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PALYNOLOGY AND CHEMOSTRATIGRAPHY OF MIDDLE TRIASSIC SUCCESSIONS IN NORTHERN SWITZERLAND (WEIACH, BENKEN, LEUGGERN) AND SOUTHERN GERMANY (WEIZEN, FREUDENSTADT)

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*Abstract***.** New Anisian to Ladinian palynology, palynofacies and stable carbon isotope records are reported for the Middle Triassic from deep Swiss wells (Weiach, Benken, Leuggern), well B3/13 (Weizen, S-Germany) and the type area of the Freudenstadt Formation in southern Germany.

A wide spectrum of moderately to well-preserved palynomorphs represent a high Middle Triassic plant diversity. Based on the distribution of diverse spore-pollen assemblages five Anisian Palynozones (A–E) and two Ladinian ones (F, G) are differentiated. Throughout these Palynozones the occurrence of spores and pollen, assigned to plant groups so far known only from the Palaeozoic, shed a new light on the evolution of plant assemblages during the Triassic. The comparison of Palynozones A–G with palynostratigraphic schemes from the central part of the Germanic Basin and from the Tethyan realm demonstrate the regional variability of marker species ranges – especially for the Anisian.

In agreement with the lithological record, two prominent transgressive events (Lower Muschelkalk, Upper Muschelkalk) are indicated by increased abundances of marine particulate organic matter in palynofacies data. Marginal marine influence is documented at the base of the studied interval, comprising the Buntsandstein and the base of the Lower Muschelkalk. Carbonate carbon isotopes data show a negative shift at the boundary between Lower and Middle Muschelkalk. Coincidently, a prominent change in relative abundances of climate-sensitive plant groups (e.g. *Triadispora* spp. vs. Pteridophytes) indicate a change to relatively dryer climatic conditions during the Middle Muschelkalk.

Status of Anisian palynological research and goal of the present study

The Middle Triassic is often considered to represent the time when plants had fully recovered after the Permian–Triassic and Early Triassic crises (e.g., Looy et al. 1999). Palynology is an important tool to assess the diversity of floras, since plant macro-remains are comparatively rare and show a more erratic geographic and stratigraphic distribution. In most areas, the Early Triassic is characterised by poorly diversified palynofloras. In the Germanic Basin and in the Southern Alps Early Triassic palynological assemblages often consist of a few species, mostly spores (e.g., Orłowska-Zwolińska

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1984; Reitz 1988; Spina et al. 2015), whereas in other areas, parts of the Early Triassic yield well-diversified assemblages (e.g., Barents Sea, see Vigran et al. 2014 and refs. therein; and Antarctica, Lindström & McLoughlin 2007). In contrast Middle Triassic palynomorphs seem to be much more diversified, but for some reasons Anisian assemblages of the Germanic Basin are relatively poorly known, and studies including more than a few marker species are rare (i.e., Heunisch 1999, in press; Orłowska-Zwolińska 1985). Kürschner & Herngreen (2010) compiled the biostratigraphic results of numerous studies from the Germanic realm and proposed a new zonation scheme (for additional references see Kürschner & Herngreen 2010). Attempts have been made to correlate the palynological successions of the Germanic realm with the better-calibrated zonation scheme from the Southern Alps and Hungary (e.g., Van der Eem 1983; Brugman 1986; Kürschner & Herngreen 2010), but this correlation is hampered by pronounced regional differences in the composition of the palynological assemblages and by possibly diverging ranges of the marker species (van der Eem 1983; Brugmann 1986; Kustatscher & Roghi 2006; Hochuli et al. 2015). Moreover, the ranges of most of the few stratigraphic marker species generally mentioned lack independent age control.

For some markers similar ranges are generally assumed over distant areas (e.g., *Densoisporites nejburgii* and *Stellapollenites thiergartii*); other markers are restricted to the Tethyan realm (e.g., *Strotersporites tozeri*) or to the Germanic Basin (e.g., *Tsugaepollenites oriens*), respectively.

Contrary to the Anisian, terrestrial or marginal marine sections of the Ladinian and younger intervals attracted more interest and were extensively studied (e.g., Scheuring 1970; Heunisch 1986; Mädler 1964; Klaus 1964; Orłowska-Zwolińska 1983). Numerous reports have been generated by Dutch palynologists although only relatively few publications are accessible in the literature (for lists see Kürschner & Herngreen 2010 and Heunisch in press). Detailed range charts are essentially missing. Thus, in this study reference is made only to published reports.

In an attempt to improve coverage and age calibration in this article we present and discuss new palynological and palynofacies results along with stable carbon isotope data from cores and outcrops of Middle Triassic (Anisian – Ladinian) Muschelkalk successions of the southernmost part of the Triassic Germanic Basin (northern Switzerland and southern Germany) (Fig. 1). Unfortunately, the temporal calibration of data from marine sections in the epicontinental Germanic domain is hampered by poor and only punctual age-diagnostic biostratigraphic constraints. In spite of this shortcoming, we consider the few ammonoid data from this domain as principal guides for a reliable chronostratigraphic comparison with open marine counterparts of Western Tethys where well-defined Middle/Upper Anisian (Pelsonian - Illyrian) to Ladinian (Fassanian - Longobardian) successions have been described (e.g., Brack et al. 1999, 2005). Thus, a combination of available stratigraphic information from southern Germany and northern Switzerland allows us to compare the new data within a larger framework of Triassic successions throughout the Germanic Basin and even further.

Stratigraphic framework and age constraints

The Triassic System was established in southwestern Germany on the basis of the classical tripartition of Buntsandstein, Muschelkalk and Keuper (e.g., Hagdorn & Nitsch 2009). The assembly of clastic and carbonate sediments and evaporite intervals extends over a vast area of central and northern Europe and characterizes the infill of the epicontinental Germanic Basin. Connections between the restricted basin and open marine shelf areas surrounding western Tethys existed temporarily during Middle Triassic times (e.g., Brack et al. 1999; Bernasconi et al. 2017).

Middle Triassic sediments of southern Germany and northern Switzerland (Fig. 1) formed in a somewhat peripheral portion of the Germanic Basin, far away from the marine gates. Stratigraphic intervals in this sector are thus generally thinner when compared with successions in basin portions of central/northern Germany.

Outcrops of Middle Triassic sediments are scattered throughout the eastern Jura mountains and somewhat more continuous along a rim south and east of the Black Forest Massif (Fig. 1). In adjacent areas of northern Switzerland Triassic successions are known from a number of shallow and deep boreholes.

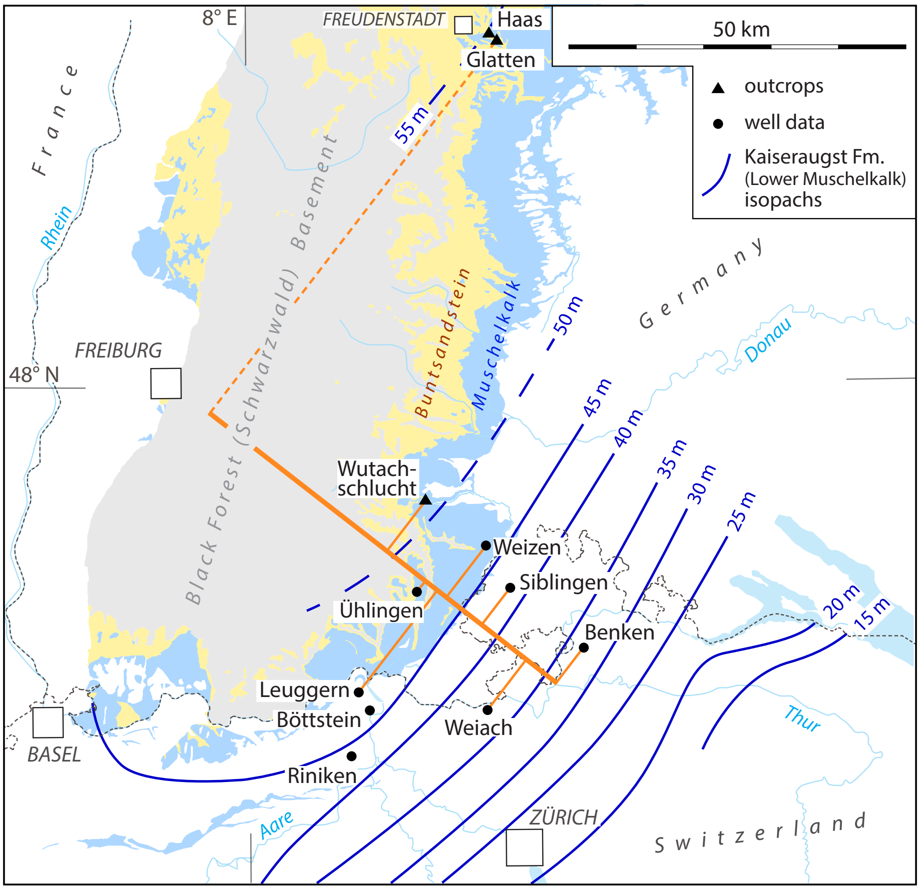


Fig. 1 - Distribution of Lower to Middle Triassic outcrops (Buntsandstein and Muschelkalk) in northern Switzerland and southern Germany (after Rupf & Nitsch 2008 [in Hagdorn & Nitsch 2009]; Jordan 2016). Isopachs of the Lower Muschelkalk are modified and extended after Jordan (2016, Fig. 5). The locations of outcrops and well data referred to in this study are indicated. The thick brown line perpendicular to the isopachs marks the trace of the pannel of projected stratigraphic data of Fig. 2 a,b.

The correlation of the borehole and outcrop successions of this study relies on the tracing of marker beds and cycles along with general stratigraphic trends. For the Lower Muschelkalk the gamma ray log correlation of Becker et al. (1997) is extended to other wells of northern Switzerland. In the Upper Muschelkalk, Pietsch et al. 2015 have identified marker beds in core and outcrop logs of northern Switzerland. Warnecke & Aigner (2019) provided a basin-wide correlation of Upper Muschelkalk cycles recognised from stacking patterns of lithofacies-types. A similar approach, though restricted to the Swiss portion and with somewhat different cycle patterns, was applied by Adams & Diamond (2019). Intervals of the Lower and Upper Muschelkalk in boreholes of northern Switzerland can thus be correlated with some confidence over a distance of a few tens of kilometres to outcrop successions along the border of the Black Forest Massif (southern Germany) (Figs. 2 and 3).

Because stratigraphic intervals for the Triassic in Germany and Switzerland have recently been assigned to formations with different names, throughout this article reference is made also to the traditional terminology as used in numerous drilling reports, e.g., by Nagra (National Cooperative for the Disposal of Radioactive Waste).

In the following paragraphs the main arguments behind the age calibration here used for the Muschelkalk stratigraphy are briefly summarized. A thorough discussion would go well beyond the scope of this article.

Following Bachmann and Kozur (2004), specific levels in the uppermost Solling Fm. and in the Röt pelites of central Germany are adopted here for the base of the Anisian stage and the Bithynian substage respectively (Fig. 2). The Bithynian interval thus comprises the main occurrences of the ammonoids *Noetlingites strombecki* and *Beneckeia buchi* as e.g., in the area around Freudenstadt (Hagdorn & Nitsch 2009). In lower and upper Silesia these taxa occur below levels with the first specimens of *Balatonites* (*B. ottonis* group) also known from Tethyan successions (see Brack et al. 1999 for a summary and references) and considered pre-Pelsonian in age (Vörös 2003a).

The Pelsonian substage largely corresponds to the *Balatonites balatonicus* and *Bulogites zoldianus* ammonoid zones of the Southern Alps (Monnet et al. 2008) and in the Balaton Highland of Hungary

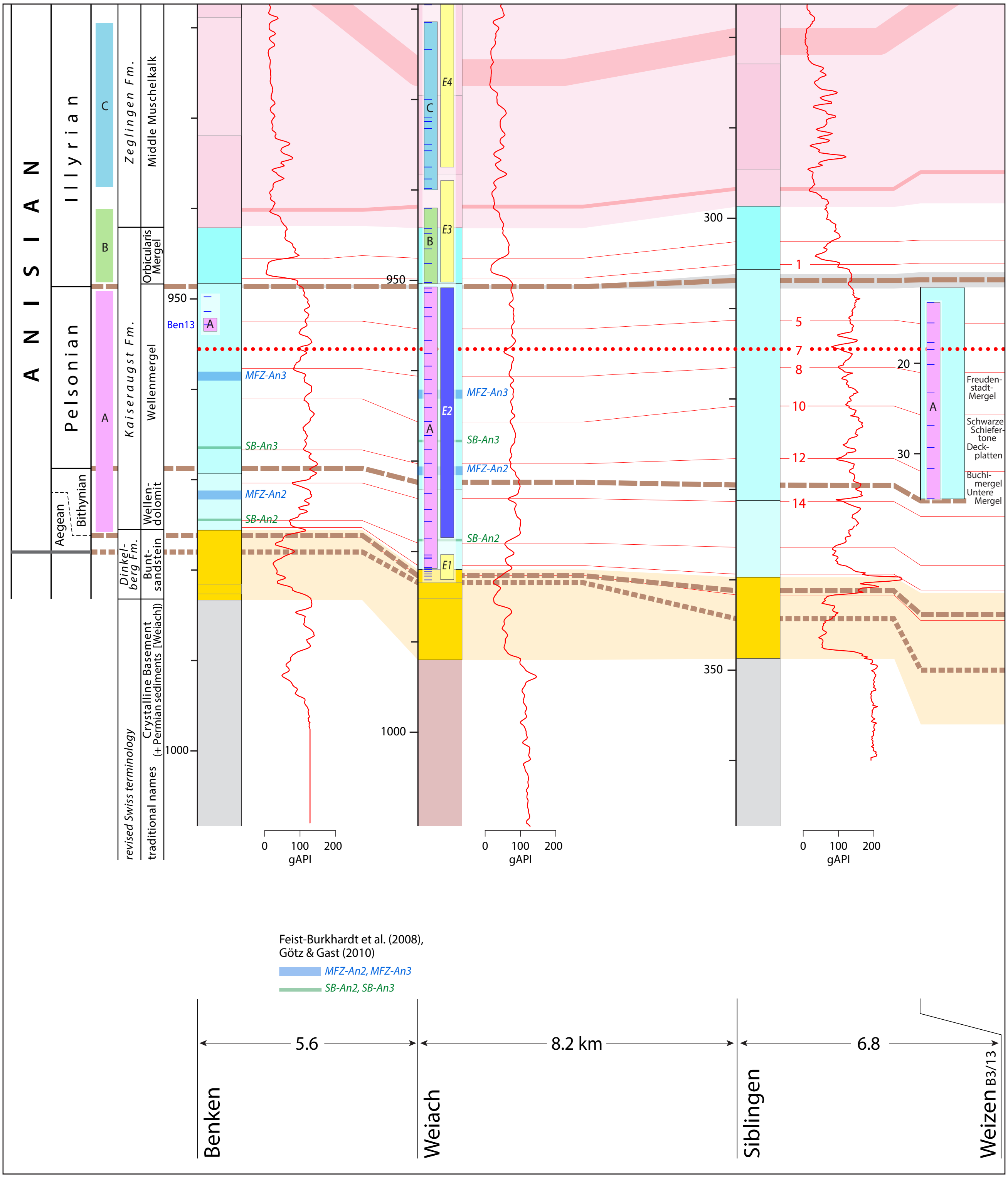


Fig. 2a - Logs of stratigraphic intervals of Buntsandstein and Lower Muschelkalk from outcrops and wells projected on a plane perpendicular to the isopachs shown in Fig. 1. The correlation of the Muschelkalk intervals is based primarily on gamma ray logs from deep Nagra-boreholes (Benken, Weiach, Siblingen, Leuggern; electronic versions courtesy of Nagra) and Ühlingen-2 (Becker et al. 1997) along with the tracing of key layers such as the "Spiriferinabank" (red dotted line) known from outcrops and their supposed positions in the Nagra-cores (well reports).

Thin blue stippled lines mark the correlation between Wutach, Ühlingen-2 and Nagra boreholes (Leuggern, Böttstein, Riniken) proposed by Becker et al. (red numbers correspond to levels labelled by these authors, 1997) and the correlation is extended here to Weiach and Benken. Names of marker beds at Ühlingen and Wutach are from Becker et al. (1997) and those for the shallow drilling (core B3/13) at Weizen from E. Nitsch (pers. comm.).

Official German formation names as well as traditional and revised recent Swiss terms (Jordan 2016) are indicated along the right and left margins of the figure, respectively.

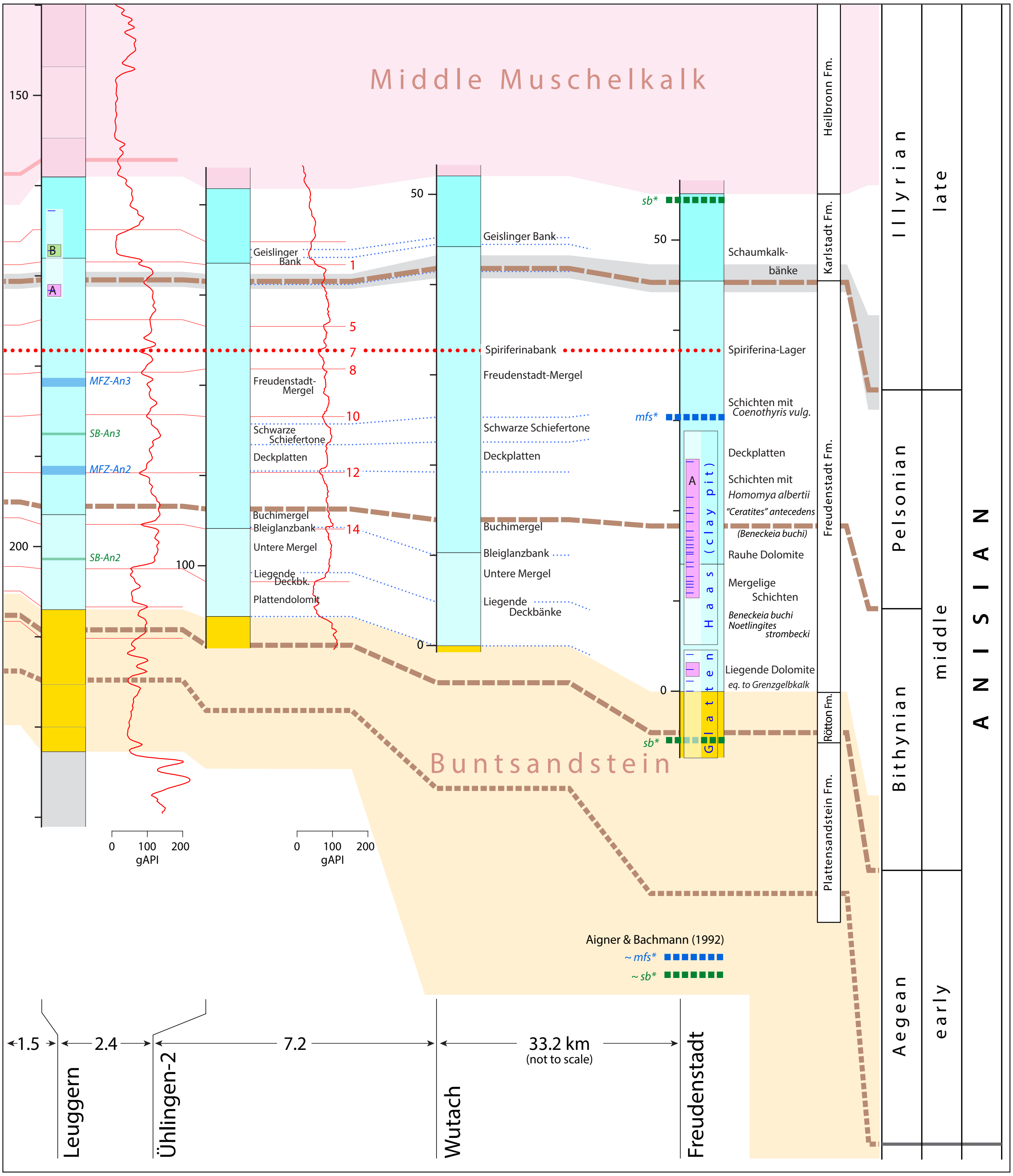


Fig. 2b - The positions of palynological samples of this study are marked by black dashes inside the logs and our Palynozones are highlighted by coloured bars labelled A to C and the POM episodes are shown besides the Palynozones as E1 to E4. According to our POM analysis episode E2 marked with blue colour is marine, in contrast to the predominantly terrestrial episodes in yellow.
The boundaries of the Anisian substages shown (brown dashed lines) correspond to the levels projected from numerous sources onto the succession at Freudenstadt and their extensions into the Swiss sector using the combined litho- and gamma ray log correlation. A supposed condensation or gap around the Pelsonian-Illyrian boundary is indicated in grey. This interval is thought to largely correspond to the Schaumkalkbank Member in central Germany (northern Württemberg, Hessen, Thüringen).
The simplified log for Freudenstadt comprises the successions reported for Stop 2 (Glatten quarry) and Stop 3 (Dietersweiler clay pit, Mundlos 1966) along with the general succession for the Lower Muschelkalk at Freudenstadt as shown in Hagdorn & Nitsch (2009). Levels of sequence stratigraphic markers are indicated by thick horizontal bars. The markers of Feist-Burkhardt et al. (2008) and Götz & Gast (2010) are labelled (SB-An2, MFZ-An2; SB-An3, MFZ-An3) for Benken, Weiach and Leuggern. The approximate levels defining Sequence 1 of the Muschelkalk in Aigner & Bachmann (1992) and Aigner et al. (1999) are also shown (mfs*, sb*).

(Vörös 2003a, b). In the Lower Muschelkalk its base lies probably somewhere within or just below the base of the "Oolite beds" of Thüringen and Hessen. At Freudenstadt, the corresponding level is assumed to be in the lower part of the "Schichten mit *Homomya alberti*", i.e. below the occurrence of "*Ceratites*" *antecedens*.

Rare ammonoids of the genus *Judicarites* in the "Schaumkalke" of Thüringen indicate a base of the Illyrian substage in the lower part of this unit in central Germany (e.g., Brack et al. 1999). In southern Germany (e.g., Freudenstadt, Wutach) only residuals of a corresponding interval may be present and a distinct stratigraphic gap is indicated, e.g., by a marked discontinuity in the $\delta^{13}C_{carb}$ data for Weiach (Fig. 4).

The base of the Ladinian Stage proposed here for the Upper Muschelkalk corresponds to a level near "Tonhorizont beta" in the *C. spinosus* ammonoid zone or slightly higher (Urlichs 1993). As shown later in this article at Weiach this level should be just above the LO of *Stellapollenites thiergartii* (top of Palynozone "E"). In the Southern Alps *S. thiergartii* has its LO in zone TrS-B at Val Gola (Hochuli et al. 2015) and this zone corresponds to a short stratigraphic interval immediately below the GSSP-level. The exact position of this marker has recently been traced from the reference section (Bagolino; Brack et al. 2005) to Seceda and other localities (Wotzlaw et al. 2018).

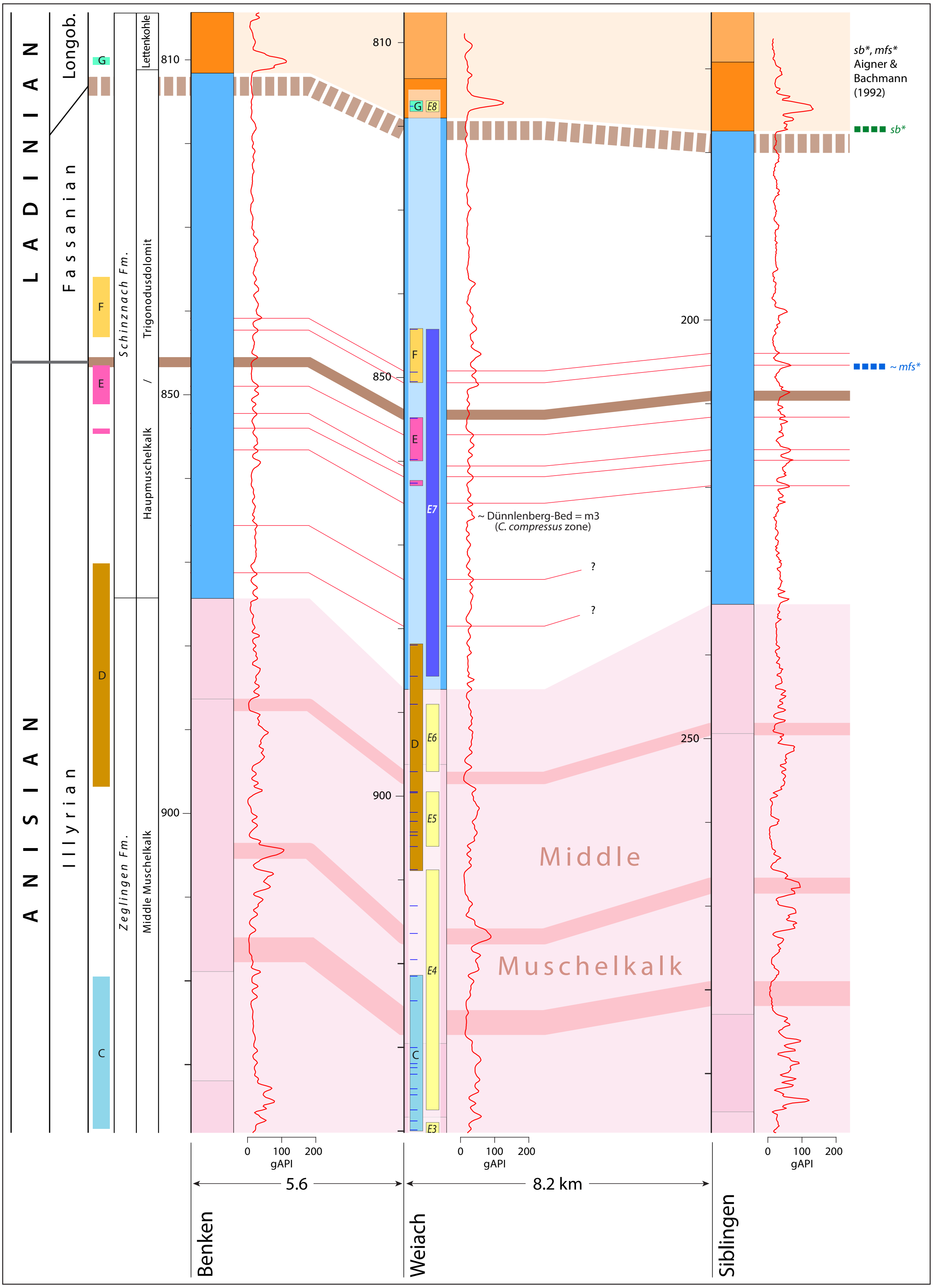
The base of the Ladinian as applied here to the Swiss Muschelkalk conforms with the age indicated by *Ceratites* collected by Merki (1961) from the only known ammonoid-bearing interval in the Upper Muschelkalk of northern Switzerland ("Mergelhorizont III" = "Dünnlenberg Bed" in Pietsch et al. 2016). Merki's (1961) specimens are stored in the reference collection at ETH Zurich. The recent (2019) re-examination of a selection of these ammonoids by Max Urlichs indeed confirms the occurrence of *Ceratites compressus* Philippi in the "Dünnlenberg Bed" and of *Ceratites evolutus* Philippi at a slightly higher level. *C. robustus* and other forms indicated by Merki (1961) are misidentifications of insufficiently preserved or juvenile specimens. The "Dünnlenberg Bed" thus clearly represents a level of the uppermost *C. compressus* ammonoid zone.

In the Weiach core, the correlative position of the "Dünnlenberg Bed" may fall into the interval 866-867 m (Fig. 3). The corresponding level indicated by Pietsch et al. (2016) on the gamma ray log of well Riniken matches the intermediate cycle of set CS3 of Warnecke & Aigner (2019, Fig. 24). According to the time frame provided by these authors, the age of this cycle should be somewhat older (*pulcher* to *robustus* zone) while the following younger cycle comprises the *compressus* zone. The reason for this slight mismatch remains unclear. It could be the result of an incorrect positioning of the level of the "Dünnlenberg Bed" on well logs or due to a miscorrelation of cycle patterns but only by a single cycle.

Note that Franz et al. (2015) use an even older level (i.e., below the *compressus* zone) for the base of their Ladinian. This deep position for the stage boundary lacks paleontological evidence and correlations of stratigraphic sequences with, e.g., the Alpine realm and based upon this age assignment are likely erroneous.

The base of the Longobardian substage (brown dashed line in Fig. 3) is uncertain because of the hitherto rather patchy ammonoid record in Tethyan reference sections. In the Southern Alps Brack et al. (2005) and Hochuli et al. (2015) have placed this boundary in the uppermost Buchenstein Fm. at Seceda, i.e., at the base of the *P. archelaus* ammonoid zone. At Weiach, palynomorph associations comparable with those of zone TrS-E at Seceda, occur in a single sample defining zone G. Hence the base of the Longobardian is drawn here provisionally somewhat below the "Lettenkohle" (= Asp Mb. of the Schinznach Fm. in Pietsch et al. 2016) but it might correspond to the gap indicated by missing cycles below this level (Warnecke & Aigner 2019).

Fig. 3 - Correlation of stratigraphic intervals of the Middle / Upper Muschelkalk - Lettenkohle in three Nagra-wells of northern Switzerland (electronic versions of gamma ray logs courtesy of Nagra). The traditional names and revised recent Swiss terms (Jordan 2016; Pietsch et al. 2016) are indicated along the left margin of the figure. The positions of palynological samples of this study are marked by black dashes and Palynozones are highlighted by coloured bars labelled C to G and the POM episodes are shown besides the Palynozones as E4 to E8. According to our POM analysis episode E7 marked with blue colour is marine, in contrast to the predominantly terrestrial episodes in yellow.
The tracing of layers based on the gamma ray logs is tentative only. It respects the proportional thicknesses of intervals. The lateral persistence of stratigraphic intervals over long distances has been shown for numerous sections along the eastern Black Forest to the Swiss border (Paul 1971).


LADINIAN
Longob.
Fassanian
ANISIAN
Illyrian
Schinznach Fm.
Zeglingen Fm.
Lettenkohle
Trigonodusdolomit / Hauptmuschelkalk
Middle Muschelkalk
G
F
E
D
C
E8
E7
E6
E5
E4
E3
810
850
900
200
250
sb*, mfs*
Aigner & Bachmann (1992)
sb*
~ mfs*
~ Dünnlenberg-Bed = m3
(C. compressus zone)
?
?
Middle
Muschelkalk
0
100
200
gAPI
5.6
8.2 km
Benken
Weiach
Siblingen

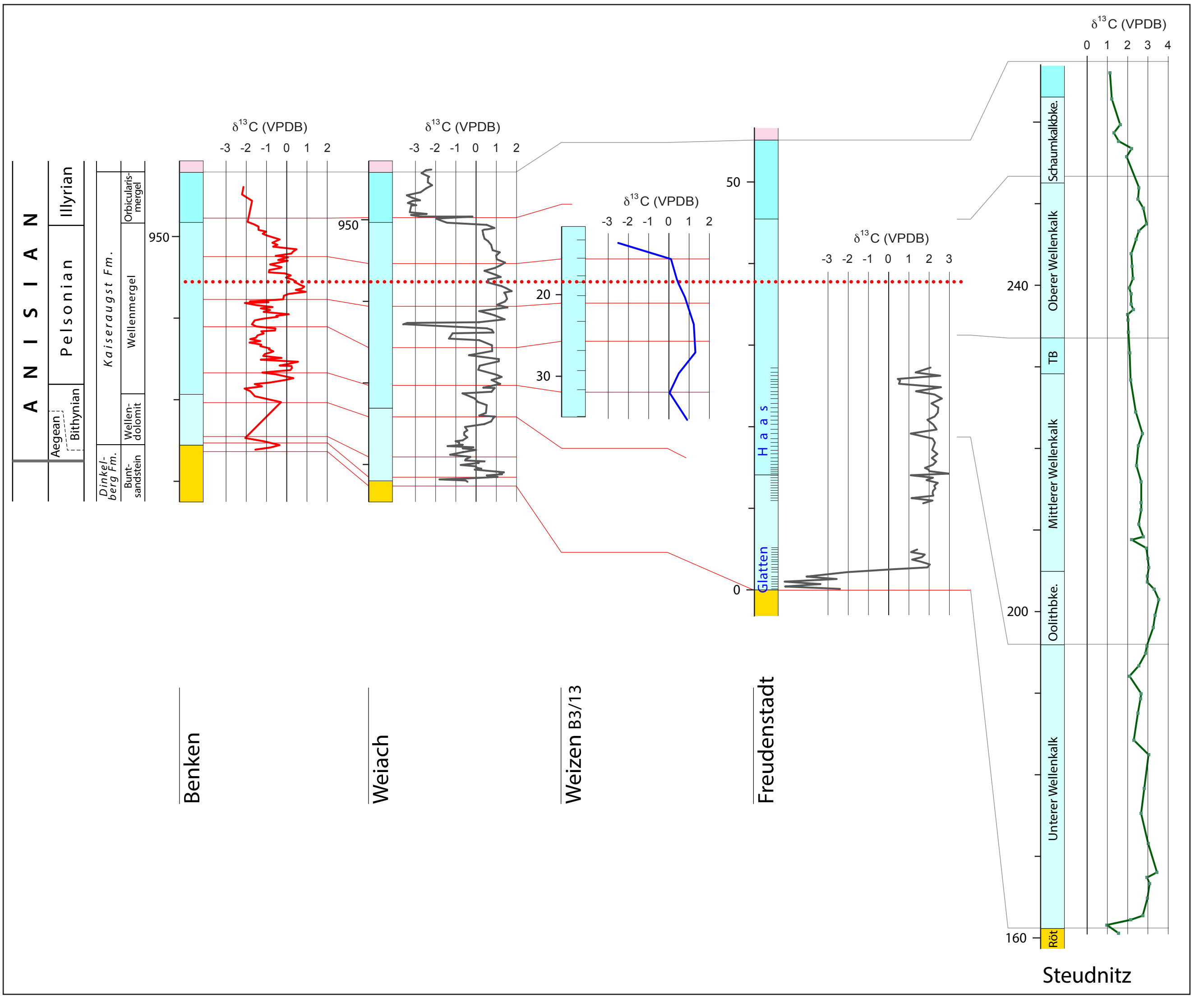


Fig. 4 - δ^{13}C-data for Benken, Weiach, Weizen, Freudenstadt and Steudnitz (Lippmann et al. 2005). The data suggest a vague lateral persistence of isotope variations on a per-mille scale in spite of an apparently systematic increase of δ^{13}C values between Benken and Freudenstadt/Steudnitz. The sharp shift at the 950-m-level of the Weiach core indicates a stratigraphic gap possibly corresponding to a part of the missing interval of "Schaumkalke" of central Germany (see also Fig. 2).

Material and methods

Studied material

This study is essentially based on samples from the fully cored Weiach well, drilled by Nagra covering the lithostratigraphic range from the Plattensandstein (Buntsandstein) up to the Lettenkohle (Matter et al. 1988a, b). Fourty-eight core samples have been selected and prepared in order to extend the stratigraphic range of the 22 samples previously studied by Feist-Burkhardt et al. (2008). For lithostratigraphic and palynological comparisons of the lower part of the succession (Plattensandstein up to the Orbicularis Mergel) additional samples were studied from two neighbouring wells, Benken (see Nagra 2001; 21 samples, Feist-Burkhardt et al. 2008) and Leuggern (see Peters et al. 1988; 26 samples, Feist-Burkhardt et al. 2008). However, the sedimentary environment of the upper part of the succession (i.e., Hauptmuschelkalk - Trigonodusdolomit) is unfavourable for the preservation of organic matter. Carbonate-rich beds are usualy dominated by strongly oxidized organic residue and thus not suitable for palynological studies. Hence, sample coverage is quite uneven, with high resolution in the lower part of the Muschelkalk and more scattered samples in its middle and upper part. Ten core samples from core B3/13 drilled into the lower part of the Lower Muschelkalk near Weizen supplement this study (Fig. 2).

In order to obtain a direct comparision of our well-based information with the Freudenstadt Formation in its type area a series of samples has been studied from the abandoned clay pits Haas (19 samples) and quarry Glatten (4 samples, Hagdorn & Nitsch 2009) near Freudenstadt (southern Germany) (Fig. 1). See Appendix A for a detailed description of outcrops and core.

All samples are stored in the repository of the Paleontological Institute and Museum under collection numbers A/VI 147, A/VI 148, and A/VI 149.

Palynofacies and palynology

For palynofacies and palynological analysis, samples of siltstones, preferentially of dark grey colour, have been selected and prepared following standard procedures for particulate organic matter (POM) and palynological analysis (Traverse 2007).

POM data is plottet as quantitative distribution of POM types. These POM types represent the optical-predicted equivalents to geochemically defined kerogen types (see Tyson 1993, 1995).

POM type I represents the least oxidation resistant fraction of the assemblages. It usually consists of algal remains such as prasinophyceae and *Botryococcus* and of amorphous organic matter (AOM). All constituents of POM type I are of aquatic origin.

POM type II comprises most of the palynomorphs (acritarchs, sporomorphs, and algal colonies (e.g. *Nostocopsis* spp. and *Plaesidictyon* spp.) as well as membranes / cuticles and degraded terrestrial organic matter. Thus, type II includes OM of marine and terrestrial origin.

POM type III consists mainly of translucent woody particles, but also includes chitineous foraminiferal linings of marine origin. Their presence probably reflects normal marine conditions.

POM type IV includes strongly oxidized or charred OM such as charcoal, inertinite and opaque phytoclasts. It represents the residual part of the POM after exposure to strong oxidation. Abundance of inertinite is commonly associated with low representation, poor preservation or absence of palynomorphs. Thus, POM type IV shows an antithetic distribution compared to the POM types I and II. Charred particles document wild fires.

Palynofacies data of 70 samples from the Weiach well and 10 samples from core B3/13 (Weizen) are based on counts of a minimum of 250 particles per sample. To prepare the palynological slides the organic residue has been slightly oxidized with fumic nitric acid. The quantitative distribution of sporomorphs is based on counts of a minimum of 250 sporomorphs in 65 samples from the Weiach well, nine samples from core B3/13 (Weizen) and 13 samples from the outcrop location s near Freudenstadt. For each sample, at least one slide has been completely scanned for rare species. Palynological zones were identified using changes in relative abundances of prominent taxa as well as first appearance and last appearance data of taxa.

Chemostratigraphy

Stable isotope measurements were performed on bulk samples from core material at regular intervals of approx. 30 cm. From the Weiach core 299 samples, from Weizen 10 samples, from Benken 100 samples, and from Freudenstadt 57 samples were analyzed.

Carbon stable isotope analysis was performed by reacting 150 -200 μg of powdered sample in the on-line automated extraction system of Finnigan (Gas Bench II) for 80 minutes in 100% H_3PO_4 at 72 °C. Measurements were carried out on a Finnigan Delta V Advantage mass-spectrometer equipped with an automated carbonate preparation system at the Institute of Geological Sciences, University of Bern, Switzerland. The isotopic ratios are quoted relative to VPDB. Isotopic reproducibility (2σ) of standard material is ±0.06 ‰ for $\delta^{13}C$ and ±0.07 ‰ for $\delta^{18}O$.

Results

Palynofacies analysis - Composition of the particulate organic matter (POM)

Palynofacies analysis revealed a variable origin and changing quantitative distribution of the particulate organic matter classified as POM type I to IV (Figs. 5 and 6). The relative abundances of the four POM types change significantly throughout the studied succession. According to these changes, the POM data in Figs. 5 and 6 are structured into episodes in order to describe the distribution consequently.

Weiach core. In the Weiach core, terrestrial organic particles (sporomorphs, woody particles and membranes) dominate in all samples (Fig. 5). Particles of marine origin (AOM, acritarchs, prasinophycean algae and foraminiferal linings) are restricted to the lower and to the uppermost part of the section (Fig. 5). The composition of the POM types reflects eight main episodes in the depositional environment.

Episode 1 (983.10 m – 980.35 m): In the interval comprising the top part of the Buntsandstein (Plattensandstein) up to the lowermost part of the Wellendolomit, the composition of the POM assemblages varies considerably. POM type III and IV (translucent woody and opaque particles) are most abundant in the majority of the samples; some of them are largely dominated by the latter group. In these samples sporomorphs occur sporadically. In the few samples where POM type II is more abundant palynomorphs are also more common. Rare acritarchs and prasinophycean algae occurring in the samples at 981.99 m, 980.69 m and 980.57 m.

Episode 2 (978.45 m – 950.82 m): This episode covers the major part of the Lower Muschelkalk including middle part of the Wellendolomit up to the top of the Wellenmergel. In contrast to the interval below, POM assemblages are quite homogeneous and show strong representation of POM type II (namely bisaccate pollen and membranes). The abundance of POM type IV is reduced. From the base up to 959.45 m a consistent increase of marine palynomorphs (acritarchs, foraminiferal linings and prasinophycean algae) can be observed. Above this level and up to 950.82 m the abundance of marine forms (namely acritarchs) decreases. In the latter sample, acritarchs and foraminiferal linings are missing. This general decrease is accompanied by an increase of POM type II (bisaccates and membranes) and POM type IV (opaque woody particles and charcoal).

Episode 3 (950.20 m – 938.97 m): This interval, comprising the Orbicularis Mergel and cycle VI of the overlying Sulfatschichten (Middle Muschelkalk), is characterised by a strong dominance of terrestrial OM, including POM type II, III and IV. Among the latter there is a noticeable increase in charcoal. The basal sample at 950.20 m is strongly dominated by membranes (POM type II) and lacks

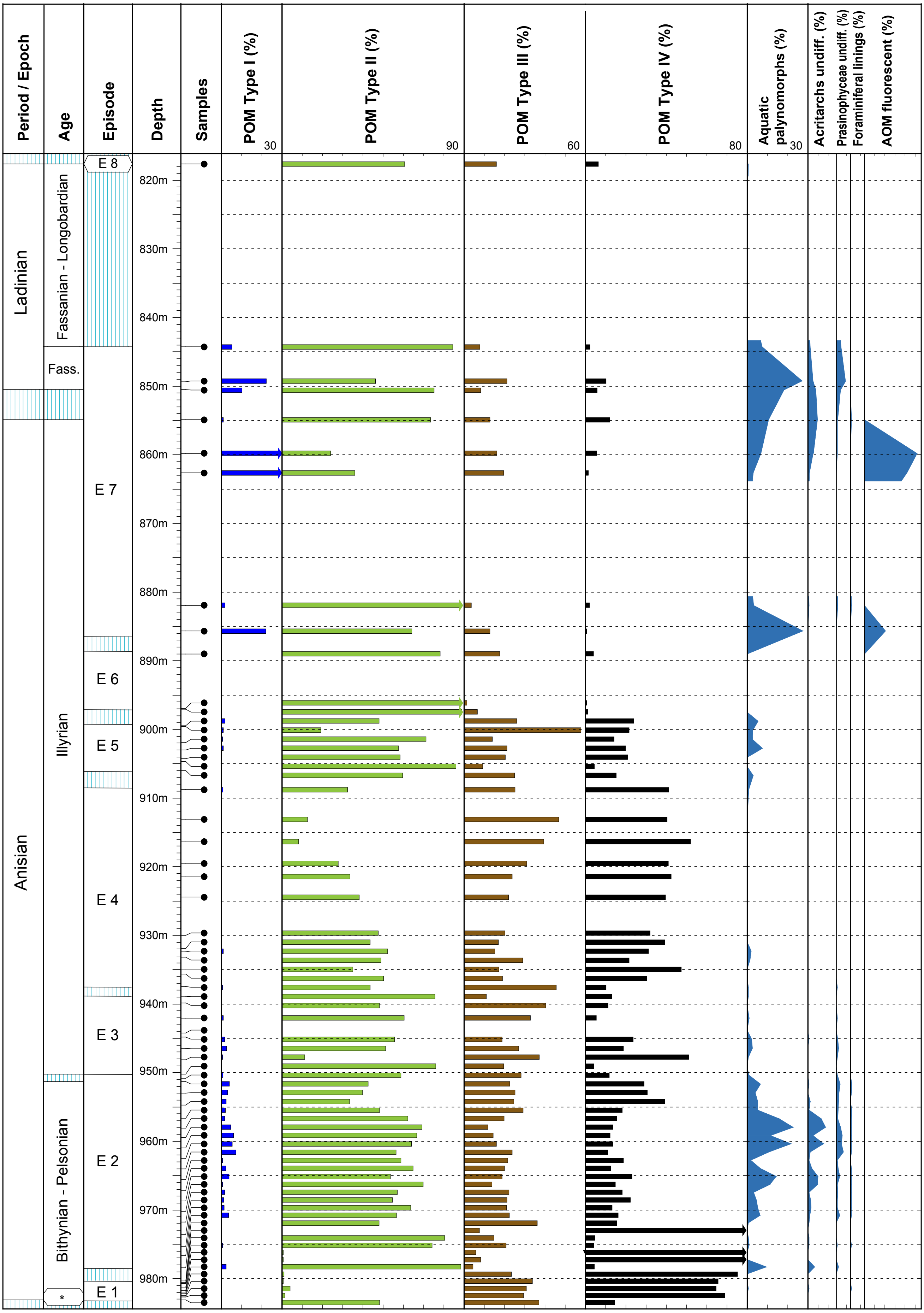


Fig. 5 - Particulate organic matter of the Weiach well. Asterisk corresponds to ?Aegean. Aquatic palynomorphs include colonies of *Nostocopsis* spp., *Plaesiodictyon* spp., and *Botryococcus* spp.

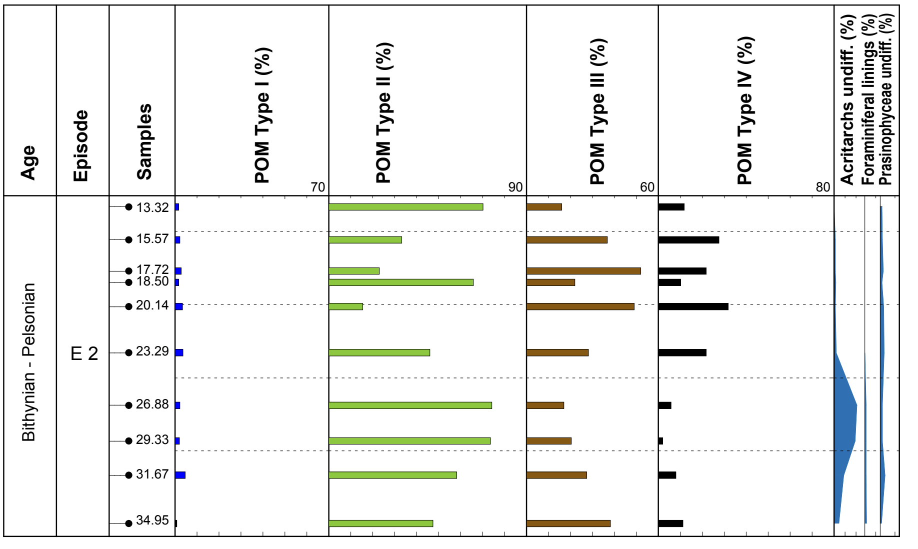


Fig. 6 - Particulate organic matter of core B3/13 Weizen well. Sample names correspond to positions in metres in the log.

marine palynomorphs. Minor marine influence can again be documented for the samples between 948.11 m and 944.81 m with the presence of prasinophycean algae and a few acritarchs. The first mentioned sample shows a distinct peak of opaque phytoclasts (Fig. 5).

Episode 4 (937.47 m – 908.80 m): Except for the lowermost sample this interval corresponds to cycles IV.A to III.A of the Sulfatschichten (Middle Muschelkalk) and it contains only terrestrial OM (Fig. 4). Generally, it is characterised by a distinct decrease in the abundance of POM type II, essentially due to the decrease of bisaccate pollen and membranes; POM type III and VI show a corresponding increase. Palynomorphs of aquatic origin (e.g., *Botryococcus* spp.) have been found in a few samples (932.41 m and 908.80 m).

Episode 5 (905.99 m – 899.47 m): This episode corresponds to the upper part of the Sulfatschichten (Middle Muschelkalk). Typical for this interval is a distinct increase in the abundance of POM type II (membranes and palynomorphs) and a corresponding decrease in the abundance of POM type IV. Aquatic palynomorphs, represented by *Botryococcus* and other algal remains (e.g., *Nostocopsis* spp.) occur in most samples.

Episode 6 (897.06 m – 889.02 m): The assemblages of this interval, representing the Dolomit der Anhydritgruppe, consist almost exclusively of membranes and some translucent woody particles.

Episode 7 (885.68 m – 844.30 m): This interval comprises the major part of the Hauptmuschelkalk and the lower part of the Trigonodus Dolomit. It shows a strong dominance of membranes similar to the interval below. However, the regular presence of AOM, acritarchs, Prasinophyceae, *Botryococus* and other algal remains showing a distinct marine influence and increased preservation of the organic matter.

Episode 8 (817.65 m): The only sample from the Lettenkohle contains only POM of terrestrial origin (mainly POM type II). There is no evidence for marine influence. Aquatic palynomorphs like *Plaesiodictyon mosellanum* of fresh water origin and a few *Botryococus* spp. can be occasionally observed.

Core B3/13 (Weizen). For palynofacies and palynological analysis of core B3/13 ten siltstone samples of the interval between 34.95 m and 13.32 m have been selected. In the studied interval POM type II dominates in most samples (Fig. 6). Particles of marine origin – namely prasinophycean algae - are present throughout the section. Acritarchs show a distinct increase in its lower part – reaching about 5% in the lowermost sample (34.95 m) to increase to over 20% at 26.88 m. Foraminiferal linings and prasinophycean algae are consistently present within this interval. The latter group reaches percentages up to 5%. Above 26.88 m the number of acritarchs decreases considerably and foraminiferal linings have not been observed (Fig. 6). The reduction in the diversity and the number of marine palynomorphs concurs with an increase in the percentage of POM type IV.

The above described succession corresponds to the one observed in the Wellenmergel of the Weiach well (episode 2). The composition of the assemblages in the interval between 29.33 m and 26.88 m, reflecting the strongest marine influence, is closely comparable to the lowermost distinct marime peak in the Weiach core. Above this level the abundance of marine forms decreases considerably in both sections. Acritarchs have not been observed in the uppermost sample of core B3/13.

Abandoned quarries near Freudenstadt. Palynofacies of the sections (Haas and Glatten quarries) has not been studied in detail. The assemblages are strongly dominated by terrestrial organic matter probably due to the comparatively high maturity of the organic matter.

Characteristics of palynological assemblages

The Middle Triassic section of the Weiach core yielded moderately to well-preserved sporomorph assemblages. Compared to other coeval successions the assemblages from the studied section seem to be exceptionally diverse. Based on the quantitative and qualitative distribution of sporomorphs seven Palynozones (A–G) have been defined (Figs. 7–11) based predominantly on data from Weiach. A summary chart of palynological data is shown in Fig. 12. Within the intervals covered by these zones the density and the number of samples varies considerably. Intervals lacking palynomorphs separate Palynozones C-D, D-E and F-G, respectively.

Results from additional samples from the Plattensandstein up to the Orbicularis Mergel in the neighbouring wells Benken and Leuggern (samples kindly provided by Annette Götz) were identical with those from Weiach. Outcrop samples from the Glatten and Haas quarries (Freudenstadt) and samples from core B3/13 (Weizen, S-Germany) yielded palynomorphs attributable to Palynozone A (Figs. 10 and 11).

The preservation of the palynomorphs from the studied wells is generally good and sporomorph coloration indicates immature conditions (Plates I-III). Converseley, the preservation of palynomorphs from the outcrops in the vicinity of Freudenstadt is rather poor and their brown coloration documents higher maturity - within the oil window.

In the Weiach core, the basal sample at 983.10 m contains only few sporomorphs, including *Densoisporites nejburgii*, *Endosporites papillatus* and *Lundbladispora* spp. thus it has not been included in Palynozone A.

Palynozone A: Weiach core 981.99 m–950.82 m; Weizen core B3/13; Freudenstadt (Haas and Glatten quarries). The most characteristic features of Palynozone A are the relatively common occurrence and diversity of trilete spores, namely representatives of the lycopods including genera like *Lycospora, Densoisporites*, *Lundbladispora, Pechorosporites* spp., and *Endosporites papillat*us (see Table 1). Bisaccate gymnosperm pollen are abundant, especially the undifferentiated (non-taeniate) and alete grains (e.g., *Voltziaceaepollenites heteromorphus*). Trilete and monolete bisaccates of the *Angustisulcites / Illinites group* are relatively common. In comparison to the overlying intervals representatives of the *Triadispora* group occur in relatively low numbers, whereas monosulcate pollen of the *Cladaitina*- and the *Cycadopites*-group are relatively common and diverse. *Doubingeriaspora filamentosa and Kuglerina meieri* appear near the top of this interval (Table 1). Noteworthy are the occurrences of the genera *Lycospora* spp., *Cladaitina* spp. and *Florinites* spp., which are generally considered to have disappeared in the Late Palaeozoic (Plate I-III) (Bek 2012; Zavatterieri & Guttierez 2012).

Palynozone B: Weiach core: 950.20 m–942.05 m. Palynozone B comprises only a short interval of the Weiach core. The most typical features are the distinct increase in the abundance of *Triadispora* spp. to over 40% and a decrease in spore abundance. Other characteristic events are listed in Table 1. The Palaeozoic elements like *Cladaitina* spp. and *Lycospora* spp. disappear within this interval.

A rare element is *Afropollis* sp., which occurs in the basal part of Palynozone B.

Palynozone C: Weiach core: 939.83 m–921.48 m. Palynozone C is also characterized by the dominance of *Triadispora;* the common occurrence of *Triadispora plicata* might represent a specific feature of this interval. In contrast to the underlying section, spores are rare and a number of taxa disappear, namely the cavate spores *Kraeuselisporites apiculatus, Pechorosporites* spp. and *Endosporites papillatus*. Characteristic of Palynozone C is the presence of *Dyupetalum vicentinensis* and the first occurrence of *Porcellispora longdonensis*. Except for another marked decrease in spore abundance, affecting all spore groups, the general aspect of Palynozone C is closely comparable to that of zone B (Table 1). An interval including several barren samples separates Palynozone C from Palynozone D.

Palynozone D: Weiach core: 908.80 m–881.94 m. Assemblages of Palynozone D are still characterised by high abundance of the *Triadispora* group and

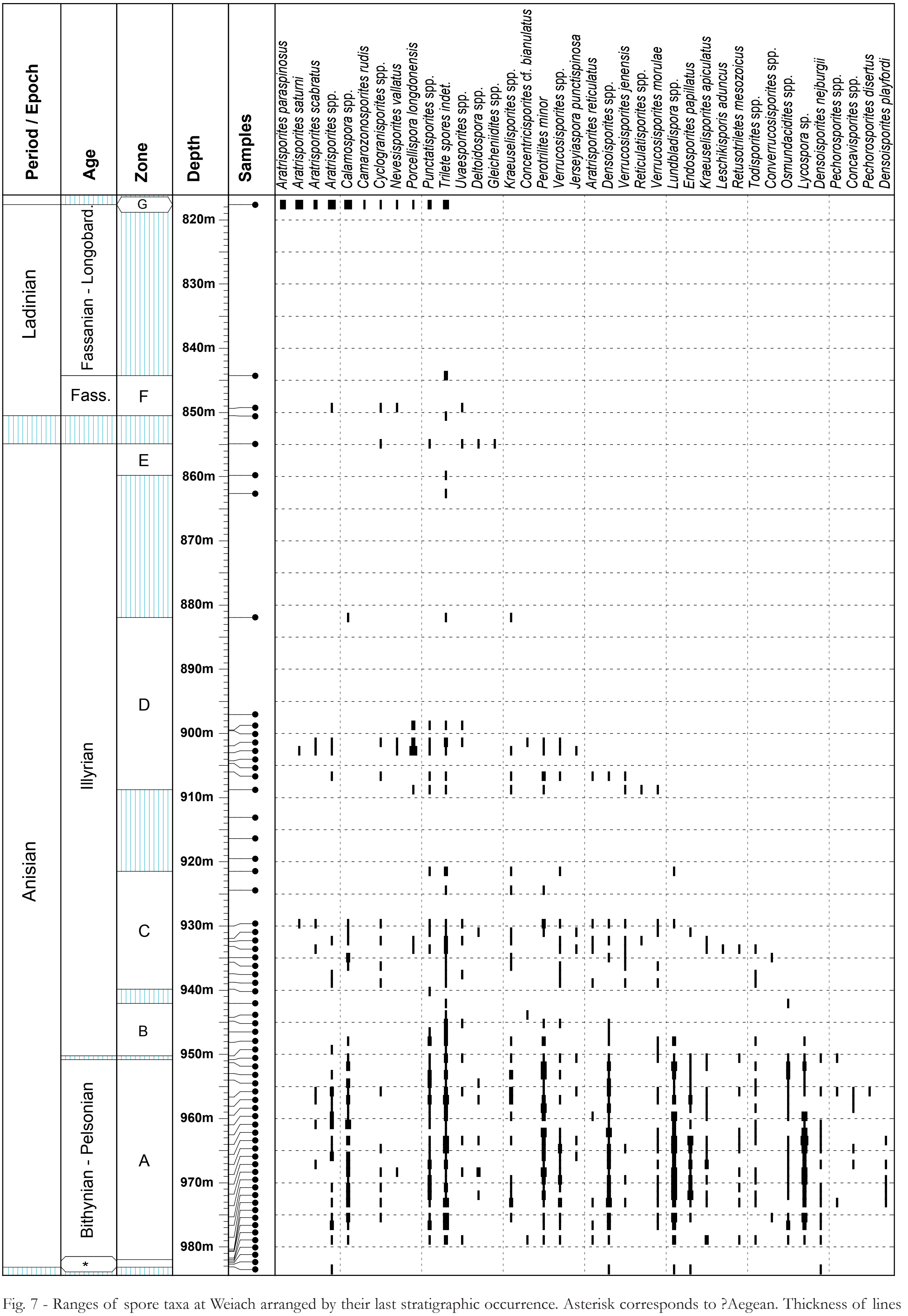


Fig. 7 - Ranges of spore taxa at Weiach arranged by their last stratigraphic occurrence. Asterisk corresponds to ?Aegean. Thickness of lines representing semiquantitive data ranging from present (thinnest line), to common, to dominant, and to abundant (thickest line).

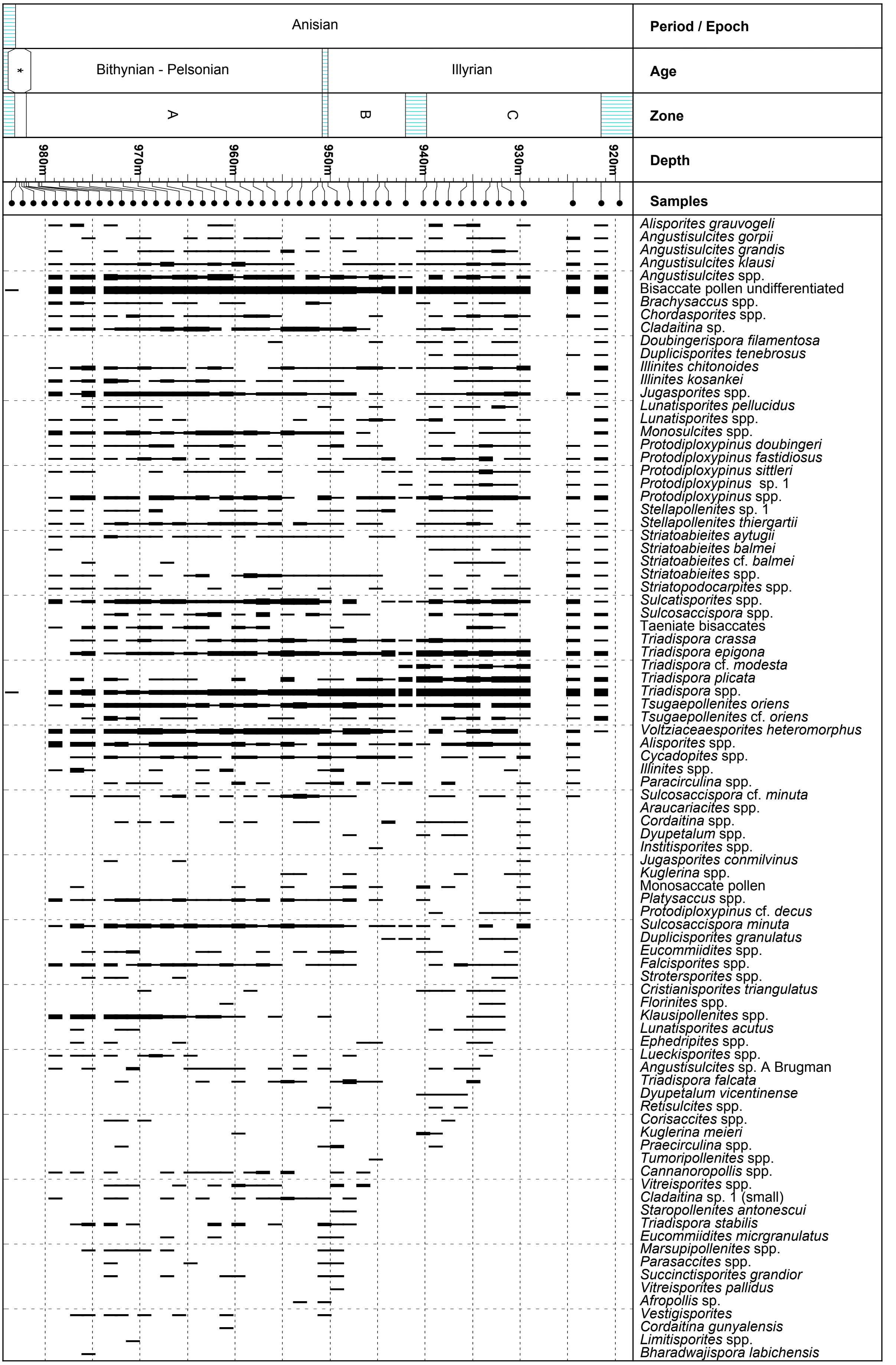


Fig. 8 - Ranges of pollen taxa at Weiach (base to 910 m) arranged by their last stratigraphic occurrence. Asterisk corresponds to ?Aegean. Thickness of lines representing semiquantitive data ranging from present (thinnest line), to common, to dominant, and to abundant (thickest line).

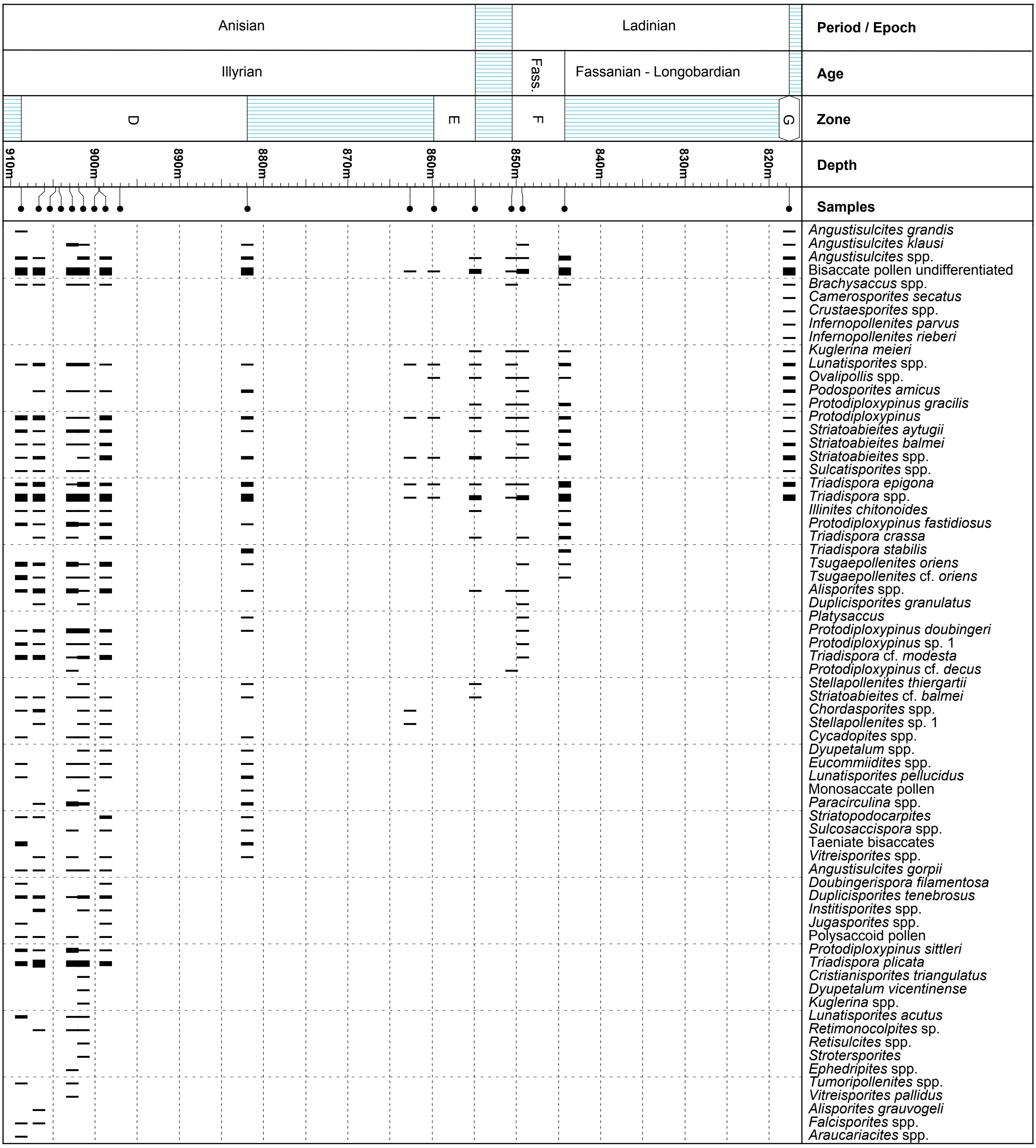


Fig. 9 - Ranges of pollen taxa at Weiach (910 m to top) arranged by their last stratigraphic occurrence. Thickness of lines representing semi-quantitive data ranging from present (thinnest line), to common, to dominant, and to abundant (thickest line).

by undifferentiated bisaccate pollen. Three groups - *Protodiploxypinus*, Circumpolles, and taeniate bisaccates - show slight increases in abundance. Last occurrences include mainly characteristic spores (see Table 1). The bryophyte spore *Porcellispora longdonensis* shows a sporadic distribution and is common in a few samples. *Podosporites amicus* appears within this zone whereas numerous species have their last occurrence. Noteworthy is the disappearance of *Cristianisporites triangulatus* and of the *Sulcosaccispora* group (Fig. 9). The "polysaccoid pollen" sensu Visscher et al. (1993) is restricted to this interval. In a previous study, Hochuli & Feist-Burkhardt (2013) described *Afropollis* spp. to occur in a distinct interval between

Interval	Palynozone	FADs	LADs and other specific features
Weiach: 817.65 m	G	*Camerosporites secatus* *Infernopollenites parvus* *Infernopollenites rieberi* *Camarozonosporites rudis*	**Increase of spore abundance and diversity** **Increase of *Ovalipollis* spp.** **Decrease of *Protodiploxypinus* spp.** ***Angustisulcites* and *Illinites* groups**
Weiach:850.50 – 844.30 m	F		*Protodiploxypinus* sp. 1 *Protodiploxypinus* cf. *decus* *Tsugapollenites oriens* *Tsugapollenites* cf. *oriens* *Ovalipollis* spp. (regular occurrence)
Weiach ?862.66, 859.79 – 854.90 m	E	*Ovalipollis* spp. *Protodiploxypinus gracilis* *Gleichenidiites* spp.	*Stellapollenites thiergartii* *Stellapollenites* sp. 1 (862.66)
Weiach 908.80 – 881.94 m	D	Polysaccoid pollen *Podosporites amicus*	*Kraeuselisporites* spp. *Perotrilites minor* *Jerseyiaspora punctispinosa* *Aratrisporites reticulatus* *Verrucosisporites morulae* *Densoisporites* spp. *Cristianisporites triangulatus* Polysaccoid pollen *Dyupetalum vicentinense* *Sulcosaccispora* spp. *Tumoripollenites* spp.
Weiach 939.83 – 921.48 m	C	*Porcellispora longdonensis* *Dyupetalum vicentinense* *Duplicisporites tenebrosus* *Protodiploxypinus* cf. *decus*	*Lundbladispora* spp. *Endosporites papillatus* *Kraeuselisporites apiculatus* *Florinites* spp. *Sulcosaccispora* cf. *minuta* *Sulcosaccispora minuta* *Cladaitina* sp. *Illinites kosankei* *Voltziaceaesporites heteromorphus* *Cordaitina* spp. *Angustisulcites* sp. A
Weiach 950.20 - 942.05 m	B	*Staropollenites antonescui* *Dyupetalum* spp. *Institisporites* spp. *Tumoripollenites* spp *Duplicisporites granulatus* *Protodiploxypinus* sp. 1	**Increase of *Triadispora* spp.** Decrease of trilete spores *Lycospora* spp. *Cladaitina* sp. 1
Weiach 981.99 – 950.82 m Weizen 34.95 – 15.57 m Freudenstadt:Quarry Glatten-Haas	A	*Doubingeriaspora filamentosa* (956.68 m) *Cordaitina gunyalensis* *Marsupipollenites* spp. *Stellapollenites thiergartii* *Stellapollenites* sp. 1 *Cristianisporites triangulatus* *Tsugapollenites oriens* *Tsugapollenites cf. oriens* *Aratrisporites reticulatus* *Lycospora* spp. *Cladaitina* sp. 1 *Cladaitina* sp. *D. playfordii* *Pechorosporites* spp. + *P. disertus*	*Densoisporites nejburgii* *D. playfordii* *Pechorosporites* spp. + *P. disertus* **Common trilete spores, namely cavate lycopod spores** *Marsupipollenites* spp.
Weiach 983.10 m	?	*Densoisporites nejburgii* *Endosporites papillatus*	

Tab. 1- Main characteristics of Palynozones in the Weiach core.

901.91 m–905.99 m.

A several metres thick interval lacking productive samples separates this interval from Palynozone E.

Palynozone E: Weiach core: ?862.66 m, 859.79 m – 854.9 m. The co-occurrence of the *Stellapollenites*- and the *Ovalipollis*-groups and the first appearance of *Protodiploxypinus gracilis* characterise Palynozone E (see Table 1). This zone is based on two samples only. Due to the poor recovery, quantitative data are lacking. One non-diagnostic sample immediately below (862.66 m) possibly belongs to this zone, but the two last mentioned markers have not been observed.

Palynozone F: Weiach core: 850.50 m – 844.30 m. This zone is marked by a number of last occurrences, namely *Tsugapollenites oriens* and species of the *Protodiploxypinus* group (see Table 1). Otherwise, the composition of the assemblages is similar to the interval below.

Palynozone G: Weiach core: 817.65 m. One sample of the *Lettenkohle* yielded a characteristic assemblage, defined here as Palynozone G. Typical features are the increase in spore abundance and diversity; especially the *Aratrisporites* group is common. Furthermore, a decrease in *Protodiploxypinus* spp., *Angustisulcites* spp., and *Illinites* spp. is observed.

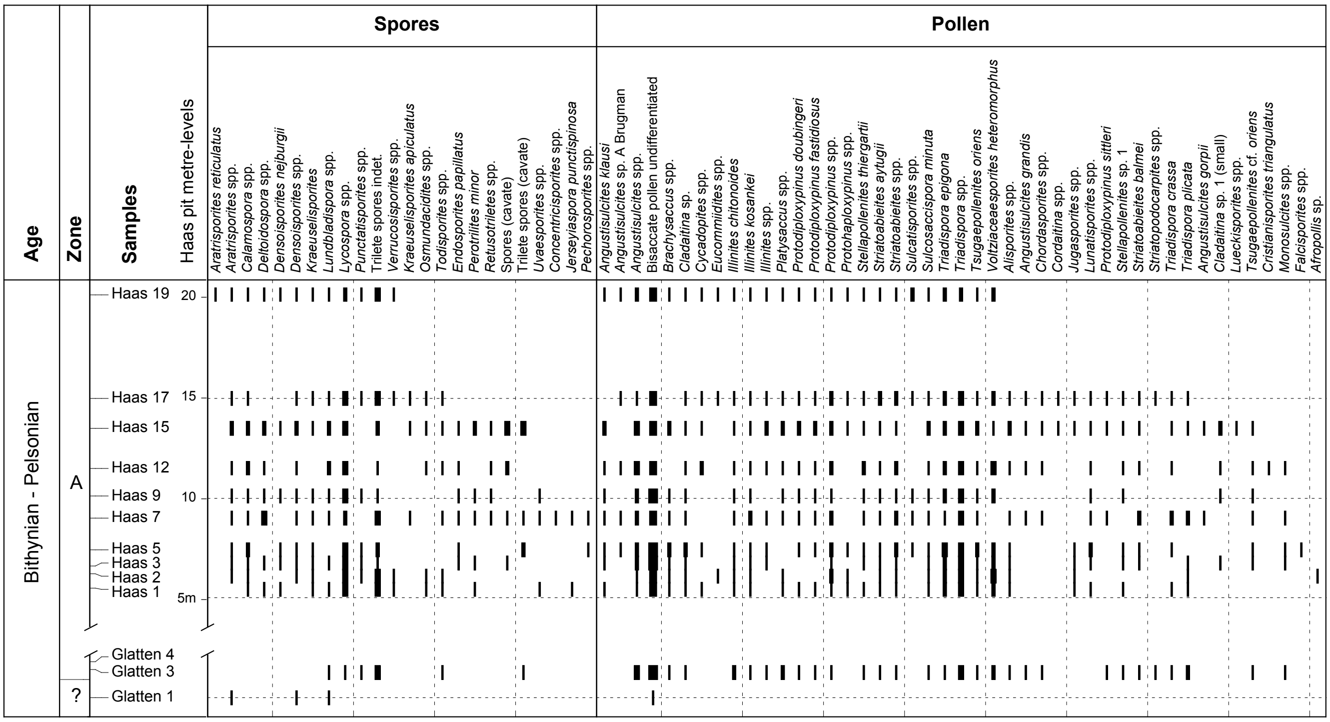


Fig. 10 - Ranges of spore-pollen taxa at Freudenstadt arranged by their last stratigraphic occurrence. ? = Age not assignable. Thickness of lines representing semiquantitive data ranging from present (thinnest line), to common, to dominant, and to abundant (thickest line). Indicated m-levels for Haas pit correspond to section illustrated by Mundlos 1966 (see Hagdorn & Nietsch 2009).

Stable carbon isotope record

Records of $\delta^{13}C$ were performed for lower to lowermost Upper Anisian intervals including the dolomitic Plattensandstein, Wellendolomit, Wellenmergel and the Orbicularis Mergel at the localities Weiach, Benken and Weizen (Fig. 1). For comparison, a new $\delta^{13}C$ record was also gained for intervals of the Freundenstadt Fm. in its type area. Figure 4 illustrates these results along with a record from the largely time-equivalent but thicker stratigraphic succession of the Jena Fm. at Steudnitz in Central Germany (Lippmann et al. 2005).

At Benken and Weiach, the records are bumpy with spikes, fluctuating between 1‰ and -2‰ and 1.5‰ and -3.5‰, respectively. Both records show a significant negative shift in the Orbicularis Mergel with values decreasing at Weiach to -3‰ (Fig. 4). The few data from Weizen, representing the middle part of the record are similar to the Weiach record.

At Freudenstadt (i.e., Haas and Glatten quarries, Fig. 4) the $\delta^{13}C$ record is again slightly spiky with a mean value around 2‰ at Haas but with a drastic increase from -6‰ at the base to 2‰ at the top of the record at Glatten.

The comparison of the new data from the southern part of the Germanic Basin with the isotope curve for Steudnitz shows a general increase of the mean $\delta^{13}C$ value from Benken to Weiach to Freudenstadt to Steudnitz from ≈ -0.5‰ to 2.5‰ (Fig. 4).

Although displaced towards negative values the isotope shift at the base of the Orbicularis Mergel of the Swiss sections could correspond to the marked decrease of $\delta^{13}C$ values between 3 and 1‰ in the upper part of the Steudnitz column (Fig. 4). The absence of a stratigraphic interval largely corresponding to the Schaumkalke at Steudnitz could explain the abrupt change at Weiach.

Discussion of palynological and palynofacies results

The new palynological data in context to literature data from the Germanic Basin and the Tethys

For the main part of the studied interval, the presence of several species such as *Stellapollenites thiergartii*, *Tsugaepollenites oriens* and *Sulcosaccispora* spp. clearly indicates an Anisian age (Brugman 1986; Hochuli 1998). Based on the scheme of Kürschner & Herngreen (2010) this interval falls within the *S.*

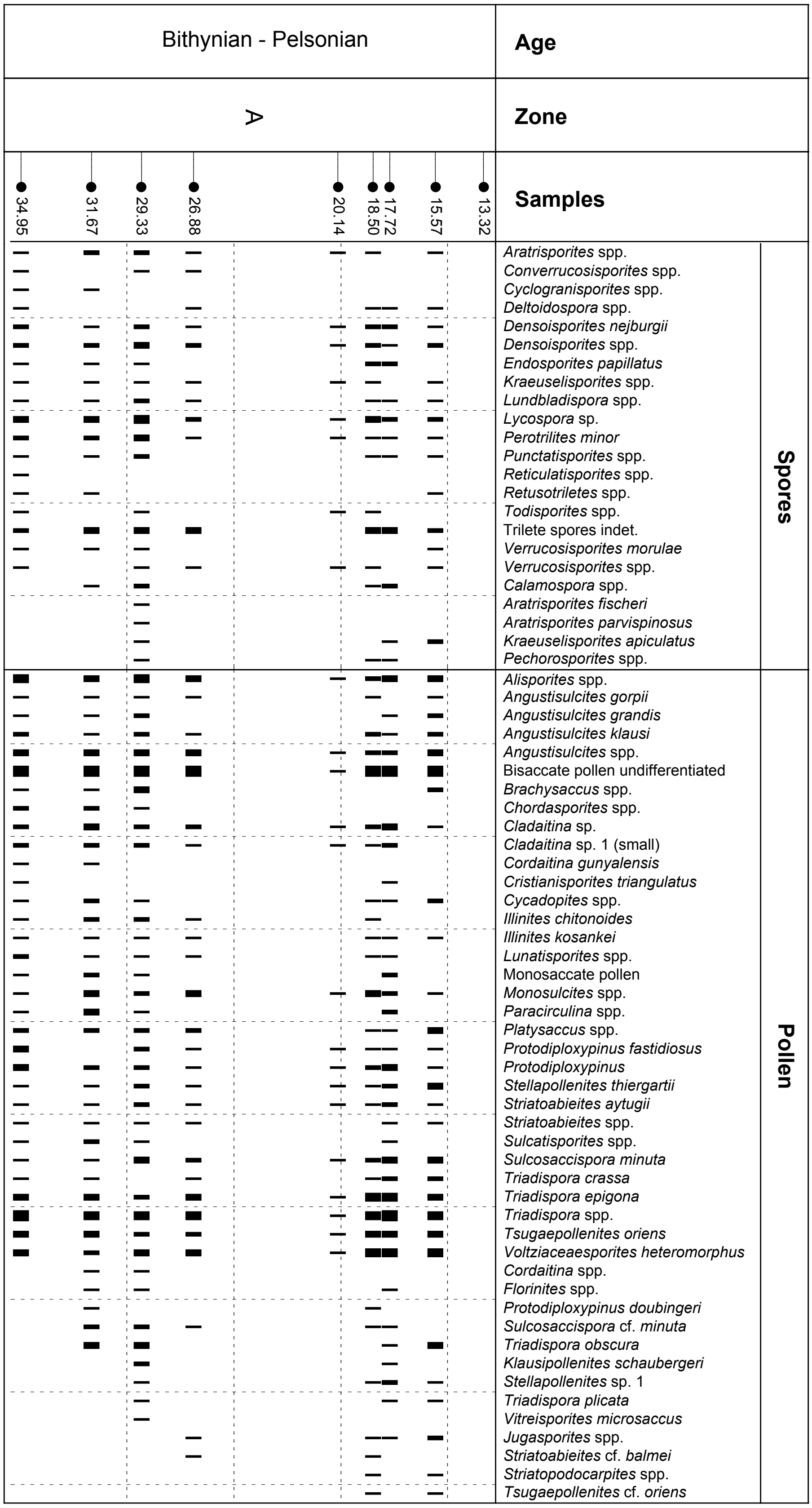


Fig. 11 - Ranges of spore-pollen taxa at Weizen arranged by their last stratigraphic occurrence. Thickness of lines representing semiquantitive data ranging from present (thinnest line), to common, to dominant, and to abundant (thickest line). Sample names correspond to positions in metres in the log.

thiergartii zone comprising the entire Anisian.

Palynozone A. Assemblages of Palynozone A have been observed between the upper part of the Buntsandstein up to the top of the Wellendomit. An ?Aegean-Bithynian age is generally attributed to the top of the Buntsandstein, whereas the

Lower Muschelkalk (Wellendomit and Wellenmergel) largely corresponds to the Bithynian-Pelsonian (Figs. 2 and 3) .

Assemblages from the upper Buntsandstein (Röt / Solling Fm.) in the Germanic Basin are known from various areas, e.g., Poland (Orłowska-Zwolińska 1977, 1984, 1985; Fijałkowska 1994; Fijałkowska-Mader 1999), Germany (Mädler 1964; Heunisch 1999, in press; Reitz 1985; Schulz 1965; Visscher et al. 1993), France and Luxembourg (Klaus 1964; Adloff & Doubinger 1969, 1977; Adloff et al. 1983), and the Netherlands (Visscher 1966; Van der Zwan & Spaak 1992). Compared to Early Triassic successions all assemblages from this interval are marked by a distinct increase of the abundance of gymnosperm pollen and the presence of the main Anisian marker *Stellapollenites thiergartii* and groups like *Tsugaepollenites, Angustisulcites, Triadispora* and *Illinites* (e.g., Reitz 1988; Heunisch in press; Orłowska-Zwolińska 1977, 1984). Most typical for this part of the section is the presence of cavate spores of lycopod affinity (*e.g., Densoisporites nejburgii, D. playfordii,* and *Lundbladispora* spp.) which are common in the Early Triassic.

Numerous palynological reports exist for the Muschelkalk of the Germanic Basin (for references see Kürschner & Herngreen 2010; Heunisch in press). The onset of the Muschelkalk is supposedly marked by the disappearance of the holdover taxa from the Early Triassic, namely *Densoisporites nejburgii* and other lycopod spores as well as a few pollen taxa, which are typical for the Rötton (e.g., *Platysaccus leschikii* and *Cordaitina gunyalensis*). In this report we document extended ranges not only of *Densoisporites nejburgii* and *Cordaitina gunyalensis,* but also of several species that were so far considered to be restricted to the Late Palaeozoic (such as *Cladaitina* spp. and *Lycospora* spp.). *Lycospora* spp. is so far typically known from the Palaeozoic (Late Devonian – Early Permian) (Bek 2012). Few younger occurrences of *Lycospora* such as in the Lower Triassic of Poland (Orłowska-Zwolińska 1977) are reported. Whether these had been reworked is not mentioned and cannot be determined. In the material presented, these taxa range up to the top of the Lower Muschelkalk (Palynozone A and B, respectively), which complicates comparison with other palynostratigraphic schemes. The mentioned species show no obvious traces of reworking, such as differing thermal alteration or preservation (Fig. 13).

Highest accordance exists between Palynozone A and assemblages described by Heunisch (1999, in press) from the upper part of the Buntsandstein and the main part of the Lower Muschelkalk and defined as Palynozone GTr 7 and GTr 8, respectively (see below).

In Germany Heunisch (1999) reported *Densoisporites nejburgii* together with *Stellapollenites thiergartii* and *Tsugaepollenites oriens* from the lower part of the upper Buntsandstein (zone GTr 7). According to the compilation of Kürschner & Herngreen (2010) zone GTr 7 is equivalent of the *Platysaccus leschikii* subzone, which is characterized - beside the last occurrence of *P. leschikii* - by the presence of *Densoisporites nejburgii* together with *Protodiploxypinus doubingeri, P. fastidioides, Illinites kosankei, I. chitonoides* and several species of the *Angustisulcites* group. Except for *Platysaccus leschikii* all species listed for this subzone are also present in Palynozone A. A characteristic feature of the upper part of the *P. leschikii* subzone is the onset of the *Triadispora* spp. acme (Kürschner & Herngreen 2010). This feature has also been observed in assemblages of zone GTr 7 (Heunisch in press). Thus, when ignoring possible regional differences, the less common occurrence of the *Triadispora* group in Palynozone A would suggest a correlation of this zone with the lower part of the Aegean *P. leschikii* subzone. However, our correlation scheme (Fig. 2) clearly indicates a Bithynian to Pelsonian age for Palynozone A.

A significant difference between the *P. leschikii* subzone of Kürschner & Herngreen (2010) and zone GTr 7 of Heunisch (1999) is the range of *Tsugaepollenites oriens*. This species is a characteristic element of zone GTr 7 and Palynozone A, whereas Kürschner & Herngreen (2010) use its first occurrence as a marker within the overlying *P. doubingeri* subzone (equivalent of GTr 8).

In the Southern Alps *Densoisporites nejburgii* has been recorded together with *Cordaitina gunyalensis, Endosporites papillatus, Platysaccus leschikii Stellapollenites thiergartii,* and *Striatoabieites balmei,* from the *conmilvinus-crassa* phase of Brugman (1986). This interval has been interpreted to correspond to the lower part of the Aegean. Although the interval lacks independent biostratigraphic control, it certainly represents the lowermost part of the Middle Triassic. The reliability of *Densoisporites nejburgii* as a marker species has been jeopardised by its report from the Pelsonian of the Dont Fm. (Kustascher & Roghi 2006) and in the Illyrian Ambata Formation (Dal Corso et al. 2015). *Cordaitina gunyalensis* has also been found in Palynozone A. In Poland *Densoisporites nejburgii* was reported to range from the middle Buntsandstein into the lower part of the upper Röt (Orłowska-Zwolińska 1977). Assemblages comparable to Palynozone A have also been recorded from the upper Röt of Poland (Orłowska-Zwolińska 1977), subsequently defined as *P. fastidioides* subzone (Orłowska-Zwolińska 1985). This author listed the regular and sometimes common occurrence of the *Protodiploxypinus* group *(P. fastidioides, P. doubingeri,* and *P. sittleri)* and the common occurrence of *Illinites chitonoides* as characteristic features of this interval. Based on this evidence the *P. fastidioides* zone is considered an equivalent of the *P. leschikii* subzone (Kürschner & Herngreen 2010). An Aegean age has been assigned to the zones GTr 7, *P. fastidioides* and the *P. leschikii* subzone (Kürschner & Herngreen 2010). In eastern France (Alsace, Lorraine) assemblages of similar composition have been described from marginal marine sediments of the lower part of the Grès à Voltzia (Adloff & Doubinger 1969). The presence of *Camerosporites secatus,* reported from these assemblages, seems to represent an essential difference to Palynozone A. However, the specimen assigned to *C. secatus* by Adloff & Doubinger (1969, plate I, Fig. 13) most probably represents a misidentified *Tsugaepollenites oriens*. Adloff & Doubinger (1969) considered the Grès à Voltzia as being of Early Triassic age. Thus relying on a conservative range of *Densoisporites nejburgii* alone would be misleading and suggest erroneously a basal Anisian age despite the Wellendolomit and Wellenmergel are Bithynian and Pelsonian in age (Fig. 2).

Differentiation of the palynological zones within the Muschelkalk is more subtle as these zones are mostly based on first appearances of a few marker species, which are generally rare (e.g., *Dyupetalum vicentinensis* and *Institisporites* spp.). The most comprehensive zonation has been published by Heunisch (1999, in press).

In her new work Heunisch (in press) defined Palynozone GTr 8 based on the co-occurrence of *S. thiergarti, C. triangulatus and T. oriens* (without mentioning *Densoisporites nejburgii).* All these species are present in Palynozone A. Palynozone GTr 8 comprises the Upper Buntsandstein (Röt Fm.) and covers the entire Lower Muschelkalk (Jena Fm.) up to the lower part of the Middle Muschelkalk (lower part of Karlstadt Fm.) The upper part of this zone (upper Karlstadt/Heilbronn Fm.) is marked by the first appearance of *Doubingerispora filamentosa* and *Kuglerina meieri*. In the Weiach core these two species first occur in the upper part of Palynozone A (Wellenmergel), thus possibly concurring with the upper part of zone GTr 8. Palynozone A falls in the interval of zone GTr 8 in the sense of Heunisch (in press) and according to Heunisch (1999) it would cover the zones GTr 7 and GTr 8. Thus an Aegean(?) to Pelsonian age is reasonable.

In addition to sporomorphs, presence and abundance of marine palynomorphs were frequently used to define palynological zones or biostratigraphic events (Orłowska-Zwolińska 1985; Fijałkowska-Mader 1999; Visscher et al. 1993), despite the fact that all the marine forms occurring in the Early and Middle Triassic are long-ranging and their abundance strongly facies dependent. However, data on these groups yield information on the depositional environment and allow for palaeogeographic considerations on the development of the basin.

Palynozone A is certainly the most peculiar assemblage when a correlation with existing schemes from the Germanic Basin and the Tethys is attempted. Some of the characteristic genera in Palynozone A (e.g., *Lycospora* spp*., Cladaitina* spp.) are new for a Middle Triassic assemblage of the Germanic Basin and other taxa show extended ranges (e.g., *D. nejburgii*) (Fig. 13). Additionally, ecological changes such as the *Triadispora* acme seem to occur later compared to other parts of the Germanic Basin, see below.

Palynozone B. Beside the disappearance of several taxa (Table 1) the essential difference between the Palynozones A and B is the distinct increase in the abundance of the *Triadispora* group. The sudden change in the sporomorph assemblages suggests a hiatus between the Wellenmergel and the Orbicularis Mergel. The onset of the abundance of *Triadispora* has been described from various levels, by Brugman (1986) from the lower part of the *crassa-thiergartii* phase, which according to this author ranges from the Aegean (*A. ugra* zone) up to the Bithynian (*A. ismidicus* zone). Kürschner & Herngreen (2010, Fig. 3) placed the acme of *Triadispora* spp. in the upper part of their *P. leschikii* zone (see above). *Kuglerina meieri* and *Doubingerispora filamentosa* both occur in the topmost part of Palynozone A. *Kuglerina meieri* ranges into the basal part of Palynozone C and *D. filamentosa* into Palynozone D. Both forms have their first appearance in the topmost part of GTr 8 (Heunisch in press). Thus, Palynozone B has a mixed character between GTr7 and upper part of GTr 8. The stratigraphic framework indicates that the top of GTr 8 (recorded in the lower part of the Heilbronn Formation) corresponds to the Orbicularis Mergel, thus, an Illyrian age is plausible.

Palynozone C. Characteristic of Palynozone C is the presence of *Dyupetalum vicentinensis* and the first occurrence of *Porcellispora longdonensis*. In the South Alpine record *D. vicentinensis* appears at the base of the *thiergartii-vicentinensis* phase (*vincentinense-antonescui* subphase) of Brugman (1986). The co-presence of *D. vicentinense* and *C. triangulatus* was observed in the Ambata Fm. of Illyrian in age (Dal Corso et al. 2015). The subsequent occurrence of *Porcellispora longdonensis* is a typical feature of the overlying *vincentinense-pallidus* subphase. According to Brugman (1986) the lower part of the *thiergartii-vicentinensis* phase, including the subphases *vincentinense-antonescui* and *vincentinense-pallidus* is of Pelsonian age and correlates with the *B. balatonicus* ammonoid zone. *Staropollenites antonescui* the marker of the *vincentinense-antonescui* subphase has not been found in our material and *Aratrisporites reticulatus,* supposedly appearing at the same level, occurs already in Palynozone A.

According to Kürschner & Herngreen (2010) *Dyupetalum vicentinensis* - regarded as a Tethyan form - has its first occurrence in the middle part of their *P. doubingeri* subzone. Other typical features of this subzone, such as the common occurrence of *P. doubingeri* and the first occurrence of *Tsugaepollenites oriens* are not applicable to our material, since *P. doubingeri* is never common and *T. oriens* occurs throughout the studied section (see above). Additionally, in our material the ranges of *Illinites kosankei* and *Dyupetalum vicentinensis* overlap in Palynozone C, whereas according to Kürschner & Herngreen (2010) *I. kosankei* should disappear prior to the first appearance of *D. vicentinensis*. Assemblages of Palynozone C have some features in common with the upper part of zone GTr 8 of Heunisch (1999) (e.g., first appearance of *Doubingerispora filamentosa* and *Kuglerina meieri* occurring in the upper part of zone GTr 8 and the last consistent occurrence of *Voltziaceaepollenites heteromorphus)*. In our material *Doubingerispora* spp. occurs sporadically in Palynozones A and B and ranges up into Palynozone D. According to Kürschner & Herngreen (2010) the *P. doubingeri* subzone coincides with zone GTr 8 and includes the interval between the uppermost part of the Röt Formation, the Jena Formation and the lowermost part of the Anhydrit Folge (i.e., Karlstadt Fm., Heilbronn Fm. and Diemel Fm.). Following the interpretation of these authors the top of the *P. doubingeri* subzone corresponds to the top of the Pelsonian. However, in Heunisch (in press) the top of GTr 8 ranges into the Heilbronn Formation, which according to the stratigraphic framework (Figs. 2 and 3) is of Illyrian age (See also Fig. 13).

Palynozone D. The undescribed form mentioned as "polysaccoid pollen" by Visscher et al. (1993) is restricted to Palynozone D. This form has been recorded from the Upper Muschelkalk of the Obernsees well in southern Germany appearing at about the same level as *P. amicus* (Visscher et al. 1993). According to Kürschner & Herngreen (2010) the appearance of *Institisporites* spp. and *Podosporites amicus* mark the *Institisporites* subzone, which represents the uppermost interval of the *S. thiergartii* zone and is considered equivalent to zone GTr 9 of Heunisch (1999) that is defined by the co-occurrence of *Institisporites* spp., *P. amicus, St. thiergartii, Tsugaepollenites oriens* and occasional *Voltziaceaepollenites heteromorphus*. With the exception of the last mentioned form all these species have been observed in Palynozone D. Assemblages of zone GTr 9 are reported from the upper part of the Middle Muschelkalk and the lower part of the Upper Muschelkalk (Heunisch 1999, in press) and cover the interval from the Heilbronn- up to the Meissner Formation. The *Institisporites* subzone and zone GTr 9 are interpreted to correspond to an Illyrian age. In the Southern Alps the palynological assemblages of this interval, possibly corresponding to the *vicentinensis - crassa* subphase of Brugman (1986) show no distinct features and provide no additional age constraints. However, due to its stratigraphic position this subphase is correlated with the Illyrian *P. trinodosus* ammonoid zone (Brugman 1986).

Palynozone E. Age diagnostic species are scarce in this zone. One of these species is *Stellapollenites thiergartii*, which is also present in GTr 9 with its last occurrence at the top of this zone (Heunisch 1999). Hochuli et al. (2015) document *Ovalipollis pseudoalatus* from the TrS-A zone (Seceda and Val Gola–Margon section, Tethyan realm). This zone has been correlated with the late Illyrian *R. reitzii* ammonoid zone. *Stellapollenites* sp. 1 is restricted to the TrS-A zone, whereas *Stellapollenites thiergartii* disappears in the overlying TrS-B zone. The TrS-B zone is correlated with the youngest Anisian *N. secedensis* zone (Brack et al. 2005; Hochuli et al. 2015). Consequently, a latest Illyrian age is proposed also for Palynozone E.

Palynozone F. According to Heunisch (in press) *Tsugapollenites oriens* disappears together with *St. thiergartii* in zone GTr 9 - at the top of the Anisian. The upper limit of zone GTr 9 falls within the upper part of the Upper Muschelkalk (basal part of Warburg Formation). In the Weiach well *T. oriens* ranges into Palynozone F, higher than *Stellapollenites* spp. However, based on the absence of *Stellapollenites* sp. 1 and *St. thiergartii* and the regular occurrence of *Ovalipollis* spp, we assign a basal Ladinian (Fassanian) age to Palynozone F.

Zone GTr 10 of Heunisch (1999) is documented from within the Warburg Fm. and marked by the first appearance of *Cordaitina minor, Cucullispora cuneata and Retisulcites perforatus,* and the common occurrence of taeniate bisaccate pollen and *Protodiploxypinus gracilis* (Heunisch in press). Only *P. gracilis* is documented to occur from the topmost sample in Palynozone E onward. The other species have not been found in the Weiach core, however, Palynozones F and G are separated by an interval of 25 m lacking palynological data (Fig. 7).

Palynozone G. Palynozone G is characterised by a significant change in the spore-pollen assemblage, with a distinct increase in the abundance and diversity of spores. A number of species has their first occurrences in this zone, namely *Camarozonosporites rudis, and Infernopollenites* spp. (Table 1).

Comparable assemblages have been described from the lower part of the Lettenkeuper from the Obernsees well (Brugman et al. 1994) as *dimorphus-saturnii* ecophase. *Heliosaccus dimorphus* and *Aratisporites saturnii* are the markers of this ecophase – however, only the latter species have been found in the Weiach core. According to Brugman et al. (1994) this phase falls within the lower part of the Longobardian.

The corresponding zone GTr 11 of Heunisch (1999), covering the Erfurt Fm. (Lettenkeuper) is defined by the first appearance of *Heliosaccus dimorphus, Echinitosporites iliacoides and Eucommiidites microgranulatus.* None of these species have been found in the studied material.

Interpretation of the palynofacies data (Weiach and Weizen cores)

High abundances of acritarchs are often associated with increased marine influence (Feist-Burkhardt et al. 2008; Tyson 1993, 1995, 1996 and references therein). Prasinophyceae are regarded as less distinct indicators of marine environments since they also occur in restricted marine and lagoonal settings (see Tyson 1995).

Episode 1: The assemblages from the lowermost part of the section including the Plattensandstein and the lower part of the Wellendolomit are characterised by strongly varying composition reflecting rapidly changing depositional environments. This concurs with the lithological interpretation of Matter et al. (1988a, b) inferring intertidal to shallow subtidal conditions. It has to be pointed out that there is no distinct change in palynofacies at the boundary between the two mentioned lithological units. The results from the present study document the first marine influence in uppermost Buntsandstein (Fig. 5). This interpretation is in accordance with the bioturbated clayey-sandy horizon at 982.55 m. The interval between 981.26 m and 980.35 m, comprising two samples barren of palynomorphs and two levels with very low representation of marine forms, probably reflects reduced marine influence. The barren interval between 981.26 m and 981.70 m with dominance of POM type IV is characterized by tepee structures, erosional surfaces and reworked dolomitic clasts (Matter et al. 1988a, b) and thus likely represents subaerial exposure during a low sea level.

Episode 2: This interval includes the upper part of the Wellendolomit and the Wellenmergel and shows a distinct increase and subsequently a decrease in the abundance of marine palynomorphs. Between 978.45 m and 959.45 m marine influence increases as inferred from higher abundance of acritarchs. Subtidal shallow marine conditions have been deduced from the lithological succession of this part of the succession (Matter et al. 1988a). Palynofacies data covering the interval between 980.35 m and 944.81 m (Wellendolomit - Orbicularis Mergel) of the Weiach and the correlative intervals of the neighbouring wells Benken and Leuggern have been published by Feist-Burkhardt et al. (2008) and Götz & Feist-Burkhardt (2012). Their maximum flooding zones of sequences An2 and An3 fall within the range of marine episode 2.

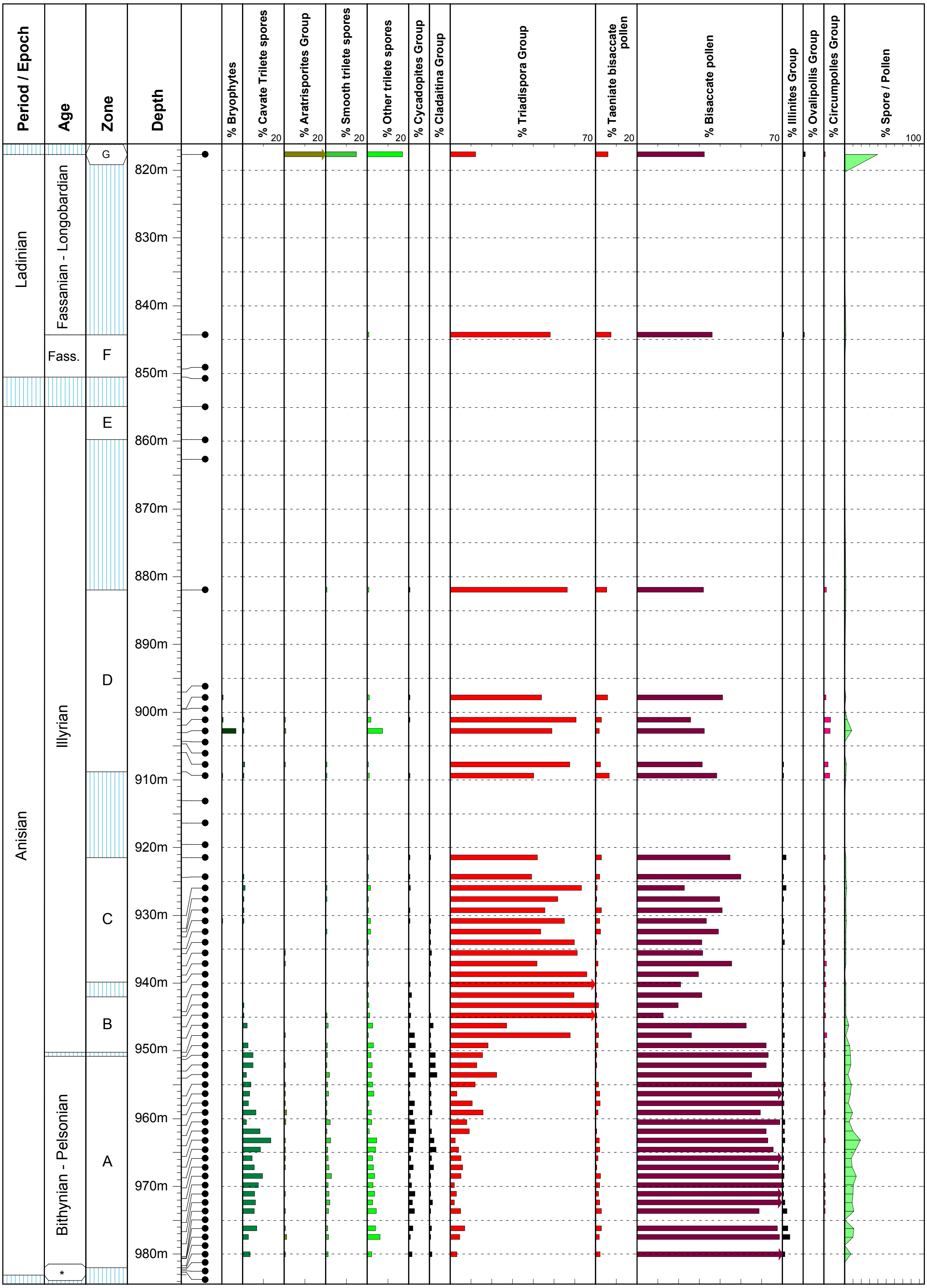


Fig. 12 - Relative abundance of terrestrial palynomorph groups of the Weiach well. Asterisk corresponds to ?Aegean.

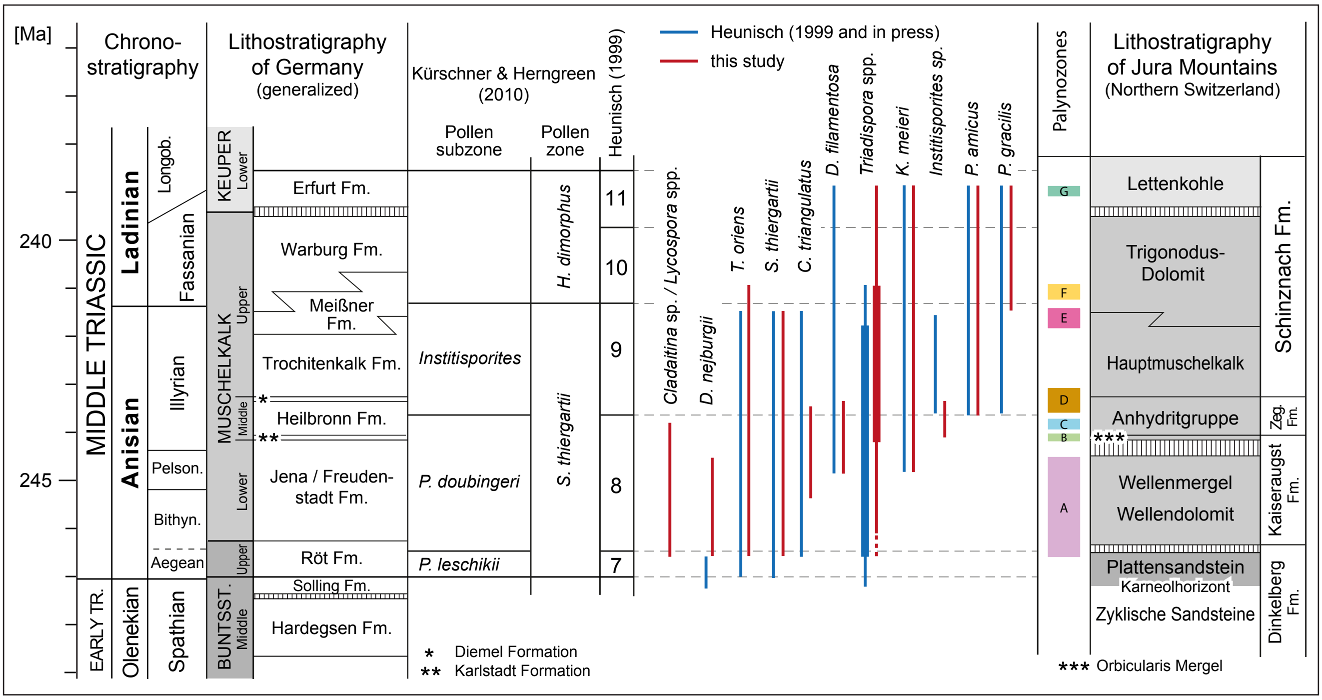


Fig. 13 - Comparison of selected taxon ranges from the central part of the Germanic Basin (after Heunisch 1999, in press) and its southern margin (this study). Middle Triassic lithostratigraphy and palynozonation of the Germanic Basin generalized after Kürschner & Herngreen (2010) and Heunisch (in press), and for northern Switzerland after Bernasconi et al. (2017).

Aigner & Bachmann (1992) also indicate a phase of increased marine influence in the Lower Muschelkalk (Fig. 2b).

Episode 3: A distinct change in palynofacies occurs at the lithological boundary between the Wellenmergel and the Orbicularis Mergel. The assemblages of the latter unit and the basal part of the overlaying Sulfatschichten (cycle VI) are dominated by terrestrial OM, namely by POM type IV. The increased abundance of charcoal provides evidence for wildfires. The distinct change of the pollen assemblage between 950.82 m and 950.20 m and the lack of marine palynomorphs in the latter sample suggest the presence of a hiatus at the base of the Orbicularis Mergel. From 948.11 m to 942.05 m a renewed, although minor marine influence is observed in the palynomorph assemblage.

Episode 4: With few exceptions this episode including the main part of the Sulfatschichten (i.e., cycles IV to III.A) contains only OM of terrestrial origin. The presence of algal remains in some of the samples indicates a subaqueous depositional environment; however, there is only scarce evidence for marine influence. Matter et al. (1988a, b) and Dronkert et al. (1990) inferred hyper-saline subaqueous pools or lagoons or inter-/supra-tidal and sabkha environments for this interval.

Episode 5: The increasing abundance of bisaccate pollen and membranes (POM type III) in the POM assemblages of episode 5, corresponding to the upper part of the Sulfatschichten (i.e., cycle II) reflect a better preservation of the OM.

From 905.99 m onwards the almost continuous presence of aquatic palynomorphs, including *Botryococcus* spp. (POM type I) provides evidence for the presence of more persistent water bodies. For the interval of the Dolomit der Anhydritgruppe palynofacies indicate special conditions.

Episode 6: Here the assemblages contain essentially membranes and some translucent woody particles. Palynomorphs are very rare or lacking. According to the lithological evidence intertidal depositional conditions prevailed.

Episode 7: The POM assemblages of the Hauptmuschelkalk are similar, but more diverse than those of the interval below. Renewed marine influence can be documented for the samples at 885.68 m and 881.94 m (acritarchs and prasinophycean algae) representing the base of the Hauptmuschelkalk.

Episode 8: The uppermost part of the studied section comprises the lower part of the Lettenkohle and is strongly dominated by terrestrial OM. Common remains of algal remains - *Plaesiodictyon* spp. and *Botryococous* ssp. reflect a lagoonal depositional environment.

In core B3/13 (Weizen, Fig 6) the distribution of the organic particles shows an increase in the marine influence in the lower part of the core, between 34.95 m and 29.33 m. Above this level the reduced abundance of acritarchs and the consistent presence of prasinophycean algae document a consistent but reduced marine environment. Thus, this interval is comparable to episode 2 in the Weiach core. The POM association corresponding to the upper part of the core B3/13 (Weizen) appears to be comparable to the interval between 956.68 m and 950.82 m at Weiach (episode 2).

The palynofacies of the Weiach section essentially reflects the depositional environments as inferred from the lithological succession (Fig. 5, Fig. A1 in the Appendix).

Palaeoclimatic implications

The assemblages from the lower part of the studied section (Palynozone A) are characterized by a considerable number and relatively high diversity of spores (Fig. 12). Noteworthy is the common occurrence of lycopsids spores *including Lycospora* spp., a lycopsidsinterpreted to represent plants of humid environments (for references see Bek 2012).

Cladaitina spp. a pollen group, which is well represented in the lower part of the studied section, has been assigned to Rufloriaceae, representing a group of Cordaites (Taylor et al. 2009; Zavattieri & Guttiérez 2012). This group also most likely requires humid conditions. Most of the mentioned forms become rare or disappear in the overlying Palynozone B. Pollen abundances show a gradual increase towards the Wellenmergel and a distinct rise occurs at the boundary between the Wellenmergel and the Orbicularis Mergel (Palynozone B). At this level the representatives of the *Triadispora* group become abundant (> 50 % of the sporomorph count, Fig. 12). This group is known to thrive under dry climatic conditions (Kürschner & Herngreen 2010; Visscher & Van der Zwan 1981). Thus, the lithological change from the Wellenmergel to the Orbicularis Mergel is interpreted to coincide with a decrease of moisture available to the plants. This change in environmental conditions is corroborated by sedimentological evidence, with the onset of evaporite deposition at this boundary.

As mentioned previously the acme of *Triadispora* occurs later in the Weiach core compared to the central part of the Germanic Basin. This might indicate an ecological differentiation between the southern margin and the central to northern parts of the Germanic Basin.

The *Triadispora* group indicating dry conditions is dominant throughout a good portion of the Muschelkalk (Palynozones B to F). With the exception of *Porcellispora longdonensis*, spores occur rather sporadically throughout this interval and are common only in a few samples. *P. longdonensis* is probably related to liverworts that thrived in temporary ponds or on humid surfaces.

Different climatic conditions are reflected in the assemblage of the Lettenkohle. Here spores reach high abundance and diversity. In contrast, the abundance of the *Triadispora* group is reduced.

Thus, the studied succession suggests relatively humid conditions during the interval dominated by clastic sediments of the Wellendolomit and Wellenmergel. Dry to arid conditions inferred for the interval of the Palynozones B to F, straddle a stratigraphic interval initially dominated by evaporites. The assemblage of the Lettenkohle again reflects more humid conditions. No synchronous changes exist between palynofacies and spore-pollen data. The influence of sea-level changes on spore-pollen composition appears to be minor compared to the climatic impact.

Discussion of isotope geochemistry

Stable isotope compositions of carbonates reflect the interplay of origin (i.e., biogenic, detrital or diagenetic), CO_2 sources and crystallization conditions, i.e., temperature, or open vs. closed system. Therefore, bulk rock analyses may not represent the $\delta^{13}C$ of the dissolved CO_2 in the water in which the carbonates crystallised or grew. However, if the calcite is primary and of biogenic origin or formed under eogenetic conditions, i.e., from depositional water, then carbon isotope signature likely represents the composition of the water. In the case of dolomite, where bacterially mediated processes or diagenetic conditions caused its formation, the isotope values may be influenced by non-depositional effects, e.g., meteoric or brine water infiltration and/or bacterial decomposition of organic matter.

The sub- to supratidal epicontinental setting of the studied sequence may strongly influence the $\delta^{13}C$ values with respect to open ocean conditions as water exchange with the ocean was restricted, freshwater runoff occurred and the degree of evaporation was much stronger than in the open ocean. Thus, our data may be influenced to variable degrees by the restricted conditions along the southern margin of the Germanic Basin.

The carbon isotopic records of Benken, Weiach, Weizen and Freudenstadt are characterized by a general increase of the mean $\delta^{13}C$ value from Benken to Freudenstadt, i.e., from ≈ -0.5‰ to ≈ 2.5‰ and further to ≈ 3‰ at Steudnitz (Fig. 4). The reason for this shift remains unclear but the succession from Thüringen (Steudnitz) formed in a central portion of the Germanic Basin that, during Lower Muschelkalk deposition, was located much closer to the more easterly connections between the basin and the open marine Tethys. In contrast, the sections at Benken and Weiach (northern Switzerland) correspond to marginal basin areas. The general increase in $\delta^{13}C$ values could thus reflect the influence of terrestrial derived water with a low $\delta^{13}C$ value for the marginal positions in northern Switzerland. This interpretation is also supported in the $\delta^{13}C$ record of Glatten (Fig. 4). Here, the $\delta^{13}C$ values in the "liegende Dolomite" just above the Rötton Fm. are strongly negative but quickly increase to the $\delta^{13}C$ values from the Haas pit. Again this increase in the $\delta^{13}C$ values may reflect the fading effect of terrestrial influence on the $\delta^{13}C$ value of the dissolved CO_2 in the marginal marine setting.

The $\delta^{13}C$ curve from Weiach and less pronounced from Benken is characterized by a sudden shift at the Wellenmergel - Orbicularis Mergel boundary (Fig. 4). The $\delta^{13}C$ curve from the central Germanic Basin (Steudnitz, Lippmann et al. 2005) displays a similar shift from 3‰ in the Oberer Wellenkalk to 1‰ in the Orbicularis Mergel (Fig. 4). This important change coincides with the supposed hiatus at this boundary but also with the turnover in the palynoflora (Palynozones A to B), i.e., from plants living under humid conditions to those adapted for dry conditions. This change in climate and palynoflora is evident also from the presence of evaporitic sediments. The lighter $\delta^{13}C$ values in the Orbicularis Mergel therefore indicate the addition of light carbon either due to oxidation of organic matter or from soil derived CO_2.

Conclusions

The stratigraphy and palaeoenvironment of upper Buntsandstein, Muschelkalk and the basal Lettenkohle of northern Switzerland and southern Germany (Weiach, neighbouring wells and outcrops) has been studied using palynolgical and carbonate carbon isotopes. The main conclusions are the following:

The palynological succession can be subdivided into 7 palynological zones (A – G). The observed ranges of species are compared with successions known from other parts of the Germanic Basin, especially with the zonation schemes of Heunisch (1999, in press) from the central basin portion, with the detailed record from Poland (Orłowska-Zwolińska 1985) and with the zonation compiled by Kürschner & Herngreen (2010). Unfortunately, independent age control for these zonation-schemes is scarce. Species ranges are also compared with the better calibrated successions of the Tethyan Realm (Brugman 1986; Hochuli et al. 2015). Based on these comparisons the studied succession covers most of the Anisian (Aegean?–Illyrian) and Ladinian (Fassanian - Longobardian) but probably includes some prominent hiatuses. (Figs. 7-11).

The present study shows highly diversified Anisian palynological assemblages.

The observed distribution of palynomorphs calls for a revision of widely accepted ranges of some taxa. For example *Lycospora* spp., *Cladaitina* spp., and *Florinites* spp. representing two plant groups – namely arborescent lycopsids (e.g., *Lepidodendron* or *Lepidophloios*) and Cordaites, known so far only from the Palaeozoic, are considered in place and prove that these groups survived up to the Middle Triassic. *Afropollis* sp., representative of a group so far known to occur regularly in Lower Cretaceous sections of low latitudes and some angiosperm-like pollen have here their oldest records in the studied sections (Hochuli & Feist-Burkhardt 2013).

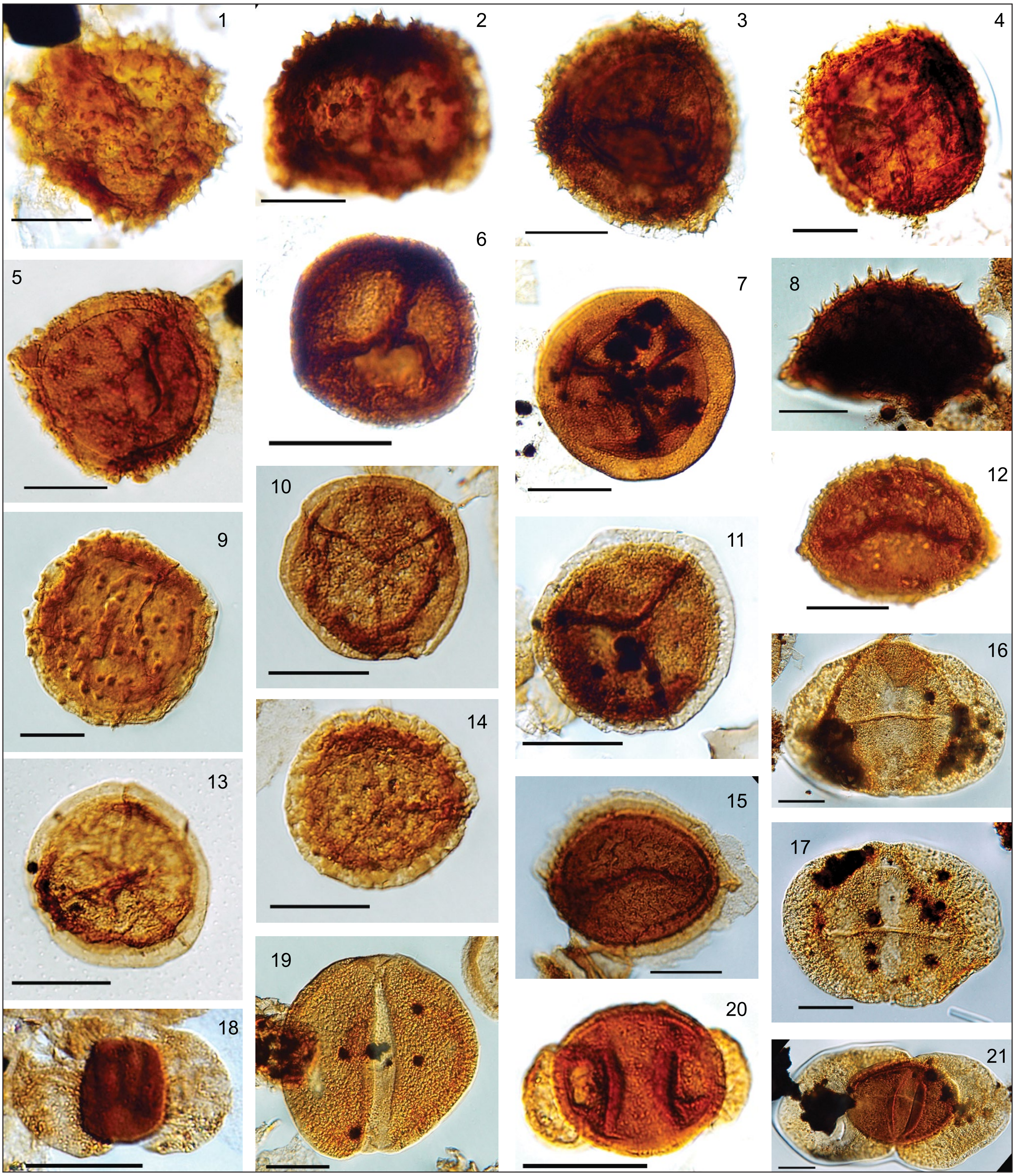


Plate 1

Taxon name is followed by the sample number, and stage coordinates for an Olympus BX 51 microscope. Scale bar is 20 µm on all photomicrographs.

1) *Pechorosporites* sp.; Weiach 956.68; 9.2/124.2; 2) cf. *Indotriradites reidii* Foster, 1979; Weiach 975.31; 9.0/127.3; 3) *Kraeuselisporites spinosus* Jansonius, 1962; Leuggern Leu-5; 11.2/118.2; 4) *Kraeuselisporites wargalensis* Balme, 1970; Weiach 978.45; 9.3/122.8; 5) *Pechorosporites* sp.; Weiach 951.28; 17.6/142.6; 6) *Densoisporites nejburgii* (Schulz) Balme, 1970; Weiach 976.66; 6.8/129.6; 7) *Densoisporites playfordi* (Balme) Playford, 1965; Weiach 976.66; 22.8/137.7; 8) *Kraeuselisporites apiculatus* Jansonius, 1962; Weiach 976.66; 19.8/126.0; 9) *Kraeuselisporites* cf. *cuspidus* Balme, 1963; Leuggern Leu-3; 3.4/137.2; 10) *Lycospora* sp.; Leuggern Leu-18; 12.8/132.6; 11) *Lycospora* sp.; Weiach 976.66; 10.0/117.2; 12) *Aratrisporites «densispinosus»* (informal species); Leuggern Leu-16;6.1/125.7; 13) *Lycospora* sp. Weiach 968.72; 17.8/132.1; 14) *Lycospora* sp.; Leuggern Leu-16; 7.0/145.7; 15) *Aratrisporites reticulatus* Brugman, 1986; Weiach 978.45; 15.0/140.2; 16) *Illinites kosankei* Klaus, 1964; Weiach 976.66; 12.0/125.3; 17) *Illinites chitonoides* Klaus, 1964; Weiach 978.45; 7.3/135.2; 18) *Angustisulcites* sp. (small form); Leuggern Leu-16; 4.5/142.0; 19) *Sulcatisporites kraeuseli* Mädler, 1964; Weiach 978.45; 5.2/135.7; 20) *Protodiploxypinus doubingeri* Klaus, 1964; Leuggern Leu-14; 6.0/119.8; 21) *Angustisulcites grandis* (Freudenthal) Visscher, 1966; Weiach 978.45; 13.1/126.4.

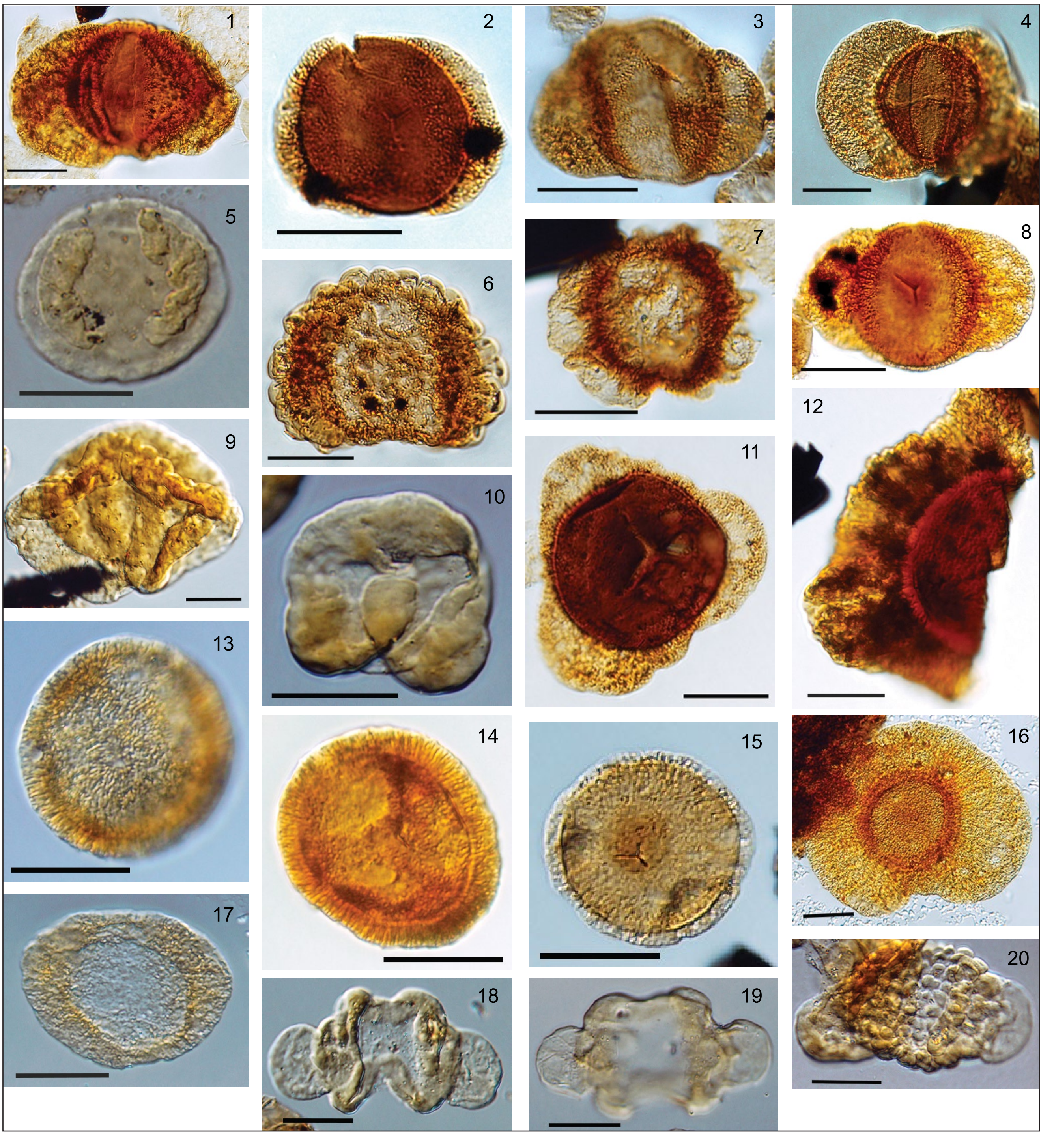


Plate 2

Taxon name is followed by the sample number, and stage coordinates for an Olympus BX 51 microscope. Scale bar is 20 µm on all photomicrographs.

1) *Angustisulcites* sp. A sensu Brugman, 1986; Leuggern Leu-16; 13.3/123.5; 2) *Triadispora epigona* Klaus, 1964; Weiach 978.45; 15.8/129.8; 3) *Triadispora falcata* Klaus, 1964; Weiach 976.66; 14.4/126.7; 4) *Angustisulcites klausii* Freudenthal, 1964; Weiach 978.45; 6.0/129.0; 5) *Podosporites amicus* Scheuring, 1970; Weiach 903.02; 17.1/121.8; 6) *Tsugaepollenites oriens* Klaus, 1964; Weiach 975.31; 12.2/135.7; 7) *Tsugaepollenites* cf.*oriens*; Leuggern Leu-20; 18.1/127.2; 8) *Triadispora crassa* Klaus, 1964; Leuggern Leu-20; 16.6/141.7; 9) *Institisporites* cf. *crispus* Pautsch, 1971; Weiach 944.81; 9.7/122.7; 10) *Protodiploxypinus* sp.1; Weiach 901.91; 16.1/136.1; 11) *Cristianisporites triangulatus* Antonescu, 1969; Leuggern 18; 5.7/134.7; 12) *Dyupetalum vicentinensis* Brugman, 1983; Weiach 935.67; 19.27/140.6; 13) *Kuglerina meieri* Scheuring, 1978; Weiach 930.1; 15.7/139.1; 14) *Doubingerispora filamentosa* Scheuring, 1970; Weiach 938.79; 22.8/140.7; 15) Circumpolles; Weiach 930.1; 7.5/120.4; 16) *Florinites* sp.; Weiach 962.53; 15.4/119.8; 17) *Florinites* sp.; Weiach 932.41; 18.9/123.3; 18) Polysaccoid pollen; Weiach 905.99; 4.1/123.9; 19) Polysaccoid pollen; Weiach 903.02; 24.1/120.4; 20) *Tumoripollenites* sp.; Weiach 903.02; 24.3/115.8.

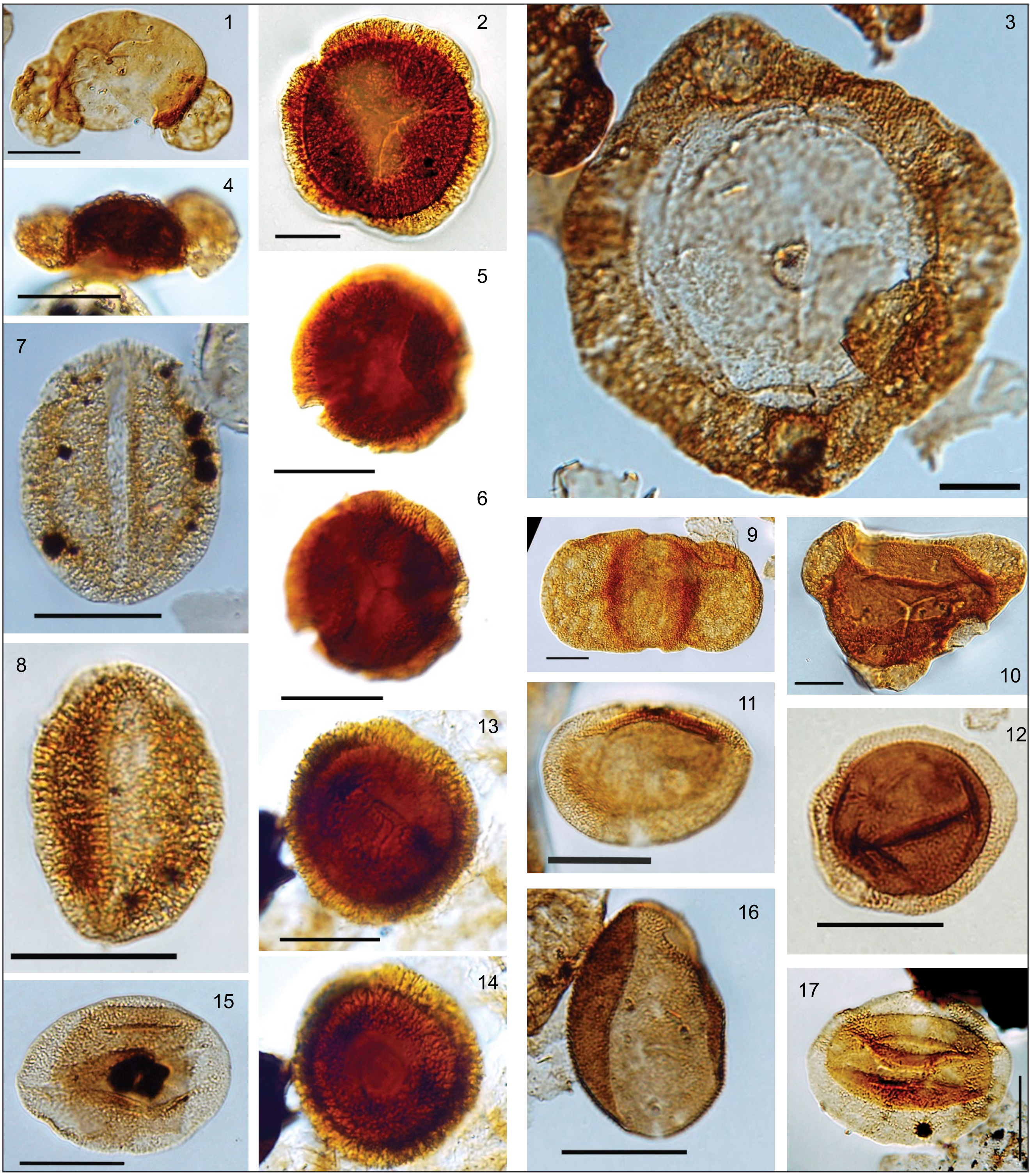


Plate 3

Taxon name is followed by the sample number, and stage coordinates for an Olympus BX 51 microscope. Scale bar is 20 µm on all photomicrographs.

1) *Protodiploxypinus sittleri* Klaus, 1964; Leu-3; 7.4/127.2 ; 2) *Stellapollenites thiergartii*; Weiach 948.11; 19.0/137.8; 3) *Cordaitina gunyalensis*; Weizen 34.95; 7.0/114.2; 4) *Protodiploxypinus* sp.; Weiach 965.56; 965.56; 13.8/113.0; 5-6) *Stellapollenites* sp. 1 (small species); Weiach 933.18; 22.6/118.8; 7) *Sulcosaccispora minuta* Klaus, 1964; Weiach 976.66; 7.7/141.3; 8) *Sulcosaccispora* sp.1; Weiach 976.66; 21.1/137.0; 9) *Voltziaceaesporites heteromorphus* Klaus, 1964; Leuggern 3; 15.0/142; 10) *Cristianisporites triangulatus*; Leuggern 3; 9.1/127.3; 11) *Cladaitina* sp.; Weiach 978.47; 7.0/138.9; 12) *Cladaitina* sp.; Weiach 970.20; 10.2/125.8; 13-14) *Doubingerispora* cf. *filamentosa* Scheuring, 1978; Weiach 956.68; 956.68; 9.2/124.2; 15) *Cladaitina* sp.; Weiach 976.66; 12.4/115.45; 16) Monosulcate pollen, probably internal body of *Cladaitina*; Weiach 978.45; 7.0/138.9; 17) *Cladaitina* sp.; Weiach 976.66; 12.4/115.45

The presence of marine palynomorphs in the Plattensandstein (upper Buntsandstein), document a first transgression in the southern part of the Germanic Basin. Two pronounced marine intervals also emerge from the palynofacies record: the first one in the Wellendolomit and Wellenmergel (episode 2) and the second one in the Hauptmuschelkalk (episode 7).

Paleoclimatic information inferred from the palynological dataset indicate relatively humid conditions during deposition of Wellendolomit and Wellenmergel, whereas dry to arid conditions prevailed during the interval dominated by evaporate deposition of the Middle Muschelkalk. For the uppermost interval (Lettenkohle) again more humid conditions are indicated.

Carbonate carbon isotope data demonstrate a negative shift across the Lower–Middle Muschelkalk boundary in Weizen, Weiach, and Benken coinciding with the change to a drier climate.

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