

# Jurassic–Cretaceous radiolarian-bearing strata from the Gresten Klippen Zone and the St. Veit Klippen Zone (Wienerwald, Eastern Alps, Austria): Implications for stratigraphy and paleogeography

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## KEYWORDS

Klippen Zone; Wienerwald; Jurassic; Cretaceous; Radiolaria; biostratigraphy

## Abstract

Two sections of the klippen zones in the Wienerwald area have been investigated for their stratigraphy: (1) The Gern section of the Main Klippen Zone, a part of the Gresten Klippen Zone, and (2) the St. Veit Klippen Zone in the Lainz Tunnel and the neighboring outcrops in western Vienna. New biostratigraphic data are based on radiolaria from siliceous intervals and a few findings of calcareous nannofossils from marlstones. In the Gresten Klippen Zone, radiolarian assemblages from limestones of the Gern locality indicate a middle Oxfordian to early Kimmeridgian age of the Scheibbsbach Formation.

Radiolarian and nannofossil data from the St. Veit Klippen Zone in the Lainz railway tunnel locality, as well as correlated outcrops from the Lainzer Tiergarten and the Gemeindeberg in the southwest of Vienna, indicate the presence of mainly Bajocian to lower Oxfordian red radiolarites and cherts (Rotenberg Formation). Siliceous, grey limestones and cherts of the Fasselgraben Formation range from the upper Oxfordian–Kimmeridgian to the Valanginian–Barremian.

The Main Klippen Zone was derived from the European margin to the north, and this zone is regarded as a Helvetic paleogeographic unit. The St. Veit Klippen Zone in the Lainz Tunnel section contains no ophiolitic material and shows a tectonic contact with the surrounding Rhenodanubian nappe system, which indicates no primary sedimentary contact of the St. Veit Klippen Zone with the Flysch units, as well as demonstrating the presence of two structurally separated Alpine tectonic units. Thus, a direct correlation with the Ybbsitz Zone is not supported, and an original paleogeographic position in the transition from the Penninic Ocean to the Austroalpine continental fragment is proposed.

## 1. Introduction

Klippen-style geology, known since more than 150 years (Pusch, 1833; Čížek, 1849), denotes a structural style that is characterized by huge and solid rock cliffs, built by indurated carbonates and siliceous rocks, within a hilly, mostly vegetation-covered lowland composed of soft rocks, primarily shales and turbidites. The Pieniny Klippen Belt (PKB) of the West Carpathians, mainly extending from Slovakia to Poland and Ukraine, was described as the classical klippen area (Uhlig, 1890), both based on the picturesque landscapes and the extremely complex geology of the area, where meter- to kilometer-sized, often dismembered, exposed blocks had to be fitted together for a reasonably coherent geology.

The geological term 'Klippen' was also applied for the inferred continuation of the klippen-style PKB into the (outer parts of the) Eastern Alps, especially the Wienerwald area from Vienna westwards (Čížek, 1849; Stur, 1894). In this area, mainly the Main Klippen Zone (MKZ; corresponding to the Gresten Klippen Zone further to the

west of Lower Austria) and the St. Veit Klippen Zone (SVK) were of interest, and these are important elements for stratigraphic, paleogeographic and tectonic interpretations of Alpine orogeny (e.g. Schnabel, 1992).

Correlations of klippen units, and thus large-scale paleogeographic and paleo-tectonic reconstructions, were hindered by the fact that large Neogene basins of the Pannonian Basin system partly obliterate continuations to the west and to the east. Especially, the Neogene Vienna Basin obscures the contact of the West Carpathians with its PKB (in Slovakia) and the Eastern Alps (in Austria). Several contrasting models have been proposed for the continuation of klippen zones from Slovakia into Austria (e.g. Tollmann, 1985; Faupl and Wagreich, 1992) based on various pieces of evidence, ranging from stratal successions to carbonate facies and heavy mineral data. However, correlations remained ambiguous, and no ultimate conclusion has been reached so far.

In this paper, we present new stratigraphic data from both the MKZ and the SVK, based on radiolarian and a few nannofossil data. The paleontological research based on radiolarian assemblages allowed more precise chronostratigraphic assignments. These data serve, on the one hand, for correlations with other klippen parts within the Eastern Alps and the Western Carpathians; on the other hand, we use these data for refining paleogeographic and tectonic models for the study area.

## 2. Geological setting

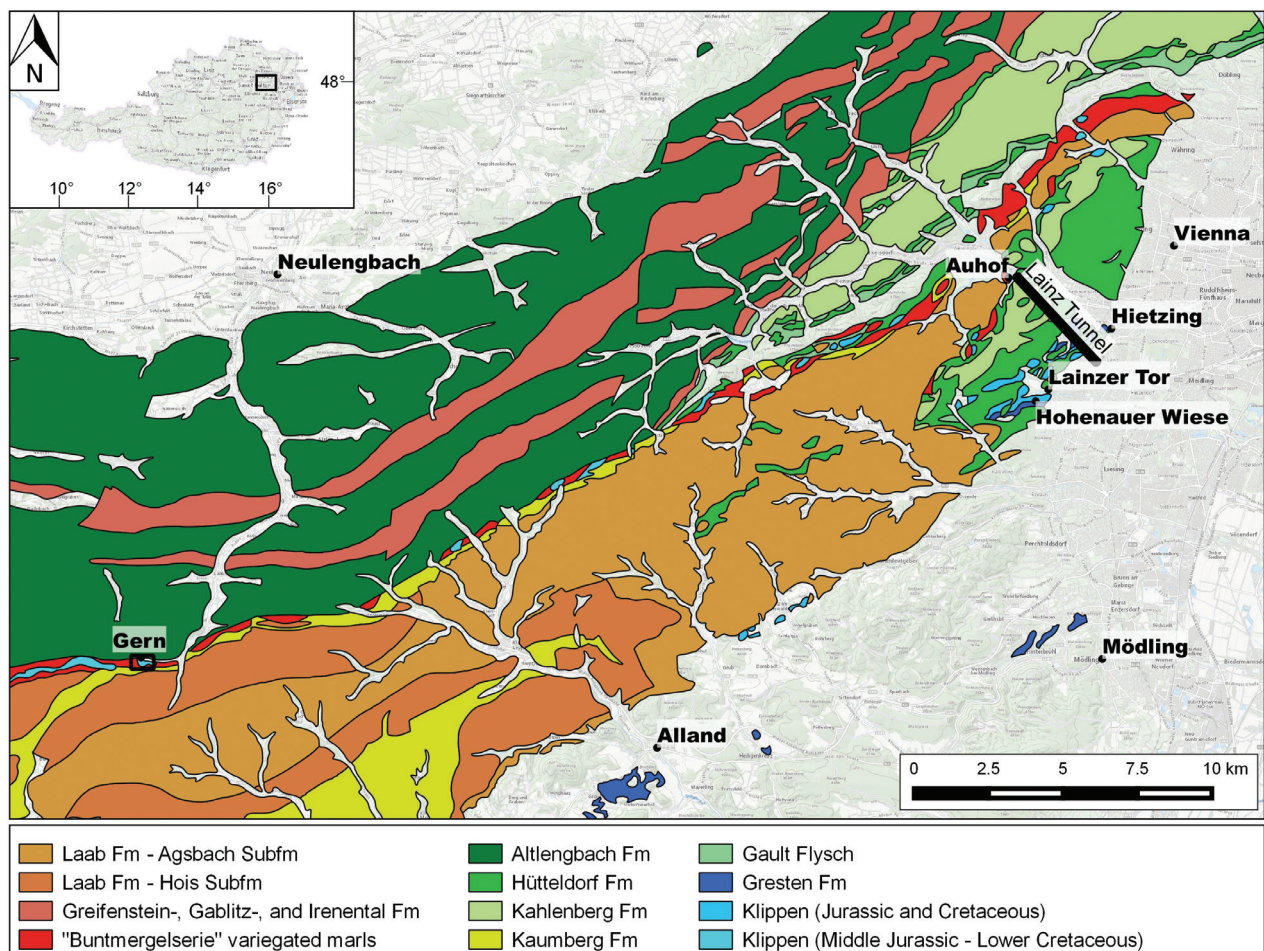
The two investigated klippen zones are part of the orogenic fold-and-thrust belt in the Wienerwald area, which forms the easternmost part of the Alps near Vienna (Fig. 1). Klippen zone rocks are poorly exposed and, in structurally complex positions, intermingled with successions of the Rhenodanubian nappe system (Schnabel, 1997, 2002; Egger and Wessely, 2014; Egger, in Egger and Ćorić, 2017). Several phases of thrusting, especially late orogenic out-of-sequence thrusting (Trautwein et al., 2001; Mattern and Wang, 2008) and strike-slip movements (Peresson and Decker, 1996), resulted in the structurally complex situation of the

Wienerwald area. Therefore, original paleogeographic positions, provenance and settings of the involved tectonic units, from klippen to flysch, are still strongly debated, and several, partly contradictory models and paleogeographic reconstructions do exist (e.g. Faupl and Wagreich, 1992; Schnabel, 1992, 2002; Faupl, 1996; Trautwein et al., 2001; Mattern and Wang, 2008; Egger and Wessely, 2014).

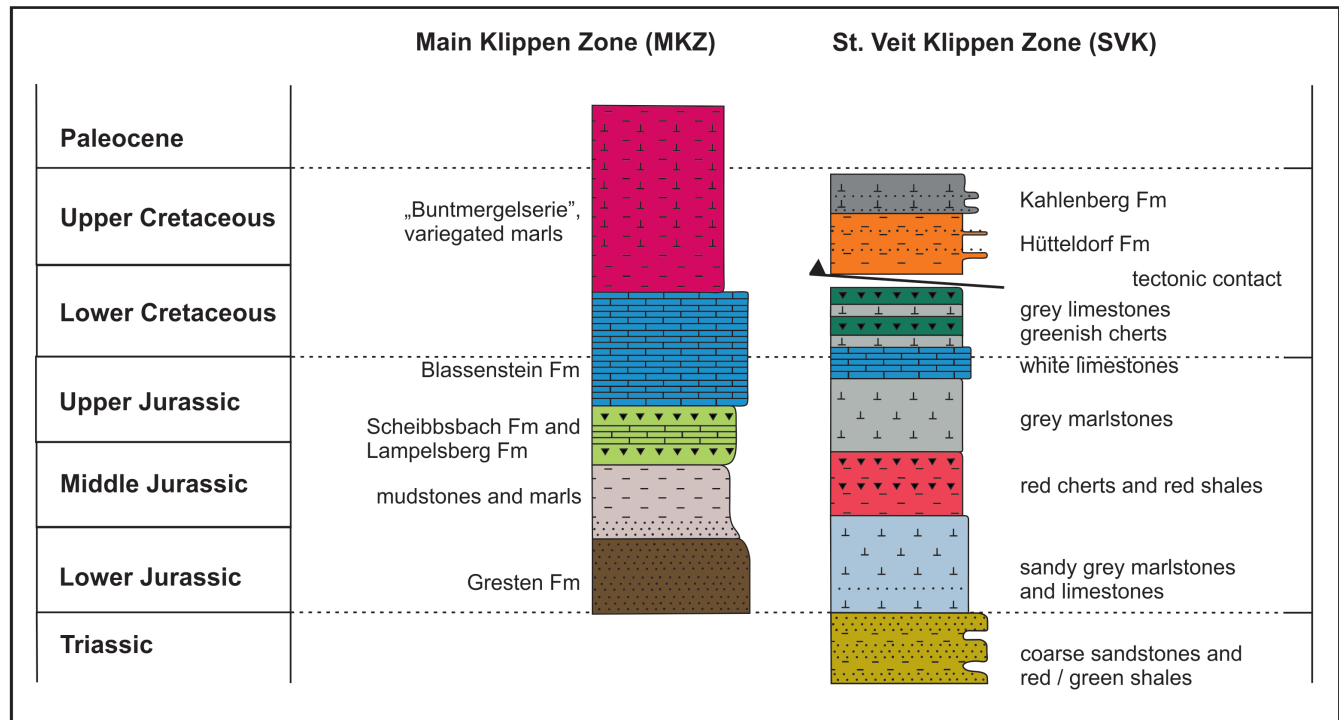
### 2.1 Gresten Klippen Zone: MKZ

The MKZ in the area of research (Figs. 1 and 2) represents a narrow, strongly tectonised zone within the SE part of the Rhenodanubian nappe system of the Wienerwald area, mainly between the Greifenstein and Laab nappes. It is regarded as a tectonic slice ('Schuppe') of the Ultrahelvetetic Zone (Tollmann, 1985; Schnabel, 1992, 1999, Faupl and Wagreich, 2000), which was originally situated along the passive continental margin to the north of the Penninic (Rhenodanubian Flysch) ocean basin (Faupl and Wagreich, 2000), termed Alpine Tethys by, for instance, Stampfli et al. (2002) and Handy et al. (2010).

In the studied part, the MKZ is built up mainly by variegated coloured (red and grey) Upper Cretaceous marlstone and claystone (Buntmergelserie), as well as



**Figure 1:** Geological overview of the studied area of Vienna and the Wienerwald. Investigated sections of the Main Klippen Zone (MKZ) - Gresten Klippen Zone (represented by the red signature: 'Buntmergelserie') at Gern, as well as the St. Veit Klippen Zone (represented by the blue signatures: 'Klippen') of the Lainz Tunnel (Vienna, between Auhof and Hietzing) and the Lainzer Tiergarten (Lainzer Tor and Hohenauer Wiese), are indicated (based on Schnabel, 1997, 2002).



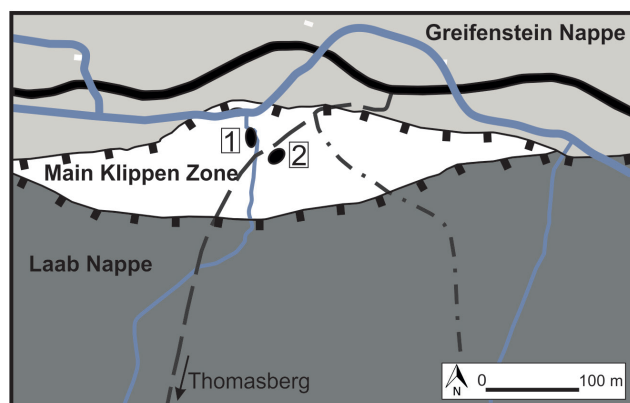
**Figure 2:** Stratigraphic overview of the Main Klippen Zone/Gresten Klippen Zone (based on Decker, 1987, 1990; Schnabel, 1992, 2002) and the St. Veit Klippen Zone (based on Janoschek et al., 1956; Prey, 1975; Pfersmann, 2013).

more indurated blocks of Lower Jurassic-to-Lower Cretaceous rocks (Küpper, 1962, Gottschling, 1966, Prey, 1979, Prey, in Schnabel, 1993). Čížek (1842) was the first to describe the fine-grained carbonates from the area of Stollhofen, named ‘Stollberg Beds’ by Hauer and Richthofen (1859) and ‘Blassenstein Formation’ by Trauth (1950). The Gern locality south of Laaben was reported to contain blocks of white Tithonian–Valanginian limestones with *Aptychus*, described by Prey (in Schnabel, 1993) and Egger and Wessely (2014).

During mapping for the Austrian Geological Survey, a new exposure of variegated limestones and marls of the MKZ was found in the year 2006 (Ślaczka, 2007). The outcrop (Fig. 3) is situated along a small southern tributary of the Gernbach stream (49° 05′ 04″ N, 15° 50′ 50″ E) near

the well-known abandoned Gern quarry (Gottschling, 1966; Schnabel, 1993), from which Tithonian–Lower Cretaceous whitish limestones and traces of Upper Cretaceous variegated marls have been already described. These strata are overthrust onto the Greifenstein Formation (lower Eocene) of the Greifenstein Nappe towards the North and are tectonically covered by the overthrusting Kaumberg Formation (Cenomanian–lower Campanian) of the Laab Nappe, both representing flysch-type successions of the Rhenodanubian nappe system.

A more complete succession of the MKZ is exposed nearby in several separated outcrops between Stollberg and Bernreith, to the west of Gern (Gottschling, 1966). The oldest part of this succession is represented by the Lower Jurassic Gresten Formation, sandstones with thin coal intercalations found only in the western part near Bernreith, as well as grey and brown sandy marls and marly limestones lacking precise stratigraphic data, probably representing Lower-to-Middle Jurassic strata. More frequent are massive and platy, mainly red and green, limestones with radiolaria, alternating with thinner-bedded greenish and reddish calcareous marls. Their deposition took place from the Bathonian to the Tithonian. Upper Jurassic (Oxfordian or Kimmeridgian) is represented by a block of dark grey cherts, found also south of the Gern quarry. A 2-m-thick fragment of green and red radiolarites, which was found only in one place, is also attributed to the Upper Jurassic (Oxfordian–lower Tithonian). Generally, younger strata are represented by light grey and spotted Tithonian *Aptychus* limestones (Stollberg Beds). In the uppermost part of these limestones, intercalations



**Figure 3:** Simplified geologic map of the Gern area (black = roads; blue = Gernbach Creek). 1 = Oxfordian–Kimmeridgian, 2 = Tithonian outcrops.



of Lower Cretaceous ('Neocomian') black marls appear up to a thickness of 20 m. The uppermost part of the Lower Cretaceous (Albian 'Gault') is represented by green limestones and green spotted marly shales, light red dotted marls (upper Albian, Gottschling, 1966), as well as by red and greenish marlstones of Cenomanian age (Wagreich, 2008). Upper Cretaceous deposits are mainly represented by variegated marlstone ('Buntmergelserie'). Another Upper Cretaceous lithofacies is represented by thick-bedded grey marly limestones, exposed to the east of Gern, in a right tributary of the Laaben River near Wöllersdorf, south of the village Laaben. In the upper part of the same creek, green-grey marly shales and brown mudstones of the Eocene, including Bartonian, are exposed (Ślaczka, 2012).

## 2.2 St. Veit Klippen Zone (SVK)

The first information on limestones of probable Jurassic age in the area of St. Veit in the (now) southwestern districts of Vienna was reported by Čížek (1849, 'St. Veiter Klippenhügel'). Subsequently, pioneering works were published by Griesbach (1868, 1869) and Hochstetter (1897), who defined the overall stratigraphic succession. Neumayr (1886) and Uhlig (1890), based on their knowledge of the Carpathians, were the first authors who directly correlated the SVK with the PKB ('pieninsche Klippenzone') based on the tectono-geomorphological style and the similarities of some rocks. Trauth (1930, 1950) was the first author who gave more detailed stratigraphic information on the rocks, followed by Janoschek et al. (1956), Prey (1975, 1979), Schnabel (1997, 2002) and Pfersmann (2013).

The original paleogeographic position of the SVK is still debated, and interpretations may include a Helvetic (= European), Penninic (= Penninic Ocean in a wider sense) or Austroalpine derivation (e.g. Trauth, 1950; Prey, 1975, 1979; Schnabel, 1992, 2002; Faupl and Wagreich, 1992, 2000). Most recent compilations correlate the SVK with the Ybbsitz (Klippen) Zone (Decker, 1990; Schnabel, 1979, 1992; Egger and Wessely, 2014), an oceanic/ophiolitic unit interpreted as a (southern Penninic) part of the primary base of the Rhenodanubian nappe system (e.g. Schnabel, 1992, 2002).

Our study is based on SVK rocks sampled during the construction work of the Lainz Tunnel (Lainzer Tunnel, years 2007–2009, contract sections LT31, LT33; Pfersmann, 2013), including some outcrop samples from the Lainzer Tiergarten and the nearby outcrops at Gemeindeberg, Rotenberg and Antonshöhe in Vienna (Figs. 1 and 2). The route of the Lainz Tunnel, built by ÖBB Infrastruktur GmbH, passes through the southwestern outskirts of Vienna, below the protected park area of the Lainzer Tiergarten, to link the southern and western rail routes with Vienna Central Railway Station, crossing Rhenodanubian units (Pfersmann and Wagreich, 2009), the SVK and Neogene strata.

The structural position of the SVK in the study area is below the flysch sediments (mainly Upper Cretaceous of

the Kahlenberg and Hütteldorf formations), with a tectonic, strongly sheared contact between SVK and mainly the Hütteldorf Formation. These flysch formations form part of the Kahlenberg Nappe sensu Prey (1979) and Schnabel (2002). According to Egger (2013) and Egger and Wessely (2014), this unit above the SVK is attributed to the Satzberg slice, which, together with the Kahlenberg slice, forms part of the Greifenstein Nappe. In addition, to the southeast of the SVK outcrop belt, a thin unit of the same flysch sediments covers the SVK and separates this unit from the bordering Northern Calcareous Alps to the south (Fig. 1). Based on the Lainz Tunnel structural data, the SVK forms a complex anticline covered structurally by the Upper Cretaceous flysch units of the Satzberg slice (Pfersmann, 2013).

## 3. Materials and methods

### 3.1 Radiolaria

The following radiolarian assemblages were analysed both in thin sections and after extraction of skeletons from the indurated rock samples: (1) 10 samples from the Gern succession of the MKZ and (2) 14 samples from the Lainz Tunnel as well as from outcrops of the SVK at Lainzer Tiergarten (Saulackenmais, Wildpretwiese; e.g. Trauth, 1930, 1950) and neighboring outcrops (Gemeindeberg, Antonshöhe, e.g. Prey, 1975, 1991). Standard extraction methods used included treatment with diluted hydrochloric acid (HCl) and low-concentration hydrofluoric acid (HF 4%). The residuum was washed, with a final sieve size of 63 µm. Taxa were identified using both transmission light microscopy and scanning electron microscopy. Taxonomic concepts applied during this study mainly follow those in Baumgartner et al. (1995), as well as De Wever et al. (2001) and Bąk et al. (2018a).

### 3.2 Calcareous nannofossils

Smear slides of calcareous nannofossils were prepared using sediment powder and distilled water; air-dried samples were fixed on glass slides. The samples were examined qualitatively for biostratigraphic markers using a polarised-light microscope (1000× magnification). We used Perch-Nielsen (1985) and Bown and Cooper (1998) for nannofossil taxonomy.

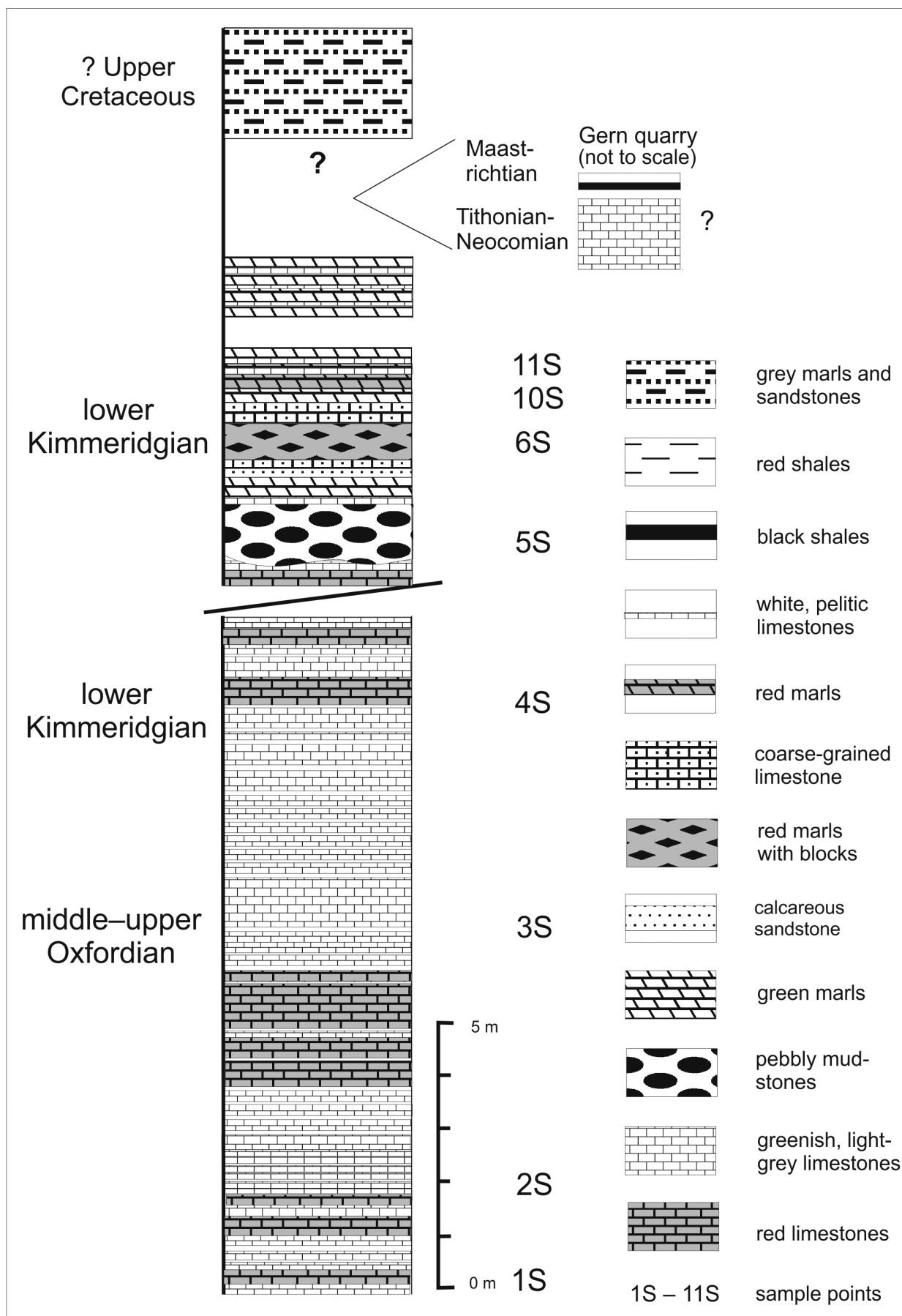
## 4. Results

### 4.1 Gern Klippen (MKZ)

#### 4.1.1 Lithology

The succession of the klippen (Figs. 2 and 4), which was well visible after a flooding event in 2006 in a creek from Thomasberg (Fig. 5), starts with a layer of grey and reddish pelitic radiolarian limestone 30 cm in thickness (sample 1S; Fig. 4A and Fig. 6A). It is followed by a 1-m succession of thin- and medium-bedded greenish-grey and red radiolaritic limestones, partly laminated, and a



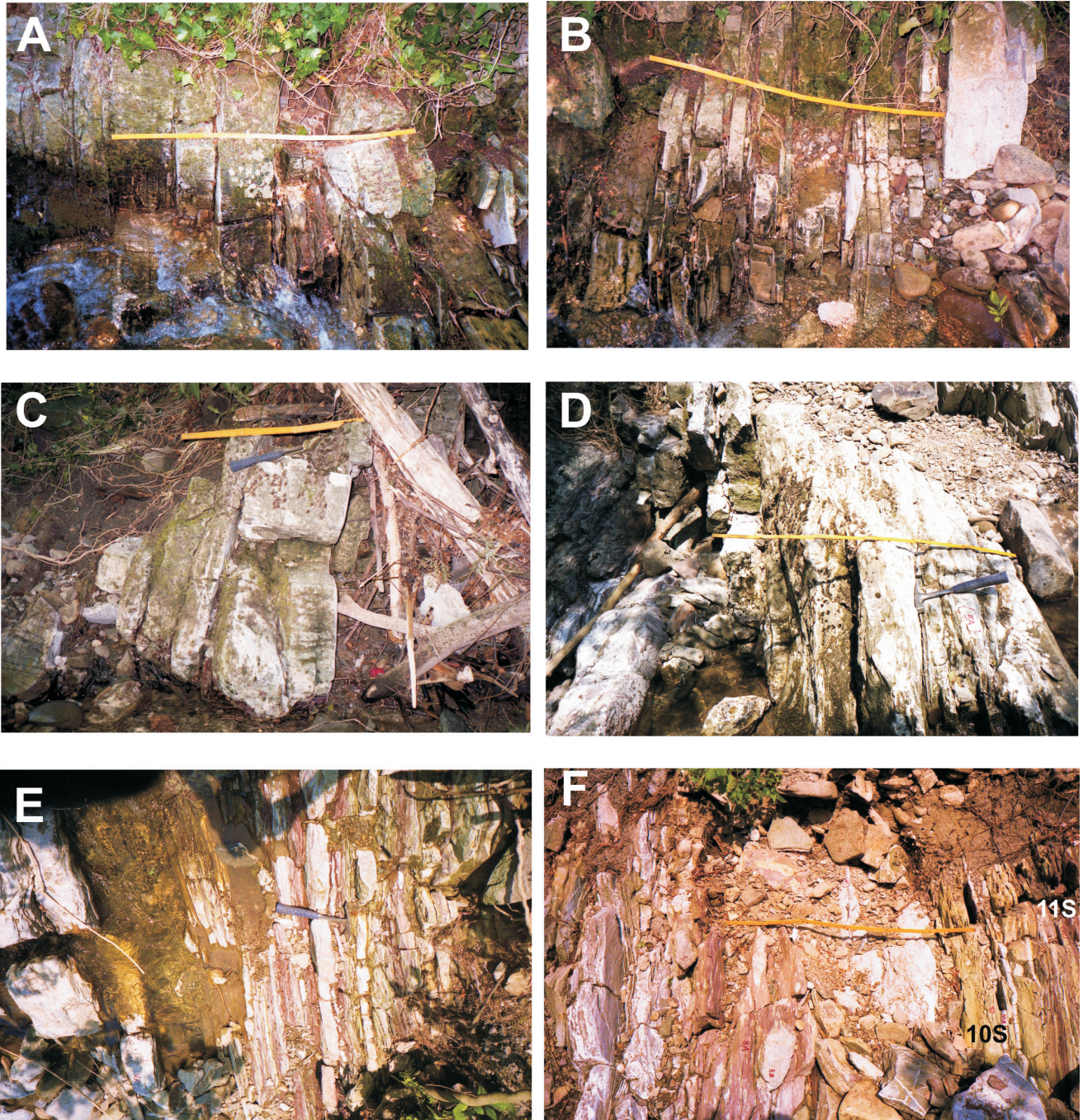


**Figure 4:** Interpretative column showing the lithology and the relationship between the exposed blocks within the Main Klippen Zone in the southern tributary of the Gernbach Stream in the Gern area.



0.5-m layer of red, medium-bedded, pelitic limestones with green lenses (sample 2S; Fig. 4B). Further up, a 1-m-thick complex of greenish-grey, medium-bedded pelitic limestones with sporadic red lenses is exposed, covered by a 20-cm-thick layer of white pelitic limestone and 1 m of light grey and white, medium-bedded, pelitic

limestones with thin intercalations of marlstones. The sequence continues with 2 m of predominantly red, pelitic radiolaritic limestones of thickness up to 50 cm, as well as a 7-m-thick interval of pelitic, light grey and greenish radiolarian limestones that are sporadically dotted and locally laminated (samples 4S and 5S) and



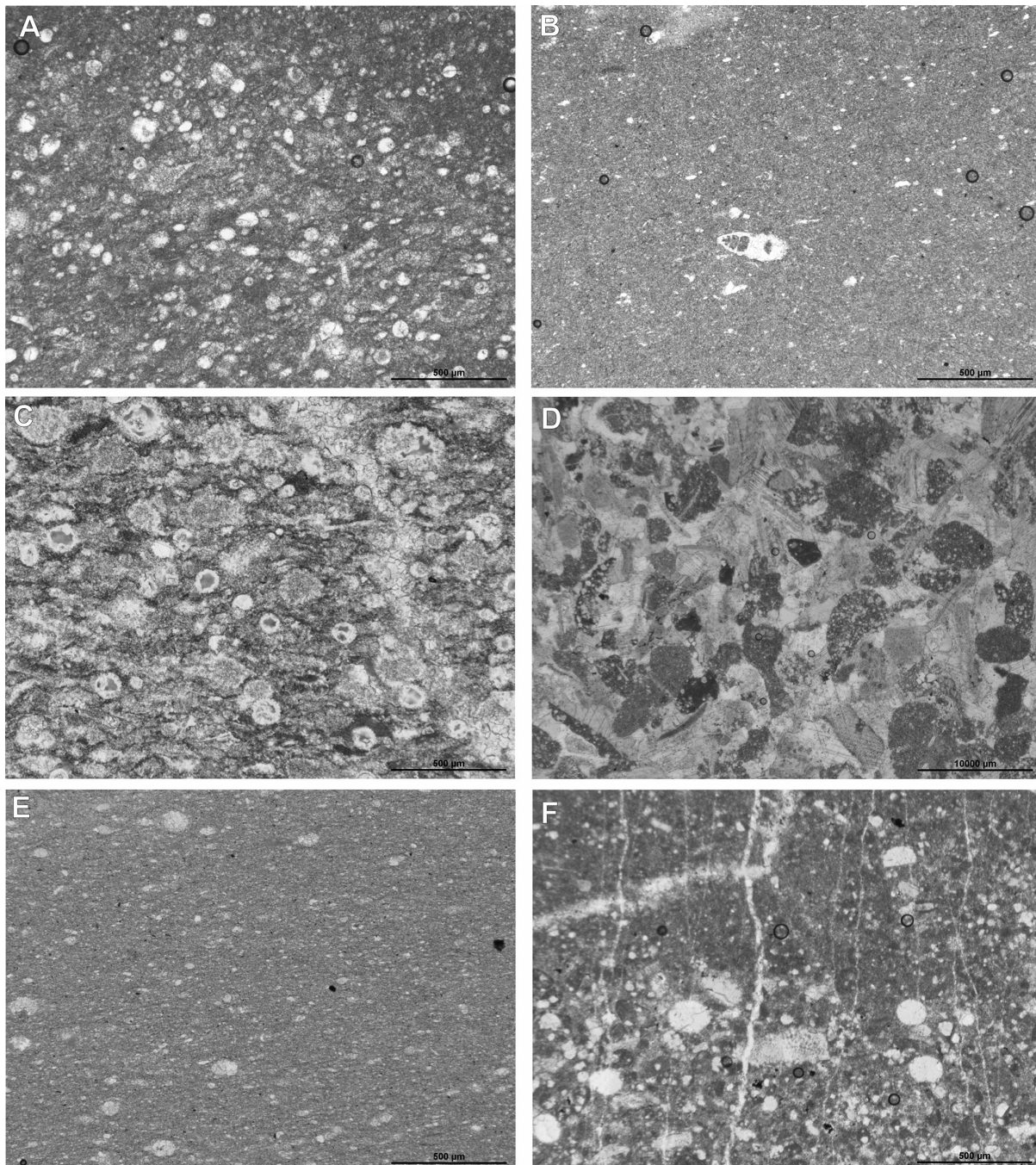
**Figure 5:** Outcrop photographs of the lithofacies within the Main Klippen Zone exposed along the southern Gernbach tributary from Thomasberg. All photographs are oriented to display upsection towards the right. (A) Medium- and thin-bedded, platy, planar, greenish radiolaritic limestone with red lenses and lamination within the higher part of the beds (Oxfordian, lowermost part of the profile; sample 1S). (B) Thin- and medium-bedded greenish-grey limestones and red lenses with intercalation of medium-bedded whitish limestones (middle part of profile, sample 3S; scale is 1 m). (C) Medium- and thick-bedded light grey and red limestones (middle part of the profile). (D) Tectonic contact between thin-bedded, greenish radiolaritic limestone (on the left side of the picture) and higher part of the profile, which begins with pebbly mudstone (on the right part of the picture) and light-grey, marly limestones with clasts up to 20 cm in diameter and sporadic *Aptychus*. Lower surface is erosive (sample 5A, scale is 1 m). (E) Red, yellow and whitish marly limestones, as well as thin- and medium-bedded marls with intercalations of thin, red and marly shales in the upper part of the profile. (F) Red and green laminated pelitic marly limestones and marls. On the left side, slump structures and elongated whitish clasts are present, which decrease to the right (samples 8–11, scale is 1 m).



which are intercalated by medium-bedded limestones and thin radiolarites in the uppermost part (Fig. 5C). This succession is terminated by a fault. Above the fault, there is a thin layer of red and light-grey radiolarian limestones similar to those below.

Further up in the section, another succession starts with pebbly mudstone that displays an erosional lower boundary. The mudstone contains sporadic *Aptychus* sp. and passes upwards into bioclastic limestones (Fig. 4D), thin pelitic limestones (Fig. 4E), bioclastic

sandy limestones, as well as layers of red marly limestones with sporadic lenses of whitish limestones (Fig. 4E) and greenish marlstones. These nodular limestones often display slumping structures increasing upwards in frequency (left side of Fig. 4F). Next, there is a 7-m-thick complex of red and green marly limestones and marls with sporadic layers of grey limestones (right side of Fig. 4F). After a covered interval of a few meters, green spotted marls and marly limestones with radiolaria similar to the previous one are exposed. Twenty



**Figure 6:** Characteristic microfacies from the Oxfordian–Kimmeridgian, radiolarian-bearing deposits of the Main Klippen Zone. (A) Silicified, radiolarian-sparse biomicrite with faecal pellets (sample 1S). (B) Silicified micrite with rare radiolarian skeletons (sample 2S). (C) Radiolarite with well-preserved radiolarian specimens (sample 4S). (D) Close-up view of coarse-grained, silicified limestone with rounded clast of radiolarite and radiolarian-bearing limestone among lithoclasts (sample 6S). (E) Radiolarian-sparse biomicrite with microlamination marked by flattened and unfilled voids after decay of radiolarian skeletons (sample 10S). (F) Radiolarite with singular echinoderm ossicles (sample 13S).



meters upstream, there is a road bridge; small outcrops 50 m above the bridge contain grey micaceous, laminated, calcareous sandstones intercalated with grey marly mudstones and shales, probably representing Upper Cretaceous Buntmergelserie of the MKZ. Ten meters further upstream, typical Kaumberg Formation (Schnabel, 1992) is exposed, represented by green shales and thin- and medium-bedded greenish and grey sandstones. This interval already belongs to the Laab Nappe of the Rhenodanubian nappe system; the contact with the MKZ is not exposed.

The relation of the described succession to the light grey limestones and spotted limestones of Tithonian–Lower Cretaceous exposed in the old quarry at Gern (Egger and Wessely, 2014) is uncertain; probably these rocks are positioned above the spotted red and green marly limestones (Fig. 3). On top of those Tithonian–Lower Cretaceous limestones, strongly disturbed red shales and marls of Maastrichtian–Paleocene age (Ślaczka, 2007), refolded with green and black shales, are exposed. Unfortunately, strong deformations did not allow the reconstruction of a reliable relation between all these shales of the Buntmergelserie, but the base seems to be unconformably above the limestones. However, Prey (in Plöschinger and Prey, 1993) supposed a sedimentary contact between the limestones and the Buntmergelserie.

#### 4.1.2 Paleontology and biostratigraphy

##### 4.1.2.1. Radiolaria

##### Radiolarian assemblage

The radiolarian fauna at Gern comprises a major component of the siliceous limestones studied. Radiolarian species are present in 10 thin sections and 10 extracted rock samples. Isolated specimens are common, but, in general, very poorly preserved, with small numbers of identifiable taxa. Some specimens underwent intensive recrystallization and/or substitution by calcite. All recognized specimens are classified into 27 species including two taxa with open nomenclature. Taxa identified are listed in Table 1, and selected species are presented in Figure 7. Nassellarians are the main components of the radiolarian assemblage (about 70% of all specimens). Most of the recognizable specimens belong to the families Sethocapsidae, Syringocapsidae and Williriedellidae. Spumellarians represent mostly three- and four-armed morphotypes from the families Emiluviidae, Hagiastriidae and Patulibracchiidae.

The radiolarian assemblage represents a low-latitude Tethyan fauna (e.g. Baumgartner et al., 1995) well recognized from Middle Jurassic–Lower Cretaceous deposits in many regions of the western part of the Tethys (e.g. in the Western Carpathians: Ožvoldová and Frantová, 1997; Michalik et al., 2008; Bąk et al. 2017; Ultrahelvetian Zone: Ślaczka et al., 2009). The assemblage is characterized by the total absence of orbiculiformids,

which are commonly present in higher paleolatitudes (e.g. Pessagno and Blome 1986; Kiessling 1999) and which are a characteristic component of radiolarian microfauna in the epicontinental seas that bordered the Tethys to the north (e.g. Górka and Bąk 2000). The studied assemblages rather represent the Northern Tethyan province (according to the paleogeographic model of Pessagno et al., 1984) based on the lack of pantanellids and 'Ristola-type' parvicungulids.

Among the 10 samples that yielded identifiable radiolarian specimens, five samples (2S, 3S, 4S, 10AS and 11AS) can be correlated with the Unitary Association Zones (UAZs) defined by Baumgartner et al. (1995). In these samples, the representatives of the genera *Parvicungula*, *Podobursa*, *Sethocapsa*, *Stichocapsa* and *Williriedellum* are most common (Table 1). The radiolarian assemblage in samples 2S and 3S can be assigned to UAZ9 of Baumgartner et al. (1995) (middle–upper Oxfordian), based on the co-occurrence of *Orbiculiforma mclaughlini* Pessagno and *Parvicungula boesii* (Parona). The species *O. mclaughlini* has a very restricted stratigraphical range and has its final occurrence during UAZ9. This event coincides with the lowermost occurrence of *P. boesii*, which took place within UAZ9 in Tethyan settings (e.g. Baumgartner et al., 1995; Bąk et al., 2018a).

The radiolarian assemblage in sample 4S is the best preserved and thus the most diversified among all samples studied. The stratigraphical range of this sample can be assigned to UAZ10 (lower Kimmeridgian) based on the co-occurrence of *Obesacapsula cetia* (Foreman), *Tetraditryma corralitosensis* s.l. (Pessagno) and *Tritrabs casmaliensis* (Pessagno). *Obesacapsula cetia* starts in UAZ10, while *T. corralitosensis* and *T. casmaliensis* have their uppermost occurrence in this zone.

The poorly preserved radiolarian assemblage in samples 10AS and 11AS shows high abundances; however, a few identifiable specimens allow correlating both samples still with UAZ10. *Tetraditryma corralitosensis* and *T. casmaliensis* are not present herein, but the correlation is possible based on the co-occurrence of *O. cetia* (Foreman) with *Higumastra inflata* Baumgartner, a species that has its lowermost occurrence in the lower Kimmeridgian.

Taxa identified in samples 1S, 5S, 6S, 13AS and 300S are very scarce, and thus these samples can be only widely correlated with the UAZs of Baumgartner et al. (1995). Sample 1S yielded very common radiolarians. However, only three specimens could be identified. This sample can be correlated with UAZ10–13 based on the co-occurrence of *Podobursa spinosa* (Ožvoldová) and *O. cetia* and, thus, be correlated with the lower Kimmeridgian to the Tithonian. Sample 5S contains seven identifiable species. Based on the co-occurrence of *O. cetia*, *Pseudoeucyrtis reticularis* Matsuoka and Yao, *Williriedellum carpathicum* Dumitrică and *Williriedellum cristallinum* Dumitrică, this sample can be assigned to the lower Kimmeridgian–Tithonian. The radiolarian assemblages in samples 6S

SAMPLES		1S	2S	3S	4S	5S	6S	10AS	11AS	13AS	300S
RADIOLARIA/AGE	UAZ	Lower Kimmeridgian to lower Berriasian	Middle to upper Oxfordian	Middle to upper Oxfordian	Upper Kimmeridgian to lower Tithonian	Upper Oxfordian to lower Tithonian	Middle Callovian to lower Tithonian	Upper Oxfordian to lower Kimmeridgian	Upper Oxfordian to lower Kimmeridgian	Middle Oxfordian to lower Kimmeridgian	Middle Callovian to lower Tithonian
<i>Acanthocircus suboblongus suboblongus</i> (Yao)	3-11							x			
<i>Archaeodictyomitra apiarium</i> (Rüst)	8-22		x		x						
<i>Podobursa chandrika</i> (Kocher)	7-11				x				x		
<i>Emiluvia orea orea</i> Baumgartner	8-11				x						
<i>Higumastra inflata</i> Baumgartner	7-10							x	x	x	
<i>Obesacapsula cetia</i> (Foreman)	10-17	x			x	x		x	x		
<i>Orbiculiforma mclaughlini</i> Pessagno	8-9		x	x							
<i>Paronaella kotura</i> Baumgartner	3-10			x						x	
<i>Parvicingula boesii</i> (Parona)	9-22		x	x	x			x	x		
<i>Parvicingula mashitaensis</i> Mizutani	8-15			x	x		x	x		x	x
<i>Perispyridium ordinarium</i> gr. (Pessagno)	5-11			x							
<i>Podobursa quadriaculeata</i> (Steiger)	9-17				x	x		x		x	
<i>Podobursa spinosa</i> (Ožvoldová)	8-13	x		x	x	x		x			
<i>Protunuma japonicus</i> Matsuoka & Yao	7-12			x							
<i>Pseudoeucyrtis reticularis</i> Matsuoka & Yao	8-11			x	x	x		x			
<i>Sethocapsa dorysphaeroides</i> (Neviani)	7-22	x							x		x
<i>Hiscocapsa funatoensis</i> (Aita)	3-11			x					x		
<i>Sethocapsa trachyostraca</i> Foreman	7-22		x		x	x			x		
<i>Spongocapsula palmerae</i> (Pessagno)	6-13		x		x						
<i>Spongocapsula perampla</i> (Rüst)	6-11										x
<i>Stichocapsa convexa</i> Yao	1-11			x							
<i>Tetraditryma corralitosensis</i> s.l. (Pessagno)	3-10				x						
<i>Tritrabs casmaliaensis</i> (Pessagno)	4-10				x					x	
<i>Tritrabs exotica</i> (Pessagno)	3-11				x					x	
<i>Williriedellum carpathicum</i> Dumitrică	7-11		x	x	x	x	x		x		x
<i>Williriedellum cristallinum</i> Dumitrică	7-11					x					
<i>Xitus magnus</i> Baumgartner	8-11									x	

**Table 1:** Radiolaria identified from the fossiliferous samples in the siliceous limestones of Gern, Main Klippen Zone of the Wienerwald area (for sample positions, see Figs. 4 and 5).

and 300S range from the middle Callovian to the Tithonian. In both samples, the correlation is based on the co-occurrence of *W. cristallinum* and *Parvicingula mashitaensis* Mizutani.

The radiolarian assemblage in sample 13AS is assigned to UAZ9–10 (middle Oxfordian to lower Kimmeridgian) based on the co-occurrence of *Podobursa quadriaculeata* (Steiger) – which first appeared in UAZ9 – and species that have their highest appearance within UAZ10 such as *H. inflata*, *Paronaella kotura* Baumgartner and *T. casmaliaensis*.

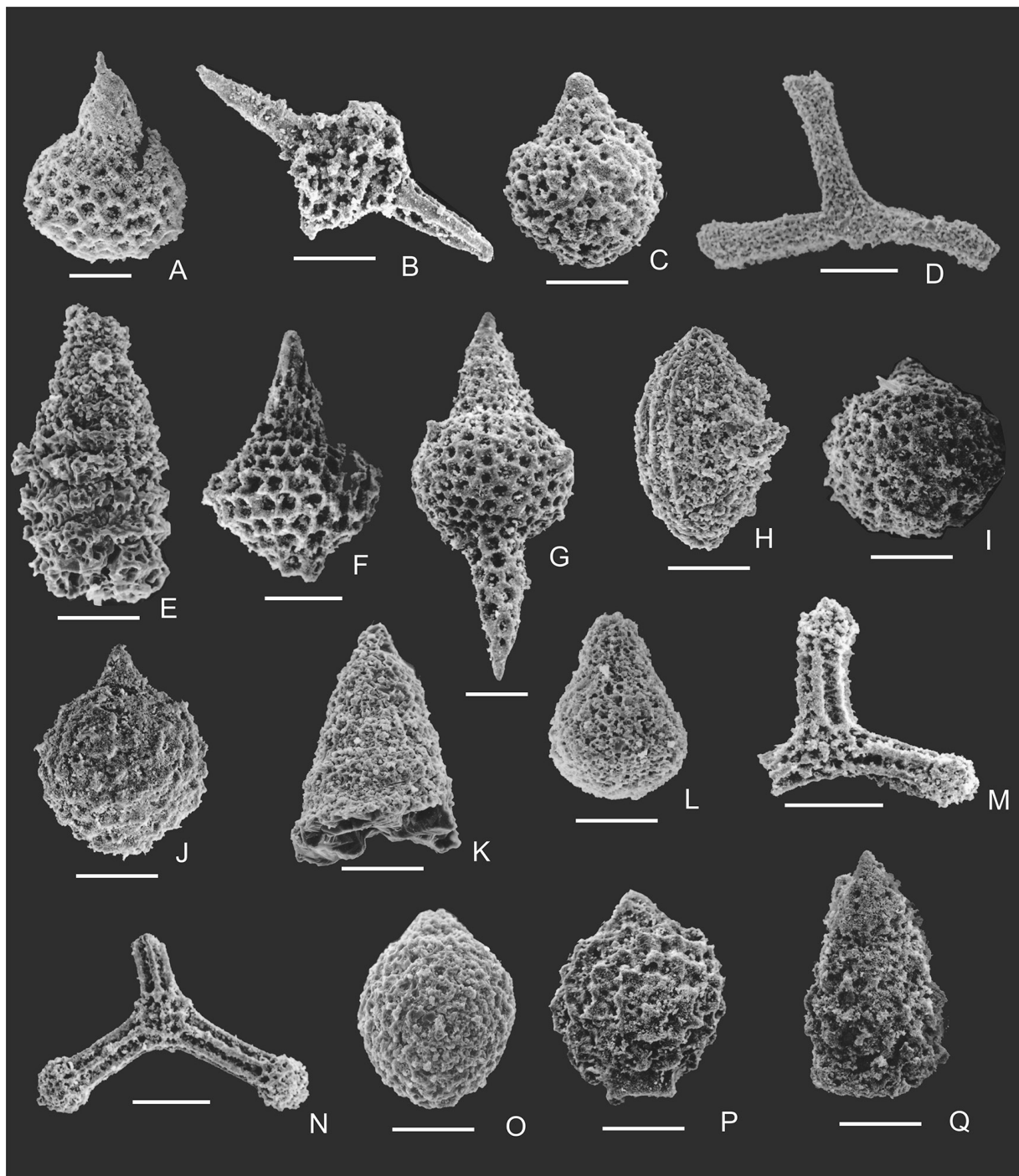
## 4.2 Lainz Tunnel and Lainzer Tiergarten (SVK)

### 4.2.1 Lithology

Rocks attributed to the SVK were found in a 1097-m-long section within the Lainz Tunnel. The rocks exposed in the tunnel comprise a 'klippen-type' block-in-matrix

structure. Tectonic blocks of indurated hard klippencore rocks, such as limestones, sandstones and cherts, show sizes ranging from centimeters to several tens of meters. The matrix consists of strongly deformed and sheared fine-grained pelitic rocks, such as Jurassic and Lower Cretaceous shales and marls; however, Upper Cretaceous pelitic rocks of Rhenodanubian nappe system origin (Hütteldorf Formation, Kahlenberg Formation) are also tectonically mixed into the matrix. No primary sedimentary contact of the Rhenodanubian nappe system with the SVK could be found.

The composite SVK succession recorded and correlated with the reported outcrops (Janoschek et al., 1956; Prey, 1975) includes the following stratigraphic units: (1) coarse quartz-rich sandstones (Keuper of probably Norian age); (2) fossiliferous grey limestones (Rhaetian, Kössen Formation); (3) sandy-silty grey marlstones and limestones with crinoids (Lower/Middle Jurassic, partly Hohenauer Wiese



**Figure 7:** Radiolaria: (A) *Podobursa chandrika* (Kocher), sample 4S; (B) *Emiluvia oreo oreo* Baumgartner, sample 4S; (C) *Obesacapsula cetia* (Foreman), sample 11AS; (D) *Paronaella kotura* Baumgartner, sample 3S; (E) *Parvingula mashitaensis* Mizutani, sample 3S; (F) *Podobursa spinosa* (Ožvoldová), sample 4S; (G) *Podobursa* (?) *quadriaculeata* aff. (Steiger), sample 4S; (H) *Protunuma japonicus* Matsuoka & Yao, sample 3S; (I) *Hiscocapsa funatoensis* (Aita), sample 3S; (J) *Sethocapsa trachyostraca* Foreman, sample 4S; (K) *Spongocapsula palmerae* (Pessagno), sample 4S; (L) *Stichocapsa convexa* Yao, sample 3S; (M) *Tritrabs casmaliaensis* (Pessagno), sample 4S; (N) *Tritrabs exotica* (Pessagno), sample 4S; (O) *Williriedellum carpathicum* Dumitrică, sample 4S; (P) *Williriedellum cristallinum* Dumitrică, sample 5S; (Q) *Xitus magnus* Baumgartner, sample 13AS; scale bars: 0.1 mm.

Formation); (4) red cherts/radiolarites and red shales (Middle/Upper Jurassic, Rotenberg Formation; see Fig. 8); (5) grey marls to argillaceous limestones (Upper Jurassic/Lower Cretaceous, lower part of Fasselgraben Formation); (6) *Aptychus* limestones, white siliceous limestones and green cherts (Lower Cretaceous, upper part of Fasselgraben Formation).

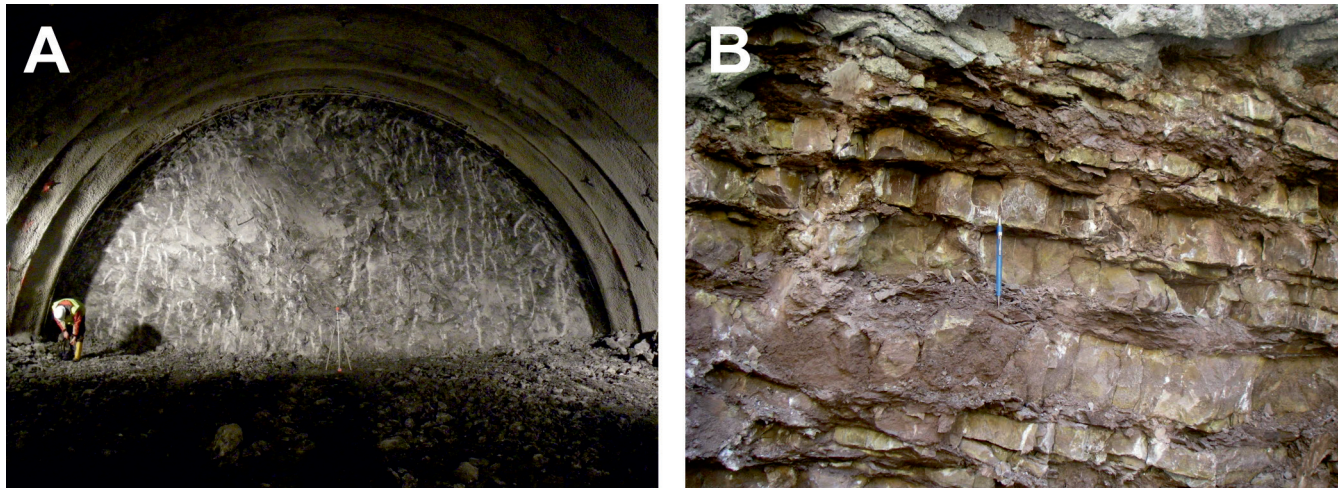
## 4.2.2 Paleontology and biostratigraphy

### 4.2.2.1. Radiolaria

#### Radiolarian assemblage

Fourteen of the 69 tested samples of the SVK yielded identifiable radiolarian species (Tables 2 and 3), which





**Figure 8:** Photographs of rocks from the St. Veit Klippen Zone. (A) Grey calcareous marlstone in the Lainz Tunnel, sampling site LT33/2505.20m, Middle-to-Upper Jurassic. (B) Red shale and siliceous limestones/radiolarites (lower–middle Bajocian), LT31-R55.2m.

are common but moderately preserved in the studied sediments. The identified specimens in the radiolarian assemblages consist of 42 species and 26 genera. The assemblage includes 19 spumellarians belonging to the genera *Alievium*, *Angulobracchia*, *Emiluvia*, *Higumastra*, *Homoeoparonaella*, *Pantanellium*, *Triactoma*, *Crucella* and *Paronaella*. The nassellarians are more diversified and represent the genera *Archaeodictyomitra*, *Crolanium*, *Hiscocapsa*, *Mirifusus*, *Obesacapsula*, *Parvicingula*, *Sethocapsa*, *Spongocapsula*, *Xitus*, *Yamatoum* and *Zhamoidellum*. Entactinarian radiolarians are represented by one genus *Quinquecapsularia*. These taxa were described from Jurassic and Cretaceous Tethyan settings, such as the Pieniny Klippen Belt (e.g. Ožvoldová and Frantová, 1997; Båk, 1999; Michalik et al., 2008; Båk et al., 2018a,b), the Tatra Mountains (e.g. Båk and Båk, 2013; Michalik et al., 2017) and the Apennines (O'Dogherty, 1994; Båk, 2011), but in those areas, they form part of more diverse assemblages.

The chronostratigraphic position of the radiolarian assemblages is again discussed in terms of the UAZ zones (Baumgartner et al., 1995). The ranges of the radiolarian species are juxtaposed in Tables 2 and 3. Red radiolarites and cherts of sample RS/1 from the tunnel shaft Veitingergasse yielded a radiolarian assemblage with *Paronaella skowkonaensis* Carter, *Parvicingula dhime-naensis dhime-naensis* Baumgartner, *Parvicingula school-honsensis* gr. Pessagno and Whalen, *Quinquecapsularia megasphaerica* Dumitrică and Baumgartner, *Hiscocapsa funatoensis* (Aita) and *Yamatoum spinosum* Takemura. Based on the co-occurrence of these specimens, the deposits could be assigned to the UAZ3 interval of Baumgartner et al. (1995), attributed to the lower/middle Bajocian.

Middle Callovian to lower Oxfordian (UAZ8) age has been identified in the samples LT33/2775A and GEM (Rotenberg Formation) based on the co-occurrence of radiolarian species such as *Archaeodictyomitra apiarium* (Rüst), *Emiluvia orea orea* Baumgartner, *Higumastra*

*gratiosa* Baumgartner, *Pseudoeucyrtis reticularis* Matsuo-ka and Yao, *Parvicingula mashitaensis* Mizutani, *Podobursa spinosa* (Ožvoldová) and *Higumastra wintereri* Baumgartner and Kito.

A middle–late Oxfordian to early Kimmeridgian age (UAZ9–10) has been assigned to samples LT33/2331.0, LT31/1326.4 and RSAG/239A based on the presence of *Angulobracchia digitata* Baumgartner, *Angulobracchia purissimaensis* (Pessagno), *Higumastra inflata* Baumgartner, *Podobursa helvetica* (Rüst), *Spongocapsula obesa* Jud and *Zhamoidellum ovum* Dumitrică.

Zone UAZ9–11, representing the upper Kimmeridgian–to-lower Tithonian interval, can be assigned to sample RS/34.5 based on the co-occurrence of *Alievium helenae* Schaaf with species such as *Emiluvia orea orea* Baumgartner, *W. carpathicum* Dumitrică, *Zhamoidellum ovum* Dumitrică and *Zhamoidellum ventricosum* Dumitrică.

The radiolarian assemblage in sample LT33/2535.1 is poorly preserved; thus, only two species could be identified (*W. carpathicum* and *W. cristallinum* Dumitrică), which indicate an upper Bathonian to lower Tithonian level (UAZ7–11).

All other samples of grey siliceous limestones (Fasselgraben Formation) yielded radiolarian assemblages including *Crucella lipmanae* Jud, *Sethocapsa tricornis* Jud (sample Lainz Tunnel LT33/2165m, Valanginian [UAZ16–17]), *Homoeoparonaella speciosa* (Parona) *Triactoma luciae* Jud and *Spongocapsula* sp. aff. *S. coronata* (Squinabol) (sample from cherty limestones of Antonshöhe MM08/28, upper Valanginian to lower Barremian [UAZ17–21]), *Zhamoidellum testatum* Jud and *Obesacapsula verbana* (Parona) (sample from Lainzer Tiergarten outcrop Saulackenmais MM08/65, upper Valanginian to upper Hauterivian [UAZ18–20]), *Crucella* sp. aff. *C. espartoensis* Pessagno, *Paronaella annemarie* Jud, *Spongocapsula* sp. aff. *S. coronata* (Squinabol), *Zhamoidellum testatum* Jud; *Obesacapsula bullata* Steiger, *Xitus channelli* Jud, *Crolanium pythiae* Schaaf (sample from Lainzer Tiergarten outcrop

SAMPLES		RS/34.5 m	RS/1 m	GEM	MM08/70	MM08/65	MM08/28
RADIOLARIA/AGE	UAZ	Upper Kimmeridgian to lower Tithonian	Lower- to mid-Bajocian	Mid-Callovian to lower Oxfordian	Upper Valanginian to lower Hauterivian	Upper Valanginian to upper Hauterivian	Upper Valanginian to lower Barremian
<i>Alievium helenae</i> Schaaf	11-22	x					
<i>Archaeodictyomitra apiarium</i> (Rüst)	8-22			x			
<i>Archaeodictyomitra excellens</i> (Tan)	11-22						x
<i>Crolanium pythiae</i> Schaaf	17-22				x		
<i>Crucella</i> sp. aff. <i>C. espartoensis</i> Pessagno	17-21				x		
<i>Emiluvia orea orea</i> Baumgartner	8-11	x					
<i>Higumastra wintereri</i> Baumgartner and Kito	1-8			x			
<i>Hiscocapsa funatoensis</i> (Aita)	3-11		x				
<i>Homoeoparonaella speciosa</i> (Parona)	13-21						x
<i>Mirifusus diana diana</i> (Karrer)	7-12	x		x			
<i>Obesacapsula bullata</i> Steiger	13-19				x		
<i>Obesacapsula verbana</i> (Parona)	11-20					x	
<i>Pantanellium riedeli</i> Pessagno	7-12			x			
<i>Paronaella annemariae</i> Jud	14-21				x		
<i>Paronaella kotura</i> Baumgartner	3-10		x				
<i>Paronaella skowkoniaensis</i> Carter	1-2		x				
<i>Parvicingula dhimenaensis</i> Baumgartner	3-11		x				
<i>Parvicingula mashitaensis</i> Mizutani	8-15			x			
<i>Parvicingula schoolhonsensis</i> Pessagno and Whalen	3-3		x				
<i>Podobursa spinosa</i> (Ožvoldová)	8-13			x			
<i>Quinquecapsularia megasphaerica</i> Dumitrică and Baumgartner	3-11		x				
<i>Sethocapsa dorysphaeroides</i> (Neviani)	7-22	x					x
<i>Spongocapsula</i> sp. aff. <i>S. coronata</i> (Squinabol)	17-22				x		x
<i>Triactoma blakei</i> (Pessagno)	4-11			x			
<i>Triactoma foremanae</i> Muzavor	7-11			x			
<i>Triactoma luciae</i> Jud	13-21						x
<i>Triactoma tithonianum</i> Rüst	6-22					x	
<i>Williriedellum carpathicum</i> Dumitrică	7-11	x					
<i>Xitus channelli</i> Jud	16-21				x		
<i>Yamatoum spinosum</i> Takemura	1-4		x				
<i>Zhamoidellum ovum</i> Dumitrică	9-11	x					
<i>Zhamoidellum testatum</i> Jud	18-22				x	x	
<i>Zhamoidellum ventricosum</i> Dumitrică	8-11	x					

**Table 2:** Radiolaria assemblages from the SVK of the Lainz Tunnel (LT31 and LT33 refer to different parts of the tunnel constructions) and side shaft Arbeitergasse (RSAG).

Wildpretwiese MM08/70, upper Valanginian–lower Hauterivian [UAZ18–21]), the co-occurrence of which indicated a Lower Cretaceous age.

Samples LT31/1308A and LT31/1317B yield radiolarian assemblages (*Sethocapsa trachyostraca* Foreman, *Spongocapsula* (?) *tripes* Jud, *Spongotripus* (?) *satoi* (Tumanda) and *Syringocapsa* aff. *S. spinosa* (Squinabol), which indicate an early Hauterivian to early Barremian or early Aptian age (UAZ19–21 or UAZ19–22, respectively).

#### 4.2.2.2. Calcareous nannofossils

Only one sample of grey, sandy-silty, marly limestones from the SVK of the Lainz Tunnel (LT33/2666m,

poor preservation, one nannofossil found in every two fields of view) yielded a biostratigraphically significant nannofossil assemblage, which can be assigned to the Jurassic (possible range: upper Toarcian–middle Oxfordian): *Lotharingius* cf. *sigillatus* (upper Pliensbachian?/lower Toarcian–middle Oxfordian), *Discorhabdus* sp. aff. *D. striatus* (Toarcian–upper Oxfordian) and *Watznaueria* sp. (first occurrence in upper Toarcian). This nannofossil assemblage indicates probably roughly a Middle Jurassic age. Two other samples from the grey marly limestones are also assigned tentatively to the Jurassic due to the occurrence of *Discorhabdus* sp. (LT33/2731m), *Schizosphaerella* sp.

SAMPLES	UAZ	RSAG/239A	LT31/1326,4	LT31/1317B	LT31/1308A	LT33/2775A	LT33/2535,1	LT33/2331,0	LT33/2165,0
		Mid- to upper Oxfordian to lower Kimmeridgian	Upper Oxfordian to lower Kimmeridgian	Lower Hauteriviian to lower Aptian	Lower Hauteriviian to lower Barremian	Mid-Calloviaian to lower Oxfordian	Upper Bathonian to lower Tithonian	Upper Oxfordian to lower Kimmeridgian	Lower Valanginian to uppermost Valanginian
<i>Angulobracchia digitata</i> Baumgartner	3-10	x							
<i>Angulobracchia purissimaensis</i> (Pessagno)	3-10	x							
<i>Crucella lipmanae</i> Jud	17-19								x
<i>Emiluvia orea orea</i> Baumgartner	8-11					x			
<i>Higumastra gratiosa</i> Baumgartner	3-8					x			
<i>Higumastra inflata</i> Baumgartner	7-10					x		x	
<i>Mirifusus diana diana</i> (Karrer)	7-12		x			x			
<i>Paronaella mulleri</i> Pessagno	6-10					x			
<i>Podobursa spinosa</i> (Ožvoldová)	8-13					x			
<i>Podobursa helvetica</i> (Rüst)	3-10		x						
<i>Pseudoecyrtis reticularis</i> Matsuoka and Yao	8-11					x			
<i>Sethocapsa trachyostraca</i> Foreman	7-22			x					
<i>Sethocapsa tricornis</i> Jud	13-16								x
<i>Spongocapsula obesa</i> Jud	10-22		x					x	
<i>Spongocapsula perampla</i> Rüst	6-11	x							
<i>Spongocapsula</i> (?) <i>tripes</i> Jud	19-21				x				
<i>Spongotripus</i> (?) <i>satoi</i> (Tumanda)	19-22				x				
<i>Syringocapsa</i> aff. <i>S. spinosa</i> (Squinabol)	19-22			x					
<i>Triactoma tithonianum</i> Rüst	6-22							x	
<i>Williriedellum carpathicum</i> Dumitrică	7-11	x	x				x	x	
<i>Williriedellum cristallinum</i> Dumitrică	7-11		x				x	x	
<i>Zhamoidellum ovum</i> Dumitrică	9-11	x							

**Table 3:** Radiolaria assemblages from the SVK of a side shaft of the Lainz Tunnel at Veitingergasse near Gemeindeberg (samples RS), the Gemeindeberg outcrop (GEM), the Lainzer Tiergarten (outcrop samples MM08/65 and MM08/70) and Antonshöhe (MM08/28).

and *Watznaueria* sp., besides other unidentifiable nanofossils (LT31/1367m).

## 5. Discussion

### 5.1 Gresten/Main Klippen Zone

Biostratigraphic investigations of the limestone package in the Gernbach stream profile indicate mainly chronostratigraphic positions of the lower part of the Upper Jurassic. The composition of the radiolarian assemblages (samples 2 and 3) shows that the lower and middle parts of the succession of radiolarian limestones with intercalations of thin radiolarites represent the middle–upper Oxfordian, whereas the upper part (sample 4) ranges already into the lower Kimmeridgian (Fig. 3). Probably, the dark cherts described by Gottschling (1966) south of Gern also belong to the same interval. This part of the succession can be correlated with the Scheibbsbach Formation (sandstone turbidites with siliceous limestones and marlstones) from the type area of the Gresten Klippen Zone

near Scheibbs and Gresten (Decker, 1987; Widder, 1988). The upper part of the profile, represented by variegated coloured marly limestones with sporadic intercalation of thin bioclastic limestones, contains radiolarian assemblages (samples 5, 6 and 30), which suggest a general Kimmeridgian to Tithonian age. However, the occurrence of radiolarian assemblages from the upper Oxfordian–lower Kimmeridgian in the overlying units (samples 10 and 11) also indicates that the upper part is not younger than lower Kimmeridgian. This interval corresponds to the appearance of sporadic whitish bioclastic limestones, implying a correlation with the carbonate breccias of the Konradsheim Formation (mainly Oxfordian–Tithonian–Berriasian; Decker, 1987), as well as the transition to the Tithonian light grey limestones representing the Blassenstein Formation (Decker, 1987; Egger and Wessely, 2014) as exposed in the Gern quarry.

Generally, siliceous limestones with radiolaria represent a deep-water carbonate facies deposited near the carbonate compensation depth (CCD) (Decker, 1990; Egger and



Wessely, 2014), and they show similarities to the Scheibbs Facies (Schnabel, 1979) of the Gresten Klippen Zone and the MKZ. However, based on the lack of pure radiolarites and on the merely sporadic occurrence of cherts, slightly shallower water depths are interpreted for these siliceous limestones. The appearance of re-deposited sediments in the higher part of the section implies a period of tectonic instability, which triggered slump movements along the slope of the sedimentary basin. The composition of the radiolarian assemblages within these limestones suggests that the depositional area was a part of the Northern Tethyan province. Black and variegated shales, which are in sharp contact with the underlying limestone, may correspond to the Cenomanian–Turonian sediments of the Buntmergelserie and to the red marlstone containing Upper Cretaceous foraminifera.

The succession described is composed of separate exposed blocks from a few up to tens of meters in diameter, which derive from the northern passive continental margin of the Penninic basin. These blocks may either be interpreted as tectonically detached slices or as re-deposited components in debris flow deposits. However, an alternative hypothesis that is becoming increasingly widespread is also worth mentioning: similar sedimentary bodies with scattered blocks are interpreted to represent a part of large re-deposited sedimentary units such as olistostromes (Festa et al., 2010), also in the northern Carpathians (e.g. Cieszkowski et al., 2009; Golonka et al., 2017). Naturally, in the poorly exposed Gern locality, there is not enough data available to solve this problem.

Another suggestion is the lithological and stratigraphic correlation of parts of the MKZ with the Hluk Formation (Stranik et al., 1995; Svabenická et al., 1997), from the inner part of the Magura Nappe (Bile Karpaty Unit). Consequently, following this interpretation, the MKZ has to be regarded as the remnant of sediments of a submarine swell within the Rhenodanubian Basin. However, one ought to remember that sandstones of the Gresten Formation, typical for the Alpine foreland and sourced from the European side outside the Alpine orogenic belt (Faul, 1975; Nehyba and Opletal, 2016), are also present in the MKZ, indicating an external primary position for both the Gresten Klippen Zone and the MKZ and argue against an original position south of the Rhenodanubian Basin and the Penninic Ocean.

## 5.2 St. Veit Klippen Zone

Based on the stratigraphic results from the Lainz Tunnel and correlated outcrops, the SVK in the Lainz Tunnel displays the following stratigraphic units as derived from blocks within a sheared matrix: (1) Upper Triassic sandstones (Keuper; not biostratigraphically dated) and limestones ('Kössen Formation'); (2) Lower–Middle Jurassic grey sandy marlstones and limestones dated by ammonites (Trauth, 1930; Schnabel, 1997; Pfersmann, 2013) and calcareous nannofossils as Sinemurian to Bajocian/Bathonian; (3) Middle–Upper

Jurassic red radiolarites, cherts and red shales (lower/middle Bajocian to lower Oxfordian, dated by radiolaria); and (4) grey marlstones to argillaceous limestones, white silicified limestones and greenish cherts (upper Oxfordian to Barremian/Aptian, dated by radiolaria).

Lower-to-Middle Jurassic sandy–silty and marly grey limestones are both known from outcrops in the Lainzer Tiergarten as well as from the Lainz Tunnel section. A Middle Jurassic age could be ascertained herein by calcareous nannofossils, and tentatively, this interval is correlated with the Hohenauer Wiese Formation (Schnabel, 1997, 2002). However, the Bajocian/Bathonian position – as indicated by ammonites from the grey limestones of the type locality, the Hohenauer Wiese outcrop in the Lainzer Tiergarten – is in conflict with the early-to-middle Bajocian radiolarian age indicated for parts of the siliceous rocks from the Lainz Tunnel. These red radiolarites, cherts and shales, lithologically attributed to the Rotenberg Formation (Trauth, 1950; Decker 1987, 1990), partly display a lower-to-middle Bajocian age based on radiolaria; this may indicate the presence of blocks of more than one facies type, both siliceous (deeper water) and carbonate (shallower water depths) types, within the SVK. This is a common feature of Klippen units, which is attributed to a tectonic melange derived from several geological units.

Above this interval, Callovian to Oxfordian siliceous limestones and cherts occur, followed by Upper Jurassic to Lower Cretaceous up to Barremian/Aptian mainly grey siliceous limestones with minor cherts, attributed to the Fasselgraben Formation (Trauth, 1950; Decker 1987, 1990), a siliceous equivalent of the Blassenstein Formation of the MKZ.

In contrast to former interpretations of the Triassic–Lower Cretaceous rocks of the SVK as the sedimentary substrate of the Upper Cretaceous flysch deposits of the Kahlenberg Nappe sensu Prey (1975) and Schnabel (2002), we interpret the Lainz Tunnel section as evidence for the presence of two independent structural, tectonically separated units: (1) the SVK, comprising a succession of Triassic–Lower Cretaceous rocks; and (2) Upper Cretaceous rocks of the overlying Rhenodanubian nappe system (Kahlenberg Nappe or Satzberg slice of Greifenstein Nappe). The relation of the Rhenodanubian nappe system to the SVK is clearly a tectonic superposition according to data from the Lainz Tunnel (Pfersmann, 2013). No evidence for a sedimentary contact between these two units could be detected in the tunnel section. Furthermore, the sampled rocks do not indicate any unknown intervening units, as speculated by Prey (1985: 'Klippen-Hüllflysch' or 'Buntmergelserie'). In contrast, a remarkable stratigraphic gap is ascertained between the youngest age of the Fasselgraben Formation of probably Barremian age (upper boundary ca. 125 Ma) to the oldest age of the surrounding formations of the Rhenodanubian nappe system (Hütteldorf Formation, probably Upper Albian to Cenomanian, lower boundary ca. 107 Ma; Wagreich,

2008). This suggests a stratigraphic gap of nearly 20 Ma. Taking this into account, a continuous succession of the SVK into the Rhenodanubian nappe system becomes strongly doubtful, and thus, an attribution of the SVK as a primary basement of parts of the Rhenodanubian Flysch units including the Kahlenberg Nappe (in the sense of Prey, 1979, and Schnabel, 2002) is highly uncertain.

In paleogeographic reconstructions and tectonic classifications (Schuster et al., 2014; Egger and Wessely, 2014), the SVK is correlated with the Ybbsitz (Klippen) Zone, a (South) Penninic ophiolite/deep-water unit similar to the Arosa Zone in the western part of the Eastern Alps. The complete lack of ophiolitic rocks, especially serpentinites as remnants of ultrabasic rocks, in the Lainz Tunnel (as compared to the Ybbsitz Zone), as well as the presence of Upper Triassic continental rocks of Keuper facies strongly argue against a primary position within the Rhenodanubian Basin as part of the Penninic Ocean (or Alpine Tethys). Consequently, a transitional position at the southern continental margin adjacent to the Penninic Ocean, i.e. a northern Austroalpine microplate position (corresponding in parts to the Lower Austroalpine facies belt of Tollmann, 1976), is inferred. The correlation of the SVK with the Drietoma Unit (Hók et al., 2009) of the peri-klippen part of the PKB (for details, see Wagreich et al., 2012; Pfersmann, 2013) further supports this hypothesis.

Comparing radiolaria data from various klippen units (Fig. 9), the biostratigraphic assignments from the SVK for the red radiolarites, cherts and shales of the Rotenberg Formation (UAZ3–8, lower–middle Bajocian to lower Oxfordian) do not correlate at all, neither with the Gresten Klippen Zone (Lampelsberg Formation, UAZ7, upper Bathonian–lower Oxfordian, Ožvoldová and Faupl, 1993), nor with the Ybbsitz Klippen Zone (cherts and radiolarites of the Rotenberg Formation, UAZ7–9, upper Bathonian–upper Oxfordian), nor with the MKZ (Gern, UAZ10, upper Oxfordian–lower Kimmeridgian). Remarkably, the only known radiolarites of the same significantly older (Bajocian) chronostratigraphic position comprise the Ruhpolding Formation of the Northern Calcareous Alps, with ages from UAZ3 to UAZ11 (e.g. Gawlick et al., 2009), another argument for an Austroalpine paleogeographic position of the SVK.

However, today's structural position of the Rhenodanubian nappe system of Penninic derivation on top of the SVK with a proposed marginal Austroalpine derivation has to be explained by large-scale out-of-sequence thrusting during Alpine orogenic wedge deformation, a feature that is presumed in several models of Alpine flysch wedge deformation (e.g. Mattern and Wang, 2008; Beidinger and Decker, 2014).

### 5.3 Lithostratigraphy

These new biostratigraphic data and arguments concerning the derivation of units has also implications for lithostratigraphic nomenclature. Both the Rotenberg Formation (type locality at Roter Berg, Ober St. Veit,

southwest of Vienna; Trauth, 1930, 1950) and the Fasselgraben Formation (klippe in the Fasselgraben creek in the Lainzer Tiergarten; Trauth, 1950) have their type localities within the SVK in the southwestern part of Vienna. Nowadays, these names are used for lithostratigraphic units within the Ybbsitz Klippen Zone (Ožvoldová and Faupl, 1993; Schnabel, 2002). Referring to our data, neither the age nor the primary paleogeographic and tectonic positions of the siliceous rocks in the Ybbsitz Klippen Zone and the SVK coincide. Thus, using lithostratigraphic names originally defined in the SVK (Trauth, 1950) for units occurring in the Ybbsitz Klippen Zone is strongly misleading and should be abandoned in the future.

## 6. Conclusions

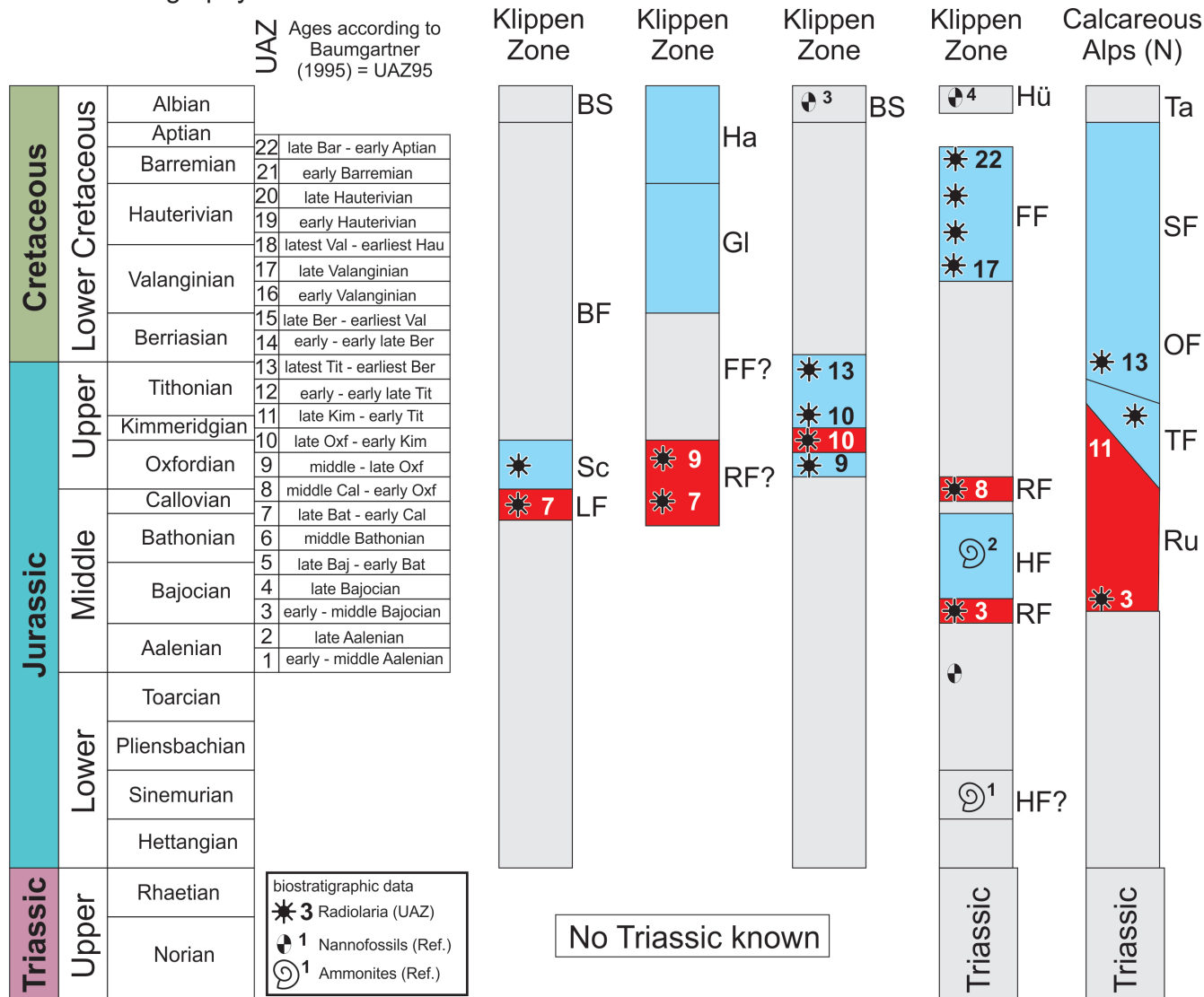
Biostratigraphic data from radiolarians and calcareous nannofossils constrain siliceous and radiolaria-bearing intervals in the MKZ (a part of the Gresten Klippen Zone) and the SVK Zone of the Wienerwald area to the west of Vienna.

The radiolarian limestones of the Gern locality indicate a middle Oxfordian to lower Kimmeridgian chronostratigraphic position and can be correlated with the siliceous, but more turbiditic, Scheibbsbach Formation of the Gresten Klippen Zone. A northern and orogen-external derivation from the European passive margin is probable for this unit, in accordance with the paleogeographic position inferred for the Gresten Klippen Zone.

Radiolarian and nannofossil data for the SVK Zone from the Lainz railway tunnel and correlated outcrops from the Lainzer Tiergarten and other outcrops in the southwest of Vienna indicate an Early Jurassic age for the grey limestones, as well as an early-to-middle Bajocian to early Oxfordian age for the red radiolarites and cherts. This constrains the age of the Rotenberg Formation at the type area in Vienna. Siliceous limestones and cherts are present upwards, from the Upper Jurassic (upper Oxfordian–Kimmeridgian) up to the typical grey pelagic limestones of the Fasselgraben Formation of the Lower Cretaceous, indicating Valanginian–Hauterivian to Barremian/lower Aptian ages mainly.

As no remnants of ophiolitic rocks could be found in the tunnel, and no continuous succession into the tectonically overlying Kahlenberg Nappe (or Satzberg slice) could be determined either, a direct correlation of the SVK Zone with the Ybbsitz Zone is not supported. The SVK and the units of the Rhenodanubian nappe system thus comprise two structurally separated units of the Alpine orogenic wedge. However, a transitional position of the SVK Zone from the Penninic Ocean to the Austroalpine continental fragment at the northern margin of the Austroalpine microplate is inferred, which is supported by the occurrence of lower–middle Bajocian radiolarites, similar to stratigraphic data reported for the Northern Calcareous Alps. Thus, the lithostratigraphic units such as Rotenberg Formation and Fasselgraben Formation, which were originally defined in

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**Figure 9:** Schematic lithological successions of various Jurassic to Lower Cretaceous klippen units of the Eastern Alps and the northern thrust sheets of the Northern Calcareous Alps, indicating radiolarite and chert units (red) and siliceous/radiolarian limestones (blue). Chronostratigraphy scaled to Unitary Association Zones (UAZs) of Baumgartner (1995). Biostratigraphic data for Main Klippen Zone (equivalent to the Gresten Klippen Zone) and St. Veit Klippen Zone from this study; ammonite data (1) from Hohenauer Wiese locality of Trauth (1930) and (2) from the Lainz Tunnel (Lukeneder in Pfersmann, 2013); nannofossil data (3) from Wagreich (2012) and (4) from Wagreich (2008); Ybbsitz and Gresten Klippen Zone radiolaria data from Ožvoldová and Faupl (1993), correlated with the UAZs and ages according to Baumgartner (1995). Ybbsitz Klippen Zone lithostratigraphy from Decker (1990) and Homayoun and Faupl (1992). Northern Calcareous Alps radiolaria data from Gawlick et al. (2009). Abbreviations: BF–Blassenstein Formation; BS–Buntmergelserie; FF–Fasselgraben Formation; GI–Glosbach Formation; Ha–Haselgraben Formation; HF–Hohenauer Wiese Formation; Hü–Hütteldorf Formation; LF–Lampelsberg Formation; OF–Oberalm Formation; RF–Rotenberg Formation; Ru–Ruhpolding Formation; Sc–Scheibbsbach Formation; SF–Schrambach Formation; Ta–Tannheim Formation; TF–Tauglboden Formation; Ref.–Reference to biostratigraphic data.

the SVK Zone, cannot be used for units occurring in the Ybbsitz Klippen Zone.

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