3rd International Conference of Continental Ichnology

2019

Field Trip Guide

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& Oliver Wings

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ICCI 2019 Field Trip Schedule

Day 1 – Friday, 27th September 2019

Departure: Domplatz Halle (Saale) at 7.45 am.

Stop 1. Schlehenmühle at the river Rotmain, SE Bayreuth at 10.30 am.
Lunch at Ausflugsgaststätte Schlehenberg.

Stop 2. Schönebachsmühle at 2 pm..

Stop 3. Neubrunn/Hassberge at 3.45 pm.

Stop 4. Hildburghausen at 5.30 pm.

Stop 5. Schloss Bertholdsburg in Schleusingen at 7 pm.
Supper in Schleusingen.

Overnight: Hirschbach, Gasthof „Zum Goldenen Hirsch" at 10 pm.

Day 2 – Saturday, 28th September 2019

Breakfast at the hotel at 7 am and **departure from Hirschbach** at 8 am.

Stop 6. Bromacker Quarry / Tambach-Dietharz at 9 am.

Stop 7. Museum collection, Gotha at 11 am.
Lunch: packages handed out in Gotha. The participants are visiting the collection facility in two groups - with time for lunch in the nearby park area for the non-visiting group.

Stop 8. Konberg Quarry / Rothenschirmbach at 2.30 pm.

Stop 9. Solvay Quarry / Bernburg at 4.30 pm

Overnight: Hotel (Slotel Budget) in Bernburg will be reached at 6.30 pm.

Diner/supper – possibilities in the city centre of Bernburg.

Day 3 – Sunday, 29th September 2019

Breakfast at the hotel at 7.30 am and **departure from Bernburg** at 8.15 am

Stop 10. Mammendorf Quarry at 9.30 am.

Stop 11. Dinosaurier-Park Münchehagen at 1 pm
Lunch in the Dinopark restaurant.

Stop 12. Obernkirchen Quarry at 3.30 pm.

Return to Halle (Saale) and **arrival at 8 pm**.

The stops are situated in northern Bavaria, Thuringia, Saxony-Anhalt and Lower Saxony (Fig.I); they cover a stratigraphic range from the Carboniferous/Permian boundary to the Early Cretaceous (Fig. II).

Fig. I. Geographic position of ICCI 2019 field trip stops no. 1 – 12 and hotels in Hirschbach and Bernburg (based on https://commons.wikimedia.org/wiki/File:Relief_Map_of_Germany.svg).

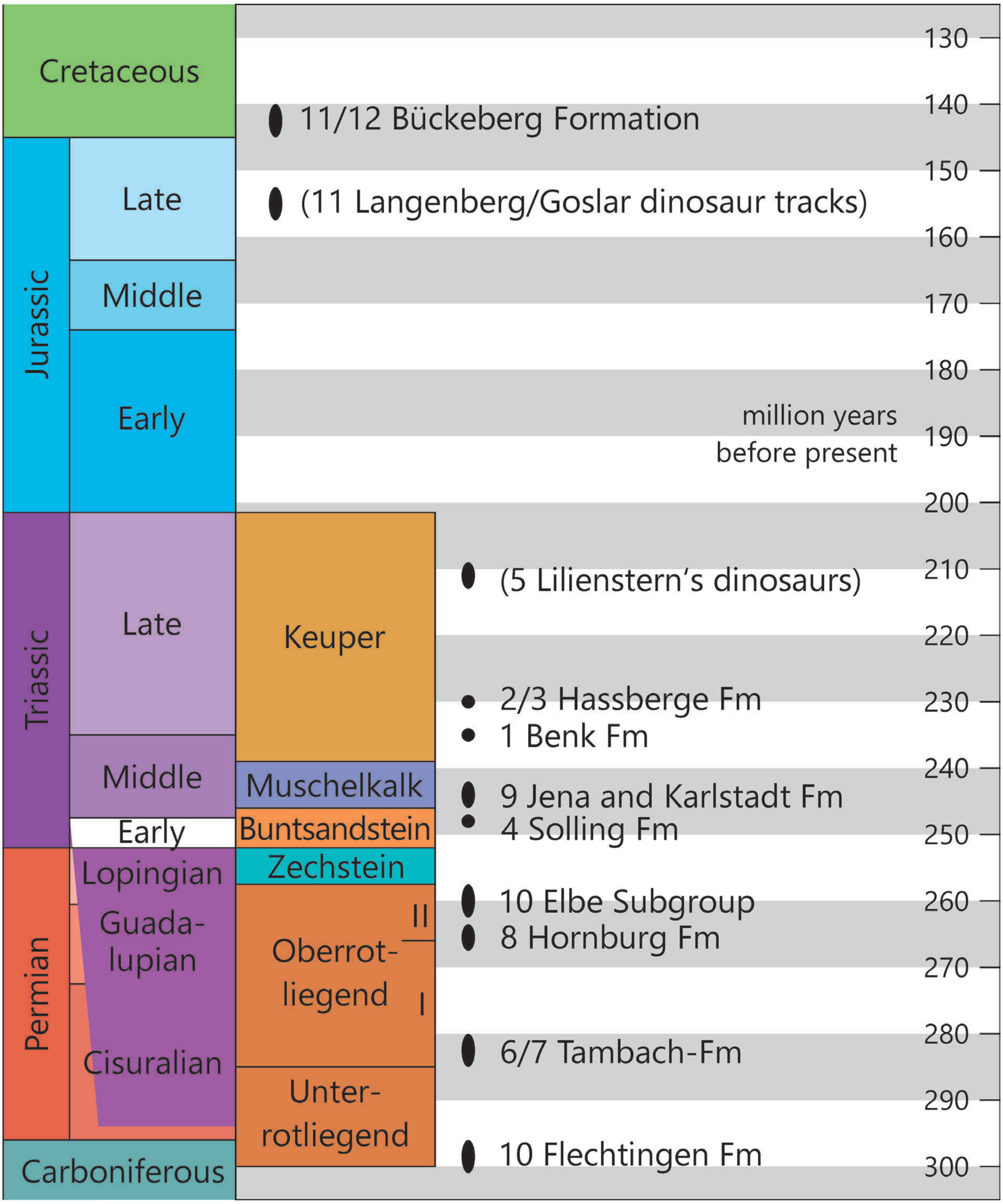


Fig. II. Stratigraphic position of localities 1 – 12.

Day 1 – Friday, 27 September 2019

The Triassic of the Germanic Basin

General overview: The Germanic Basin, or Central European Basin is one of the most important regions for ichnological research and extremely rich in trace fossil horizons and localities (see distribution of vertebrate tracks in Figs. 1-2). This is an epicontinental (Peri-Tethyan) depositional area that extended from Great Britain in the west to Poland in the east and from the North Sea to southern Germany. Borders were the Fennoscandian Massif to the north and northeast, the London-Brabant and Gallian Massifs to the west, and the Bohemian-Vindelician Massif to the east and southeast. These mainlands were the source of clastic deposits transported into the basin by fluvial activity. In northern Germany about 3000 meters of Triassic sediments have been deposited. The early formation of this structure goes back to the end of the variscan orogeny in the latest Carboniferous and Permian. Connections to the Tethyan ocean in the south existed by the Burgundy Gate, the Silesian-Moravian Gate and the East Carpathian Gate.

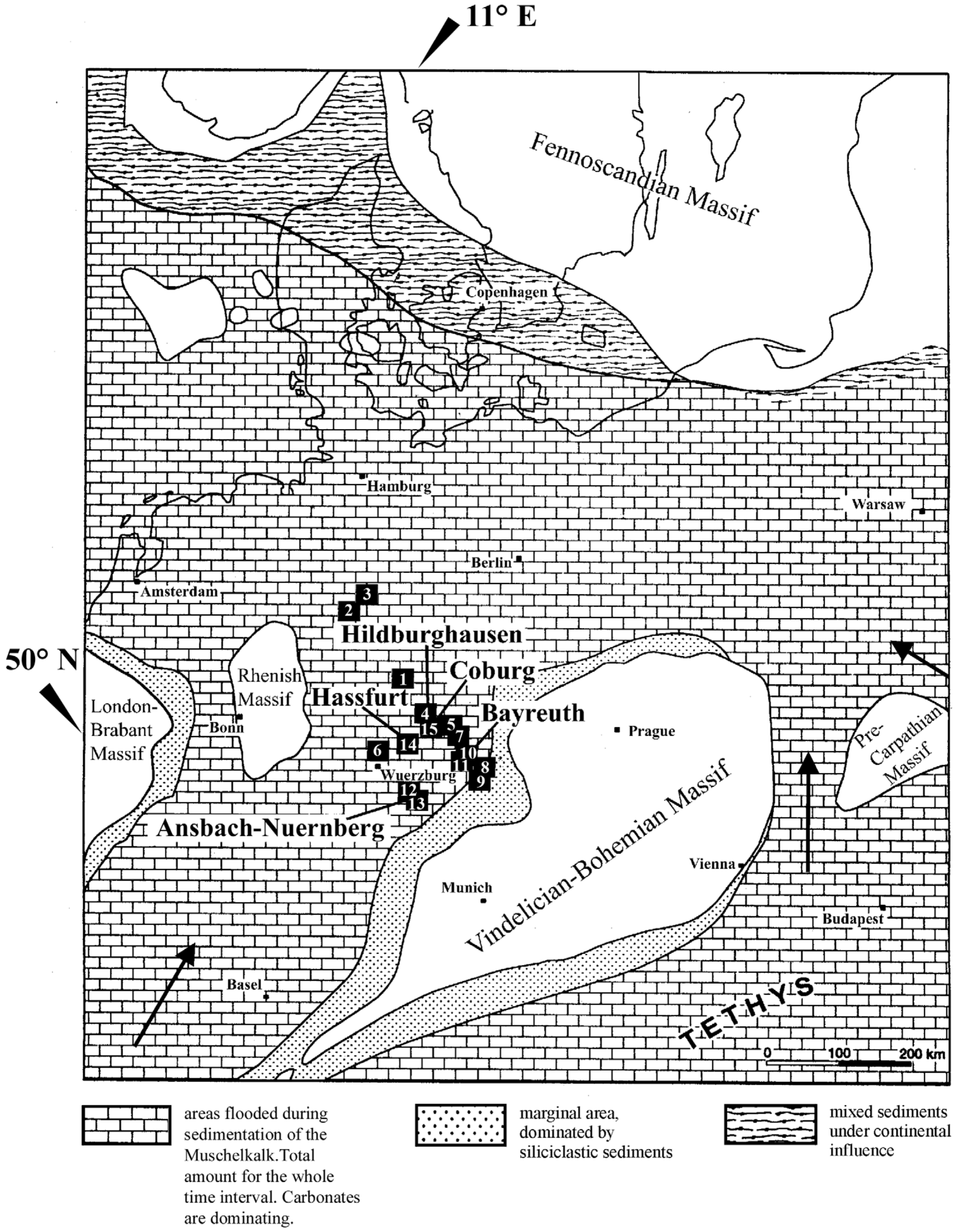


Fig. 1. Paleogeographic map of the Germanic Basin during deposition of the Muschelkalk (Middle Triassic, Anisian-Ladinian), with distribution of track localities of the whole Triassic along the Bohemian-Vindelician massif. Numbers correspond to those in Fig. 2. Base map from Geyer (2000) and Ziegler (1982).

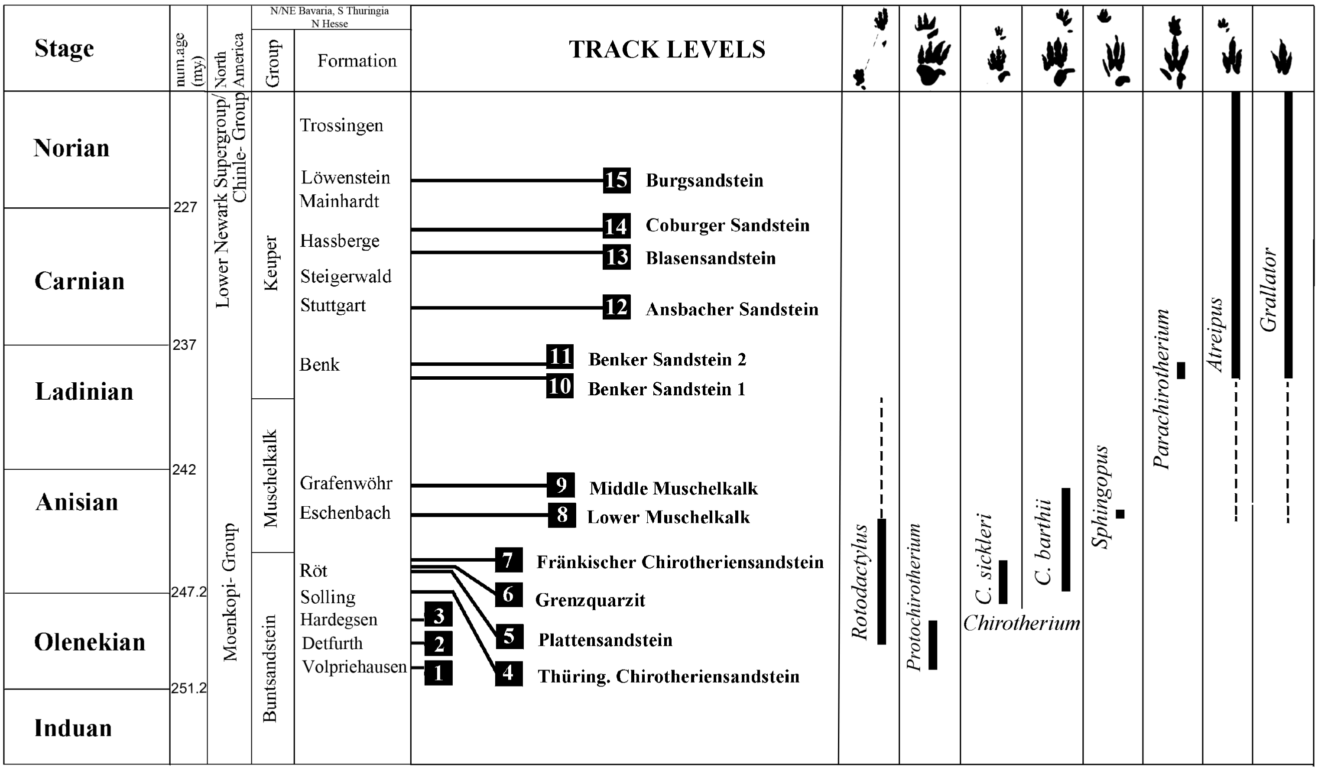


Fig. 2. Tetrapod footprint horizons and range chart of archosaur tracks from the Lower-Upper Triassic of the Germanic Basin of northern and northeastern Bavaria, southern Thuringia and Hesse. Numbers correspond to those in the map of Fig. 1.

Classical stratigraphy devides the Triassic deposits of the Germanic Basin into lower, continental redbeds (Buntsandstein), the middle part that is characterised by carbonatic and evaporitic, essentially marine sedimentation (Muschelkalk), and an upper continental redbed succession (Keuper). The continentally dominated deposits furthermore show marine transgressions in the upper part of the Buntsandstein (Roet Formation) and a transition from marine to continental sedimentation in the lower part of the Keuper (Erfurt Formation).

Lithologically the Buntsandstein is composed mostly of sandstones and shales deposited in fluvial and playa depositional environments. The upper part (Roet Formation) yields gypsum, anhydrite, halite and carbonates. The Muschelkalk is dominated by limestones and marls, with abundant dolomites, gypsum, anhydrite and halite forming the middle part. The Keuper shows marine dolomites and continental siliciclastic deposits such as sandstones and shales in the lower part (Erfurt Formation), and playa deposits with siliciclastic beds, partly alternating with gypsum, anhydrite and dolomite layers in the middle part. The Schilfsandstein of the Stuttgart Formation represents a fluvial deposit that has its origin in the Fennoscandian Massif of the north. The upper part of the Keuper (Rhaetian) has marine sandstones and shales.

Buntsandstein: The Buntsandstein succession in the Germanic Basin (Fig. 3) has a thickness of about 500-1200 meters. It is subdivided into a lower (Calvörde and Bernburg formations), middle (Volpriehausen, Detfurth, Hardegsen, Solling formations) and upper part (Roet Formation). Formations can be cross-correlated to the international time scale, with the Bernburg and Calvörde formations representing the Induan, the Volpriehausen, Detfurth, Hardegsen formations and most of the Solling Formation representing the Olenekian, and the uppermost Solling Formation and the Roet Formation belonging to the early Anisian. Known ichnofossils include rich vertebrate track assemblages and invertebrate traces (see below), bodyfossils are vertebrate skeletal remains such as fishes, temnospondyl amphibians, procolophonids, and archosaurs, invertebrates with crustaceans, insects and bivalves, furthermore plants. Biostratigraphically conchostracans as well as some chirothere tracks are important (LEPPER & RÖHLING, 1998; BACHMANN & KOZUR, 2004; KLEIN & LUCAS, 2010).

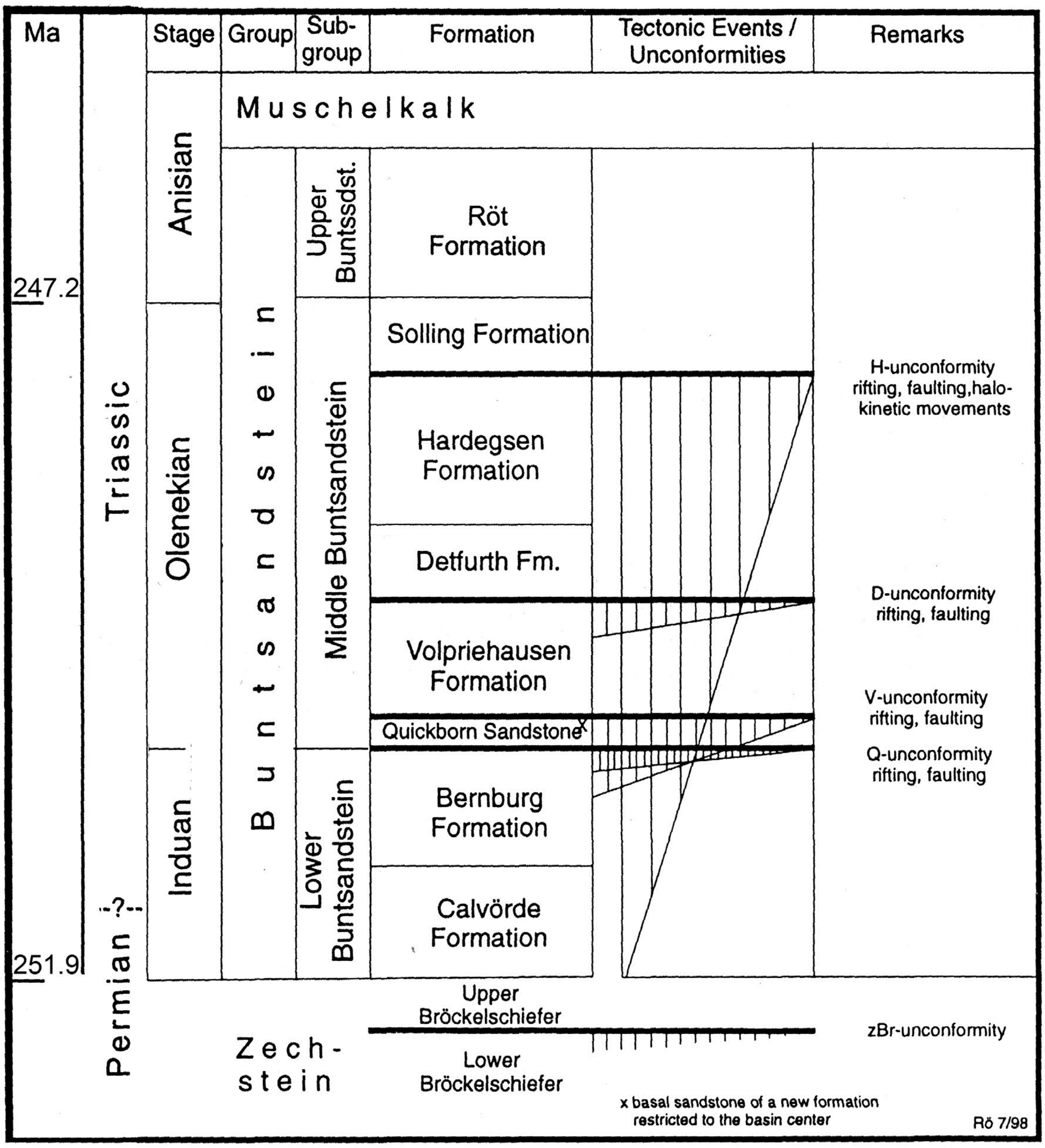


Fig. 3. Chronostratigraphy and lithostratigraphy of the Buntsandstein in Germany. From Lepper & Röhling (1998). Numerical ages updated according to Cohen et al. (2013).

Muschelkalk: The Muschelkalk succession in the Germanic Basin (Fig. 4) has a maximum thickness of about 250 meters. It is subdivided into the lower part (Jena Formation), middle part (Karlstadt, Heilbronn, Diemel formations), and upper part (Trochitenkalk, Meißner formations). These can be cross-correlated to the international time scale with the Jena to Diemel formations representing the Anisian, and the Trochitenkalk Formation belonging to the Ladinian. Ichnofossil assemblages from marginal marine deposits of the Muschelkalk include abundant vertebrate tracks and invertebrate trace fossils (see below), bodyfossils are vertebrates with fishes and marine reptiles, furthermore rich invertebrate faunas with cephalopods, crustaceans, bivalves, brachiopods and echinoderms. Biostratigraphically, in particular cephalopods (ceratites), conodonts, brachiopods, bivalves, echinoderms, ostracods and marine reptiles are important as well as some plant fossils (HAGDORN et al., 1998).

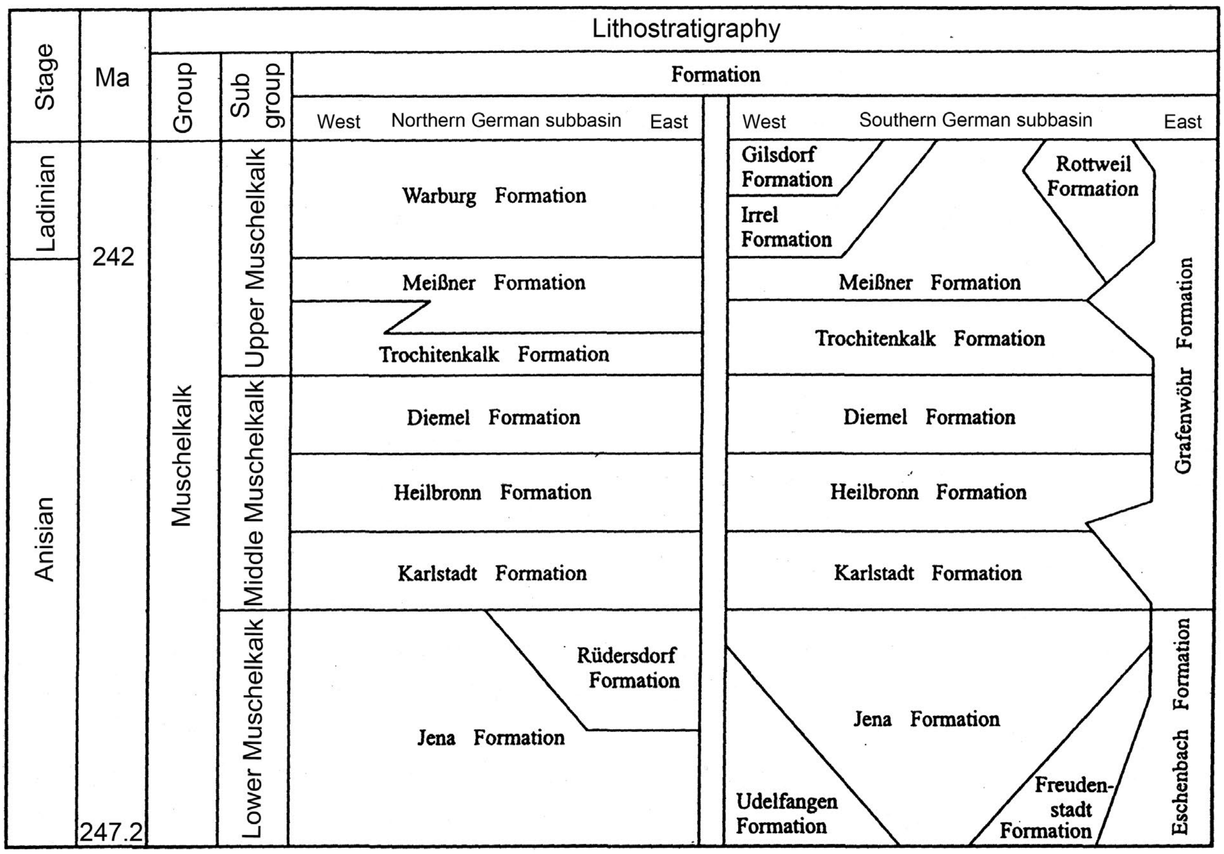


Fig. 4. Chronostratigraphy and lithostratigraphy of the Muschelkalk in Germany. From HAGDORN et al. (1998). Numerical ages updated according to COHEN et al. (2013).

Keuper: The Keuper succession in the Germanic Basin (Fig. 5) has a maximum thickness of 700 meters, except in some graben structures where it can reach several thousand meters.

It is subdivided into the lower part (Erfurt Formation), the middle part (Grabfeld, Weser, Arnstadt formations), and upper part (Exter Formation) with equivalents at the southern margin along the Bohemian-Vindelician Massif, such as the Grafenwöhr, Benk, Stuttgart, Steigerwald, Hassberge, Mainhardt, Löwenstein and Trossingen formations. Correlations to the international time scale are Ladinian (Erfurt Formation-lower Grabfeld Formation), Carnian (upper Grabfeld Formation-Weser Formation), Norian (Arnstadt Formation) and Rhaetian (Exter Formation). Ichnofossils occur with abundant invertebrate traces in all units of the Keuper, vertebrate tracks are present with diverse assemblages in particular in the middle Keuper. Bodyfossils include vertebrates with fishes, temnospondyl amphibians, procolophonids, turtles, archosaurs including phytosaurs, aetosaurs and dinosaurs like plateosaurs and theropods. Invertebrates are also present and reveal bivalves, crustaceans, insects and abundant plants. Biostratigraphically palynomophs, ostracods and bivalves are important (BEUTLER, 1998).

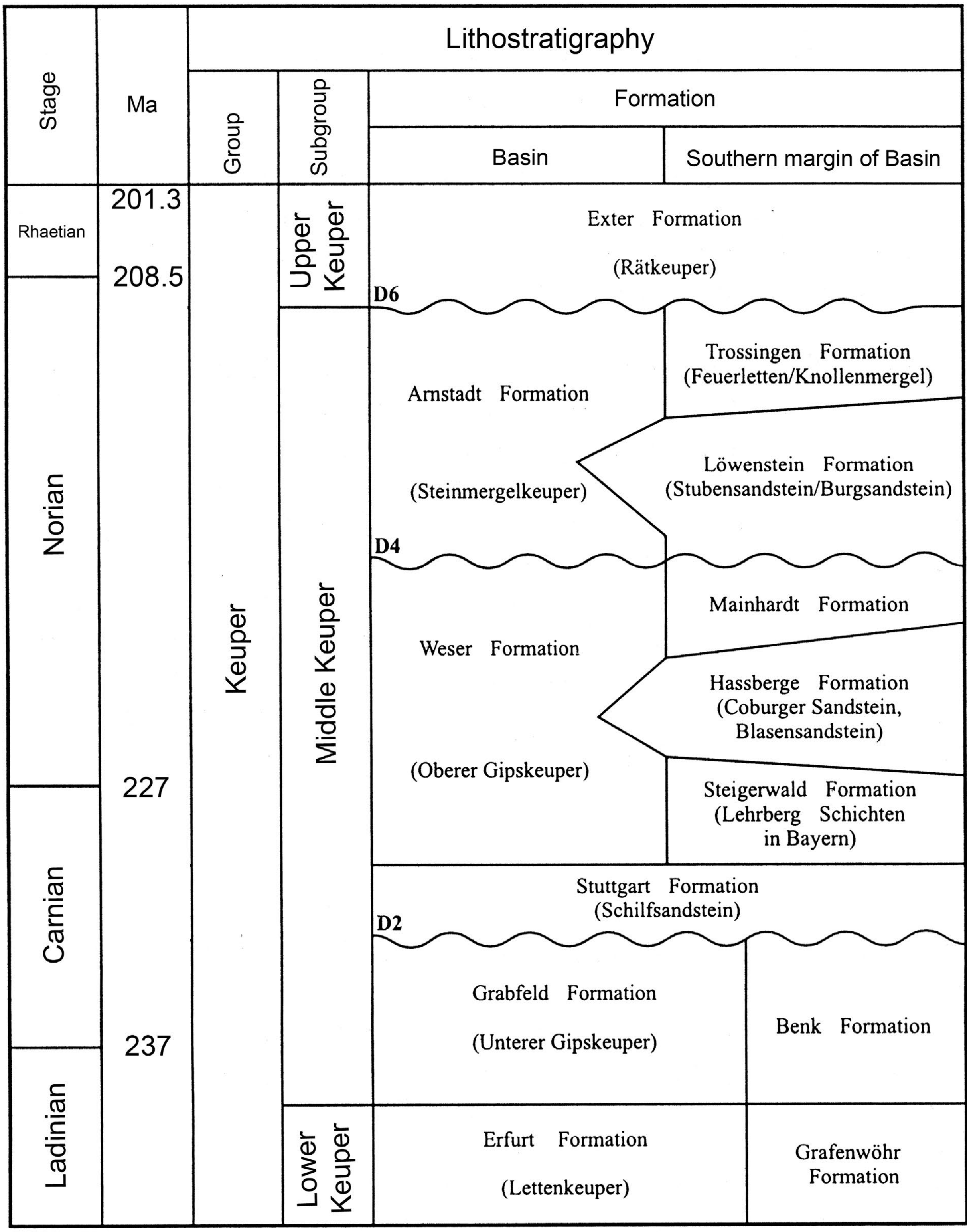


Fig. 5. Chronostratigraphy and lithostratigraphy of Middle-Upper Triassic units in Germany. From Beutler (1998). Numerical ages updated according to Cohen et al. (2013).

Fig. 6. Outcrop along the Red Main River SE of the city of Bayreuth, with sandstone-claystone succession of the trace-fossil bearing Benker Sandstein (Benk Formation, Middle Triassic, late Ladinian) as overview (top) and detail (bottom).

Stop 1. Schlehenmühle, SE Bayreuth

Location. Outcrop along the bank of the Red Main River, which belongs to the headwaters of the Main River, where the city of Frankfurt is situated. It lies in a hilly and wooded area southeast of the city of Bayreuth with continental and marine Triassic-Jurassic rocks, commonly exposed in isolated fault-blocks. The succession is in the lower Benk Formation of the Middle Keuper (Middle Triassic, latest Ladinian).

GPS. 49°54'28.2"N 11°37'19.6"E

Features to be seen.
1. Section in fluvial siliciclastic rocks with archosaur and other tetrapod tracks, including the chirotheriid ichnotaxon "*Parachirotherium*" *postchirotherioides*.
2. abundant invertebrate traces.

Geology/Ichnology. The outcrop consists of arcosic white to yellowish, mostly medium to fine-grained sandstones and siltstones, alternating with red and green claystone layers (Fig. 6). Characteristic features are crossbedding, rip-up clasts, mudcracks, halite crystal casts. The succession belongs to the Benk Formation (Middle Triassic, latest Ladinian), that interfingers with the marginal marine-playa Grabfeld Formation of the basin (Figs. 5, 7). Deposition took place along the Bohemian Massif in an alluvial fan/alluvial plain environment with occasional sheetflood events. This is the type locality of the chirotheriid "*Parachirotherium*" *postchirotherioides* (Fig. 8A). The ichnotaxon is characterized by the trackways of a quadruped with a functionally tridactyl pes imprint that has strongly reduced and posteriorly shifted digits I and V. Trackmakers are considered to be dinosauriform archosaurs. The late Ladinian is an important time interval for the evolution of dinosauriforms. Deposits of this age also contain mesaxonic tridactyl pes imprints, that are occasionally accompanied by a manus trace, documenting trackways of a facultative biped. They can be assigned to the *Atreipus-Grallator* plexus and represent some of the oldest representatives of these ichnotaxa (Fig. 8B), that have their very first appearance in the late Anisian. This has been documented from a global record (Klein & Lucas, 2010). Co-occurring tetrapod tracks are "*Brachychirotherium*" isp. (Fig. 8C) and *Rhynchosauroides* isp. that can be attributed to basal archosaurs and archosauromorphs/lepidosauromorphs, respectively. Invertebrate traces are present with abundant *Skolithos* and *Scoyenia* (Fig. 8A, C). For vertebrate ichnofauna see Haubold & Klein (2000, 2002). Bodyfossils present in the Benk Formation are plants, conchostracans and bivalves. A skull of a capitosaurian temnospondyl is also known (Kamphausen, 1990).

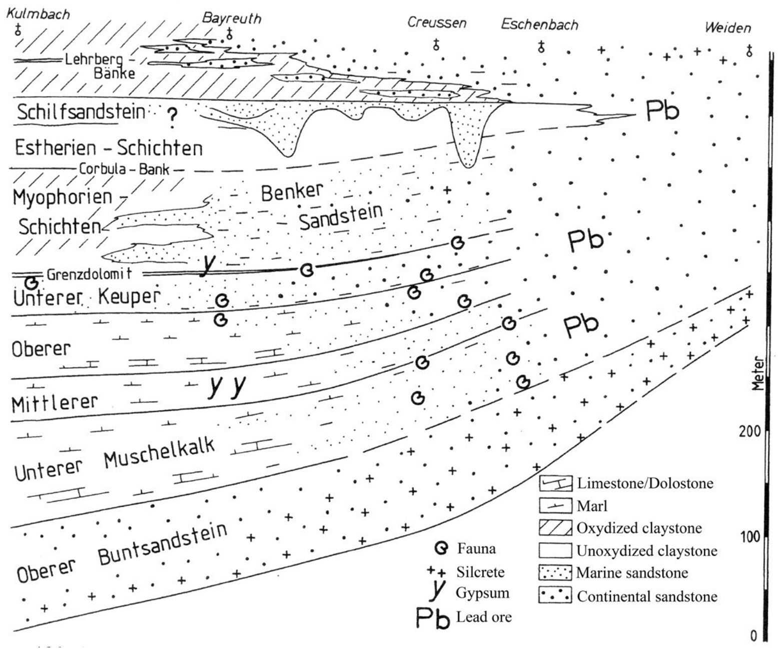


Fig. 7. Lithologic section with Middle-Upper Triassic (Anisian-Carnian) deposits SE of the city of Bayreuth. From Schröder et al. (1998).

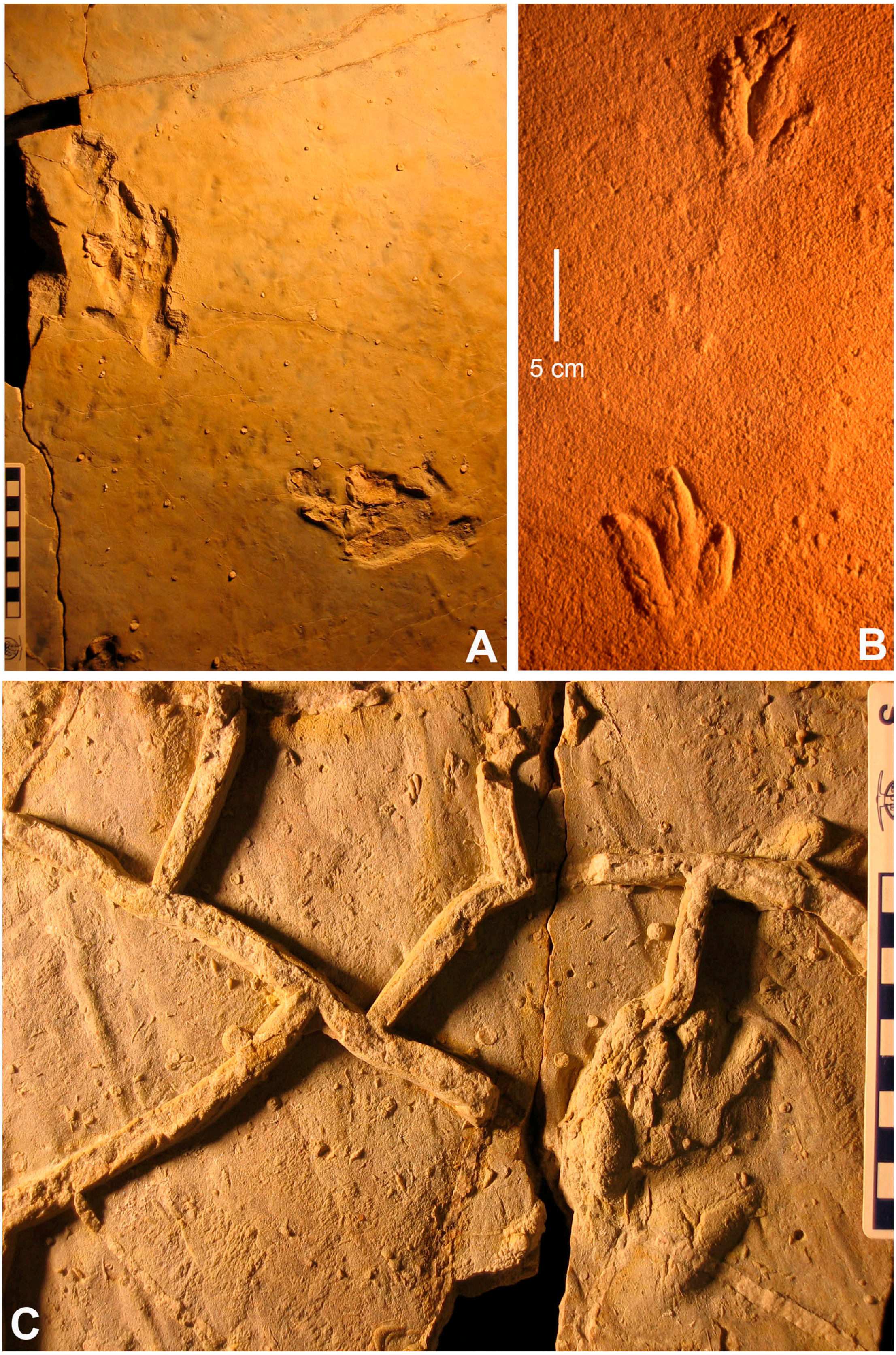


Fig. 8. Trace fossils from the Benker Sandstein (Benk Formation, Middle Triassic, late Ladinian) southeast of Bayreuth City. A. Section with detail of crossing trackways of "*Parachirotherium*" *postchirotherioides* from the type locality, showing two pes-manus sets preserved as concave epirelief, together with numerous *Skolithos* isp. B. Section of trackway with two pes and overstepped manus imprints of tridactyl *Atreipus-Grallator*, preserved as convex hyporelief. C. Mudcracked surface with "*Brachychirotherium*" isp., pes-manus set (right), together with small *Rhynchosauroides* isp. footprints, scratch marks and *Skolithos* isp. Scale bar increments 1 cm.

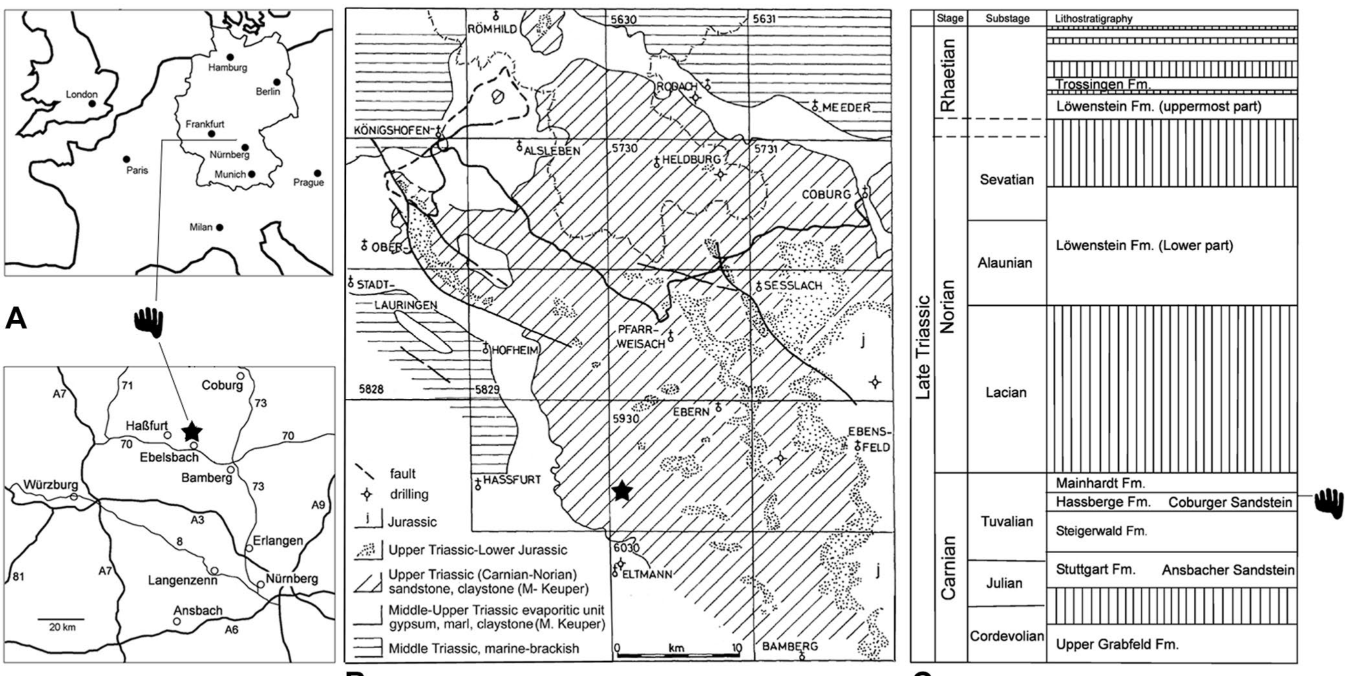
Stops 2 and 3. Schönbachsmühle and Neubrunn, Hassberge, NW Bamberg.

Location. Two (largely abandonded) quarries in the Coburger Sandstein of the Hassberge Formation (Middle Keuper, Upper Triassic, Carnian). They are situated in the Hassberge, smooth forested hills (altitude ~500 m) northwest of the city of Bamberg and north of the Main River, that gave the name to the formation. At their basis they consist of continental deposits of the Upper Triassic Keuper (Carnian-Rhaetian). Exposed in the quarries is a section of about ten meters, with thick channel sandstones at the base that have been quarried for building stones.

GPS. 50°00‘42.0“N 10°40‘15.8“E and 50°01‘56.7“N 10°40‘10.5“E

Features to be seen.
1. Characteristic fluvio-lacustrine Keuper succession.
2. Archosaur tracks, including *Brachychirotherium*, *Atreipus-Grallator* and *Apatopus*.
3. Rich invertebrate ichnofauna with *Planolites*, cf. *Asterosoma*, *Skolithos* and others.

Geology/Ichnology. The Coburger Sandstein forms the upper part of the Hassberge Formation (Fig. 9). Deposits are Late Triassic (Late Carnian) in age. The quarries show a perfect architecture of a fluvio-lacustrine environment with successions of deep sandstone channels and playa-lacustrine overbank deposits with claystones, siltstones and sandstones, partly exhibiting extensive layers of ochre-coloured carbonatic concretions, as well as overlying crevasse-splay sandstones (Figs. 10A, B, 11). Features are trough bedding, tabular cross bedding, horizontal bedding, with some layers showing carbonate concretions, intraclasts, mud cracks, halite crystal casts, rootlets and more extensive bioturbation.



B C

Fig. 9. Geographic and geologic maps (A-B), and lithostratigraphic section of the Upper Triassic in southern Germany (C), with position of outcrops and tetrapod footprints in the Coburger Sandstein. From Klein & Lucas (2013).

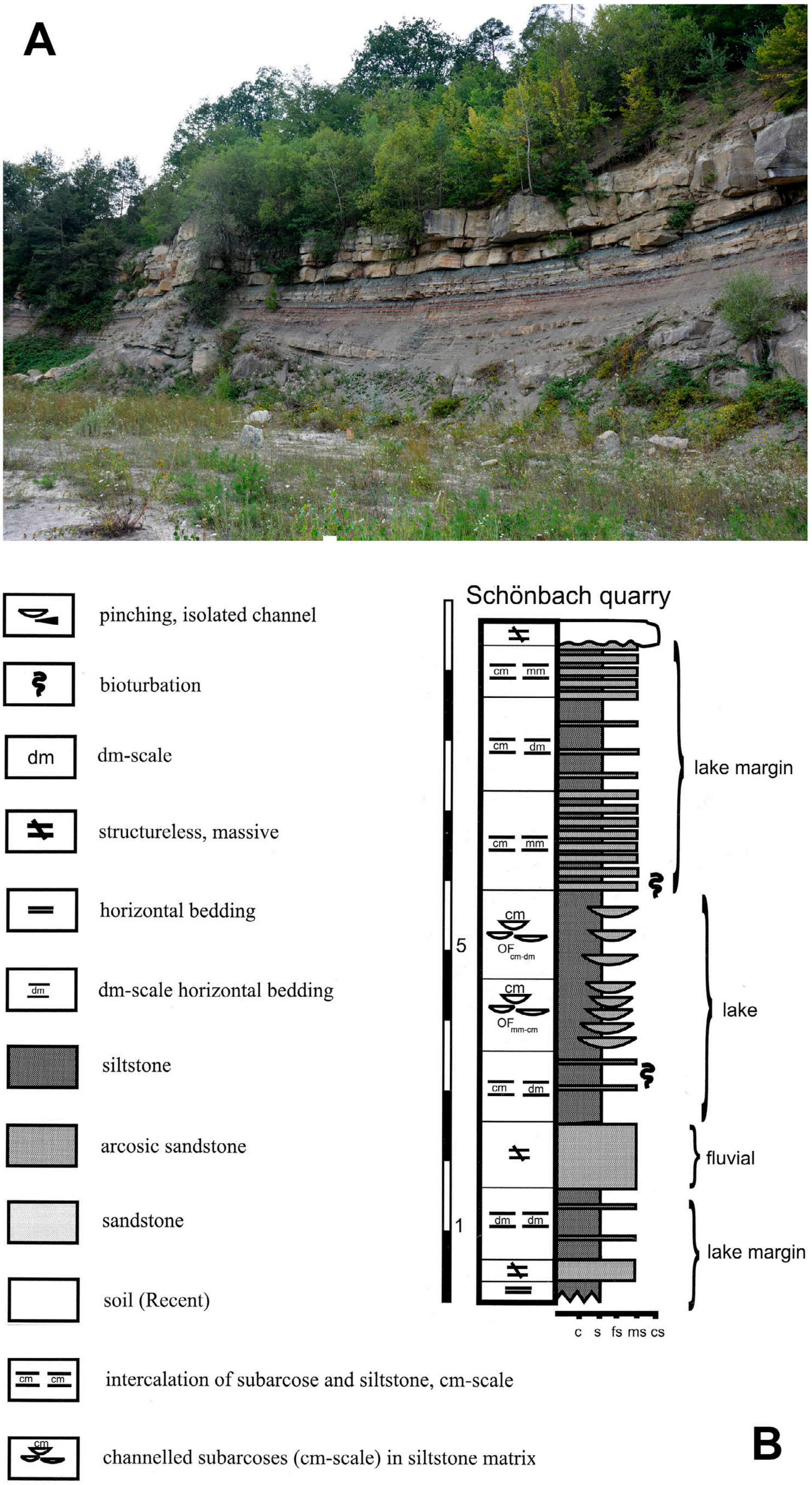


Fig. 10. Quarry in the Coburger Sandstein unit (Hassberge Formation, Upper Triassic, Carnian) at Schönbachsmühle locality. A. Overview photograph showing fluvio-lacustrine succession with thick channel sandstones at the base, followed by overbank playa and crevasse splay deposits. B. Lithological section with sedimentary features and distribution of trace fossils. From SCHLIRF et al. (2001).

The Coburger Sandstein is the type horizon of the ichnogenus *Brachychirotherium* Beurlen 1950 that has been documented thus far from a global distribution (Karl & Haubold, 1998; Klein & Lucas, 2010). It is present in this unit with two ichnospecies: *B. hassfurtense* (type ichnospecies) and *B. thuringiacum* (Karl & Haubold, 1998)(Fig. 12A). *Brachychirotherium* can be attributed to crocodylian-stem archosaurs, that were either aetosaur or rauisuchid pseudosuchians. Characteristic are pes and manus imprints with short broad digit traces and tiny claw marks. *Brachychirotherium* has also some biostratigraphic significance, being the index fossil of the Late Triassic *Brachychirotherium* biochron (Klein & Lucas, 2010). Associated vertebrate tracks are tridactyl dinosauromorph tracks of the *Atreipus-Grallator* plexus (Fig. 12B) as well as small lacertoid *Rhynchosauroides* representing lepidosauromorph and/or archosauromorph trackmakers. In recent years further ichnotaxa such as *Apatopus lineatus* (phytosaur) and a new ichnotaxon *Procolophonichnium lockleyi* (therapsid) have been described from the Coburger Sandstein (Klein & Lucas, 2013; Klein et al., 2015)

(Fig. 12C-D). The unit has also a rich invertebrate ichnofauna with the ichnogenera *Skolithos*, *Scoyenia*, *Taenidium*, *Lockeia*, *Rusophycus*, *Cruziana*, *Polykladichnus*, *Helminthoidichnites*, *Planolites* and others (Schlirf et al., 2001)(Fig. 13A-B). Body fossils are known with crustaceans (*Triops*), insects, fishes and plants. The lower part of the Hassberge Formation (Blasensandstein) has yielded a rich vertebrate fauna with skeletal remains of temnospondyls and phytosaurs (Kuhn, 1936).

Fig. 11. Quarry in the Coburger Sandstein unit (Hassberge Formation, Upper Triassic, Carnian) W of Neubrunn village with fluvial channel sandstones and overbank deposits. This locality yielded a rich vertebrate ichnofauna with *Brachychirotherium*, *Atreipus-Grallator*, *Apatopus*, *Rhynchosauroides* and *Procolophonichnium*.

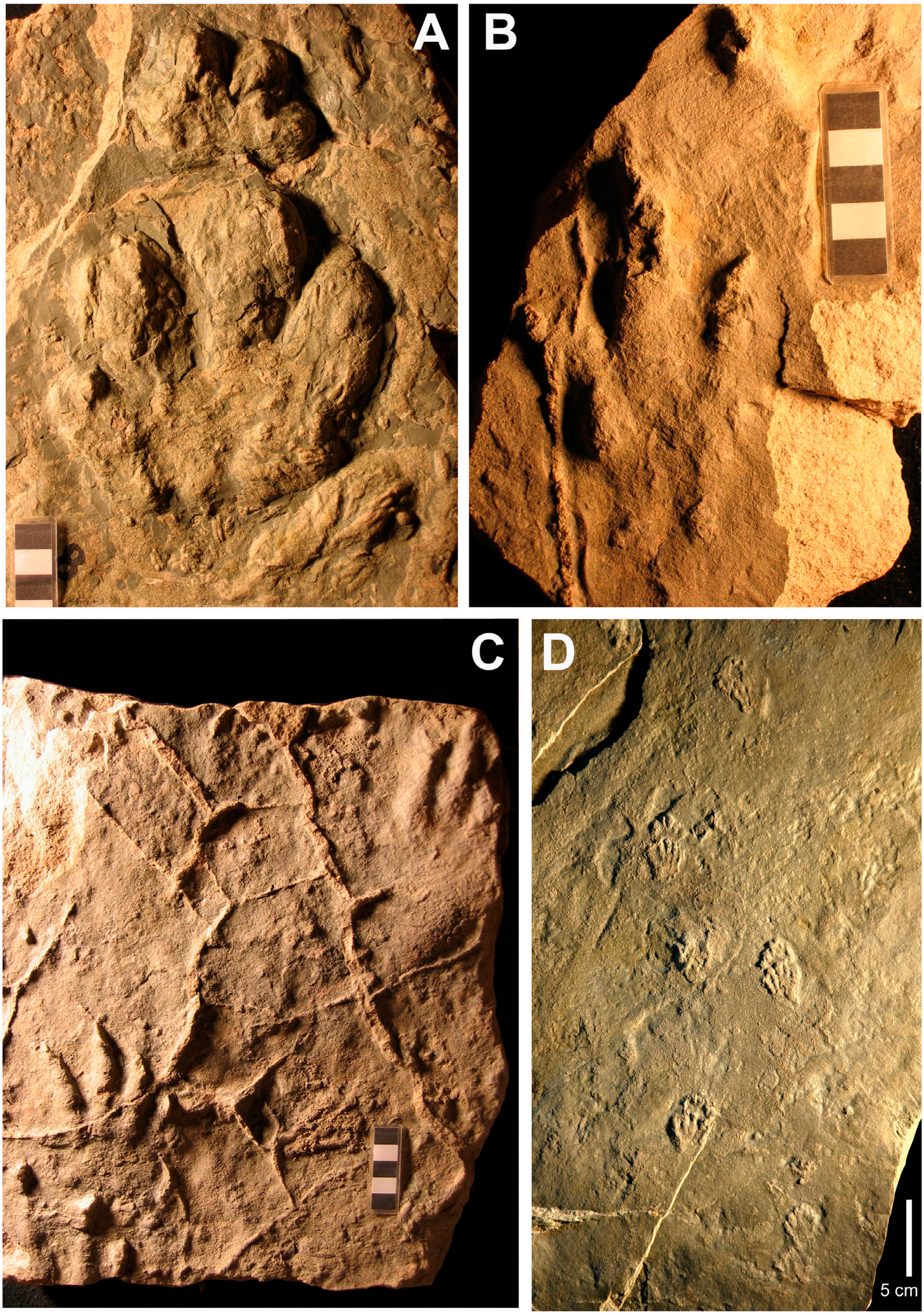


Fig. 12. Trace fossils from the Coburger Sandstein unit (Hassberge Formation, Upper Triassic, Carnian) of the Germanic Basin. A. *Brachychirotherium thuringiacum*, pes-manus set. B. *Atreipus-Grallator*, pes-manus set. C. *Apatopus lineatus*, partial trackway with pes-manus set and pes imprint. D. *Procolophonichnium lockleyi*, holotype trackway. Scale bar increments 1 cm.

Fig. 13. Invertebrate trace fossils from the Coburger Sandstein (Hassberge Formation, Upper Triassic, Carnian) of the Germanic Basin. A. cf. *Asterosoma*. B. *Planolites* isp. (pers. comm. M. Schlirf, Haßfurt).

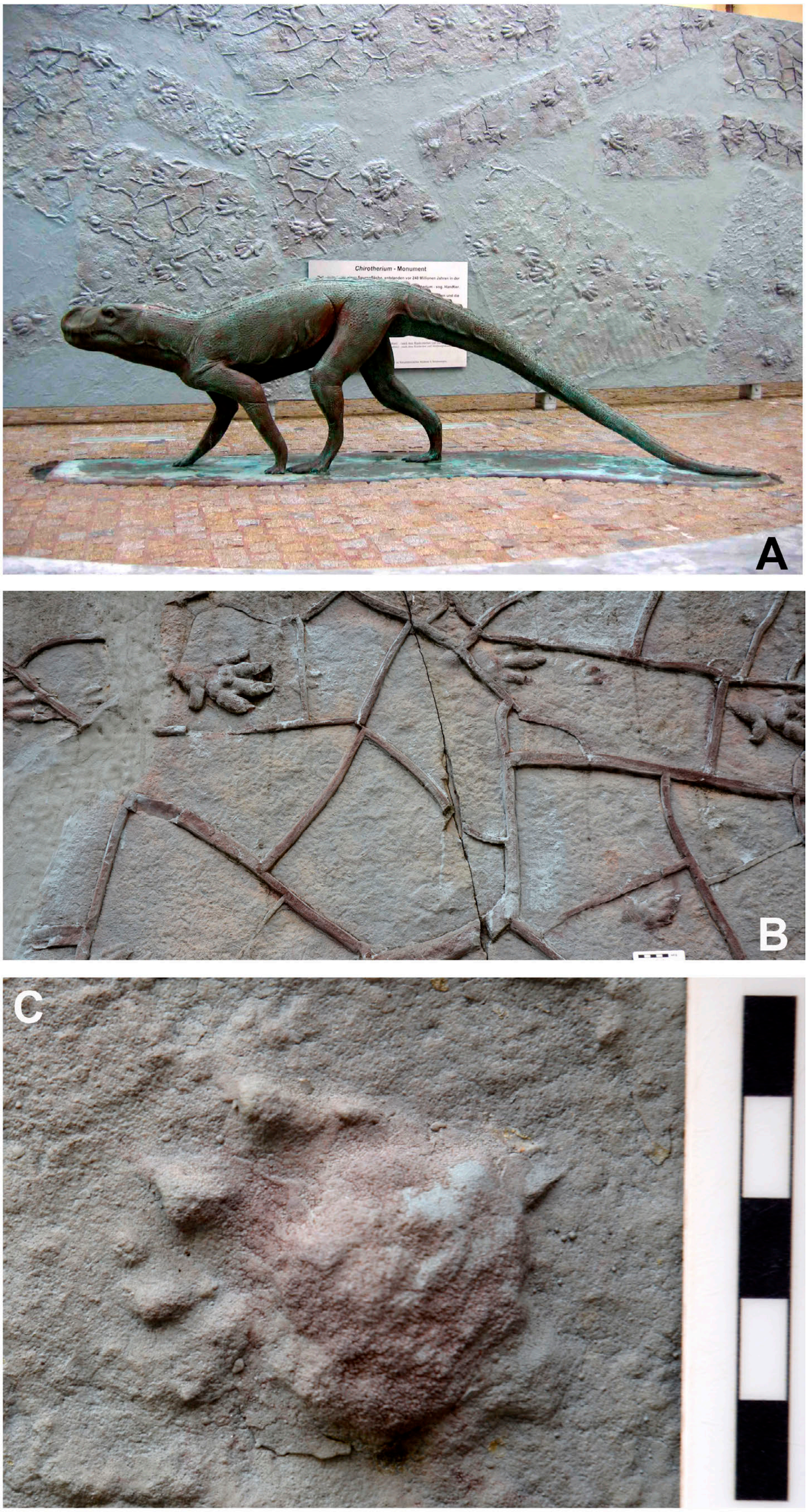


Fig. 14. Chirotherium Monument, market place of Hildburghausen, southern Thuringia, Germany. A. reconstructed type surface of *Chirotherium barthii* and *Chirotherium sickleri* and lifesize model of *C. barthii* trackmaker by HARTMUT HAUBOLD and MARTIN KRONIGER. B. Section of reconstructed type surface with trackways of *C. barthii* (top) and *C. sickleri* (bottom). C. Associated synapsid tracks *Dicynodontipus geinitzi*. Scale bar increments 1 cm. Photograph in A: RALF WERNEBURG, Schleusingen.

Stop 4. Hildburghausen

Location. Chirotherium Monument on the historical market place of the city.

GPS. 50°25’34.4”N 10°43’47.6”E

Features to be seen.
1. Replica of original *Chirotherium* type surface from the Middle Buntsandstein of Hildburghausen, with numerous trackways; top reference for tetrapod ichnological research.
2. Associated tetrapod ichnofauna.
3. Lifesize model of *Chirotherium barthii* trackmaker.

Ichnology. This is a reconstruction of the type surface of *Chirotherium barthii* and *C. sickleri*, which was discovered in 1833 by the school director F. K. L. Sickler and described and scientifically named by Kaup (1835a, b) from the Winzer Quarry (named after the owner) at Hessberg in the surroundings of Hildburghausen (Fig. 14A). The quarry was in the uppermost Solling Formation (Thüringischer Chirotheriensandstein, Anisian). Hartmut Haubold, renowned ichnologist from the University of Halle-Wittenberg spent several years, puzzling together different slabs with the footprints that were scattered in various institutions and museum collections all over Europe (Haubold, 2006). The original map of Winzer with sketches of the trackways gave a first idea of the orientation, however, it was soon clear that Winzer had made this drawing from memory, after the slabs were sold to the different institutions. Therefore Haubold, besides concrete features from the trackways, used significant landmarks from sedimentary structures such as mud-cracks to reconstruct the original relationship of the pieces. Together with the preparator Martin Kroniger, he made replicas of the slabs in the collections and puzzled them together step by step. Furthermore he made a reconstruction of the *C. barthii* trackmaker as a lifesize model in bronze, based on the skeletons of the archosaurs *Saurosuchus galilei* and *Euparkeria capensis*. The replicas of the slabs show all details, with accompanying ichnofauna such as *Rotodactylus matthesi* (dinosauromorph) and *Dicynodontipus geinitzi* (cynodont therapsid) tracks (Fig. 14B-C).

Stop 5. Schleusingen

Location. Museum of Natural History, Schloss Bertholdsburg.

GPS. 50°30'33.5"N 10°44'59.3"E

Features to be seen.
1. Rich collections of Paleozoic-Mesozoic fossils from the Thuringian Forest, including famous specimens of Permian tetrapods, invertebrates, plants, Triassic dinosaurs and tetrapod tracks.
2. Old castle from the 13th century (Fig. 15).

Ichnology/paleontology. The museum has one of the best collections of Paleozoic-early Mesozoic ichno and body fossils in Germany. Important are vertebrate, invertebrate and plant body fossils from well-known Permian localities in Thuringia such as Friedrichroda, Manebach and Tambach. Ichnofossils are *Ichniotherium*, *Dimetropus*, *Amphisauropus*, *Dromopus*, *Tambia* and many others. Also present are fossils from the Zechstein (Late Permian) period and finally original slabs with tetrapod footprints from the Buntsandstein (Middle Triassic, Anisian) of Hildburghausen and other localities, showing trackways of *Chirotherium*, *Isochirotherium*, "*Brachychirotherium*", *Rotodactylus*, *Rhynchosauroides*, *Dicynodontipus* and *Chelonipus*. The latter are one of the oldest known turtle tracks. Further fossils and reconstructions on display concern the marine Muschelkalk (Middle Triassic, Anisian-Ladinian), fluvio-lacustrine depositional environments with temnospondyl amphibians from the Middle Triassic (Ladinian) lower Keuper and finally dinosaur fossils from the Norian locality "Großer Gleichberg". The latter is well-known for the dinosaur skeletons of *Liliensternus* and *Ruehleia,* found by Hugo Ruehle v. Lilienstern who lived in nearby Bedheim castle. Other attractions of the museum are minerals from the Thuringian Forest and rich zoological collections.

Fig. 15. Museum of Natural History Schloss Bertholdsburg, Schleusingen, southern Thuringia. Old castle from the 13th century hosting the museum (top). Exhibition with dinosaur skeletons. Photos: https://www.museum-schleusingen.de.

Day 2 – Saturday, 28th September 2019

Stop 6: Bromacker Quarry near Tambach-Dietharz

Location: The Bromacker sandstone quarry and the nearby tetrapod excavation site are located in proximity to the town Tambach-Dietharz in the northern Thuringian Forest. This locality is now part of the National Geopark of Thuringia and its "Saurian Event Path" (Saurier-Erlebnispfad). Due to its rich ichnofauna and well-preserved tetrapod skeletons the Bromacker lagerstätte represents the most important European site for Early Permian tetrapods and their tracks.

GPS: 50°48'35.8"N 10°37'17.4"E.

Features to be seen:
1. Inactive sandstone quarry and the former excavation site of the Museum der Natur Gotha. Sedimentary succession of the Tambach Formation (Artinskian, Early Permian) including trace-bearing sandstones and mudflow deposits which yielded bones and skeletons of various tetrapod species (Fig. 16).
2. Trackways of *Ichniotherium sphaerodactylum*, tetrapod scratches and scrabbling/ shallow burrowing traces (*"Megatambichnus"*). Mudcrack horizons with tetrapod tracks usually display impressions of plant detritus and invertebrate ichnia (Fig. 17A-B).
3. Invertebrate burrowing traces, especially *Tambia spiralis* in varying morphologies (Fig. 17C).

Fig. 17: Tambach sandstone slabs with A, tetrapod scratches ("*Megatambichnus*"); B, the diadectid ichnotaxon *Ichniotherium sphaerodactylum*; C, the invertebrate burrowing trace *Tambia spiralis*.

Fig. 16. Sites of the Bromacker lagerstätte: A, Bromacker Quarry, featuring sandstones of the Tambach Sandstone Member that are overlain by the Bromacker Siltstones; B, Excavation site of Thomas Martens and his former Museum der Natur Gotha team.

Geology of the Thuringian Forest Basin*: The Thuringian Forest Basin, an approximately 40 to 60 km wide NW-SE orientated depression, is largely exposed in the horst structure of the Thuringian Forest. It belongs to the classical Rotliegend areas in Europe (Fig. 18) because of the mining of Permian Zechstein Kupferschiefer deposits along the borders of this horst, sulfide ores in Rotliegend lacustrine black shales, Stephanian and Rotliegend coals, and Mesozoic vein deposits. In 1775 F.G. Gläser published one of the worldwide oldest hand-coloured geological maps that included parts of the Thuringian Forest. Nowadays, this Rotliegend basin is one of the biostratigraphically best investigated and correlated basins in the Variscan area (Schneider, 1996, 2001; Lützner et al., 2007; Andreas et al., 2005; Schneider & Werneburg, 2006; Werneburg & Schneider, 2006, 2012). The basin is situated on deeply eroded Variscan basement of the Saxothuringian Zone in the southeast, Visean granites in the center, and the inverted Mid-German Crystalline Zone (MGCZ) as well as the Rhenohercynian zone in the northwest. Basin development, sedimentation and volcanism were controlled by various distinctly striking fault systems, which caused a changing pattern of subsiding and uplifting blocks during sedimentation. In consequence, small sub-basins with partially strong relief gradients were created (see Andreas, 1988, 2014; Lützner, 1988; Lützner et al., 2007, 2012).

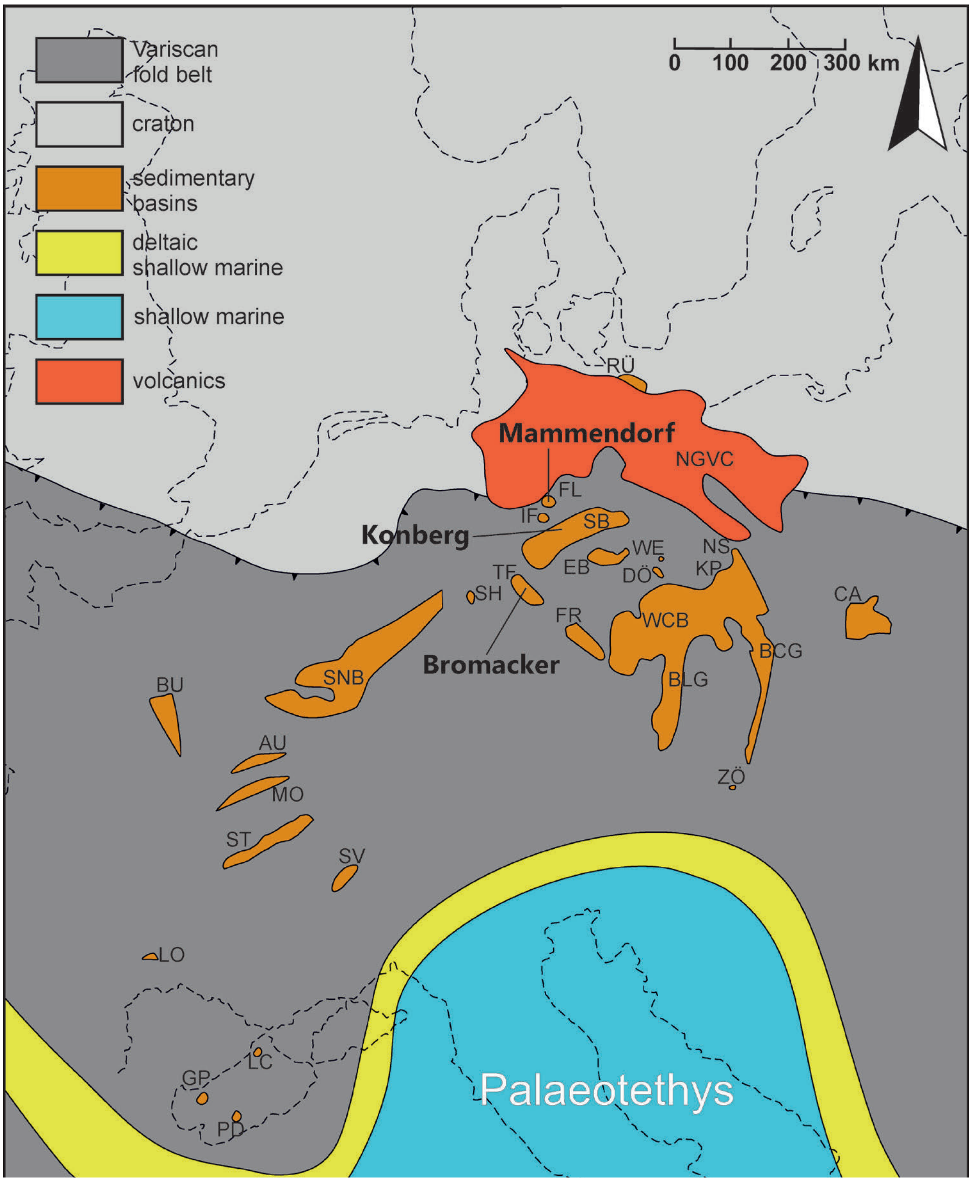


Fig. 18: Simplified maps of Central European Rotliegend basins: EB – Erzgebirge Basin, FL – Flechtingen depositional area, IF – Ilfeld Basin, SB – Saale Basin, SNB – Saar-Nahe Basin, TF – Thuringian Forest Basin. The map was provided by Jan Fischer of the Urweltmuseum Geoskop in Kusel.

After deposition of the Rotterode Formation and a hiatus, the up to 250 m thick **Tambach Formation** was deposited on a volcanic relief dissected in part by canyons (LÜTZNER & MÄDLER, 1994; LÜTZNER et al., 2007). Facies patterns range from very coarse, matrix supported wadi-fill conglomerates to proximal and distal debris-flow dominated alluvial fan clastics as well as floodplain sandstones and floodbasin siltstones. The sandstones are interpreted as fluvial reworked aeolian sandstones, primarily accumulated in the hinterland (SCHNEIDER & GEBHARDT, 1993). Scoyenia-facies, indicative for wet red beds, is typical of these alluvial plain deposits (MARTENS et al., 1981). The flora consists of xerophilous walchians and cones of the drought-adapted *Calamites gigas*.

Tambach is famous for complete, articulated vertebrate skeletons, preserved in mud flows (MARTENS, 1988; BERMAN & MARTENS 1993; EBERTH et al., 2000). The fauna includes reptiles and terrestrially adapted amphibians, which at the genus level are close to North American Early Permian tetrapod faunas. Based on tetrapods and insects (*Moravamylacris kukalovae*), the Tambach Formation is correlated with the North American late Wolfcampian/early Leonardian, i.e. the Artinskian/earliest Kungurian (SCHNEIDER & WERNEBURG, 2006; LUCAS, 2006). The Tambach Formation is followed by the 400 m to 600 m thick completely red-coloured sediment revealing Eisenach Formation.

Facies, paleoecology and paleoenvironment of the Tambach Formation*: The red beds of the Tambach Formation have been deposited in an S-N stretching depression on and at the flanks of the Oberhof Volcanite Complex; drainage was possibly to the North into the Saale basin (LÜTZNER et al., 2012). Simplified, the formation starts with up to 125 m alluvial fan conglomerates (Bielstein conglomerate Member), which laterally and vertically grade into the up to 100 m thick Tambach Sandstone Member (Mb). Tectonical activity caused the progradating of a new alluvial fan and braid plain system, the up to 50 m thick upper conglomerate (Finsterbergen Conglomerate Member). The basal conglomerates were deposited as debris flows and hyperconcentrated flash flood-flows. The upper conglomerate represents shallow alluvial fans with transitions into a braid plain environment. Regardless the longer transport distances from a crystalline and granitic source (Ruhla Crystalline Complex) the roundness of the pebbles is much lower than in the basal conglomerates. The fossiliferous Tambach sandstone originates in an alluvial braid plain environment. Typical are flat channels and sheetflood bodies with intercalated short-termed pontic claystones and siltstones as well as lateral and vertical transitions into floodplain siltstones. Horizons rich in mud clasts and containing articulated tetrapod skeletons result from repeated catastrophic flood events.

Exposed in the quarry areal are the **Tambach Sandstone Mb.** with the Bromacker Siltstones in the top. The mostly well sorted fine to middle grained sandstones form stacked decimetre to metre thick internally indistinct horizontal plane to rarer distinct small to large scale trough bedded horizons. The single sandstone bodies fill elongated decameter long shallow channels. Decimeter deep and meter wide gutter casts are common. Single beds are mostly separated by centimeter thick desiccation crack horizons of mud drapes. Those features indicate that these single sandstone beds correspond to single flood events. The mud drapes are settled down after floods. They contain a variety of tetrapod tracks, invertebrate traces and in places the freshwater jellyfish *Medusina limnica*. The tracks and traces were later dissected by desiccation cracks. Concentric and parallel water level marks in about 0.5 cm to 1 cm distance from one another are interpreted as the result of strongly changing day/night (noctidiurnal) temperatures and therefore evaporation rates as known from modern semiarid to arid climates. Counting of those marks result in time durations of 30 to 100 days of water fill of those puddles and ponds. The about 4 m thick **Bromacker Siltstones** are dominated by two facies: about 1.5 m 2 m basal, decimeter-scaled massive siltstones to very fine-grained sandstones, which are sharply overlain by beds of finely laminated siltstone and claystone. Essentially all of the hundreds of vertebrate skeletal specimens collected from the Bromacker, ranging from isolated elements to partial and complete, articulated skeletons were recovered from two closely associated sheetflood deposits within a stratigraphic interval of 1.2 m within the massive clay pebble containing siltstones. The overlying facies of very finely interlaminated siltstone and claystone beds, up to 15 cm thick, have yielded impressions of conchostracans, insect wings, and myriapod fragments (Martens et al., 1981). Altogether these fine clastics were interpreted as an upper-flow-regime sheetflood deposit and waning flood deposits in an ephemeral-lacustrine to flood basin setting. The sheetfloods originated in the wadis at the margins of the Tambach Basin and, when sufficiently intense, spread across the low sloping land surface of the basin center. Bedding planes with densely packed adult conchostracans, buried in living position, represent in analogy to modern examples dried up puddles and ponds on the flood plain. The duration of the ontogenetic development of conchostracans from their dry-resistant eggs to adult stages, which takes place in minimally 4 weeks, coincide well with the standing duration of the water bodies in the sandstone facies.

Fossil content*: The Bromacker locality became well-known for the well-preserved and very common tetrapod tracks discovered here since more than 100 years (Pabst, 1895; for details see Voigt, 2005). In 1974 the first tetrapod bone was discovered by Thomas Martens, since then about 40 skeletons of 13 different early terrestrial tetrapods were excavated by a German – North American team (Martens, Berman, Sumida, Henrici), documented in numerous publications (e.g., Voigt et al., 2007, 2010), and allow unique insights into a rare Permian terrestrial upland ecosystem. With respect to the unique finds of tetrapod tracks and skeletons, the Bromacker locality has consequently emerged to one of the most important sites of Late Palaeozoic vertebrates in Europe. It is also the place with the first well-documented species-level identification trackmakers among Palaeozoic vertebrates: *Ichniotherium cottae* are the tracks of *Diadectes absitus*, and *Ichniotherium sphaerodactylum* are the tracks of *Orobates pabsti* (see Voigt et al., 2007).

The flora is dominated by walchians and *Calamites gigas*; callipterids are very rare. Aquatic invertebrates a represented by *Medusina limnica* and conchostracans. Terrestrial invertebrates include the relatively common wings of blattids (*Moravamylacris kukalovae*, *Phylloblatta* sp.) and one 8 cm long (?)orthopteran wing fragment, diplopods and arachnids. Very common are invertebrate traces, such as *Tambia spiralis* (Fig. 17C), *Striatichnium bromackeri*, *Scoyenia gracilis*. Skeletons of several distinct tetrapod taxa have been excavated: the temnospondyl amphibians *Georgenthalia clavinasica*, *Rotaryus gothae* and *Tambachia trogallas*, the reptiliomorph anamniotes *Seymouria sanjuanensis*, *Diadectes absitus* and *Orobates pabsti*, the reptiles *Eudibamus cursoris* and *Thuringothyris mahlendorfae*, the synapsids *Tambacarnifex unguifalcatus*, *Dimetrodon teutonis*, an unnamed microsaur and an unnamed caseid (Wings & Eckert 2018). Tetrapod tracks have been referred to five ichnotaxa: *Ichniotherium cottae*, *Ichniotherium sphaerodactylum*, *Dimetropus leisnerianus*, *Varanopus microdactylus* and *Tambachichnium schmidti*.

**These paragraphs have largely been replicated with friendly permission from Schneider, J. W., Rössler, R., Werneburg, R., Scholze, F. & Voigt, S. (2014): Part II. The Carboniferous–Permian basins in Saxony, Thuringia, and Saxony-Anhalt of East Germany. In: Schneider, J.W., Oplustil, S. & Scholze, F. (Eds.): CPC-2014 Field Meeting on Carboniferous and Permian Nonmarine–Marine Correlation. July 21st–27th, Freiberg, Germany. Excursion Guide. – Technische Universität Bergakademie Freiberg, Wissenschaftliche Mitteilungen des Institutes für Geologie, 4: 55–121.*

Stop 7: Museum der Natur Gotha – Bromacker collection

Location: The Museum der Natur (Museum of Nature) in Gotha belongs to the foundation Stiftung Schloss Friedenstein Gotha and its exhibition is housed in the eponymous Friedenstein castle in the centre of Gotha. The Bromacker collection is currently stored in a nearby building.

GPS: 50°56'51.7"N 10°42'38.6"E

Features to be seen:
1. Tambach Formation sandstone slabs with *Ichniotherium*, *Varanopus*, *Dimetropus*, *Tambachichnium*, *"Megatambichnus"* and invertebrate trace fossils. Some of the specimens show skin impressions of the belly, tail and legs associated with in association footprints (Fig. 19).
2. Skeletons and partially articulated skeletons of Bromacker tetrapods – including amphibians, reptiliomorph anamniotes (*Seymouria*, *Orobates*), synapsids and reptiles (Fig. 20; some of the material is currently under study by researchers of the Museum für Naturkunde Berlin and may not be available during our visit).

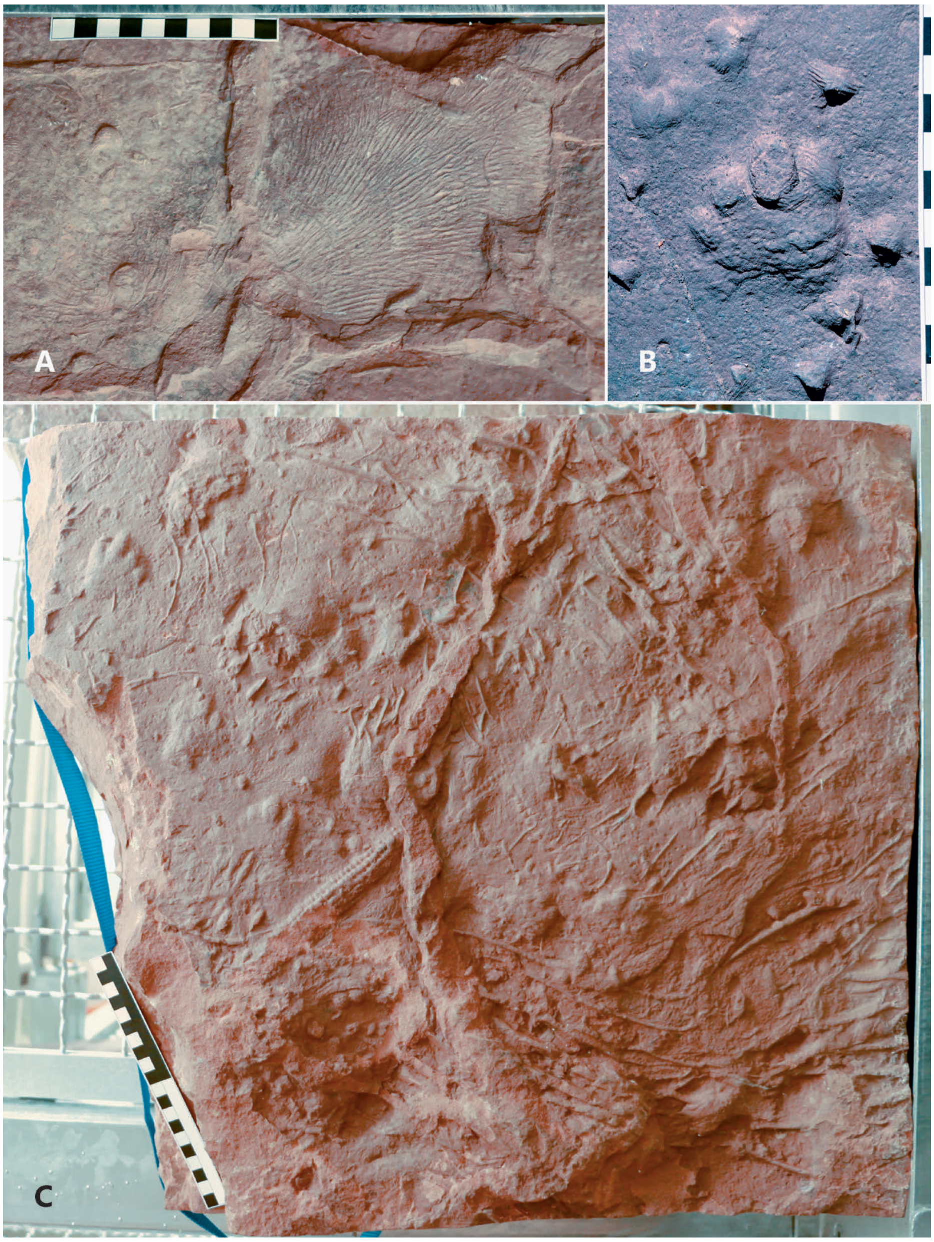


Fig. 19. Trace fossils of the Bromacker collection: A, *Striatichnium bromackerense*; B, Footprint of *Dimetropus leisnerianus*, C, Slab with skin imprints of the body and tail that are associated with *Dimetropus* footprints as well as scratch marks.

Fig. 20. Skeletal specimens of the Bromacker collection stored in the external collection building of the Museum der Natur Gotha: A, *Seymouria sanjuanensis*, the "Tambach Lovers"; B, left hindlimb of *Dimetrodon teutonis*; C, partial skeleton of *Orobates pabsti*.

Stop 8: Konberg Quarry in Rothenschirmbach

Location: In the Konberg Quarry, sedimentary rocks of the Hornburg Formation (Upper Rotliegend, Middle Permian) are exposed. The now inactive sandstone quarry lies in a small forest at the north-eastern margin of the village Rothenschirmbach, which now forms a part of the town Eisleben.

GPS: 51°27'28.3"N 11°33'14.8"E

Features to be seen: Sandstones of the Feinkörniger Sandstone Member and laminated shalestones and thin-bedded sandstones of the Blätterton Member with arthropod tracks, tetrapod swimming traces and impressions of hydromedusae (Figs. 21 and 22).

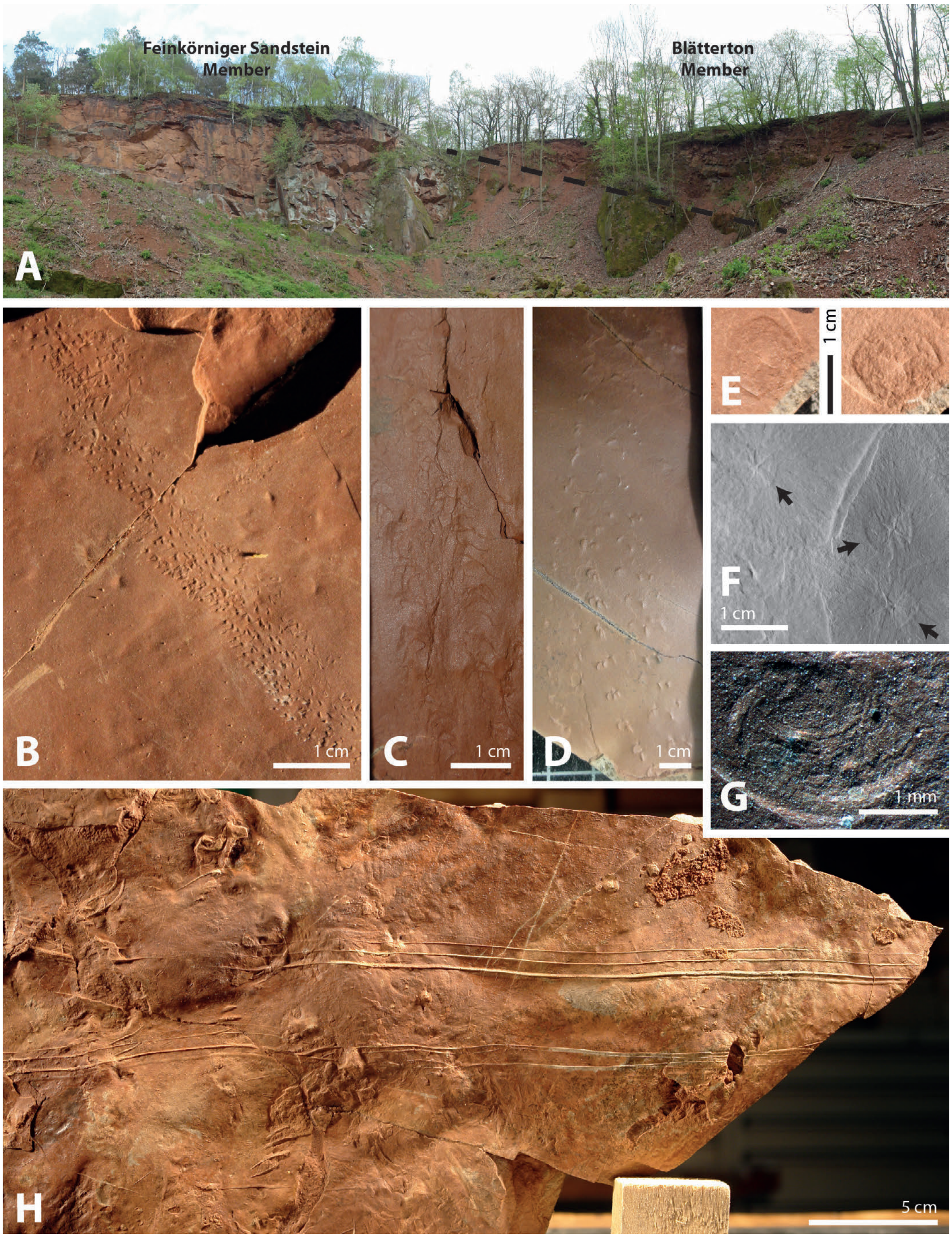


Fig. 21. Konberg Quarry: A, exposed strata of the Hornburg Fm; B-D, arthropod tracks; E-F, impressions of hydromedusae; G, conchostracan shell imprint; H, tetrapod swim traces.

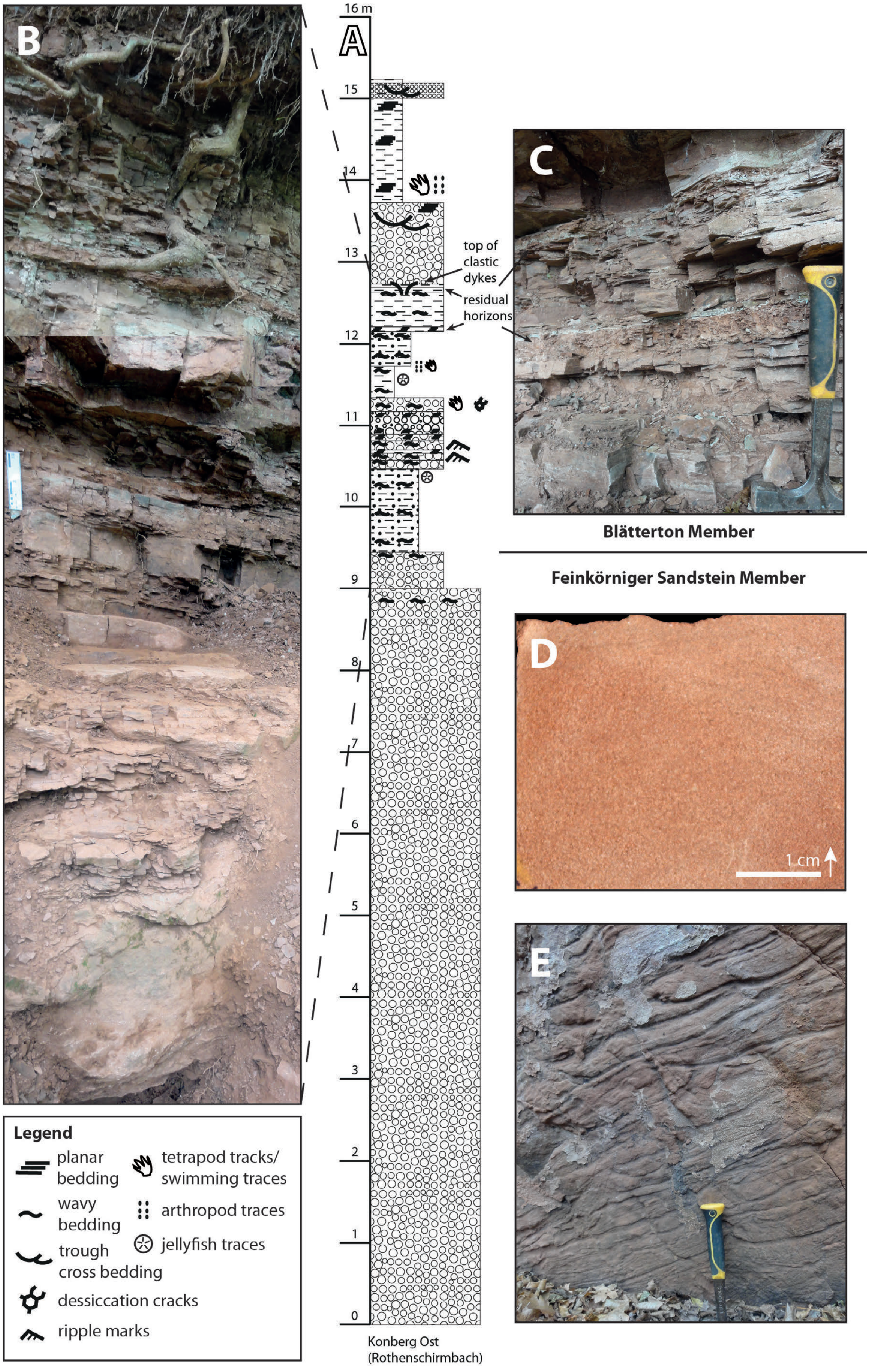


Fig. 22. Succession of sedimentary rocks at Konberg-East.

Stratigraphy of the Hornburg anticline/Saale Basin: The nowadays Hornburg anticline (Saxony-Anhalt) was part of the northeastern margin of the Carboniferous -Permian Saale Basin (150 km x 90 km). The Rotliegend basin fillings of that area are lithostratigraphically subdivided into the Halle, Hornburg and the Eisleben Formation (Ehling & Gebhardt 2012). Whereas the Unterrotliegend (pre-Illawarra) Halle Formation (»300 Ma to »285 Ma) comprises volcanic intrusions, lava flows and volcanic tuffs hosted in clastic greyish and reddish sediments, the Hornburg Formation represents a postvolcanic stage of basin development (Ehling & Gebhardt 2012). Due to erosion, faulting and a lack of absolute and relative age dating requirements the exact age of the base of the Hornburg Formation is still uncertain. Magnetostratigraphy revealed a lower Oberrotliegend II syn- to post-Illawarra age for the lower cycle (Menning et al. 1988). Lithostratigraphical correlations with sediments of the Northern German Depression lead also to the post-Illawarra-Oberrotliegend (Oberrotliegend II, Gebhardt & Lützner 2012). The top of the upper cycle is overlain by an unconformably bedded conglomerate of the Eisleben Formation which further includes reddish fanglomerates and sand- and siltstones interpreted as marginal deposits of the Northern German depression. The top of the Eisleben Formation is associated with the end of the Oberrotliegend II, which is followed by the deposits of the marine Zechstein transgressions (»257 Ma, Ehling & Gebhardt 2012).

Hornburg Formation: The Middle Permian syn- to post-Illawarra Hornburg Formation is located a few kilometers southern of the town of Eisleben (Saxony-Anhalt). It was deposited in a small playa basin south of and transitional to the mega-playa system of the Southern Permian Basin. The outcrops of the Hornburg Formation are an exceptional window into the continental environment and biota of the Euramerican mid-Permian northern trade wind zone. Sedimentary and paleontological features are indicative for the semi-arid to arid dry red beds that are in contrast to the Late Carboniferous - Early Permian wet red-beds of the study area (Schneider et al. 2006, Ehling & Gebhardt 2012).

At the Hornburg anticline, the Hornburg Formation consists of two fining-up mega-cycles, which contain six lithofacies members (Mb) (Hoyningen-Huene 1960, Falk 2014, 2016, 2018). The lower cycle starts with (1) the Unteres Quarzit Konglomerat Mb and is followed by (2) the Blankenheim Sandstein Mb. The upper cycle comprises in ascending order (3) the Oberes Quarzit Konglomerat Mb, (4) the Rundkörniger Sandstein Mb, (5) the Feinkörniger Sandstein Mb, and (6) the Blätterton Mb.

The members forming a complete fan and playa system with its biota which is rarely preserved in the Permian of Europe. The playa basin is filled with conglomerates and sandstones of an alluvial fan to braid plain system (members 1-3), laterally and vertically followed by braid plain and evaporitic sand flat deposits (members 4 and 5) (Fig. 23). Aeolian transport is indicated by bimodal coarse to fine grained sandstones outcropping at the Wickenberg site (in the north of Hornburg) and by well-sorted, fine- to medium-grained fluvial reworked and redeposited aeolian sandstones, which were formerly quarried in the abandoned Konberg Quarry (to the north of Rothenschirmbach, Fig. 22D, E). They are overlain by fossiliferous lacustrine laminated silty claystones, pure claystones and intercalated channel sandstones of up to a thickness of 10 cm (member 6). Those playa lake successions partly outcrop in the Konberg Quarry, too (Fig. 21A, Fig. 22A-C).

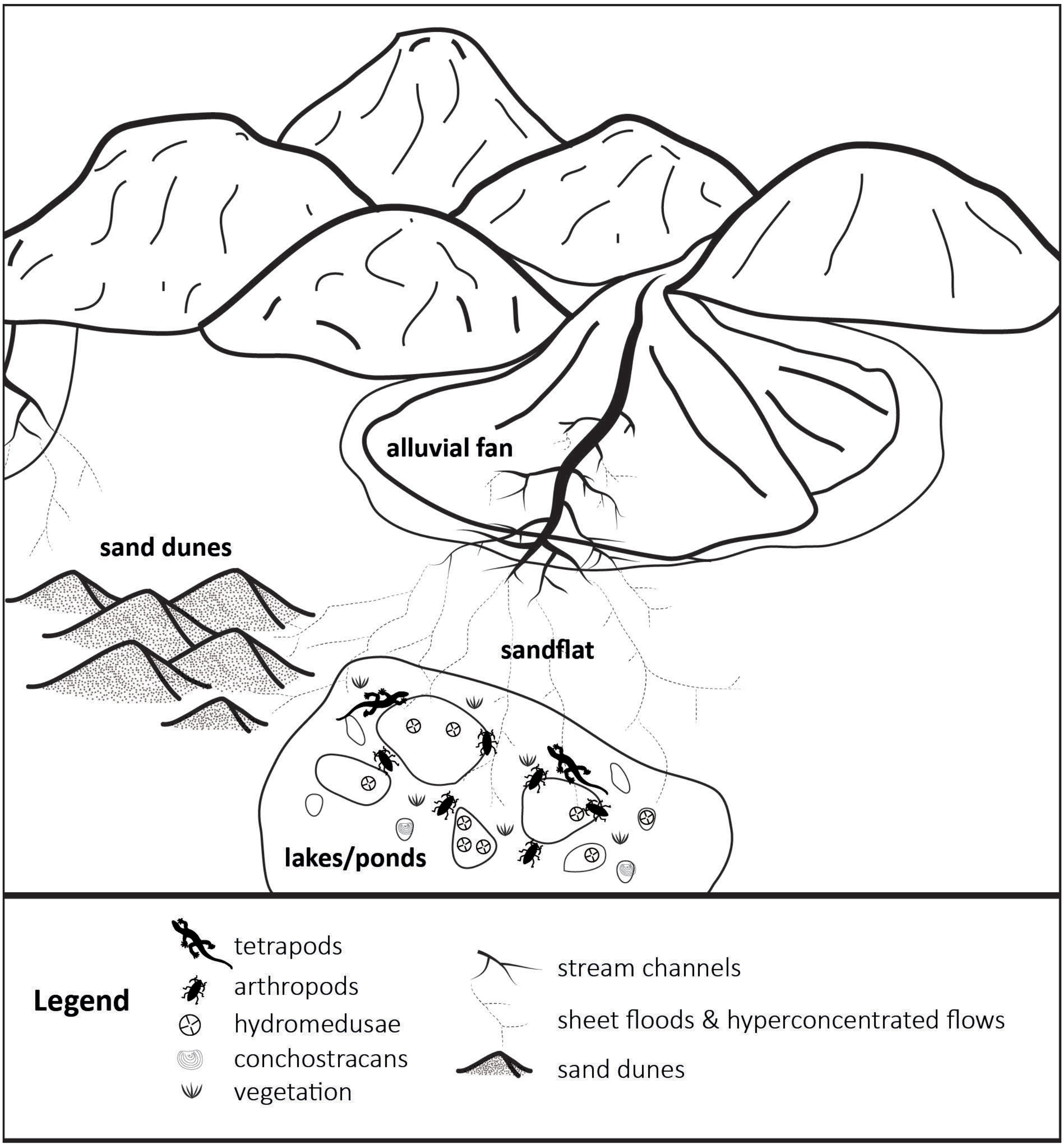


Fig. 23. Reconstruction of Hornburg Formation palaeoenvironment.

The **Konberg Quarry** site reveals a fine to medium and angular grained quartz sandstone of several meters thickness (Feinkörniger Sandstein Mb). The centimeter- to 10-centimeter-thick, homogeneous beds are mainly horizontally bedded, but rarely show trough crossbedding. Local occurrences of wavy sediment and convolute bedding indicate deformation due to slumping. The sandstone beds are fossil-free and represent fluvial redeposited aeolian sediments (Fig. 21A, Fig. 22A, D, E).

The sandstone is overlain by an alternating succession of bedded sandstones and laminated claystones (Blätterton Mb). Both units are highly ichnofossiliferous (see below, Fig. 21B-H). The lacustrine claystones represent lake and pond slack water deposits, whereas the intercalated, well-sorted, fine grained horizons of quartz sandstone indicate conditions of the higher flow regimes (flash floods). Sometimes, these beds show ripple marks on the upper surface as well as load casts and hyporeliefs of desiccation cracks on the lower surface. Halite pseudomorphs may be common on mudstone surfaces. Furthermore, residual horizons point to temporarily hypersaline conditions. A curiosity is displayed by clastic dykes (desiccation crack fillings) with more than 2 meters in length crosscutting several clay and silt stone horizons (FALK 2014, SCHNEIDER & GEBHARDT 1993).

Fossil finds: Plant remains are extremely rare and only represented by one cone of a conifere. Ichnofossils have only been found in the Blätterton Mb (Fig. 21B-H, Fig. 22A). Tetrapod tracks, tetrapod scratch marks/swimming traces (Fig. 21H), local mass occurrences of imprints of jellyfish (Fig. 1E, F) as well as arthropod trackways (Fig. 21B-D) were excavated during systematic study of different profiles including the site "Konberg Ost". Rarely, conchostracan shell imprints were found (Fig. 1G). The investigation was focused on the relation between sedimentology and track preservation as well as on biostratigraphy (FALK 2014). Poorly preserved and undetermined small tetrapod tracks (up to four cm in length and width) are embedded in mud- to siltstone layers. Tracks and swimming trails of tetrapods as e.g. *Dromopus* (GEINITZ 1861) and cf. *Amphisauropus* (GEINITZ & DEICHMÜLLER 1882) are preserved at the bottom of the small intercalated fluvial channels and in lacustrine claystone, too.

Circular-shaped imprints (2 to 10 mm in diameter) are assigned to jellyfish *Medusina limnica* MÜLLER 1978. Traces of hydromedusa and microbial mats are most common and indicative for dry lake and pond deposits. Conchostracan shell imprints belong to *Pseudestheria graciliformis* MARTENS 1983. They were excavated from restricted single fine silt- and claystone beds.

Locally, mass occurrences of arthropod (mainly insect) tracks are associated with claystones, fluvial siltstones and silty sandstones. After WALTER (1983), the following genera are known: *Lineatichnus, Multipodichnus, Acripes, Euproopichnus, Heteropodichnus, Permichnium, Lithographus*, *Secundumichnus, Heterotripodichnus, Etterwindichnus, Tarsichnus, Striatichnium, ?Tripodichnus, ?Taslerella* and *Avolatichnus*. They include up to 21 different arthropod ichnospecies described by WALTER 1983, which reveal trackways, landing traces from flying invertebrates ("Volichnia") and potential invertebrate swimming traces ("Natichnia"). Neither traces of burrowing organisms nor body fossils were found. Considering all ichnological observations taken together, the biota can be referred to a new type of ichnofacies which is in many aspects similar to the *Scoyenia* ichnofacies, but under much drier climatic conditions and without appearance of *Scoyenia* itself.

Stop 9: Solvay Quarry in Bernburg

Location: In the western part of the Solvay Quarry, where the Wesling Mineralstoffe GmbH has its production area, yellowish strata of the Middle Muschelkalk are exposed and form the top of bedrock. This area is accessible from the west via Federal Street (Bundesstraße) B 71.

GPS: 51°49'11.9"N 11°43'23.7"E

Features to be seen:

1. Stratigraphic section through shallow marine and coastal deposits of the Germanic Basin, ranging from the Upper Wellenkalk Member of the Lower Muschelkalk to the lower part of the Middle Muschelkalk (Fig.24A).
2. Mud crack horizons within laminated marlstones of the Middle Muschelkalk (Fig. 24B) with limulid tracks of *Kouphichnium*, invertebrate burrows, tetrapod scratches, and the tetrapod footprint ichnogenera *Rhynchosauroides* and *Procolophonichnium* (Fig. 25).

Fig. 24: Muschelkalk sediments exposed in the western part of the Solvay Quarry: A, the display part of the succession ranges from the Upper Wellenkalk Member of the Lower Muschelkalk (Jena Formation) to the yellowish Middle Muschelkalk beds (Karlstadt Formation) with the harder Schaumkalk limestone beds in the middle. B, Excavation site in Middle Muschelkalk layers exposed on the bedrock surface; the track-bearing horizons usually display a pattern of polygonal mudcracks.

Fig. 25: Examples for *Rhynchosauroides* and *Procolophonichnium* tracks on laminite slabs from the Middle Muschelkalk of Bernburg. A, Slab with manus and pes imprints of *Rhynchosauroides* and several couples of small *Procolophonichnium* footprints. B, *Rhynchosauroides* manus imprint with scalation pattern preserved as shallow relief.

Geology/Ichnology: The Solvay Quarry represents one of 14 (mostly in Anisian age) tetrapod track localities in Saxony-Anhalt listed by Diedrich & Trostheide (2007), six of whom lie in the Subhercynian Basin in central Saxony-Anhalt. These localities cover a succession of limestones, marlstones and dolomites, reaching from the Upper Buntsandstein through the Middle Muschelkalk. It was deposited in a subtidal to supratidal environment and includes several distinct layers with tracks, most of them represent biolaminites. In Bernburg twelve track horizons have been documented within the Middle Muschelkalk (Diedrich 2011). Five of these horizons, which lie in close succession, are still exposed just below the bedrock surface and can be accessed from the western (Wesling) quarry entrance.

The ichnofossil horizons are usually structured by mudcrack polygons and display only very shallow footprint reliefs. However, in some layers preservation of scalation patterns on digit traces and heel pads are common. The Bernburg tetrapod track record is dominated by *Rhynchosauroides tirolicus* and (to a lesser degree) *Procolophonichnium haarmuehlensis*, whereas chirotheriid archosaur tracks occur more rarely, even if several long trackways have been documented. Diedrich & Trostheide (2007) considered this pattern as indicative for a *Rhynchosauroides*-dominated tidal flat ichnocoenosis, which they distinguished from a more continental *Chirotherium*-dominated ichnocoenosis that occurred along the outer margins of the Germanic Basin. Tanystropheid archosauromorphs are suggested to be likely producers of the *Rhynchosauroides* tracks, whereas *Procolophonichnium* can be attributed to therapsids or parareptiles.

In terms of abundance and quality of the tracks, the Solvay Quarry turned out to be the most important locality in Saxony-Anhalt. It represents one of the few Triassic tracksites that exposed very long trackways of *Chirotherium barthii*, *Isochirotherium herculis* and *Rhynchosauroides*, including dozens of step cycles, which were documented in detail before they were finally collected. Some material discovered during original exploration work between 2006 and 2007 is now stored in the Museum für Naturkunde Magdeburg. The longest and most complete trackways were discovered during the later extensive excavations of the Landesmuseum für Vorgeschichte Halle led by C. G. Diedrich and are now part of the Landesmuseum collections. Apart from tetrapod tracks this quarry also yielded an extensive record of long *Kouphichnium* trackways produced by limulids. Furthermore, nothosaur and hybodont skeletal remains have been found in association with the tracks.

Day 3 – Sunday, 29th September 2019

Stop 10: Mammendorf Quarry

Location: This andesite quarry is located about 10 km to the northwest of the city of Magdeburg between Mammendorf and Irxleben (Hohe Börde community), where the Flechtingen-Rosslau block becomes visible as an elevation (Flechtingen High). In the Flechtingen-Rosslau block greywackes and quartzites of the Rhenohercynian basement are unconformably overlain by post-Variscan volcanic and subvolcanic rocks and by sedimentary rocks of the Southern Permian Basin. The quarry is run by Cronenberger Steinindustrie (https://www.cronenberger-steinindustrie.de).

GPS: 52°10'34"N 11°26'23"E

Features to be seen:
1. Sedimentary successions of (a) Lower Rotliegend (?Eiche Member, Flechtingen Formation, Earliest Permian) with abundant tuff horizons and (b) Upper Rotliegend (Elbe Subgroup, late Middle to early Late Permian) including sheet flood deposits of a distal alluvial fan and sand flat deposits (Figs. 26-27).
2. Sedimentary structures, such as desiccation cracks, various ripple types, halite crystal marks, rain droplets. Traces of haloturbation and calcrete formation.
3. Slabs with tetrapod scratches and tetrapod burrowing traces of varying size and shape (Fig. 28C); invertebrate burrows.
4. Examples for tetrapod footprints (cf. *Pachypes*, indet. therapsid tracks) and *Erpetopus* trackway (Fig. 28A-B)

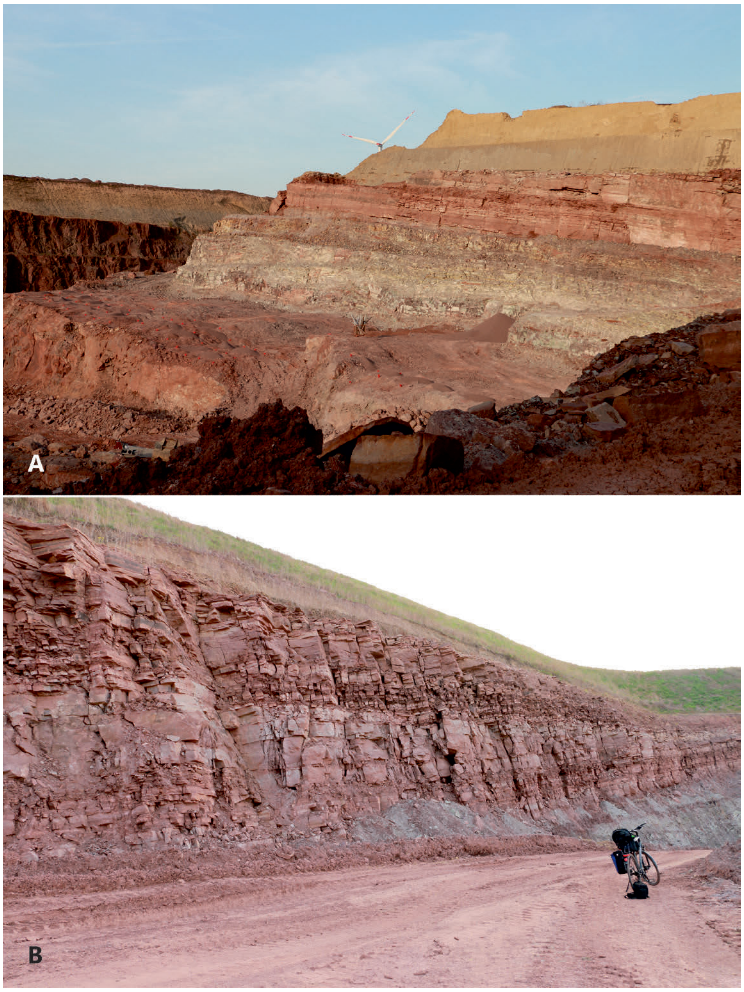


Fig. 26. The Mammendorf Rotliegend succession features light-coloured pyroclastic-rich mudstones of the Lower Rotliegend (Eiche Member, Flechtingen Formation) that are unconformably overlain by mostly red-coloured conglomerates and sandstones of the Upper Rotliegend II.

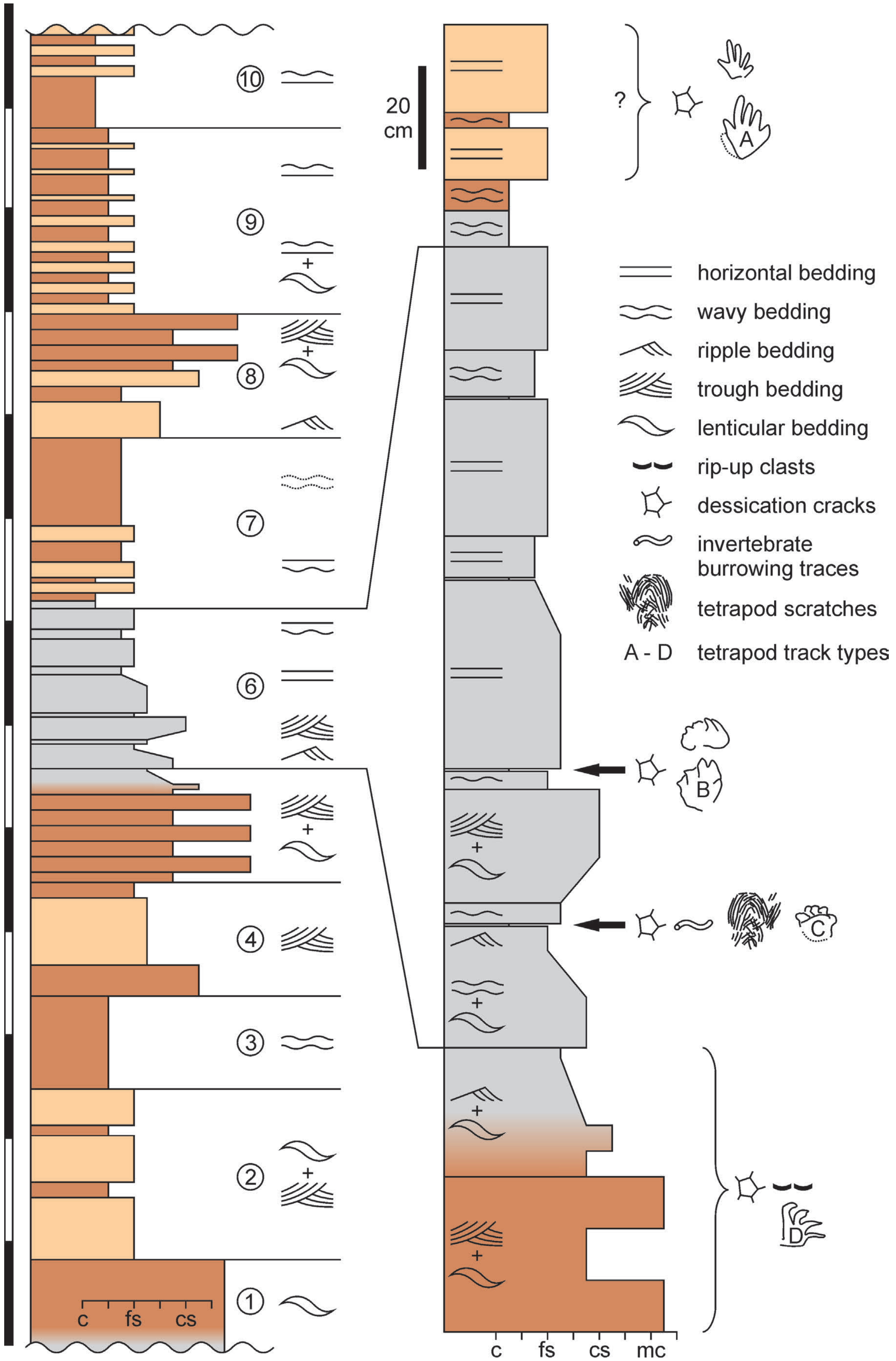


Fig. 27. Simplified stratigraphic section for 2016 excavation site at the southeastern end of Mammendorf Quarry. Tetrapod tracks: A, cf. *Procolophonichnium*, B, cf. *Pachypes*, C, indeterminate therapsid tracks, D, *Erpetopus* isp.

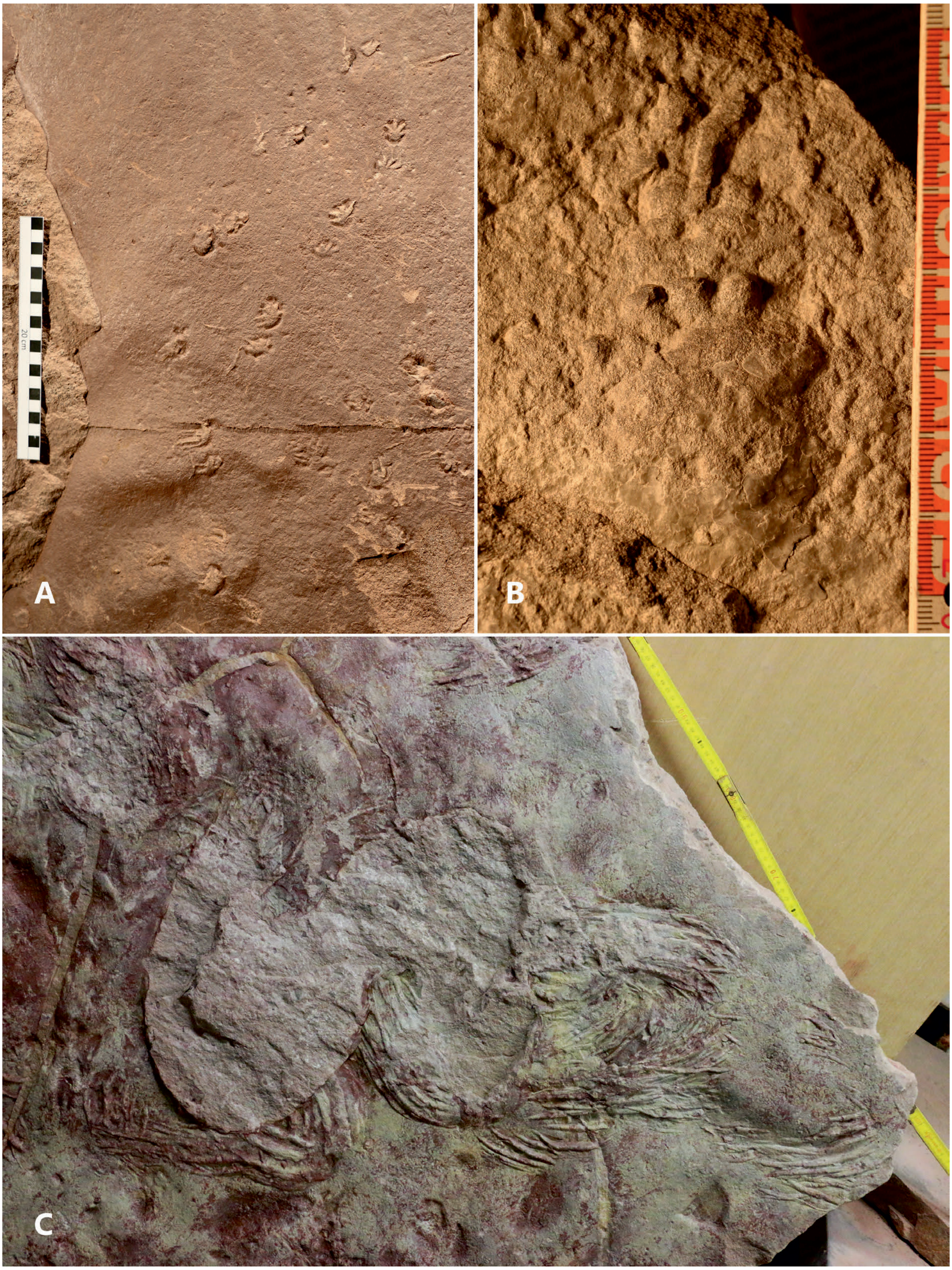


Figure 28. Tetrapod trace fossils: A, trackway of *Erpetopus* isp.; B, therapsid footprint couple; C, tetrapod scrabbling traces and distinct outlines of hole-like perforations due to shallow burrowing behavior.

Geology of the Southern Permian Basin*: During the deposition of the Upper Rotliegend succession Mammendorf was located at the southern margin of the **Southern Permian Basin,** which formed as an intracontinental basin in Northern Pangea at palaeolatitudes of 10–15° N. Arid to semi-arid conditions prevailed, leading to deposition in a desert environment (Glennie, 1972; Roscher & Schneider, 2006). The 1700×600 km large Southern Permian Basin stretched from England over the North Sea and Northern Germany to Poland. Approximately 2500 m thick continental sediments were deposited in the depocentre within a period of 6 to 10 Ma. The general facies distribution reveals alluvial deposition at basin margins and a centripetally adjoined belt of dominantly aeolian sediments. In the basin centre a huge saline lake existed (Gast, 1995). The Rotliegend saline lake covered an area of approximately 17,000 km² during lake level lowstands, but doubled to quadrupled its size during wet periods (Gebhardt, 1994) and then covered wide areas of northeastern Germany, Schleswig-Holstein and the North Sea. Zechstein transgression terminated the continental Rotliegend deposition. Rotliegend sedimentation was controlled by two main parameters, tectonics and climatic fluctuations. Gebhardt et al. (1991) described the Altmark I to IV tectonic movements. They resulted in a restructuring of the basin and triggered the formation of fining upward successions with coarse clastics (fanglomerate or sandstone) at the base of the Parchim, Mirow, Dethlingen, and Hannover formations. The duration of deposition of each formation can be estimated at 2 to 3 Ma.

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Schneider, J. W., Rössler, R., Werneburg, R., Scholze, F. & Voigt, S. (2014): Part II. The Carboniferous–Permian basins in Saxony, Thuringia, and Saxony-Anhalt of East Germany. In: Schneider, J.W., Oplustil, S. & Scholze, F. (Eds.): CPC-2014 Field Meeting on Carboniferous and Permian Nonmarine–Marine Correlation. July 21st–27th, Freiberg, Germany. Excursion Guide. – Technische Universität Bergakademie Freiberg, Wissenschaftliche Mitteilungen des Institutes für Geologie, 4: 55–121.

Stratigraphic assignment and ichnology: The exact stratigraphic position of the Mammendorf Upper Rotliegend deposits is still unclear – their facial patterns appear to be distinct from those of the nearby Bebertal sites (Hünenküche, Sventesius Quarry) and they are likely to represent either Dethlingen or Hannover Formation and thus have a Capitanian or early Wuchiapingian age. About 50 metres of siliciclastics have been documented in exploration drillings in the SE of the Mammendorf Quarry (Drilling No. 4/12, Luthardt 2013) but only the basalmost 20 meters are exposed along the southwestern quarry wall as of 2019. A 10-m-thick succession of mass flow and sheet flow deposits on a distal alluvial fan, which is marked by three distinct conglomeratic horizons and a stable facies architecture (flow units ranging over hundreds of meters), is overlain by fine sandstones and siltstones of an alluvial plain. The latter are altered by haloturbation and pedogenesis. Tetrapod and invertebrate traces have mainly been found within thin mudstone horizons close to the second conglomerate and adjacent sandstone layers. Apart from invertebrate burrowing traces, paired tetrapod scratches of varying shape (half-oval or elongate/rail-like, bilobate or flat) in transition to hole-like shallow tetrapod burrowing traces (width between 8 and 27 cm) represent the most common type of ichnia. Finds of tetrapod footprints include several slabs with multiple tracks and one longer trackway of *Erpetopus* isp., one other small reptilian track type (cf. *Procolophonichnium*), a few roundish footprints and a trackway which may represent *Pachypes* and paw-like therapsid tracks and short trackways that are most similar to *Dicynodontipus* and *Dolomitipes*. Only one slab with plant root traces has been found; traces of algae mats are more common.

Stop 11: Dinosaurier-Park Münchehagen

Location: Münchehagen, about 50 km west of Hannover, is a popular tourist destination because of its large dinosaur park featuring more than 230 life-sized reconstructions of dinosaurs and other extinct vertebrates. On a 2.5 km circuit trail you can explore the vertebrate evolution throughout the Phanerozoic. The park was created around an old quarry – now protected as a National Monument – yielding the only Lower Cretaceous sauropod tracks found in Germany. Since 2004, the active Wesling Quarry adjacent to the Dinosaurier-Park Münchehagen has produced further track-bearing levels in Berriasian strata.

GPS: 52°26'32.4"N 9°11'58.6"E

Features to be seen:
1. Several trackways of sauropods, ornithopods and theropods that occur in silty mudstones and sandstones of the Early Cretaceous (Berriasian) Bückeberg Formation. Many tracks are excellently preserved as concave epireliefs and/or natural casts. Among recently excavated dinosaur tracks are least eight trackways of theropod dinosaurs with a total of >100 footprints.
2. Late Jurassic (Kimmeridgian) dinosaur tracks and other fossils from Langenberg Quarry near Goslar.

Fig. 29. The Dinosaurier-Park Münchehagen: A variety of life size reconstructions of Meszoic vertebrates surrounds the hall built for the protection of the sauropod trackways.

Stratigraphy: The Münchehagen tracksite is located on the southwestern flank of the Rehburg Mountains/Rehburg anticline about 50 km west of Hannover. Although the Berriasian (approx. 145-140 Ma) clastic sediment successions of Lower Saxony are mainly covered by Cenozoic sediments, several outcrops unveil Mesozoic era sediments along the flanks of the Rehburg anticline (Jordan 1979). Geological uplift took place by basin inversions, revealing the buried Jurassic and Cretaceous sediments. The uplift processes were triggered by local halotectonics of Permian evaporites since the Late Cretaceous. Erosion of Jurassic marls and mudstones uncovered the underlying Cretaceous clastic successions. The exposed, more weathering-resistant sandstones are quarried since medieval times and still unveil palaeontological treasures (Jordan 1979, Wings et al. 2012, Wings et al. 2016). Stratigraphically, the strata of the Münchehagen quarries belong to the Obernkirchen Sandstone which is a sub-unit of the Bückeberg Formation (= 'German Wealden', Fig. 29A; Hornung et al. 2012). Palaeogeographically, the Münchehagen site is situated in the Eastern Lower Saxony Basin (Fig. 30A), the southern part of the North German Basin (Fischer 1998, Blumenberg 2019).

Fig. 30. A. Sauropod trackways in the protection hall of the Old Wesling Quarry. B. Tridactyl theropod and ornithopod tracks during excavation in the New Wesling Quarry in 2011. C. The New Wesling Quarry with the excavation site in 2011.

The Obernkirchen Sandstone has an age between 142 and 138 Ma (HORNUNG & BÖHME, 2012). The clastic sediments were part of a prograding delta system of a large river which probably matured the sand grains in the Münchehagen and especially in the Obernkirchen sandstones (PELZER, 1998; HORNUNG & BÖHME, 2012). Formation of barrier systems was facilitated by landward transport of sand during storm events, and possibly also by longshore currents (PELZER, 1998).

The Natural Monument 'Saurierfährten Münchehagen' includes large sauropod dinosaur tracks, which were discovered in the 1970s at the so-called "Old Wesling-Quarry" (Figs. 29A, 31F). After protection as a Natural Monument by the Federal State of Lower Saxony during the following years, continuing dinosaur track research has been successfully associated with public outreach. The Dinosaur Park Münchehagen opened in the early 1990s for the public and displays real-sized dinosaur and other prehistoric animal models as well as the original sauropod tracksite ("National Geotope", Fig. 29A). Excellently preserved tridactyl iguanodontid and 'allosauroid' trackways were discovered in the active Wesling-Quarry adjacent to the Dinosaurier-Park in 2004 and subsequently excavated since then (Figs. 29B, 31E).

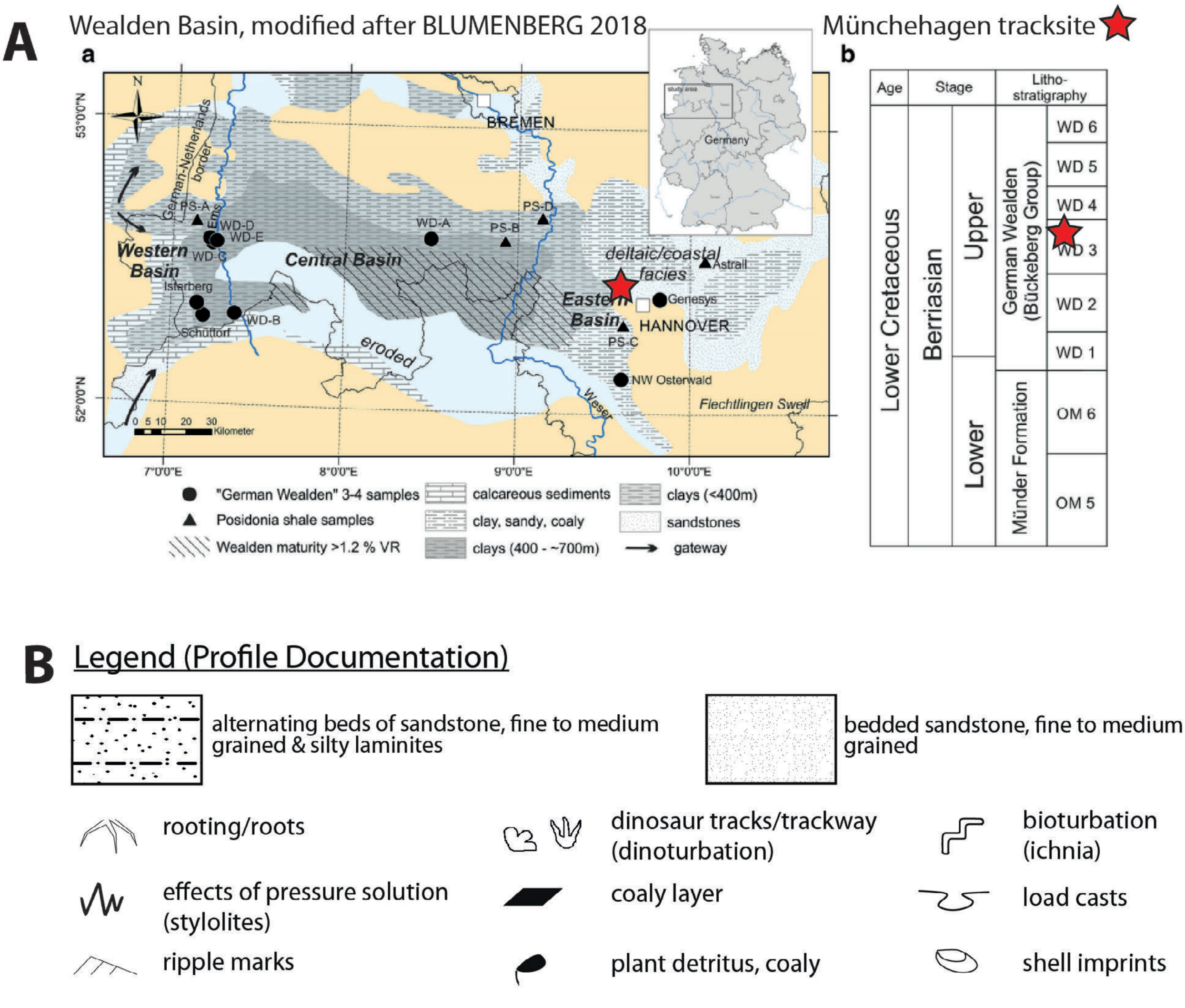

Fig. 31. Palaeogeographic and stratigraphic position of the Münchehagen tracksite (A) and legend for the sedimentary log (B) that is displayed in Fig. 32.

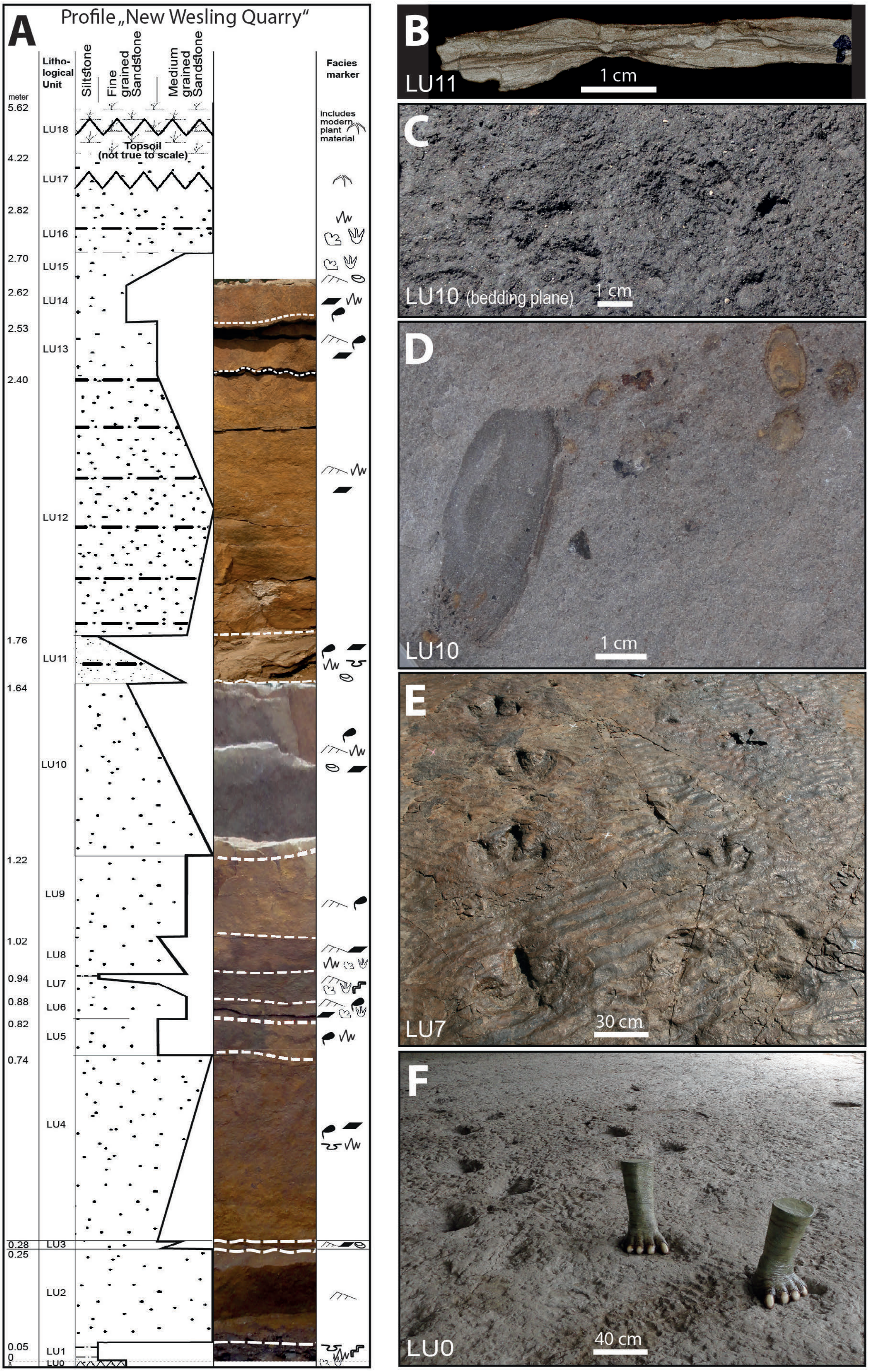

Fig. 32. Lithostratigraphic profile (A) and ichnofossils (B-F) of the active Wesling Quarry.

The Wesling Quarry is still active, producing brownish to yellow-grey sandstones as working stones and road gravel (Fig. 30C). Both Wesling Quarries yield predominantly fine- to medium-grained quartz sandstones which are siliceously cemented (Fig. 32A, D). True (tridactyl) tracks are embedded in thin mud- to siltstone layers, interpreted as slack water deposits. Undertracks are preserved in fine-grained sandstones, indicating higher flow regimes. In addition to dinosaur bioturbation, invertebrate bioturbation occurs in some beds. The sandstone beds show colorful dark brown-grey dissolution sutures/cracks, and bioturbation by invertebrates and dinosaurs. Ripple marks are often present on bedding planes and may show a rough jagged surface (Figs. 30A, B, 32A, E, F). Some bedding planes have drainage structures and/or are partially covered with coaly layers, which often coincide with pressure dissolution sutures (Fig. 32A, C). Inhomogenously embedded coal particles from mainly terrestrial plant detritus are very common. Chemical (dis)coloration ('Liesegang rings') was probably caused by organic carbon and/or mineral ions. Small (1–3 cm) oval impressions are interpreted as bivalve shell imprints (Fig. 32A, D; Wings et al. 2012).

The exposed geological profile of the active Wesling Quarry has a total thickness of 5.62 m (Figs. 31B, 32A). Individual beds can be traced on a centimetre to decimetre scale but are often laterally variable (Wings et al. 2012).

Sauropod trackways, as part of the natural monument, and invertebrate bioturbation are common at the quarry base (LU0, Fig. 31F). In the upper part of LU7, the sandstone is overlain from a layered 0.5–2 cm thick silty mudstone. True iguanodontid and theropod tracks are embedded in that silty mudstone layer, which contains the best-preserved tracks in the profile (Fig. 30 B, 32E, Wings et al. 2012). Drag marks, probably made by drifted plant remains, occur rarely. LU6 and LU5 reveal the clearly visible undertracks of the LU7-footprints. Furthermore, extensive dinoturbation occurs in LU8, LU15 and LU16 on thin silty layers on top of medium-grained sandstone beds.

Siltstone and mudstone layers or beds represent slack water deposits whereas sandstone beds indicating temporarily higher flowing regimes (e.g. storm events) (Schwennicke 1998, Wings et al. 2012). Small-scale wave ripple marks occur on many bedding planes and were generated by an unidirectional undulating consistent water flow (foreset laminae) in shallow water offshore areas with a temporary influence of currents. The minimal water depth has been calculated within the range of 2.7 cm to 5.4 cm, the maximum water depth cannot be determined (Wings et al. 2012, Schwennicke 1998).

The Münchehagen locality is part of the Eastern Lower Saxonian Basin which is dominated by the clastic successions of the German Wealden. The basin is characterized by mainly freshwater conditions and high sediment influx by fluvial-deltaic transport. Based on sedimentology, fossil content and palaeogeography, a distal deltaic realm for the Münchehagen tracksite is assumed (Fig. 31A) (Fischer 1998, Falk 2011, Blumenberg 2019).

Ichnology: Sauropod track impressions (Figs. 30A, 32F) were originally described as '*Rotundichnus muenchehagensis*' (Wright 2005), but lack enough morphological details to be considered diagnostic of any particular type of sauropod or trackway (Wright 2005). They reveal an oval to elongated-oval shape, appearing slightly triangular, with the longest 'peak' pointing backwards. The tip of the triangular oval is the deepest point altogether. The medial sides of the imprints are always deeper, which indicates medial sides bearing more weight. The same applies for the tip of the toes I and II. Even on imprints that show better preservation features, there is still a lack of claw or single toe imprints preservation (Fischer 1998, Wings et al. 2012). Some imprints show ripple marks in their inner floor (Fig. 32F). More than seven sauropod trackways yield at least 256 footprints. Most imprints were discovered not only in the old quarry, but new exposures of the track bearing surface in the "new" Wesling Quarry resulted in additional findings too. The same sandstone bed at the quarry base also produced poorly preserved tridactyl tracks as well as hollow sandstone casts of shark spines.

Most tridactyl imprints were discovered and excavated in the active quarry (Figs. 30 B, C, 32E). These well-preserved imprints have been the basis for several publications (Wings et al. 2005, Wings et al 2012, Lallensack et al. 2016, Wings et al. 2016, Lallensack 2019). The imprints belong to the ichnotaxa *Iguanodontipus* (iguanodontid trackmaker) and *Megalosauripus* ('allosauroid' theropod trackmaker). The wide size ranges indicate subadult and adult individuals for both groups. All tridactyl trackways show bipedal gaits.

Several excavations on different quarry levels revealed more than 150 imprints – more than 100 imprints (three trackways) were exposed on the single bedding plane of LU7 (the so-called Lower Level, Falk et al. 2013). Theropod trackways are crossing iguanodontid trackways. The longest trackway (LU16) comprised 57 consecutive well-preserved and two weakly preserved *Iguanodontipus* imprints (Wings et al. 2012).

Siltstone and mudstone layers yield at least partly horizontal invertebrate burrows (millimetre-scale), which disturbed the fine laminated strata (Fig. 31A). *Thalassinoides* and *Planolites* can be found in such "pre-storm sediments" (Schwennicke 1998). Rough jacked, partly coaly surfaces are often linked to microbial mats, which stabilized the wet sediment and supported the track preservation (Falk et al. 2013). Bivalve imprints due occur in nests (Fig. 31C). The sandstone rarely yields Gingko leaf or horsetail fossils, usually preserved by a thin coaly layer.

Langenberg tracks: Apart from Early Cretaceous tracks of the Obernkirchen Sandstone, the Dinosaurier-Park Münchehagen has also stored and exhibited materials from Langenberg Quarry, a Late Jurassic (late Oxfordian to Kimmeridigian) limestone quarry close to the town of Goslar at the northern margin of the Harz Mountains. Sedimentary rocks exposed in this quarry include limestones and mudstones, which were deposited in a shallow marginal basin of the Late Jurassic Germanic Basin (Fischer 1999, Zuo et al. 2018). The Langenberg locality is well-known for skeletal remains of the dwarfed sauropod *Europasaurus holgeri* and other terrestrial vertebrates, which are thought to have inhabited islands within this part of the Germanic Basin (e.g., Sander et al. 2006, Wings & Sander 2012, Martin et al. 2019). Tridactyl dinosaur tracks has been reported from the upper part of the Langenberg section (bed 93) – about 5 m above the *Europasaurus* horizon. Some of these tracks belong to large theropods and may indicate that the existence of an isolated insular fauna ended due to a sea level decrease that led to the immigration of large carnivores (Lallensack et al. 2015).

Stop 12: Oberkirchen

Location: This locality represents another example for the Berriasian track-bearing sandstones from the Obernkirchen Sandstone unit in the Bückeberg Formation. It was the first site in the region were dinosaur tracks have been found - more than two centuries ago!

GPS: 52°15′36.9″N 9°11′58.9″E

Features to be seen: Obernkirchen Quarry (Fig. 33) is well-known for its moderately to heavily dinoturbated "Chicken Yard" (Fig. 34). This site is characterised by an extraordinary high density of true tracks including several morphotypes and size classes of theropods and ornithopods. Additionally, there is an upper track level in the Obernkirchen Quarry, which has produced mainly iguanodontian tracks (Fig. 35A).

Fig. 33. The Obernkirchen Quarry is also known for its well-sorted quartz sandstones producing high quality workstones.

Ichnology: Apart from abundant tridactyl dinosaur tracks, the Obernkirchen tracksite has produced remarkable didactyl tracks (Fig. 35B) of a new deinonychosaurian ichnotaxon (Richter & Böhme 2016). It is assumed that the exceptional preservation of most tracks is due to microbial mats covering sandy lagoonal flats (Richter et al. 2011).

The "Chicken Yard" (Fig. 34) footprints comprise 424 tridactyl theropod, 55 didactyl deinonychosaurian dinosaur, 196 medium-sized and large iguanodontid ornithopod, and only 20 small possible ornithopod tracks. The tracks appear to represent multiple generations of trackmakers and show no preference in walking direction. Some of the didactyl tracks may be referred to troodontids that had sizes between 3 and 4 m. Some of the ornithopod tracks can be assigned to *Iguanodontipus* isp. The Upper Level of tracks at the northern margin of the Obernkirchen quarry differs from the "Chicken Yard" in its preservation and types of tracks and is more similar to other tracksites of the Oberkirchen Sandstone. The Obernkirchen site has also produced well-preserved impressions of bones in the sandstone, the original bone material dissolved during diagenesis.

Fig. 34. The "Chicken Yard", a heavily dinoturbated sandstone layer.

Furthermore, the Obernkirchen Quarry is known for peculiarly preserved hollow moulds of larger bones such as crocodyliform skulls (Fig. 35C) and turtle shells.

Fig. 35. Vertebrate remains from the Obernkirchen Quarry. A. Typical large tridactyl footprint (?*Iguanodontipus)* from Obernkirchen. B. Well-preserved didactyl track of a ?troodontid producer. C. Natural hollow sandstone mould of the skull of the crocodyliform *Goniopholis*.

References

Andreas, D. (1988): The structural dual character of the Rotliegendes in the Thuringian Forest and its surroundings. Z. Geol. Wiss.,16, 979-992.

Andreas, D. (2014): Der Thüringer Wald im Zeitraum der Stefan-Unterperm-Entwicklung - ein Abschnitt der Zentraleuropäischen N-S-Riftzone innerhalb des Mitteleuropäischen Großschollenscharniers. Dissertation, TU Bergakademie Freiberg, 181 pp., Online-Ressource.

Andreas, D., Lützner, H. & Schneider, J.W. (2005): Karbon des Thüringer Waldes, der Kraichgau-Main-Senke, der Thüringisch-Fränkischen Graben- bzw. Riftzone und Thüringisch-Nordostbayerisches Scherzonensystem. Cour. Forsch.-Inst. Senckenberg, Frankfurt, 254, 403-418.

Bachmann, G. H. & Kozur, H. W. (2004): The Germanic Triassic: correlations with the international chronostratigraphic scale, numerical ages and Milankovitch cyclicity. Hall. Jb. Geowiss., B 26, 17-62.

Berman, D. S., Henrici, A. C., Sumida, S. S. & Martens, T. (2000): Redescription of *Seymouria sanjuanensis* (Seymouriamorpha) from the Lower Permian of Germany based on complete, mature specimens with a discussion of paleoecology of the Bromacker locality assemblage. J. Ver. Paleontol., 20 (2), 253-268.

Berman, D.S. & Martens, T. (1993): First occurrence of *Seymouria* (Amphibia: Batrachosauria) in the Lower Permian Rotliegend of Central Germany. Ann. Carnegie Mus., 62, 63-79.

Berman, D.S., Reisz, R.R., Martens, T. & Henrici, A.C. (2001): A new species of *Dimetrodon* (Synapsida: Sphenacodontidae) from the Lower Permian of Germany records first occurrence of genus outside of North America. Canadian J. Earth Sci., 38, 803-812.

Beutler, G. (1998): Keuper. In: Bachmann, G.H., Beutler, G. & Lerche, I. (eds.): Excursions of the International Symposium on the epicontinental Triassic, Halle, Saale. Hall. Jb. Geowiss, B 6, 45-58.

Blumenberg, M., Zink, K. G., Scheeder, G., Ostertag-Henning, C. & Erbacher, J. (2019): Biomarker paleo-reconstruction of the German Wealden (Berriasian, Early Cretaceous) in the Lower Saxony Basin (LSB). Intern.J. Earth Sci., 108(1), 229-244.

Cohen, K. M., Finney, S. C., Gibbard, P. L. & Fan, J.-X. (2013): The ICS International Chronostratigraphic Chart, Episode 36, 199-204.

Diedrich, C. & Trostheide, F. (2007): Auf den Spuren der terrestren Muschelkalksaurier und aquatischen Sauropterygier vom obersten Röt bis zum Mittleren Muschelkalk (Unter-/Mitteltrias) von Sachsen-Anhalt. Abh. Ber. Naturk. Magdeburg, Band 30, 5-56.

Diedrich, C. (2011): Die Saurierspuren im basalen Mittleren Muschelkalk (Anis, Mittel-Trias) von Bernburg (Sachsen-Anhalt). Archäologie in Sachsen-Anhalt, Sonderband 15, Landesamt Archäol. Denkmalpfl./ Landesmus. Vorgesch. Halle, 64 p.

Ehling, B.-C. & Gebhardt, U. (2012): Rotliegend im Saale-Becken. Schrift. Deutschen Ges. Geowiss., 61, 504-516.

Eberth, D.A., Berman, D., Sumida, S.S. & Hopf, H. (2000): Lower Permian Terrestrial Paleoenvironments and Vertebrate Paleoecology of the Tambach Basin (Thuringia, Central Germany): The Upland Holy Grail. Palaios, 15 (4), 293-313.

Falk, D. (2011): Sedimentologie und 3D-Modellierung im Dinosaurier-Fährtenvorkommen der untersten Kreide (Berriasium, Bückeberg-Formation) von Münchehagen (Niedersachsen). Institut für Geologie, Fakultät for Geowissenschaften, Geotechnik und Bergbau. unpublished, TU Bergakademie Freiberg, Thesis: Bachelor of Science, 61 p.

FALK, D. (2014): Sedimentologie, Paläontologie und Environment-Rekonstruktion der Hornburg-Formation des südlichen Permbeckens (spätes Guadalupian, Permian). Institut für Geologie. Freiberg, TU Bergakademie Freiberg. M.Sc. thesis, 237 p.

FALK, D., SCHNEIDER, J. W., GEBHARDT, U. & EHLING, B.-C. (2016): Lithologie und Lebewelt des Fächer- und Playa-Systems der Mittel-Permischen Hornburg Formation (Sachsen-Anhalt). 5. Workshop Harzgeologie 2016, Göttingen, Universitätsverlag Göttingen.

FALK, D., SCHNEIDER, J. W., GEBHARDT, U. & WALTER, H. (2018): The Ichnofauna of a singular Middle to Late Permian Playa Lake in Europe (Upper Hornburg Formation, Saxony-Anhalt, Germany). Proceedings of the 2nd International Conference of Continental Ichnology (ICCI 2017), Nuy Valley (Western Cape Winelands), 1–8 October 2017. BORDY, E. M. (ed.): Abstract book, Nuy Valley (Western Cape Winelands), South Africa. Palaeontol. Africana, 52, 152-153.

FALK, D. & WINGS, O. (2013): Correlation between sedimentology and the preservation of dinosaur tracks at the Early Cretaceous Dinosaur Tracksite in Münchehagen (Lower Saxony, Germany). Palaeobiology and Geobiology of Fossil Lagerstätten through Earth History: A Joint Conference of the" Paläontologische Gesellschaft" and the" Palaeontological Society of China", Göttingen, Germany, September 23-27, 2013. REITNER, J., YANG, Q., WANG, Y. & REICH, M. (eds.), Abstract book, Göttingen, Universitätsverlag Göttingen, 44.

FISCHER, R. (1998): Die Saurierfährten im Naturdenkmal Münchehagen. In: FISCHER, R. (ed.): Das Naturdenkmal „Saurierfährten Münchehagen". Mitt. Inst. Geol. Paläontol. Univ.Hannover, 37, 3-59.

FISCHER, R. (1999): Die Oberjura-Schichtenfolge des Langenbergs bei Oker. Arbeitskreis Paläontologie Hannover, 19, 21-36.

GAST, R. (1995): Sequenzstratigraphie. In: PLEIN, E. (ed.): Stratigraphie von Deutschland I. Norddeutsches Rotliegendbecken. Rotliegend-Monographie Teil II. Courier Forsch.- Inst. Senckenberg, Frankf., 183, 47-54.

GEBHARDT, U. (1994): Zur Genese der Rotliegend-Salinare in der Norddeutschen Senke (Oberrotliegend II, Perm). Freiberger Forschungsh., C 452:, 3-22.

GEBHARDT, U. & LÜTZNER, H. (2012): Innervariscische Rotliegendbecken und Norddeutsches Becken; Fragen ihrer stratigraphischen Verknüpfung. Schrift. Deutschen Ges. Geowiss., 61, 715-730.

GEBHARDT, U., SCHNEIDER, J. W. & HOFFMANN, N. (1991): Modelle zur Stratigraphie und Beckenentwicklung im Rotliegend der Norddeutschen Senke. Geol. Jb., A 127, 405-427.

GEINITZ, H. B.(1861): „Dyas I." W. Engelmann, Leipzig, 130 p.

GEINITZ, H. B. & DEICHMÜLLER J. (1882): „Die Saurier der unteren Dyas von Sachsen." Palaeontographica (1846-1933), 29(1), 1-46; Kassel.

GEYER, G. (2000): Geologie von Unterfranken und angrenzenden Gebieten. Fränkische Landschaft Band 2. Gotha and Stuttgart, Klett-Perthes, 588 pp.

GLENNIE, K.W. (1972): Permian Rotliegendes of northwest Europe interpreted in light of modern desert sedimentation studies. AAPG Bull., 56:,1048-1071.

HAGDORN, H., HORN, M. & SIMON, T. (1998): Muschelkalk. In: BACHMANN, G.H., BEUTLER, G. & LERCHE, I. (eds.): Excursions of the International Symposium on the epicontinental Triassic, Halle, Saale. Hall. Jb. Geowiss., B 6, 35-44.

HAUBOLD, H. (2006): Die Saurierfährten *Chirotherium barthii* Kaup, 1835 – das Typusmaterial aus dem Buntsandstein bei Hildburghausen/Thüringen und das Chirotherium-Monument. Veröff. Naturhist. Mus. Schleusingen, 21, 3-31.

HAUBOLD, H. & KLEIN, H. (2000): Die dinosauroiden Fährten *Parachirotherium – Atreipus – Grallator* aus dem unteren Mittelkeuper (Obere Trias: Ladin, Karn, ?Nor) in Franken. Hall. Jb. Geowiss., B 22, 59-85.

HAUBOLD, H. & KLEIN, H. (2002): Chirotherien und Grallatoriden aus der Unteren bis Oberen Trias Mitteleuropas und die Entstehung der Dinosauria. Hall. Jb. Geowiss., B 24, 1-22.

HORNUNG, J., BÖHME, A., VAN DER LUBBE, T., REICH, M. & RICHTER, A. (2012): Vertebrate tracksites in the Obernkirchen Sandstone (late Berriasian, Early Cretaceous) of northwest Germany: their stratigraphical, palaeogeographical, palaeoecological, and historical context. Paläontol. Z., 86, 231-267.

HOYNINGEN-HUENE, E. v. (1960): „Das Permokarbon im östlichen Harzvorland." Freiberger Forschungshefte, C 93, 1-116.

JORDAN, H. (1979): Blatt Rehburg, Nr. 3521. In: Niedersächsisches Landesamt für Bodenforschung (ed.): Erläuterungen zur Geologischen Karte von Niedersachsen (1:25 000): 134 pp.; Hannover (Landesamt für Bodenforschung).

KAMPHAUSEN, D. (1990): Die taxonomische Stellung von *Capitosaurus arenaceus* Münster, 1836 (Stegocephalia, Amphibia) aus dem Keupersandstein Oberfrankens (Süddeutschland): Ber. Naturwiss. Ges. Bayreuth, XXI, 187-198.

KARL, C. & HAUBOLD, H. (1998): *Brachychirotherium* aus dem Coburger Sandstein (Mittlerer Keuper, Karn/Nor) in Nordbayern: Hall. Jb. Geowiss., B 20, 33-58.

KAUP, J.J. (1835a): Über Thierfährten bei Hildburghausen. N. Jb. Min. Geol. Paläontol. 1835, 327-328.

KAUP, J.J. (1835b): Fährten von Beuteltieren. In: Das Tierreich, 246-248.

KLEIN, H. & LUCAS, S.G. (2010): Tetrapod footprints – their use in biostratigraphy and biochronology of the Triassic. In: LUCAS, S.G. (ed.): The Triassic Timescale. Geol. Soc. London Spec. Publ., 334, 419-446.

KLEIN, H. & LUCAS, S.G. (2013): The Late Triassic ichnotaxon *Apatopus lineatus* (Bock 1952) and its distribution. New Mexico Mus. Nat. Hist. Sci. Bull., 61, 313-324.

KLEIN, H., LUCAS, S.G. & VOIGT, S. (2015): Revision of the ?Permian-Triassic tetrapod ichnogenus *Procolophonichnium* NOPCSA 1923 with description of the new ichnogenus *P. lockleyi*. Ichnos, 22, 155-176.

KUHN, O. (1936): Weitere Parasuchier und Labyrinthodonten aus dem Blasensandstein des Mittleren Keupers von Ebrach. Palaeontographica A, 83, 61-94.

LALLENSACK J.N. (2019): Automatic generation of objective footprint outlines. PeerJ 7:e7203 https://doi.org/10.7717/peerj.7203

LALLENSACK, J.N., VAN HETEREN, A. H. & WINGS, O. (2016): Geometric morphometric analysis of intratrackway variability: a case study on theropod and ornithopod dinosaur trackways from Münchehagen (Lower Cretaceous, Germany). PeerJ 4:e2059 https://doi.org/10.7717/peerj.2059

LALLENSACK, J. N., SANDER, P. M., KNÖTSCHKE, N., & WINGS, O. (2015): Dinosaur tracks from the Langenberg Quarry (Late Jurassic, Germany) reconstructed with historical photogrammetry: Evidence for large theropods soon after insular dwarfism. Palaeontol. Electron., 18.2.31A, 1-34.

LEPPER, J. & RÖHLING, H.-G. (1998): Buntsandstein. In: BACHMANN, G.H., BEUTLER, G. & LERCHE, I. (eds.): Excursions of the International Symposium on the epicontinental Triassic, Halle, Saale. Hall. Jb. Geowiss., B 6, 27-34.

LUCAS, S.G. (2006): Global Permian tetrapod biostratigraphy and biochronology. In: LUCAS, S.G., CASSINIS, G. & SCHNEIDER J.W. (eds.): Non-marine Permian Biostratigraphy and Biochronology. Geol. Soc. Spec. Publ. London, 265, 65-93.

Luthardt, L. (2013): Kartierung der Pyroklastit-Sediment-Folge im Steinbruch Mammendorf, Flechtingen Block. M.Sc. Mapping Report, TU Bergakademie Freiberg, 107 p.

Hornung, J.J., & Böhme, A. (2012): The 'German Wealden' and the Obernkirchen sandstone: an introduction. In: Richter, A. & Reich, M. (eds.), Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011, Abstract Volume. Göttingen (Universitätsdrucke Göttingen), 62–72.

Hornung, J.J., Böhme, A., van der Lubbe, T., Reich, M. & Richter, A. (2012): Vertebrate tracksites in the Obernkirchen Sandstone (late Berriasian, Early Cretaceous) of northwest Germany: their stratigraphical, palaeogeographical, palaeoecological, and historical context. Pal. Z. 86, 231–267.

Lützner, H. (1988): Sedimentology and Basin Development of Intramontane Rotliegend Basins in Central Europe. Z. Geol. Wiss., 16 (9), 845-863.

Lützner, H., Littmann, S., Mädler, J., Romer, R.L. & Schneider, J.W. (2007): Stratigraphic and radiometric age data for the continental Permocarboniferous reference-section Thüringer-Wald, Germany. In: Wong, Th.E. (ed.): Proc. XVth Int. Congr. Carboniferous and Permian Stratigraphy, Utrecht 2003. Roy. Netherlands Acad. Arts Sci., 161-174.

Lützner, H., Andreas, D., Schneider, J.W., Voigt, S. & Werneburg, R. (2012): Stefan und Rotliegend im Thüringer Wald und seiner Umgebung. In: Deutsche Stratigraphische Kommission (ed.): Stratigraphie von Deutschland X. Rotliegend. Teil I: Innervariscische Becken. Schrift. Deutschen Gesell. Geowiss., 61, 418-487.

Martens, T. (1988): First evidence of terrestrial tetrapods with North-American faunal elements in the red beds of Upper Rotliegendes (Lower Permian, Tambach beds) of the Thuringian Forest (G.D.R.) - first results. Acta Mus. Reginaehrad., S. A.: Scient. Natural., Hradec Kralove, 23, 99-104.

Martens, T., Schneider, J. & Walter, H. (1981): Zur Paläontologie und Genese fossilführender Rotsedimente - Der Tambacher Sandstein, Oberrotliegendes, Thüringer Wald. Freiberger Forschungsh., C 363: 75-100.

Martin, T., Averianov, A.O., Schultz, J.A., Schwermann, A.H. & Wings, O. (2019): Late Jurassic multituberculate mammals from Langenberg Quarry (Lower Saxony, Germany) and palaeobiogeography of European Jurassic multituberculates, Historical Biology, DOI: 10.1080/08912963.2019.1650274

Menning, M.; Katzung, G. & Lützner, H. (1988): Magnetostratigraphic investigations in the Rotliegendes (300–252 Ma) of central Europe. Z. Geol. Wiss., 16 (11/12), 1045-1064.

Müller, A. H. (1978): Über Hydromedusen (Coelenterata) und medusoide Problematica aus dem Rotliegenden von Mitteleuropa. Freiberger Forschungsh., C 342, 29-44.

Richter, A., Hornung, J.J., Boehme, A. & Stratmann, U. (2011): Excursion Guide A1: Obernkirchen Sandstone Quarries - A Natural Workstone Lagerstaette and a Dinosaur Tracksite. In: Richter, A. & Reich, M. (eds.): Dinosaur Tracks 2011, An International Symposium, Obernkirchen, April 14-17, 2011, Abstract Volume and Fieldguide to Excursions, Universitaetsverlag Goettingen, 2012.

Richter, A. & Böhme, A. (2016): Too many tracks: Preliminary description and interpretation of the diverse and heavily dinoturbated Early Cretaceous "Chicken Yard" ichnoassemblage (Obernkirchen Tracksite, Northern Germany). In: In: Falkingham P.L., Marty, D. & Richter, A. (eds.): Dinosaur Tracks: The Next Steps. Bloomington (Indiana University Press), 335-357.

Roscher, M. & Schneider, J.W. (2006): Permocarboniferous climate: Early Pennsylvanian to Late Permian climate development of central Europe in a regional and global context. In: Lucas, S.G., Cassinis, G. & Schneider J.W. (eds.): Non-marine Permian Biostratigraphy and Biochronology. Geol. Soc. London, Spec. Publ., 265, 95-136.

Sander, P.M., Mateus, O., Laven, T. And Knötschke, N. (2006): Bone histology indicates insular dwarfism in a new Late Jurassic sauropod dinosaur. Nature, 441, 739-741.

Schlirf, M., Uchman, A. & Kümmel, M. (2001): Upper Triassic (Keuper) non-marine trace fossils from the Haßberge area (Franconia, south-eastern Germany). Pal. Z., 75 (1), 71-96.

Schröder, B., Klare, B., Menzel, D. & Peterek, A. (1998): Das Permomesozoikum des Vorlandes der Böhmischen Masse (Exkursion K am 18. April 1998). Jber. Mitt. Oberrhein. geol. Ver. N F., 80, 251-270.

Schwennicke, T. (1998): Sedimenttexturen und Lebensspuren der Sohlbank des Naturdenkmals „Saurierfährten Münchehagen". In: Fischer, R. (ed.): Das Naturdenkmal „Saurierfährten Münchehagen". Mitt. Inst. Geol. Paläontol. Univ. Hannover, 37, 61-102.

Schneider, J.W. (1996): Xenacanth teeth - a key for taxonomy and biostratigraphy. Mod. Geol., 20, 321-340.

Schneider, J.W. (2001): Rotliegendstratigraphie - Prinzipien und Probleme. Beitr. Geol. Thüringen, N.F., 8, 7-42.

Schneider, J.W. & Gebhardt, U. (1993): Litho- und Biofaziesmuster in intra- und extramontanen Senken des Rotliegend (Perm, Nord- und Ostdeutschland). Geol. Jb., A,131, 57-98.

Schneider, J.W. & Werneburg, R. (2006): Insect biostratigraphy of the European late Carboniferous and early Permian. In: Lucas, S.G., Cassinis, G. & Schneider J.W. (eds.): Non-marine Permian biostratigraphy and biochronology. Geol. Soc. Spec. Publ., London, 265, 325-336.

Schneider, J.W., Körner, F., Roscher, M. & Kroner, U. (2006): Permian climate development in the northern peri-Tethys area – the Lodève basin, French Massif Central, compared in a European and global context. Palaeogeogr., Palaeoclimatol., Palaeoecol., 240, 161-183.

Schneider, J.W., Lucas, S.G., Werneburg, R. & Rössler, R. (2010): Euramerican Late Pennsylvanian/Early Permian arthropleurid/tetrapod associations; implications for the habitat and paleobiology of the largest terrestrial arthropod. New Mexico Mus. Nat. Hist. Sci. Bull., 49, 49-70.

Schneider, J.W., Rössler, R. & Fischer, F. (2011): Rotliegend des Chemnitz-Beckens. In: Deutsche Stratigraphische Kommission (ed.): Stratigraphie von Deutschland X. Rotliegend. Teil I: Innervariscische Becken. Schriftenr. Dt. Ges. Geowiss., 61, 319-377.

Schneider, J.W., Rössler, R., Werneburg, R., Scholze, F. & Voigt, S. (2014): Part II. The Carboniferous–Permian basins in Saxony, Thuringia, and Saxony-Anhalt of East Germany. In: Schneider, J.W., Oplustil, S. & Scholze, F. (eds.): CPC-2014 Field Meeting on Carboniferous and Permian Nonmarine–Marine Correlation. July 21st–27th, Freiberg, Germany. Excursion Guide. Techn. Univ. Bergakad. Freiberg, Wiss. Mitt. Inst. Geol., 4, 55-121.

Schneider, J.W., Lucas, S.G. & Barrick, J.E. (2013): The Early Permian age of the Dunkard Group, Appalachian basin, U.S.A., based on spiloblattinid insect biostratigraphy. Int. J. Coal Geol., 119, 88-92.

Schüler, F. & Seidel, G. (1991): Zur Ausbildung der Zechstein/Buntsandstein in Grenze in Ostdeutschland. Zeitschrift für Geologische Wissenschaften, 19 (5), 539-547.

Schulze, G. (1969): Der Untere Buntsandstein der Scholle von Calvörde und benachbarter Gebiete. Geologie, 18 (1), 5-20.

Seidel, G. & Wiefel, J. (1981): Zur Ausbildung des Zechsteins und Buntsandsteins im Gebiet von Gera. Z. Geol. Wiss., 9 (5), 479-488.

Voigt, S. (2002): Erstnachweis von fossilen Hydromedusen aus dem Tambacher Sandstein (Rotliegend, Unteres Perm, Thüringen). Freiberger Forschungsh., C 497, 45-57.

Voigt, S. (2005): Die Tetrapodenichnofauna des kontinentalen Oberkarbon und Perm im Thüringer Wald - Ichnotaxonomie, Paläoökologie und Biostratigraphy. Göttingen, Cuvillier Verlag, 179 pp.

Voigt, S. (2012): Fossilführung und Stratigraphie: Tetrapodenfährten. In: Deutsche Stratigraphische Kommission (ed.): Stratigraphie von Deutschland X. Rotliegend. Teil I: Innervariszische Becken. Schrift. Deutschen Gesell. Geowiss., 61, 92-106.

Voigt, S., Berman, D.S. & Henrici, A.C. (2007): First well-established track-trackmaker association of Paleozoic tetrapods based on *Ichniotherium* trackways and diadectid skeletons from the Lower Permian of Germany. J. Vert. Paleontol., 27 (3), 553-570.

Walter, H. (1983): Zur Taxonomie, Ökologie und Biostratigraphie der Ichnia limnisch-terrestrischer Arthropoden des mitteleuropäischen Jungpaläozoikums. Freiberger Forschungsh., C 382, 146-193.

Werneburg, R. & Schneider, J.W. (2006): Amphibian biostratigraphy of the European Permo-Carboniferous. In: Lucas, S.G., Cassinis, G. & Schneider J.W. (eds.): Non-marine Permian biostratigraphy and biochronology. Geol. Soc. Spec. Publ., London, 265, 201-215.

Wings, O., Broschinski, A. & Knötschke, N. (2005): New theropod and ornithopod dinosaur trackways from the Berriasian of Münchehagen (Lower Saxony, Germany). In: Current Research in Vertebrate Palaeontology, 3rd Annual Meeting of the European Association of Vertebrate Palaeontologists (EAVP). Kaupia. Darmstädter Beitr. Naturgesch., 14, 105.

Wings, O. & Eckert, C. (2018): Chapter 23. GOTHA: Museum der Natur, Stiftung Schloss Friedenstein Gotha. In: Beck, L.A. & Joger. U. (eds.): Paleontological Collections of Germany, Austria and Switzerland, Natural History Collections, 249-260. Cham (Springer).

Wings, O., Falk, D., Knötschke, N. & Richter, A. (2012): Excursion Guide B1: The Early Cretaceous dinosaur trackways in Münchehagen (Lower Saxony, Germany) – The Natural Monument ‚Saurierfährten Münchehagen' and the adjacent Wesling Quarry. Dinosaur Tracks 2011 - An International Symposium, Obernkirchen, April 14-17, 2011, Abstract Volume and Field Guide to Excursions, Obernkirchen, Universitätsdrucke Göttingen, Landesmuseum Hannover, 113-142.

Wings, O., Lallensack, J.N., Mallison, H. (2016): The Early Cretaceous Dinosaur Trackways in Münchehagen (Lower Saxony, Germany)—3D photogrammetry as basis for geometric morphometric analysis of shape variation and evaluation of material loss during excavation. In: Falkingham P.L., Marty, D. & Richter, A. (eds.): Dinosaur Tracks: The Next Steps. Bloomington (Indiana University Press), 57-70.

Wings, O. & Sander, P.M. (2012): The Late Jurassic Vertebrate Assemblage of the Langenberg Quarry, Oker, Northern Germany. In: Royo-Torres, R., Gascó, F. and Alcalá, L., (eds.). (2012). 10th Annual Meeting of the European Association of Vertebrate Palaeontologists. ¡Fundamental!, 20, 280-284.

Wright, J.L. (2005): Steps in understanding sauropod biology. In: Curry Rogers, K.A. & Wilson, J.A. (eds.): The Sauropods: Evolution and Paleobiology. Berkeley (University of California Press), 252-285.

Ziegler, P.A. (1982): Geological Atlas of Western and Central Europe. The Hague (Elsevier & Shell Intern. Petrol. Maatschappij B.V.), 130 pp.

Zuo, F., Heimhofer, U., Huck, S., Luppold, F.W., Wings, O. & Erbacher, J. (2018): Sedimentology and depositional sequences of a Kimmeridgian carbonate ramp system, Lower Saxony Basin, Northern Germany. Facies 64, 1, https://doi.org/10.1007/s10347-017-0513-0.