoteške in bornove formacije. Vse slike so 10x povečane.

Fig. 1. (Sl. 1.) *Rugosofusulina latispiralis* Forke, 2002, axial section (osni presek), PR51_jkl, section (profil) TB 1/Born Formation (bornova formacija).

Fig. 2. (Sl. 2.) *Dutkevitchia complicata* (Schellwien, 1898), axial section (osni presek), 379_01_a, section (profil) TB 1/Born Formation (bornova formacija).

Fig. 3. (Sl. 3.) *Pseudoschwagerina* aff. *uddeni* (Beede & Kniker, 1924), excentric axial section (ekscentrični osni presek), 140_08_a1, section (profil) DS 2/ Born Formation (bornova formacija).

Fig. 4. (Sl. 4.) *Rugosofusulina*? *minuta* Forke, 2002, axial section (osni presek), 073_01_b1, section (profil) DS 2/ Born Formation (bornova formacija).

Fig. 5. (Sl. 5.) *Pseudoschwagerina* aff. *muongthensis* (Deprat, 1915), axial section (osni presek), 068_09_b1, section (profil) DS 2/ Born Formation (bornova formacija).

Fig. 6. (Sl. 6.) *Darvasites eocontractus* Leven & Shcherbovich, 1980, axial section (osni presek), 068_12_hi, section (profil) DS 2/ Born Formation (bornova formacija).

Fig. 7. (Sl. 7.) *Sphaeroschwagerina carniolica* (Kahler & Kahler, 1937), axial section (osni presek), 140_04_b1, DS 2/BF, section (profil) DS 2/ Born Formation (bornova formacija).

Fig. 8. (Sl. 8.) *Paraschwagerina mukhamedjarovica* Rauzer-Chernousova, 1949, axial section (osni presek), 795_01_a, section (profil) DS 2/ Born Formation (bornova formacija).

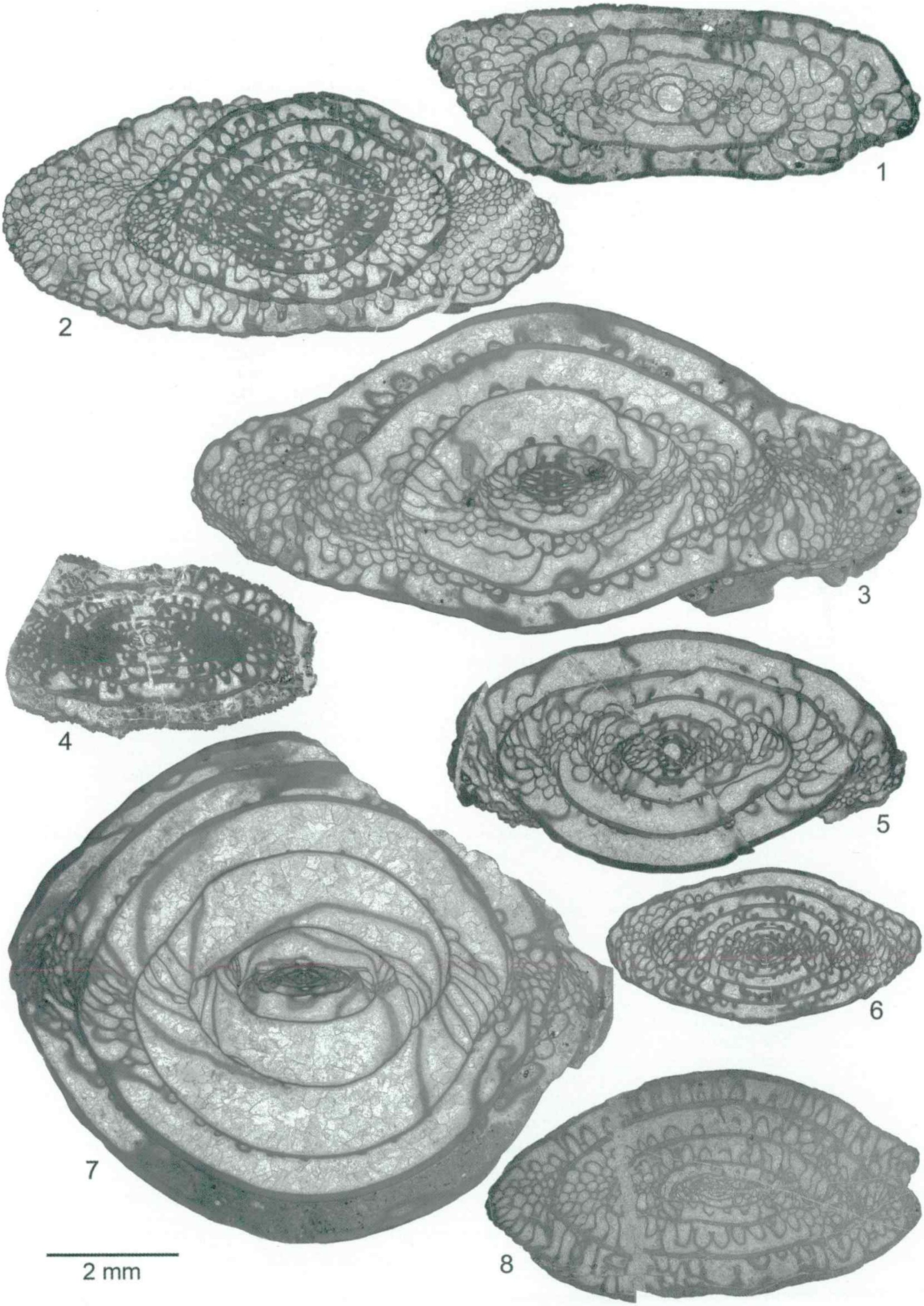
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Plate 3 / Tabla 3

Fusulinoidean assemblage of *Rigelj beds*. All figures are 10x magnified.
Fuzulinoidejna združba *rigeljskih plasti*. Vse slike so 10x povečane.

Fig. 1. (Sl. 1.) *Quasifusulina tenuissima* (Schellwien, 1898), axial section (osni presek), 519_04_abc, section (profil) R1/*Rigelj beds(rigeljske plasti)*.

Fig. 2. (Sl. 2.) *Pseudochusenella* sp., axial section (osni presek), 519_27_a, section (profil) R1/*Rigelj beds (rigeljske plasti)*.

Fig. 3. (Sl. 3.) *Sphaeroschwagerina* cf. *asiatica* (Miklucho-Maklay, 1949), axial section (osni presek), 519_16_a, section (profil) R1/*Rigelj beds (rigeljske plasti)*.

Fig. 4. (Sl. 4.) *Dutkevitchia* cf. *splendida* (Bensh, 1962), axial section (osni presek), 201_II_05_b1, section (profil) C1/*Rigelj beds (rigeljske plasti)*.

Fig. 5. Western slope of Vratni vrh above the Dovžanova soteska with a broad ridge of reddish limestone and Kušpegar rocky pyramids.

Sl. 5. Zahodno pobočje Vratnega vrha nad Dovžanovo sotesko s širokim hrbtom rožnatega apnenca in Kušpegarjevimi turni.

Fig. 6. Micritic algal core microfacies. Algal biomicrite (boundstone). Unbroken thalii of *Anthracoporella spectabilis* in growth position and intermediate voids are filled with micrite, peloids and spar cement (section ZD 1/Auernig Formation).

Sl. 6. Mikrofacies mikritnega algnega jedra. Algni biomikrit tipa boundstone. Nepoškodovane taluse *Anthracoporelle spectabilis* v življenjskem položaju in prostore med njimi zapolnjujejo mikrit, peloidi in sparitni cement (profil ZD 1/auerniška formacija).

Fig. 7. Algal wackestone. *Archaeolithophyllum missouriense* (in the upper right corner) and crusts of *A. lamellosum*, accompanied by *Tubiphytes* and encrusting foraminifers (in the centre) in micritic matrix. Other bioclasts are smaller foraminifers (*Bradyina* in the upper centre), echinoderm fragments and sponge spicules (section ZD 1/Auernig Formation).

Sl. 7. Algni apnenec tipa wackestone. *Archaeolithophyllum missouriense* (v desnem zgornjem kotu) in skorje *A. lamellosum*, skupaj s tubifiti in sesilnimi foraminiferami (v sredini) v mikritni osnovi. Drugi bioklasti so še manjše foraminifere (v sredini zgoraj *Bradyina*), fragmenti ehinodermov in spikule spongij (profil ZD 1/auerniška formacija).

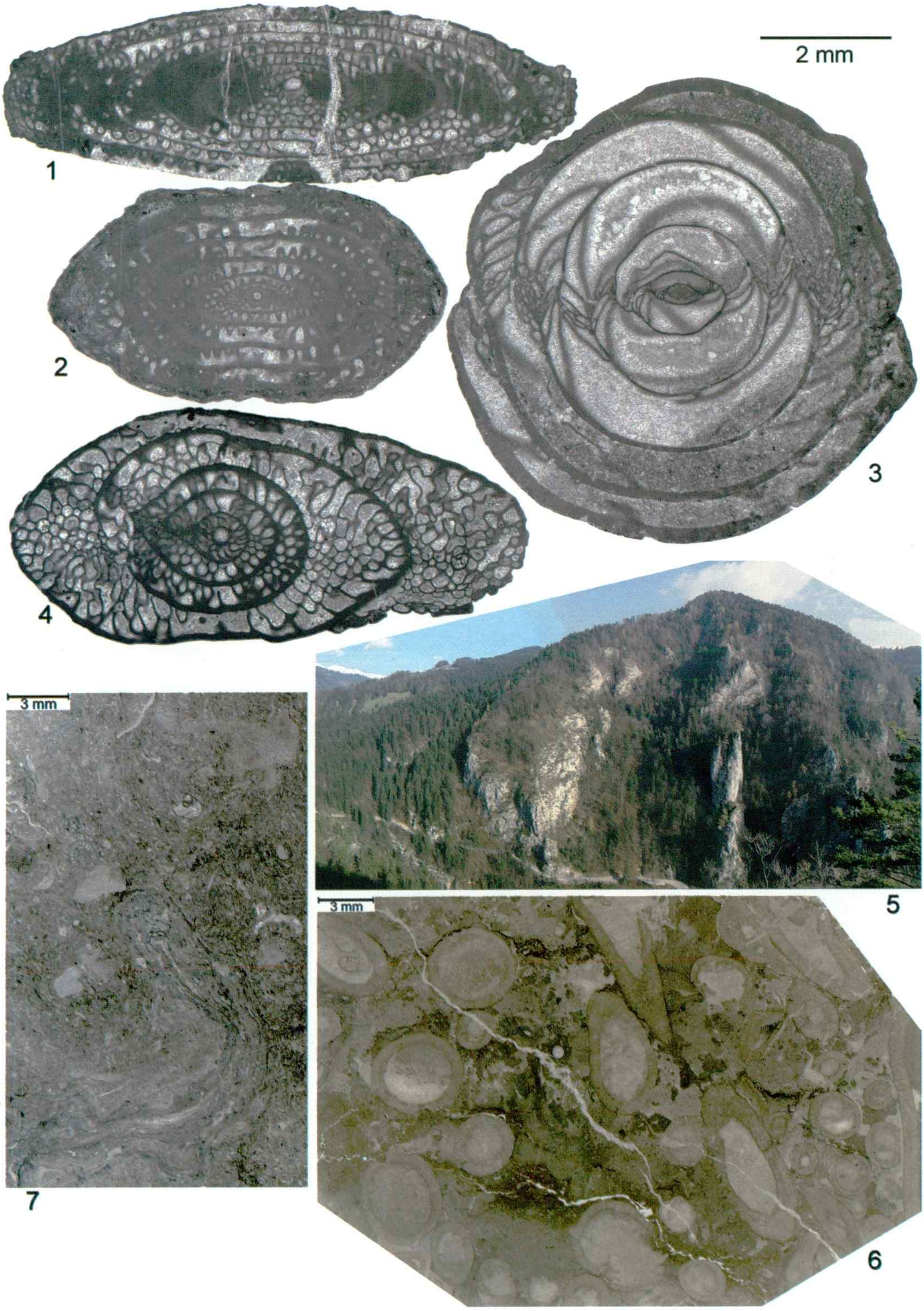
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Plate 4 / Tabla 4

Fig. 1. Algal mound of the biohermal configuration above the Kušpegar farm (section ZD 1/Auernig Formation). Massive algal core overlained by the flanking, crestal and capping beds.

Sl. 1. Algna kopa s konfiguracijo bioherme nad kmetijo Kušpegar (profil ZD 1/auerniška formacija). V sredini je masivno algno jedro, ki ga prekrivajo bočne, temenske in krovne plasti.

Fig. 2. Microfacies of the bedded intermound limestone. Bioclastic packstone with fusulinoidean foraminifers, bryozoans and algal fragments as predominant bioclasts. In the micritic matrix there are also gastropods, echinoderm fragments, ostracods and smaller foraminifers (section ZD 1/Auernig Formation).

Sl. 2. Mikrofacies plastnatega apnenca med kopami. Bioklastični apnenec tipa packstone s fuzulinidnimi foraminiferami, briozoji in algnimi fragmenti kot prevladujočimi bioklasti. Poleg teh so v mikritnem vezivu še polži, fragmenti ehinodermov, ostrakodi in manjše foraminifere (profil ZD 1/auerniška formacija).

Fig. 3. Algal mound of the biostromal configuration above the Kušpegar farm (section ZD 2/Auernig Formation). Between the underlying and overlying thick-bedded limestone local algal accumulations occur.

Sl. 3. Algna kopa s konfiguracijo biostrome nad kmetijo Kušpegar (profil ZD 2/auerniška formacija). V sredini so lokalna nakopičenja alg, v talnini in krovnini pa debeloplastnat apnenec.

Fig. 4. Algal boundstone. Recrystallized thalli of phylloid algae are locally encrusted by *Tubiphytes*. Voids in the peloidal micritic matrix are filled by spar cement. Broken thalli indicate *in situ* brecciation (section ZD 2/Auernig Formation).

Sl. 4. Algni apnenec tipa boundstone. Rekristalizirani talusi filoidnih alg so ponekod obraščeni s tubifiti. Osnova je peloidno-mikritna, vmesni prostori pa so zapolnjeni s sparitnim cementom. Pretrgani talusi kažejo na *in situ* porušitve (profil ZD 2/auerniška formacija).

Figs. 5, 6. Ichnofossil association of the *Cruziana* ichnofacies (section K 4/Schulterkofel Formation): fig. 5 *Thalassinoides*, fig. 6 *Zoophycos*.

Sl. 5, 6. Ihnofosilna združba *Cruziana* ihnofaciesa (profil K 4/Schulterkofelska formacija): sl. 5 *Thalassinoides*, sl. 6 *Zoophycos*.

Figs. 7, 8. Ichnofossil association of the *Skolithos* ichnofacies (section K 4/Schulterkofel Formation): fig. 7 *Arenicolites*, fig. 8 *Skolithos*.

Sl. 7, 8. Ihnofosilna združba *Skolithos* ihnofaciesa (profil K 4/Schulterkofelska formacija): sl. 7 *Arenicolites*, sl. 8 *Skolithos*.

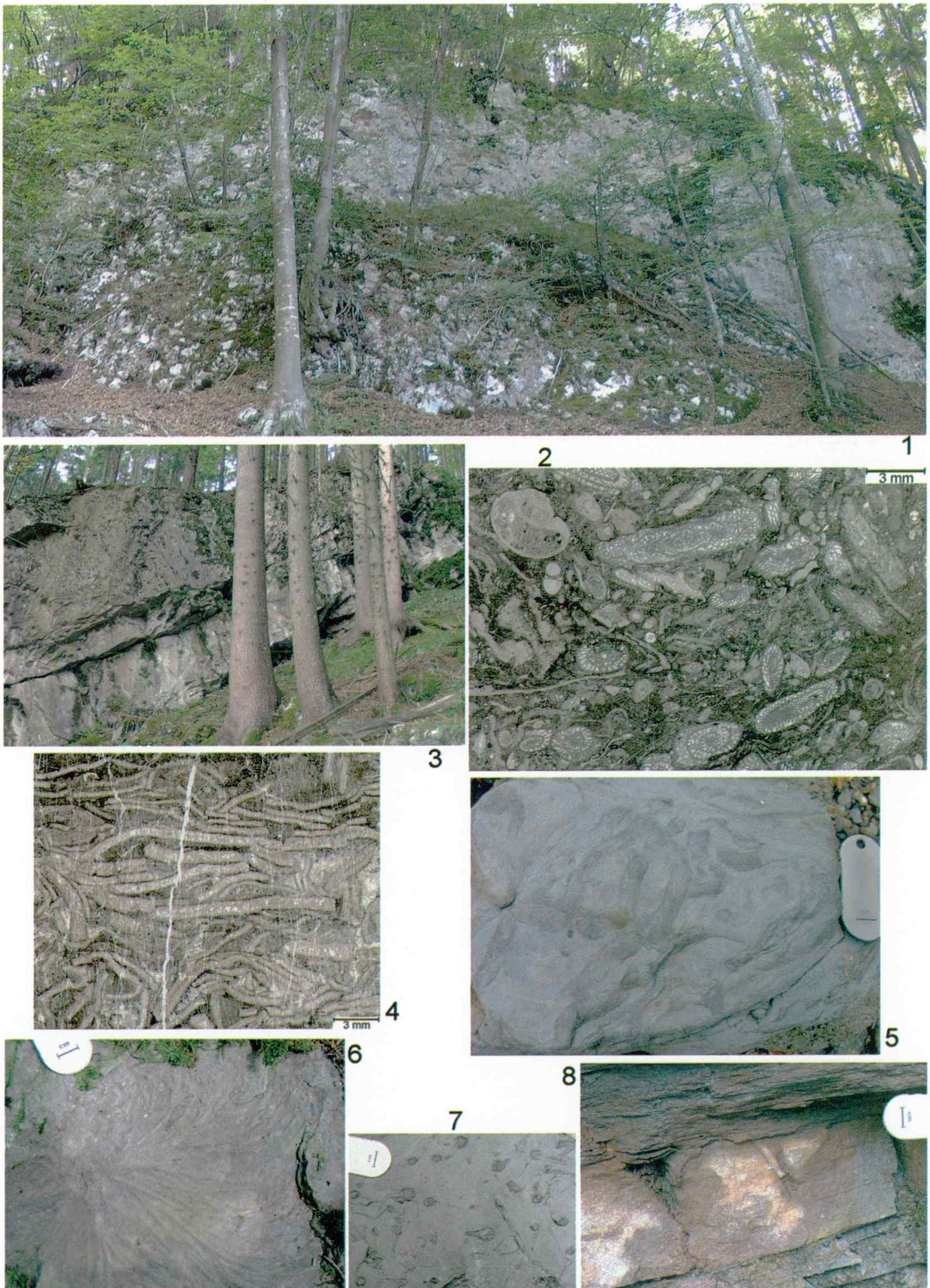
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Plate 5 / Tabla 5

Fig. 1. Amalgamed beds of fine-grained quartz sandstones with hummocky cross-stratification by the Tržiška Bistrica river-bed (Schulterkofel Formation).

Sl. 1. Amalgamirane plasti drobnozrnatih kremenovih peščenjakov s kupolasto navzkrižno plastnatostjo ob strugi Tržiške Bistrice (Schulterkofelska formacija).

Fig. 2. Skeletal carbonate siltstone (tempestite) with sharp boundary between the two storm events and gradation of crinoid fragments, briozoans and fusulinoideans (Schulterkofel Formation).

Sl. 2. Skeletni karbonatni meljevec (tempestit) z ostro mejo med dvema nevihtnima dogodkoma in gradacijo fragmentov krinoidov, briozojev in fuzulinoidej (schulterkofelska formacija).

Fig. 3. Brachiopod shell lag interlayered in the hummocky cross-stratified sandstone beds (section K 4/Schulterkofel Formation).

Sl. 3. Pola nakopičenih brahiopodnih lupin med plastema kupolasto navzkrižno stratificiranega peščenjaka (profil K 4/schulterkofelska formacija).

Fig. 4. Transgressive contact between the quartz conglomerate and siltstone in transitions to calcarenite and oolitic limestone (section K 1 /Schulterkofel Formation).

Sl. 4. Transgresijski kontakt med kremenovim konglomeratom in meljevcem s prehodi v kalkarenit in oolitni apnenec (profil K 1 /schulterkofelska formacija).

Fig. 5. Recrystallized brachiopod valves are thoroughly encrusted by the cystoporid bryozoans (of the genus *Fistulipora*) while the latter are encrusted by *Tubiphytes obscurus*. Bioclastic micritic wackestone of the upper part of the Dovžanova soteska Limestone (section DS 1/Dovžanova soteska Formation). 20x magnified.

Sl. 5. Prekristaljene brahiopodne lupine so popolnoma inkrustrirane s cistoporidnimi briozoji (rodu *Fistulipora*), te pa obrašča *Tubiphytes obscurus*. Bioklastični mikritni apnenec tipa wackestone iz zgornjega dela grebenskega apnenca Dovžanove soteske (profil DS 1/dovžanovosoteška formacija). Povečano 20x.

Fig. 6. Meshed system of wide irregular vertical fissures (neptunian dikes) exhibit multiple phases of filling with marine sediment (section DS 1/Dovžanova soteska Formation).

Sl. 6. Mrežast sistem širokih nepravilnih vertikalnih razpok (neptunskih dajkov), zapolnjenih z morskimi sedimenti v več fazah (profil DS 1/dovžanovosoteška formacija).

Fig. 7. Infillings of neptunian dike in the limestone of the reef-flank, where internal brecciation of the bioclastic packstone occured first. Opened fissures were filled with marine sediment with intraclasts, echinoderms and bryozoans (section DS 1/Dovžanova soteska Formation).

Sl. 7. Zapolnitve neptunskega dajka v apnencu grebenskega pobočja, kjer je najprej prišlo do notranje porušitve bioklastičnega apnenca tipa packstone. Odprte razpoke so bile zapolnjene z morskim sedimentom z intraklasti, ehinodermi in briozoji (profil DS 1/dovžanovosoteška formacija).

Fig. 8. Bioclastic packstone. Larger bioclasts are brachiopod and bivalve shells with micritic envelops and bioturbated by endolithic organisms. Rare fusulinoideans occur also. Smaller bioclasts are phylloid algae (predominantly *Epimastopora alpina*), *Tubiphytes*, and echinoderm and bryozoan fragments. Several generations of cements can be noticed. The first is the fibrous cement, suggesting phreatic marine environment. Corrosion vugs and intragranular pores were filled with red internal sediment in the first phase and in the second phase with sparite. Note geopetal fabric ("umbrella porosity") in the reefal limestone, indicating that the limestone bed has been cut by a vertical fissure (on the left). The latter was filled in two phases. In the first one with dark marine sediment with bryozoans, echinoderms, trilobites and rare grains of quartz, muscovite and sandstone. The second generation of infilling is represented by similar marine sediment (section DS 1/Dovžanova soteska Formation).

Sl. 8. Bioklastični apnenec tipa packstone. Večji bioklasti so brahiopodne in školjčne lupine z mirkitnimi ovoji, bioturbirane z endolitskimi organizmi in redke fuzulinidne foraminifere. Manjši bioklasti so filoidne alge (največ *Epimastopora alpina*), tubifiti ter fragmenti ehinodermov in briozojev. Opaznih je več generacij cementa. Prvo generacijo tvori vlaknati cement, ki kaže na cementacijo v morski freatični coni. Korozijske votlinice in intragranularne pore so bile v prvi fazi zapolnjene z rdečim internim sedimentom, v drugi pa s sparitom. Jasno vidne geopetalne strukture (dežnikasta poroznost) v grebenskem apnencu kažejo na to, da je razpoka (levo) presekala plast vertikalno. Zapolnjena je bila v dveh fazah. V prvi se je odložil temnejši morski sediment z briozoji, ehinodermi, trilobiti in redkimi zrni kremena, muskovita ter peščenjaka. V drugi fazi je odprto razpoko zapolnil podoben morski sediment (profil DS 1/dovžanovosoteška formacija).

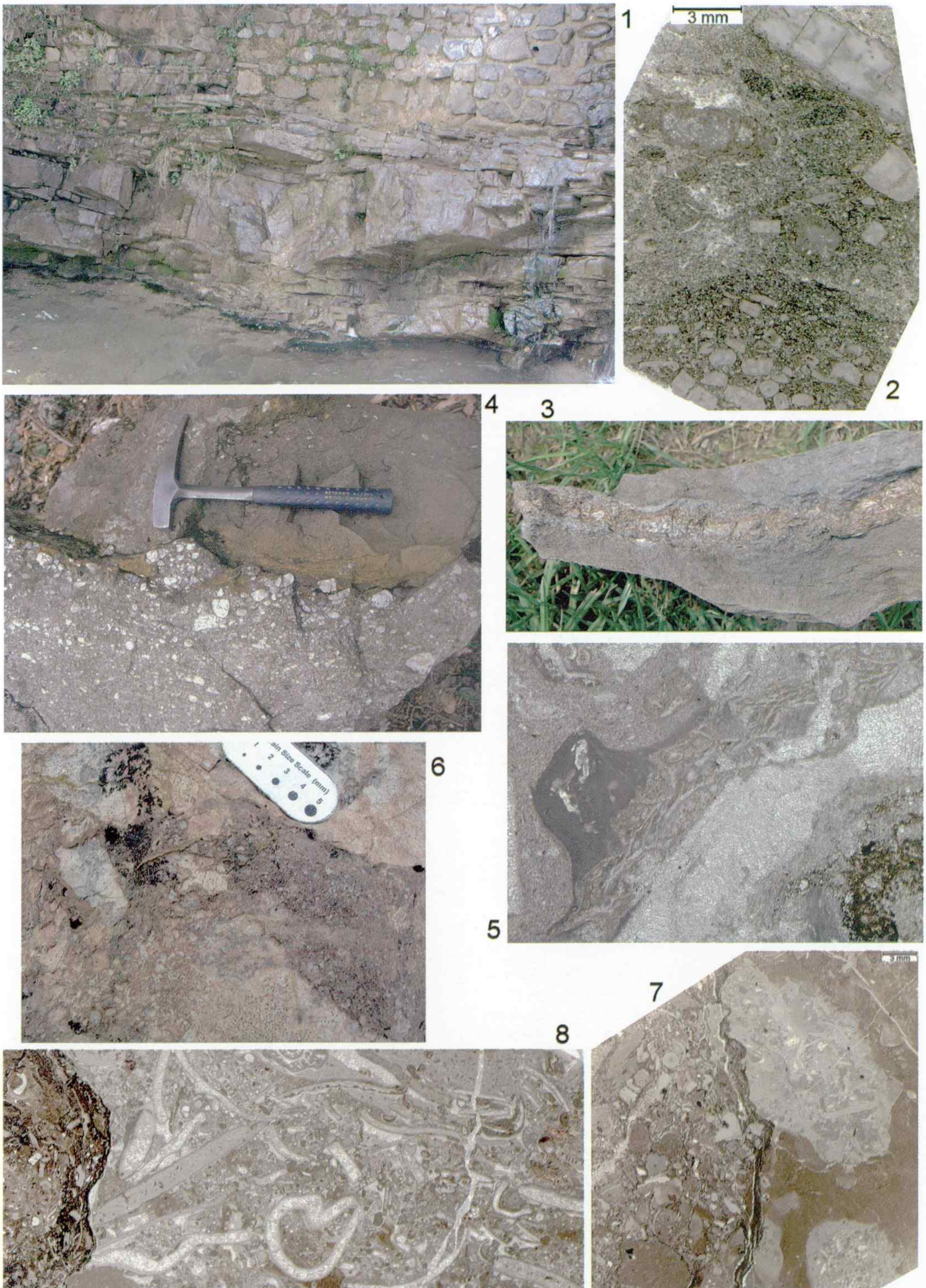
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Plate 6 / Tabla 6

Fig. 1. Red thin-bedded bioclastic limestones with clayey-silt crusts representing omission surfaces of the hardground type (section DS 1/Dovžanova soteska Formation).

Sl. 1. Rdeči tankoplastnati bioklastični apnenci z glineno-meljastimi skorjami, ki kažejo na prekinitve sedimentacije in tvorbo površin tipa "hardground" (profil DS 1/dovžanovosoteška formacija).

Fig. 2. Gastropod shells on the hardground surface of the red limestone with silty crust (section DS 1/Dovžanova soteska Formation).

Sl. 2. Hišice polžev na "hardground" površini plasti rdečega apnenca z meljasto skorjo (profil DS 1/ dovžanovosoteška formacija).

Fig. 3. Erosional unconformity between the bedded Dovžanova soteska Limestone and quartz conglomerate in the base of Born Formation (section DS 1).

Sl. 3. Erozijski kontakt med plastnatim apnencem Dovžanove soteske in kremenovim konglomeratom v bazi bornove formacije (profil DS 1).

Fig. 4. Oosparitic grainstone overlying transgressional contact of the Born Formation with the Dovžanova soteska Formation. Constituents of ooid nuclei are fusulinoideans, crinoid fragments, gastropods, *Tubiphytes*, shell fragments and intraclasts. The majority of nuclei was dissolved and replaced with coarse-grained spar, indicating fresh-water diagenesis. Ooids were obviously washed in biopelmicritic sediment in the lower-energy environment (section DS 1/Born Formation).

Sl. 4. Oosparitni apnenec tipa grainstone nad transgresijskim kontaktom bornove z dovžanovosoteško formacijo. Jedra ooidov tvorijo fuzulinoideje, krinoidi, polži, tubifiti, fragmenti lupin in intraklasti. Večina jeder je bilo raztopljenih in zapolnjenih z zrnatim sparitom, kar kaže na sladkovodno diagenezo. Ooidi so bili naplavljeni v biopelmikritni sediment mirnejšega okolja (profil DS 1/bornova formacija).

Fig. 5. Biocalcarenitic limestone (grainstone). Among bioclasts algae (*Neoanchicodium, Gyroporella*), gastropods, echinoderms, fusulinoideans and *Tubiphytes* predominate. Vadose zone cementation is indicated by the geopetal textures, such as stalactitic fibrous cement and "umbrella porosity" (section DS 2/Born Formation).

Sl. 5. Biokalkarenit tipa grainstone. Med bioklasti prevladujejo alge (*Neoanchicodium, Gyroporella*), gastropodi, ehinodermi, fuzulinoideje in tubifiti. Na cementacijo v vadozni coni kažejo geopetalne strukture v obliki stalaktitičnega vlaknatega cementa in dežnikaste poroznosti (profil DS 2/bornova formacija).

Fig. 6. Intensely bioturbated bioclastic mud- to bindstone. Bioturbation burrows were filled with spar. Stacked phylloid algae binded micritic sediment. Stylolitic seams indicate later compaction (section TB 1/Born Formation).

Sl. 6. Močno bioturbiran bioklastični apnenec tipa mud- do bindstone. Bioturbacijski rovi so bili zapolnjeni s sparitom. Nakopičene filoidne alge so vezale mikritni sediment. Stilolitski kontakti kažejo na kasnejšo kompakcijo (profil TB 1/bornova formacija).

Fig. 7. Nodular limestone beds with clayshale intercalations in the Tržiška Bistrica river-bed exhibit pressure dissolution effects and calcitic vein systems (section TB 1/Born Formation).

Sl. 7. Gomoljaste plasti apnenca z interkalacijami glinavca v strugi Tržiške Bistrice kažejo posledice raztapljanja pod pritiskom in sisteme kalcitnih žil (profil TB 1/bornova formacija).

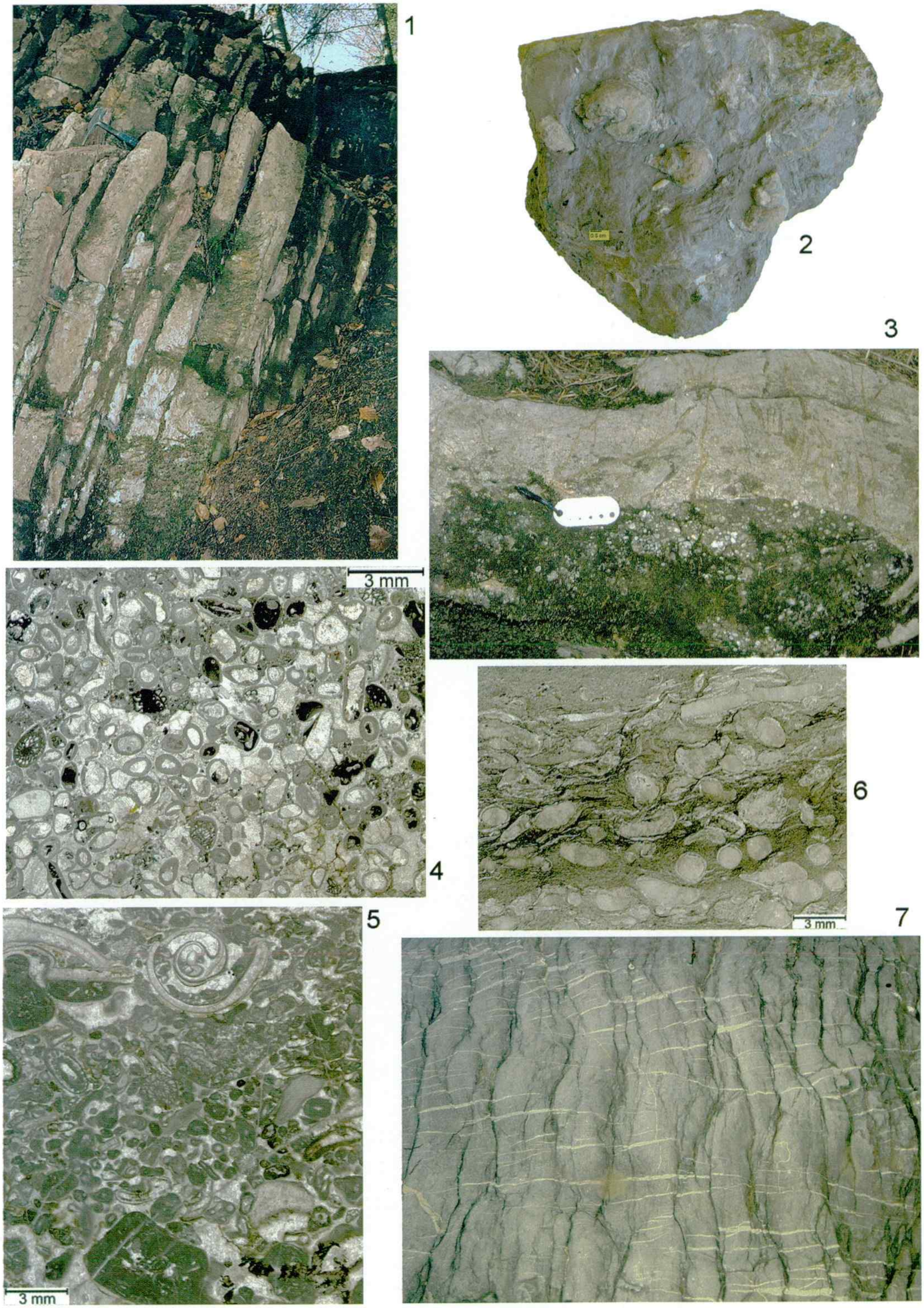
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Plate 7 / Tabla 7

Fig. 1. Quartzose paraconglomerate with hybrid siliciclastic-carbonate arenitic matrix. The carbonate of the matrix is bio-intramicritic packstone with fusulinoideans, crinoids, algae, *Tubiphytes* and smaller foraminifers. Spar cement around quartz pebbles and larger bioclasts indicate pressure-shadow cementation during compaction (section TB 1/Born Formation).

Sl. 1. Kremenov parakonglomerat s hibridno karbonatno-siliciklastično arenitno osnovo. Karbonat osnove je bio-intramikrit tipa packstone s fuzulinoidejami, krinoidi, algami, tubifiti in manjšimi foraminiferami. Obrobni sparitni cement ob prodnikih in večjih bioklastih kaže znake cementacije v senci pritiskov pri kompakciji (profil TB 1/bornova formacija).

Fig. 2. Beds of pebbly limestone (paraconglomerate) of debris-flow origin overlying sandstone by the Tržiška Bistrica river-bed (section TB 1/Born Formation).

Sl. 2. Plasti prodnatega apnenca (parakonglomerata), odloženega z debritnim tokom na peščenjaku ob strugi Tržiške Bistrice (profil TB 1/bornova formacija).

Fig. 3. Alternation of biocalcarenite and sandy limestone indicates periodic influx of terrigenous sediment (section DS 2/Born Formation).

Sl. 3. Menjavanje biokalkarenita in peščenega apnenca kažejo na periodičen vnos terigenega sedimenta (profil DS 2/Bornova formacija).

Fig. 4. Fusulinid packstone. Tests of fusulinoideans (*Darvasites* spp., "*Triticites* sp.") with slightly abraded and micritized peripheries suggest pre-depositional transport. Matrix is formed of peloidal micrite and spar cement. Fusulinoideans, thriving in high-energy environments, were transported into the lower-energy setting (section DS 2/Born Formation).

Sl. 4. Fuzulinski apnenec tipa packstone. Hišice fuzulinoidej (*Darvasites* spp., "*Triticites* sp.") so na obodih rahlo abradirane in mikritizirane, kar kaže na transport pred odložitvijo. Vezivo je iz peloidnega mikrita in sparitnega cementa. Fuzulinoideje, ki živijo v visokoenergijskih okoljih, so bile transportirane v nižjeenergijsko okolje (profil DS 2/bornova formacija).

Fig. 5. Biosparitic grainstone containing high-diversity of dasyclad (*Mizzia*, *Epimastopora*, *Neoanchicodium*) and other algae (*Ortonella morikawai* in the middle of the right edge). Other bioclasts are fusulinoideans and smaller foraminifers, echinoderms and fragments of brachiopod and gastropod shells. Abiotic components are aggregate grains and peloids (*Rigelj beds*).

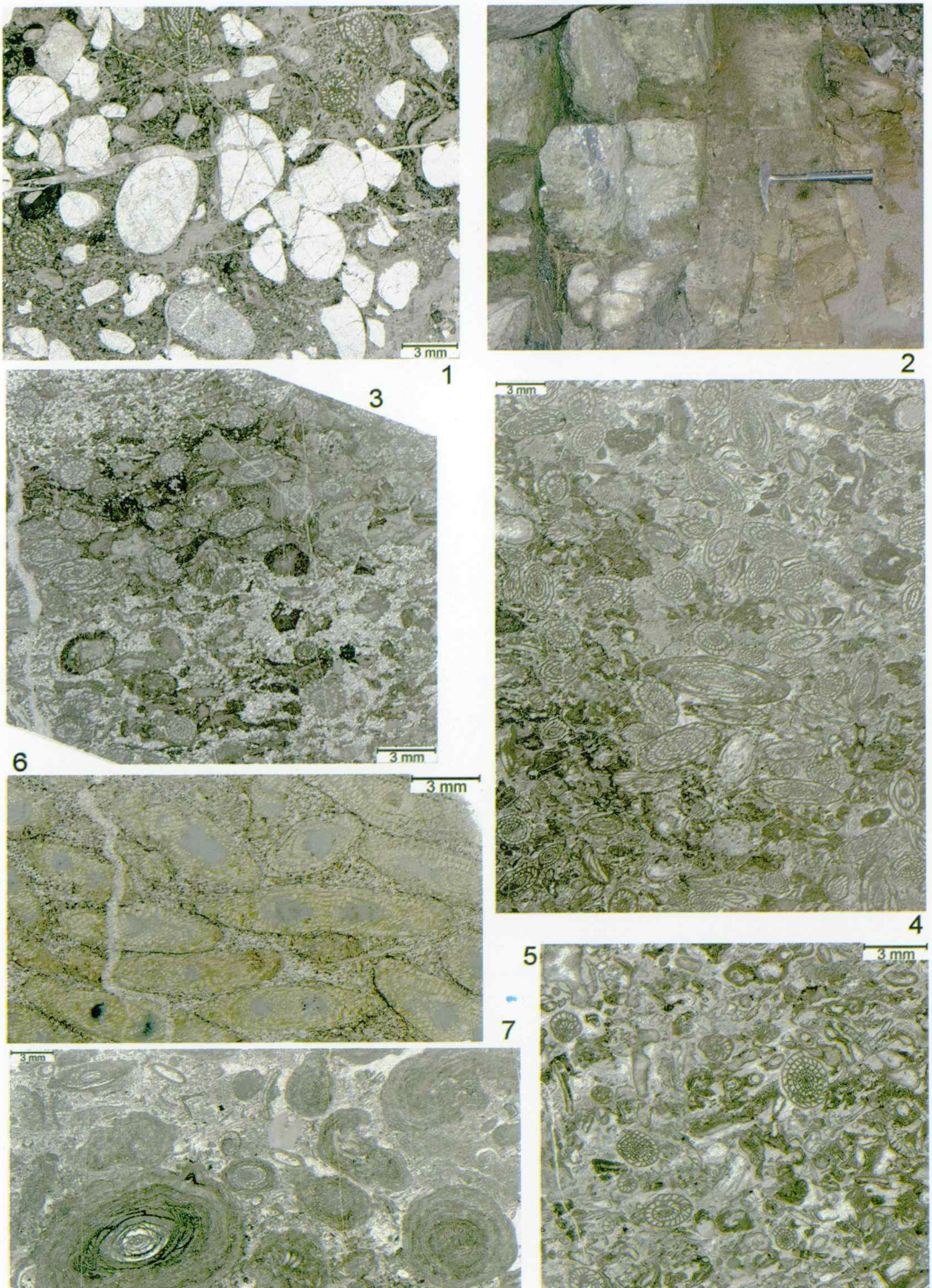
Sl. 5. Biosparitni apnenec tipa grainstone z raznoliko floro dazikladacejnih (*Mizzia*, *Epimastopora*, *Neoanchicodium*) in drugih alg (ob desnem robu na sredini *Ortonella morikawai*). Drugi bioklasti so fuzulinidne in manjše foraminifere, ehinodermi ter fragmenti brahiopodnih in gastropodnih lupin, ostalo pa so agregatna zrna in peloidi (*rigeljske plasti*).

Fig. 6. Fusulinid siltstone. An interesting monospecific suite of elongated fusulinoideans (*Quasifusulina tenuissima*) has been redeposited into the quartzitic silty sediment. Imbrication of tests suggests current transport mechanism (section R 1/*Rigelj beds*).

Sl. 6. Fuzulinski meljevec. Zanimiva monospecifična združba podolgovatih hišic fuzulinidnih foraminifer vrste *Quasifusulina tenuissima* je bila transportirana v kremenov meljast sediment. Imbrikacija hišic kaže na tokovni transport (profil R 1/*rigeljske plasti*).

Fig. 7. Oncobiosparitic grainstone. *Osagia*-type oncoids are constructed of calcitic microtubes of encrusting foraminifers (*Hedraites*, *Apterinella*) and algae *Girvanella* and *Claracrusta*, that overgrow other skeletal grains. Highly diverse bioclasts are represented by fusulinoideans, palaeotextularians, brachiopods, echinoderms, bivalves, gastropods, ostracods, dasyclad (*Epimastopora*, *Globuliferoporella*), and codiacean (*Neoanchicodium*) algae. This type of limestone was deposited in restricted shelf lagoons but also in high-energy environment on the open shelf edges (section R 1/*Rigelj beds*).

Sl. 7. Onkobiosparitni apnenec tipa grainstone. Onkoide tipa *Osagia* tvorijo kalcitne cevke inkrustrirajočih foraminifer (*Hedraites*, *Apterinella*) in alge *Girvanella* ter *Claracrusta*, ki obraščajo druga skeletna zrna. Pestra združba bioklastov je zastopana s fuzulinoidejami, paleotekstularijami, brahiopodi, ehinodermi, školjkami, polži, ostrakodi in dazikladacejnimi (*Epimastopora*, *Globuliferoporella*) in kodiacejnimi (*Neoanchicodium*) algami. Ta tip apnenca je nastajal v zaščitenih šelfnih lagunah in tudi visokoenergijskem okolju na robovih odprtih šelfnih platform (profil R 1/*rigeljske plasti*).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