Swiss Journal of Geosciences (2018) 111:99–115
https://doi.org/10.1007/s00015-017-0286-z

Palynology of Triassic–Jurassic boundary sections in northern Switzerland

Elke Schneebeli-Hermann[1] · Nathan Looser[2] · Peter A. Hochuli[1] · Heinz Furrer[1] · Achim G. Reisdorf[3] · Andreas Wetzel[3] · Stefano M. Bernasconi[2]

Received: 26 April 2017 / Accepted: 22 November 2017 / Published online: 11 December 2017

Abstract

A first palynostratigraphic scheme of Upper Triassic deposits in northern Switzerland was established based on spore-pollen associations and dinoflagellate cyst records from the upper part of the Upper Triassic Klettgau Formation and the lower part of the Lower Jurassic Staffelegg Formation. Drill cores from the Adlerberg region (Basel Tabular Jura) and from Weiach (northern part of Canton Zurich) as well as from an outcrop at the Chilchzimmersattel (Basel Folded Jura) were studied and five informal palynological associations are distinguished. These palynological associations correlate with palynological association of the Central European Epicontinental Basin and the Tethyan realm and provide a stratigraphic framework for the uppermost Triassic sediments in northern Switzerland. Throughout the uppermost Triassic to Jurassic palynological succession a remarkable prominence of *Classopollis* spp. is observed. Besides *Classopollis* spp. the three Rhaetian palynological associations A to C from the Upper Triassic Belchen Member include typical Rhaetian spore-pollen and dinoflagellate taxa (e.g., *Rhaetipollis germanicus*, *Geopollis zwolinskae*, *Rhaetogonyaulax rhaetica*, and *Dapcodinium priscum*). Association B differs from association A in a higher relative abundance of the sporomorph taxa *Perinopollenites* spp. and the consistent occurrence of *Granuloperculatipollis rudis* and *Ricciisporites tuberculatus*. Spore diversity is highest in the late Rhaetian palynological association C and includes *Polypodiisporites polymicroforatus*. A Rhaetian age for the Belchen Member is confirmed by palynological associations A–C, but there is no record of the latest Rhaetian and the earliest Jurassic. In contrast to the Rhaetian palynological associations the Early Jurassic associations W and D include *Pinuspollenites* spp., *Trachysporites fuscus* (in association W*)*, and *Ischyosporites variegatus*. In the view of the end-Triassic mass extinction and contemporaneous environmental changes the described palynofloral succession represents the pre-extinction phase (associations A and B) including a distinct transgression, the extinction phase (association C) associated with a regression, and the post-extinction phase (association W).

Keywords Triassic · Jurassic · Palynology · Palaeoenvironment · Switzerland

1 Introduction

The Triassic–Jurassic boundary is known to be associated with one of the big five mass extinctions (Raup and Sepkoski 1982). Marine invertebrates were severely affected whereas the impact on terrestrial flora is discussed controversially. Analysis of European macro- and microflora databases on stage-level resolution do not indicate increased extinction rates across the boundary (Barbacka et al. 2017). However, high time resolution palynological studies clearly indicate changes in floral composition that are interpreted as reactions to environmental changes (e.g. Lindström 2016). The palynofloral successions includes

---

Editorial Handling: Wilfried Winkler.

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00015-017-0286-z) contains supplementary material, which is available to authorized users.

✉ Elke Schneebeli-Hermann
Elke.Schneebeli@pim.uzh.ch

[1] Institute and Museum of Palaeontology, University of Zurich, Karl Schmid-Str. 4, 8006 Zurich, Switzerland

[2] Department of Earth Sciences, ETH Zurich, Sonneggstrasse 5, 8092 Zurich, Switzerland

[3] Geologisch-Paläontologisches Institut, Universität Basel, Bernoullistrasse 32, 4056 Basel, Switzerland

stable pre- and post-extinction phases, and an extinction phase with high turnover-rates and taxonomic losses as well as a recovery phase between the two stable phases. The Triassic–Jurassic extinction phase is marked by high relative abundances of spores and especially the taxon *Polypodiisporites polymicroforatus* is very prominent (*Polypodiisporites polymicroforatus* abundance interval after Lindström et al. 2017). This palynological extinction phase can be traced globally and coincides with the main marine extinction pulse (Lindström et al. 2017). A sea-level rise predates the extinction interval in NW Europe and the Northern Calcareous Alps followed by a major regression during the extinction episode (Hallam and Wignall 1999; Hesselbo et al. 2004; Hillebrandt et al. 2013). The recovery period coincides with a prominent transgression (Hallam and Wignall 1999; Lindström et al. 2017). Increased tectonic activity and sea-level fluctuations at the Triassic–Jurassic boundary, especially during the extinction phase, caused sedimentary hiatuses in many basins (Lindström et al. 2017).

During Late Triassic–Early Jurassic times northern Switzerland was situated at the southern margin of the Central European Epicontinental Basin (=Germanic Basin). Sedimentation was discontinuous due to terrestrial and shallow marine conditions, respectively (Ziegler 1990; Hallam 2001; Jordan et al. 2016). The terrestrial to shallow marine sediments are characterised by strong terrestrial influx from the Vindelician–Bohemian High in the Southeast and the Central Massif in the Southwest (Ziegler 1990). Marine ingressions from the Tethys occurred recurrently through the Burgundy–Alemannic gateway (Ziegler 1990; Fischer et al. 2012) (Fig. 1a). Sedimentary gaps and the rare occurrence of marine index fossils account for an incomplete biostratigraphic subdivision of the Upper Triassic to Lower Jurassic deposits in northern Switzerland. However, proximity to the land facilitated short-distance transport and fast deposition of land plant fragments as well as sporomorphs. The Upper Triassic flora found near Basel is famous for its rich macrofossil content (Heer 1865; Leuthardt 1903, 1904; Kräusel 1955, 1959; Kräusel and Schaarschmidt 1966). Leschik (1955) and Scheuring (1970) described palynological associations from the Ergolz Member of the Klettgau Formation (Jordan et al. 2016; formerly called "Schilfsandstein") and correlated these with Carnian palynological associations from the Tethyan realm. Achilles and Schlatter (1986) described Norian palynomorphs from the upper part of the Gruhalde Member of the Klettgau Formation (Jordan et al. 2016; "Zanclodonmergel" or "Knollenmergel" in Achilles and Schlatter 1986) near Schaffhausen. Samples of the Gruhalde Member (formerly called "Obere Bunte Mergel") from the Belchentunnel were barren (Scheuring 1970). The Gruhalde Member was also found to be unproductive with respect to palynomorphs in the clay pit in Frick (Carole Gee in Sander 1992: 266). There, Schlatter (1975) described palynomorphs from the Lower Jurassic Schambelen Member (formerly called "Insektenmergel") of the Staffelegg Formation.

In order to establish a palynostratigraphic zonation across the Triassic–Jurassic boundary in northern Switzerland, palynomorph assemblages are described from five localities. These assemblages are correlated with successions in the Central European Epicontinental Basin and the Tethyan realm. Additionally, their relevance with regard to the end-Triassic abiotic and biotic events is highlighted.

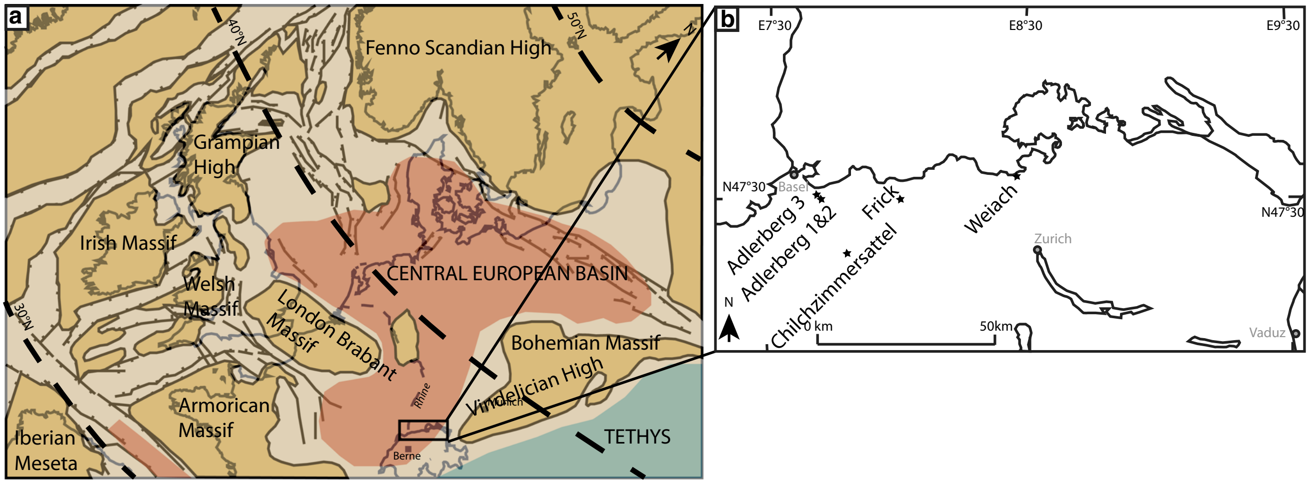


Fig. 1 **a** Palaeogeographic map of central and northern Europe in Late Triassic time, based on Ziegler (1990) and Stampfli and Kozur (2006). **b** Study area

2 Study sites and stratigraphic framework

Three cores from a drilling campaign for the Adlerberg railway tunnel in the Tabular Jura southeast of Basel (Adlerberg 1–3) were studied (Fig. 1b). The Adlerberg Core 1 (34.R.3 in the borehole cadaster of canton Basel-land, Swiss coordinates LV95: 2620027/1261176) and the Adlerberg Core 2 (34.R.8, LV95: 2620083/1261127) were drilled west of Frenkendorf with a lateral distance of ca. 70 m. The Adlerberg Core 3 (41.R.117, LV95: 2618725/1262213) was drilled ca. 1.7 km northwest of Adlerberg Core 1. Additionally, the Weiach core (Swiss coordinates LV95: 2676745/1268618) from the northern part of canton Zurich, ca. 50 km east of the Adlerberg cores, drilled by the National Cooperative for the Disposal of Radioactive Waste (NAGRA; Matter et al. 1988) was studied. Moreover, samples from a trench at the type locality of the Belchen Member at the Chilchzimmersattel hill in the Folded Jura, ca. 18 km southeast of the Adlerberg locality form part of the study (Fig. 1b).

The Upper Triassic–Lower Jurassic deposits in northern Switzerland comprise the Gruhalde Member and the Belchen Member of the Klettgau Formation (Upper Triassic, Jordan et al. 2016) and the Schambelen Member and Beggingen Member of the Staffelegg Formation (Lower Jurassic, Reisdorf et al. 2011). The Gruhalde Member (formerly "Obere Bunte Mergel", "Knollenmergel", or "Zanclodon-Mergel"; Sander 1992; Meyer and Furrer 1995; Meyer 2001; Jordan et al. 2016) consists of grey, green and red terrestrial to shallow marine dolomitic marl and claystone (e.g. Jordan et al. 2016). Its stratigraphical age is under debate to be Norian (Sander 1992) or Rhaetian (Etzold et al. 2010).

The Belchen Member consisting of black, greyish and reddish mudstone or fine-grained sandstone is of Rhaetian age and forms the top of the Klettgau Formation (Fischer et al. 1964; Tanner 1978; Brenner 1986; Nagra 2001; Jordan et al. 2016). Facies and thickness of the Belchen Member vary strongly, even within distances of hundreds of metres (Reisdorf et al. 2011; Jordan et al. 2016). It occurs in the Folded and the Tabular Jura of the cantons Baselland and Solothurn as well as in the Zurich Weinland (Benken core, NAGRA 2001) while it is missing in central northern Switzerland (Reisdorf et al. 2011; Jordan et al. 2016). Based on lithology and/or TOC content the Belchen Member is subdivided into four lithological units uI–uIV. Units uI and uII are composed of sandy siltstone and siltstone with high TOC content in uI and lower TOC content in uII. A fining upward trend combined with very high TOC content marks uIII. Unit uIV is characterised by very low TOC content and predominance of claystone and silty claystone (Looser et al. 2017, in prep.).

The overlaying Schambelen Member (formerly "Insektenmergel", "Psiloceras-Schichten" or "Psilonoten-Tone") consists of marly terrigenous mudstone being early to middle Hettangian in age (Jordan 1983; Schlatter 1983; Reisdorf et al. 2011). It forms the lowest part of the Staffelegg Formation except in the Passwang and Weissenstein area of the Folded Jura. At the type locality sediments yielded insects and fragmentary remains of land plants that may suggest proximity to land (Heer 1865; Felber 2006; Etter 2016). In the Basel Tabular Jura the Schambelen Member is locally developed as a thin bed of grey to black terrigenous mudstone. Ammonites indicate an early Hettangian age (Reisdorf et al. 2011 and references therein). In the Adlerberg cores, however, the Schambelen Member was not encountered.

The lower Hettangian to upper Sinemurian Beggingen Member of the Staffelegg Formation (formerly "Angulatenkalk" and "Arietenkalk") is a fossiliferous limestone interlayered with marl beds (Maisch et al. 2008; Reisdorf et al. 2011). Its thickness varies laterally and it always overlies an erosive surface (Reisdorf et al. 2011). In the eastern Tabular Jura of the canton Baselland the lower part of the Beggingen Member is missing and the oldest ammonites found in the Adlerberg region belong to the early Sinemurian Bucklandi Zone (e.g., Reisdorf et al. 2011).

3 Methods

Twenty-eight samples were collected from the Adlerberg Core 1 (34.R.3), eight from the Adlerberg Core 2 (34.R.8), two from Adlerberg Core 3 (41.R.117), four from the Chilchzimmersattel section, and five from the Weiach core. The samples were cleaned, crushed and weighed (13–20 g) and subsequently treated with concentrated hydrochloric and hydrofluoric acid as described byTraverse (2007). The residues were sieved over an 11 µm mesh screen. Where necessary, a short oxidation with concentrated nitric acid was performed before the residues were sieved again over an 11 µm mesh screen. From strew mounts a minimum of 250 spores and pollen grains per sample were counted. Aquatic palynomorphs have been counted alongside sporomorphs until the target sporomorph count was reached. Additionally, one slide per sample was completely scanned for rare palynomorphs. Based on their botanical affinity and ecological preferences of parent plants, spore and pollen taxa have been assigned to different Sporomorph Ecogroups (SEGs) as described by Abbink (1998) and Abbink et al. (2004) (see supplementary material). These represent specific plant communities. We used this approach to describe palaeoenvironmental changes as reflected in the palynological assemblages in Adlerberg Core 1 and Weiach core.

The Upland SEG consists mainly of conifers, represented by pollen taxa such as *Pinuspollenites* spp. or *Lunatisporites* spp. In the Upland–Lowland SEG all bisaccate gymnosperm pollen taxa are grouped that represent either conifers or seed ferns. *Alisporites* spp. (Corystospermales) is typical of lowland communities whereas alete bisaccate pollen in general are grouped into the upland SEG (Abbink 1998; Lindström 2016). The Lowland SEG consists of fern and lycopod spores and *Vitreisporites* spp. (Caytoniales). Fern spores (Osmundaceae), bryophyte spores, and lycopod spores (Selaginellales) represent the Lowland marsh SEG. Taxodiaceae pollen taxa represent swamp conditions (River-Lowland marsh SEG), whereas sphenopsids (*Calamospora* spp.) preferential grow along rivers (River SEG). Pioneer plants grow on instable or newly established grounds. The two fern spore genera *Deltoidospora* and *Dictyophyllidites* are assigned to pioneer ferns (Pioneer SEG) (Abbink 1998). Pleuromeiaceae (*Aratrisporites* spp., *Densoisporites* spp., and *Lundbladispora* spp.) and Cheirolepidaceae (*Classopollis* spp., *Geopollis zwolinskae*, and *Granuloperculatipollis* spp.) were able to cope with salt spray and inhabited coastal areas (Coastal/Coastal marsh SEG) (Abbink 1998). The indeterminate group contains spore and pollen taxa with unknown botanical affinity.

4 Results

For stratigraphic assessment of the five studied sections five different palynological associations (A, B, C, W, and D) are distinguished. The palynological content is mainly characterised by the relative abundance of prominent taxa and the focus on presence/absence of stratigraphically important taxa (Figs. 2, 3, 4). The discussion of the assemblages A–C refers to Adlerberg Core 1. The reported relative abundance (in %) refers to the palynological data of this section. The few exeptions where assemblages from the other localities differ from those of the Adlerberg Core 1 are indicated. Aquatic palynomorphs are generally low in numbers with a maximum of 93 counts in one sample.

Association A Samples of the Adlerberg Core 1 affiliated to the Gruhalde Member (interval between 37.40 and 36.00 m) were basically barren. In the sample at 36.00 m only two palynomorphs were observed: *Classopollis* sp. and *Rhaetipollis germanicus*. The interval from 35.77 to 35.03 m including the lithological units uI, uII and the lower part of uIII belongs to the Belchen Member and yields assemblages described as association A as follows (Fig. 5, Online Resources 1, 2): The low diversity assemblages are dominated by representatives of the *Classopollis* group (~ 66% on average including *Classopollis* spp., *C. meyeriana* and *C. torosus-classoides*). The *Ovalipollis* group, including *Ovalipollis* spp. and *O. pseudoalatus* account for ~ 6%, *Rhaetipollis germanicus* for ~ 3%, *Geopollis zwolinskae* for ~ 3%. Spores are mainly represented by *Converrucosisporites* spp. (~ 10%) and *Deltoidospora* spp. (~ 3%). In these assemblages dinoflagellate cysts include *Dapcodinium priscum*, *Rhaetogonyaulax rhaetica*, and *Valveodinium* spp.

Association A occurs also in the lithological units uI and uII of the Adlerberg Core 2 (Fig. 6; Online Resources 3–5), the lithological unit uI of the Adlerberg Core 3 (Fig. 6; Online Resource 6), and the lithological unit uII at Chilchzimmersattel (Fig. 6; Online Resources 7, 8).

Association B appears in the Belchen Member of the Adlerberg Core 1 (upper part of the lithological unit uIII; interval from 34.83 to 34.27 m). The dominant palynofloral element is still *Classopollis* spp. (~ 50%). *Geopollis zwolinskae* accounts for ~ 9% on average. Another characteristic element of these assemblages is *Perinopollenites* spp. (including *P. elatoides*) which accounts for ~ 24% of the assemblages. *Ovalipollis* spp. represents ~ 3%, while *Rhaetipollis germanicus*, *Ricciisporites tuberculatus* and *Granuloperculatipollis rudis* are consistently present. In addition to the spore genera documented below, association B includes *Trachysporites fuscus*, and common occurrences of *Punctatisporites* spp. Dinoflagellate cysts are represented only in one sample by *Rhaetogonyaulax rhaetica* at 34.65 m.

The high relative abundance of *Perinopollenites* spp. in the Adlerberg Core 1 might represent a local phenomenon. In the Adlerberg Core 2 association B ranges from 33.42 to 31.65 m. It is identified based on the common occurrences of *Trachysporites fuscus* and *Punctatisporites* spp., as well as the consistent occurrence of *Ricciisporites tuberculatus* and *Granuloperculatipollis rudis* (Online Resources 3–5). The uppermost two samples at Chilchzimmersattel show similar palynofloras, however, *Punctatisporites* spp. is missing in these samples (Fig. 6; Online Resource 7, 8).

Association C encompasses the lithological unit uIV of the Belchen Member from 34.07 to 33.30 m depth in the Adlerberg Core 1. Generally, assemblages of this interval are highly diverse especially due to the increased spore content. Assemblages of association C are again dominated by *Classopollis* spp. (~ 45%). *Ovalipollis* spp. accounts for ~ 6%, Bisaccate pollen account for ~ 7%, *Rhaetipollis germanicus* for ~ 2.3%, *Ricciisporites tuberculatus* ~ 2.5%, and *Geopollis zwolinskae* for ~ 3%. *Granuloperculatipollis rudis* and *Ricciisporites umbonatus* are present. The diverse spore assemblages are dominated by *Deltoidospora* spp. (~ 6.5%) and *Polypodiisporites polymicroforatus* (~ 3.5%). *Dictyophyllidites* spp. accounts for ~ 3%. Spores that are regularly

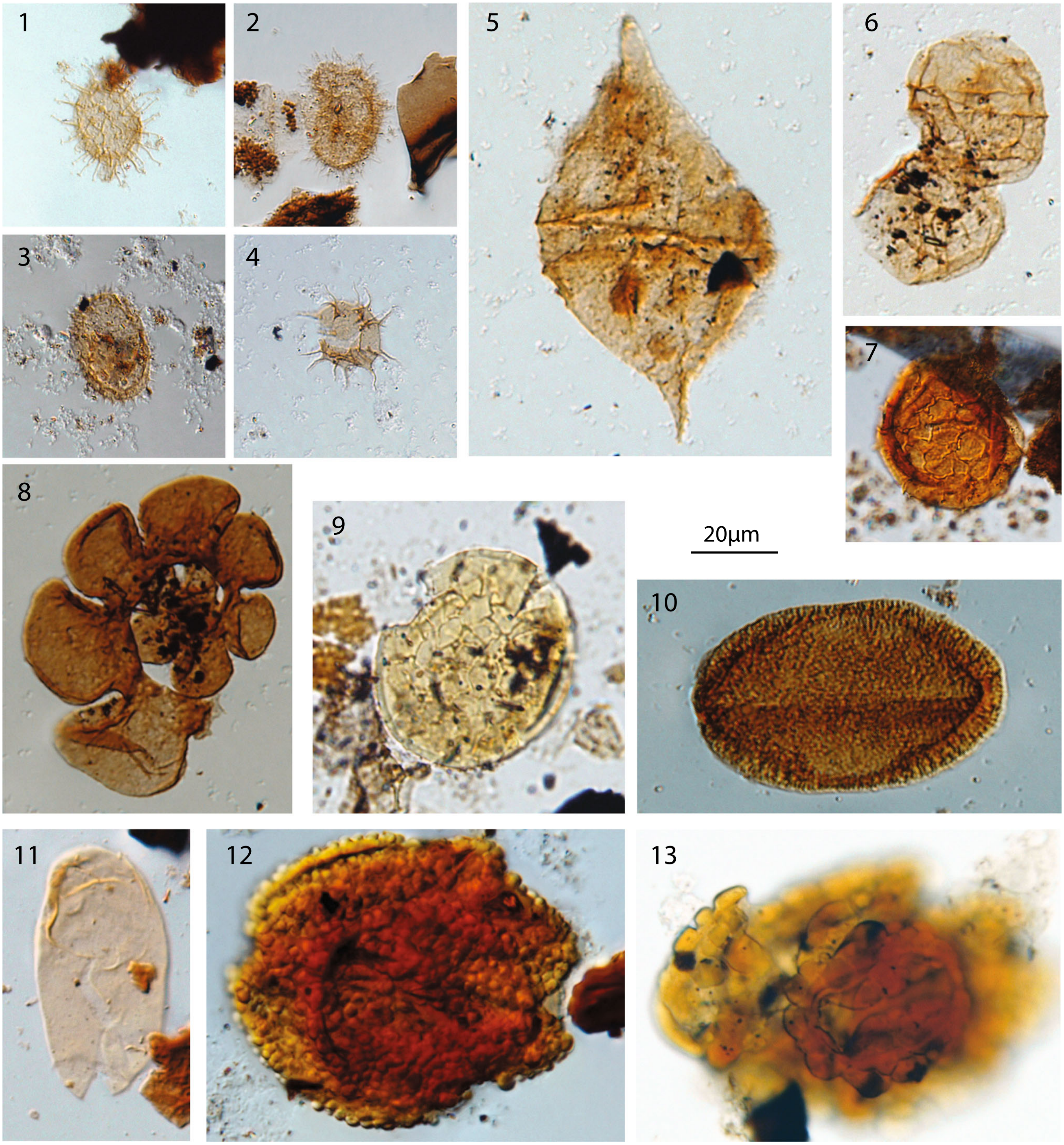
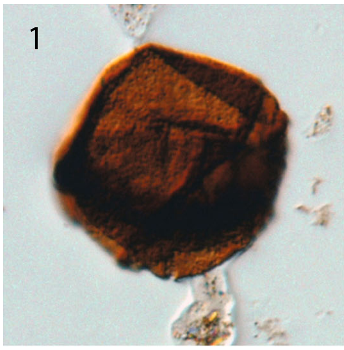
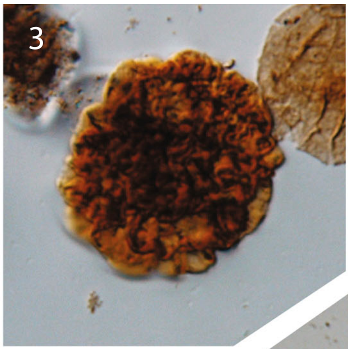


Fig. 2 Palynomorphs (dinoflagellate cysts, miscellaneous aquatic palynomorphs, and pollen) in the described associations Taxon name is followed by sample name (bold), slide specification (brackets) and stage coordinates for an Olympus BX 51 microscope. Scale bar is 20 µm for all photomicrographs. 1, *Beaumontella langii*, **Q 33.65** (O a), 12.3/153.9; 2, *Beaumontella* sp., **Q 33.65** (O a), 18.5/141.0; 3, *Valveodinium* sp., **Q 34.70**, 10.7/144.7; 4, *Comparodinium diacrorhaetium*, **Q 33.30**, 16.3/142.7; 5, *Rhaetogonyaulax rhaetica*, **Q 33.30**, 19.3/150.7; 6, *Dapcodinium priscum*, **Q 33.30**, 14.0/114.9; 7, ?*Suessia swabiana*, **Q 33.47** (O), 7.1/116.4; 8, foraminiferal test lining, **Q 33.30**, 11.7/150.1; 9, *Cymatiosphaera* sp., **TP 23** (O), 15.1/137.0; 10, *Ovalipollis pseudoalatus*, **BLNQ 33.90** (a), 13.5/159.9; 11, *Schizosporis* sp., **BLNQ 34.65** (O a), 10.5/110.9; 12, *Ricciisporites tuberculatus*, **TP 4b** (O), 16.2/135.9; 13, *Ricciisporites umbonatus*, **TP 6** (O), 10.0/114.0

encountered include: *Annulispora folliculosa*, *Camarozonosporites laevigatus*, *Camarozonosporites rudis*, *Carnisporites* spp., *Cingulizonates rhaeticus*, *Kyrtomisporis laevigatus*, *Limbosporites lundbladii*, *Osmundacites*


1


2

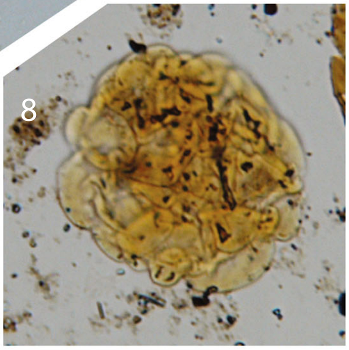

3

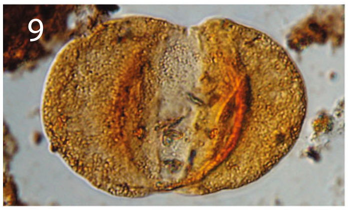

4

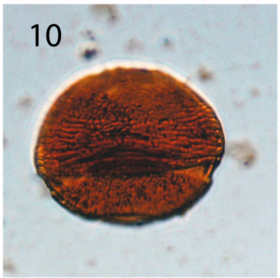

5

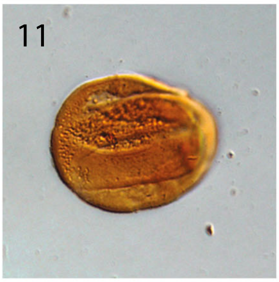

6

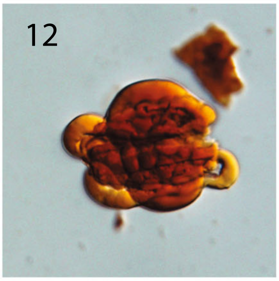

7


8

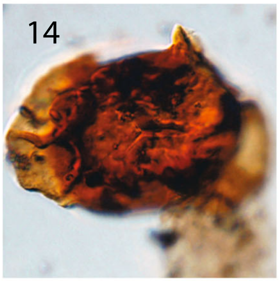

9


10


11


12


13


14


15


16


17


18

◀**Fig. 3** Palynomorphs (pollen) in the described associations. Taxon name is followed by sample name (bold), slide specification (brackets) and stage coordinates for an Olympus BX 51 microscope. Scale bar is 20 µm for all photomicrographs. 1, *Araucariacites* sp., **Q 33.65** (O a), 12.2/127.4; 2, *Quadraeculina anellaeformis*, **Q 33.30**, 16.0/144.1; 3, *Cerebropollenites* sp., **BLNQ 33.90** (a), 17.2/122.5; 4, *Eucommidites* sp., **Q 33.65** (O a), 18.9/148.9; 5, *Chasmatosporites* sp., **Q 33.35** (O), 8.4/143.6; 6, *Classopollis meyeriana*, **Q 35.77** (K a), 14.7/127.7; 7, *Granuloperculatipollis rudis*, **Q 33.20** (O a), 17.3/126.3; 8, *Tsugaepollenites pseudomassulae*, **TP 13/12** (O a), 8.9/111.4; 9, *Falcisporites* sp., **Q 33.35** (O), 11.3/147.0; 10, *Classopollis torosus-classoides*, **Q 33.35** (O), 11.0/138.6; 11, *Geopollis zwolinskae*, **BLNQ 34.65** (O a), 10.8/142.0; 12, *Rhaetipollis germanicus*, **BLNQ 34.65** (O a), 10.7/139.2; 13, *Striatoabieites* sp. small form, **Q 34.07**, 10.8/147.4; 14, *Triadispora* sp., **Q 33.35** (O), 9.5/142.6; 15, *Alisporites* sp. small form, **BLNQ 33.90** (a), 10.9/123.6; 16, *Lunatisporites rhaeticus*, **Q 33.70** (O), 11.3/120.3; 17, *Platysaccus papillionis*, **BLNQ 33.90** (a), 11.9/112.6; 18, *Alisporites robustus*, **BLNQ 33.90** (a), 11.1/132.9

sp., *Perinosporites thuringiacus*, *Punctatisporites* spp., *Stereisporites* spp., *Trachysporites fuscus*, *Triancoraesporites ancorae*, *T. reticulatus*, *Zebrasporites interscriptus*, *Zebrasporites laevigatus*. Dinoflagellate cysts are represented by *Rhaetogonyaulax rhaetica*, *Dapcodinium priscum*, *Valveodinium* spp., ?*Suessia swabiana*, *Beaumontella* spp., and in one sample (33.65 m) by *Cleistosphaeridium* spp. Other aquatic palynomorphs in these assemblages include *Cymatiosphaera* spp., *Leiosphaeridia* spp., *Schizosporis* spp., *Chomotriletes* spp., and undifferentiated algal cysts.The only other locality in which association C was encountered is the topmost sample at 31.25 m of the Adlerberg Core 2 (Fig. 6; Online Resources 3–5).

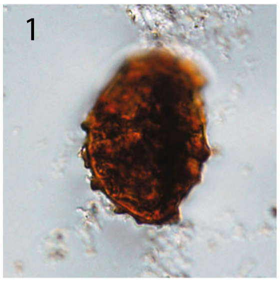
Association W appears in the Lower Jurassic Schambelen Member. Amongst the studied sections and drill cores, the Schambelen Member occurs only in the Weiach core. The assemblages are characterised by common occurrences of *Classopollis* spp. (32%), *Perinopollenites* spp. (28%), *Pinuspollenites* spp. (5%), *Trachysporites fuscus* (8%), and *Deltoidospora* spp. (5%). Accessory elements are *Calamospora* spp., *Kraeuselisporites reissingeri*, *Ischyosporites variegatus*, *Chasmatosporites* spp., and *Araucariacites* spp. Marine palynomorphs are characterised by the presence of *Dapcodinium priscum* and *Micrhystridium* spp. *Rhaetogonyaulax rhaetica* is absent (Online Resources 9, 10).

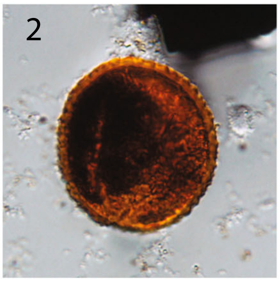
Association D is restricted to the Beggingen Member. In the Adlerberg Core 1 it ranges from 33.25 m to 32.72 m depth. This low diversity assemblages are dominated by *Classopollis* spp. (∼ 80%). Bisaccate pollen account for ∼ 8%. *Ovalipollis* spp. is absent. Spores are represented by *Kyrtomisporis laevigatus*, *Converrucosisporites* spp., and *Ischyosporites variegatus*. Generally, spores show an extremely reduced diversity compared to association C. Dinoflagellate cysts are rare. *Dapcodinium priscum* is present in the sample at 33.25 m (Fig. 5, Online Resources 1, 2). *Rhaetipollis germanicus* and *Granuloperculatipollis rudis* found in sample at 33.25 m might be reworked.

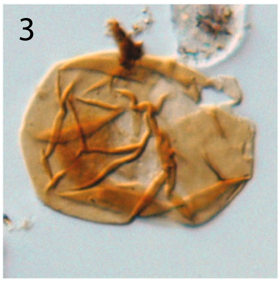
5 Biostratigraphic significance of the palynological associations

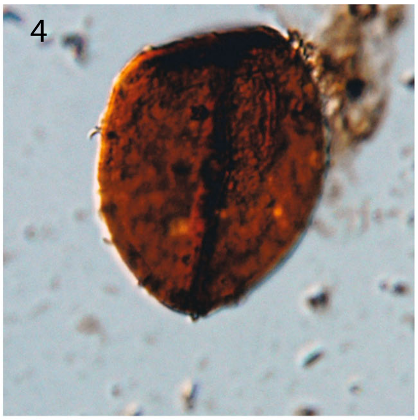
For the evaluation of the stratigraphic significance, the encountered palynological associations have been compared with two sporomorph and one dinoflagellate cyst zonation of the Germanic Basin and two sporomorph based zonation schemes from the Tethyan realm (Fig. 7). The presence of *Rhaetipollis germanicus* in associations A–C allows an overall stratigraphic assignment of these assemblages to the Rhaetian *Rhaetipollis germanicus* assemblage Zone of Kürschner and Herngreen (2010).

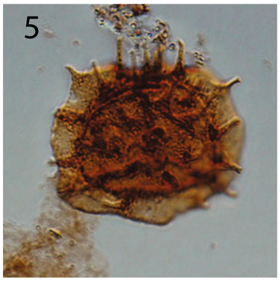
In the *Ricciisporites Conbaculatisporites* Zone described by Lund (1977) from the northwestern part of the Central European Epicontinental Basin, *Classopollis* spp. is the dominant element together with ornamented trilete spores (*Conbaculatisporites*/*Trachysporites*). In this zone *Enzonalasporites* is absent while it is prominent in the older *Corollina Enzonalasporites* Zone. Also *Limbosporites lundbladii* is absent, which is a marker of the younger *Rhaetipollis Limbosporites* Zone (Lund 1977). Thus, in *association A* the low diversity assemblages dominated by *Classopollis* spp. and *Converrucosisporites* spp. correlate well with the *Ricciisporites Conbaculatisporites* Zone. *Rhaetipollis germanicus* and *Classopollis* spp. are also characteristic features of GTr 18/19 from the Central European Basin (GTr: abbreviation "*Germanische Trias*" and consecutive number for palynological associations established for Triassic sediments in Germany Heunisch 1999). GTr 18/19 share some common characteristics with association A and B, but GTr 18 and GTr 19 differ from the palynological assemblages described herein. GTr 18 includes *Enzonalasporites* spp. and *Ricciisporites umbonatus* and GTr 19 includes *Limbosporites lundbladii* and shows a decrease of *Geopollis zwolinskae* in the upper part of GTr 19. Thus GTr 18 and GTr 19 can only be tentatively correlated with association A and B (Fig. 7). Microfaunal evidence indicates an early to middle-Rhaetian age for the *Ricciisporites Conbaculatisporites* Zone in the Eitzendorf 8 well (North Germany; Lund 1977). Therefore an early Rhaetian age is suggested for association A. The occurrence of *Rhaetipollis germanicus* at the top of the Gruhalde Member (36.00 m, Adlerberg Core 1) might indicate a Rhaetian age for these sediments. The first ocurrence of *Rhaetipollis germanicus* is assumed to correspond with the base of the Rhaetian; however, clear evidence is still missing due to the lack of independently dated Norian–Rhaetian successions (Kürschner and

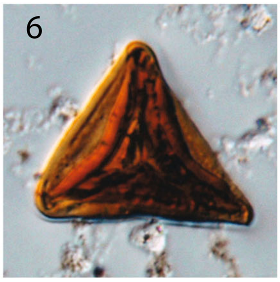

1


2

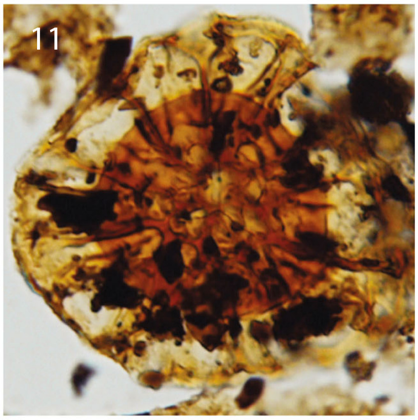

3

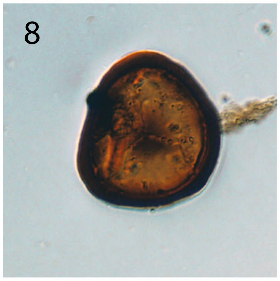

4


5

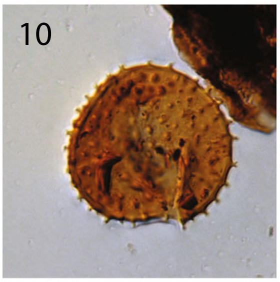

6


7

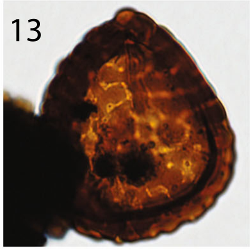

11


8

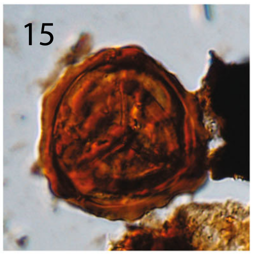

9

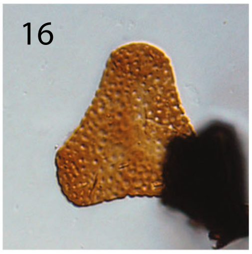

10


12

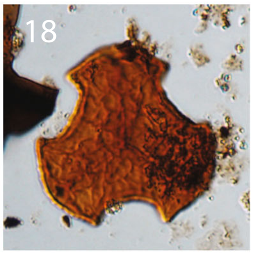

13


14


15


16

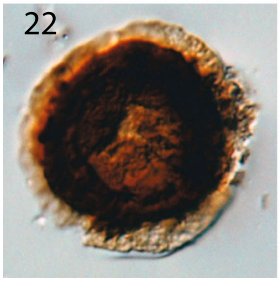

17


18

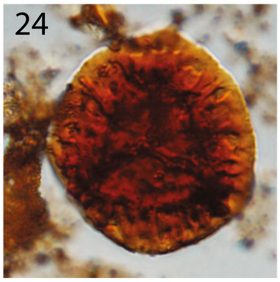

19


20


21

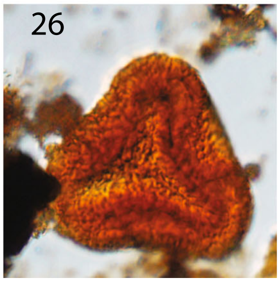

22


23


24


25

20µm


26

◀**Fig. 4** Palynomorphs (spores) in the described associations. Taxon name is followed by sample name (bold), slide specification (brackets) and stage coordinates for an Olympus BX 51 microscope. Scale bar is 20 µm for all photomicrographs. 1, *Polypodiisporites ipsviciensis*, **Q 34.07**, 10.6/142.3; 2, *Polypodiisporites polymicroforatus*, **Q 34.07**, 10.3/125.0; 3, *Calamospora tener*, **Q 33.65** (O a), 12.2/118.2; 4, *Aratrisporites fimbriatus*, **Q 33.35** (O), 17.3/124.7; 5, *Kraeuselisporites reissingeri*, **Q 33.65** (O a), 19.2/128.9; 6, *Kyrtomisporis laevigatus*, **Q 34.07**, 8.2/119.0; 7, *Dictyophyllidites harrisii*, **B 4083 31.65** (K a), 11.3/138.5; 8, *Stereisporites australis*, **BLNQ 33.90** (a), 12.0/122.5; 9, *Annulispora folliculosa*, **Q 33.47** (O), 9.5/114.4; 10, *Carnisporites anteriscus*, **Q 35.77** (K a), 12.9/107.0; 11, *Semiretisporis gothae?*, **Q 33.43** (O), 11.3/113.7; 12, *Camarozonosporites rudis*, **BLNQ 33.90** (a), 7.0/118.9; 13, *Ischyosporites variegatus*, **W 701.2** (K a), 15.0/127.2; 14, *Zebrasporites interscriptus*, **BLNQ 33.90** (a), 9.3/106.8; 15, *Polycingulatisporites liassicus?*, **Q 33.35** (O), 10.5/126.0; 16, *Selagosporis mesozoicus*, **BLNQ 33.90** (a), 11.0/118.0; 17, *Rogalskaisporites cicatricosa*, **Q 33.65** (O a),14.6/138.8; 18, *Triancoraesporites reticulatus*, **Q 33.47** (O), 9.5/127.0; 19, *Triancoraesporites ancorae*, **Q 33.30**, 14.2/125.0; 20, *Densosporites fissus*, **Q 33.35** (O), 11.5/121.0; 21, *Perinosporites thuringiacus*, **BLNQ 33.90** (a), 18.2/107.5; 22, *Cingulizonates rhaeticus*, **BLNQ 33.90** (a), 14.4/129.1; 23, *Cornutisporites* sp., **BLNQ 33.90** (a), 15.8/123.7; 24, *Limbosporites lundbladii*, **Q 33.47** (O), 11.1/118.7; 25, *Reticulatisporites* sp., **BLNQ 33.90** (a), 9.3/107.9; 26, *Trachysporites fuscus*, **Q 33.47** (O), 12.9/127.9

Herngreen 2010). In the Barents Sea *R. germanicus* is already present in sediments of Norian age (Hochuli et al. 1989).

The *Rhaetipollis Limbosporites* Zone from the northwestern part of the Central European Basin is defined by the co-occurrence of *Rhaetipollis germanicus*, *Limbosporites lundbladii*, and *Ricciisporites tuberculatus*. *Cingulizonates rhaeticus* is also present (Lund 1977). In this study the prominent features of the *Rhaetipollis Limbosporites* Zone (occurrence of *Classopollis* spp., *Rhaetipollis germanicus* and *Ricciisporites tuberculatus)* are also documented in *association B*. Based on that, association B is correlated with the *Rhaetipollis Limbosporites* Zone (despite the absence of *Limbosporites lundbladii* and *Cingulizonates rhaeticus*, Fig. 7). *Classopollis* spp. and *Limbosporites lundbladii* are also characteristic features of GTr 19 (Heunisch 1999). The top of this zone is marked by the last occurrence of *Granuloperculatipollis rudis*, which is not confirmed for association B in this study. The high relative abundance of *Perinopollenites* spp. is rarely ascertained, only Heunisch (1996) mentioned slightly increased *Perinopollenites ela-*

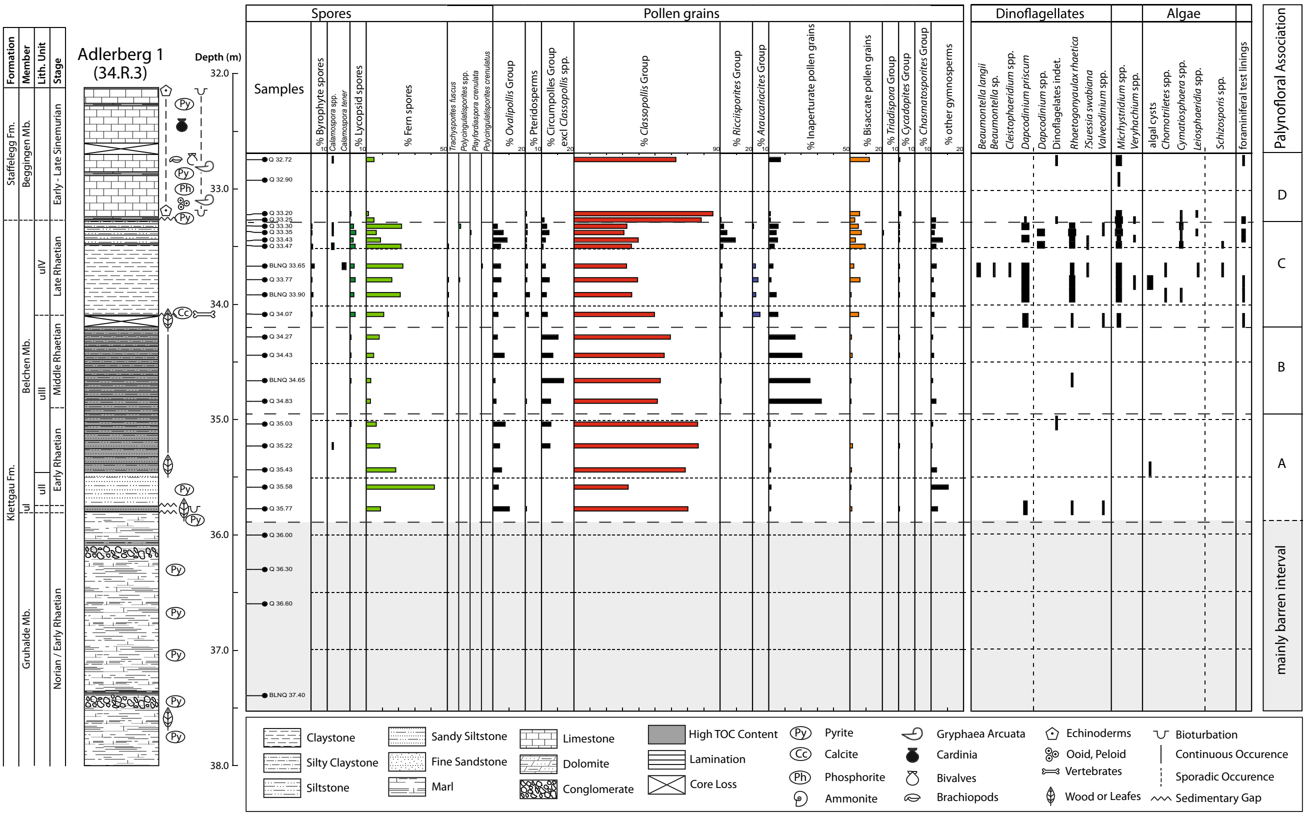


Fig. 5 Relative abundances of spore-pollen groups and dinoflagellates ranges and studied floral associations sampled from the Adlerberg Core 1 (34.R.3)

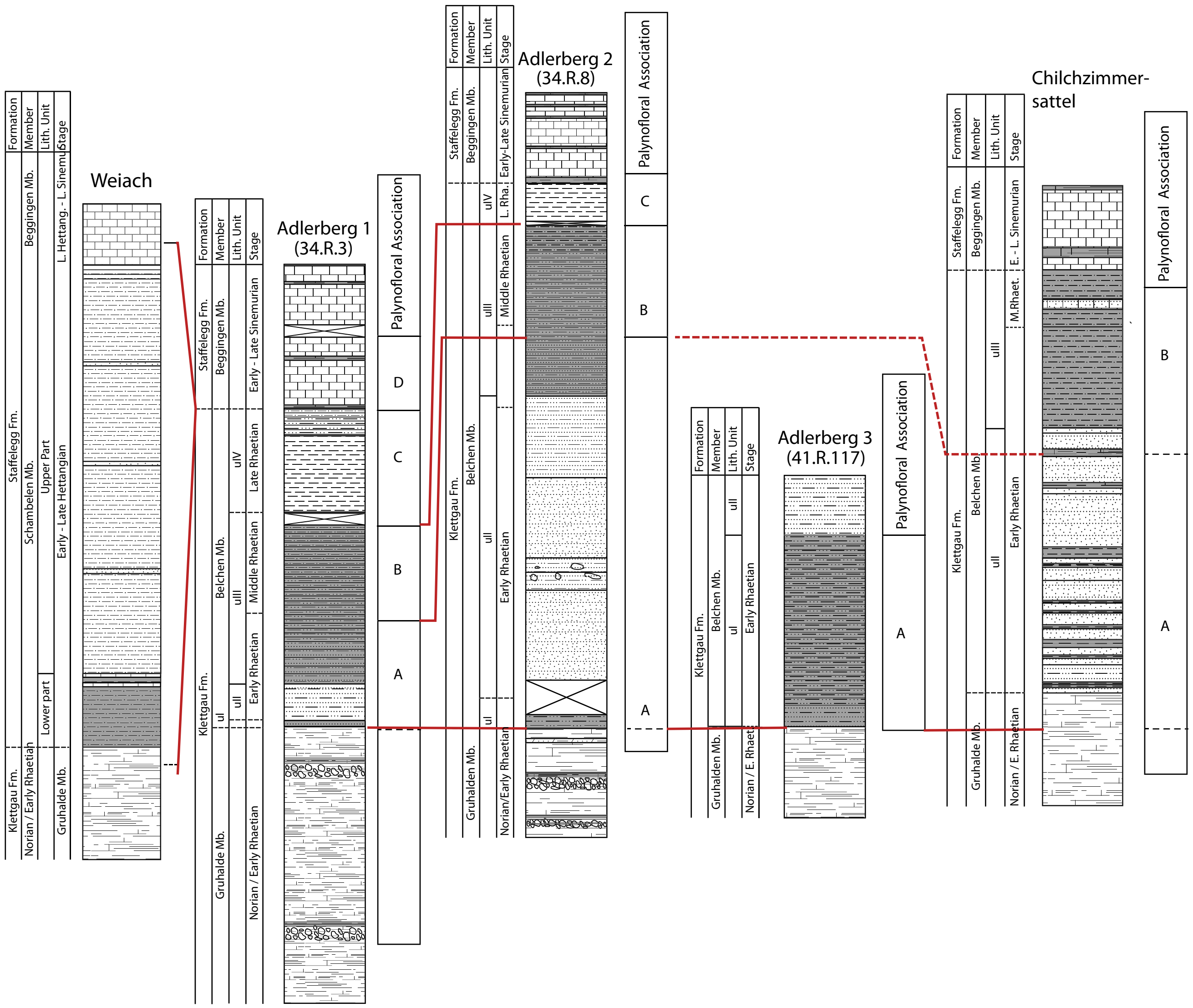


Fig. 6 Correlation of the palynological associations described for the study area. See Fig. 5 for legend

toides content in assemblages from NW Germany, which she correlated with the *Rhaetipollis Limbosporites* Zone. Bonis et al. (2009) described palynological assemblages from two Tethyan sections, in the Hochalplgraben (H1, H2, H3, H4a, and H4b) and at Kuhjoch (=Global Stratotype Section and Point; Hillebrandt et al. 2013; K1, K2, K3, and K4 Bonis et al. 2009) in the Northern Calcareous Alps. H1 and K1 assemblages of these authors are characterised by low diversity, dominant *Classopollis* spp., prominent *Ovalipollis pseudoalatus* and *Rhaetipollis germanicus*. These features correlate with Lund's (1977) *Rhaetipollis Limbosporites* Zone and association B in this study. In the Hochalplgraben and Kuhjoch sections *Limbosporites lundbladii* and *Cingulizonates rhaeticus* are also absent in H1 and K1, but occur in the overlying H2/K2 assemblages. The *Rhaetipollis Limbosporites* Zone has been described to occur together with middle Rhaetian microfauna in the Eitzendorf 8 well (Lund 1977). Therefore the correlation with the *Rhaetipollis Limbosporites* Zone suggests a middle Rhaetian age for association B.

The *Ricciisporites Polypodiisporites* Zone has been defined based on the common presence of *Polypodiisporites polymicroforatus* or *Semiretisporis* together with high diversity of trilete spores for the northwestern part of the Central European Basin (Lund 1977). In *association C* the prominent occurrence of *Polypodiisporites polymicroforatus*, *Ricciisporites tuberculatus*, the presence of *Rhaetipollis germanicus* and *Ovalipollis pseudoalatus* together with overall high spore diversity is suggestive of a correlation with the *Ricciisporites Polypodiisporites* Zone of Lund (1977). Besides the prominence of *Polypodiisporites polymicroforatus* Heunisch's (1999) GTr 20 is also marked by the presence of *Densosporites* spp. and *Polycingulatisporites* spp., which are also observed in

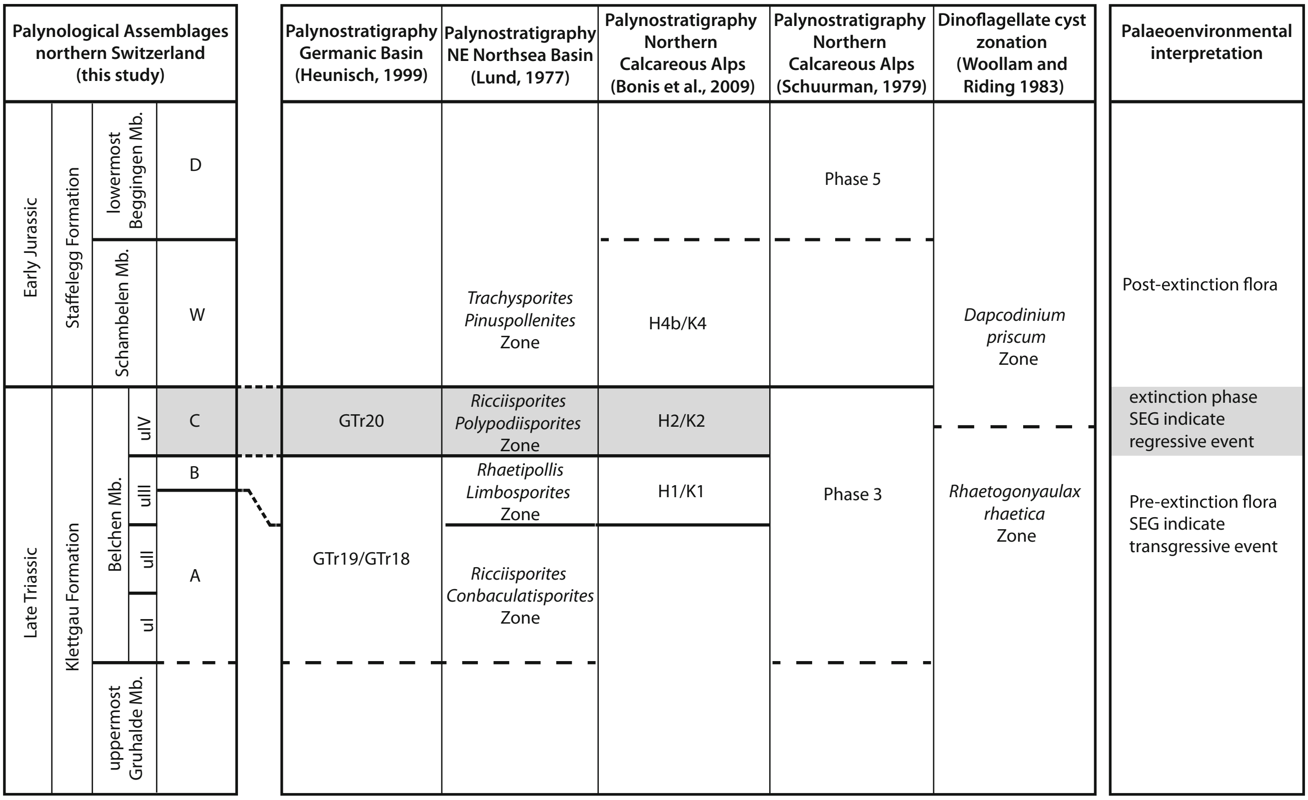


Fig. 7 Correlation of the described palynological associations with palynological schemes of the Central European Basin and the Tethyan realm

association C. The palynological assemblages H2/K2 described from the Hochalplgraben and Kuhjoch sections (Bonis et al. 2009) are marked by an overall increase in spore abundance and diversity. *Polypodiisporites polymicroforatus* is very prominent, and *Acanthotriletes varius*, *Camarozonosporites rudis, Cingulizonates rhaeticus*, *Densosporites fissus*, *Kyrtomisporis laevigatus*, *Limbosporites lundbladii*, *Cingulizonates rhaeticus*, *Polypodiisporites ipsviciensis* and *Triancoraesporites ancorae* appear in assemblage H2 of Bonis et al. (2009). These spore taxa appear also in the northern Swiss association C. Taking this into account association C correlates with assemblages H2/K2 of Bonis et al. (2009) and indicates a late Rhaetian age of association C.

The Triassic–Jurassic boundary is marked by a distinct carbon isotope curve pattern that consists of an initial carbon isotope excursion (CIE) and a main CIE (Hesselbo et al. 2002; Galli et al. 2005; Ruhl et al. 2009). A recent revision demonstrates that the C-isotope pattern across the boundary is even characterised by a three negative CIEs (Lindström et al. 2017). The boundary between H1/K1 and H2/K2 in the Northern Calcareous Alps coincides with the negative peak of the initial CIE (Bonis et al. 2009; Marshi CIE after Lindström et al. 2017). It coincides with the last occurrence of the Rhaetian ammonite *Choristoceras marshi* (Ruhl et al. 2009). However, this initial δ^{13}C peak was not encountered in the study area because of a supposed sedimentary gap in between associations B and C (Nitsch et al. 2005; Looser et al. 2017, submitted).

Associations A, B, and C show common characteristics with floral Phase 3 of Schuurman (1979) which is characterised by high abundances of *Ovalipollis pseudoalatus* and *Classopollis* spp., occurrences of *Granuloperculatipollis rudis*, *Rhaetipollis germanicus* and various trilete spores (Schuurman 1979; see Fig. 7).

In northern Switzerland, sediments of the latest Rhaetian are probably missing supported by a decrease in the relative abundance of *Rhaetipollis germanicus* that is otherwise documented for GTr 20 of the Germanic Basin (Heunisch 1999; Nitsch et al. 2005). In addition, representatives of the correlative *Ricciisporites Polypodiisporites* Zone of Lund (1977) were not observed in the studied samples. A sedimentary gap at the contact between Belchen and Beggingen Member comprises probably the uppermost Rhaetian and the earliest Jurassic (the Schambelen Member as well as the basal part of the Beggingen Member: Nitsch et al. 2005; Reisdorf et al. 2011; Jordan et al. 2016). The sedimentary gap is indicated by an abrupt excursion in the δ^{13} record (Looser et al. 2017, in prep.) and ammonite biostratigraphy (Reisdorf et al. 2011). Further evidence for the lack of latest Rhaetian sediments in the study area is given by the distribution of dinoflagellate cysts. The base of the *Dapcodinium priscum* Zone is characterized by a marked decrease in *Rhaetogonyaulax rhaetica* abundance and it was dated to be latest Rhaetian in age (Woollam and Riding 1983). In the Barents Sea area *Rhaetogonyaulax rhaetica* is present in Norian to basal Jurassic sediments (Hochuli et al. 1989). Since aquatic palynomorphs are not very abundant in the studied sections the relative abundances of dinoflagellate cyst species are not very reliable. *Rhaetogonyaulax rhaetica* shows a slight peak in relative abundance at 33.43 m of the Adlerberg Core 1 and decreases up-section, but occurs regularly up to the boundary between association C and D (Fig. 7). *Dapcodinium priscum* shows higher relative abundances than *Rhaetogonyaulax rhaetica* throughout association C. This might be caused by the environmental requirements of *Rhaetogonyaulax rhaetica*, which is commonly found in more distal settings and in reduced numbers in proximal settings (Riding et al. 2010).

Based on the co-occurrence with *Psiloceras spelae* the palynological assemblages H3–H4a and K3 in the Northern Calcareous Alps with prominent *Heliosporites reissingeri* (corresponding to *Kraeuselisporites reissingeri* in this study), *Trachysporites fuscus* and *Classopollis* spp. are basal Early Jurassic in age. Equivalent palynological assemblages were not encountered in the present study; therefore, the most basal Jurassic beds are missing. Early Jurassic sediments are represented by associations D and W.

Association W and association D Based on the ammonoid biostratigraphy from the Schambelen Member in northern Switzerland association W encompasses the upper part of the Planorbis and the Liassicus zones (Early Hettangian; Reisdorf et al. 2011). In the Adlerberg area the Schambelen Member is missing and the basal beds of the Beggingen Member are dated as Bucklandi Zone, the top beds as Obtusum Zone (Early to early Late Sinemurian; Reisdorf et al. 2011). This implies that association W (Schambelen Member, in the Weiach core) is older than association D (Beggingen Member, of Adlerberg Core 1). However, from a taxonomical perspective the palynological content of the two associations is quite similar; the difference is mostly due to variable relative abundance of individual groups (e.g., increased *Perinopollenites* spp. in association W). Due to the uniformity of sporomorph assemblages in Jurassic successions (Weiss 1989) a detailed age assignment for association W and D based on their palynological content is impossible. Thus the following discussion merely shows how they correlate with published stratigraphic schemes.. Palynological differentiation based on sporomorphs of the Lower Jurassic stages is hardly possible (Visscher et al. 1980). Additionally, stratigraphic ranges of some Jurassic taxa vary regionally and hamper reliable correlations across Europe (Batten and Koppelhus 1996; Visscher et al. 1980).

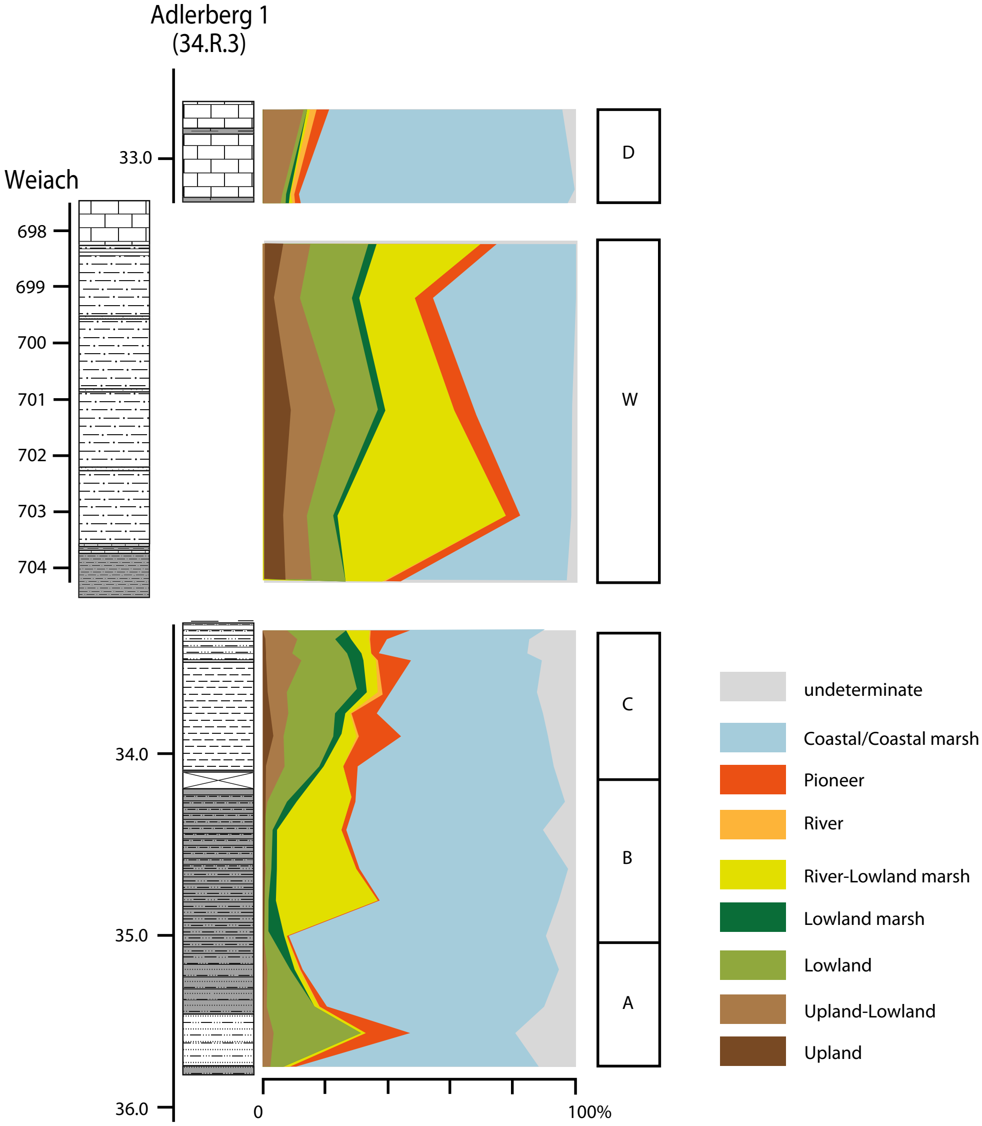
Achilles and Schlatter (1986) described a palynological assemblage from the Hallau Bed (base of the Schambelen Member in the Schaffhausen area) containing *Leptolepidites argenteaeformis*, *Concavisporites* spp., *Conbaculatisporites baculatus*, *Gliscopollis meyeriana* (named *Classopollis meyeriana* in this study), *Kraeuselisporites reissingeri*, *Chasmatosporites magnolioides*, and *Tasmanites* spp. Based on ammonite finds it represents the late Planorbis and Liassicus Zones (early Hettangian; Schlatter 1983; Achilles and Schlatter 1986). However, the sporomorph assemblage has only *Classopollis meyeriana* and *Kraeuselisporites reissingeri* in common with associations D and W, respectively (Fig. 5, Online Resources 1, 2, 9, and 10).

In the Northern Calcareous Alps the basal Jurassic palynological assemblages were described together with ammonoids. The assemblages H4b/K4 are marked by the increase of *Pinuspollenites minimus*, the absence of *Ovalipollis pseudoalatus*, *Rhaetipollis germanicus* and a general decrease in spore diversity (Bonis et al. 2009). These features are also characteristic for association W. H4b/K4 assemblages co-occur with the ammonite *Psiloceras* cf. *pacificum,* which belongs to the Early Hettangian Tilmanni Zone (at the Global Stratotype Section and Point (Bonis et al. 2009; Hillebrandt et al. 2013). *Ischyosporites variegatus*, regarded as marker for an Early Jurassic age (Bonis et al. 2009; Kürschner and Herngreen 2010) has been recorded in association W. The correlation with the dated Tethyan successions confirms an early Jurassic age for association W. The common occurrence of *Pinuspollenites minimus*, *Trachysporites fuscus*, and absence of typical Rhaetian spore taxa has also been described as features of the Hettangian Pinuspollenites Trachysporites Zone in NW Europe by Lund (1977). In the Salzburg area (Austria), Phase 5 of Schuurman (1979) is marked by the dominance of *Classopollis* spp., the presence of *Kraeuselisporites reissingeri* (named *Heliosporites reissingeri* in Schuurman 1979), and the absence of *Ovalipollis pseudoalatus*, *Rhaetipollis germanicus*, *Granoperculatipollis rudis* as well as many Rhaetian spore taxa. These are also typical features of association D in northern Switzerland (Fig. 7). Schuurman's Phase 5 coincides with the Planorbe beds of the Alpine "Fleckenmergel" suggesting an early Hettangian age which does not exclude that the palynological assembalges of phase 5 range up into the Sinermurian due to the low palynostratigraphic time resolution in Lower Jurassic successions.

6 Environmental changes

The palynological assemblages are composed of floral elements assigned to different SEGs. Changes in the relative contribution of the different SEG through time reflect environmental changes (Fig. 8) (Abbink et al. 2004).

Fig. 8 Relative abundance of SEGs in the Adlerberg Core 1 and the Weiach core



Assemblages of association A are generally dominated by floral elements prominent in the coastal SEG. However, in the lower part of association A also a high contribution of lowland elements is recorded compared to the upper part in which coastal elements are clearly dominant. Thus assemblages of association A reflect a slight shift from lowland plant communities with seed ferns, ferns, bryophytes and lycopsids to a more coastal plant community with Cheirolepidaceae. These changes can be interpreted as a slight sea level rise (Abbink et al. 2004). In assemblages of association B typical marsh elements such as Taxodiacae increase in abundance, thus indicating restricted drainage of the coastal area and continued high sea-level. Assemblages of association C show again a stronger influence by lowland, river, upland SEG elements such as conifers, and pioneer SEG elements, thus indicating a falling sea-level. Basal assemblages of association W indicate high contributions of coastal plant communities, thus a high sea-level. In the following lowland elements, especially those indicating waterlogged conditions increase. Assemblages of association W show generally a higher contribution of upland and lowland floral elements that may reflect a deposition closer tor the hinterland at Weiach. Assemblages of association D again are dominated by coastal SEG element s and indicate a higher sea-level. Thus two episodes of transgressive events are documented based on changes in SEG representation: A first sea-level rise is documented in the topmost part of association A and a second between association Wand D (Fig. 9).

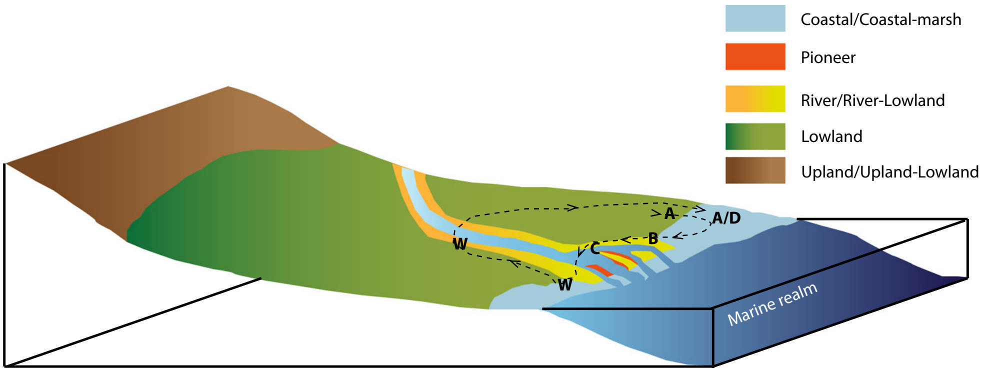


Fig. 9 Spatial distribution of SEGs after Abbink et al. 2004. The palynofloral associations are plotted with respect to their SEG composition. Arrows directing towards the marine realm indicate transgression, arrows directing towards the hinterland indicate regression or a stagnating high water table

7 The palynoflora of northern Switzerland in context of the end-Triassic events

The Triassic–Jurassic environmental changes not only caused a mass extinction in the marine realm but also affected palynofloral composition worldwide (Lindström 2016; Lindström et al. 2017). Pre-extinction palynofloras are usually rather stable in composition. The pre-extinction interval is associated with a transgression in northern Europe (Hesselbo et al. 2004; Lindström et al. 2012, 2017). In the present study, stable palynofloral composition is documented for associations A and B. Furthermore, the strong contribution of coastal SEG elements in association A indicates that the pre-extinction transgression also affected the southern margin of the Central European Basin.

The marine extinction interval coincides with the main floral extinction interval the so-called *Polypodiisporites polymicroforatus* abundance interval (Lindström 2016; Lindström et al. 2017). This interval is globally marked by high spore abundance and it probably represents the floral response to environmental changes associated with the activity of the Central Atlantic Magmatic Province Association (van de Schootbrugge et al. 2009; Lindström 2016). In the palynofloral succession from northern Switzerland, association C is marked by a high floral turnover. Together with high spore diversity and high relative abundance of *Polypodiisporites polymicroforatus* this suggests a correlation with the globally recognised extinction interval after Lindström (2016). In the Stenlille core (Denmark) this interval lack evidence for trace fossils and bivalves (Lindström et al. 2012) which is also true for this interval in the Adlerberg Core 1 (Fig. 5).

In the marginal marine setting of the studied area, the regression caused a substantial sedimentary hiatus. Thus the floral recovery phase observed in numerous Triassic–Jurassic successions after the extinction interval (Lindström 2016) is not recorded in northern Switzerland. A second major sea-level rise is correlated with this recovery interval (Hallam and Wignall 1999; Lindström et al. 2017). Due to the sedimentary hiatus this sea-level is only partially documented in association W, characterized by high contribution of lowland/marsh floral components indicating high ground-water level. Palynofloras in association W and D represent stable post-extinction flora.

8 Summary and conclusions

The biostratigraphical resolution of the deposits at the Triassic–Jurassic boundary in northern Switzerland has been refined by establishing characteristic palynological associations. They have been studied at five localities and they can be correlated with palynostratigraphical schemes of the Central European Epicontinental Basin and the Tethyan realm. Five palynological associations (A, B, C, W and D) characterised by the relative abundances of significant palynomorph groups and by ranges of age relevant taxa have been estabished:

- Association A is marked by low diversity, dominant *Classopollis* spp., common *Ovalipollis* spp. (including *O. pseudoalatus*), *Rhaetipollis germanicus*, *Geopollis zwolinskae*, *Converrucosisporites* spp., and *Deltoidospora* spp. ($\sim 3\%$). Dinoflagellate cysts include *Dapcodinium priscum* and *Rhaetogonyaulax rhaetica*. The correlation with the dated *Ricciisporites Conbaculatisporites* Zone from the NW Central European Basin (Lund 1977) suggests an early Rhaetian age. Increasing relative abudances of *Classopollis* spp. indicates a sea-level rise.
- Association B is still dominated by *Classopollis* spp., however, *Perinopollenites* spp. (including *P. elatoides*) is also prominent. *Geopollis zwolinskae*, *Ovalipollis* spp., *Rhaetipollis germanicus*, *Ricciisporites*

tuberculatus, Granuloperculatipollis rudis, Punctatisporites spp. are consistently present. *Trachysporites fuscus* and *Rhaetogonyaulax rhaetica* occur sporadically. Correlation with the dated *Rhaetipollis Limbosporites* Zone from the NW Central European Epicontinental Basin (Lund 1977) implies a middle Rhaetian age. Increasing relative abundances of *Perinopollenites* spp. can be interpreted as continues high sea-level.

- Association C is characterised by high relative abundance of *Classopollis* spp., common *Ovalipollis* spp., bisaccate pollen grains, *Rhaetipollis germanicus, Ricciisporites tuberculatus*, and *Geopollis zwolinskae, Deltoidospora* spp., *Polypodiisporites polymicroforatus*, *Dictyophyllidites* spp. *Granuloperculatipollis rudis* and *Ricciisporites umbonatus* are present. Remarkable is a high spore diversity including *Cingulizonates rhaeticus*, and *Limbosporites lundbladii*, dinoflagellate cysts are represented by *Rhaetogonyaulax rhaetica*, *Dapcodinium priscum*, *Valveodinium* spp., *Suessia swabiana*, *Beaumontella* spp. and in one sample *Cleistosphaeridium* spp. The base of the correlative H2/K2 assemblages in the Northern Calcareous Alps coincides with the initial negative carbon isotope excursion; therefore a late Rhaetian age is highly likely. A higher contribution of lowland floral elements indicates a regression. The high abundances of spores especially *Polypodiisporites polymicroforatus* allows the correlation with the globally recognised end-Triassic extinction interval (Lindström 2016; Lindström et al. 2017).
- Association W is characterised by common occurrences of *Classopollis* spp., *Perinopollenites* spp., *Pinuspollenites* spp., *Trachysporites fuscus*, and *Deltoidospora* spp.; *Calamospora* spp., *Kraeuselisporites reissingeri*, *Ischyosporites variegatus*, *Chasmatosporites* spp., and *Araucariacites* spp. are present. Marine palynomorphs are characterised by the presence of *Dapcodinium priscum* and *Micrhystridium* spp. *Rhaetogonyaulax rhaetica* has not been observed. Correlation with dated Tethyan palynological assemblages confirms an Early Jurassic age.
- Association D comprises low-diversity assemblages dominated by *Classopollis* spp., while bisaccate pollen grains are common. *Ovalipollis* spp. is absent and spore diversity is strongly reduced but includes *Ischyosporites variegatus*. Correlation with dated Tethyan palynological assemblages confirms an Early Jurassic age. Increased coastal SEG elements indicate a sea level rise between association W and D.

The succession of these associations forms the base to establish a palynostratigraphic framework for the uppermost Triassic sediments in northern Switzerland. A Norian age for the uppermost part of the Gruhalde Member cannot be confirmed because of the presence of *Rhaetipollis germanicus,* which is supposed to be restricted to the Rhaetian. However, its first occurrence is not yet independently dated (Kürschner and Herngreen 2010). The lower part of the Belchen Member (association A, lithological units uI to middle uIII) is of early Rhaetian age. Its upper part (association B and C, lithological units middle uIII to uIV) is of middle to late Rhaetian age, whereas the latest Rhaetian and the most basal Jurassic are probably missing (Figs. 6, 7).

Acknowledgements We are grateful to the NAGRA for access to core material. We thank three anonymous reviewers for their helpful comments.

References

Abbink, O. A. (1998). Palynological investigations in the Jurassic of the North Sea region. LPP contribution series 8. Utrecht: LPP Foundation, University of Utrecht.

Abbink, O. A., Van Konijnenburg-Van Citter, J. H. A., & Visscher, H. (2004). A sporomorph ecogroup model for the Northwest European Jurassic–Lower Cretaceous: concepts and framework. *Netherlands Journal of Geosciences, 83,* 17–38.

Achilles, H., & Schlatter, R. (1986). Palynostratigraphische Untersuchungen im ''Rhät-Bonebed'' von Hallau (Kt. Schaffhausen) mit einem Beitrag zur Ammonitenfauna im basalen Lias. *Eclogae Geologicae Helvetiae, 9,* 149–179.

Barbacka, M., Pacyna, G., Kocsis, Á. T., Jarzynka, A., Ziaja, J., & Bodor, E. (2017). Changes in terrestrial floras at the Triassic–Jurassic boundary in Europe. *Palaeogeography, Palaeoclimatology, Palaeoecology, 480,* 80–93.

Batten, D. J., & Koppelhus, E. B. (1996). Biostratigraphic significance of uppermost Triassic and Jurassic miospores in Northwest Europe. In: J. Jansonius, & D. C. McGregor (Eds.), *Palynology: principles and applications* (vol. 2, pp. 795–806). Dallas, Texas: American Association of Stratigraphic Palynologists Foundation.

Bonis, N. R., Kürschner, W. M., & Krystyn, L. (2009). A detailed palynological study of the Triassic-Jurassic transition in key sections of the Eiberg Basin (Northern Calcareous Alps, Austria). *Review of Palaeobotany and Palynology, 156,* 376–400.

Brenner, W. (1986). Bemerkungen zur Palynostratigraphie der Rhät-Lias-Grenze in SWDeutschland. *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen, 173,* 131–166.

Etter, W. (2016). Palaeoecology of the Lower Jurassic Schambelen member of northern Switzerland. In: *Swiss geoscience meeting*, Abstract Volume, pp. 144–145.

Etzold, A., Franz, M., & Heunisch, C. (2010). Die Forschungsbohrung Trossingen (Baden- Württemberg) und Ausführungen zum Knollenmergel und Oberkeuper der Umgebung. *LGRB Informationen, 25,* 105–142.

Felber, P. (2006). *Die klassische Fossilienfundstelle Schämbelen (Insektenmergel, unterer Lias) in Windisch.* Kt. Aargau: Unpublished report.

Fischer, H., Hauber, L., & Oesterle, H. (1964). Das Rhät und der untere Lias in der Baugrube des Schulhauses Erlimatt in Pratteln. *Tätigkeitsbericht der naturforschenden Gesellschaft Baselland, 24,* 93–102.

Fischer, J., Voigt, S., Franz, M., Schneider, J., Joachimski, M., Tichomirowa, M., et al. (2012). Palaeoenvironments of the late Triassic Rhaetian Sea: Implications from oxygen and strontium isotopes of hybodont shark teeth. *Palaeogeography, Palaeoclimatology, Palaeoecology, 353–355,* 60–72.

Galli, M. T., Jadoul, F., Bernasconi, S. M., & Weissert, H. (2005). Anomalies in global carbon cycling and extinction at the Triassic/Jurassic boundary: evidence from a marine C-isotope record. *Palaeogeography, Palaeoclimatology, Palaeoecology, 216,* 203–214.

Hallam, A. (2001). A review of the broad pattern of Jurassic sea-level changes and their possible causes in the light of current knowledge. *Palaeogeography, Palaeoclimatology, Palaeoecology, 167,* 23–37.

Hallam, A., & Wignall, P. B. (1999). Mass extinctions and sea-level changes. *Earth-Science Reviews, 48,* 217–250.

Heer, O. (1865). *Die Urwelt der Schweiz.* Zürich: Schulthess.

Hesselbo, S. P., Robinson, S. A., Surlyk, F., & Piasecki, S. (2002). Terrestrial and marine extinction at the Triassic–Jurassic boundary synchronized with major carbon-cycle perturbation: a link to initiation of massive volcanism? *Geology, 30,* 251–254.

Hesselbo, S.P., Robinson, S.A., & Surlyk, F. (2004). Sea-level changes and facies development across potential Triassic-Jurassic boundary horizons, SW Britain. *Geological Society of London Journal*, *161*, 365–379.

Heunisch, C. (1996). Palynologische Untersuchungen im oberen Keuper Nordwestdeutschlands. *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen, 200,* 87–105.

Heunisch, C. (1999). Die Bedeutung der Palynologie für die Biostratigraphie und Fazies in der Germanischen Trias. In N. Hauschke & V. Wilde (Eds.), *Trias, eine ganz andere Welt* (pp. 207–220). München: Verlag Dr. Friedrich Pfeil.

Hillebrandt, A. V., Krystyn, L., Kürschner, W. M., Bonis, N. R., Ruhl, M., Richoz, S., et al. (2013). The global stratotype sections and point (GSSP) for the base of the Jurassic System at Kuhjoch (Karwendel Mountains, Northern Calcareous Alps, Tyrol, Austria). *Episodes, 36,* 162–198.

Hochuli, P. A., Colin, J. P., & Vigran, J. O. (1989). Triassic biostratigraphy of the Barents Sea area. In J. D. Collinson (Ed.), *Correlation in hydrocarbon exploration* (pp. 131–153). London: Graham and Trotman.

Jordan, P. (1983). Zur Stratigraphie des Lias zwischen Unterem Hauenstein und Schinznach (Solothurner und Aargauer Faltenjura). *Eclogae Geologicae Helvetiae, 76*(2), 355–379.

Jordan, P., Pietsch, J. S., Bläsi, H., Furrer, H., Kündig, N., Looser, N., et al. (2016). The middle to late Triassic Bänkerjoch and Klettgau formations of northern Switzerland. *Swiss Journal of Geosciences, 109*(2), 257–284.

Kräusel, R. (1955). Die Keuperflora von Neuewelt bei Basel. *Abhandlungen der Schweizerischen paläontologischen Gesellschaft, 71,* 1–27.

Kräusel, R. (1959). Die Keuperflora von Neuewelt bei Basel. *Abhandlungen der Schweizerischen paläontologischen Gesellschaft, 77,* 1–19.

Kräusel, R., & Schaarschmidt, F. (1966). Die Keuperflora von Neuewelt bei Basel. *Abhandlungen der Schweizerischen paläontologischen Gesellschaft, 84,* 1–64.

Kürschner, W. M., & Herngreen, G. F. W. (2010). Triassic palynology of central and northwestern Europe: a review of palynofloral diversity patterns and biostratigraphic subdivisions. *Geological Society, London, Special Publications, 334,* 263–283.

Leschik, G. (1955). Die Keuperflora von Neuewelt bei Basel. II. Die Iso- und Mikrospuren. *Abhandlungen der Schweizerischen paläontologischen Gesellschaft, 72,* 1–70.

Leuthardt, F. (1903). Die Keuperflora von Neuewelt bei Basel, 1. Teil. *Abhandlungen der Schweizerischen paläontologischen Gesellschaft, 30,* 1–23.

Leuthardt, F. (1904). Die Keuperflora von Neuewelt bei Basel, 2. Teil. *Abhandlungen der Schweizerischen paläontologischen Gesellschaft, 31,* 24–46.

Lindström, S. (2016). Palynofloral patterns of terrestrial ecosystem change during the end-Triassic event—a review. *Geological Magazine, 153,* 223–251.

Lindström, S., van de Schootbrugge, B., Dybkjær, K., Pedersen, G. K., Fiebig, J., Nielsen, L. H., et al. (2012). No causal link between terrestrial ecosystem change and methane release during the end-Triassic mass-extinction. *Geology, 40,* 531–534.

Lindström, S., van de Schootbrugge, B., Hansen, K. H., Pedersen, G. K., Alsen, P., Thibault, N., et al. (2017). A new correlation of Triassic-Jurassic boundary successions in NW Europe, Nevada and Peru, and the Central Atlantik Magmatic Province: A timeline for the end-Triassic mass extinction. *Palaeogeography, Palaeoclimatology, Palaeoecology, 478,* 80–102.

Looser, N., Furrer, H., Hochuli, P. A. & Bernasconi, S. M. (2017) Environmental changes at the Triassic–Jurassic Boundary in Northern Switzerland—Insights from stable carbon and nitrogen isotope. Geochemistry, Sedimentology and Palynology. Bridging gaps and generations in Swiss sedimentology. *Swiss Journal of Geosciences* (**submitted**).

Lund, J. J. (1977). Rhaetic to Lower Liassic palynology of the onshore south-eastern North Sea Basin. *Danmarks Geologiske Undersøgelse II*, 109, 1–129 (Række).

Maisch, M. W., Reisdorf, A. G., Schlatter, R., & Wetzel, A. (2008). A large skull of Ichthyosaurus (Reptilia: Ichthyosauria) from the Lower Sinemurian (Lower Jurassic) of Frick (NW Switzerland). *Swiss Journal of Geosciences, 101,* 617–627.

Matter, A., Peters, T., Bläsi, H. R., Meyer, J., Ischi, H., & Meyer, C. (1988). Sondierbohrung Weiach Untersuchungsbericht (Gemeinde Weiach, Kanton Zürich, Schweiz), Textband. Nagra Technischer Bericht, NTB 88-08. *Beiträge zur Geologie der Schweiz, Geotechnische Serie, 73,* 1–183.

Meyer, M. (2001). Die Geologie des Adlertunnels. *Bulletin für angewandte Geologie, 6,* 199–208.

Meyer, C.A., Furrer, H. (1995) Taphonomie und paläoökologische Rekonstruktionen: Beispiele aus dem Mesozoikum des Jura. *Eclogae Geologicae Helvetiae*, *88*, 711–720.

Nagra (2001). Sondierbohrung Benken Untersuchungsbericht. Textband. Nagra Technischer Bericht NTB 00-01. Wettingen: Nagra.

Nitsch, E., Seegis, D., Vath, U., & Hauschke, N. (2005). Sedimente und Sedimentationspausen im deutschen Keuper: Wie vollständig ist die Überlieferung der späten Triaszeit? *Newsletters on Stratigraphy, 41,* 225–251.

Raup, D. M., & Sepkoski, J. J. (1982). Mass extinction in the marine fossil record. *Science, 215,* 1501–1503.

Reisdorf, A. G., Wetzel, A., Schlatter, R., & Jordan, P. (2011). The Staffelegg Formation: a new stratigraphic scheme for the Early Jurassic of northern Switzerland. *Swiss Journal of Geosciences, 104,* 97–146.

Riding, J. B., Mantle, D., & Backhouse, J. (2010). A review of the chronostratigraphical ages of Middle Triassic to Late Jurassic dinoflagellate cyst biozones of the North West Shelf of Australia. *Review of Palaeobotany and Palynology, 162,* 543–575.

Ruhl, M., Kürschner, W. M., & Krystyn, L. (2009). Triassic–Jurassic organic carbon isotope stratigraphy of key sections in the western Tethys realm (Austria). *Earth and Planetary Science Letters, 281,* 169–187.

Sander, P. M. (1992). The Norian Plateosaurus bonebeds of central Europe and their taphonomy. *Palaeogeography, Palaeoclimatology, Palaeoecology, 93,* 255–299.

Scheuring, B. W. (1970). Palynologische und palynostratigraphische Untersuchungen des Keupers im Bölchentunnel (Solothurner Jura). *Schweizerische paläontologische Abhandlungen, 88,* 1–119.

Schlatter, R. (1975). Geologische und paläontologische Untersuchungen im Unteren Lias des Donau-Rheinzuges und im Kanton Aargau. Unpublished Diplomarbeit, ETH Zürich.

Schlatter, R. (1983). Erstnachweis des tiefsten Hettangium im Klettgau (Kanton Schaffhausen, Schweiz). *Mitteilungen der naturforschenden Gesellschaft Schaffhausen, 32,* 159–175.

Schuurman, W. M. L. (1979). Aspects of late Triassic palynology. 3. Palynology of latest Triassic and earliest Jurassic deposits of the northern Limestone Alps in Austria and southern Germany, with special reference to a palynological characterization of the Rhaetian Stage in Europe. *Review of Palaeobotany and Palynology, 27,* 53–75.

Stampfli, G. M., & Kozur, H. W. (2006). Europe from the Variscan to the Alpine cycles. In D. G. Gee, & R. A. Stephenson (Eds.), *European lithosphere dynamics* (vol. 32, pp. 57–82). London: Memoir of the Geological Society.

Tanner, K. M. (1978). Die Keuper-Lias Fundstelle von Niederschönthal, Kanton Baselland. *Bulletin der Schweizerischen Vereinigung von Petroleum-Geologen und –Ingenieuren, 44,* 13–23.

Traverse, A. (2007). *Paleopalynology*. Dordrecht: Springer.

van de Schootbrugge, B., Quan, T. M., Lindström, S., Püttmann, W., Heunisch, C., Pross, J., et al. (2009). Floral changes across the Triassic/Jurassic boundary linked to flood basalt volcanism. *Nature Geoscience, 2,* 589–594.

Visscher, H., Schuurman, W. M. L., & van Erve, A. W. (1980). Aspects of a palynological characterization of Late Triassic and Early Jurassic "Standard" units of chronostratigraphical classification in Europe. *Proceedings of the International Conference IV, Lucknow, 2,* 281–287.

Weiss, M. (1989). Die Sporenfloren aus Rät und Jura Südwest-Deutschlands und ihre Beziehung zur Ammonitenstratigraphie. *Palaeontographica Abteilung B, 215,* 1–168.

Woollam, R., & Riding, J. B. (1983). Dinoflagellate cyst zonation of the English Jurassic. *Institute of Geological Sciences Report*, 83/2.

Ziegler, P. A. (1990). *Geological atlas of Western and Central Europe* (2nd edn.). *Shell Internationale Petroleum Maatschappij B.V.* Bath: Geological Society Publishing House.