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The Schilfsandstein and its flora – arguments for a humid mid-Carnian episode?

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Abstract

Recently intensified research on the mid-Carnian episode stimulated discussions about the mid-Carnian climate and a supposed humid climate shift. This basin-scale study on the Schilfsandstein, the type-example of the mid-Carnian episode, applied sedimentological, palynological and palaeobotanical proxies of the palaeoclimate to a large data set of cored wells and outcrops. The results demonstrate the primary control of circum-Tethyan eustatic cycles on the Central European Basin (CEB) where transgressions contributed to basin-scale facies shifts. The palaeoclimate proxies point to a uniform arid to semi-arid Carnian climate with low chemical weathering and high evaporation. Consequently, transgressions into the CEB led to increased evaporation forcing the hydrological cycle. The increased runoff from source areas resulted in high ground water stages at lowlands characterised by hydromorphic palaeosols and intrazonal vegetation with hygrophytic elements. During lowstands, reduced evaporation and runoff led to increased drainage and desiccation of lowlands characterised by formation of vertisols, calcisols and gypsisols and zonal vegetation with xerophytic elements. The herein proposed model of sea-level control on the hydrological cycle integrates co- and subsequent occurrences of wet and dry lowlands, hydromorphic and well drained palaeosols, and intrazonal and zonal vegetations. Thus, the Schilfsandstein does not provide arguments for a humid mid-Carnian episode.
Introduction

The Schilfsandstein represents the type-example of a mid-Carnian episode of increased siliciclastic influx to Tethyan and peri-Tethyan basin and beyond (see reviews of Arche & Lopez-Gomez 2014; Ogg 2015; Ruffell et al. 2015 and references therein). Since the proposal of a “Carnian Pluvial Event” by Simms & Ruffell (1989) and the following rejection by Visscher et al. (1994), numerous studies contributed to an increased knowledge (Dal Corso et al. 2018).

Here, the descriptive term mid-Carnian episode is used collectively for various phenomena which had occurred in the late Julian to early Tuvalian substages, such as sea-level fluctuations (e.g. Brandner 1984; Bechstädt & Schweitzer 1991; Aigner & Bachmann 1992; Gianolla et al. 1998; Franz et al. 2014) and related oceanographic responses (e.g. Keim et al. 2001, 2006; Hornung et al. 2007a, b; Gattolin et al. 2013, 2015), biotic turnovers of marine organisms (e.g. Simms & Ruffell 1989; Erba 2004; Rigo et al. 2007; Balini et al. 2010; Preto et al. 2010; Martinez-Perez et al. 2014), volcanism (Furin et al. 2006; Greene et al. 2010; Dal Corso et al. 2012; Xu et al. 2014), climate change (Roghi et al. 2010; Stefani et al. 2010; Trotter et al. 2015; Mueller et al. 2016a, b; Sun et al. 2016; Miller et al. 2017) and carbon-cycle perturbations (Dal Corso et al. 2012, 2015; Mueller et al. 2016a, b; Sun et al. 2016; Miller et al. 2017). These phenomena are reviewed in detail by Arche & Lopez-Gomez (2014), Ogg (2015), Ruffell et al. (2015) and Dal Corso et al. (2018).

Concerning its significance for the mid-Carnian climate, the Schilfsandstein is still a subject of discussions. Simms & Ruffell (1989), Mader (1990) and Fijałkowska-Mader (1999) reconstructed a pronounced pluvial event, Nitsch (2005) and Kozur & Bachmann (2010) argued for a rather wet phase, whereas Visscher & Van der Zwan (1981), Reitz (1985), Visscher et al. (1994), Kelber (1998), Heunisch (1999) and Franz et al. (2014) rejected significant climate changes. These inconsistencies may result from the fact that previous studies employed only individual palaeoclimate proxies and/or were limited to certain areas of the Central European Basin (CEB).

This paper presents results of the first integrated study employing compositional maturity, palaeosols, macroflora and palynoflora of the Schilfsandstein as climate proxies. Of special importance is the herein employed extensive data set of the Schilfsandstein macroflora, one of the most famous and important floras of the Germanic Triassic (e.g. Schenk 1864; Schönlein & Schenk 1865; Sandberger 1882; Frentzen 1922a, 1922b, 1930-31; Mader 1990; Kelber & Hansch 1995). The Schilfsandstein takes its name from the cane- or rush-like structures of the horsetail stems that are often preserved in
situ in the rocks. The agglomeration of groups of stems of *Equisetites arenaceus* of up to 25 cm in diameter give, thus, the impression of a fossil reed bed (Frentzen 1930-31).

**Methods and data base**

The study is based on 17 cored wells and 19 outcrops of the Schilfsandstein which have been measured and lithostratigraphically classified according to Beutler in DSK (2005) and Franz et al. (2014, 2018a). The consecutive analysis of lithofacies types, facies associations and depositional environments followed Shukla et al. (2010) and Franz et al. (2014). Palaeosols were described and classified according to Mack et al. (1993). The results obtained were compared with published and unpublished data of 10 wells and 2 outcrops (Fig. 1). Wells and outcrops were sampled for granulometry, detrital mineralogy, geochemistry and palynology. For grain-size analyses, 87 samples were sieved with standard mesh sieves according to DIN 66165. Granulometric values, such as the median grain-size, were calculated according to Folk & Ward (1957). For petrography and diagenesis of sandstones, 98 thin sections were investigated by means of transmitted light, SEM-EDX and cathodoluminescent microscopy. The quantitative detrital mineralogy was estimated from point counting; results were classified following Pettijohn (1957) and McBride (1963).

For geochemical characterisation, 335 samples of the Morsleben 52A well, 64 samples of the Neubrandenburg 2 well and 62 samples of the Apolda 1 well were analysed by means of inorganic and organic geochemical methods. Samples from the Morsleben 52A well were measured at Federal Institute for Geosciences and Natural Resources Hannover (Bundesanstalt für Geowissenschaften und Rohstoffe, BGR). Preparation and XRF measurements followed standard procedures already described in Franz et al. (2014). Samples from the Neubrandenburg 2 and Apolda 1 wells were processed at ALS Laboratories Galway (Ireland). Carbon and sulphur were determined by combustion furnace and acid digestion, major elements and base metals by ICP-AES (LiBO$_2$ fusion, four acid digestion), and trace elements and REE's by ICP-MS (LiBO$_2$ fusion).

More than 900 plant macro fossils of the Schilfsandstein were integrated into a macroflora data set. This comprehensive data set comprises previously published specimens (e.g. Bronn 1851-52; Schenk 1864; Chrustschoff 1868; Sandberger 1882; Engel 1896; Frentzen 1922a, 1922c, 1930-31; Roselt 1952-53; Kelber & Hansch 1995) as well as all the plant remains from the Schilfsandstein studied in various European museums [e.g. NBC (Leiden), Utrecht University, NNMP (Prague), NRM]
(Stockholm), NHMW (Vienna), SMNS (Stuttgart), BSPG (Munich), Tübingen University and MfN (Berlin), see Supplement for details]. The localities mentioned in literature and on the labels of the fossils were corrected, standardised and the stratigraphic attribution were checked as much as possible. The determinations were, at genus level, reviewed for this paper.

For the Schilfsandstein palynoflora data set, previously published data of outcrop Sehnde (see Heunisch in Beutler et al. 1996), Neubrandenburg 2 and Morsleben 52A wells (see Franz et al. 2014) were re-evaluated and new data of the Obernsees 1 (2 samples) and Medbach wells (3 samples) added. Preparation of samples and application of the Palynomorph Eco Group (PEG) method (sensu Paterson et al. 2017) to the Schilfsandstein palynoflora were detailed in Franz et al. (2014).

**Stratigraphic control**

According to Beutler in DSK (2005), the informal term Schilfsandstein was replaced by the formal term Stuttgart Formation. In the northern CEB, the Stuttgart Formation is composed of the sandy Lower and Upper Schilfsandstein Members and the predominantly shaly Neubrandenburg, Gaildorf and Beaumont Members (Franz et al. 2014). The base of the Stuttgart Formation is drawn at the base of the Neubrandenburg Member and the top of the formation is drawn at the base of the Beaumont Member (Weser Formation). Detailed descriptions of the Stuttgart Formation in the North German Basin (NGB) are provided by Beutler & Häusser (1982), Franz (2008), Barnasch (2010), and Franz et al. (2014, 2018a). In the southern CEB, the presence of the Neubrandenburg Member could not be demonstrated so far. Therefore, the base of the formation is drawn at the base of the Lower Schilfsandstein (Fig. 2). Detailed descriptions of the Stuttgart Formation in the southern CEB are provided by Schröder (1977), DSK (2005) and Kozur & Bachmann (2010).

Biostratigraphic control to the Stuttgart Formation is provided by conchostracans, ostracods and palynomorphs (Heunisch 1999; Kozur & Bachmann 2010; Kozur & Weems 2010). In particular the ostracod assemblage of the Neubrandenburg Member enables the time-constrained correlation (Kozur & Bachmann 2010; Franz et al. 2014). Based on biostratigraphic arguments, the Stuttgart Formation was correlated with the late Julian upper *Austrotachyceras austriacum* zone (Kozur & Bachmann 2010). Based on sequence-stratigraphic arguments, Franz et al. (2014) suggested that the Stuttgart Formation may range into the early Tuvalian. The time-spans estimated to about 0.8 Myr for the
Stuttgart Formation (Kozur & Bachmann 2010) and to about 1.2 Myr for the mid-Carnian episode (Zhang et al. 2015; Miller et al. 2017) are in general agreement.

The Schilfsandstein (Stuttgart Formation)

Eustatic control

The record of the pre-, intra- and post-Schilfsandstein transgressions enables the time-constrained N-S correlation of continuous successions of the basin centre and discontinuous successions of the southern CEB (Franz et al. 2018a). The architecture of transgressive shales and progradational clastics evidence the principle control of mid-Carnian sea-level cycles on the Stuttgart Formation (Aigner & Bachmann 1992; Köppen 1997; Shukla & Bachmann 2007). Based on correlations with Tethyan examples, Franz et al. (2014) reconstructed a set of circum-Tethyan 4th-order T-R sequences. The pre-Schilfsandstein transgression, representing the most distinct transgression of the Lower and Middle Keuper in the NGB, triggered the fundamental facies shift from shaly-evaporitic lithologies of the Grabfeld Formation to shaly-sandy lithologies of the Stuttgart Formation. Resulting from this transgression of the first 4th-order T-R sequence, dark shales and silts of a marine-brackish inland sea and associated coastal environments covered larger parts of the CEB. Following the maximum extension of the inland sea, the falling sea-level enabled the basin-wards progradation of the fluvio-deltaic Lower Schilfsandstein (Fig. 2). Active fluvial channel belts were flanked and delta lobes were at least partly covered by vegetated wetlands in which remnants of the Schilfsandstein macro- and palynoflora could be preserved. Avulsion of channels and abandonment of delta lobes led to drainage, desiccation, pedogenesis and decomposition of macro- and palynofloral remains. The maximum regression is reflected by the maximum basin-wards progradation of the Lower Schilfsandstein corresponding to a pedogenic maximum in some localities. The following second 4th-order T-R sequence resulted in the repetition of the depositional theme of transgressive shales and progradational clastics (Gaildorf Mb, Upper Schilfsandstein).

Granulometry, detrital and authigenic mineralogy of sandstones

The median grain sizes (Folk & Ward 1957) of 87 samples of the Lower and Upper Schilfsandstein range from 2.1 to 4.2 Phi. According to Wentworth (1922), 24 samples are classified fine sand, 53
samples are classified very fine sand and 10 samples are classified coarse silt. Samples from channel fills, proximal crevasse splays and sheetsands are characterised by coarser grain sizes whereas samples from levees, distal crevasse splays and sheetsands as well as wetlands are characterised by finer grainer sizes. Thus, lateral facies shifts and associated changes from bedload to suspension load processes are considered responsible for these grain size variations.

Detrital grains of proximal and distal samples are of low to moderate sphericity and subangular to subrounded grain shape (Wentworth 1922). Resulting from this uniform low textural maturity, a downstream trend towards a more accentuated roundness in the basin centre is not indicated.

The compositional maturity of the Schilfsandstein is remarkably low. According to Pettijohn (1957), the mineralogical maturity indexes of 98 samples range from 0.2–1.4. Following McBride (1963), 6 samples are classified arkose, 86 are classified lithic arkose and 5 are classified feldspathic litharenites (Fig. 3). In individual samples, feldspar has a range of 24.4–68.5 %, quartz has a range of 17.4–58.8 % and lithics have a range of 3.9–42.3 % of all detrital grains identified to feldspar, quartz and lithics. The feldspar assemblage is dominated by untwinned and twinned plagioclase outweighing K-feldspar. The quartz assemblage is dominated by monocrystalline quartz followed by polycrystalline quartz followed by chert. Metamorphic rock fragments, mainly schists and gneisses, dominate the assemblage outweighing rock fragments of igneous and sedimentary sources.

The detrital mineralogy, in particular the abundance of lithics, seems to be grain-size-dependent. An increase of grain-size corresponds to an increased abundance of lithics. Within fine-grained samples, the lowered abundance of lithics is balanced out by increased abundances of quartz and feldspar. Interestingly, the detrital mineralogy is obviously not related to transport distances as a downstream increase of compositional maturity could not be observed. Likewise, In situ feldspar weathering is not indicated as feldspar ratios of pedogenic sandstones are not systematically lowered (Fig. 3).

Intense burial diagenesis is witnessed by corrosion of and authigenic overgrowth on detrital grains and authigenic cementation of open intergranular pore space. Detrital feldspars range from apparently unaltered to almost completely corroded but, important to note, unaltered to slightly altered feldspar grains predominate. Lithics are only subordinately affected by alteration such as quartz. Authigenic quartz and feldspars occur as overgrows on detrital quartz and feldspar grains. Pedogenic sandstones show hematite and clay mineral overgrowth on practically all detrital grains. Open pore space is partly to completely filled with nests of small euhedral analcime crystals or larger poikilotopic patches as well
as larger patches of calcite, dolomite, anhydrite and gypsum. Authigenic clay minerals are mainly represented by illite/smectite and chlorite and less abundant by kaolinite (Fig. 3).

**Palaeosols**

The distribution of palaeosol orders is clearly related to depositional environments. Protosols and spodosols *sensu* Mack *et al.* (1993) were frequently observed throughout the Stuttgart Formation (Tab. 1). Histosols *sensu* Mack *et al.* (1993) occur mainly in the Neubrandenburg Member but are sparse above. Vertisols, calcisols and gypsisols *sensu* Mack *et al.* (1993) occur from the Lower Schilfsandstein upwards.

A typical feature is the formation of a hydromorphic palaeosol (protosol or gleysol) during early pedogenesis followed by overprint to a vertisol, calcisol or gypsisol due to increased drainage, desiccation and evaporation (Fig. 4; Nitsch 2005; this work). According to basin topography, earliest calcisols and gypsisols were formed at well drained floodplains of the Lower Schilfsandstein in South and Central Germany. For the less drained basin centre, these palaeosol types are proven for the Upper Schilfsandstein (Fig. 2).

Histosols are associated to floodplain wetlands flanking fluvial channels and delta plain wetlands of the Neubrandenburg Member and Lower Schilfsandstein (Fig. 2). All observed cases of histosols were characterised by remarkably thin coaly horizons not exceeding 20 cm thickness. At many localities, only one histic horizon of a few centimetres thickness was evolved. At only a few localities, for example the Neubrandenburg 2 well, several thin histic horizons were evolved but occurred in a narrow interval of less than 4 m thickness (Franz *et al.* 2014). Moreover, the outcrop example Am Hohnert showed that Schilfsandstein histosols are laterally restricted.
Spodosols *sensu* Mack et al. (1993) are recognised by reddish to violet spodic horizons which are a typical feature of sand-prone successions of crevasse splays and sheetsands. These horizons formed from subsurface illuviation of iron oxides and/or iron hydroxides resulting in impregnation of sandstones (Mack et al. 1993). Due to this, iron oxides and/or iron hydroxides form ferritic cutans, spots, irregular nests or nodules or may accentuate bedding structures. The spodosols observed herein are lacking clear evidence of illuviation of organic matter. This may result from alteration of illuvial organic matter during burial diagenesis and/or erosion of Bh horizons due to truncation of palaeosols as already noted by Nitsch (2005). Vertisols occur at distal floodplains and abandoned delta lobes of the Lower Schilfsandstein and practically throughout the Upper Schilfsandstein. In the Lower Schilfsandstein, the occurrence of vertic horizons is limited to the upper part. In contrast to this, stacked vertic horizons may dominate the complete succession of the Upper Schilfsandstein. The occurrence of calcisols and gypsisols largely follows this pattern. In particular shaly successions of the Upper Schilfsandstein comprise stacked calcisols and/or gypsisols and therefore resemble much the Weser Formation above (Fig. 5, 6).

*The Schilfsandstein macroflora*

Most plant remains available in collections were recovered in Schilfsandstein quarries of South Germany (see Kelber & Hansch 1995). Accordingly, 80 % of all specimens investigated originate from localities in Baden-Württemberg (61 localities out of 82 in total) and 14 % from Bavarian localities (14 localities). Thuringia, Hesse, Lower Saxony and Rhineland-Palatinate are represented with less than 5 localities. The localities of about 3 % of all specimens are questionable. The localities Stuttgart (177 specimens), Feuerbacher Heide (105 specimens, today part of Stuttgart), Eyershausen (45 specimens) and the surroundings of Eberstadt-Lennach-Buchhorn (33 specimens) were the most productive *fossil lagerstätten*, whereas 31 localities were only represented by one fossil.

The more than 900 specimens belong to 37 different genera as well as plant remains that could not be classified at generic level. The most abundant taxa are *Equisetites* (251 specimens), not better defined
equisetoid axis and rhizome remains (150 specimens), *Pterophyllum* (137 specimens), *Voltzia* (42 specimens) and *Lepidopteris* (36 specimens) (Fig. 7). Thus, the horsetails (48 %) are the most abundant group, followed by the cycadophytes (16 %), ferns (14 %) and conifers (9 %; Fig. 8). The least abundant are the seed ferns (5 %) and lycophytes (1 %). Positioning the various plant genera within their respective Macroplant Eco-Groups (MEG, Supplement; see also Kustatscher et al. 2010, 2012; Costamagna et al. 2018) it becomes evident that the River MEG dominates (51 %), followed by the wet Lowland MEG (22 %), the Hinterland MEG (9 %) and the dry Lowland MEG (9 %). The least abundant is the Coastal MEG (2 %). This reflects a general picture of the Schilfsandstein macroflora, which shows a rich and diverse flora dominated by reed-like aggregations of horsetails standing on rivers banks, with fern- and bennettitalean-dominated wetlands (wet lowland) flanking fluvial channels, seed fern-dominated dry floodplain areas (dry lowland) and a conifer-dominated Hinterland.

Comparing the neighboured localities Stuttgart and Feuerbacher Heide, the composition of the Schilfsandstein macroflora shows only minor changes (Fig. 9). Both macrofloras are dominated by the River MEG (Stuttgart: 58 % and Feuerbacher Heide: 61 %), followed by the wet Lowland MEG (22 % and 16 %) and the dry Lowland MEG (10 % and 13 %). Noticeable is the occurrence of the Coastal MEG with 1 % at Stuttgart and 3 % at Feuerbacher Heide.

The comparison of the distant localities Eberstadt and Eyershausen (about 190 km distance) suggests more pronounced changes. The Eberstadt macroflora is dominated by conifers (Hinterland MEG) with several not better defined plant remains and a reduced amount of horsetails, supporting a flora that may have been subjected to a higher transport and/or drier conditions. Interestingly, the Hinterland MEG is completely missing in the Eyershausen macroflora. Instead, the flora is composed of 44 % wet Lowland MEG, followed by 33 % River MEG and 22 % dry Lowland MEG (Fig. 9). But it is important to note, both macrofloras are represented limited amount of specimens.
The Schilfsandstein palynoflora and its associations

Herein investigated samples could be assigned to palynomorph zones GTr 13–15 of Heunisch (1999). 35 productive samples are assigned to the GTr 14 zone covering the Stuttgart Formation. As these samples mainly originate from the lower part of the formation, whereas most samples of the upper part were unproductive, the preservation potential was obviously higher for marine-brackish and fluvio-deltaic environments associated to the first 4th-order T-R sequence (Fig. 10).

In terms of quantitative composition, the palynoflora of the investigated interval can be grouped into five hypothetical palynofacies associations: (1) Ovalipollis association, (2) Inland sea association, (3) Leschikisporites association, (4) Aulisporites association, and (5) Trilete laevigate spores association.

(1) Ovalipollis association

Ovalipollis spp. is present with abundances of 35 % up to 70 % (Fig. 11). Triadispora spp. and other bisaccate pollen grains (e.g., Striatoabieites) may be present with increased abundances of up to 20 % (Supplement). Locally elements of the Coastal PEG (Aratrisporites spp., Leschikisporis aduncus, Duplicisporites granulatus) may occur with higher abundances. Deltidospora spp. is of accessory occurrence. The Ovalipollis association occurred in dark grey but also variegated shales and siltstones of the topmost Grabfeld and basal Weser Formations. In the NGB, the association ranges into the basal Neubrandenburg Member. As the Ovalipollis association appears to be limited to these intervals, it most probably represents the pre- and post-Schilfsandstein palynoflora dominated by dry Lowland and Hinterland PEGs.

(2) Inland sea association

The occurrence of this association is limited to grey to blackish shales of the lower Neubrandenburg Member yielding acritarchs (Micrhystridium spp.), prasinophycean algae (Tasmanites spp., Leiosphaeridia spp.) and green algae (Botryococcus sp., Plaesiodictyon mosellanum, Zygnemataceae). In this interval, the aquatic-marine and aquatic-brackish-freshwater PEGs are present with abundances of >50 % (Fig.10). The terrestrial sporomorphs are still mostly represented by elements of the Hinterland (bisaccate pollen grains, Triadispora spp.) and dry Lowland (mostly Ovalipollis spp.) PEGs.
(3) Leschikisporites association

*Leschikisporites aduncus* constitutes 25–75 % of the assemblage and *Aulisporites astigmosus* is present with less than 10 % (Fig. 11). For individual localities, *A. astigmosus* may be missing in the palynomorph association (Kahlert et al. 1970). Another important taxon is *Aratrisporites* spp. which is present with up to 7 %. The taxa *Deltoidospora* spp., *Calamospora* spp., *Osmundacidites wellmanii*, *Baculatisporites* sp., *Punctatisporites* spp., *Cycadopites* spp., undifferentiated bisaccate pollen and acritarchs may occur accessorially. The *Leschikisporites* association is dominated by the Coastal PEG but also the wet Lowland, dry Lowland, River and Highland PEGs (up to 15 %) may be common. As the association could be only observed in dark shales of lower delta plain wetlands in the Neubrandenburg 2 well, its occurrence seems to be limited to central parts of the NGB (Fig. 10).

(4) Aulisporites association

*Aulisporites astigmosus* constitutes >30 % of the assemblage whereas *Leschikisporites aduncus* is present with less than 10 % (Fig. 11). For individual samples, the maximum abundances of *A. astigmosus* (wet lowland PEG) even exceed 80 % (Supplement). Other important forms of the *Aulisporites* association are elements of the Coastal PEG (*Aracariacites australis, Aratrisporites* spp.), River PEG (*Punctatisporites* spp.) and Hinterland PEG (bisaccate pollen grains). Prasinophyceen algae, such as *Leiospheridia* spp., may occur accessorially. The *Aulisporites* association was recorded in dark grey to blackish and often carbonaceous shales and coals of delta plain and floodplain wetlands (Fig. 10).

(5) Trilete laevigate spores association

This association is characterised by a mix of palynomorphs of the dry Lowland, River and Hinterland PEGs. Trilete laevigate spores, such as *Deltoidospora* spp., *Calamospora* spp. and *Punctatisporites* spp., are present with percentages of up to 30 %. *A. astigmosus* and *L. aduncus* are also present but with percentages below 25 %. Of further importance are *Triadispora* spp. (< 15 %), bisaccate pollen grains (< 25 %) and ornamented spores (< 15 %). The trilete laevigate spores association was recorded in dark shales but also in laminated silts of floodplain and delta plain wetlands in North Germany (Fig. 10).
Discussion

Low chemical weathering and high evaporation

For this study, only palaeosols and compositional maturity of sandstones were evaluated as palaeoclimate proxies. As authigenic feldspar overgrowths and formation of clay minerals, as a result of burial diagenesis, are common features (Fig. 3; Wurster 1964; Heling 1965; Förster et al. 2010; this study), clay mineral analysis and geochemical weathering indices (e.g. CIA) were ruled out. The herein presented detrital mineralogy is largely in agreement with data of Wurster (1964), Heling (1965), Dockter et al. (1967), Häusser & Kurze (1975), Heling & Beyer (1992), Förster et al. (2010). A comparison of Rotliegend and Mesozoic sandstones of the NGB points to a long-term shift towards increasing maturities (Fig. 3; Häusser & Kurze 1975; this work). This corresponds to published data of the Danish Basin (Ahlberg et al. 2002) and East Greenland (Decou et al. 2017). Beside other arguments, these examples were employed to reconstruct a long-term change from arid Early Triassic climates to humid Jurassic climates (e.g. Ahlberg et al. 2002, 2003; Decou et al. 2017). The low compositional maturity of the Schilfsandstein is apparently not in-line with this long-term trend. From the Buntsandstein to Middle Jurassic, the NGB was mainly fed from Scandinavian sources to the North (Bachmann et al. 2010; Lott et al. 2010; Zimmermann et al. 2018). Considering the stable basin centre and, at least for the Keuper, comparable fluvio-deltaic routing systems (see Franz et al. 2018b), the climatic significance of the low compositional maturity of the Schilfsandstein is underlined by comparisons with the Lower Keuper and Rhaetian (Fig. 3). For the Danish, North German and Polish Basins, the Ladinian climate was reconstructed semi-humid to humid and the Rhaetian climate was reconstructed humid (Ahlberg et al. 2002, 2003; Fijałkowska-Mader 2015; Franz et al. 2015; Szulc 2000). Consequently, the low compositional maturity of the Schilfsandstein is ascribed to an arid to semi-arid mid-Carnian climate herein.

The mid-Carnian clastic equivalents are of comparable low compositional maturities. Arkoses to subarkoses were reported by Palain (1966) and Wurster (1963) from the Grès à Roseaux of the Paris Basin and by Díaz-Martínez (2000) and Arche & López-Gómez (2014) from the Manuel Formation and equivalents of the Iberian Peninsula and Balearic Islands. Behrens (1973), Seeflinga (1988) and
Aubrecht et al. (2017) reported lithic arkoses and feldspathic litharenites from the Lunz Beds (type area), Sýkora et al. (2011) and Marschalko & Pulec (1967) reported feldspathic litharenites from the Lunz Beds of the Carpathians and Jerz (1966) reported arkoses and feldspathic litharenites from the North Alpine Raibl beds.

High abundances of chemically instable detrital feldspars but also rock fragments are related to low degrees of chemical weathering and short residence time of the sediment (e.g. Johnsson & Meade 1990; Ibbeken & Schleyer 1991). According to Van de Kamp (2010), arkoses in which plagioclase is dominant in abundance over K-feldspar are the product of feldspathic crystalline sources and glacial or arid to semi-arid climates characterised by a predominance of physical weathering. Chemical weathering in source areas and the basin, for example during pedogenesis, will result in hydration of feldspars and formation of clay minerals (Nesbitt & Young 1982). Longer times of residence, for example in intermediate deposits, and subsequent reworking will also result in an increase of alteration in downstream direction (Johnsson & Meade 1990; Van de Kamp 2010). Consequently, the low maturities of mid-Carnian sandstones of the NW Tethys and peri-Tethyan realm indicate low degrees of chemical weathering in source areas and basins.

The herein described record of Schilfsandstein palaeosols corresponds to Nitsch (2005). The occurrence of histosols and hydromorphic soils in the Neubrandenburg Member and Lower Schilfsandstein is clearly related to facies shifts triggered by the pre-Schilfsandstein transgression (Fig. 2). During the following regressive phase, the falling sea-level resulted in increased drainage and desiccation of floodplains and delta plains, overprint of hydromorphic soils and formation of vertisols, calcisols and gypsisols (Fig. 4; Nitsch 2005; this work). Due to short-term flooding of the intra-Schilfsandstein transgression, hydromorphic soils evolved only locally in the Upper Schilfsandstein whereas stacked successions of gypsisols became abundant (Fig. 6). The wide-spread occurrence of vertisols, calcisols and gypsisols in the Schilfsandstein provides evidence for a mid-Carnian hydrologic regime with high evaporation rates exceeding precipitation rates (e.g. Dan & Yaalon; 1982; Retallack 1994; Sheldon & Retallack 2004; Retallack & Huang 2010) in which hydromorphic soils and histosols could develop locally at delta plains and floodplains during phases characterised by high ground water stages. A comparable scenario was described by Palain (1966) from the Grès à Roseaux, the equivalent of the Schilfsandstein in the Paris Basin.

From NW Tethyan localities, Behrens (1973), Jelen & Kušej (1982), Pott et al. (2008), Breda et al. 2009 and others described histosols associated to high ground water stages at coastal plains.
The Schilfsandstein macroflora

The Schilfsandstein macroflora database may be influenced by collecting and taphonomic biases, since no material could be collected *in situ* and/or by the authors themselves. However, the presence of abundant badly preserved plant fossils (especially sphenophyte stem remains) suggests that perhaps this bias is not too high. As most of the Schilfsandstein macroflora was recovered from sandstones the preservation is often poor. Nonetheless, it is possible to observe *in situ* stems as well as several generations of stems growing on top of each other (e.g. Kelber & Hansch 1995).

Frentzen (1930-31) found that the Schilfsandstein flora does not show xerophytic characters. The big leaves of *Chiropteris* and *Danaeopsis* demonstrate that there was enough water available and plants did not need to reduce the lamina or use other adaptations to reduce transpiration. The author reconstructed the vegetation of swamped lowlands laterally associated to fluvial channels.

According to our database, the swamped lowlands, e.g. backswamps, were mainly colonised by horsetails (*Equisetites, Neocalamites, Schizoneura*) and *Pterophyllum*. Although Bennettitales are generally considered xerophytes and are indicators of arid environments, Pott *et al.* (2008) have shown that the macromorphological and epidermal features of *Pterophyllum* leaves from the mid-Carnian Lunz ecosystem supported peat-forming environments. In the Schilfsandstein ecosystem, the osmundaceous ferns *Cladophlebis* and *Neuropteridium* were growing close to and on the riverbanks. The community of the wet Lowland MEG was probably richest in species. The understory and clearings were filled with a high diversity of ferns (*Danaeopsis, Chiropteris, Osmundites, Dictyophyllum; Kustatscher *et al.* 2012*) and shrubby conifers (*Pelourdea; Kustatscher *et al.* 2014*).

*Sphenopteris schoenleiniana* would be mostly climbing on the tree-like plants (Kustatscher & Van Konijnenburg-van Cittert 2011a).

The cuticles in the Ladinian specimens of *Scytophyllum* show adaptations to drier or more stressful environments (Kustatscher & Van Konijnenburg-van Cittert 2010; Kustatscher *et al.* 2012). Also some other seed ferns (*Sagenopteris, Lepidopteris*) and Bennettitales (*Anomozamites, Zamites*) may have grown in dry lowlands or in the hinterland. Some ferns (*Asterotheca, Clathropteris*) are characterised by a thick, leathery lamina of the pinnules suggesting drier (low ground water table) or stress-related habitats (e.g. Kustatscher & Van Konijnenburg-van Cittert 2011a; Kustatscher *et al.* 2012).

*Lepacyclotes*, the only lycophyte present in the flora, is considered to grow in coastal areas (Kustatscher *et al.* 2010, 2012) as well as the fern *Symopteris* (Kustatscher *et al.* 2011b, 2012) and
the seed fern *Ctenozamites* (comparable with *Ptilozamites*, see Kustatscher & Van Konijnenburg-van Cittert 2005; Popa & McElwain 2009). The conifers grew mainly in drier and more distant floodplains or the hinterland. The longer transport could explain the stage of fragmentation and preservation and the relatively low amount of material, in comparison with the palynoflora.

**The Schilfsandstein palynoflora**

The herein proposed associations of the Schilfsandstein palynoflora corresponds to results of previous studies by Kahlert *et al.* (1970), Visscher *et al.* (1994), Orlowska-Zwolińska (1983), Heunisch in Beutler *et al.* (1996), Fijalkowska-Mader *et al.* (2015) and others. From the Obernsees 1 well, Visscher *et al.* (1994) reported the dominance of *Ovalipollis pseudoalatus* from below the Schilfsandstein. The Lower Schilfsandstein is dominated by *Aulisporites astigmosus* (wet Lowland PEG; Visscher *et al.* 1994; this work). Interestingly, Visscher *et al.* (1994) observed the shift back to the *Ovalipollis* association (dry Lowland PEG) already in the upper part of the Lower Schilfsandstein (Fig. 10). High abundances of *A. astigmosus* were also reported by Orlowska-Zwolińska (1983) and Fijalkowska-Mader *et al.* (2015) from the Polish Basin. From the NGB, Kahlert *et al.* (1970) reported diverse palynomorph assemblages characterised by *Leschikisporites aduncus* and acritarchs. Interestingly, *A. astigmosus* was not recorded. From the Kziaz IG 2 and Sulechow IG 1 wells, Orlowska-Zwolińska (1983) reported an assemblage dominated by *Leschikisporites aduncus* from the lower part of the Schilfsandstein. In accordance to the herein proposed *Leschikisporites* association, the abundances of *A. astigmosus* are below 25 %. Associations characterised by a mix of trilete laevigate spores, ornamented spores, bisaccate pollen grains and other palynomorphs were also reported by Orlowska-Zwolińska (1983).

**A tentative reconstruction of the Schilfsandstein flora**

Any integration of macro- and palynoflora data sets is biased by statistic, palaeogeographic, stratigraphic and palaeoecologic limitations. Statistic limitations are given as for Palynomorph Eco Group analysis (PEG) more than 200 specimens could be counted per sample, whereas only for two localities, Stuttgart and Feuerbacher Heide, more than 100 macroplant specimens were available in collections. As the macrofloras of both localities show comparable compositions, the Stuttgart macroflora is considered statistically relevant.

Palaeogeographic limitations result from the lack of macroflora data from northern Germany. A palaeogeographic overlap may be provided by the Obernsees palynoflora and the macrofloras of
Eyershausen, Gochsheim, Iphofen and Zeil am Main. But as only 14–45 specimens were available from these localities, none of the macrofloras is statistically significant. However, as the macroflora of Iphofen resembles the macroflora of Stuttgart it may be considered statistically relevant (Fig. 9). The Obernsees palynoflora is well-constrained to the Lower Schilfsandstein but the Iphofen macroflora can only be tentatively assigned to this unit. Due to the grey to yellowish rock slabs lacking features of intense pedogenesis, the assignment to the Lower Schilfsandstein appears feasible. The macroflora was recovered from a sandy near-channel succession and the palynoflora from floodplain wetlands, but as both originate from the same channel-floodplain system a comparison is attempted.

The Iphofen macroflora is dominated by the River MEG (63 %) followed by the wet Lowland MEG (26 %), dry Lowland MEG (5 %) and Hinterland MEG (5 %). The Obernsees palynoflora is dominated by the wet Lowland PEG (up to 49 %), followed by the Hinterland PEG (up to 23 %), coastal PEG (up to 21 %), River PEG (up to 11 %) and dry Lowland PEG (up to 5 %). The different abundances of the River MEG and PEG are ascribed to the different environments. Accordingly, the macroflora is dominated by a (para)autochthonous riparian vegetation of sphenophytes, mainly large articulated plant remains and in situ stems, growing at river banks. In the palynoflora the River PEG is less abundant due to episodic introduction of spores to floodplain wetlands, for example crevassing. In accordance with lithofacies, the palynoflora shows high abundances of the wet Lowland PEG and subordinated abundances of the coastal PEG. This is due to high abundances of A. astigmosus, a Bennettitean pollen grain assigned to Williamsonianthus keuperianus (Kräusel & Schaarschmidt 1966). Bennettitales are allocated to the wet Lowland MEG (see above) and therefore, A. astigmosus was assigned to the wet Lowland PEG herein. Considering these results, a vegetation of ferns (mostly Marattiales, Osmundales and Dipteridaceae), cycadophytes (Pterophyllum), and shrubby conifers (Pelourdea) is reconstructed for the floodplain lowland and a vegetation of sphenophytes (Equisetites mostly) and osmundaceous ferns (Cladophlebus, Neuropteridium) for the banks of backswamps. The dry Lowland and Hinterland elements represent distant localities. The 26 % abundance of the wet Lowland MEG either may result from mixed riparian vegetation of sphenophytes, bennettitales and ferns, or from mixing during transport processes.

Comparisons of the Schilfsandstein flora with pre- or postcursor Keuper floras are limited as the Grabfeld and Weser Formations yielded only palynomorphs but not macroplant remains. This and the high abundances of the dry Lowland PEG in these palynofloras emphasise two aspects. (1) Wet floodplains represent a taphonomical window enabling the preservation of the Schilfsandstein flora. (2)
The Schilfsandstein flora represents an intrazonal flora related to a sea-level highstand in the CEB. Recently, examples of taphonomical windows were reported by Kustatscher et al. (2014, 2017). In particular, the intrazonal riparian Bletterbach flora, which occurred in an arid environment due to sea-level highstand (Kustatscher et al. 2017), seems to be an analogue for the Schilfsandstein flora.

Sea-level controlled evaporation forcing the hydrological cycle of the CEB

The herein presented data argue for a rather uniform arid to semi-arid Carnian climate. Considering this and the principle control of circum-Tethyan eustatic 3rd-order and 4th-order cycles (Köppen 1997; Franz et al. 2014), the Schilfsandstein is herein related to changes of the hydrologic cycle of the CEB. This was already concluded by Kozur & Bachmann (2010), but the authors considered the short-term redirection of the NW Tethyan monsoon across the CEB responsible for a pluvial climate in the Scandinavian source area. However, such an unusual circulation pattern remains speculative and a pluvial climate in the Scandinavian source area is not in agreement with the immature Schilfsandstein.

Considering this and herein presented data, the Schilfsandstein may not be explained in terms of monsoonal circulation or increased seasonality.

Instead, the accelerated hydrological cycle seem to be related to mid-Carnian transgressions into the CEB. Under arid to semi-arid Carnian climate, the flooded basin contributed to increased evaporation and formation of moisture-laden air masses. Probably transported by northwesterly flowing trade winds, these air masses led to increased rates of precipitation over source areas. During regressive phases, fluvio-deltaic environments prograded basin-wards and supplied detritus predominantly formed of first cycle sands (Wurster 1964; Van de Kamp 2010). High ground water stages favoured the establishment of an intrazonal flora and their preservation in backswamps and floodplain lakes (taphonomical window). From late to maximum regression, the hydrological cycle ceased due to the retreat of the inland sea and resulting lowered evaporation. Low ground water stages were responsible for increased drainage, desiccation and pedogenesis.
The pre-Schilfsandstein transgression represents the most pronounced transgression of the Lower and Middle Keuper. The control of 3rd- and 4th-order mid-Carnian T-R sequences on the hydrological cycle compares to the Upper Muschelkalk and Rhaetian, where pronounced transgressions were followed by progradations of fluvio-deltaic environments from northern sources (Franz et al. 2015; Barth et al. 2018) but, as discussed above, under semi-humid to humid climates.

Conclusions

The herein presented study of sedimentary, palynological and palaeobotanical climate proxies of the Schilfsandstein points to the following conclusions.

1. The Stuttgart Formation was primarily controlled by 3rd- and 4th-order mid-Carnian T-R cycles. Transgressions into the CEB resulted in formation of large inland seas, regressions enabled the progradation of fluvio-deltaic environments.

2. For this epicontinental setting, the detrital mineralogy and palaeosols represent reliable proxies of the palaeoclimate. Due to burial diagenesis, clay minerals and geochemical weathering indices reflect detrital and authigenic signals and thus, do not represent reliable proxies of the palaeoclimate.

3. The employed palaeoclimate proxies point to a rather uniform arid to semi-arid Carnian climate with low chemical weathering and high evaporation in which flooding of the CEB contributed to increased evaporation rates and formation of moisture-laden air masses. The forced hydrological cycle led to increased precipitation over source areas and increased runoff led to high ground water stages at delta plains and floodplains.

4. The application of MEG and PEG analyses to macro- and palynoflora datasets enables the preliminary reconstruction of the Schilfsandstein flora. Local high abundances of the wet Lowland PEG and MEG are considered intrazonal vegetation of wet lowland habitats. These habitats represent a taphonomical window which was controlled by high ground water stages at delta plains and floodplains. Laterally, the (more xerophytic) zonal Carnian vegetation prevailed in habitats of dry floodplains.
5. The herein proposed model of sea-level control on the hydrological cycle integrates the low compositional maturity and the co- and subsequent occurrences of wet backswamps and dry floodplains, hydromorphic and well drained palaeolsols, and intrazonal and zonal vegetations. By means of this, the Schilfsandstein does not provide arguments for a humid mid-Carnian episode.

6. The herein proposed model may be of significance for other epicontinental basins of the NW peri-Tethyan realm as well as for basins of the NW Tethys controlled by circum-Tethyan eustatic cycles. In these basins, the mid-Carnian clastic equivalents are of low compositional maturity and the occurrence of hydromorphic soils is related to high ground water stages at coastal plains.

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Figure captions

Fig. 1: Upper Triassic palaeogeography of the Central European Basin (CEB) according to Ziegler (1990) with wells and outcrops referred to as in the text; hatched – maximum extension of Neubrandenburg Member (pre-Schilfsandstein transgression), ECG – East Carpathian Gate, SMG – Silesian-Moravian Gate; inlet shows late Triassic global palaeogeography (Stampfli, unpublished) with the CEB and basins referred to as in the text: NCA – Northern Calcareous Alps, IP – Iberian Plate (several basins), PB – Paris Basin; modified from Franz et al. (2014). Cored wells, this work: 1 – Kb Barth 6A/65; 2 – Kb Goritz 1/62; 3 – E Klütz 1/65; 4 – E Lütow 3/66; 5 – Kb Wolgast 1A/63; 6 – Kb Tarnow At 1/65; 7 – Gt Neubrandenburg 2/85; 8 – Kb KSS 1/66; 9 – Kb Brustorf 1/62; 10 – Kb Gartz
1/65; 11 – Kb Strausberg 1/63; 12 – Ug Ketzin 38/72; 13 – Dp Morsleben 52A/95; 14 – Kb Burg M 2/61; 15 – Kb Schillingstedt 1/64; 16 – TB Obernsees 1; 17 – W Medbach. Cored or logged wells cited herein: 18 – K 5-1; 19 – E Ückeritz 1/70; 20 – E Angermünde 1/68; 21 – Nidzica IG 1; 22 – Wagrowiec IG 1; 23 – Płońsk IG 2; 24 – Ośno IG 2; 25 – Książ Wlkp IG 2; 26 – Sulechów IG 1; 27 – Woźniki K1. Outcrops, this work: 1 – Sehnde; 2 – Großmonra; 3 – Altengottern; 4 – Gispersleben; 5 – Ilversgehofen; 6 – Eyershausen; 7 – Zeil am Main; 8 – Gochsheim; 9 – Iphofen; 10 – Sinsheim; 11 – Eppingen; 12 – Sulzfled; 13 – Eberstadt; 14 – Heilbronn; 15 – Kleinheppach; 16 – Stuttgart; 17 – Feuerbacher Heide; 18 – Leonberg; 19 – Sulz am Neckar. Outcrops cited herein: 20 – Gaildorf; 21 – Basel Neuwelt.

Fig. 2: Sequence-stratigraphic scheme linking discontinuous successions of South Germany to continuous successions of North Germany; for location of wells and outcrops see Fig. 1: outcrops Basel and Gaildorf (Etzold & Bläsi 2000; Etzold & Schweizer 2005, Seegis 2005a,b), outcrops Heilbronn and Iphofen (Bachmann & Wild 1976; this work), Obernsees 1 and Medbach wells (this work), Schillingstedt 1 well (Kozur 1970a; this work), outcrop Sehnde (Beutler et al. 1996; this work), Morsleben 52A and Ketzin 38 wells (Franz et al. 2014; this work), Angermünde 1 well (Kahlert et al. 1970), Tarnow 1, Neubrandenburg 2, Brustorf 1 and Ückeritz 1 wells (Kozur 1970b; Franz et al. 2014; this work), K 5-1 well (unpublished core report). Vertical red bars – productive palynomorph samples.

Fig. 3: Detrital mineralogy revealing low compositional maturity of the Schilfsandstein. A – Ternary plot (McBride 1963) of 98 samples investigated herein in comparison to previously published examples; Q: mono- and polycrystalline quartz and chert, F: feldspar, L: lithics (unstable rock fragments), black circle and arrow: sample Wolgast 1A/65 11-11, blue circle and arrow: sample Gartz 1/65 12-17, red circle and arrow: sample Brustorf 1/62 11-12. B – Mineralogical Maturity Index (Pettijohn 1957) versus Provenance Index (Pettijohn 1957) of the Schilfsandstein in comparison to Palaeozoic to Mesozoic sandstones of the North German Basin; modified from Franz et al. (2018b). C – Thin section overview of sample Wolgast 1A/65 11-11, showing low compositional maturity with abundant greenish-brownish lithics and dark heavy minerals; Q: 30.0 %, F: 35.5 %, L: 34.5 %, median grain size: 2.3 Phi (Folk & Ward 1957); scale bar is 0.5 cm, parallel nicols. D, E – Detail of C showing detrital plagioclase (F) with authigenic overgrowth of K-feldspar (arrow); scale bar is 100 µm, D: parallel nicols, E: crossed nicols. F–H – Detail of C with quartz (Q), feldspar (F), lithics (L) and mica (M), authigenic feldspar overgrowth

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(black arrows) and Fe-rich dolomite cement (white arrow); scale bar is 100 µm, F: parallel nicols, G: crossed nicols, H: CL. I – SEM image of sample Gartz 1/65 12-17, pore filling authigenic kaolinite booklets; Q: 49.6 %, F: 28.0 %, L: 22.4 %, median grain size: 2.9 Phi (Folk & Ward 1957); scale bar is 50 µm. J – SEM image of sample Brustorf 1/62 11-12, authigenic overgrowth of idiomorph analcime crystals; Q: 29.0 %, F: 40.8 %, L: 30.2 %, median grain size: 2.1 Phi (Folk & Ward 1957); scale bar is 50 µm.

Fig. 4: Outcrop example of Upper Schilfsandstein palaeosols at Gispersleben (Thuringia). A – Overview with litholog showing stacked sheet sands with protosols in the lower part and mature vertisols above. In the upper part (above 50 cm), individual palaeosols were initially formed as gley soils and subsequently overprint to calcic vertisols. B – Disrupted root traces with halos in destratified red shales; C – Reddish hematite nodule, note the faintly horizontal-lamination of the lower greyish part (black arrow); D – Columnar carbonate nodule; scale bar (B-D) is 10 cm.

Fig. 5: Outcrop and cores examples of Schilfsandstein palaeosols. A – Calcsol at Altengottern (Thuringia, Upper Schilfsandstein) with vertical columnar carbonate nodules (arrows) and large horizontal carbonate nodules (encircled) in destratified shales, hammer marks the palaeosol top, scale is 2 m. B – Stacked sheet sands with vertic gypsisols in the Neubrandenburg 2 well, depth in metres refers to drillers depth. Boxes 1-3 show the upper part of a sheet sand characterised by partly destratified red shales with deep desiccation cracks (black arrow). Gypsum occurs as fillings of desiccation cracks and displacive nodules and columns (white arrows); note the upwards increasing size of nodules. Boxes 4-5 show the lower part of the next sheet sand (base marked by white line) composed of greenish sandstone and partly destratified red shales with gypsum nodules (white arrows).

Fig. 6: Schilfsandstein palaeosols in the North German Basin on the example of the Morsleben 52A well. Floodplain fines of stacked sheet sands were modified to spodosols and calcic-gypsic vertisols in the Lower Schilfsandstein and spodosols, calcisols and gypsisols in the Upper Schilfsandstein.

Fig. 8: Quantitative composition of the Schilfsandstein macroflora: 16 localities of South and central Germany, for position see Fig. 1.
Fig. 9: Macroplant Eco Groups (MEG) of the Schilfsandstein macroflora: 16 localities of South and central Germany, for position see Fig. 1.

Fig. 10: Palynomorph Eco Groups (PEG) and palynomorph associations of the Schilfsandstein, O – *Ovalipollis* association, I – Inland sea palynomorph association, L – *Leschikisporites* association, A – *Aulisporites* association, Trilete laevigate spores association, *– redrawn from Visscher et al. (1994), for details and vertical scale see Fig. 2.

Tab. 1: Overview on palaeosol classes of the Schilfsandstein in the CEB. South Germany emended after Nitsch (2005).

Figure 7: Plant macrofossils of the Schilfsandstein flora; scale bars is 1 cm for all figures. A – Sporophyll of *Lepacyclotes*, Korber Korb (SMNS Pb645). B – Apical axis fragment of *Equisetites*, Stuttgart (SMNS P.563). C – Axis with elongate microphylls of *Neocalamites*, Stuttgart (SMNS P.666-2). D – Frond fragment of *Dictyophyllum*, Stuttgart (SMNS P.196). E – Frond fragment of *Clathropteris*, Stuttgart (SMNS P.778). F – Almost complete leaf of *Lepidopteris*, Stuttgart (SMNS P.666-1). G – Leaf of *Pterophyllum*, Öhringen (SMNS P.21419). H – Two cone fragments of *Glyptolepis*, Stuttgart (SMNS P.1866). I – Big root fragment, Stuttgart (SMNS P.761).

Figure 11: Schilfsandstein palynoflora. Fig. 1–16 Obernsees 1 well: 1, 2 – *Anapiculatisporites* spp., P80644. 3 – *Leschikisporis aduncus*, P80644. 4 – *Lycospora* sp., P80644. 5 – *Kraeuselisporites* spp., P80643. 6–8 – *Aratrisporites* spp., P80643. 9, 10 – *Aulisporites astigmosus*, P 80643, P80644. 11 – cf. *Camerosporites secatus*, P80644. 12 – cf. *Chasmatosporites* spp., P80644. 13 – *Platysaccus* spp., P80644. 14 – *Triadispora crassa*, P80644. 15 – *Araucariacites australis*, P80643. 16 – overview of P80644, arrows: *Aulisporites astigmosus*. 17 – overview of P80639, Medbach well, mass occurrence von *Ovalipollis pseudoalatus*. Scale bar is 50 µm for figures 1–15, figures 16, 17 are out of scale.
|                | South Germany          | Thuringia/Subhercyn | North Germany          |
|----------------|------------------------|---------------------|------------------------|
| Lower Weser Fm | vertisols, calcisols,  | protosols, spodosols,  | protosols, spodosols,  |
|                | gypsols                | vertisols, calcisols | vertisols, calcisols   |
| Upper Schiffsandstein | protosols, histosols, | protosols, spodosols,  | protosols, spodosols,  |
|                | spodosols, vertisols,  | vertisols, calcisols | vertisols, calcisols   |
|                | calcisols and gypsols  | and gypsols          | and gypsols            |
| Lower Schiffsandstein | protosols, histosols, | protosols, histosols,  | protosols, histosols,  |
|                | spodosols and calcisols| spodosols, vertisols,| vertisols, and gypsols |
|                |                        | calcisols and gypsols|                        |
| Upper Gatzfeld Fm | vertisols, calcisols,  | vertisols, calcisols,  |                         |
|                | gypsols                | gypsols              |                         |