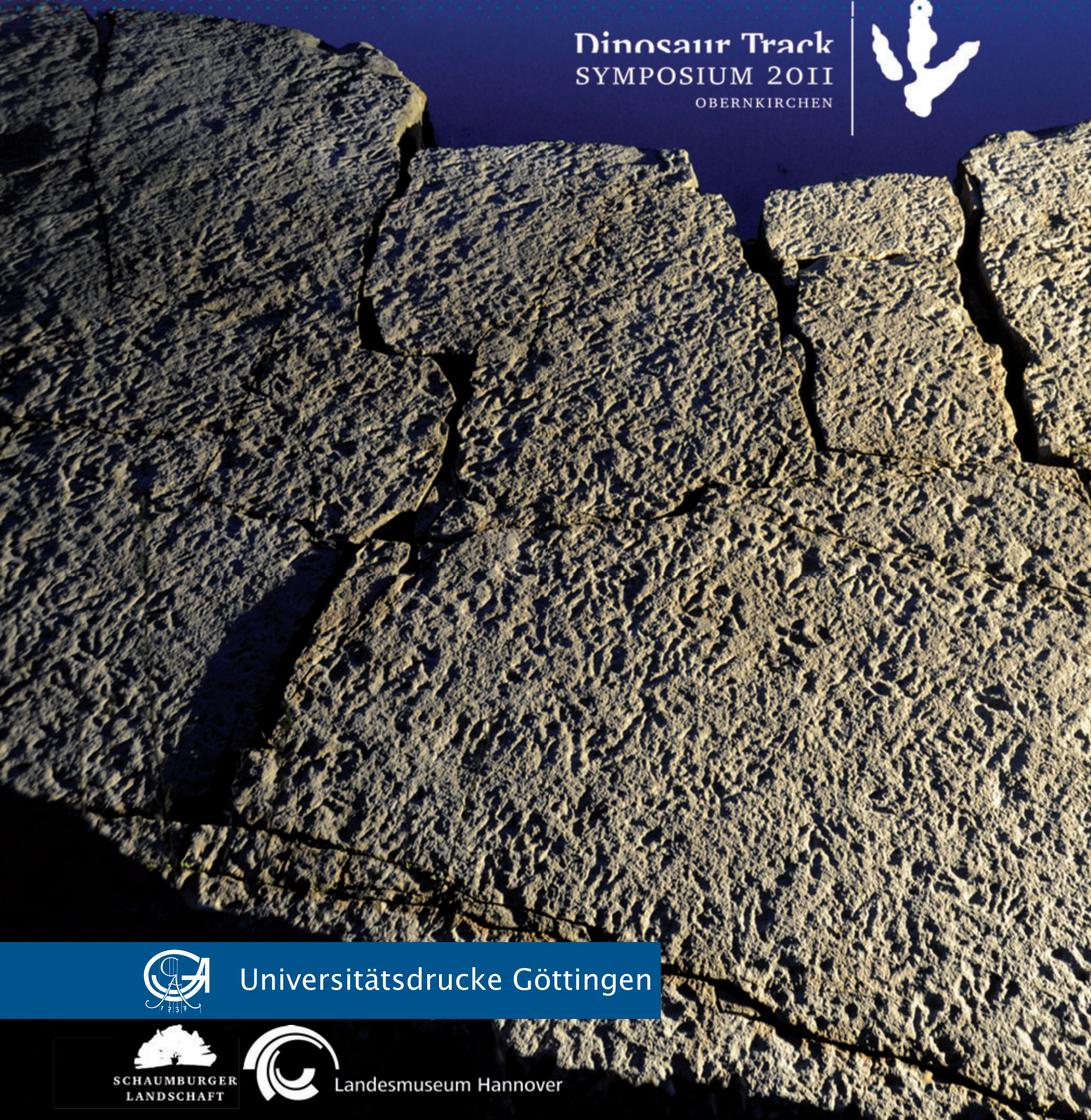
Annette Richter, Mike Reich (Eds.)

Dinosaur Tracks 2011

An International Symposium,
Obernkirchen, April 14–17, 2011

Abstract Volume and Field Guide to Excursions

Dinosaur Track
SYMPOSIUM 2011
OBERNKIRCHEN



Universitätsdrucke Göttingen

SCHAUMBURGER LANDSCHAFT

Landesmuseum Hannover

Annette Richter and Mike Reich (Eds.)

Dinosaur tracks 2011

erschienen in der Reihe der Universitätsdrucke
im Universitätsverlag Göttingen 2012

Annette Richter
and Mike Reich (Eds.)

With the collaboration of Annina Böhme,
Jahn J. Hornung, Tom R. Hübner,
Tanja R. Stegemann

Dinosaur tracks 2011

An International Symposium, Obernkirchen, April 14-17, 2011

Abstract Volume and Field Guide to Excursions

Universitätsverlag Göttingen
2012

Bibliographische Information der Deutschen Nationalbibliothek

Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliographie; detaillierte bibliographische Daten sind im Internet über <http://dnb.ddb.de> abrufbar.

Editorial contact
Dr Annette Richter
Annina Böhme
Dr Tom R. Hübner
Hannover State Museum
Willy-Brandt-Allee 5
30169 Hannover, Germany
http://www.landesmuseum-hannover.de

Dr Mike Reich
Jahn J. Hornung
Tanja R. Stegemann
Geoscience Centre of the
Georg-August University of Göttingen
Goldschmidtstraße 1-5
37077 Göttingen, Germany
http://www.geomuseum.uni-goettingen.de
http://www.geobiologie.uni-goettingen.de

Graphics and Layout: Mike Reich
Cover Design: Conny Hundertmark & Mike Reich
Cover Photos: Geoscience Museum Göttingen,
Hannover State Museum, Tobias Landmann

http://univerlag.uni-goettingen.de
ISBN: 978-3-86395-105-4

Contents

The printing of this volume was funded by:

SCHAUMBURGER LANDSCHAFT

Landesmuseum Hannover

GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

Preface

On behalf of the "Schaumburger Landschaft" and the "Niedersächsisches Landesmuseum Hannover", we gave a very warm welcome to almost 100 participants in our *Dinosaur Track Symposium Obernkirchen 2011* on April 14th.

The conference took place at the historical Protestant monastery in Obernkirchen and, therefore, we are deeply grateful to Abbess Wöbbeking, the landlady, for her hospitality and patience while accommodating the symposium for four central days and quite a few more during the preparatory work: Some parts of the monastery are more than 800 years old. Of course, 800 years may mean almost nothing to palaeontologists, compared to the millions of years that were dealt with during this symposium. Nevertheless, all our guests were pleased to be, and enjoyed their stay, in this charming old building.

When the spectacular new dinosaur track finds occurred at Obernkirchen, the idea to organize an international symposium came up immediately.

The "Schaumburger Landschaft", which is a foundation dedicated to the support of culture in our region, quickly decided to initiate a project in support of the museum which was the scientific partner in raising funds for the meeting. For the Schaumburger Landschaft, it is an honour to have hosted this event just after the completion of the first steps of field documentation.

Arriving from all over the world, the conference members brought international renown and sparkle to the symposium and the region of Schaumburg during these exciting days. Therefore, we would like to thank all the attendees for the interest they have expressed, and especially those who travelled thousands of miles in order to make a personal contribution to the success of our event. We are sure that all of the participants returned home from this conference with a vast amount of new experience and knowledge.

A symposium requires a great deal of preparation as well as a perfect organization. It also costs quite a lot of money. Therefore, on behalf of both the "Schaumburger Landschaft" and the "Niedersächsisches Landesmuseum Hannover", we would like to thank our sponsors: the "Stiftung Niedersachsen", the foundation of Lower Saxony, represented by Secretary General Joachim Werren, the "Sparkassenstiftung Schaumburg", our regional bank, represented by Director Rolf Watermann and the "Klosterkammer Hannover", a foundation responsible among others for the monasteries of Lower Saxony.
Aside from the very important financial promotion, it is obvious that without the permanent support of the "Obernkirchener Sandsteinbrüche GmbH" (Obernkirchen Sandstone Quarries) and especially their owner, Mr Klaus Köster, we would have had no knowledge of the new tracks. Moreover, there would not have been a symposium at all.

We would also like to express our gratitude for all their fantastic support to the cooperational partners of the museum: the Geoscience Museum as well as the Department of Geobiology of the University of Göttingen and the "Dinosaurier-freilichtmuseum Münchehagen/Dinopark".

Even though the symposium was to be a specialists' conference, we had decided to invite the general public to Obernkirchen on the first evening.
Taking account of the fact g that dinosaurs are a highly interesting topic not only for children but also for a number of adults, we added Professor Dr Haubold's public lecture to the programme on the first evening.
Since a symposium must not only consist of professional work and discussions, we carried out a spectacular illumination of the quarry of Obernkirchen on the second evening of the symposium. On the third and fourth days, field trips to our cooperational partners took us to Münchehagen and Göttingen, and a splendid conference dinner was enjoyed at the Renaissance castle of Hülsede, which was an unforgettable highlight.

May this collection of abstracts catch and keep the spirit of the *Dinosaur Track Symposium Obernkirchen 2011* for a long time and enhance progress in this special field of palaeontology, namely palaeo-ichnology.

Sigmund Graf Adelmann
Schaumburger Landschaft

Dinosaur Track
SYMPOSIUM 2011
OBERNKIRCHEN

Dr Annette Richter
Niedersächsisches Landesmuseum Hannover

April, 2011

Words of Welcome

Ladies and Gentlemen,

It is a great pleasure for me, as Secretary General of "Stiftung Niedersachsen", to welcome you to this important event. I would like to give a special welcome to our guest from Tokyo, and to extend our heartfelt sympathy regarding the disaster in Japan. Allow me to express the hope that the great and technologically highly advanced nation of Japan will master this situation and will rise like a phoenix.

Dinosaurs in general are species that most children but also many adults are interested in. Considering the never-ending and often badly researched media hype on this topic, it is a relief to be reminded that there are many scientists who take these early chapters of history seriously. Looking at the list of speakers, I am quite thrilled by the international stature of this symposium. It appears that the Obernkirchen finds are achieving wide recognition, not just among the scores of dinosaur-track tourists in the area, but also among this audience of experts in palaeontology.

Trace fossils in general give clues to biological activity and thereby provide indirect evidence of life in the past. Footprints in particular offer insights into the movement patterns, and also allow substantial speculation about the appearance, height and weight, of the early inhabitants of the earth. Today's possibilities of communication and travel, not to mention new methods of investigation and preservation, have had a major impact on science. Imagine living and working under the conditions of the 19th century! In those days much greater efforts were required to communicate new findings and discuss them with international colleagues. Thanks to technological advances, the inspection and comparison of dinosaur tracks all over the world is much easier today, and only costs money.

Allow me to point out that Germany's geological expertise is concentrated in Hannover. The geosciences are strongly represented in this state by such institutes as the "Bundesanstalt für Geowissenschaften" (the Federal Institute for Geosciences and Natural Resources), the "Landesbehörde für Bergbau, Energie und Geologie" (the State Authority for Mining, Energy and Geology) and the "GeoZentrum". It is only in this context that the wealth of dinosaur species in the past and the trace fossils that have survived down to today can be fitted into a coherent pattern. I expect this symposium to throw even more scientific light on these topics.

As a state foundation we are exceedingly happy about the discovery of the 49 dinosaur tracks in Obernkirchen, because one of our goals is to publicise, in Europe and beyond, those aspects of Niedersachsen that set it apart. Moreover, we support the efforts to enable local scientists to have access to the results of research carried out at other institutes. Therefore we considered it our duty to make a financial contribution to this symposium, at which the trace fossils found in 2007/08, including the first didactyl dinosaur tracks to be found in Europe, will be discussed by a circle of international experts. We are not the only ones, however, to be fascinated by the objectives of this project. We are very pleased to be associated with a number of other partners in the project: the "Klosterkammer Hannover", the Trustees of the local savings bank, "Sparkasse Schaumburg", and the "Niedersächsisches Landesmuseum", the Niedersachsen State Museum. All of us are looking forward with great anticipation to the outcome of the very interesting presentations and lively discussions.

For more than 20 years now, "Stiftung Niedersachsen" and its staff have been working to support the arts and sciences throughout Niedersachsen. There have been a number of changes over the years in the environment in which we work – in the whole area of foundations, in cultural policy and in culture itself. All of these factors have influenced the focus and direction of the Foundation's grant policy and have sharpened its profile. Our funding is now directed towards structural measures and projects that contribute to Niedersachsen's development. The main focus of our grants policy is on the quality and sustainability of the projects applying for grants. Furthermore, innovative methods of conveying culture and new approaches to research are considered closely by our team.

The Foundation makes a particular contribution with its operational goals. Its programmes include the Joseph Joachim International Violin Competition, Spectrum - an international Award for Photography, the Literatur-Labor for young German-language authors and the Europa-Kolleg for pupils from all over Europe.

Let me express my best wishes for these four days in Obernkirchen. I hope all of you will enjoy insightful field trips, presentations and discussions.

Joachim Werren
Stiftung Niedersachsen
Secretary General

April 14th, 2011

Photographic Impressions

Fig. 1 Group photograph of participants – Göttingen Geopark at the Geoscience Centre, University of Göttingen [Photograph: Geoscience Museum Göttingen, G. Hundertmark].

(1) Maik **Raddatz**
(2) Boban **Filipović**
(3) Joao **Marinheiro**
(4) Torsten **van der Lubbe**
(5)
(6)
(7) Matteo **Belvedere**
(8) Corwin **Sullivan**
(9) Anthony **Romilio**
(10) Stephen M. **Gatesy**
(11)
(12) Oliver **Gerke**
(13) Denver W. **Fowler**
(14)

(15) Cory **Kumagai**
(16)
(17) Annina **Böhme**
(18) Alexander **Gehler**
(19) Tanja R. **Stegemann**
(20) Phil **Manning**
(21) Michael **Romano**
(22) Christian A. **Meyer**
(23) Laura **Piñuela**
(24)
(25) Diego **Castanera**
(26) Peter L. **Falkingham**
(27) James O. **Farlow**
(28) Brent H. **Breithaupt**
(29) Andrew R. C. **Milner**
(30) Alexander **Mudroch**
(31) Jose Joaquin **Moratalla**
(32) Ute **Richter**
(33) **Xu** Xing
(34) Oliver **Wings**
(35) Octávio **Mateus**
(36) Tom R. **Hübner**
(37) Jahn J. **Hornung**
(38) Uwe **Stratmann**
(39) Dragana **Petrovic**
(40) Daniel **Marty**
(41) Abdulkarim **Al-Subbary**
(42) **Li** Ri-hui
(43) Mohammed **Al-Wosabi**
(44) Mike **Reich**
(45) Annette **Richter**
(46) Masaki **Matsukawa**
(47) Richard T. **McCrea**
(48) Lisa G. **Buckley**
(49) Annika **Beckmann**
(50) Nadine **Rachimow**
(51)
(52) Verena S. **Frank**
(53) Nicolas **Régent**
(54)

Fig. 2 Group photograph of participants – Hülsede Water Castle in the Weser Renaissance style, located between the Süntel and Deister ridges, Lower Saxony [Photograph: Schaumburger Landschaft, K. Koldeweyh].

Part I: Oral & Poster Presentations

The Dinosaur Track Road in Teruel (Spain) *[poster presentation]*

Luis **Alcalá** & Alberto **Cobos**

Fundación Conjunto Paleontológico de Teruel-Dinópolis, Teruel, Spain

In Teruel, the first dinosaur bones were documented in the 19th century and the first Spanish dinosaur, *Aragosaurus*, was described in 1987. Recently, dinosaur tracksites have been described. Most of them come from Tithonian–Berriasian sediments (Villar del Arzobispo Fm.): since the first sauropod and theropod footprints were described from Ababuj in 1995, more than twenty have been registered. Some are outstanding: at Las Cerradicas (Galve) there are trackways left by small sauropods and ornithopods walking quadrupedally and El Castellar is the type locality for *Deltapodus ibericus* (stegosaurid trackmaker).

Driving about 70 km along a rural road you can visit up to six villages with more than twenty dinosaur tracksites: 7 in Galve (Maestrazgo European & Global Geopark), 3 in Aguilar del Alfambra, 1 in Ababuj, 4 in Cedrillas, 6 in El Castellar and 3 in Formiche Alto. All of them belong to Villar del Arzobispo Fm., except Ríos Bajos (Higueruelas Fm., Lower Tithonian) and Corrales del Pelejón (El Castellar Fm., Hauterivian-Barremian) in Galve, and El Hoyo (Camarillas Fm., Lower Barremian) in El Castellar. 10 of them are catalogued with the first-level figure in the Spanish Heritage Laws.

The tour begins in Galve, where you can find a satellite of Dinópolis, a municipality exhibition, a paleontological park, and two sites with footprints which have been prepared to be visited: Las Cerradicas and Corrales del Pelejón. Then you arrive at Aguilar del Alfambra, where trackways assigned to stegosaurid and bipedal dinosaurs, parallel to each other, have been found. Next is the aforementioned Ababuj, after that there is a site with sauropod footprints in Cedrillas. El Castellar, including stegosaurid, sauropod, ornithopod and theropod footprints, is not far away and, finally, Formiche Alto connects the Road with Dinópolis-Teruel, the largest facility to diffuse palaeontology in Spain.

In a day tour, the Dinosaur Track Road in Teruel allows researchers and visitors to enjoy a variety of dinosaur tracksites, particularly from the Jurassic–Cretaceous transition.

Acknowledgements: Dep. Educación, Dep. Ciencia (Gobierno Aragón), DINOSARAGÓN CGL2009–07792 (Ministerio Ciencia Innovación-FEDER funds), Grupo Investigación FOCONTUR (E-62), IAF and Comarca Teruel.

Dinosaur tracksites in the Arhab area, Yemen *[oral presentation]*

Mohammed **Al-Wosabi[1],** Anne S. **Schulp[2,3],** Nancy J. **Stevens[4]** & Basheer **Al-Botaily[5]**

[1]*Department of Geology, Sana'a University, Sana'a, Republic of Yemen*

[2]*Natuurhistorisch Museum Maastricht, Maastricht, The Netherlands*

[3]*Faculty of Earth and Life Sciences, Vrije Universiteit Amsterdam, The Netherlands*

[4]*Department of Biomedical Sciences, College of Osteopathic Medicine, Ohio University, Athens, Ohio, USA*

[5]*Yemen Geological Survey and Mineral Resources, Sana'a, Republic of Yemen*

In 2003, dinosaur trackways were discovered in the Arhab area, about 50 km north of Sana'a, Republic of Yemen. The Yemen Geological Survey and Mineral Resources Board assembled a team including the authors of this contribution and geologists from the Geological Survey Authority. The first fieldwork in 2006 and 2007 at Serwah near Madar village resulted in the identification of two additional trackways of tridactyl bipedal dinosaurs as well as 11 trackways of quadrupedal dinosaurs. Also, two trackways of a quadrupedal dinosaur were discovered at nearby Bait Al-Washr village.The bipedal trackways could be referred to ornithopod dinosaurs; the quadrupedal trackways attributed to Sauropoda.

Prospecting continued in the region over the past three years with very encouraging results: so far an additional 38 sites have been recognized, featuring tracks and trackways similar to the tracks described so far, as well as poorly preserved, elongate tracks not unlike tracks recorded along the Paluxy River inTexas.

Most trackways are within a single stratigraphic level, except for a few sites such as Al-Nadef where four track-bearing levels were recognized. This leaves all the dinosaur tracksites (over 40 now) discovered in Yemen within the upper part of the Amran Group, which spans a Middle Jurassic–earliest Cretaceous (Berriasian) age. The available data at this time suggests a Kimmeridgian–?Tithonian age for the main track-bearing level.

Rock samples were collected from two sections for analysis of the depositional system of the Amran Group and to correlate the sequence with the Amran Group sequences in the wider area; this research is currently ongoing.

Efforts are ongoing to establish a geopark and linking it with the International Network of Geoparks. Work began in the assessment following the request of the UNESCO Regional Office in Cairo, and will be discussed during the next meeting of UNESCO in Paris.

The impact of the digital trend on ichnology: ICHNOBASE

[poster presentation]

Matteo **Belvedere**[1], Andrea **Baucon**[2,3], Stefano **Furin**[4], Paolo **Mietto**[1], Fabrizio **Felletti**[2] & Giovanni **Muttoni**[2]

[1]*Università di Padova, Dipartimento di Geoscienze, Padova, Italy*

[2]*Università degli Studi di Milano, Dipartimento di Scienze dalla Terra, Milan, Italy*

[3]*UNESCO Geopark Naturtejo Meseta Meridional, Geology and Paleontology Office, Centro Cultural Raiano, Idanha-a-Nova, Portugal*

[4]*Università di Ferrara, Dipartimento di Scienze della Terra, Ferrara, Italy*

Since its beginning, vertebrate ichnology has based the sharing of data and morphologies on outline drawings and qualitative descriptions of tracks. Though these methods are fundamental for the definition and the understanding of vertebrate tracks, they introduce a high level of subjectivity, due both to the drawing ability and to the sharing methods (e.g. copies from old journals), which do not allow a precise quantitative approach to ichnology, as e.g. shape analysis.

During the last decade, several research groups have started using new methods for the documentation of footprints (laserscanning, photogrammetry) which led to the spreading of three-dimensional models. However, exchange of data is still mostly dependent on direct contact among authors, thus preventing the jump towards a quantitative approach that ichnology needs.

The ICHNOBASE project aims to create a free open-access online database, containing information concerning both invertebrate and vertebrate traces, bibliographic references, descriptions, updated pictures, and 3D models. The database will also comprise sedimentological and stratigraphical information as well as a preservation grade value which rapidly resume the details preserved by the track (0 = no details; 5 = skin impressions).

Once compiled and tested, the ICHNOBASE could become the reference database for ichnologists, easing the exchange of information and 3D models, and enlarging the chance for each researcher to access new objective data, thus improving the shift towards a more quantitative ichnology.

The Lower Cretaceous (Berriasian) dinosaur tracksite of Obernkirchen, Lower Saxony, northern Germany – Preliminary report on the "Upper Track Layer" *[poster presentation]*

Annina **Böhme[1,4]**, Torsten **van der Lubbe[2]**, Annette **Richter[2]**, Manfred **Wiggenhagen[3]** & Uwe **Stratmann[2]**

[1]*Geoscience Museum of the University of Göttingen, Göttingen, Germany*

[2]*Hannover State Museum, Hannover, Germany*

[3]*Institut of Photogrammetry and GeoInformation, Leibniz University Hannover, Hannover, Germany*

[4]*Department of Geobiology, Geoscience Centre of the University of Göttingen, Göttingen, Germany*

In 2009, we reported on new parallel and facultatively bipedal ornithopod trackways of an *Iguanodontipus–Caririchnium*-like morphology from the uppermost part of the track-bearing succession of the Obernkirchen sandstone quarries (Obernkirchener Sandsteinbrüche). The exposed Obernkirchen Sandstone (Bückeberg Formation, German 'Wealden', late Berriasian) represents a freshwater to brackish, deltaic to lagoonal palaeo-environment.

In 2010, the area of this "upper track layer" was extended to approx. 4500 m^2 (formerly c. 2500 m^2) and has been accessible to the public since November 2010. About 1200 m^2 are still covered with thin sandstone beds. The latter also exhibit tracks, which will be documented and analysed in the near future.

For the first approx. 2000 m^2 of the "upper track layer", a track map was produced by using high resolution digital images. Additional tie points were used for geometric transformation of the images into a reference system in order to generate a complete mosaic of images. A closer look at the new track-type so far revealed: (1) approx. 30 trackways with more than 400 tracks in total, (2) two groups, each with more than ten individuals, walked in NW/N and SE/S direction, respectively; two individuals walked in NE and E direction, respectively, (3) the longest trackway comprises 41 tracks, (4) the size of the pes tracks varies from 30 to 60 cm in width and 34 to 61 cm in length (n = 152), the size of the manus tracks ranges from 7 to 14 cm in width and 11 to 21 cm in length (n = 15), (5) pace length varies from 52 to 129 cm (n = 149), stride length from 132 to 250 cm (n = 137). The total track-inventory counts more than 700 tracks and comprises ornithopod tracks of the new track-type plus ornithopod tracks of '*Iguanodontipus*'-type and a few theropod tracks.

Neoichnology and photogrammetric ichnology to interpret theropod community dynamics *[oral presentation]*

Brent H. **Breithaupt**[1] & Neffra A. **Matthews**[2]

[1]*Bureau of Land Management Wyoming State Office, Cheyenne, Wyoming, USA*

[2]*Bureau of Land Management National Operations Center, Denver, Colorado, USA*

One of the most extensive ichnofaunal records is that of Mesozoic dinosaurs. Close-range photogrammetry (along with digital spatial data utilized in Geographic Information Systems) provides an excellent tool for ichnological documentation and is the basis for photogrammetric ichnology. The key to more fully understanding dinosaur community dynamics is detailed 3D documentation and the creation of a digital archive from sites worldwide. Close-range photogrammetric images have the quality, reliability, and authenticity necessary for scientific use. Digital ichnology data, along with digital spatial data, provide excellent tools for capturing the incredible wealth of information provided at dinosaur tracksites. In western North America, geospatial documentation has been conducted at tracksites administered by the Bureau of Land Management, in particular, the Sundance Vertebrate Ichnofaunal Province (SVIP) in north-central Wyoming. Within SVIP, the activities of a monotaxonomic community of hundreds of Middle Jurassic (Bathonian), carnivorous dinosaurs are preserved. Thousands of tridactyl pes impressions are arranged into hundreds of trackways, providing evidence for the family structure and community dynamics of a population of dinosaurs on the shores of the ancient Sundance Sea. Evidence indicates the tracks were made by primitive, tetanuran theropod dinosaurs (ranging in age from yearling to adult) traveling together in gregarious family groups. To better understand the meaning of the ontogenetic and behavioral implications of the fossil footprints, the tracks and activities of modern emus have been studied. Emus are excellent modern analogues for understanding growth and community dynamics of small- to medium-sized carnivorous dinosaurs.

Neoichnological data were collected from emus of various ages and footprint growth curves developed. This information is being used to interpret the ichnological record of theropod dinosaurs. Neoichnological and photogrammetric ichnological studies can be used to help unravel numerous ichnological complexities and can provide a unique glimpse on the paleoecology, paleobiology, and paleoethology of theropod dinosaur communities.

A novel avian ichnotaxon from the Early Cretaceous (Albian) Boulder Creek Formation of northeast British Columbia: multivariate analysis and modern avian osteology as interpretive tools in vertebrate palaeoichnology tracksites *[oral presentation]*

Lisa G. **Buckley** & Richard T. **McCrea**

Peace Region Palaeontology Research Centre, Tumbler Ridge, British Columbia, Canada

A trackslab containing several avian tracks and trackways, as well as several small theropod tracks, was discovered from the Boulder Creek Formation (Early Cretaceous: Albian) in northeast British Columbia in 2005. The trackslab contains five trackways and 19 isolated tracks of a novel ichnogenus and ichnospecies which are currently being described. One distinct feature of the novel ichnotaxon is that digit divarication II–III is significantly larger than digit divarication III–IV. As the avian ichnotaxon *Barrosopus slobodai* of Argentina (Late Cretaceous: Campanian) also has a larger II–III than III–IV divarication, multivariate analyses (principal component, discriminant, and canonical variate analysis) were performed to 1) test quantitative support for separating the new ichnotaxon from *B. slobodai* and 2) test quantitative support for the erection of a new ichnofamily, to include *B. slobodai* and the new ichnotaxon, as distinct from the existing ichnofamily Avipedidae. Analyses support both the new ichnotaxon as significantly different from *B. slobodai*, and the new distinct ichnofamily.

Investigation of modern analogs to further interpret the tracks of the new ichnotaxon shows tracks of the extant plover *Charadrius vociferus* (Killdeer) are similar to those of the new ichnotaxon in that divarication II–III is significantly larger than divarication III–IV. Comparing the distal tarsometatarsus of *C. vociferus* and *C. semipalmatus* (Charadriidae) to those of the extant sandpipers *Actitis macularia* and *Caladris melanotos* (Scolopacidae) reveals there are interfamilial skeletal differrences in morphology of distal tarsometatarsi that may contribute to footprint morphology. We are currently testing the correlation between ichnologic and osteologic discreteness for extant shorebirds.

Juvenile or dwarf sauropods? The case of the titanosauriform herd from Las Cerradicas tracksite (Teruel, Spain)

[poster presentation]

Diego **Castanera**[1], José Luis **Barco**[1,2], Ignacio **Díaz-Martínez**[1,3,4], Jesús Herrero **Gascón**[5], Félix **Pérez-Lorente**[3,4] & José Ignacio **Canudo**[1]

[1]*Universidad de Zaragoza, Zaragoza, Spain*

[2]*Paleoymás, Polígono INBISA-Empresarium-C, Cartuja Baja, Zaragoza, Spain*

[3]*Universidad de La Rioja, Logroño, Spain*

[4]*Fundación Patrimonio Paleontológico de La Rioja, Enciso, Spain*

[5]*Moscardón, Spain*

The Las Cerradicas tracksite (Galve, Iberian Range, Spain) is a reference point in the study of dinosaur tracks. Theropod trackways showing gregarious behavior and an ornithopod trackway showing quadrupedal locomotion have been described. The tracksite has been included in the Iberian Dinosaur Track Project (IDPI) as a candidate for a UNESCO World Heritage Site. Recently, new sauropod trackways have been discovered during preparation of the outcrop for the IDPI project. Las Cerradicas is located near the top of the Villar del Arzobispo Formation (upper Tithonian–middle Berriasian).

The sauropod footprints exhibit an interesting morphology. Features, such as the wide-gauge condition and the absence of pollex marks in the manus, suggest that the trackmakers were probably titanosauriform sauropods. The parallel direction of the trackways, as well as the size of the footprints (no more than 30 cm in length), suggests that they were made by a herd of small sauropods travelling close together.

Some sauropod tracksites in the global record are dominated by small footprints. Some of them preserve bigger ones attributable to the same ichnotaxon. In other cases, similar footprints of larger size have been described from the same formation. The interpretation in both cases was that the footprints were made by juvenile or subadult individuals. The footprints of Las Cerradicas seem to be different from those found at other sauropod tracksites of the Iberian Range, so another explanation may also be possible: dwarfism.

Recent work in palaeohistology has demonstrated that some of the small sauropods described in the fossil record are true "dwarves". This would be a consequence of their palaeogeographic location and insular habitat. As yet, we cannot demonstrate dwarfism merely on the evidence of footprints, so we consider both hypotheses (juvenile-dwarfism) to be possible.

Applying objective methods to subjective track outlines

[oral presentation]

Peter L. **Falkingham**

School of Earth, Atmospheric and Environmental Science, University of Manchester, Manchester, UK

Formally communicating the morphology of a dinosaur track generally occurs via a two dimensional medium (i.e. paper). For this reason, track outlines are often used to convey the geometry and morphology of a track. However, these track outlines are routinely subjective, based on the interpreter's opinion of where the track ends and the surrounding substrate begins. While such outlines are not a problem themselves, the application of numerical, objective methods such as multivariate analyses or equations using track parameters can be strongly influenced by the subjective nature of the outline. This effect is compounded in deeper tracks with sloping sides such as those formed in soft to firm mud. However, although there are numerous ways in which to define track extents objectively (horizontal plane intercept, maximum inflexion, direct track impression etc.), none are applicable to all tracks and there is no universally 'correct' objective definition of a track outline.

To illustrate this point, outlines were produced from laser scan data of real fossil tracks. In order to produce objective outlines, a 'base-line' surface was produced by fitting a plane to three points picked on undisturbed surrounding sediment. This virtual plane acted as a reference, approximating the pre-track sediment surface. From this plane, outlines were produced from height isolines taken at regular intervals. A multivariate analysis was then applied to each outline separately. Individual tridactyl tracks were shown to be distinctly theropodan or ornithopodan depending upon which isoline was used, and track length was shown to vary by as much as 25 %. Rather than carrying out such objective analyses on single outlines, it is suggested that a "best guess and bracketing" approach is adopted, where minimum and maximum outlines are used to constrain, rather than specify interpretations and conclusions.

Emus, alligators, and *Eubrontes*: assessing intraspecific and interspecific variability in foot and footprint shape *[oral presentation]*

James O. **Farlow**[1], Matthew E. **Bonnan**[2], Emma C. **Rainforth**[3], Jana **Benson**[1] & Kate **Shearer**[1]

[1]*Indiana-Purdue University, Fort Wayne, Indiana, USA*

[2]*Western Illinois University, Macomb, Illinois, USA*

[3]*Ramapo College of New Jersey, Mahwah, New Jersey, USA*

Dinosaur tracksites often exhibit large numbers of tridactyl footprints of different size and shape. Determining how well footprint shapes serve as proxies for the diversity of trackmakers requires criteria for assessing shape variability both within and across species. We considered these questions by studying shape variability of footprints of the emu (*Dromaius novaehollandiae*) and at least 45 other species of ground birds, hindfeet of the American alligator (*Alligator mississippiensis*), and the classic Early Jurassic Newark Supergroup (eastern North America) tridactyl footprint series *Grallator–Anchisauripus–Eubrontes* (here provisionally regarded as different ichnospecies of the single ichnogenus *Eubrontes*).

We ran emus ranging in size from near hatchlings to adults in a variety of substrates, and collected footprints from at least 36 individual birds, both in zoos and in the wild in Australia. We measured the feet of an ontogenetic series of more than 90 alligators, ranging in size from near hatchlings to large adults. Measurements were made in such a way as to be as comparable as possible across emus and other bird footprints, alligator feet, and *Eubrontes*. Data were analyzed using both traditional morphometric methods and (for emu prints) geometric morphometrics.

Substrate conditions and bird gaits showed no consistent effects on emu footprint shape. Emu footprints are nearly isometric across the ontogenetic size range, except for a decreasing relative footprint width, and decreasing interdigital angle, with increasing footprint size. Alligator feet are also nearly isometric, except for possible relative increases in digit stoutness, and decreases in the sharpness of claws, with increasing size. In contrast, the *Eubrontes* size series showed a relative increase in lengths of digits II and IV compared with III, a relative increase in footprint width, and an increase in interdigital angle, with increasing footprint size. Shape variability in the *Eubrontes* series was greater than that for emus and alligators. Thus it is likely that the *Eubrontes* size series is at least in part interspecific in nature.

Comparison of foot and footprint shapes across ground bird species showed that tracks of conspecifics are commonly more alike than similar to prints of other species. Footprint shapes track some of the known phylogenetic relationships of ground birds, such as often discriminating prints of ratites from galliform birds. Unfortunately, there are numerous cases of convergence in foot and footprint shape among bird clades that are not close relatives (e.g. bustards with emus, and kiwi with pheasants). This suggests that footprint shape is not always a reliable proxy for the relationships of trackmakers.

The predatory ecology of Deinonychosauria: foot use compared among dromaeosaurids, troodontids, and basal birds

[oral presentation]

Denver W. **Fowler**[1], Elizabeth A. **Freedman**[1], John B. **Scanella**[1] & **Robert E. Kambic**[2]

[1]*Museum of the Rockies & Dept. of Earth Sciences, Montana State University, Bozeman, Montana, USA*

[2]*Brown University, Providence, Rhode Island, USA*

Our recently completed studies on pes functional morphology of extant birds of prey and extinct Deinonychosauria (Dinosauria: Theropoda) presented a new predatory model emphasizing adaptations for grasping and flapping in prey restraint strategy.

In extant birds of prey, proportional variation of the feet is associated with factors such as speed, strength, agility, and even diet. Although specific combinations of foot morphological characters in extinct non-avian theropods are not identical to extant raptors, likely predatory behaviours can be elucidated by comparison of individual characters and their function in extant birds of prey.

In most Late Cretaceous ecosystems, Deinonychosauria are represented by both Troodontidae and Dromaeosauridae, whose feet exhibit different (often opposite) morphological trends indicating variation in their predatory ecology. Dromaeosaurids exhibit increasing adaptation for taking larger prey with strong, but slow feet, and unusually hypertrophied D-II unguals. By comparison, troodontids instead evolved towards a more cursorial habit, being fast and nimble with weaker, but quick feet, and a more mobile D-I. This perhaps afforded a more even grip, better adapted for snatching and subduing smaller prey. The strongly cursorial adaptations of troodontids suggest speed and/or pursuit was important to their predatory strategy, but derived dromaeosaurids do not exhibit limb proportions that suggest significant cursorial ability: rather, they were probably ambush predators.

Other aspects of our predatory model suggest that many of the features we typically associate with modern birds (powered flight, perching feet) may have been exapted from unrelated ancestral predatory behaviours. Our description of stability flapping strengthens the view that basal paravians utilized flapping for a number of behaviours unrelated to flight, and that it was only in birds where this was exapted into powered flight. These findings open many new directions for further research, and emphasize the importance of exaptation in evolution of novel structures and behaviour.

Tracks as 3-D Particle Trajectories *[oral presentation]*

Stephen M. **Gatesy** & Richard G. **Ellis**

Department of Ecology and Evolutionary Biology, Brown University, Providence, Rhode Island, USA

How do sedimentary particles move from their starting locations in undisturbed ground to their ultimate resting places in a fossil footprint? The geometric relationship between a foot's changing position through time (kinematics) and the sediment's final conformation is poorly known, especially for deep tracks. Experimental studies using stratified clay, sand, cement, and plaster are well suited for documenting distortion of interfaces between layers, but are unable to discern the displacement of sediment within each layer. Moreover, opaque materials require destructive sectioning or splitting, which precludes real-time analysis of the sequence of track development.

We describe the novel application of biplanar X-ray 3-D motion analysis to the study of footprint formation. Hardware and software tools originally created for reconstructing skeletal motion are used to relate sediment deformation, both spatially and temporally, to the moving foot. We present results from two case studies in which a volume of artificial mud was laced with lead beads and displaced by a moving turkey foot. This methodology has the potential to yield a detailed understanding of track formation mechanisms, link track morphology to specific foot motions, provide validation of computational models, and set a new standard for evidence-based reconstruction of movement from fossil footprints.

Dinosaur footprints: taxonomy, phantom taxa and the relation between core and surface investigation *[oral presentation]*

Hartmut **Haubold**

Institut für Geowissenschaften, Martin-Luther-Universität, Halle (Saale), Germany

Taxonomy concerns determination and systematic ordering. In cases of fossil tetrapod footprints (including dinosaurs), this leads to some principal questions: Into which system should a specimen be classified? What are the criteria of the system? And how are these criteria represented in an ichnofossil?

First of all, the decision seems to be subjective. This is further affected by vertical and horizontal variability in both isolated fossil tracks and individual tracks within trackways. Two prominent arguments are forthcoming, one positive: the larger the sample size, the lower the ichnodiversity (and *vice versa*); and one negative: Palichnology is "soft science": the author's decision is open (not to say chaotic).

Therefore, whether an ichnotaxon is useful or not depends on the classification system preferred by the student:

1) Ichnological activity. Here, every ichnological structure and variation (controlled by movement and behaviour) would be of taxonomic value.

2) The anatomy of the trackmaker, its autopodials and body proportions. This system is based on optimal tracks and trackways.

However, in both cases the resulting taxonomy depends on the available information. Which situation is preserved vertically and horizontally at the exposed surface? The best looking track preservation is not necessarily in optimal relation to the criteria in ichnotaxonomy, respectively to those of a preferred system.

3) Classification is also formally linked to taxon-specific anatomy, where each taxon is paralleled by an ichnotaxon. This can include extant taxa as well, e.g. *Hominipes modernus* might be formally established. But is this useful? Could it be helpful regarding the acceptance of tetrapod ichnology as science? Or is it a vehicle promoting the author's reputation? The next step would be from extant to fossil taxa. Remembering the experience of F. E. Peabody, of the shift from osteological to ichnological taxonomy from genus to species level, would it be useful separating tracks of Hominidae or only Hominini by ichnogenera, like *Praehominipes* for the site of Laetoli?

From the knowledge of about 200 years of paleontology and palichnology, it is clear that each paradigm is related to the horizon of its author. In 1836, to Edward Hitchcock the concept of Dinosauria was unknown. He knew birds and classified footmarks of the Early Jurassic as *Ornithichnites*. Today, we are presented with a highly diverse phylogenetic system that needs restriction by consensus to keep it practicable. One crucial aspect in this regard is: Which of the Late Triassic ichnomorphs/ichnotaxa could be related to sauropodomorphs? We have just learned that *Eoraptor* is no longer considered a theropod but rather a basal sauropodomorph.

One final example of subjectivity and paradigmatic perfectionism: An ichnoassociation of sediments in a Pleistocene or even Holocene cave with *Hominipes* and some tracks of carnivores formally belonging to the "*Grallator* ichnofacies" would be readily embraced by a certain group as evidence supporting creationism.

We should therefore take care, keeping tetrapod palichnology, in particular dinosaur ichnology, acceptable.

Rotodactylus **- dinosauromorph footprints from Lower/Middle Triassic** *[poster presentation]*

Hartmut **Haubold**

Institut für Geowissenschaften, Martin-Luther-Universität, Halle (Saale), Germany

Peabody (1948) first described *Rotodactylus* as ichnotaxon of the Pseudosuchia from few specimens found in the Moenkopi Formation of Arizona. About 20 years later, the ichnogenus was identified in the Solling Formation of the German Buntsandstein (about late Early Triassic) besides *Chirotherium* as evidence of an additional intercontinental Triassic ichnotype. The ichnospecies *Rotodactylus matthesi* Haubold, 1967 was preserved between thin sandstone-mudstone layers in the upper part of the Thuringian "Chirotherien-Sandstone".

It is the intention of the poster to show the optimal track record at the type locality of *R. matthesi*. The presented cast of about 1 m^2 is a part of an extended surface with almost excellent preserved tracks of small animals. *Rotodactylus* is present with several hundreds of manus and pes tracks per square meter.

Over the years, the interpretation of *Rotodactylus* appeared rather enigmatic due to the missing skeletal information as well as due to the lack of an adequate phylogenetic hypothesis. But since definition of Dinosauria and the closely related sister group Lagosuchia, a model has been established that confirms both the morphology and the early geological record of *Rotodactylus*. Moreover, with the hypothesis of Dinosauromorpha - the last common ancestor of Lagosuchia + Dinosauria - the existence of *Rotodactylus* might be used as evidence predating ancestral Dinosauria back into the late Early Triassic.

Under optimal conditions, *Rotodactylus* appears as the most frequent ichnospecies at the track bearing surfaces of the Chirotherian Sandstone and its correlatives. Associated ichnotypes at the present ichno-assemblage are *Chirotherium sickleri*, *Isochirotherium soergeli*, *Brachychirotherium harrasense*, and rare trackways of *Rhynchosauroides*. An additional significant track type is *Dicynodontipus*, interpreted as made by cynodonts.

The croc puzzle: a fairly complete specimen of *Goniopholis* (Mesoeucrocodylia: Goniopholididae) from the Bückeberg Formation (Berriasian) of Bückeburg, northern Germany

[poster presentation]

Jahn J. **Hornung**[1] & Mike **Reich**[1,2]

[1]*Department of Geobiology, Geoscience Centre of the University of Göttingen, Göttingen, Germany*

[2]*Geoscience Museum of the University of Göttingen, Göttingen, Germany*

In the late Berriasian Obernkirchen Sandstone (Bückeberg Formation) of south-western Lower Saxony, crocodiles are rather common faunal components and have been described from the 1840s onwards. The larger part of the specimens is referable to the basal neosuchian genera *Goniopholis* (Goniopholididae) and *Pholidosaurus* (Pholidosauridae).

Most of the available material has been neglected in scientific literature since the 19th century. With the exception of a single well-preserved skull, which served as a base for a thorough redescription of *Goniopholis simus* Owen, 1878 (see Salisbury et al. 1999; Andrade & Hornung 2011), the bulk of the crocodiles from the Bückeburg Formation remained unstudied until most recent times.

The former collection of Ballerstedt comprises a number of crocodile specimens, including several sandstone blocks containing mandibles and various postcranial elements referable to *Goniopholis*. The association of these blocks to a single individual was not immediately obvious. However, a few of the slabs fitted together, and it was revealed by collection notes of Ballerstedt that all specimens with a plain roman number belong to a single specimen of *Goniopholis*, while those with a roman number followed by an 'A' are counterslabs to the former. Furthermore, a cranium, kept isolated in the collection (old number "Sch.1") was identified as belonging to the same specimen. It consists of the skull, mandible, several isolated teeth, a cervical vertebra, a dorsal neurapophysis, thoracal ribs, two haemapophyses, both scapulae, a coracoid, both humeri, both ilia, an ischium, and numerous paravertebral and ventral osteoderms. The bones are disarticulated and embedded "floating" in a texturally massive sandstone bed.

The specimen will allow the description of considerable parts of the postcranium and provides new information potentially useful for the alphataxonomy in *Goniopholis*. It enables comparison with *G. crassidens* Owen, 1842 from the Purbeck Limestone Group of England (Hornung et al. 2009). The latter was formerly suspected to be a senior synonym of *G. simus*, but this hypothesis could not be tested due to the lack of overlap in the holotypes. *G. simus* was preferred by later authors due to the availability of cranial material, which is morphologically indistinguishable from the German material.

The type material of the theropod ichnotaxon *"Buecke-burgichnus" maximus* Kuhn, 1958 – reconsidered *[poster presentation]*

Jahn J. **Hornung**[1], Annina **Böhme**[1,2] & Mike **Reich**[1,2]

[1]*Department of Geobiology, Geoscience Centre of the University of Göttingen, Göttingen, Germany*

[2]*Geoscience Museum of the University of Göttingen, Göttingen, Germany*

The amateur palaeontologist Max Ballerstedt recovered a number of unusual hypichnial casts from the Bückeberg Formation (late Berriasian) near Bückeburg, Lower Saxony (Ballerstedt 1905). The large footprints of a biped dinosaur exhibit claw-marks and the impression of an opposed hallux. The trackmaker was later correctly identified as a large theropod (?*Megalosaurus* in Abel 1935).

Over the last century, various ichnotaxonomic concepts have been woven around Ballerstedt's material which was dispersed and considered lost by many authors. Original material was not used in studies done between 1905 and 2000. Two ichnogenera, *Megalosauripus* Lessertisseur, 1955 and *Bueckeburgichnus* Kuhn, 1958, were erected for it, though both were based upon a schematic outline sketch made by Ballerstedt and first published by Abel (1935). Subsequently, the validity of both ichnogenera was questioned independently and contradictorily (Lockley 2000 contra Thulborn 2001). None of these opposite views have yet found equivocal acceptance, and a solution to these problems will have far reaching consequences for theropod ichnotaxonomy.

Recently, we were able to retrieve some specimens of *"Bueckeburgichnus"*, belonging to the original material collected by Ballerstedt around 1900-1905. The material, as known at present, comprises at least 9-10 hypichnia and 1 epichnium. Based upon this hypodigm and a careful reconsideration of the ichnotaxonomical history of *"Bueckeburgichnus"*, we draw the following conclusions: (1) As explicitly stated by Ballerstedt (1905), all footprints in his figs. 1–7 were left by the same species, they therefore represent implicitly ichnosyntypes; (2) Ballerstedt collected an unknown but considerable number of ichnotopotypoids, which he did not figure; (3) Neither Abel (1935), Lessertisseur (1955), nor Kuhn (1958) referred their figure explicitly to a specimen from Ballerstedt's type series (though it was most probably an idealised depiction of Ballerstedt's specimen in his fig. 4). Therefore, an ichnoholotype was never formally designated; (4) The status of the specimen identified by Lockley (2000) as the ichnoholotype of *Bueckeburgichnus* is unclear, as it is no ichnosyntype and there is no published evidence that it is even an ichnotopotypoid; (5) Among the remaining material, one ichnosyntype (Ballerstedt 1905: fig. 7) is currently relocated (on exhibit at the Gymnasium Adolfinum Bückeburg), and all others are considered ichnotopotypoids.

A well-preserved isolated turtle footprint from the lowermost Cretaceous (Berriasian) of northern Germany *[poster presentation]*

Jahn J. **Hornung**[1], Hans-Volker **Karl**[1,3] & Mike **Reich**[1,2]

[1] *Department of Geobiology, Geoscience Centre of the University of Göttingen, Göttingen, Germany*

[2] *Geoscience Museum of the University of Göttingen, Göttingen, Germany*

[3] *Thuringian State Office for the Preservation of Historical Monuments and Archaeology, Weimar*

Turtle tracks are relatively rare but geographically widespread components of Mesozoic aquatic ichno-assemblages. Here we present the hypichnial cast of an isolated turtle manus imprint, apparently left during "bottom-walking" or swimming. The excellently preserved specimen is located on the underside of a slab of fine-grained sandstone from the late Berriasian Bückeberg Formation (Obernkirchen Member, Obernkirchen Sandstone) of the area of Bückeburg, Lower Saxony, NW Germany.

The large imprint (12 cm wide, 6 cm long) was left by a right manus which clearly shows the impression of four digits. The digits are thin and interphalangeal joints can be discerned at least on digit IV. All digits are enclosed in an extensive skin web with only vestigial if any free ungual claws. The skin shows folding, especially between digits III and IV, but no distinctive epidermal texture or traces of osteoderms.

The appendicular skeleton of most Berriasian turtles is unknown, hampering a straightforward assignment of the footprint to a certain orthotaxon. However, of the turtle fauna from the Bückeburg Formation (Karl et al. 2007), only the abundant *Hylaeochelys menkei* (Roemer, 1836), with a carapace length of up to 70 cm, reaches a size comparable to the dimensions of the footprint producer.

The autopodial morphology exhibited by the track is remarkable as it evidences the aquatic adaptation of the turtle and shows several derived features when compared to the plesiomorphic conditions in the turtle's manus. It represents a degree in adaptation intermediate between those of less specialised semiaquatic turtles (e.g. Emydidae, including a semiplantigrade gait and a considerably short and broad manus) and highly specialised aquatic turtles (e.g. Trionychoidea, including gracile phalanges, extensive webbing, reduced ungual claws, and a smooth skin surface). The specimen sheds a rare light on the poorly known modifications in the appendicular morphology of Early Cretaceous limnic turtles.

The type material of the ankylosaurian ichnospecies *Metatetrapous valdensis* Nopcsa, 1923 (Early Cretaceous, northern Germany) *[poster presentation]*

Jahn J. **Hornung**[1], Julia **König**[1] & Mike **Reich**[1,2]

[1]*Department of Geobiology, Geoscience Centre of the University of Göttingen, Göttingen, Germany*

[2]*Geoscience Museum of the University of Göttingen, Göttingen, Germany*

From the late Berriasian Obernkirchen Sandstone of the Harrl hill near Bückeburg, Max Ballerstedt (1922) published a figure of an 11 m long, tetradactyle trackway, which he referred to a non-sauropod, "secondary quadrupedal" dinosaur contrasting the abundant tracks of bipedal ornithopods and theropods from the same stratum. Unfortunately, he did not provide further details on the structure or morphology of the tracks.

Until today, this discovery remains unique and Ballerstedt did not make any note on the whereabouts of this trackway or whether any parts of it were recovered and incorporated into his collection. This led to the fact that several later workers doubted its existence. During the reinvestigation of the Ballerstedt collection, which is now housed in the GZG, two hypichnial natural casts were found in 2007, which can be unequivocally related to the quadrupedal dinosaur trackway depicted by Ballerstedt.

In March 1923, Franz Baron Nopcsa visited Max Ballerstedt in Bückeburg. In his synopsis "Die Familien der Reptilien", Nopcsa (1923) published the name *Metatetrapous valdensis* for this trackway, giving a brief description.

The isolated hypichnia, both showing tetradactyle imprints of the left pes, were found isolated among the Ballerstedt collection without label or accompanying numbers. However, they are referred to *Metatetrapous valdensis* and to the type material of this trackway for the following reasons: (1) their morphology and metric dimensions are fully congruent with the morphology of some of the pes imprints illustrated by Ballerstedt, (2) they show the same slip-faces at the base of the pes imprints as the type trackway, (3) no other tracks of this morphology have ever been reported from the Obernkirchen Member.

The hypichnia from the Ballerstedt collection reconfirm the validity of *Metatetrapous valdensis* as an ichnotaxon. It can be identified as an ankylosaurian trackway based upon the characters published by Canadian authors. Worldwide, nearly 20 localities with purported ankylosaurian trackways have so far been reported, ranging from the Lower Jurassic to the Upper Cretaceous. A total of six ichnospecies have been erected for putative ankylosaurian tracks, of which *M. valdensis* is the first formally named ichnotaxon.

Dinosaur tracksites from the Early Cretaceous (Bückeberg Formation, Berriasian) of Lower Saxony, northern Germany

[poster presentation]

Jahn J. **Hornung**[1], Annina **Böhme**[1,2] Torsten **van der Lubbe**[3], Mike **Reich**[1,2] & Annette **Richter**[3]

[1]*Department of Geobiology, Geoscience Centre of the University of Göttingen, Göttingen, Germany*

[2]*Geoscience Museum of the University of Göttingen, Göttingen, Germany*

[3]*Hannover State Museum, Hannover, Germany*

The late Berriasian Obernkirchen Member of the Bückeberg Formation in the southern Lower Saxony Basin, to the west and to the south of Hannover, yields abundant and diverse dinosaur tracks. During the 1850s to 1870s, structures, often found during quarrying, were already recognised as tracks formed by animals or, more precisely, "giant birds". The subsequent research history can be subdivided into several, partly discontinuous, epochs: (1) c. 1879–1881: Pioneering epoch, discovery and identification of iguanodontian dinosaurs as trackmakers; (2) c. 1900–1930: Intensive collecting and sporadic research, identification of various types of trackmakers, including ankylosaurs and theropods; (3) c. 1950–1979: Sporadic theoretical discussion of results from previous research, only one new find recovered and described; (4) 1979–1998: Discovery of in-situ sauropod tracks, first concept for conservation and touristic exploitation developed during the 1980s; (5) since 2004: Discovery of new track horizons at various locations with abundant trackway assemblages, excavation campaigns, and concept development for partial conservation.

Numerous individual tracksites have been reported, but the decrease of quarrying operations since the early 20th century led to a loss of several outcrops. The identification of single tracksites is further complicated by imprecise locality descriptions and careless application of locality names. A recent survey resulted in the identification of at least 13 tracksites, 5 of which are still accessible: (1) Rehburg Mountains (4 localities): 2 localities still accessible, 1 with completed and active conservation and public access concept and protected under conservational law as a "natural monument", 1 with active research and excavation program; (2) Bückeburg–Harrl hill (2 localities): 2 localities still accessible, protected under conservational law and with active research program; (3) Bückeberg–Obernkirchen (5 localities): 1 locality still accessible, with active research and excavation program, with partial public access since November 2010; (4) Osterwald mountains (2 localities): Both largely inaccessible, but current status under study.

The diverse suite of trackmakers includes several morphotypes of theropods and ornithopods (various ontogenetic stages), other small and bipedal ornithischians, rare ankylosaurs, and sauropods.

A morphometric analysis of the autopodia of the American crocodile (*Crocodylus acutus*) in Costa Rica *[oral presentation]*

Cory **Kumagai** & James O. **Farlow**

Indiana-Purdue University, Fort Wayne, Indiana, USA

Interpreting the number of kinds of trackmakers in an archosaurian footprint assemblage is difficult when all of the footprints, both large and small, are basically similar in morphology. To gain a better understanding of this problem, we must consider if footprint shapes would be expected to change in an ontogenetic series. We investigated this by analyzing autopodial shape in an ontogenetic series of an extant archosaur, the American crocodile (*Crocodylus acutus*), in Costa Rica. We measured overall body proportions and autopodial (both manus and pes) dimensions for a series of crocodiles ranging in total length from 31.5–314 cm, and used both bivariate (reduced major axis [RMA] analysis) and multivariate analyses (RMAs of scaled autopodial dimensions against overall body size; principal components analysis [PCA]) to test for allometric shape changes. Both bivariate and multivariate analyses indicated slight negative allometry of both manus and pes size with overall body size. In contrast, bivariate and multivariate comparisons of intra-manus or intra-pes parameters indicated isometry in manus and pes shape. Our results indicate that there is little or no change in manual and pedal proportions as crocodiles increase in size during ontogeny. This suggests that size series of generally similar dinosaur tracks that show distinct changes in proportions (e.g. the classic *Grallator–Anchisauripus–Eubrontes* complex of the Early Jurassic Connecticut Valley ichnofauna) are at least in part interspecific rather than intra-specific in nature.

The Early Cretaceous didactyl dinosaur tracks and related tracks from Shandong Province, China *[oral presentation]*

Ri-hui **Li**[1] & Martin G. **Lockley**[2]

[1]*Qingdao Institute of Marine Geology, Qingdao, Peoples Republic of China*

[2]*Dinosaur Tracks Museum, University of Colorado at Denver, Denver, Colorado USA*

The Early Cretaceous Tianjialou Formation (Barremian–Aptian) in Houzuoshan Dinosaur Park (HDP) in Junan County, Shandong Province, China, is becoming globally famous in recent years for its unique, rich vertebrate tracks. Among them, the most attractive are two kinds of coeval didactyl deinonychosaurian footprints. The large ones (foot length up to 28.5 cm) were named *Dromaeopodus shandongensis* and attributed to a large dromaeosaur. The smaller ones (foot length ~10 cm) represented by a single trackway, were attributed to *Velociratorichnus*. The avian track *Shandongornipes* – the first zygodactyl track ever reported from the fossil record – was also described from the same Formation in HDP.

The holotype trackway of *Dromaeopodus shandongensis* at level 4 of the section, consists of four consecutive footprints, level 5 reveals six parallel *Dromaeopodus* trackways. Each trackway comprises between one and five footprints, giving a total of only 13 footprints on this level. The striking feature of the level 5 surface is that all six trackways are oriented in the same WSW direction (towards 245°). This suggests a gregarious 'pack' of animals. The fact that tracks are all similar in size, suggests that all were large, *Utahraptor*-sized animals and presumably adults.

Velociraptorichnus tracks, occurring at level 15, consist of a single, well-preserved left footprint followed after a gap of 166.5 cm (evidently representing two missing tracks) by what appears to be a slightly less well-preserved right footprint. This suggests a mean step of 55.5 cm.

The footprint evidence found in HDP lends some support to the prediction that Asia served as a source of biogeographic dispersal of large *(Utahraptor)* and medium-sized *(Deinonychus)* dromaeosaurids to North America during or shortly before the Barremian.

Interpreting Korean dinosaur tracksites: Gregarious behavior and group hunting *[oral presentation]*

Jong-Deock **Lim**[1], Kyoung-Soo **Kim**[2], Dal-Yong **Kong**[1] & Tae-Hyung **Kim**[1]

[1]*Natural Heritage Center of Korea, National Research Institute of Cultural Heritage, Daejeon, South Korea*

[2]*Department of Science Education, Chinju National University of Education, Jinju, South Korea*

Dinosaur trackways provide solid evidence for their behavior and activities. They are used by paleontologists to infer that dinosaurs traveled in herds or might have hunted in packs. The Southern coast of Korea has produced well-preserved dinosaur tracksites from the Cretaceous. A new dinosaur tracksite was discovered from Euiseong County. It lies within the Sagok Formation (110 mya) of the Gyeongsang Basin. The total number of footprints is 114, arranged in seven trackways. 62.3 % of them are sauropod footprints and 33.3 % are theropod footprints. The close association of two very small sauropod trackways indicates that the juvenile trackmakers walked together towards a herd of adult sauropods. The new site also exhibits 38 tracks of theropods arranged in four trackways. The tracksite suggests that theropods potentially interacted with the baby sauropods since the direction of travel was the same and the tracks are spatially close to each other.

Recent fieldwork (2009–2010) in the southeastern part of Korea revealed a new tracksite near Jinju in the Haman Formation of the Gyeongsang Basin. The new tracksite yielded more than 100 footprints. Theropod tracks are the most abundant with three different types. The theropod footprints are well-preserved exhibiting sharp claw marks. The theropod trackways exhibit the same travelling direction as those of the sauropods and may indicate group hunting behavior.

Another site, the L2 level of the Hwasun Seoyu-ri site (Neungju Basin, Late Cretaceous) in the Jeollanam-do, a Natural Monument, sports 22 small theropod trackways in a small area suggesting gregarious behavior. Based on the walking patterns and directions of the theropod trackways, we consider it quite possible that the small theropods tried to surround and chase small ornithopods as a form of group hunting.

Two-toed tracks through time: on the trail of "raptors" and their allies *[oral presentation]*

Martin G. **Lockley**[1] & Jerald D. **Harris**[2]

[1]*Dinosaur Tracks Museum, University of Colorado Denver, Denver, Colorado, USA*

[2]*Dixie State College, St. George, Utah, USA*

The term "raptor" has a broad meaning in zoology and the popular mind. However, in paleontology, it refers specifically to a clade of deinonychosaurian dinosaurs with a distinctive retracted pedal digit II with a well-developed, "sickle claw."

Because dromaeosaurs were known before their tracks were identified, ichnologists predicted two-toed tracks representing digits III and IV. In 1995, small (footprint length FL = 10 cm) tracks from the Cretaceous of Sichuan, China were described as *Velociraptorichnus*. In 2008, *Dromaeopodus*, a much larger track (FL = 28 cm) was reported from the Cretaceous of Shandong, China (co-occurring with *Velociraptorichnus*) and *Dromaeosauripus*, a medium-sized track (FL ~15 cm), was reported from the Cretaceous of Korea. *Velociraptorichnus* and *Dromaeopodus* display rounded impressions representing the proximal portion of digit II, but no such trace is recorded for *Dromaeosauripus*. The only known dromaeosaur trackway from North America originates from the Cedar Mountain Formation (Lower Cretaceous) of Utah, which also yields two isolated tracks with sub-optimal preservation.

Possible, poorly-preserved dromaeosaur tracks occur in the Early Cretaceous of Hebei and Gansu Provinces, China. Like the abundant tracks from the Early Cretaceous of Germany and an Upper Cretaceous report from Poland these remain un-named. Thus, eight of nine credible reports from the Lower Cretaceous and three of the five reports from Asia represent all named ichnotypes.

Late Triassic "Dromaeosaur-like" didactyl tracks from North America with rounded impressions representing the proximal portion of digit II compare with ichnogenus *Evazoum*, and are probably of prosauropod affinity. We infer a non-deinonychosaurian track maker and suggest convergence in foot morphology between two groups of saurischian dinosaurs appearing ~100 million years apart. There are separate reports of didactyl tracks from the Early and Middle Jurassic of North Africa. In the former case ostensibly didactyl footprints may be preservational anomalies, but the Middle Jurassic track *Paravipus*, evidently represents a functionally didactyl theropod.

Some modern birds, notably seriamas, have unusual foot morphologies somewhat convergent with deinonychosaur anatomy. But didactyly in extant avian dinosaurs (e.g., ostriches) is rare and morphologically distinctive. Thus, functional didactyly is rare in saurischian dinosaurs, reaching its highest and most consistent expression in Early Cretaceous deinonychosaurs.

Sorting out the sickle-claws: how to distinguish between dromaeosaurid and troodontid tracks *[oral presentation]*

Torsten **van der Lubbe**[1], Annette **Richter**[1], Annina **Böhme**[2,3], Corwin **Sullivan**[4] & Tom R. **Hübner**[1]

[1]*Hannover State Museum, Hannover, Germany*

[2]*Department of Geobiology, Geoscience Centre of the University of Göttingen, Göttingen, Germany*

[3]*Geoscience Museum of the University of Göttingen, Göttingen, Germany*

[4]*IVPP, Chinese Academy of Sciences, Beijing, Peoples Republic of China*

To date, more than 100 didactyl tracks have been discovered in the Lower Cretaceous (Berriasian) sandstones of the Bückeberg Formation, near Obernkirchen, Germany. All didactyl tracks reported so far (except an enigmatic didactyl variant of the "*Pseudotetrasauropus* morphotype" from the Upper Triassic Chinle Group of the United States, *Menglongipus* from the Tuchengzi Formation of Hebei Province, China, and *Paravipus* from the Tiouaren Formation of Niger) have been assigned to the Dromaeosauridae. A key question regarding the didactyl footprints preserved at the new German tracksite is whether they were also made by dromaeosaurids, or alternatively represent the first unambiguous fossil track record of the Troodontidae.

In the didactyl tracks from Obernkirchen, two characters visibly stand out: an angle of divarication between the digit III & IV impressions ranging from 21 to 36 degrees (n = 67), and a digit IV impression that is substantially shorter (up to 20 %) than that of digit III (n = 67). Published skeletal data on troodontid and dromaeosaurid pedal skeletons suggest that digit IV was slightly shorter than III in Troodontidae, but the two digits were of subequal length in Dromaeosauridae. Firsthand examination of specimens (*Sinovenator*, *Sinornithoides*, *Mei*, *Tianyuraptor*, and *Microraptor*) tends to confirm this suggestion. The fact that the Obernkirchen tracks show a digit IV impression that is even shorter than expected based on the skeletal data is related to the configuration of the metatarsus in Troodontidae (arctometatarsalian condition in Troodontidae vs. a more basal configuration in Dromaeosauridae). In the arctometatarsalian pes, phalanx IV-1 articulates with metatarsal IV slightly further proximally relative to metatarsus III than in non-arctometatarsalian theropods, reducing the apparent length of the digit IV impression. Furthermore, in arctometatarsalian pedes the distal end of metatarsal III extends farther distally between II and IV than in non-arctometatarsalians, adding to the apparent length of the digit III impression in tracks. The "rule of thumb" outlined above may not be applicable to (hypothetical) tracks of very basal forms though.

3-Dimensional Dinosaur Tracks: the hidden depths and geometry of vertebrate traces *[oral presentation]*

Phil **Manning**

School of Earth, Atmospheric and Environmental Sciences, The University of Manchester, Manchester, UK

Vertebrate tracks potentially offer unique sources of information, providing insight to past environments, gait and posture, locomotion and behavior. However, such information is potentially flawed when based on poorly recorded or incorrectly interpreted tracks. Laboratory-based track simulations have provided some insight to the complex 3-dimensional, subsurface failure associated with track formation. The recovery of subsurface tracklayers provides a quantitative approach to understanding subsurface track morphology relative to 'true' surface track features.

Subsurface track relief and geometry, recovered from laboratory simulations, have been shown to correlate with the magnitude and distribution of load acting on surface sediments, transmitting through and deforming subsequent layers. The distribution of load is a function of the kinematics of a step-cycle, foot morphology and the properties/prevailing conditions within a substrate at the time of track formation. The key factor controlling track morphology, surface or subsurface, is the moisture/density relationship prevailing in a substrate at the time of track formation.

Laboratory simulated tracks confirm that many fossil tracks/traces collected and described are transmitted features and do not represent 'true' surface tracks. Variation in the geometry/morphology of simulated tracks, relative to surface tracks, indicate that caution should be exercised when using fossil track/trackways to identify hip-height, speed, age, track-maker and population dynamics. Rheological conditions in soils directly control track preservation and the resulting assemblage. Therefore, using fossil vertebrate ichnocoenoses to diagnose specific ichnofacies is rejected, on the grounds that vertebrate tracks are not substrate-specific, but are a function of the prevailing lithofacies/rheology.

Track-maker identity is impossible to define in most cases beyond the familial level, suggesting there is little use in applying an osteologically-related binomial framework to track taxonomy. Vertebrate ichnotaxa should reflect morphological differences resulting from formational and preservational processes, not the affinity of alleged track-makers.

Formation, taphonomy, and preservation of vertebrate tracks

[oral presentation]

Daniel **Marty**

Office de la culture, Section d'archéologie et paléontologie, Paléontologie A16, Hôtel des Halles, Porrentruy, Switzerland

Vertebrate tracks are a palaeo-engineering test of a foot with the substrate at a given time in a given environment. After the foot impact, specific structures are apparent on the surface (true track, overall track, underprint) and others hidden within the substrate (undertrack, deep track). Depending on substrate properties and behaviour, a trackmaker may produce a wide range of track morphologies. Only when a foot is put in a perfect way into an ideal substrate, a true track may reveal details of the foot anatomy and therefore readily be identified as a true track, capable of yielding diagnostic (ichno-) taxonomic information about the track-maker.

The time period between track formation and burial affects the track preservation potential and degree of time-averaging of an ichnoassemblage. If a track is rapidly consolidated and covered up, it may be preserved as an unmodified true track, while (internal) overtracks may be formed simultaneously. Otherwise, it is likely affected by (mostly destructive) taphonomic processes, resulting in a modified true track or weathered track. Accretion and erosion may occur on many time-scales and in the fossil record, tracks undergo different stages of taphonomy and are at different stages within the diagenetic sequence of development.

On recent tidal-flats, microbial mats play a crucial role during and after track formation because they are ubiquitous and have particular properties compared to substrate without a microbial mat. They are strongly facies-specific and may – during periods of drought – quickly consolidate or lithify to resist trampling or heavy rainfall. Renewed and/or repeated growth may modify track leading to the formation of a modified true track and (internal) overtracks, which are frequently encountered amongst consolidated or (partially) lithified footprints. These recent processes can be inferred from fossil tracks and this is facilitated by analysing overlying and underlying layers (e.g., level-by-level excavation, serial sectioning of tracks).

To conclude, detailed sedimentological and taphonomical analyses of vertebrate tracks help understanding the substrate properties at the time of track formation, sediment consolidation history, and the palaeoenvironment and processes acting within. This is indispensable for their pertinent interpretation in terms of ichno-taxonomy, palaeoecology, and biomechanics.

Status quo of dinosaur track excavations on highway A16 (Canton Jura, NW Switzerland) with emphasis on documentation, research, and geoconservation *[oral presentation]*

Daniel **Marty,** Géraldine **Paratte,** Christel **Lovis,** Marielle **Cattin** & Wolfgang A. **Hug**

Office de la culture, Section d'archéologie et paléontologie, Paléontologie A16, Hôtel des Halles, Porrentruy, Switzerland

Since 2002, the Paléontologie A16 (www.pal-a16.ch) excavates dinosaur tracksites prior to the construction of highway A16 near Porrentruy (Canton Jura, NW Switzerland). Six tracksites with four Late Jurassic (Kimmeridgian, Reuchenette Formation) track-bearing intervals, deposited on tidal flats of the Jurassic carbonate platform, were identified on the future course of the highway. Three intervals are laminites, each with several (up to 20) superimposed track-bearing levels, systematically excavated and documented level-by-level.

To date, 58 ichnoassemblages (equalling 12,600 m²) with over 10,000 tracks including 250 sauropod trackways and 302 trackways of tridactyl bipedal dinosaurs (mainly left by theropods) were documented with standard ichnological and state-of-the-art 3D imaging technologies (laserscanning, close-range photogrammetry). Sauropod and tridactyl tracks both vary from very small to huge (10–120 cm for sauropods; 5–80 cm for tridactyl tracks). Different size classes and morphotypes are commonly associated on single ichnoassemblages. Trackways are up to 115 m long including different patterns and configurations (also along single trackways), and turning trackways. These rich and diverse dinosaur ichnoassemblages give important insights into the dinosaur fauna of a tidal-flat palaeoenvironment, dinosaur ichnotaxonomy, palaeoecology and biomechanics.

Moreover, the tracksites are recognized as an important part of Switzerland's natural heritage, and to date, two sites are protected by the construction of an additional highway bridge ("Combe Ronde") on the one hand, and underneath a viaduct ("Crât") on the other hand, while discussions concerning the construction of another bridge to make the "Sur Combe Ronde" site accessible to the public are still under way. "Béchat Bovais", with more than 4000 m² the largest site, will be protected by covering up, whereas "Tchâfouè" and "Bois de Sylleux" were partially destroyed and are today covered up by the highway.

Excavations will cease in 2011 but an evaluation phase is financed until 2018 encompassing (1) data (documentation & collection) processing; (2) compilation of the documentation in directories/catalogues and a data base; (3) fundamental scientific research and publication of results in scientific journals and monographs; and (4) a more far-reaching valorisation of the data by including it in projects with a broad research spectrum in collaboration with other institutions.

New dinosaur and pterosaur tracksites from the Late Jurassic of Portugal *[oral presentation]*

Octávio **Mateus**[1] & Jesper **Milàn**[2]

[1]*Universidade Nova de Lisboa, Faculdades de Ciências e Tecnologia- CICEGE & Museu da Lourinhã, Portugal*

[2]*Geomuseum Faxe, Østsjællands Museum, Denmark*

Portugal is rich on dinosaur remains (bones, eggs, and tracks) from Early Jurassic to Late Cretaceous ages, but mainly from the Late Jurassic, in which dozens of tracksites have been reported. Here we report new or poorly known track localities: 1) Five tracksites share the preservation substrate (marine carbonated limestone), age (Late Jurassic), geographic area (Leiria district of Portugal), kind of preservation (true tracks), and completeness (trackways of multiple individuals): (i) Praia dos Salgados includes eight trackways, mostly ornithopods and theropods, and one wide gauge sauropod, made in very soft sediment; some preserve the hallux impression. (ii) Serra de Mangues is mostly covered with vegetation but seems to include dozens of tracks comprising theropods, thyreophorans, ornithopods, and sauropods. (iii) Sobral da Lagoa (Pedreira do Rio Real) include six trackways but poorly preserved; (iv) Serra de Bouro that preserves four sauropod trackways in one single layer; (v) Pedrógão preserved, at least, one theropod trackway and several isolated tracks of theropods and ornithopods were found in different layers in the Early Oxfordian. 2) The locality in Praia de Porto das Barcas yielded natural casts of stegosaur tracks (including pes print with skin impression) and a very large sauropod pes print of about 1.2 m in length. 3) A new pterosaur tracksite was found in the Late Jurassic of Peralta, Lourinhã (Sobral Member, Lourinhã Fm.; Late Kimmeridgian/Early Tithonian). More than 220 manus and pes tracks have been collected in about five square meters, all ascribed to pterosaurs. The tracks were produced in a thin mud layer that has been covered by sand which preserved them as sandstone mould infill (natural casts). The manus of the largest specimens is 13 cm wide and 5.5 cm long and the pes measures 14.5 cm in length and 9 cm in width. This shows the occurrence of very large pterosaurs in the Late Jurassic. Other pterosaur tracksites in the Late Jurassic of Portugal are: Porto das Barcas (Lourinhã Municipality), South of Consolação (Peniche Municipality), and Zambujal de Baixo (Sesimbra Municipality).

Dinosaur faunal change: interpreting the track record from the Jurassic–Cretaceous transition in East Asia *[oral presentation]*

Masaki **Matsukawa**[1] & Martin G. **Lockley**[2]

[1]*Tokyo Gakugei University, Tokyo, Japan*

[2]*University of Colorado at Denver, Denver, USA*

Early Cretaceous dinosaur ichnofaunas in East Asia are dominated by slender-toed small theropod and ornithopod tracks. This dinosaur ichnofauna was established in East Asia after the Pangean split. As a result, Early Cretaceous dinosaur ichnofaunas from Asia exhibit a recognizable degree of provincialism.

In northeast China, Upper Jurassic to Lower Cretaceous strata can be divided into eight formations in ascending order, Haifanggou, Lanqi, Tuchengzi, Yixian, Jiufotang, Shahai, Fuxin and Sunjiawan. Dinosaur tracks occur in the Tuchengzi, Jiufotang and Fuxin formations. Theropod tracks predominated over ornithopods in the lower succession, but the situation reverses in the upper succession. This indicates that small theropods were the first to establish their ecological niches, whereas ornithopods established theirs later.

Body record from the Jehol Group shows the same pattern: the Yixian Formation produces many feathered theropod dinosaurs and early birds, but in the Jiufotung Formation, ornithopods predominated in the biota. This indicates that some ecological niche spaces were previously occupied by a more diverse group of theropods, ornithopods and ceratopsids in the fluvio-lacustrine ecosystems during Yixian time, but were occupied by ornithopods during Jiufotung time.

Dinosaur tooth records from the Shahai and Fuxin formation, however, are highly diverse and theropods dominated, suggesting an adaptive radiation of dinosaurs at that time. This contrasts with mutually exclusive theropod or ornithopod track assemblages in the "middle" Cretaceous of Korea.

That dinosaur faunal dominance shifted from theropods to ornithopods in northeast China is shown by time-averaging. This suggests a means of understanding dinosaur ecological development. In particular, many track records that have long-time spans are shown to be as useful as body fossil records for demonstrating such patterns.

Taking measure of geospatial technology: Innovations in close-range photogrammetry for 3D ichnology *[oral presentation]*

Neffra A. **Matthews**[1] & Brent H. **Breithaupt**[2]

[1]*Bureau of Land Management – National Operations Center, Denver, Colorado, USA*

[2]*Bureau of Land Management – Wyoming State Office, Cheyenne, Wyoming, USA*

In 1998, research on the footprints at the Red Gulch Dinosaur Tracksite (RGDT) in the Bighorn Basin of Wyoming began BLM's use of close-range photogrammetry for the documentation of vertebrate fossil sites. Decision to use the best science to capture the scientific values of this site led to one of the most thoroughly documented fossil tracksites in the world. During the early days of 3D photodocumentation at RGDT, the process was very labor intensive and could require as much as a week to get a final dataset for a single footprint. As documentation technology advanced, stereoscopic photographs provided a wealth of 3D data for interpretation and analyses. This not only increased the knowledge of unique, paleontological resources, but also provided a visual and quantifiable baseline to be used to evaluate changes that occur to the track-bearing surface. Today, close-range photogrammetry (CRP) has been used to document and interpret tracksites throughout the western United States. Following the model established at RGDT, cameras and photographers have taken to the air, using blimps, helicopters, and ladders to obtain the needed photographic perspectives. Individual tracks, trackways, and even entire tracksites have been documented using CRP around the world. Close-range photogrammetry has experienced a rapid technological evolution. Economic, high-resolution, digital cameras, increasing capabilities of computers, and advancements in the analytical software have simultaneously decreased the costs and increased the portability and usability of CRP. Now available are low and no cost solutions for successfully processing stereoscopic photography taken with 60 to 70 % overlap. Currently, the field photographer can receive almost immediate feedback on the success of image capture while doing CRP documentation. With the new software, the processing of close-range photogrammetric images is no longer confined to a few locations, thus reducing the limitations on generating, using, and sharing 3D data of ichnological features.

Observed changes in vertebrate ichnofaunas from the uppermost Jurassic/lowermost Cretaceous (Tithonian/Berriasian) to Lower Cretaceous (Albian) of western Canada *[oral presentation]*

Richard T. **McCrea**

Peace Region Palaeontology Research Centre, Tumbler Ridge, British Columbia, Canada

Western Canadian Mesozoic track sites span a range of time from the uppermost Jurassic (Tithonian) to the Upper Cretaceous (Maastrichtian). Fossil vertebrate footprints are found from almost every terrestrial formation in western Canada providing a relatively complete record of terrestrial vertebrate ichnofaunas through 75 million years of history.

In ascending order the composition of the ichnofaunas of four main track-bearing formations considered are the Mist Mountain (Tithonian/Berriasian), Gorman Creek (Valanginian), Gething (Aptian) and Gates (lower Albian) formations. The traces of many groups of vertebrates are represented through many formations and include those of dinosaurs, birds, turtles, crocodilians, pterosaurs, etc. The vertebrate body fossil record of the Mesozoic of western Canada is limited to the Upper Cretaceous with the main record concentrated in the Campanian and Maastrichtian making the ichnological record an indispensable resource for observations on terrestrial vertebrate faunal composition and changes.

Patterns of ichnofaunal change through time in western Canada are emerging, however some caution must be exercised as some ichnofaunal changes due to facies influences could be misinterpreted as temporal succession. The palaeoenvironments which preserve the vertebrate track record in many western Canadian formations are quite variable, even within single formations. Differences in the character and composition of the sedimentary deposits at different track site localities occurring at the same stratigraphic interval reflect lateral shifts in depositional environments which may have influenced the composition of the vertebrate ichnofaunas. For example, the composition of the vertebrate ichnofaunas from twenty-five different track sites in the Gates Formation (most sites occurring stratigraphically within a few metres below the #4 Coal Seam) show a correlation based on the nature of the track-bearing substrate: coarse-grained, low organic content substrate correlates to high diversity, biped-dominant ichnofaunas while fine-grained, heavy organic content substrate correlates to low diversity ichnofaunas which are quadruped-dominant (or exclusively quadruped in composition).

The hitch-hikers guide to the Late Jurassic and Early Cretaceous – Dinosaur tracks from the Swiss and French Jura Mountains in a sequence stratigraphic context *[oral presentation]*

Christian A. **Meyer**

Naturhistorisches Museum Basel, Basel, Switzerland

Since the first discovery of a megatracksite in the Late Jurassic (Late Kimmeridgian) in the northern Swiss Jura Mountains, numerous dinosaur tracksites have come to light. Bio- and lithostratigraphic correlations indicate different levels of Mid to Late Kimmeridgian age. Today we know of at least seven intervals with tracks and bones that span from the Oxfordian into the Berriasian in the Swiss and adjacent French Jura covering a surface of about 4000 km^2. Within these recurrent associations four different morphotypes of dinosaur tracks are present. Among those are small, medium-sized and large sauropods (wide- and narrow-gauge type) and theropods of different sizes classes. The fossil sites occur at the end of shallowing-upward cycles and are often found in barren micrites that show fenestrate fabric, birds-eyes and stromatolites indicating a tidal flat environment.

The recurrent association of sauropod and theropod footprints over a large area is consistent with the Vertebrate Ichnofacies concept. When seen in a larger palinspastic context, all those fossil sites occur at conspicuous locations. Contra the idea of megatracksites that are large continuous surfaces we can conclusively demonstrate that the occurrence of these recurrent tracksite complexes is controlled by ancient basement structures. When plotted on the subsurface Permian horst and graben structure it becomes evident that all track and bone sites lie above former horst structures. This shallow water to emergent areas is arranged in ESE–NNW direction and link the northeastern corner of the Massif Central with the southwest corner of the London Brabant massif. These travel corridors are open during short periods each 400,000 years and are linked to eccentric orbital cycles. This “Stargate” hypothesis explains repeated migration routes for “hitch-hiking” dinosaur travelling from Central France to Germany and Great Britain. Furthermore, it shows that these highlands were most of the time connected landmasses and not islands, which would have been too small to host large populations of dinosaurs.

Early Jurassic Tracks of the America Southwest: Paleoenvironments and the Animals that Loved Them *[oral presentation]*

Andrew R. C. **Milner**[1] & Martin G. **Lockley**[2]

[1]*St. George Dinosaur Discovery Site at Johnson Farm, St. George, Utah, USA*

[2]*Dept. of Geology, University of Colorado at Denver, Denver, Colorado, USA*

The position of the Triassic–Jurassic boundary in the American Southwest is disputed. Some place it within the lacustrine Whitmore Point Member of the Moenave Formation (lower Glen Canyon Group), while we place the entire member in the Early Jurassic (Hettangian) based on abundant, well-preserved trace and body fossils collected in southwestern Utah. A wide variety of dinosaur and other vertebrate behaviors, and sedimentary structures are preserved in the area of the St. George Dinosaur Discovery Site at Johnson Farm (SGDS) allowing for a thorough analysis.

Twenty-six track-bearing horizons have been recognized from the SGDS. These are typically dominated (in rank order of abundance) by *Grallator* (small theropod), *Batrachopus* (small crocodylomorph), and *Eubrontes* (large theropod) tracks. However, the "Main Track Layer" (MTL) is dominated by *Eubrontes*. Traces at the base of the MTL are preserved as natural casts in fine-grained, beach-deposited sandstone overlying a basal mudstone. This surface is covered by large and small mudcracks with some scoured surfaces. Most of the *Grallator* tracks occur on scoured surfaces or within larger *Eubrontes* tracks. A thick crust of dried mud over wet, soft mud biased MTL preservation because heavier *Eubrontes* trackmakers broke through this crust producing footprints in the soft mud below, whereas, lighter *Grallator* trackmakers rarely broke through and only made tracks when they stepped into freshly made *Eubrontes* tracks. Based on dominance of *Grallator* tracks at other horizons and the abundance of *Grallator*-type dinosaur swim tracks (*Characichnos*) preserved on off-shore MTL, *Grallator* trackmakers were likely more abundant on the on-shore MTL.

Younger rocks (Sinemurian-Pliensbachian) of the Kayenta and Navajo formations (middle-upper Glen Canyon Group) preserve vertebrate ichnofaunas, both different and very similar to those in the Moenave. Megatracksites on the very top of the Springdale Member and lower part of the "Silty Facies" of the Kayenta Formation were produced in braided river and lacustrine environments. Progression through the Kayenta Formation which transitions into erg deposits of the Navajo Formation, show evidence of semi-arid to extremely arid conditions and a corresponding change in vertebrate ichnofaunas is clear. The variation in track types and preservation are discussed in relationship to the types of facies present.

The Lower Cretaceous dinosaur movements through the lacustrine system of the Cameros Basin (Spain) written in their tracks *[oral presentation]*

Jose Joaquin **Moratalla**

Instituto Geológico y Minero de España (Museo Geominero), Madrid, Spain

The Cameros Basin -located about 300 km northeast from Madrid City- is of about 5,500 km^2 in extension that includes more than 100 catalogued Lower Cretaceous localities with dinosaur tracks. The temporal succession ranges from the Tithonian–Berriasian (Upper Jurassic-Lower Cretaceous) to the Aptian (Lower Cretaceous). This long episode took place during the second Mesozoic rifting phase of the Iberian Plate. The synrift infill (more than 10,000 m thick) consists of continental sediments with occasional marine influences distributed along five big episodes and alternating with fluvio-lacustrine (Tera, Urbión and Oliván Groups) and lacustrine environments (Oncala and Enciso Groups). Nevertheless, the track localities are mainly concentrated in the Oncala Group (Berriasian) and, largely, in the Enciso Group (Lower Aptian), both representing more than 90 % of the Cameros ichnocenosis.

The Cameros tracksites include dinosaur, pterosaur, crocodile, turtle, and bird-like tracks. However, dinosaur prints clearly dominate, representing 98 % of the Cameros ichnocenosis. Among those, theropod tracks are the most abundant (85 % of the track record), followed by ornithopods (about 12 %). The dinosaur track composition changes from the Berriasian to the Aptian: i.e., there is an increase in relative size of ornithopod tracks, an increase in the abundance of sauropod trackways during the Aptian, and there are some differences in general theropod footprint shape. The absolute domination of theropods suggests that these dinosaurs were significantly more active than others, a likely reflection of their searching-hunting behavior.

The orientation of the dinosaur trackways during the Berriasian was strongly influenced by the local paleogeographical landscape, interpreted as an alluvial plain distally connected with a playa-lake. The dinosaur tracksites are located throughout the alluvial plain facies, and the preferential orientation of the trackways was strongly influenced by the presence of that central lake. In contrast, the Aptian is represented by a wide and shallow lacustrine system connected with marine environments towards the SE and the NW. Thus, the Cameros lacustrine area became the only continental connection between two land masses, and the fluctuation of the shallow water level allowed dinosaurs to pass through the lake basin. As a consequence of these paleogeographic restrictions, the dinosaur trackways show a large-scaled bidirectional NE–SW preferential orientation.

Didactyl theropod dinosaur tracks from the Tiouraren Fm. near Azènak (Rep. Niger) *[poster presentation]*

Alexander **Mudroch**[1], Ute **Richter**[1], Ulrich **Joger**[2] & Ralf **Kosma**[2]

[1]*Initiative of Independent Palaeobiologists (IIPD.de), Hannover, Germany*

[2]*Staatliches Naturhistorisches Museum Braunschweig, Braunschweig, Germany*

In 2006, some dinosaur tracks were found in the continental red beds ("Continental Intercalaire") of the plains SW of Agadez near Azènak in the Republic of Niger. They were stratigraphically placed below or at the basis of the Tiouraren Formation (Late Jurassic) of the Irhazer Group. Age assignment for the Irhazer site is Middle to early Late Jurassic due to paleobiological data. Tracks were preserved in a 3–5 cm thick siltstone layer overlain by a dark-red mudstone (at least 30 cm thick). Seasonal fluvial erosion in an active wadi system exposed app. 50 m^2 of the siltstone layer's surface showing most of the tracks. They are preserved as pes impressions in the original track bearing strata with visible undertracks where the siltstone layer is lost due to weathering. Deep impressions with thick sediment bulges imply high water content of the unconsolidated sediment. All the 120 footprints of the main trackway are didactyl, lack heal pads, and show characteristic theropod pes features with two weight-bearing toes (digit III and IV). The main trackway area shows footprints in both directions – back and forth. Impressions in SW direction are often disturbed by impressions in NE direction. We recognized 5 different trackways made up of 10–30 alternating footprints with variable pace lengths (min. 80 cm, max. 150 cm) and values of around 180° for pace angulation. The deep pes impressions indicate a rather slow, cautious movement of the animals with changing velocities. Apart from the theropod trackways, 6 individual footprints of an unknown sauropod of medium size were found app. 300 m away from the main tracksite. Work on this remote site is a challenge and further scientific studies of the tracks are necessary.

A new taxon of didactyl theropod tracks from the Middle Jurassic of Gondwana *[oral presentation]*

Alexander **Mudroch**[1], Ute **Richter**[1], Ulrich **Joger**[2], Ralf **Kosma**[2], Oumarou **Idé**[3] & Abdoulaye **Maga**[3]

[1]*Initiative of Independent Palaeobiologists (IIPD.de), Hannover, Germany*

[2]*Naturhistorisches Museum Braunschweig, Braunschweig, Germany*

[3]*Intitut de Recherches en Sciences Humaines, Université Abdou Moumouni, Niamey, Niger*

A new dinosaur tracksite from Middle Jurassic sediments of the Irhazer Group in the plains of Agadez (Rep. Niger, Northwest Africa) revealed extraordinarily well preserved didactyl tracks of a digitigrade bipedal trackmaker. The distinct morphology of the pes imprints indicates a theropod trackmaker from the group of paravian maniraptorans. The early age and the morphological traits of the tracks allow for the description of the new ichnotaxon *Paravipus didactyloides*. A total of 120 tracks are assigned to 5 individual trackways. The medium sized tracks with an average footprint length of 27.5 cm and footprint width of 23.1 cm are deeply imprinted into the track bearing sandstone. A comparison with other didactyl tracks gives new insights into the foot morphology of bird-related theropods and contributes to their evolutionary history. *Paravipus* tracks provide evidence that digit II was modified (and not the result of pathology or injury), with only the proximal part of digit II involved in weight-bearing during locomotion. A comparison with the foot morphology of the African ostrich (*Struthio camelus*) shows that this might be an adaption to sustained running in a vast semi-desert. This peculiar foot morphology is an uncommon feature in tracks of Middle to Late Jurassic age. Overall features of *Paravipus* tracks imply an unknown Gondwanan member of the paravian clade Deinonychosauria as possible trackmaker, but there is no record of a medium-sized mid-Jurassic deinonychosaur from southern continents yet. The new ichnotaxon takes a unique position in the ichnological fossil record of Gondwana and the mid-Jurassic biota worldwide as it is the only convincing record of didactyl theropod tracks from Africa.

A new tetradactyl theropod ichnotaxon from the Upper Jurassic of Morocco *[poster presentation]*

Jaouad **Nouri[1]**, Mohamed **Boutakiout[1]**, Ignacio **Díaz-Martínez[2]** & Félix **Pérez-Lorente[2]**

[1]*Faculty of Sciences, University Mohamed V. Rabat-Agdal, Morocco / Geoparc M´Goun*

[2]*University of La Rioja, Logroño/La Rioja Palaeontological Heritage Foundation, Spain*

Since the discovery of the first footprint in 1937, approximately 40 sites with more than 1500 footprints have been located and two new ichnotaxa have been identified in the Iouaridène syncline (Morocco, Iouaridène Formation). Its sediments are Oxfordian–Kimmeridgian in age and comprise red silificied layers with ripple marks and mud cracks.

One of us, Nouri, defined the theropod ichnotaxon "*Eutynichnium atlasipodus*" in 2007. It is a long (37–50 cm) tetradactyl footprint with a well developed digit I which is located perpendicular to the footprint-axis. Metatarsal impressions are absent and two digital pads are sometimes visible in digit I. It is mesaxonic, longer than wide, and with thin distal claw traces. In well preserved specimens, the phalangeal formula 2-2-3-4 for digits I, II, III and IV respectively is discernible. The trackway is very narrow with a long pace length (106–166 cm).

Recently, six new trackways with the same features have been found in different parts of the syncline. This fact supports that it is a new ichnotaxon and must be defined formally.

Normally, the bipedal dinosaurs (excluding prosauropods) are functional tridactyls or, in a few cases, didactyls. Tetradactyl footprints are normally found close to abnormal stance impressions, e.g. as tail and metatarsal marks. Such abnormal stance impressions are absent in "*E. atlasipodus*" trackways.

This study provides more information about the theropod ichnocenosis of the Iouaridène syncline, previously composed of *Megalosauripus* sp, *Carmelopodus* sp., and a giant indeterminate theropod footprint.

Prosauropods, some ornithischians, and some theropods (Therizinosauroidea) have a long digit I. Although the taxonomic affinity of these tracks cannot be determined with confidence, they can preliminary be regarded as theropod footprints.

Dinosaur tracks in an ancient lower deltaic plain-interdistributary bay *[poster presentation]*

Laura **Piñuela**[1,2], José Carlos **García-Ramos**[1] & José Ignacio **Ruiz-Omeñaca**[1,2]

[1]*Museo del Jurásico de Asturias (MUJA), Colunga, Spain*

[2]*University of Oviedo, Oviedo, Asturias, Spain*

The outcrops of Upper Jurassic rocks on the sea cliffs between Gijón and Ribadesella localities (Asturias, N Spain) show many beds with dinosaur footprints. This Asturian coastal section, about 60 km in length, is known as "The Dinosaur Coast", mainly due to its abundant and well preserved tracksites. Sauropod tracks are by far the most common ichnites in this area, although theropod, ornithopod, and stegosaur tracks are also frequent. Other reptile prints include turtles, crocodiles, pterosaurs, and lizards.

The dinosaur footprints of the Tazones lighthouse tracksite are shown on the top of a muddy sandstone bed (25º seaward-dipping). Much of them are sandstone casts disposed in several trackways in opposite directions showing a preferred orientation in a range of 50º.

In many cases, the tridactyl tracks (most of them theropods) preserve the hallux and metatarsal traces. When the latter is not preserved, the "heel" is wide and deep. The digit impressions show often anomalous shapes and high divarication angles owing to soft substrate consistency. Moreover, a winding trace about 10 cm wide is preserved in the same layer and is interpreted as a dinosaur tail drag, unusual in the fossil record. Due to these observations, we think the dinosaurs were walking on an unstable soft ground. For this reason they lowered the point of gravity, and crouched down, which in turn led to the formation of the metatarsal and tail traces.

Frequent invertebrate ichnofossils, such as *Arenicolites*, predate and postdate the reptile tracks.

The dinosaurs walked on soft and intensely bioturbated muddy sands of a very shallow, subaqueous, interdistributary bay and the tracks were filled by clean sands (quartzose sand without clay minerals) from a crevasse-splay deposit.

A new track horizon in the old Obernkirchen Sandstone quarry of the Bückeberg (Lower Saxony, Germany) *[poster presentation]*

Maik **Raddatz**[1], Gerhard H. **Bachmann**[1] & Annette **Richter**[2]

[1]*Institute of Geosciences, Martin-Luther University Halle-Wittenberg, Germany*

[2]*Hannover State Museum, Hannover, Germany*

The Bückeberg Mountain, 60 km W of Hannover, consists mainly of the Lower Cretaceous Bückeberg Formation (formerly known as "North German Wealden") subdivided into the Obernkirchen and the Osterwald Member. Two quarries expose the Obernkirchen Sandstone that consists of silty, fine to middle grained, massive, well-bedded sandstones. Symmetrical ripple marks, root horizons, coal layers, terrestrial vertebrate and plant fossils, brackish bivalves (Neomiodontids, Unionids), and ostracods (*Cypridea*) are frequently found. Two track horizons made by ornithopod and theropod dinosaurs, here named I and II, have already been described. Here we present a new 3rd track horizon (named III) covering most of the upper quarry floor in a fine-grained sandstone bed. The new track horizon is dominated by juvenile and adult ornithopods (*Iguanodontipus* sp.). Some tracks indicate quadrupedal locomotion (manus and pes imprints). The pes imprints are tridactyl and show hoof marks. The manus imprints are of oval shape. Large calamite impressions are also preserved in the new track horizon. A correlation with the recently discovered new track site in the nearby active Obernkirchen Sandstone quarry is not possible because of rapid facies changes. The Obernkirchen Sandstone can be interpreted as barrier sands, deposited in the Lower Saxon Basin during the Lower Berriasian. The subaerially exposed barrier system was visited by dinosaurs (*Stenopelix valdensis*, Iguanodontids, theropods), crocodiles, and pterosaurs. Plesiosaurs, turtles, ganoid fishes and the *Hybodus* shark inhabited the lagoon behind the barrier.

The 'Wealden' collection of the Göttingen University

[poster presentation]

Mike **Reich**[1,2], Annina **Böhme**[1,2], Jahn J. **Hornung**[2] & Hans-Volker **Karl**[2,3]

[1] *Geoscience Museum of the University of Göttingen, Göttingen, Germany*

[2] *Department of Geobiology, Geoscience Centre of the University of Göttingen, Göttingen, Germany*

[3] *Thuringian State Office for the Preservation of Hist. Monuments and Archaeology, Weimar, Germany*

The Geoscientific Collections of the University of Göttingen, comprising over 4.5 million objects and series, can be traced back almost 300 years. The Georgia Augusta houses the fourth largest geoscientific collection in Germany, which is also the largest German geoscientific university collection.

The earliest collection work in the German 'Wealden' successions (Berriasian, Early Cretaceous) of present-day Lower Saxony and Westphalia was done by Johann Friedrich Blumenbach (1752–1840) nearly 200 years ago. The 'Wealden' collection underwent a considerable expansion through geological mapping under supervision of Adolf von Koenen (1837–1915), as well as with the long-term loan of the geological collection of the Gymnasium Bückeburg (Adolfinum; including the collection of Max Ballerstedt, 1857–1945), in 1976 as well as a smaller collection from the Museum Bückeburg in 2010. The Geoscientific Museum of the University of Göttingen currently holds over 6000 individual objects and series from the German 'Wealden'. These rocks and fossils originate from app. 60 single localities: Rehburg Mountains (6 localities), Bückeberg area (16 localities), Harrl hill (3 localities), Deister Mountain(s) (15 localities), Westphalia (8 localities) etc. Over a time period of more than 200 years, over fifty persons (professional and amateur palaeontologists and geologists) provided this material, most of which was collected in the second half of the 19th and the first half of the 20th century. In addition, numerous larger fossil and rock collections were donated to, or purchased by the University of Göttingen. Among the most significant personalities were Friedrich Ernst Witte (1803–1872), Friedrich Wilhelm Burchard (1804–1887), Carl A. L. Seebach (1839–1880), Carl E. F. Struckmann (1833–1898), Heinrich F. W. Grabbe (1858–18??), Erich Meyer (1874–1915), Erich Harbort (1879–1929), Karl Andrée (1880–1959) and many others. Part of this material provided the basis for research on the 'Wealden' fauna and flora (e.g. by v. Meyer 1841, 1857, 1859; Schenk 1871; v. Seebach 1871; Grabbe 1883, 1884; Koken 1883, 1886, 1887, 1896; Branco 1885; Ballerstedt 1905, 1914, 1921, 1922; Michael 1936; Huckriede 1967; Schmidt 1969; Schultze 1970 etc.).

The last comprehensive reviews on the German 'Wealden' were published in the late 19th century (v. Seebach 1871, Struckmann 1880); since then, only publications and monographs on selected animal or plant groups have been written. A modern overview on the 'Wealden' fauna and flora of northern Germany is currently being prepared by members of the Göttingen University, in cooperation with the Hannover State Museum – with further contributions from various palaeontologists and geologists.

Obernkirchen – an old becomes a new dinotrack locality

[oral presentation]

Annette **Richter**[1], Torsten **van der Lubbe**[1], Annina **Böhme**[2,3] & Uwe **Stratmann**[1]

[1]*Hannover State Museum, Hannover, Germany*

[2]*Geoscience Museum of the University of Göttingen, Göttingen, Germany*

[3]*Department of Geobiology, Geoscience Centre of the University of Göttingen, Göttingen, Germany*

Well known since the beginnings of true palaeontology, the Berriasian "Obernkirchener Sandsteinbrüche GmbH" (Obernkirchen Sandstone Quarries, OSQ) have yielded large amounts of quality workstones as well as fossils. According to modern sedimentology, each sandstone bank represents a series of several tempestites which carried fine-grained quartz sand from a transgressive barrier island system during regular events (hurricane-like storms) into a palaeo-lagoon. Almost no tidal influence and a generally low water level allowed dinosaurs to migrate through the lagoons, leaving trackways which must have been stabilised by microbial mats and then filled by the sand.

Typical isolated natural casts (hypichnia) have been found and published since the end of the 19th century. In contrast, most of the body fossils were lost to typical secondary solution during diagenesis or preserved solely as hollow cavities albeit comprising important fossils (small dinosaur *Stenopelix,* crocodile *Goniopholis,* etc.).

Until the millennium, almost no attention was paid to the Obernkirchen dinosaur tracks because they were considered to be "known". Therefore, new finds from the OSQ in 2008 opened up that field again, especially as they represent imprints (epichnia) on large horizontal surfaces with long, well-preserved trackways, and especially many theropod tracks on a spot called "chicken yard" for its extremely high density of tracks (dinoturbation). The historical *Bueckeburgichnus,* described as a theropod track including hallux impression, again known solely by isolated hypichnia, will have to be discussed again, covering sedimentological and quantitative aspects available to modern ichnology. Literally speaking, no trace of *Bueckeburgichnus* has turned up during three field seasons at the OSQ. Instead, the (ichno-) fossil record of 400 m^2 "chicken-yard" comprises more than 1500 small- to moderately large-sized tridactyl theropod tracks of variable outline – still awaiting description and careful reconsideration of the often discussed ichnotaxon *Megalosauripus.* The surprising discovery of small didactyl tracks added to the wealth of this new tracksite.

Re-interpretation of the dinosaur track-maker identities and tracksite scenario at Lark Quarry, of the mid-Cretaceous (late Albian–Cenomanian) Winton Formation, central-western Queens-land, Australia *[oral presentation]*

Anthony **Romilio** & Steven W. **Salisbury**

School of Biological Sciences, The University of Queensland, Brisbane, Australia

A re-examination of the track morphology and sedimentary structures does not appear to support the original interpretation of the Lark Quarry tracksite presser-ving the movements of an *Allosaurus*-sized theropod in pursuit of prey, the mixed herding of small-bodied theropod and ornithopod dinosaurs, or the occurrence of a stampede. Comparative and multivariate data supports the reinterpretation of the large track-maker as an ornithopod, with the tracks assigned to *Amblydactylus* cf. *A. gethingi*. Three-dimensional track morphology shows that the small, purportedly theropod prints assigned to *Skartopus australis* are preservational variants of the ornithopod tracks assigned to *Wintonopus latomorum*. These re-evaluations remove any evidence for the presence of theropods in the Lark Quarry ichnofauna. The presence of asymmetrical ripples, vegetation drag marks, small dinosaur swimming tracks, and a footprint of a small dinosaur standing in flowing water indicate that the tracks were preserved in a fluvial environment. Superposition of tracks and other sedimentary structures suggests that the *Amblydactylus* cf. *A. gethingi* track-maker moved across the ancient Lark Quarry site earlier than the *Wintonopus* trackmakers, such that the two trackmaker species probably did not interact.

A large tridactyl trackway from the Late Jurassic–Early Cretaceous of Yemen *[oral presentation]*

Anne S. **Schulp**[1,2], Mohammed **Al-Wosabi**[3] & Nancy J. **Stevens**[4]

[1]*Natuurhistorisch Museum Maastricht, Maastricht, The Netherlands*

[2]*Faculty of Earth and Life Sciences, Vrije Universiteit Amsterdam, The Netherlands*

[3]*Department of Geology, Sana'a University, Sana'a, Republic of Yemen*

[4]*Department of Biomedical Sciences, College of Osteopathic Medicine, Ohio University, Athens, Ohio, USA*

One of the best preserved trackways at the Serwah tracksite (near Madar, Arhab area, Republic of Yemen) was made by a large, bipedal tridactyl dinosaur. In our initial description, we identified the trackmaker as an ornithopod, based on criteria including the track length/width ratio, u-shaped outline of digits with bluntly rounded tips, the digit III width/length ratio (~0.5), absence of curvature or hallucal impression on digits, divarication angle of digit II-IV (~65°) and the smooth, convex margin of the rear edge of the track.

Recent work by Anthony Romilio and Steven Salisbury on the mistaken identity of an ornithopod trackway in Australia prompted us to have a second look at our previous identification. Romilio and Salisbury applied a more detailed, quantitative analysis, building on previous work by Moratalla et al. Following the same approach, we can now even more confidently assign the trackways at the Serwah site to ornithopods based on a larger set of quantitative criteria.

This conclusion is of additional interest and importance considering the age of the trackway. The material is currently dated at Late Jurassic (or earliest Early Cretaceous at most) based on a foraminiferal assemblage. The relatively large size makes it an unusually early appearance of a very large ornithopod in the fossil record. One earlier report on a similarly large ornithopod track of similar age from Portugal leaves this occurrence a rare additional piece of evidence hinting at the appearance of large ornithopods at this early point time.

Ichnological implications of structural variations in the paravian foot *[oral presentation]*

Corwin **Sullivan**[1], Torsten **van der Lubbe**[2] & Xing **Xu**[1]

[1]*IVPP, Chinese Academy of Sciences, Beijing, Peoples Republic of China*

[2]*Hannover State Museum, Hannover, Germany*

The vast majority of non-avian theropod dinosaur tracks are characteristically tridactyl. However, it is clear that at least some members of the theropod clade Deinonychosauria, closely related to birds and containing the troodontids and dromaeosaurids, would have left essentially didactyl tracks because specialisation of pedal digit II diminished its utility in terrestrial locomotion. Didactyl deinonychosaur tracks, including a recently discovered sample in Berriasian strata near Obernkirchen, Germany, are indeed known in the palaeoichnological record. Among the most fundamental problems involved in identifying likely trackmakers for didactyl footprints is that of determining which members of Paraves, the clade including the deinonychosaurian and avian lineages, would have engaged in didactyl locomotion. The classic 'raptorial' specialisation of digit II in deinonychosaurs actually represents a suite of modifications, including an enlarged ungual and a proximal heel on phalanx II-2, that do not always co-occur. Facultative didactyly probably required only one key feature: elaboration of the distal articular surface of phalanx II-1 to allow hyperextension of the more distal phalanges. Obligate didactyly, by contrast, would have been present only if the ungual was greatly elongated and/or (during normal terrestrial locomotion) permanently plantarflexed on the penultimate phalanx during normal terrestrial locomotion, as in derived troodontids and dromaeosaurids. Didactyl paravian tracks can sometimes be difficult to distinguish from tridactyl tracks in which the impression of digit II is simply poorly preserved. However, a consistent feature of well-preserved genuine didactyl tracks is the presence of a sub- to semi-circular impression positioned more or less posteromedial to the proximal pad of digit III, probably representing a pad associated with the distal part of phalanx II-1. Known didactyl paravian tracks also show low track-length to width ratios, narrow trackway widths, and very low pace angulation values.

New titanosaur trackways from southern Pyrenees: Orcau-2 Locality (Late Cretaceous) revisited *[poster presentation]*

Bernat **Vila**[1], Jorge Joaquin **Moratalla**[2], Vanda faria dos **Santos**[3,4], Rodrigo **Gaete**[5] & Angel **Galobart**[1]

[1]*Institut Català de Paleontologia, Sabadell, Spain*

[2]*Instituto Geológico y Minero de España (Museo Geominero), Madrid, Spain*

[3]*Museu Nacional de História Natural (Mineralogia e Geologia), Lisboa, Portugal*

[4]*Centro de Geofísica da Universidade de Coimbra, Coimbra, Portugal*

[5]*Museu de la Conca Dellà, Isona i Conca Dellà, Spain*

Titanosaurs are a very diverse group within Sauropoda whose fossil remains, including body fossils, ichnites and oological evidence, have been reported worldwide. The remaining localities with tracks originally attributed to sauropods from the latest Cretaceous of Europe, except for the large tracksites of Fumanya (Southern Pyrenees, NE Iberian Peninsula), exhibit equivocal characteristics and none of them preserve complete trackways. The Orcau-2 locality (Early Maastrichtian, Tremp basin, Pyrenees) was originally reported by Llompart and colleagues in 1984. Two distinct ichnogenera, *Orcauichnites garumniensis* and *Ornithopodichnites magna*, were described and attributed to ornithopods. The third and most abundant morphotype was assigned to sauropods. In 2004, a reassessment of the site revealed at least three new sauropod trackways and several isolated tracks of sauropod affinity. The trackways are wide-gauged and exhibit an alternating sequence of small and rounded to crescent-like manus tracks and large, oval-shaped pes tracks. The trackways are assigned to titanosaurs based on the clear wide-gauge character, the heteropody ratio and the manus-pes distance. In addition, some of the isolated tracks exhibit an U-shaped manus morphology lacking the digit I impression and four claw marks in the pes tracks, which support the titanosaur attribution. Finally, as pointed out by Lockley & Meyer (2000), the state of preservation and the intense dinoturbation observed in all locations prevent the reliable identification of the previously named ornithopod ichnogenera. Apart from the ichnological interest, the discovery of new titanosaur tracks and trackways in the south Pyrenean basins is significant in terms of regional palaeobiogeography of the ancient coastal areas (mud flat and lagoon environments).

Dinosaur tracks in the Middle Jurassic Bemaraha Formation of Madagascar: a history of their discovery and future research perspectives *[oral presentation]*

Alexander **Wagensommer**[1], Marianna **Latiano**[1] & Simone **D'Orazi Porchetti**[1]

[1]*GRID (Gruppo di Ricerca sulle Impronte di Dinosauro), San Giovanni Rotondo, Italy*

In 2005, dinosaur tracks were discovered in Middle Jurassic intertidal to supratidal limestones of the Bemaraha Formation in Western Madagascar. This discovery, a "by-product" of an Italian–Malagasy speleological expedition to the Tsingy de Bemaraha National Park, was quite unexpected because no dinosaur tracks had ever been reported from Madagascar and because no fossils of other terrestrial organisms are known from the Bemaraha Formation, which otherwise yields a quite abundant and diverse marine invertebrate fauna. A first study of the Bemaraha dinosaur tracks took place in 2007. It was realized that the tracks are both abundant and well preserved. The discovery of a second tracksite, a few hundreds of meters from the first one and on the same stratigraphic level, gave a first hint at a greater lateral extension of the track-bearing surface than previously suspected. Integrating field data with satellite images and topographic maps, a prediction was made as to where the track-bearing surface could be expected to crop out again. A new field campaign in 2009 verified part of this prediction. At present, ten individual tracksites have been recognized on the Main Track-bearing Sequence (MTS), yielding several hundred tracks and covering an area of more than two square kilometers, but the total extension of the MTS is expected to be much larger, in the order of tens or even hundreds of square kilometers. The ichnofauna is dominated by mid-sized theropod tracks, with a few sauropod tracks (about 1 % of total tracks). Future research will aim at locating new tracksites, understanding their stratigraphic, paleogeographic and paleoenvironmental context, and ichnotaxonomy.

Stegosaur swimming tracks *[oral presentation]*

Martin A. **Whyte** & Mike **Romano**

Department of Geography, University of Sheffield, Sheffield, United Kingdom

The ichnogenus *Deltapodus* was first described from the early Middle Jurassic (Aalenian) of the Cleveland Basin of Yorkshire, UK and has now been recorded from other localities in Portugal, Spain, United States and possibly Morocco and from ages ranging up into the Upper Jurassic. Evidence from the ichnogeneric type horizon reveals a distinctive type of swimming track and trackway associated with the walking tracks of *Deltapodus*. The morphology of the prints shows that both track types were made by the same animal in that the numbers of digit imprints and their separation, as well as the width of the trackways are common to both. *Deltapodus* is interpreted as having been made by a stegosaur and the associated footprints thus show that stegosaurs could swim. The Middle Jurassic sequence of Yorkshire was deposited in a paralic alluvial plain and the ability of stegosaurs to cross river channels and other water bodies was essential for their success in this environment. It also has significant implications for their dispersal.

The Lower Cretaceous dinosaur tracksite in Münchehagen, Germany – Track record, preservation, and potential

[oral presentation]

Oliver **Wings**

Dinosaurier-Park Münchehagen, Rehburg-Loccum, Germany

Lower Cretaceous sandstones of Lower Saxony in northern Germany yield abundant fossil dinosaur tracks. Currently, the two most productive sites are the Obernkirchener Sandsteinbrüche GmbH quarry in Obernkirchen and the Wesling GmbH quarry in Münchehagen. Adjacent to the active quarry in Münchehagen, situated approximately 50 km west of Hannover, there are two former track-bearing quarries: the Stadtländer quarry and the natural monument "Naturdenkmal Saurierfährten" in the Dinosaurier-Park Münchehagen. The latter is well-known as the only locality with Lower Cretaceous sauropod trackways in Germany.

The Berriasian sediments in all three quarries belong to the Bückeberg Formation, Obernkirchen Folge, Hauptsandstein, 1–5 m above the Hauptflöz coal seam. Dinosaur tracks have been found on at least five different horizons in these quarries. Tridactyl trackways are very abundant in the Wesling quarry, and more than 30 trackways have been recorded in the last eight years. Most common is *Iguanodontipus* known from at least 3 different size stages, including the longest *Iguanodontipus* trackway world-wide with 59 pes and 6 manus imprints which was exposed in 2005. *Megalosauripus* as well as at least two gracile theropod ichnospecies have been found.

Most horizons show only mediocre track preservation as they represent either undertracks or early sediment solidification probably caused by biomats. However, one trackway layer, about 2 m above the Hauptflöz, is a fine-grained mudstone/siltstone which superbly preserved abundant tridactyl tracks as well as ripple marks in an approximately NE–SW-oriented, 10–20 m wide band. Long trackways of slow-walking medium-sized ornithopods (*Iguanodontipus*) as well as fast-moving small and large theropods have been documented. Lateral to this band, isolated small theropod tracks are preserved. Current excavation is focussed on tracks and natural casts from this horizon. The Wesling quarry has an unbroken high potential for wide-ranging trackways and for new ichnotaxa including smaller vertebrates. The ongoing co-operation between the Wesling quarry company, the Dinosaurier-Park, and the Hannover State Museum secures future excavation.

Phylogenetic relationships among basal paravian theropods

[oral presentation]

Xing **Xu** & Corwin **Sullivan**

IVPP, Chinese Academy of Sciences, Beijing, Peoples Republic of China

Phylogeny is the basis for evolutionary reconstruction. A robust phylogenetic hypothesis is a key prerequisite for an accurate reconstruction of the evolutionary history of the theropod-bird transition. Because of the large number of reversals and convergences in coelurosaurian evolution, basal members of maniraptoran subgroups have a particularly important role in reconstructing maniraptoran phylogeny. Recent discoveries of basal oviraptorosaurs, basal avialans, basal dromaeosaurids, and basal troodontids provide significant new information on paravian phylogeny. Our phylogenetic analysis incorporating data from these new discoveries removes the Archaeopterygidae from the Avialae and places it at the base of the Deinonychosauria, which challenges the long-held opinion that the iconic and historically important *Archaeopteryx* represents a pivotal taxon for understanding the transition to birds. Rather, *Archaeopteryx* offers important information about the early evolution of deinonychosaurs, and its placement at the base of this group is one indication that the primitive paravian condition may have been more 'bird-like' than has previously been appreciated. This new paravian phylogeny also reveals an interesting divergent pattern at the base of the Paraves: basal birds probably retained the akinetic skull and herbivorous diet of their ancestral maniraptoran relatives, whereas deinonychosaurs evolved a more kinetic skull and a carnivorous diet. The highly raptorial second pedal digit seen in many deinonychosaurs is probably among the modifications associated with this evolutionary trend.

Part II: Excursion Guides & Classic 'German Wealden' Localities and Collections

---

Excursion Guides A-C: *Introduction*

Excursion Guide A1: *Obernkirchen*
Excursion Guide A2: *Harrl hill*

Excursion Guide B1: *Münchehagen*
Excursion Guide B2: *Wölpinghausen*

Excursion Guide C1: *Göttingen Geoscience Museum*
Excursion Guide C2: *Göttingen Geopark*

Excursion Guides A-C: **The 'German Wealden' and the Obernkirchen Sandstone – an Introduction**

Jahn J. **Hornung**[1*], Annina **Böhme**[1,3] & Mike **Reich**[1,2*]

[1]*Department of Geobiology, Geoscience Centre of the University of Göttingen, Göttingen, Germany*

[2]*Geoscience Museum of the University of Göttingen, Göttingen, Germany*

[3]*Hannover State Museum, Hannover, Germany*

[*]*corresponding authors:* jhornun@gwdg.de & mreich@gwdg.de

The so-called 'German Wealden' succession in northwestern Germany has benefited the region with important resources for centuries. The high quality working and dressing stones of the Obernkirchen Sandstone were valued in uncounted buildings across Europe and the world (Graupner 1977; Broschinski 2004), the quartzose sandstone were used as raw material for the production of glass (Krumsiek 1981), and the thin intercalated coals were mined from medieval times up to the 1960ies (Graupner 1980). In modern times, the bituminous shales became economically interesting as a hydrocarbon play (Berner et al. 2010; Berner 2011), and – last but not least – the dinosaur tracks boosted the geotouristical potential of the region on a grand scale.

The excursions described in this field-guide will reach in the area W and SW of Hannover (Fig. 1). In order to set the stage for the more detailed outcrop descriptions below, we provide here a short introduction into the terminology, stratigraphy, palaeogeography, and palaeoclimatology of this Early Cretaceous treasure trove. However, it has to be kept in mind that many aspects are not yet studied in depth and there are many more questions to solve. For a more extensive introduction, overview of dinosaur track localities throughout the formation, and additional references please refer to Hornung, Böhme et al. (2012).

What is the 'German Wealden' ?

The term 'German Wealden' (i.e. here the 'northwest German Wealden') is used for an informal stratigraphic concept, to describe a succession of continental, predominantly siliciclastic deposits of earliest Cretaceous age in northwestern Germany. It is in use since the early 19th century (Hoffmann 1830) and was coined following the observation that lithofacies and fossil content of this succession was quite similar to the Early Cretaceous sediments in southeastern England known as 'Wealden beds'.

Refined stratigraphic work has since shown that the 'German Wealden' in fact is mid-Berriasian to early Valanginian in age (e.g. Kemper 1973; Casey et al. 1975), while the English Wealden Supergroup ranges from the late Berriasian through lower Aptian. Therefore the 'German Wealden' correlates chronostratigraphically more tightly with the English Purbeck Limestone Group (Allen & Wimbledon 1991).

Allen (1955) restricted the use of the term 'Wealden' to the English deposits and proposed 'Wealden facies' for successions of similar age and genesis across western and central Europe. 'German Wealden' became therefore obsolete as a formal stratigraphic term and was superseded by the Bückeberg Formation (Casey et al. 1975). It is further used to characterize a Berriasian, limnic to brackish, continental facies complex exposed in northwestern Germany. However, Wolburg (1949) introduced a sixfold lithostratigraphical subdivision (Wealden 1 to 6) which is still in use in recent works.

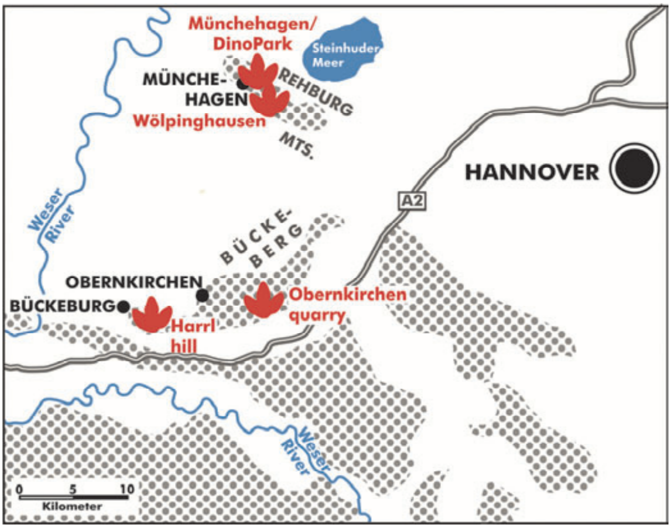


Fig. 1 Location of the outcrops described in this field-guide. Mountainous areas are shaded. A2: Federal highway BAB2.

Stratigraphy

The Bückeberg Formation (Fig. 2) is covered by younger strata across most of its extend. The most important outcrops are located in southern Lower Saxony in mountainous areas between Hannover in the E and the River Weser in the W and S. Smaller exposures exist also in North-Rhine Westphalia.

The Bückeberg Formation encompasses two members, the lower Obernkirchen Member (Wealden 1 to 4) and the upper Osterwald Member (Wealden 5 and 6). In the depocentre of the formation it consists mainly of up to 500–700 m of clay-stones and black-shales with rarely intercalated sideritic carbonates and coquinas. Coarser-grained (sandy) marginal sedimentary bodies prograded from the margins of the basin especially along its southern and eastern fringes (Kemper 1973), including the dinosaur track-bearing Obernkirchen Sandstone.

The predominantly limnic origin of this formation hampers an idle correlation with the marine Early Cretaceous and its biostratigraphy is based upon ostracods (e.g. Martin 1940; Wolburg 1949, 1959), charophytes (Schudack 1996), and palyno-morphs (e.g. Dörhöfer 1977; Strauss et al. 1993; Pelzer 1998).

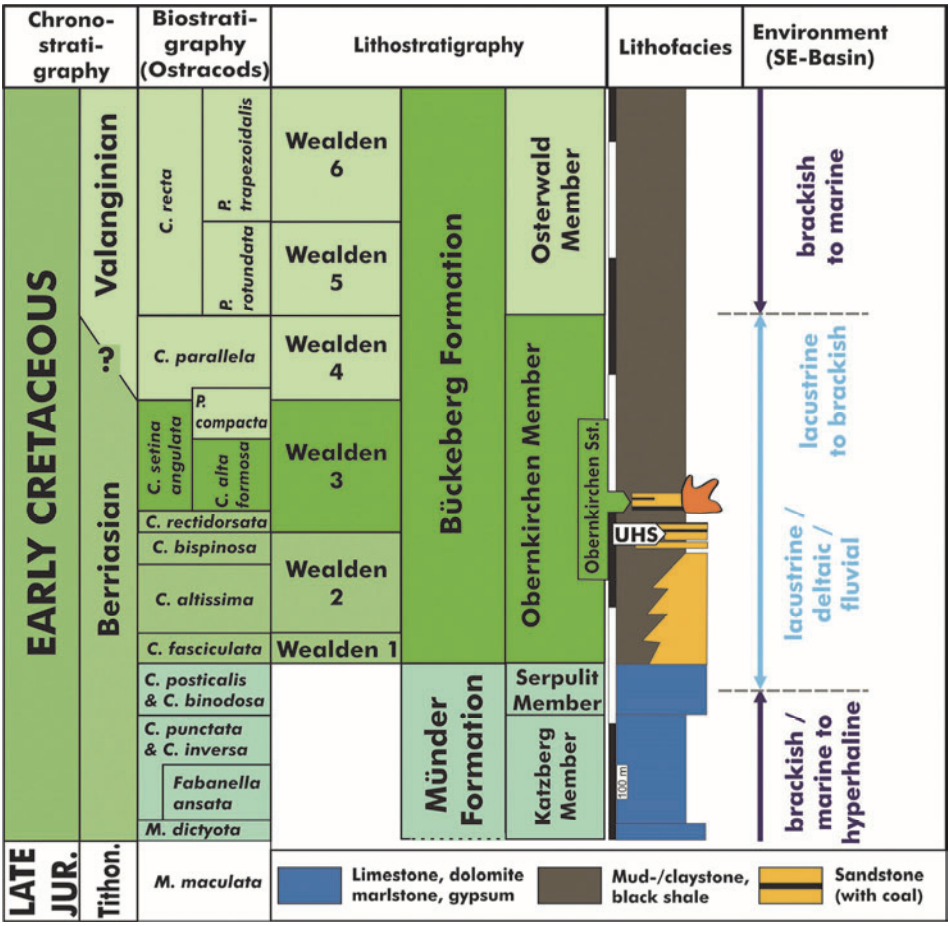


Fig. 2 Stratigraphy of the Berriasian and early Valanginian in the southeastern Lower Saxony Basin. UHS = 'Unterer Hauptsandstein' (lower main sandstone); Ostracods: *C.* = *Cypridea*, *M.* = *Macrodentina*, *P.* = *Pachycytheridea* (after Kemper 1973; Strauss et al. 1993; Elstner & Mutterlose 1996; Gramann et al. 1997; Mutterlose 1997a, 2000, modified).

The Bückeberg Formation overlies the Münder Formation, which was correlated in the classic literature with the English Purbeck and considered Late Jurassic in age. However, the current concept (Strauss et al. 1993; Elstner & Mutterlose 1996; Hoedemaeker & Herngreen 2003) indicates the Jurassic/Cretaceous boundary within the Münder Formation, the upper part of which has been deposited during the early Berriasian. The Berriasian/Valanginian boundary is not well defined in the continental succession, but is considered at or near the boundary between the Obernkirchen and Osterwald Members. The Bückeberg Formation is concordantly overlain by Valanginian marine deposits (*Platylenticeras* Beds; Mutterlose 1997a).

The deposition of the Bückeberg Formation is modeled to have lasted about 3.4 Myr (Berner 2011). Depending on the placement of the Berriasian/Valanginian boundary (140.2 ± 3.0 Ma; Ogg et al. 2008) at the base of the Osterwald Member or alternatively at the base of Wealden 4, the absolute age of the Bückeberg Formation is assumed to ~142.0–138.6 (± 3.0) Ma, or ~142.4–139.0 (± 3.0) Ma, respectively.

The dinosaur tracks occur in the Obernkirchen Sandstone, a thin marginal successsion. Typically it consists of thin- to thick-bedded, structureless, horizontally or cross-stratified, quartzose sandstone, interbedded with thin layers of clay- to siltstone, and coal seams. There are some inconsistencies and ambiguities in the use of this term as a lithostratigraphical unit, as several outcrops of unconfirmed isochrony and depositional history have been considered to represent the Obernkirchen Sandstone (Hornung, Böhme et al. 2012). In the widest sense it might encompass two coal-bearing sandstone tongues at the southeastern basin margin, separated by some tens of metres of pelites. They are exposed in the Bückeberge, the adjacent Harrl hill area, as well as in the Rehburg Mountains, c. 15 km to the N. These sandstone intercalations are often termed 'Unterer Hauptsandstein' and 'Oberer Hauptsandstein' ('lower main sandstone' and 'upper main sandstone'), respectively. Dinosaur tracks are limited so far to the thicker 'Oberer Hauptsandstein', which is considered the Obernkirchen Sandstone *sensu stricto*. In this guide we use the term Obernkirchen Sandstone according to the latter scheme (Fig. 2). In an even more restrictive use, the Obernkirchen Sandstone may be confined to the central Bückeberge type region.

The Obernkirchen Sandstone correlates to the *Cypridea alta formosa* ostracod subzone (Wealden 3) and is therefore late Berriasian in age (Elstner & Mutterlose 1996; Mutterlose 1997b).

Palaeogeography and Palaeoclimate

The Bückeberg Formation was deposited in the Lower Saxony Basin (LSB), a southern subbasin of the North German Basin that stretches from the Netherlands in the W across most of northern Germany (Figs. 3-4). Subsidence of the basin began during the Late Jurassic and terminated by inversion in early Late Cretaceous (Betz et al. 1987; Bachmann & Grosse 1989). The surrounding uplands were probably of low relief, not reaching more than a few hundred metres in altitude (Abbink et al. 2001).

After local highstand and marine flooding of most of the incipient LSB during the Late Jurassic (e.g. Gramann et al. 1997; Kästner et al. 2008) a major fall in sea level and early basin subsidence led to isolated, shrinking perimarine water bodies in the developing LSB during deposition of the Tithonian through earliest Berriasian Münder Formation. Increasing precipitation during the earliest Berriasian resulted in reduced salinities and peripheral haloclinal stratification of the lagoons in peripheral areas (Hils Embayment), though a marine connection still existed (Arp & Mennerich 2008). With onset of the Bückeberg Formation, the water body in the basin was oligohaline (Mutterlose & Bornemann 2000; Berner 2011). C_{org}-rich claystones and shales in the basin centre indicate a dysoxic hypolimnion in the deepest parts of the lake (Berner et al. 2010). The history of the lake level is not well known yet, but the continuity of fine-grained sediments in the central LSB indicates a permanent presence throughout the Berriasian. River systems drained into the lake. Two of them on the southern basin margin are documented by extensive deltaic deposits. The western drainage formed the Osnabrück Delta (Lill & Riegel 1991; Pelzer et al. 1992; Wilde & Schultka 1996), while the eastern one occupied the Hils Embayment, an southern emargination of the LSB (Kauenhowen 1927). Progradation of the river resulted in the deposition of a complex barrier and delta system W of Hannover, including the Obernkirchen Sandstone (Pelzer 1998). The most proximal areas of the Hils Embayment (Hils, Osterwald Mountains) were filled with fluvial and perifluvial deposits (Pelzer 1984; Pelzer et al. 1992) which also yielded dinosaur tracks (Naumann 1927). The delta system consisted of a complex array of subenvironments, as represented in various lithofacies. These include barrier-related deposits, lagoonal and swamp facies, and various types of mouth-bar complexes (Pelzer 1998; Hornung, Böhme et al. 2012; Richter, Hornung et al. 2012; Hornung, Böhme & Reich 2012c; Wings et al. 2012; Hornung, Böhme & Reich 2012d; Böhme, Reich et al. 2012; Hornung & Reich 2012b; ► p. 73ff., this volume). The formation and preservation of the barrier facies was probably related to landward transport of sand during storm events under during a transgressing lake level and by wind-induced SW–NE longshore currents (Pelzer et al. 1992; Pelzer 1998).

The lake basin communicated with the North German Basin extension via a gateway in the W and SW (in the Netherlands). Sea level rises and tectonic modifications of the basin geometry resulted in several short-term incursions of marine waters into the lake (e.g. Berner 2011).

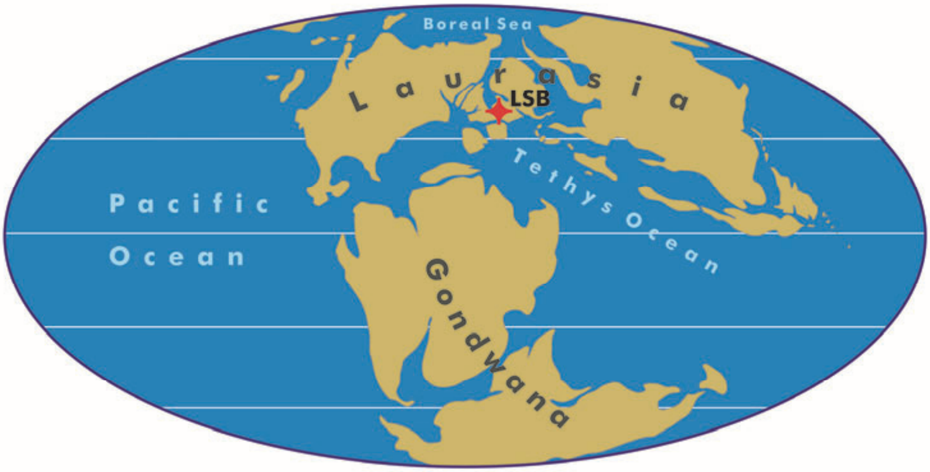


Fig. 3 Global Berriasian palaeogeography with the position of the Lower Saxony Basin (LSB) (after Scotese 2002, modified).

Fig. 4 Regional palaeogeography of the Lower Saxony Basin (LSB) during the Berriasian. **(A)** Setting in the central European context, the roughly coeval Purbeck Limestone Group was deposited mainly in the Wessex Basin (after Mutterlose 1997a, modified). **(B)** Basin palaeogeography with the position of delta systems along the southern basin margin and the trackway localities (after Schott et al. 1967, 1969; Kemper 1973, modified).

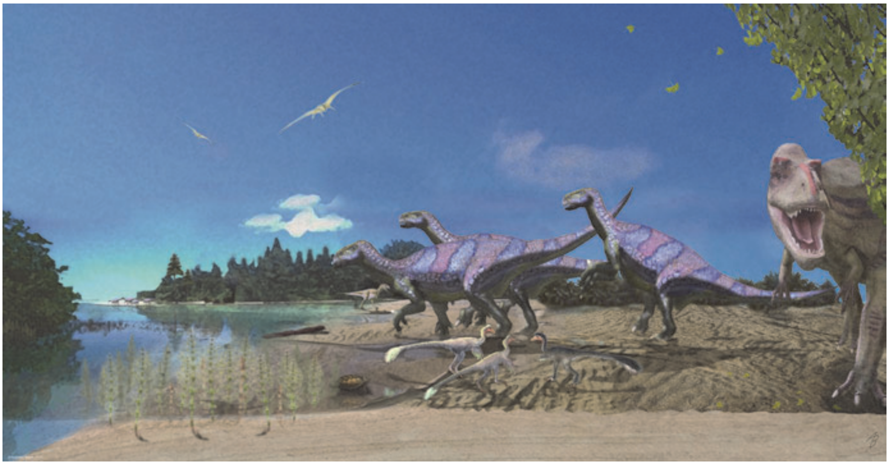


Fig. 5 Life and environments of the Obernkirchen Sandstone. Illustration by A. Basse.

During deposition of the lower and middle Obernkirchen Member, these were confined to the western part, resulting in an W–E decreasing salinity gradient throughout the basin (Mutterlose & Bornemann 2000). Increasing eustatic sea level rise and local tectonics during the latest Berriasian and early Valanginian (Wealden 4 to 6) resulted in ingression and brackish conditions within the LSB (Elstner & Mutterlose 1996; Mutterlose & Bornemann 2000), which concluded in marine flooding during the Valanginian (Mutterlose 1997a).

During the Berriasian, the LSB was situated at c. 32°–33° N palaeolatitude. Palaeoclimatological models (Pelzer & Wilde 1987; Abbink et al. 2001) postulate a rapid change from hot-arid climate during the latest Jurassic (evaporites within the Münder Formation) towards a warm-humid subtropical to paratropical climate in the lowermost Berriasian (brackish to lacustrine deposits in the upper Münder Formation). Seasonal droughts and storm events became more abundant during late Berriasian/earliest Valanginian times.

The deltaic and alluvial plains fringing the rivers support a rich and lush vegetation which may have had the character of rain- and swamp forests (Pelzer 1984, 1998; Abbink et al. 2001). The forests were dominated by conifers, ginkgoes, and arborescent ferns. Drier areas and probably the hinterland were covered by a more open, savannah-like vegetation comprising cycads and bennettitales. Shrub-like vegetation was composed mainly of various ferns. The areas of active deposition and sediment transport (mouth-bars, barriers) supported only a pioneer vegetation dominated by shrub-like horsetails.

Vertebrate Fossil Preservation and Taphonomy

In the sandstone facies rapid deposition of the highly matured, fine-grained sand resulted often in a very high quality of preservation of morphological detail, especially in fossil vertebrates. The sand invaded quickly nearly every cavity of bones and shells, supporting the three-dimensional preservation of even very delicate structures. However, due to the carbonate-depleted geochemistry of the Obernkirchen Sandstone, the original bone substance was transformed diagenetically into a soft, argillaceous matter. Fossil-bearing sandstone slabs commonly split through this substance, which cannot be preserved and freed from the much harder encasing sandstone. It has to be removed and an artificial cast of the remaining, highly detailed cavities has to be made. Historically, casts were made with plaster, while today casts are made with highly detailing, flexible silicone.

In contrast, fossils from the argillaceous and carbonate facies are preserved as fully mineralized specimens, which are, though generally well preserved, often affected by pyrite efflorescence.

The track record clearly shows that a broad diversity of dinosaur taxa, including iguanodontian ornithopods, ankylosaurs, sauropods, and a broad variety of theropods, crossed the delta and barrier system in the Hils Embayment (Fig. 5). In opposite to the very abundant tracks, and with exception of the articulated postcranium of *Stenopelix valdensis*, there are only a few scattered bone remains of dinosaurs known from the Obernkirchen Sandstone and equivalents. As other reptile groups (turtles, crocodiles) are abundant and often well preserved, this represents probably a primary bias rather than a gap in the record. The presence of the dinosaurs was probably migratorial as they used the emerged mouth-bars and barriers as a passage to wander along the southern and southeastern shore of the LSB.

References

Abbink, O.; Targarona, J.; Brinkhuis, H. & Visscher, H. (2001): Late Jurassic to earliest Cretaceous palaeoclimatic evolution of the southern North Sea. *Global and Planetary Change* **30** (3-4): 231-256.

Allen, P. (1955): Age of the Wealden in North-Western Europe. *Geological Magazin* **92** (4): 265-281.

Allen, P. & Wimbledon, W. A. (1991): Correlation of NW European Purbeck–Wealden (nonmarine Lower Cretaceous) as seen from the English type-areas. *Cretaceous Research* **12** (5): 511-526.

Arp, G. & Mennerich, C. (2008): Ostracod associations, palaeoenvironment and cyclicity of Purbeck-type sediments of the Münder Formation (Lower Cretaceous, Hils Syncline, N-Germany). *In* Mischke, S. & Holmes, J. A. (eds.): Applications of lacustrine and marginal-marine Ostracoda to palaeoenvironmental reconstruction, 15th International Symposium on Ostracoda. *Palaeogeography, Palaeoclimatology, Palaeoecology* **246** (3-4): 230-249.

Bachmann, G. H. & Grosse, S. (1989): Struktur und Entstehung des Norddeutschen Beckens – geologische und geophysikalische Interpretation einer verbesserten Bouguer-Schwerekarte. *In* Das Norddeutsche Becken. Geophysikalische und geologische Untersuchungen des tieferen Untergrundes: Vorträge. *Veröffentlichungen der Niedersächsischen Akademie der Geowissenschaften* **2**: 23-47.

Berner, U. (2011): The German Wealden, an Unconventional Hydrocarbon Play ? *Erdöl, Erdgas, Kohle* **127** (7/8): 303-306.

Berner, U.; Kahl, T. & Scheeder, G. (2010): Hydrocarbon potential of sediments of the German Wealden Basin. *Oil Gas. European Magazine* **II/2010**: 80-84.

Betz, D.; Führer, F.; Greiner, G. & Plein, E. (1987): Evolution of the Lower Saxony Basin. *Tectonophysics* **137** (1-4): 127-170.

Böhme, A.; Reich, M.; Hornung, J. J. & Karl, H.-V. (2012): Excursion Guide C1: Northern 'German Wealden' – the collection of the Göttingen University. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, 151-167; Göttingen (Universitäts-Verlag). [this volume]

Broschinski, A. (2004): Exkursion 3: Der Obernkirchner Sandstein – Naturwerkstein und Fossilfundgrube der Unterkreide. *In* Reitner, J.; Reich, M. & Schmidt, G. (eds.): *Geobiologie 2. 74. Jahrestagung der Paläontologischen Gesellschaft in Göttingen 02. bis 08. Oktober 2004. Exkursionen und Workshops*, 53-72; Göttingen (Universitäts-Verlag).

Casey, R.; Allen, P.; Dörhöfer, G.; Gramann, F.; Hughes, N. F.; Kemper, E.; Rawson, P. F. & Surlyk, F. (1975): Stratigraphical subdivision of the Jurassic–Cretaceous boundary beds in NW Germany. *Newsletters on Stratigraphy* **4** (1): 4-5.

Dörhöfer, G. (1977): Palynologie und Stratigraphie der Bückeberg-Formation (Berriasium, Valanginium) in der Hilsmulde (Nordwest-Deutschland). *Geologisches Jahrbuch (Reihe A: Allgemeine und regionale Geologie BR Deutschland und Nachbargebiete, Tektonik, Stratigraphie, Palaeontologie)* **42**: 3-122.

Elstner, F. & Mutterlose, J. (1996): The Lower Cretaceous (Berriasian and Valanginian) in NW Germany. *Cretaceous Research* **17** (1): 119-133.

Gramann, F.; Heunisch, C.; Klassen, H.; Kockel, F.; Dulce, G.; Harms, F.-J.; Katschorek, T.; Mönnig, E.; Schudack, M.; Schudack, U.; Thies, D. & Weiss, M. (1997): Das Niedersächsische Oberjura-Becken – Ergebnisse interdisziplinärer Zusammenarbeit. *Zeitschrift der Deutschen Geologischen Gesellschaft* **148** (2):165-236.

Graupner, A. (1977): Natursteine an hannoverschen Bauwerken. *Hannoversche Geschichtsblätter* **35**: 103-152.

Graupner, A. (1980): Der Berrias-Steinkohlenbergbau in Niedersachsen 1945–1963. *Veröffentlichungen des niedersächsischen Instituts für Landeskunde und Landesentwicklung an der Universität Göttingen. Forschungen zur niedersächsischen Landeskunde* **116**: 184 pp.

Hoedemaeker, P. J. & Herngreen, G. F. W. (2003): Correlation of Tethyan and Boreal Berriasian–Barremian Strata with emphasis on strata in the subsurface of the Netherlands. *Cretaceous Research* **24** (3): 253-275.

Hoffmann, F. (1830): *Uebersicht der orographischen und geognostischen Verhältnisse vom nordwestlichen Deutschland.* xxiv + 676 pp.; Leipzig (J. A. Barth).

Hornung, J. J.; Böhme, A., Lubbe, T. van der; 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. *Paläontologische Zeitschrift* **86** (3): 231-267.

Hornung, J. J.; Böhme, A. & Reich, M. (2012): Excursion Guide A2: Harrl hill near Bückeburg. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, 101-112; Göttingen (Universitäts-Verlag). [this volume] [2012c]

Hornung, J. J.; Böhme, A. & Reich, M. (2012): Excursion Guide B2: Wölpinghausen. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, 143-149; Göttingen (Universitäts-Verlag). [this volume] [2012d]

Hornung, J. J. & Reich, M. (2012): Excursion Guide C2: Dinosaur tracks from the Berriasian Obernkirchen Sandstone on exhibit at the Göttingen University Geopark. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, 169-187; Göttingen (Universitäts-Verlag). [this volume] [2012b]

Kästner, M.; Schülke, I. & Winsemann, J. (2008): Facies architecture of a Late Jurassic carbonate ramp: the Korallenoolith of the Lower Saxony Basin. *International Journal of Earth Sciences* **97** (5): 991-1011.

Kauenhowen, W. (1927): Die Faziesverhältnisse und ihre Beziehung zur Erdölbildung an der Wende Jura–Kreide in Nordwestdeutschland. *Neues Jahrbuch für Mineralogie etc. (B: Geologie und Paläontologie), Beilagen-Band* **58**: 215-272.

Kemper, E. (1973): Das Berrias (tiefe Unterkreide) in NW-Deutschland. *Geologisches Jahrbuch (A: Allgemeine und regionale Geologie BR Deutschland und Nachbargebiete, Tektonik, Stratigraphie, Paläontologie)* **9**: 47-67.

Krumsiek, R. (1981): *Obernkirchen. Chronik einer alten Stadt.* 176 pp. Obernkirchen (Stadtverwaltung).

Lill, K. & Riegel, W. (1991): Ein fluviatil dominiertes Delta im „Unteren Wealden“ (Berrias, Bueckeberg-Folge) von Borgloh/Kloster Ösede, Osnabrücker Hügelland, Niedersachsen). *Bericht der Naturhistorischen Gesellschaft Hannover* **133**: 221-255.

Martin, G. P. R. (1940): Ostracoden des norddeutschen Purbeck und Wealden. *Senckenbergiana* **22**: 275-361.

Mutterlose, J. (1997a): Lower Cretaceous. *In* Mutterlose, J.; Wippich, M. G. E. & Geisen, M. (eds.): Cretaceous Depositional Environments of NW Germany. *Bochumer Geologische und Geotechnische Arbeiten* **46**: 7-12.

Mutterlose, J. (1997b): Münchehagen quarry. *In* Mutterlose, J.; Wippich, M. G. E. & Geisen, M. (eds.): Cretaceous Depositional Environments of NW Germany. *Bochumer Geologische und Geotechnische Arbeiten* **46**: 123-128.

Mutterlose, J. (2000): Unterkreide im Niedersächsischen Becken. *In* Stratigraphische Kommission Deutschlands (ed.): Die Kreide der Bundesrepublik Deutschland. *Courier Forschungsinstitut Senckenberg* **226**: 79-101.

Mutterlose, J. & Bornemann, A. (2000): Distribution and facies patterns of Lower Cretaceous sediments in northern Germany: a review. *Cretaceous Research* **21** (6): 733-759.

Naumann, E. (1927): Blatt Eldagsen, Nr. 2088. *Erläuterungen zur geologischen Karte von Preußen und benachbarten deutschen Ländern* **265**: 57 pp.

Ogg, J. G.; Ogg, G. & Gradstein, F. M. (2008): The Concise Geological Timescale. 150 pp.; Cambridge (Cambridge University Press).

Pelzer, G. (1984): Cross section through a fluvial environment in the Wealden of Northwest Germany. *In* Reif, W-E. & Westphal, F. (eds.): *Short papers. Third symposium on Mesozoic terrestrial ecosystems*, 181-186; Tübingen (Attempto Verlag).

Pelzer, G. (1998): Sedimentologie und Palynologie der Wealden-Fazies im Hannoverschen Bergland. *Courier Forschungsinstitut Senckenberg* **207**: 211 pp.

Pelzer, G. & Wilde, V. (1987): Klimatische Tendenzen während der Ablagerung der Wealden-Fazies in Nordwesteuropa. *Geologisches Jahrbuch (A: Allgemeine und regionale Geologie BR Deutschland und Nachbargebiete, Tektonik, Stratigraphie, Paläontologie)* **96**: 239-263.

Pelzer, G.; Riegel, W. & Wilde, V. (1992): Depositional controls on the Lower Cretaceous Wealden coals of northwest Germany. *In* McCabe, P. J. & Parrish, J. T. (eds.): Controls on the Distribution and Quality of Cretaceous Coals. *Geological Society of America, Special Paper* **267**: 227-244.

Richter, A.; Hornung, J. J.; Böhme, A. & Stratmann, U. (2012): Excursion Guide A1: Obernkirchen sandstone Quarries – A Natural Workstone Lagerstaette and a Dinosaur Tracksite. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, 73-99; Göttingen (Universitäts-Verlag). [this volume]

Schott, W.; Jaritz, W.; Kockel, F.; Sames, C. W.; Stackelberg, U. von; Stets, J.; Stoppel, D.; Baldschuhn, R. & Krampe, K.-D. (1967): Paläogeographische Karten von Nordwest-deutschland im Maßstab 1:200000. *In* Bundesanstalt für Bodenforschung (ed.): *Paläogeographischer Atlas der Unterkreide von Nordwest-Deutschland mit einer Übersichtsdarstellung des nördlichen Mitteleuropa*, 289 pp.; Hannover (Bundesanstalt für Bodenforschung).

Schott, W.; Jaritz, W.; Kockel, F.; Sames, C. W.; Stackelberg, U. von; Stets, J.; Stoppel, D.; Baldschuhn, R. & Krampe, K.-D. (1969): Erläuterungen. *In* Bundesanstalt für Bodenforschung (ed.): *Paläogeographischer Atlas der Unterkreide von Nordwest-Deutschland mit einer Übersichtsdarstellung des nördlichen Mitteleuropa*, 315 pp.; Hannover (Bundesanstalt für Bodenforschung).

Schudack, M. (1996): Die Charophyten des Niedersächsischen Beckens (Oberjura–Berriasium): Lokalzonierung, überregionale Korrelation und Palökologie. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen* **200** (1/2): 27-52.

Scotese, C. R. (2002): *PALEOMAP Project*. http://www.scotese.com [last access June 2012]

Strauss, C.; Elstner, F.; Du Chène, J.; Mutterlose, J.; Reiser, H. & Brandt, K.-H. (1993): New micropalaeontological and palynological evidence on stratigraphic position of the "German Wealden" in NW-Germany. *Zitteliana* **20**: 389-401.

Wilde, V. & Schultka, S. (1996): Die sandige Wealden-Fazies (Bückeberg-Formation, Berrias, Unterkreide) am Westrand eines Schüttungskörpers bei Osnabrück (NW-Deutschland). *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen* **199** (2): 249-268.

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. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, 113-142; Göttingen (Universitäts-Verlag). [this volume]

Wolburg, J. (1949): Ergebnisse der Biostratigraphie nach Ostracoden im nordwest-deutschen Wealden. *In* Bentz, A. (ed.): *Erdöl und Tektonik in Nordwestdeutschland*, 349-360; Hannover (Amt für Bodenforschung).

Wolburg, J. (1959): Die Cyprideen des NW-deutschen Wealden. *Senckenbergiana Lethaea* **40** (3/4): 223-315.

Excursion Guide A1: **Obernkirchen Sandstone Quarries – A Natural Workstone Lagerstaette and a Dinosaur Tracksite**

Annette **Richter[1*],** Jahn J. **Hornung[2],** Annina **Böhme[2,3]** & Uwe **Stratmann[1]**

[1]*Hannover State Museum, Hannover, Germany*

[2]*Department of Geobiology, Geoscience Centre of the University of Göttingen, Göttingen, Germany*

[3]*Geoscience Museum of the University of Göttingen, Göttingen, Germany*

[*]*corresponding author:* Annette.Richter@nlm-h.niedersachsen.de

The spectacular dinosaur track layers discovered in the 'Obernkirchener Sandsteinbrüche GmbH' (Obernkirchen sandstone quarries) in 2007 gave reason for the Dinosaur Track Symposium Obernkirchen 2011, and were visited in this context on 14th (field trip 1) and 15th (field trip 2) of April 2011.

The Obernkirchen Sandstone from the Bückeberge (translated literally: Bücke Mountains) are renowned for its building and monument stone quality for more than 1.000 years (Broschinski 2004). These greyish to yellowish fine grained quartz sandstones from the Berriasian Bückeberg Formation (= 'German Wealden') are hard and very resistant towards erosion. Generally covered by a thick overburden of younger deposits (mostly Cenozoic) they are exposed to the surface in several mountainous areas in southern Lower Saxony. These local uplifts of Jurassic and Early Cretaceous deposits resulted from basin inversion since the Late Cretaceous, locally in conjunction with halotectonic movements of Permian salt structures in the subsurface (Walter 1995). The Obernkirchen Sandstone and its lateral equivalents form a thin (max. 30 m thick) interval within the dominantly pelitic Bückeberg Formation which is up to 700 m thick (Mutterlose 1997). The most important and often fossiliferous Berriasian exposure areas are, aside of the Bückeberge, the Harrl hill, the Rehburg Mountains, and the Deister, Süntel, Nesselberg and Osterwald. All of them represent a fringing clastic depositional system at the southern rim of the Lower Saxony Basin during Berriasian times, but may differ regionally in facies. For an overview of the 'German Wealden'-group and a general map, see Hornung, Böhme et al. 2012 and Hornung, Böhme & Reich 2012b (► p. 62-72, this volume).

Before the industrialization, sandstones from the Bückeberge (under the trademark of 'Obernkirchen sandstones') were used as massive workstone blocks for churches and castles, for epitaphs and other tombstones within the region of Schaumburg, Nienburg and Hannover. Due to the efficient river system of the Weser, even large and heavy sandstone slabs could be transported via ship to the city of Bremen and from its harbours to many different destinations in Europe. This trend was even more enhanced when electrical railroad networks were established; then, the Obernkirchen sandstones (also called 'Bremer Stein') became even more distributed and besides their use for many important edifices in large German cities like Berlin, it received a European and even worldwide appreciation for representative buildings, such as the Belgian town hall of Antwerpen, the Danish National Bank in København and the Castle Amalienborg, the building of the Republic National Bank of New York in Luxemburg, the Netherlands' St. Willibrordus Church in Amsterdam and the New Town Hall in Leiden, the Norwegian Stock Exchange building in Bergen, the Russian castle Zarskoje Selo in St. Petersburg, the Switzerland Church of St. Elisabeth in Basel and the Cathedral of Lausanne, the US-American Cathedral of Baltimore (Maryland), the Brasilian National Monument in Belém do Pará and the Monument of the Dutch Queen in Jakarta, to quote just a few of the examples.

Fig. 1 'Deutsche Bank' building at Hannover, constructed with Obernkirchen sandstone.

The town of Hannover, being the capital of Lower Saxony and housing the Lower Saxony State Museum ('Niedersächsisches Landesmuseum Hannover', NLMH), can also well be described as the "capital of 'Wealden' sandstone buildings", as most of the building stones of its representative buildings from the 19th century derive from one or the other of the 'German Wealden' sandstone localities and most of the damage from World War II has almost exclusively been restored with Obernkirchen sandstones (Fig. 1). To date, even many modern buildings are constructed with Obernkirchen sandstones in contemporary face brick technique.

For quarrying building stones it is most important that the rough quarry sandstone slabs can be taken out as very large, heavy blocks, weighing up to 10 tons. One parameter is the thickness of the banks, which is usually large within the 'Oberer Hauptsandstein' from Obernkirchen (around 1 m on average). The second parameter is the horizontal width – between vertical gaps like clefts – which stands for a reasonably large lateral size of the rock slabs, necessary for all sorts of processing.

This is not naturally the case in all of the Wealden localities, as the northern German diapirism of Late Permian salt beds led to an uprise of the Mesozoic strata, causing local tectonical disturbances and a general system of fault-fold structures. Thus, there are certain zones within the Obernkirchen sandstone quarries, which cannot be used effectively by the stone industry due to too many crevices and clefts. But in general, the thick and robust banks of the Obernkirchen sandstones proved more robust than the sandstones from most other quarrying districts. Those areas which could be used were quarried increasingly intensive during the last two centuries, thereby generating large horizontal surfaces, which turned out to be of crucial importance for finding the dinosaur track layers.

There are different varieties of the Obernkirchen sandstones: Most architects of the 19th century preferred the homogenous light gray sort. Within the 20th century, a turn to the yellowish variety took place. In contemporaneous buildings, especially those stones containing lots of limonite (goethite and others) solution residue colors ('Liesegang'sche Ringe', Liesegang rings) are very popular and commonly chosen for the face brick technique.

The large-scale quarrying activities from app. 1860 on led to the first finds of dinosaur tracks in the 19th century, being interpreted by the Lower Saxonian amateur palaeontologist and collector Carl E. F. Struckmann (1833–1898) as a 'track pioneer' already in 1880 (1880a, 1880b). To correctly assign the local track fossils to dinosaurs, long before the establishment of systematic dinosaur ichnology, was an achievement of Struckmann which must be honoured *post mortem*. After some British palaeontologists had done so, for material from southern England, he also assigned the tracks – in this case found at the Rehburg Mountains (Hornung, Böhme & Reich 2012d; ► p. 143-149, this volume) – to *Iguanodon* after studies from the Belgian publications and conversation with their discoverer, Louis Dollo (1857–1931), whom he sent cast for comparisions. Later, the local teacher Max Ballerstedt (1857–1945) collected many more examples of these positive hyporeliefs and reported sites in the Obernkirchen/Harrl hill-region (e.g. Ballerstedt 1905, 1922; Hornung, Böhme & Reich 2012c; ► p. 101-112, this volume). Other German authors followed throughout the 20th century (Dietrich 1927 and others), U. Lehmann (1978) being the first to consider the 'modern' quarry as a source of dinosaur tracks. The Obernkirchen dinosaur track sites discovered in 2007 and 2008 will enhance the international knowledge about Cretaceous dinosaur faunas, as they are known today (Matsukawa et al. 2005).

This quarry field trip guide tour will be made anti-clockwise. It includes some stops which could not be made *realiter* during the Dinosaur Track Symposium Obernkirchen 2011 due to time restrictions of the conference, but it will help those colleagues revisiting the site for more detailed studies. Also, the body fossil content like *Stenopelix valdensis* von Meyer, 1857, different crocodiles and turtles and other fossils will be a detailed topic within Böhme, Reich et al. (2012; ► p. 151-167, this volume) and Hornung & Reich (2012b; ► p. 169-187, this volume), containing the collections of the University of Göttingen.

Description of Excursion Stops

***(1) Weathered quarry wall* —** At the entrance zone to the quarry proper, the typical banking of the massive, thick sandstone layers of the Bückeberg Formation is very well visible in its original appearance (Fig. 2). Looking much darker than the light fresh fracture planes, the cliff does not reveal the light coloured sandstones superficially. It appears weathered and partly colonized by lichen and moss due to the boreal climate of Northern Germany. The height of the outcrop there is about 10 m, the so-called 'Oberer Hauptsandstein' (OHS; upper main sandstone beds) as a whole amount to 12–13 m. The monotonous sandstone series is interrupted by small bands of very thin mudstone layers in between, after erosion appearing like loam. Those layers differ in colour and thickness throughout the series and will be an important topic for a detailed future investigation. To date, almost nothing is known about the microfossil content – if one is preserved at all – of these layers specifically at the contemporary Obernkirchen quarries.

Fig. 2 Outcrop exposing almost the original quarrying height, as can be seen opposite to the sawing hall.

During deposition of the lower Bückeberg Formation (Obernkirchen Member, including the Obernkirchen Sandstone) the Lower Saxony Basin was mostly filled by a large freshwater lake, which saw occasional short-time marine ingressions from the west (Netherlands). The latter resulted in locally brackish or marine conditions though in the eastern part of the basin (including the Bückeberge area) freshwater conditions prevailed for most of the time. At the southeastern rim of the basin a major river system built a complex estuarine-deltaic succession, which led to a diversity of subfacies (Pelzer 1998, see also other stops herein). The erosional products derived from as far as the Rhenish Massif and Bohemia. Highly matured sands, interbedded with low-energy fine-grained sediments, formed the littoral deposits which were crossed by the dinosaurs.

In the background of today's landscape, the enormously high dump can be seen, building up a 'secondary Bückeberge', mainly consisting of saw remains and 'thin' slices or pieces with cracks and imperfections which cannot be commercially used any more. Due to very complicated long-term regulations required by the German government, the quarrying companies have to restore the landscape they are using, afterwards. Therefore, the dumps are enlarged continuously, following the direction of the main quarrying activities and filling up the quarries.

(2) Bivalve body fossils in the sandstone — Especially at the places where the ashlar stone production scrap is dumped, isolated stones with bivalve remains can be found (Fig. 3). In general they appear to be rare, as most body fossils and especially the calcareous ones are usually not preserved abundantly in these quartzitic sandstones. Nonetheless, there are two ways of preservation of these invertebrates detectable: Firstly, they were embedded in random positions within the sandstone, without alignment or any recognizable accumulations. This is interpreted as resulting from rapid en masse deposition of the sand containing dispersed shells during high-energy-events.

Secondly, they occur as concentrated shell-lags mostly with the convex side up. Again, this can be interpreted as the result of condensation during erosion. Fascinatingly enough, in both preservational modes double-valved preservation is not uncommon. This suggests a rapid burial of the shallowly burrowing bivalves which led to their death and embedding with short if any transport.

The bivalves are characteristic of the Obernkirchen sandstones. When having to differentiate between the varieties of 'Wealden Sandstones' of Lower Saxony, it is thus easy to recognize the Obernkirchen sandstones: They typically contain double-valved lamellibranchs, whereas most other Berriasian sandstones do not contain bivalves at all or these are rare. This can be well used for macroscopical sandstone identification on building facades (Lepper & Richter 2010).

During frequent collecting, three morphotypes of bivalves could be found by the first author. Nonetheless, J. Lehmann (2003) quotes mainly the small *Neomiodon* ('*Cyrena*' of older publications).

Fig. 3 Typical appearance of a small ashlar stone containing bivalves. Some specimens are preserved with some fragmentary remains of the calcareous shell **(A)**, some merely as steinkerns **(B)**. **(C)** shows a sandstone slab from Obernkirchen with smaller (*Neomiodon*) and larger ('*Unio*') bivalves [NLMH 103.163]. Scale in **(A-B)**: 1 € coin.

Ecological interpretations of that genus differ quite markedly: Sometimes *Neomiodon* is considered to be a clear freshwater indicator, sometimes it is supposed to have tolerated brackish conditions (Huckriede 1967; J. Lehmann 2003). Struckmann (1880a) shows a slightly larger '*Unio*'-like bivalve type, which looks very similar to the Obernkirchen ones found by different members of the NLMH (Fig. 3C), in his case deriving from the 'Hastings Sandstone' as he called the sandstone banks from the Rehburg Mountains, Münchehagen, alluding to British localities. Unionids are generally considered freshwater inhabitants. Also, there is a third type of shell, ranging in size in between the other two genera. Detailed determinations of the lamellibranch molluscs are still lacking to date.

(3) Coal outcrop at a fault zone — Everywhere within the different 'Wealden' strata of Lower Saxony, coal seams are developed. They consist of thin hard coal seams producing coals with a high volatile content (gas coal) at the Bückeberge. Exploitation of coal from Obernkirchen is proven since the 15th century (Krumsiek 1981). Scarcity of alternative energy sources during the years around 1945, resulted in intensive mining for local use. However, attaining only a normal thickness of about 20 cm and maximum thickness of 70–80 cm of the 'Hauptflöz' (main coal seam) and relative impurity led to a decrease of economic interest in these coals and mining stopped in 1963 (Graupner 1980).

The main seam directly underlies the main sandstone banks ('Oberer Hauptsandstein'). At the Bückeberge this means that the adit entrances from the historical coal mining are all situated southeast of the geomorphological margin, at the steep slope of the mountain so that surface mining was not possible. Nonetheless, in the southeast corner of the Obernkirchen sandstone quarries, that coal crops out naturally on the surface due to the tectonical faults mentioned above (Fig. 4). The sandstone at that place is affected by a steeply dipping fault zone – lots of tectonical clefts within cm-distance left the resulting thin slices of sandstone to erosion. Thus, a small 'valley', a coulee, was formed.

Plant remains cannot be determined macroscopically within that type of coal, but within the layers directly below (mostly mudstones) and on top of the main seam. They contain plant fossils and have been investigated intensively by the Lower Saxony Geological survey (LBEG). The flora below the Obernkirchen main coal seam consist of ferns *(Laccopteris),* Pteridophyllids *(Pecopteris, Sphenopteris)*, water fern *(Sagenopteris)*, Ginkgophytes *(Ginkgo pluripartita, Baiera brauniana)*, Cycadophyta *(Zamiophyllum),* Nilssonians *(Nilssonia)* and conifers *(Sphenolepidium).*

The mudstone above the seam – right under the basis of the first sandstone bank – yields horsetails (shave-grass; two species of *Equisetites*), *Nilssonia* and *Sphenopteris*. In a nearby quarry of the Harrl ridge, 'fern tree logs' of *Tempskya* have been found (all botanical identifications from Graupner 1980).

Fig. 4 The coal coulee in the southern part of the Obernkirchen sandstone quarries. **(A)** showing the fault area with its heavy shear fracturing of the sandstone banks **(B)** and a natural surface outcrop of the 'German Wealden' coal **(C)**. Unfaulted, the coal seam layer would have had to be mined some 2–4 m below. Scale in **(C)**: 1 € coin.

The chemical composition of the different coal minerals has been investigated thoroughly. Thus, the origin of the coal from the former swamps of the Berriasian time at Obernkirchen is thought to derive from a conifer-dominated forest with some underbrush. Tree bogs were flooded with fresh water in seasonal rhythms, and relatively dry seasons may also have been part of that yearly climate – but no draughts (Graupner 1980; compare Pelzer 1998).

Due to the fact that once a year the official German 'Federal Day of the Geotope' takes place with hundreds of visitors in the quarry, two detached sandstone slabs are also positioned at that coal locality. They show the typical preservation of fossil tree logs on the bedding planes of the sandstones themselves and symbolize the origin of the coal from plants.

Fig. 5 The southern margin of the Obernkirchen sandstone quarries reveals zones with single dinosaur track layers, either detectable by the typical wavy sideviews **(A)** or even as overhanging positive hyporeliefs as seen in **(B)**.

(4) Root-trace horizons within the sandstones **—** Near the top of some of the sandstone slabs, especially when they have been freshly quarried and/or sawed, well preserved root-trace horizons appear very markedly (Fig. 6). Their abundance has been already observed by Grupe (1931). They are more abundant than expected for that facies, but difficult to detect on the slightly weathered surfaces with organic patina. Well-preserved root-traces on freshly broken side-views of the stored, already sorted sandstone slabs clearly show straight, vertically oriented, thin thread-like structures, some brownish, some others white colored inside. Their length varies in between some centimeters up to a maximum of ca. 14 cm (Type B? of Pelzer 1998).

Fig. 6 One of the typical root-trace horizons from the Obernkirchen sandstones **(A)**, showing the strictly vertical orientation without any horizontal layering or subdivision **(B)**.

None of the root-traces found up to now ever showed dichotomies of any kind. Also, the roots are placed reasonably close to each other, so that these horizons appear to be having been uniformly vegetated. True paleosoils did not develop, though (compare Pelzer 1998). And it must also born in mind that the main settlement layer of the plants might have been just above those fossilized remains, within the muddy uppermost surface, which had been most probably stabilized by microbial mats before. It is striking that the most marked, densely settled root-trace horizons are clearly on top of thick sandstone banks and that there are only lesser well preserved and less densely grown root horizons within the banks. This may hint to some cyclic events like storm tides or high-discharge flooding events. The development of a plant cover indicates 'longer' phases of relatively undisturbed exposure of the sediment surface followed by rapid deposition of sand masses.

It can be hypothesized that – if the plants are to be identified as land plants – the preservation of the deepest root zones from the top = 'last' layer was only possible due to a stable, uniform vegetation during quiet times, keeping the lagoonal sandy material together. It is also remarkable and well fitting that one of these rooted horizons underlies some areas of the northern part of the 'Chicken Yard' (see below), where lots of dinosaur footprints have been left exactly on top of those roots. As it cannot be detected under each surface, the vegetation must have appeared in irregular patches.

At the time of the field trip, very well preserved roots could be seen at a pile of slabs – respectively their sides – deriving from the 'Chicken Yard' continuation surface, just north of the *in situ* 'Chicken Yard'. These have been moved meanwhile.

(5) The 'Chicken Yard' and its extension northwards — On 15th September of 2007, the third author Annina Böhme (at that time museum trainee at the NLMH) and the first author discovered a dinosaur track horizon with an unexpectedly high number of individual tracks, absolutely not typical for the 'German Wealden' (Fig. 7).

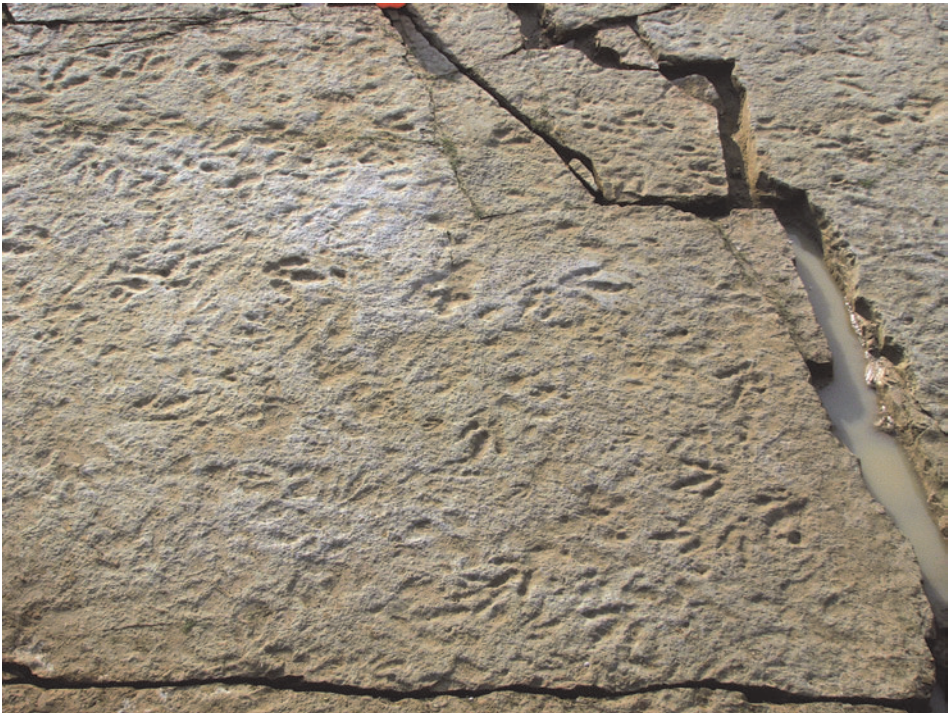


Fig. 7 An overview of the 'Chicken Yard' dinoturbation facies viewed from the cliff (app. 6.5 m) just above. Many, especially well preserved theropod and some iguanodontian footprints could be documented almost perfectly in summer of 2008, when the whole surface was freshly uncovered.

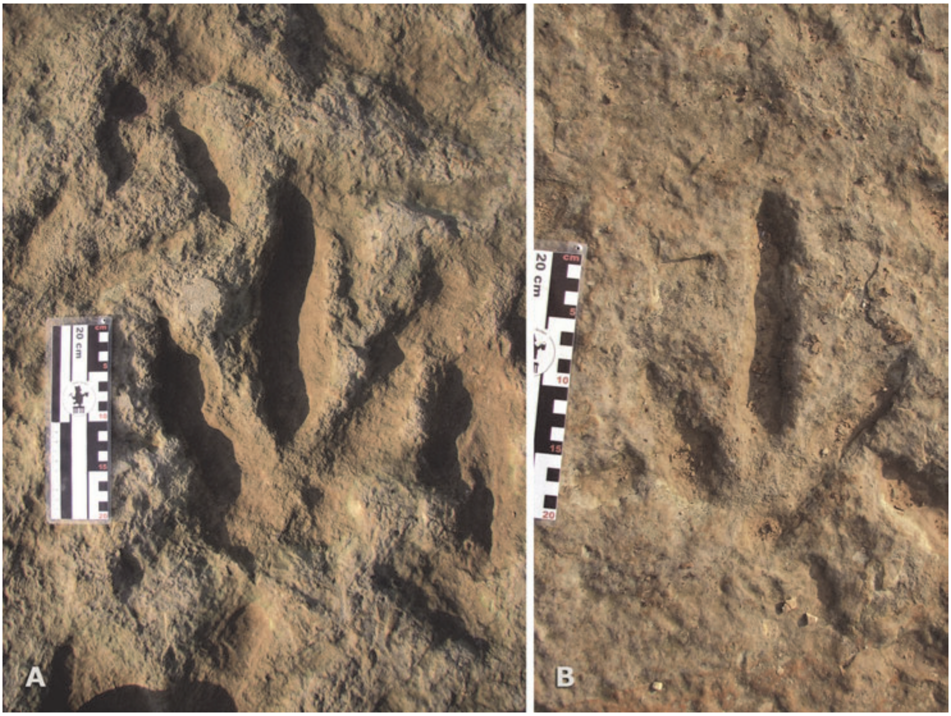


Fig. 8 Two different morphotypes of medium-sized theropod footprints. Scale bar: 20 cm.

Doing some field work there and preparing the public 'Day of the Geotope' (mentioned above) planned for the following day at the Obernkirchen sandstone quarries, the optimal light conditions at that afternoon/evening helped both authors to find that specific horizon, being experienced with the tracksite from the Wesling quarry at Münchehagen (Wings et al. 2012; ► p. 113-142, this volume). As the beginning palaeontological research disturbed the work of the quarry, this meant some degree of negotiations and compromises on both sides to keep first digging campaigns going the following season in 2008. Mostly with the help of many, many Lower Saxon volunteers, the main digging activities began that summer 2008.

Soon it was clear that the immense density of tracks meant some different preservational environment as the usual one for 'German Wealden' sandstone track surfaces as those known from Münchehagen (for example) and also an extreme treasury for the reconstruction of Lower Cretaceous times in Lower Saxony (Richter et al. 2009).

Already during the first steps of exposing that new surface, the density could be estimated as being between medium and high dinoturbation *sensu* Lockley & Conrad (1989). To date, an amount of more than 2.000 unambiguous single tracks were counted. Strikingly, the high amount of medium-sized to some larger theropod tracks of allosauroid affinities *sensu lato* (Fig. 8) did also not fit to the 'regular' German track localities. When those theropod tracks were pre-analyzed first by the first author and by Torsten van der Lubbe it also turned out that they represent at least three different morphologies, which further complicates the long-term debate about *Megalosauripus* and the rather unfortunate track genus *Bueckeburgichnus*, revisited by Hornung, Böhme & Reich (2012a; ► p. 27, this volume). The latter could not be found at all at the new layer – in spite of some hundred single theropod tracks. A reconsideration of that ichnogenus should follow new dicussions and recommenddations (Demathieu & Demathieu 2003). The photogrammetrical analysis of the theropod 'community' will have to follow some new insights from Breithaupt & Matthews (2012; ► p. 17, this volume). Also, the deeper tracks shall serve for three-dimensional investigations needed to complete the two-dimensional interpretation (Falkingham 2012; ► p. 20, this volume).

As the many tridactyl theropod tracks looked so much like bird tracks when viewed from up above the cliff overlying the east side of that locality, someone from the digging team named it 'Chicken Yard'. This name was also favoured by the authors and from then on used to describe that specific spot within the Obernkirchen sandstone quarries.

Fig. 9 Didactyl right track, left by a troodontid theropod, from the 'Chicken Yard'. Scale bar: 10 cm (Courtesy: O. Gerke).

The authors avoided a quick decision about the difficult theropod ichnotaxonomy question – which will be focused on after the symposium - and concentrated on the next new find, first: In August 2008, Torsten van der Lubbe discovered new, small tracks between the masses of larger ones. They were undisputedly didactyl and thus lead to the Deinonychosauria. As detected by van der Lubbe, they bear a characteristic overall track morphology which can be specifically assigned to the foot skeletons of the Troodontidae (van der Lubbe et al. 2009, 2012; ► p. 35, this volume), which made that special area of the quarry famous. It is the only unambiguious spot with troodontid tracks worldwide to date (van der Lubbe et al. 2009), while didactyl tracks as a whole gain increasing interest (Lockley & Harris 2012; ► p. 34, this volume). These results led to new insights within paravian foot structures as a whole and can especially well be compared to fossils from China (Sullivan et al. 2012; ► p. 55, this volume). They will be compared to the results of dromaeosaurid versus basal bird studies (Fowler et al. 2012; ► p. 22, this volume) in a final volume.

It can be stated here, too, that not only well-preserved trackways of these sickle-clawed dinosaurs have been preserved, but also two parallel ones, which enhance the biological discussions about that group. Also, there is one solitary 'double-track', with the right slightly behind the left foot, obviously in a standing pose, leaving more of the posterior structures of the feet imprints and thus alluding at a slight backleaning of the animal while resting for a moment. The 'Wealden' troodontids from Obernkirchen must have represented animals with a length of app. 3–4 m and a height of app. 1.50 m.

Among the majority of theropod tracks, many more medium-sized to large ornithopod tracks could be found during the 2010 summer's fieldwork, namely ?*Iguanodontipus* isp. Due to the very careful work of the third author, even parallel trackways of large and very small '*Iguanodon*-like' tracks could be detected to date, some of those being rather shallow but clearly recognizable. They will be topic of another publication.

There are also some more, small, tridactyl prints which cannot be assigned to any group for the moment. There is a high probability of them belonging to small ornithopods, and/or they can eventually be brought into context with the enigmatic genus *Stenopelix valdensis* von Meyer, 1857 (Butler & Sullivan 2009).

Nonetheless, Ankylosaurian tracks have not been found to date, although an Ankylosaurian ichnospecies *(Metatetrapous valdensis* Nopcsa, 1923*)* was described from that region and possibly recently rediscovered (Hornung, König & Reich 2012; ► p. 29, this volume).

The 'Chicken Yard' must represent two to four or even more generations of footprints. The last two, can be deduced, any more preceding those can not be differrentiated. Also, preservational biases must be taken into account (Falkingham et al. 2011). The walking directions show no preference at all. It rather seems that all directions are represented, and that only those tracks known to be parallel joined one direction, each.

For all 'German Wealden' sandstone dinosaur track layers, hypothetical microbial mats directly above the sand and most probably mud layers can be anticipated, stabilising the sediment surface to a certain degree, enabling the preservation of tracks at all. The overall similarity of the 'Chicken Yard' sandy lagoonal flats dinosaur track community to the one from the carbonate tidal flats of the Heritage Museum area of the Texas Hill County is striking (Farlow et al. 2006).

On the southwest corner of the 'Chicken Yard', a large but flat trough dominates a zone with almost no tracks at all. Its marginal rims contain many of the small *Neomiodon* bivalves (see above), but no further characters can be stated for the internal structure of that hollow.

The common track facies shows a uniform quality of track preservation which can be interpreted as representing a very limited time of exposure, rapid burial and 'freezing' of the tracks by subsequent sedimentation. This leads to some clear trackways in two or three directions, mostly of ornithopods and only some theropods, usually just one trackway of the latter (see: 'Stop (6)' herein and Wings et al. 2012; ► p. 113-142, this volume), and no trampling at all. The superposition of many generations of tracks, preserved in a wide range of qualities indicate a relatively long exposure of the track surface. The coverage by a thin mudstone layer and the absence of desiccation cracks may hint to a permanent shallow inundation, though the degradation of older tracks may be the result of drying up and subaerial exposure. The mudstone may represent only the latest stage in history of this track horizon, which covered the youngest tracks. The various stages of track degradation have been part of scientific studies and were observed in recent environments, even indicating exposure durations of up to one year or more (Marty 2009). Nonetheless, the best available data derive almost exclusively from calcareous tidal flats on carbonate platforms (Marty 2008), so models will have to be adjusted to the sandy, clastic systems of the 'German Wealden'.

A special event within the field trips of the Dinosaur Track Symposium Obernkirchen 2011 was another trip to the Obernkirchen sandstone quarries at the second day – say, the 'night-illumination'. Large synthetical light sources had been installed in the northwest of the 'Chicken Yard' surface (not at the 'Upper Surface') to have side light/grazing light conditions after dusk. Especially with that light source and the very flat angle of light, the heavy degree of dinoturbation appeared much more distinct. Although not showing ripple marks and only one small area with marked invertebrate life (the rim of the large trough with abundant bivalves) – in contrast to most other 'German Wealden' tracksites – the surface of the 'Chicken Yard' rocks looked very much 'unlithified' and almost recent.

Just aside the 'Chicken Yard' itself, a large pile of sawed slabs and some 20 very large, not yet processed sandstone blocks are laid out (Fig. 10A). They show exactly the same facies like the 'Chicken Yard', the same density of theropod and iguanondontid tracks and even some of the most diagnostic troodontid tracks. Some blocks, though, have narrow ripple marks on their surface. They derive from an area northwards of the 'Chicken Yard'. During the field season 2009, some of the digging group members, namely Willy Seewald and Oliver Gerke, went northwards prospecting and discovered the supposed continuation.

Fig. 10 The set of large sandstone slabs mainly quarried in the proposed northern continuation of the 'Chicken Yard' shows exactly the same dinoturbation facies **(A)**. Some more blocks derive (probably) from the 'Upper Surface' and show positive hyporeliefs. The detail **(B)** on one of these blocks proves the existence of invertebrate traces comparable to those of the Dinosaur Track Natural Monument from Münchehagen. Scale in **(B)**: 1 € coin.

Although the stratigraphical position is not yet fully clarified, this surface seemed to be the northern outcrop of the 'Chicken Yard' layer with very high probability. It could not be negotiated further with the owner for leaving that area also *in situ*, for paleontology was slowly occupying more and more 'corners' within the quarry and thus hampering the workers. Thus, a compromise was set for uncovering that surface at as last, mapping and analysing it, and afterwards aiming at selling these slabs especially to museums and other educational institutions. This did not work out fully as planned, but some of these blocks are currently under final 3D-treatment and await their partial employment for the scientifical exhibition of the NLMH and other museums.

Beside the blocks described above, there are some other slabs not belonging to the 'Chicken Yard' facies. They have been positioned with their undersides up, showing large infillings of former iguanodontian tracks (positive hyporeliefs) probably belonging to the layers which were originally situated above today's 'Upper Surface' (see below). Within one of the slabs leaning aside at a secondary dump, infillings from invertebrate tracks can also be found (Fig. 10B). They resemble closely the invertebrate ichnofossils from the Dinosaur Track Natural Monument Münchehagen.

(6) The 'Upper Surface' and the public area — A day after the discovery of the 'Chicken Yard' by the first and third author, official guidance tours around the Obernkirchen sandstone quarries were offered to the public on September 16th, 2007. Within the auditory was an extraordinarily enthusiasted, freshly retired man, fascinated by that topic, going on his own search for the Lower Saxony dinosaurs right after that 'Day of the Geotope'. It was the fourth author, Uwe Stratmann, ever since sticking to the dinosaur phenomenon and after all discovering yet another dinosaur track surface within the quarry in October/November 2007, the 'Upper Surface' at the northern margin (Fig. 11). He was turned into an official volunteer of the NLMH and successfully works together with the museum's team since 2008.

The 'Upper Surface' fits much better into the regular appearance of 'German Wealden' tracksites with single rows of more or less *Iguanodontipus*- and *Caririchnium*-like trackways and striking ripplemarks, but it is very spectacular for its size (c. 4500 m^2; compare Böhme, van der Lubbe et al. 2012; ► p. 16, this volume) and continuous lateral track facies (in contrast to most of the layers in Münchehagen, see there). Most of the tracks preserved at that site are quite deep and offer a good base for threedimensional interpretation.

Fig. 11 An overview of the 'Upper Surface' (2008).

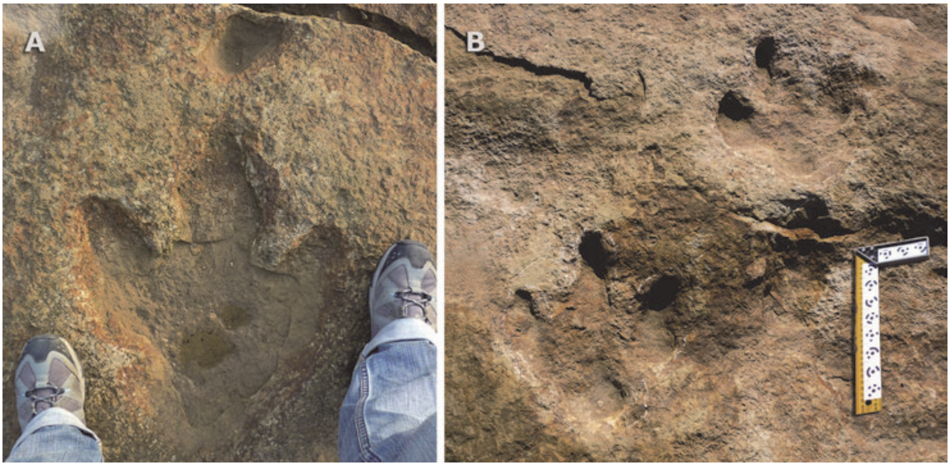


Fig. 12 ?*Iguanodontipus* isp. tracks of larger **(A)** and smaller ornithopods **(B)** from the 'Upper Surface'. Scale in **(B)**: 30 cm.

Long rows of those trackways run parallel to each other. The walking axis is N–NE/S–SW, and one group of parallel iguanodotians headed off in northern, the other in southern direction. This allows for a tentative correlation with the reconstructed landscape of Lower Cretaceous times, having current-generated sandy islands just north of the main land with the lush tropical forests of Mesozoic plants. It seems plausible, thus, to reconstruct some sort of migration for groups of large herbivores in general. In this case the iguanodontians, wandering to and fro between the main land and the islands, maybe following seasonal patterns.

Within the group wandering northwards, an 'adult' (55.0 cm total length and 55.0 cm total width) left tracks parallel to that of a subadult (44.5 cm total length and 40.0 cm total width). The gregarious behaviour of European dinosaurs can be correlated to the Asian ichnofauna, especially of Korea (Lim et al. 2012 this volume). Individuals of both groups left forehand tracks at some spots, but not in regularly appearing patterns. These forehand tracks of Wealden iguanodontians are only since the first discovery in Münchehagen (Lockley et al. 2004). Some single iguanodontians walked obliquely to the directions of the others, almost crossing them perpendicularly. On the currently exposed area, these are in the minority. The 'iguanodontian' tracks can be clearly subdivided into two types, which differ markedly from each other. One is a sligthly differing '?*Iguanodontipus*' or at least resembling it (Fig. 12), and another, new type shows the same main shape but two separate depressions yet behind the posterior metatarsal rim (Fig. 13). They are half-moon- respectively kidney-shaped and could be interpreted as keratinous appendices enforcing the soft tissues of the 'heel' at the first glance. The allover appearance closely resembles *Caririchnium* (Böhme et al. 2009), which belongs to the Upper Cretaceous. To date, we can count 400 tracks in c. 30 trackways of this morphotype within 2000 m^2 (and all together more than 700 tracks).

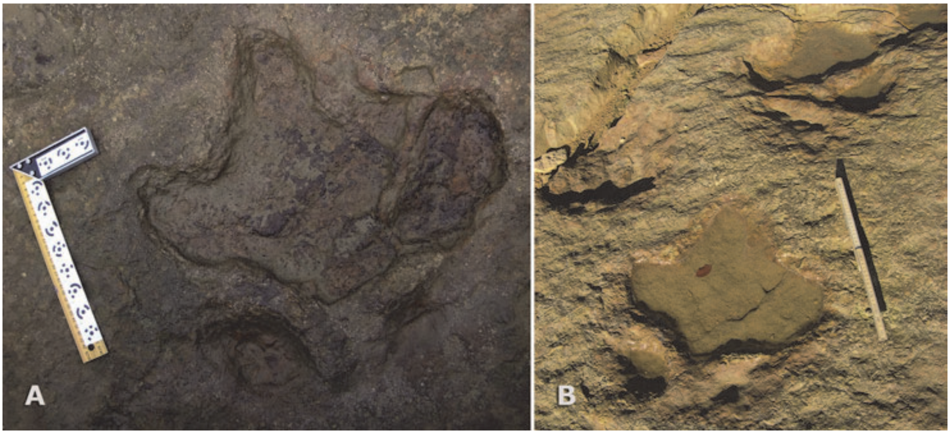


Fig. 13 Iguanodontian tracks of the ?*Caririchnium*-like morphotype (from the 'Upper Surface'). Scale in **(A)**: 30 cm, in **(B)**: 40 cm.

When the 'Upper Surface' had been cleaned off for the first time, only at a single spot, two extremely flat and two unspecific tracks of a theropod were detected by A. Böhme. Unfortunately, these tracks were confined to the very thin uppermost layer containing some degree of mudstone. It was that layer which more or less weathered away when being freshly exposed during its first winter (2009/2010). In the northern half of the 'Upper Surface', three to four spots produced fossil tree log fragments respectively their imprints. Either they appear as rather straight and very flat half-cylinders in the underground, or they may still show some wrinkles of the former 'bark'. The most well-preserved two logs lay close to each other in the vicinity of the wooden visitor walking way, one crossing the other underneath, and both of those had a weak layer of coal on top directly after unearthing, wiped away by the first rainfalls. They are also the longest fragments of trees on the 'Upper Surface'.

The North-Eastern corner of the 'Upper Surface' was not part of the digging campaign at the beginning. There had been an overburden of app. 4 m unusable, deeply clefted and thin-layered sandstone as well as the Quaternary loose sediments above it. During the final negotiations between the owner of the quarry and the rural district administration in 2010 concerning the future of that area, it could be added to the 'Upper Surface', and the quarry owner was helping to get that sedimentary package moved away. The area is now called the 'Expansion Corner' of the 'Upper Surface' (c. 1200 m^2; compare Böhme, van der Lubbe et al. 2012; ► p. 16, this volume) and could even be enlarged much more into the recent forest of the Bückeberge in the future, as that part of the northern margin belongs to the rural district, anyway.

When decision had to be made how far deep the removal of the 'Expansion Corner' overburden should take place, the whole working group decided to leave the four thinner layers above the 'Upper Surface' main level on the ground, following the advice of the fourth author. This turned out to be a wise decision, as they are much more tracks within the layers directly above, two new ones from summer 2011 even containing extremely deep iguanodontian tracks where the animal must have glided deeply into the soft mud, forwardly, and must have drawn the foot backwards again very carefully when pulling it out of the mud for making the next step. That procedure left extremely deep, hollow toe prints, and marked rims, as a lot of sediment has been moved by the pressure of the foot, obviously in a similarily complex way than shown by Gatesy & Ellis (2012; ► p. 23, this volume). This layer will deliver first-class examples for careful three-dimensional studies *sensu* Manning (2012; ► p. 36, this volume). Also, it will allow for careful studies of the vertical sediment changes around the track sensu Milàn et al. (2004), as some of the slabs can and will be taken out after documentation.

In one of the middle layers, even some theropod tracks were discovered. Now these layers are going to be taken off slowly and very thoroughly and will be mapped separately within the next three summers. The uppermost layer seems to be of special interest, as it superficially traces the autochthonous tracks from the layer below and delivers the opportunity to correlate both by taking the layers out one by one.

(7) The 'edutainment path' — Luckily, the rural district 'Landkreis Schaumburg' was very interested in the dinosaur tracks from the Obernkirchen sandstone quarries from the beginning on. When it turned out that the quarry owner was signaling to resign from the 'Upper Surface' at the very northern margin of the quarry under certain conditions – where later on even the 'Expansion Corner' could be added, see below – the rural district people, namely Fritz Klebe, went right into negotiations with the owner and also applied successfully for funding from the European Union to develop that part into an natural history hiking area (Fig. 14), hopefully as a first step towards some sort of a geopark in the near future. In contrast to the well accessible Dinopark Münchehagen, that concept took another direction – people should use the opportunity to hike in one of the last large, undisturbed forest zones of Lower Saxony and discover the different treasures of nature by themselves, helped by very informative thematic stations/stops. The 'headliner' for that, of course, were the dinosaur tracks from the 'Upper Surface'. A new team was formed, from the rural district as well as the museum (NLMH), the local tourism bureaus and some more, and a splendid hiking route was created, furnished out with stone monuments containing the different scientific content, didactically simplified (for instance: the use of the work stones in former times, their use today, the forest, forest birds, earth history of the Bückeberge, Pleistocene glaciations on top of the Bückeberge, the 'German Wealden', the fossil plants and the coal, the dinosaur tracks of Obernkirchen, and so on). This concept turned out to be very successful, although the visitors cannot reach the northern 'Upper Surface' at once, as they have to hike there for at least 30 to 45 minutes. Already this summer, visitor groups used the opportunity to discover nature as a whole on top of the Bückeberge very frequently.

Fig. 14 An overview from the highest dump peak within the Obernkirchen sandstone quarries, taken in autumn 2011, looking northwards onto the 'Upper Surface' public area, with its well-established public access to the dinosaur tracks.

Currently, the rural district negotiates again with the quarry owner for finding a solution to exclude the 'Chicken Yard' from the active part of the quarry and develop an even larger public access to be connected with the 'Upper Surface' and the 'Expansion Corner'. Also, guidance tours can be booked at the central forest administrations, the guides themselves – called the 'Bückeberge DinoScouts' – having been trained by palaeontologists (NLMH), botanists, forest experts (rural district of Schaumburg) and others since 2010.

The very beginning of the Bückeberge Tour should start at the new 'Info Pavillon' erected close to a center of youth education (JBF: Jugend Bildungs- und Freizeit-Centrum, 'centre for education and leisure time acitivites for young people'). On top of the pavilion, a most symbolical metal dromaeosaurid skeleton sculpture has been mounted, donated by a local sponsor (Lühr Filter).

Palaeontology of dinosaur tracks has proven to be attractive for the region as a whole and will continue to prove worth all necessary political activities establishing more steps towards a geopark-model.

(8) Old 'reserve quarry' and 'Top Surface West' — Whilst the actual quarrying area stretches north-east of the highest point from the Bückeberge (367 m), quarrying westward was halted in the late 20th century. The resulting morphology of a half-sided ravine or gorge adjoins the so-called 'reserve quarry', saved for future needs (Fig. 15). Although this sequence of bedding has not yet been stratigraphically mapped in detail, it can be supposed to contain the same strata like the active quarry as shown by a first practical review of the actual state by Raddatz (2010, yet unpublished diploma mapping report). Several dinosaur track layers can be detected on that upper level and those closely beneath, mostly showing large iguanodontian tracks, as documented by Raddatz et al. (2012; ► p. 50, this volume). Also, as shown by Diedrich (2004), some more 'undulating' surface borders of neighbouring layers can be seen at the largest cliff wall behind the ravine, although there are more than two track-bearing layers developed, and one of the lower ones (Diedrich's 'track bed 1') indeed bears some more distinctive characters.

Most of these layers show the typical uneven, wavy sideview on the original track surface (with the negative epirelief) as well as the uneven infillings of the underside of the overlaying bank (the positive hyporeliefs), due to the fact that both are separated by very thin mudstones. In contrast to that, the most marked bedding plane of the scarp face is overlain by a relatively thick layer of mudstone (4 cm thick) which clearly shows the same characters like the 'Chicken Yard' stratum in the active East quarry. In that layer, the undulating character is developed only at the original track surface, there are no hyporelief infillings above, and the bottom of the sandstone bank above the thick loam is even. As the 'Chicken Yard' surface also had to be freed from a substantially thick loam layer of approximately the same thickness, it may turn out as a key layer for the whole Bückeberge in the future. Fortunately, in this case the surface can be investigated, as a small relic of the succession of sandstone beds has not been quarried on the opposite side of the cliff, superficially looking like detached blocks, instead being a real, but tiny outcrop (Figs. 15B-C). Its second surface counted from the top shows exactly the same degree of bioturbation = dinoturbation like the 'Chicken Yard' layer, with some ?*Iguanodontipus*-tracks as well as medium-sized theropod prints well recognizable, even though these surfaces have not been cleaned from the gravel. If this layer was the continuation of the true 'Chicken Yard', it would greatly enlarge the extension of this special and unusual facies of German Wealden within the Bückeberge mountain area. It must be noted, though, that at least two other layers in close vicinity of the uppermost one also show higher densities of dinosaur tracks than the average (Raddatz et al. 2012; ► p. 50, this volume).

As the surface had already been freed from tree vegetation, the uppermost layer of that reserve area develops into a natural open environment for toads, croakers and newts each summer, where they populate the shallow ephemeral pools in large numbers.

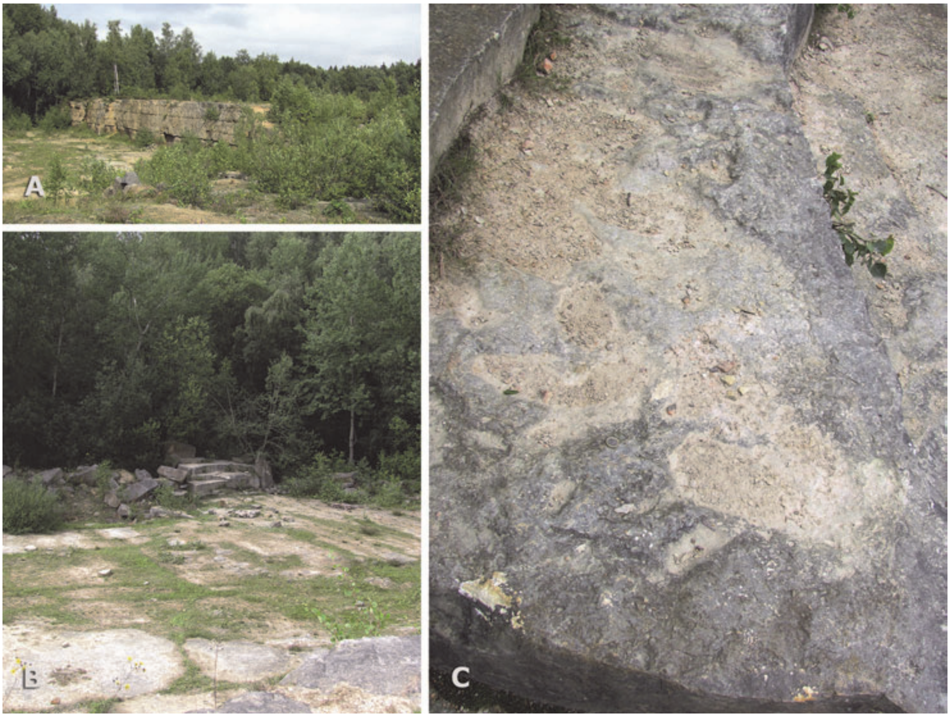


Fig. 15 The 'reserve quarry' west of the actively worked Obernkirchen sandstone quarries. Its cliff **(A)** represents the uppermost seven sandstone beds of that succession. The typical undulated appearance as well as the thick mudstone layer indicate a situation very similar to the the 'Chicken Yard', which can be proven just opposite of that cliff. On a relic-like last natural miniature outcrop **(B)** – amongst masses of large detached blocks – one of five banks shows exactly the same dinoturbation facies on its surface (C) like the 'Chicken Yard' – here still covered with gravel.

Acknowledgements

The authors wish to express their sincerest gratitude to Mr Klaus Köster, Obernkirchen, the owner of the Obernkirchen sandstone quarries, for his enormous support. His working life and the one of his quarry workers underwent quite a change since the 2007 and 2008 discoveries, and we appreciate very much that we always found solutions in spite of conflicts. Also, we would like to thank our financial sponsors for being able to organize the Dinosaur Track Symposium Obernkirchen 2011, and within them first of all Sigmund Graf Adelmann, Dr. Klaus-Henning Lemme and Irene Neumann, Bückeburg (Schaumburger Landschaft), Dr Joachim Werren, Hannover (Stiftung Niedersachsen) and Dr Stephan Lüttich, Hannover (Klosterkammer Hannover). Furthermore, we want to thank the Ministry of Science and Culture of Lower Saxony, Hannover, for financially supporting the field work, the research and parts of the symposium. We like to thank Torsten van der Lubbe, who changed the point of view towards the different theropods and brought the troodontids into the northern 'German Wealden'. His enthusiastic work from 2008 to 2011 helped the project greatly.

Dr Manfred Wiggenhagen is to be thanked enormously for his support regarding all photogrammetrical acitivities, which had not been possible without his help during many endless working hours at his computer. We like to thank Fritz Klebe, Lothar Seidel, Diana Krause and the other enthusiastic people from the rural district of Schaumburg, Stadthagen, for their continuous help and their many fruitful ideas. Dr Mike Reich deserves our highest degree of gratitude for organising the opportunity to publish this abstract volume within the qualified Göttingen University series and also for putting a lot of energy into the organizational and editorial work for it, continuously rising the quality of the volume. And last, but not least, we want to give our warmest thank you to the group all of our busy and inexhaustible volunteers, without whom this big project would never have been possible at all. Their humble and always optimistic field work qualities really made it easy to bear all sorts of expected and unexpected trouble during the last five years. Sharing the excitement about the new sites and the new tracks with all of them was more than just joy. We would like to mention our youngest helpers: Lena Weimann, Frederick Lieske and Björn Vogel, thanks to all of you and your families !

References

Ballerstedt, M. (1905): Über Saurierfährten der Wealdenformation Bückeburgs. *Naturwissenschaftliche Wochenschrift (Neue Folge)* **4** (31): 481-485.

Ballerstedt, M. (1922): Über Schreckensaurier und ihre Fußspuren. *Kosmos* **19** (3): 77-80.

Böhme, A.; Lubbe, T. van der; Richter, A.; Wiggenhagen, M. & Stratmann, U. (2012): The Lower Cretaceous (Berriasian) dinosaur tracksite of Obernkirchen, Lower Saxony, northern Germany – Preliminary report on the "Upper Track Layer". *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, p. 16; Göttingen (Universitäts-Verlag). [this volume]

Böhme, A.; Stratmann, U.; Wiggenhagen, M.; Lubbe, T. van der & Richter, A. (2009): New tracks on the rock: Parallel trackways of a new type of *Iguanodontipus*-*Carirchnium*-like morphology from the Lower Cretaceous sandstones of Obernkirchen, northern Germany. *In* 69th Annual Meeting Society of Vertebrate Paleontology and the 57th Symposium of Vertebrate Palaeontology and Comparative Anatomy (SVPCA), University of Bristol, Bristol, United Kingdom, September 23-26, 2009. *Journal of Vertebrate Paleontology* **29** (3) [suppl.]: p. 66A.

Breithaupt, B. H. & Matthews, N. A. (2012): Neoichnology and photogrammetric ichnology to interpret theropod community dynamics. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, p. 17; Göttingen (Universitäts-Verlag). [this volume]

Broschinski, A. (2004): Exkursion 3: Der Obernkirchner Sandstein – Naturwerkstein und Fossilfundgrube der Unterkreide. *In* Reitner, J.; Reich, M. & Schmidt, G. (eds.): *Geobiologie 2. 74. Jahrestagung der Paläontologischen Gesellschaft in Göttingen 02. bis 08. Oktober 2004. Exkursionen und Workshops*, 53-72; Göttingen (Universitäts-Verlag).

Butler, R. J. & Sullivan, R. M. (2009): The phylogenetic position of the ornithischian dinosaur *Stenopelix valdensis* from the Lower Cretaceous of Germany and the early fossil record of Pachycephalosauria. *Acta Palaeontologica Polonica* **54** (1): 21-34.

Demathieu, G. & Demathieu, P. (2003): Ichnologic Note Concerning the Erection of Ichnogenera and Ichnospecies in Vertebrate Ichnotaxonomy. *Ichnos* **9** (3-4): 117-121.

Diedrich, C. (2004): New important iguanodontid and theropod trackways of the tracksite Obernkrichen in the Berriasian of NW Germany and megatracksite concept of Central Europe. *Ichnos* **11** (3): 215-228.

Dietrich, O. W. (1927): Über Fährten ornithopodider Saurier im Oberkirchner Sandstein. *Zeitschrift der Deutschen Geologischen Gesellschaft* **78 [for 1926]** (4): 614-621.

Falkingham, P. L.; Bates, K. T.; Margetts, L. & Manning, P. L. (2011): The 'Goldilocks' effect: preservation bias in vertebrate track assemblages. *Journal of the Royal Society Interface* **8** (61): 1142-1154.

Falkingham, P. L. (2012): Applying objective methods to subjective track outlines. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, p. 20; Göttingen (Universitäts-Verlag). [this volume]

Farlow, J. O.; Langston, W. jr.; Dreschner, E. E.; Solis, R.; Ward, W.; Kirkland, B. L.; Hovorka, S.; Reece, T. L. & Whitcraft, J. (2006): *Texas Giants: Dinosaurs of the Heritage Museum of the Texas Hill Country*. 105 pp.; Canyon Lake (The Heritage Museums of the Texas Hill Country).

Fowler, D. W.; Freedman, E. A.; Scanella, J. B. & Kambic, R. E. (2012): The predatory ecology of Deinonychosauria: foot use compared among dromaeosaurids, troodontids, and basal birds. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, p. 22; Göttingen (Universitäts-Verlag). [this volume]

Gatesy, S. M. & Ellis, R. G. (2012): Tracks as 3-D Particle Trajectories. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, p. 23; Göttingen (Universitäts-Verlag). [this volume]

Graupner, A. (1980): Der Berrias-Steinkohlenbergbau in Niedersachsen 1945–1963. *Veröffentlichungen des niedersächsischen Instituts für Landeskunde und Landesentwicklung an der Universität Göttingen. Forschungen zur niedersächsischen Landeskunde* **116**: 184 pp.

Grupe, O. (1931): Über Wurzelböden im Wealdensandstein der Bückeberge und ihre Bedeutung für den Rhythmus dynamischer Vorgänge. *Zeitschrift der Deutschen Geologischen Gesellschaft* **83**: 224-234.

Hornung, J. J.; Böhme, A., Lubbe, T. van der; 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. *Paläontologische Zeitschrift* **86** (3): 231-267.

Hornung, J. J.; Böhme, A. & Reich, M. (2012): The 'German Wealden' and the Obernkirchen Sandstone – an Introduction. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, 62-72; Göttingen (Universitäts-Verlag). [this volume] [2012b]

Hornung, J. J.; König, J. & Reich, M. (2012): The type material of the ankylosaurian ichnospecies *Metatetrapous valdensis* Nopcsa, 1923 (Early Cretaceous, northern Germany). *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, p. 29; Göttingen (Universitäts-Verlag). [this volume]

Huckriede, R. (1967): Molluskenfaunen mit limnischen und brackischen Elementen aus Jura, Serpulit und Wealden NW-Deutschlands und ihre paläogeographische Bedeutung. *Beihefte zum Geologischen Jahrbuch* **67**: 263 pp.

Krumsiek, R. (1981): *Obernkirchen. Chronik einer alten Stadt.* 176 pp. Obernkirchen (Stadtverwaltung).

Lehmann, J. (2003): Dinosaurierfährten aus dem Obernkirchener Sandstein (Unterkreide, Berriasium) in der Geowissenschaftlichen Sammlung der Universität Bremen. *Abhandlungen des Naturwissenschaftlichen Vereins zu Bremen* **45**: 473-486.

Lehmann, U. (1978): Eine Platte mit Fährten von *Iguanodon* aus dem Obernkirchener Sandstein (Wealden). *Mitteilungen aus dem Geologisch-Paläontologischen Institut der Universität Hamburg* **48**: 101-114.

Lepper, J. & Richter, A. (Koord., 2010): *Steine an der Leine – Naturwerksteine im Stadtbild von Hannover.* 96 pp.; Hannover (LBEG).

Lim, Jong-Deock; Kim, Kyoung-Soo; Kong, Dal-Yong & Kim, Tae-Hyung (2012): Interpreting Korean dinosaur tracksites: Gregarious behavior and group hunting. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, p. 33; Göttingen (Universitäts-Verlag). [this volume]

Lockley, M. G. & Conrad, K. (1989): The paleoenvironmental context and preservation of dinosaur tracksites in the Western U.S.A. *In* Gillette, D. & Lockley, M. G. (eds.): *Dinosaur tracks and traces*, 121-134; Cambridge (Cambridge University Press).

Lockley, M. G. & Harris, J. D. (2012): Two-toed tracks through time: on the trail of "raptors" and their allies. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, p. 34; Göttingen (Universitäts-Verlag). [this volume]

Lockley, M. G.; Wright, J. L. & Thies, D. (2004): Some Observations on the Dinosaur Tracks at Münchehagen (Lower Cretaceous), Germany. *Ichnos* **11** (3-4): 261-274.

Lubbe, T. van der; Richter, A. & Böhme, A. (2009): *Velociraptor's* sisters: First report of troodontid tracks from the Lower Cretaceous of northern Germany. *Journal of Vertebrate Paleontology* **29** (3) [suppl.]: p. 194A.

Manning, P. (2012): 3-Dimensional Dinosaur Tracks: the hidden depths and geometry of vertebrate traces. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, p. 36; Göttingen (Universitäts-Verlag). [this volume]

Marty, D. (2008): *Sedimentology, taphonomy, and ichnology of Late Jurassic dinosaur tracks from the Jura carbonate platform (Chevenez – Combe Ronde tracksite, NW Switzerland): insights into the tidal-flat palaeoenvironment and dinosaur diversity, locomotion, and palaeoecology.* Doctoral thesis, Fribourg, 278 pp.

Marty, D. (2009): Formation and Taphonomy of Human Footprints in Microbial Mats of Present-Day Tidal-Flat Environments: Implications for the Study of Fossil Footprints. *Ichnos* **16** (1-2): 127-142.

Matsukawa, M.; Lockley, M. G. & Jianjun, L. (2005): Cretaceous terrestrial biotas of East Asia, with special reference to dinosaur-dominated ichnofaunas: towards a synthesis. *Cretaceous Research* **27** (1): 3-21.

Milàn, J.; Clemmensen, L. B. & Bonde, N. (2004): Vertical sections through dinosaur tracks (Late Triassic lake deposits, East Greenland) – undertracks and other subsurface deformation structures revealed. *Lethaia* **37** (3): 285-296.

Mutterlose, J. (1997): Lower Cretaceous. *In* Mutterlose, J.; Wippich, M. G. E. & Geisen, M. (eds.): Cretaceous Depositional Environments of NW Germany. *Bochumer Geologische und Geotechnische Arbeiten* **46**: 7-12.

Pelzer, G. (1998): Sedimentologie und Palynologie der Wealden-Fazies im Hannoverschen Bergland. *Courier Forschungsinstitut Senckenberg* **207**: 211 pp.

Raddatz, M. (2010): Geologische Kartierung der Bückeberg-Formation (Unterkreide) am Bückeberg bei Obernkirchen (Niedersachsen). *Unpublished Diploma mapping report, Martin-Luther University Halle.*

Raddatz, M.; Bachmann, G. H. & Richter, A. (2012): A new track horizon in the old Obernkirchen Sandstone quarry of the Bückeberg (Lower Saxony, Germany). *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, p. 50; Göttingen (Universitäts-Verlag). [this volume]

Richter, A.; Böhme, A. & Lubbe, T. van der (2009): "Chicken Run": A new unusual, heavily dinoturbated tracksite from the Lower Cretaceous sandstones of Obernkirchen, northern Germany. *In* 69th Annual Meeting Society of Vertebrate Paleontology and the 57th Symposium of Vertebrate Palaeontology and Comparative Anatomy (SVPCA), University of Bristol, Bristol, United Kingdom, September 23-26, 2009. *Journal of Vertebrate Paleontology* **29** (3) [suppl.]: p. 171A.

Schwennicke, T. (1998): Sedimenttexturen und Lebensspuren der Sohlbank des Naturdenkmals "Saurierfährten Münchehagen". *Mitteilungen aus dem geologischen Institut der Universität Hannover* **37**: 61-102.

Struckmann, C. (1880a): *Die Wealden-Bildung der Umgebung von Hannover. Eine geognostisch-paläontologisch-statistische Darstellung.* viii + 122 pp.; Hannover (Hahn).

Struckmann, C. (1880b): Vorläufige Nachricht über das Vorkommen großer, vogelähnlicher Thierfährten (*Ornithoidichnites*) im Hastingssandsteine von Bad Rehburg bei Hannover. *Neues Jahrbuch für Mineralogie etc.* **[for 1880]** (1): 125-128.

Sullivan, C.; Lubbe, T. van der & Xu Xing (2012): Ichnological implications of structural variations in the paravian foot. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, p. 55; Göttingen (Universitäts-Verlag). [this volume]

Walter, R. (1995): *Geologie von Mitteleuropa.* 566 pp.; Stuttgart (E. Schweizerbart).

Excursion Guide A2: **Harrl hill near Bückeburg**

Jahn J. **Hornung**[1*], Annina **Böhme**[1,3] & Mike **Reich**[1,2]

[1]*Department of Geobiology, Geoscience Centre of the University of Göttingen, Göttingen, Germany*

[2]*Geoscience Museum of the University of Göttingen, Göttingen, Germany*

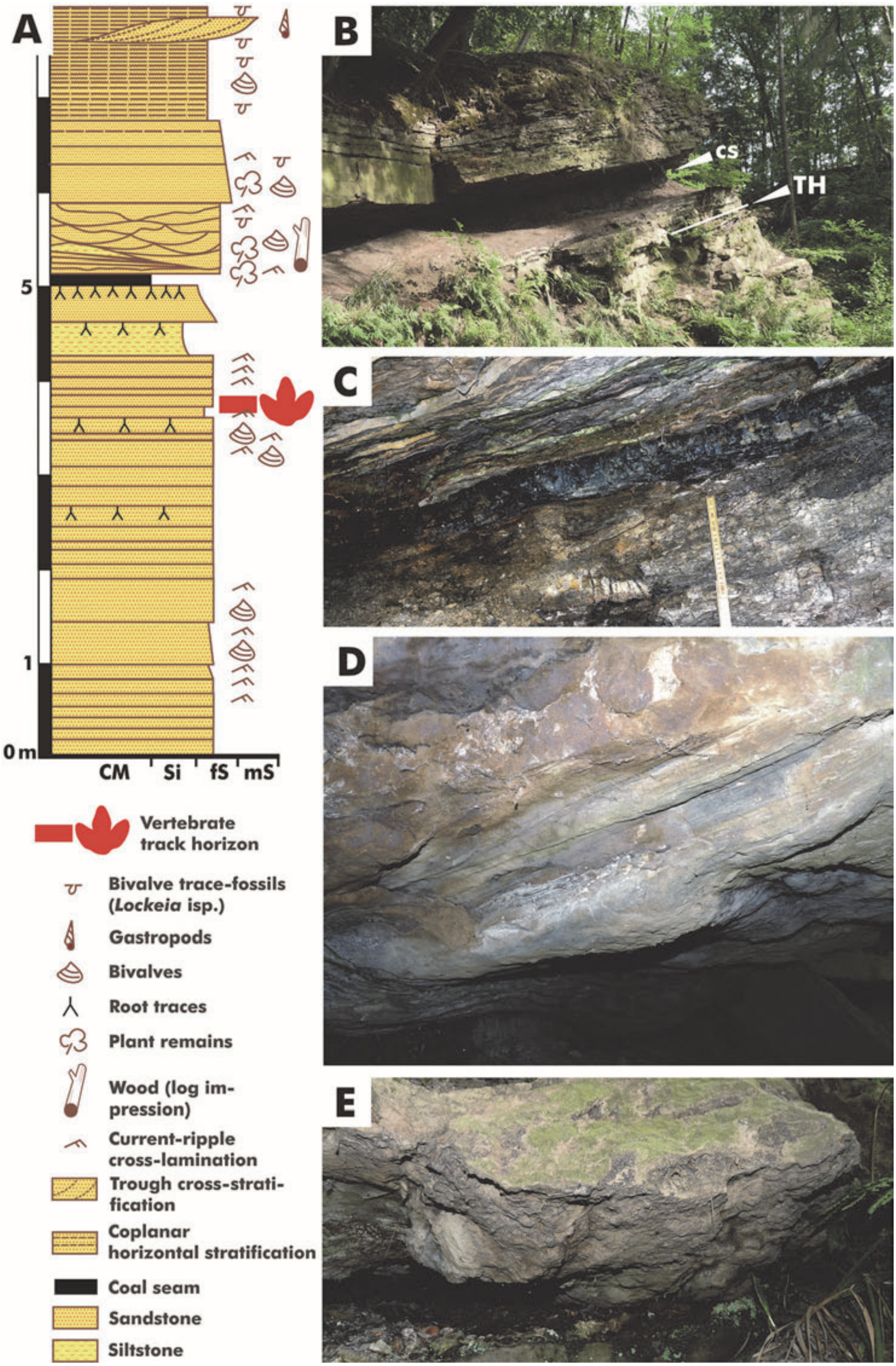
[3]*Hannover State Museum, Hannover, Germany*

[*]*corresponding author:* jhornun@gwdg.de

The Harrl hill, located c. 2 km east of Bückeburg (Hornung, Böhme & Reich 2012b: fig. 1; ► p. 62-72, this volume), is established as a Cretaceous vertebrate locality since the early 19th century. The quarries on the hill were the private property of the Princes of Schaumburg-Lippe. Therefore they are also known as 'Fürstliche Steinbrüche' ('comital quarries'). The dynasty of Schaumburg-Lippe used the stones to build their château at Bückeburg as well as other buildings in the region. Today the quarries are abandoned, partly backfilled or flooded and protected by conservation laws.

Fossils from the Harrl hill were possibly known for centuries to the quarry workers. That these finds were brought to the eyes of the then still nascent science of vertebrate palaeontology was due to the efforts of another local institution: the Adolfinum grammar school (see Böhme, Reich et al. 2012; ► p. 151-167, this volume). This school was founded during the 17th century and soon became the institution in charge of the comital natural history collection. Especially thanks to the efforts of principal Wilhelm Burchard (1804–1887), important vertebrate fossils found on the Harrl hill in the first half of the 19th century were brought to the attention of Hermann von Meyer (1801–1869), an early, very prominent authority in this field. Von Meyer (1841, 1857, 1859) published the first descriptions of a crocodile from the German 'Wealden' (*Pholidosaurus schaumburgensis*) and of a tremendously complete small dinosaur (*Stenopelix valdensis*), whose articulated skeleton only missed the head. At the time of its description, *Stenopelix* was the most complete dinosaur known, although it was not yet identified as such.

During the second half of the 19th century, the scientific interest for the Adolfinum natural history collection dwindled somewhat, until a new enthusiast entered the stage: Max Ballerstedt (1857–1945), then teacher at the Adolfinum. Ballerstedt's palaeontological research began sometime before the turn of the century and yielded first results when he published on dinosaur tracks he had unearthed at the Harrl hill between 1900 and 1905 (Ballerstedt 1905). Dinosaur tracks were first mentioned very briefly from the Harrl by Grabbe (1881), but from his description their nature become not very clear. Ballerstedt was the first to provide figures and some descriptions, including discussions on the trackmakers.


A
B
C
D
E
CS
TH
5
1
0 m
CM
Si
fS
mS
Vertebrate track horizon
Bivalve trace-fossils (Lockeia isp.)
Gastropods
Bivalves
Root traces
Plant remains
Wood (log impression)
Current-ripple cross-lamination
Trough cross-stratification
Coplanar horizontal stratification
Coal seam
Sandstone
Siltstone

The quarries on the Harrl hill were operated on an 'on-demand' basis and Ballerstedt (1921a) reported that the working activities had declined since the middle of the 19th century. However, Ballerstedt's efforts to collect fossils were probably aided by increased production activities, following an extensive building programme at nearby Bad Eilsen, initiated by Adolf II. (1883–1936), the last reigning Prince of Schaumburg-Lippe, between 1911 and 1918 (vom Hofe 2006).

Lithofacies and Cretaceous Environments

Today the exposures at the Harrl hill show a succession of more than 12 meters of sand- to claystones, dipping steeply in northeasterly directions. The erosion resistant, tectonically tilted sandstone, interbedded in soft pelites, formed the shape of the ridge-like hill, which stretches therefore roughly parallel to the strike direction of the beds. Two outcrops, a small pit closer to the town of Bückeburg, and a large quarry, situated c. 350 m to the E, expose the deposits. The smaller outcrop (Fig. 1) has previously been studied by Pelzer (1998), and Grupe (1933) provided a short overview of the whole section.

The succession begins with a c. 8 m thick unit of cm- to dm-thick, fine-grained, massive, horizontally or planar cross-stratified sandstone, deposited in laterally and vertically stacked, shallowly lenticular erosive features. These features are simple scour-and-fill-structures, up to tens of meters wide and commonly less than 0.5 m deep. Bounding surfaces of a higher order separate cosets up to several meters in thickness which occasionally show thickening-upward trends. Towards the top this unit increasingly contains finer-grained, partly silty, massive, plane- or flaser bedded, and current-ripple cross-laminated sandstones. At the small, western outcrop the upper part of this unit was studied in detail (Figs. 1A-B). From about 2.1 m below the coal seam, thinly-bedded massive to ripple cross-laminated, partly silty-clayey fine-grained sandstone contain root horizons in some levels. The successsions shows an overall fining-upward trend.

The lower unit is concluded by a 5–10 cm thick coal seam (seam 'no. 2' of Grupe 1933; Fig. 1C). The upper unit begins with thin, massive, current-ripple cross-laminated, or wavy bedded, fine-grained, partly silty sandstones with abundant plant-remains.

◄ **Fig. 1** Harrl hill near Bückeburg, western quarry, Obernkirchen Sandstone. **(A)** Lithological log. CM: claystone/mudstone, Si: siltstone, fS: fine-grained sandstone, mS: medium-grained sandstone. **(B)** Overview of outcrop, exposed thickness c. 8 m, cs: coal seam, TH: track horizon. **(C)** Coal seam. **(D)** Accumulation of wood fragments, preserved as flattened impressions at the base of sandstone scour-fills, overlying the coal seam. Length of log fragments c. 40 cm. **(E)** Hypichnial cast of a massive, tridactyle footprint, probably of an iguandontian ornithopod, *in situ*. Width of picture c. 60 cm.

The sandstone forms isolated, lenticular, convex-up bedforms, several meters wide and up to 0.3 m thick. The internal bedding surfaces are concordant to the surface of the bedforms. The bedforms are overlain without marked erosion by a 0.4–0.5 m thick complex of fine-grained, massive sandstone, deposited in very shallow, laterally extensive, lenticular erosional features (up to >5 m wide and 0.15 m thick). The infill of these features often begin with a lag consisting of numerous wood logs, preserved as impressions up to 50 cm long (Fig. 1D), and a few but relatively large (3–5 cm) bivalve resting traces (*Lockeia* isp.) are preserved at the base of the unit.

The following c. 2 m of the log are composed of fining- and thinning-upward, massive, predominantly thinly-bedded fine-grained sandstones. With decreasing bed-thickness (from 15 to 1 cm) the abundance of thin clay drapes on the bed boundaries increase upwards. The thinly-bedded layers (5 to 1 cm thickness) show mass-occurrences of small *Lockeia* isp., and occasional double-valved neomiodontid bivalves. Incised in the top of this unit, a small convex-down, lenticular erosional feature is filled with trough cross-stratified medium-grained sandstone, containing numerous plant fragments, neomiodontids and gastropods.

Overlying the former unit, a similar succession of thin-bedded sandstones with abundant *Lockeia* follow after a distinctive erosive boundary. At the large outcrop to the east the same boundary surface can be traced which is overlain by southeastwardly thickening and coarsening sandstone, while the underlying beds tend to be finer-grained and thinner-bedded. This suggests a fan-shaped architecture of both units with fan-diameters in the size range of several 100 meters.

This succession was preliminary interpreted by Pelzer (1998) as tidal channel deposits. However, there is no lithofacies texture indicative of bidirectional currents, which would evidence astronomically controlled tidal cycles. Though storm-induced tides may form unidirectional flow deposits in inlets and breaches, the succession is obviously to complex and records to many different lithofacies to be unified as result of a single event.

The lower part of the section shows quite homogenous facies of beds with marked erosive bases, deposited from turbulent flows. They form complex fills within wide multistorey channels and are interpreted as proximal sandy mouth bar deposits. The presence of flaser and wavy bedding in some of these beds indicate fluctuating flow strength (e.g. Martin 2000), probably related to seasonally changing discharge. Under peak-efflux the stoss-sides of these bars commonly underwent extensive scouring, when the flow-depth is reduced by accumulating sediment (Wright 1977; Van Dijk et al. 2009). Rooting and vertebrate tracks towards the top shows decreasing flow-energy and very shallow water depth.

Dense rooting in the bed underlying the coal seam indicates surface colonization by plants and a distinct ochre coloration as well as high content of clay minerals point toward an initial pedogenesis in this horizon. The coal was probably formed under transgressive conditions, drowning the vegetation and forming a peat-bog swamp (Pelzer 1998).

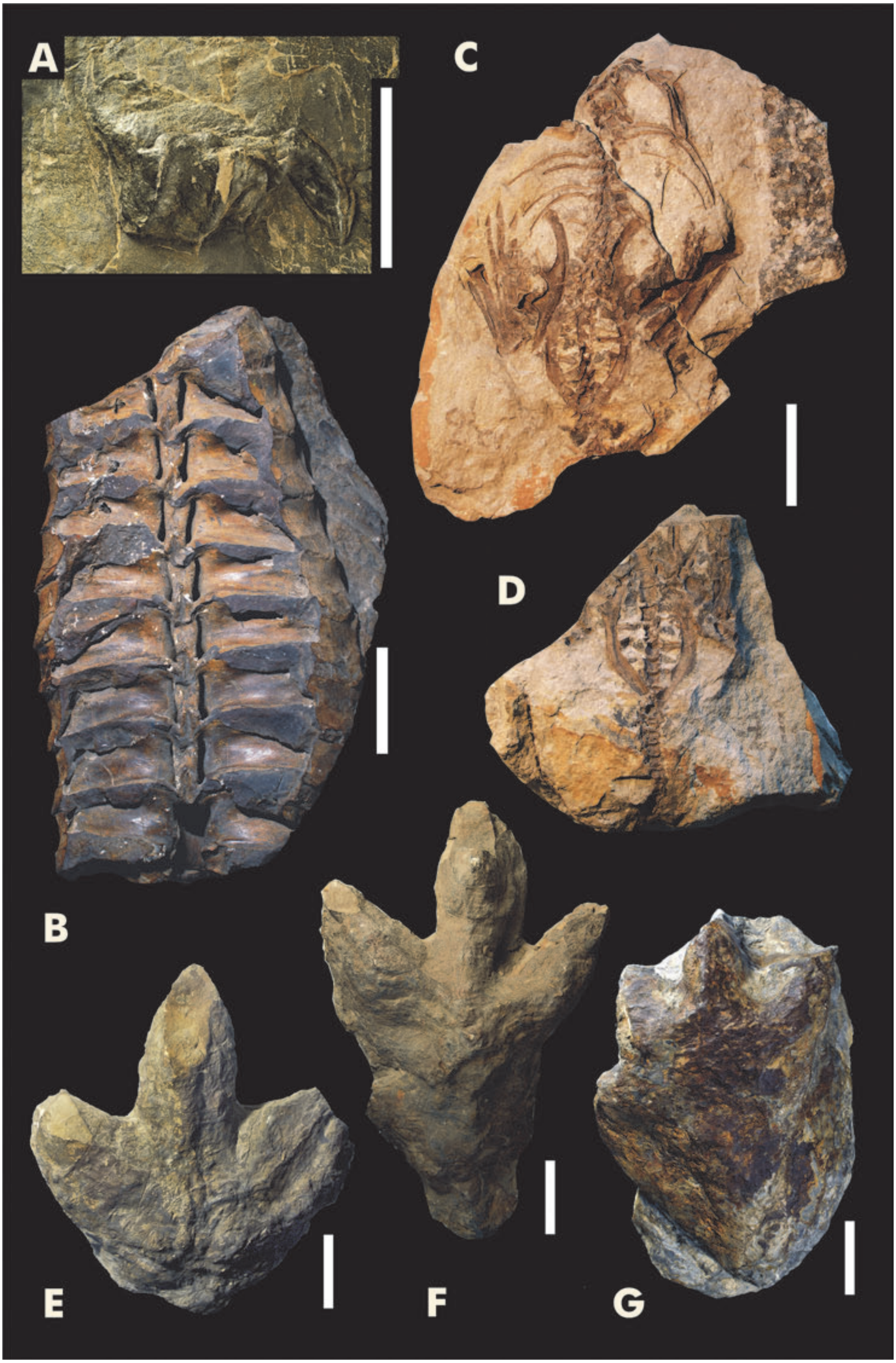
The succession overlying the coal is interpreted as distal mouth bar deposits, forming lobes of thinly-bedded sand interbedded by finer-grained basinal sediments. The sand-sheets have been extensively exploited by neomiodontid bivalves, which left the abundant *Lockeia* traces. Near the base of the unit, a slightly more proximal facies is intercalated including a bed with a basal lag of plant debris, wood logs, and intraclasts. Near the top, channelizing and erosive truncation indicates a regressive stage.

Fossil Fauna and Flora

Due to incomplete records it is not entirely clear for any specimen in the (Göttingen) Ballerstedt collection if it was found on the Harrl hill or in the nearby Bückeberg (Obernkirchen area). This situation will hopefully be improved by the painstaking evaluation of Ballerstedt's personal archive, also kept in Göttingen. His digging and acquisitions at least yielded a number of turtles and crocodiles from the Harrl as well as a large number of vertebrate tracks, invertebrates and plants.

(1) Vertebrates — Among the vast number of turtle specimens in the Ballerstedt collection the situation regarding the origin of specimens is currently especially confusing. About seven species are known from the Bückeberg Formation (Karl et al. 2007a, 2007b, 2012) and it can be anticipated, that at least *Pleurosternon bullockii*, *Ballerstedtia bueckebergensis*, and *Hylaeochelys menkei* (cf. Karl, Staesche et al. 2007), three very common, basal cryptodirans, occur at the Harrl hill. Turtles from the Obernkirchen Sandstone are nearly exclusively known from their shells (impressions and moulds, see Böhme, Reich et al. 2012; ► p. 151-167, this volume), while skulls are entirely missing, despite the abundance of this group. Among the Ballerstedt collection, recently a well preserved manus track hypichnium, left by a swimming or 'bottom-walking' large turtle, was recognized (Hornung, Karl & Reich 2012; ► p. 28, this volume; Fig. 2A).

Crocodilians (e.g. von Meyer 1841; Koken 1886, 1887; Salisbury et al. 1999; Hornung et al. 2009; Andrade & Hornung 2011) include two rather abundant mesoeucrocodylian genera: the short-snouted *Goniopholis* and the long-snouted *Pholidosaurus*. The latter is represented by the holotype of *P. schaumburgensis* (Fig. 2B) and a number of skulls and postcranial elements, some of which evidently were found in the Harrl quarries. Though already identified by Koken (1886) in the Obernkirchen Sandstone, numerous specimens of *Goniopholis* in the Ballerstedt collection remained undescribed (the origin of the well preserved skull at the Goldfuss Museum, University of Bonn, described by Salisbury et al. 1999 is unknown). Recently a skull and large part of the postcranium was reidentified on several blocks dispersed among the collection (Hornung et al. 2009; Andrade & Hornung 2011; Hornung & Reich 2012a; ► p. 26, this volume). This specimen was found before 1925, most probably at the Harrl hill, and is figured in part (skull) in Böhme, Reich et al. (2012; ► p. 151-167, this volume).


A
C
D
B
E
F
G

The holotype of *Stenopelix valdensis* still remains the only reasonably complete dinosaur from the Obernkirchen Sandstone (Figs. 2C-D). Identified as a dinosaur for the first time by Koken (1887), the lack of a skull of this small, bipedal ornithischian led to a great number of hypotheses about its relationships. It was considered a basal 'hypsilophodontid', a primitive pachycephalosaur or a psittacosaurid ceratopsian. The latest thorough revision of the specimen (Butler & Sullivan 2009) came to the conclusion that it is best regarded a marginocephalian of uncertain affinities. However, a recent more inclusive cladistic analysis (Butler et al. 2011) found it to be a very basal ceratopsian, closely related to the Upper Jurassic *Yinlong downsi* from China.

Other dinosaur remains include isolated bones and bone fragments of which at least an iguanodontian pubis was found on the Harrl hill (letter of Max Ballerstedt to Othenio Abel, 02 February 1922; see Karl & Tichy 2007: 288f.)

The dinosaur tracks include those of the ubiquitous iguanodontian ornithopods (Ballerstedt 1905, 1914; Fig. 2E) but also those of a large theropod (Fig. 2F). The latter, described already by Ballerstedt (1905), were identified as those of a carnivorous dinosaur ('*Megalosaurus*') by Abel (1935) and finally named *Bueckeburgichnus maximus* (Fig. 2F; see Kuhn 1958; Lockley 2000; Thulborn 2001; Hornung, Böhme & Reich 2012a; ► p. 27, this volume). Later he found massive, didactyle tracks which he compared to the didactyle foot of an ostrich and named them *Struthopus schaumburgensis* Ballerstedt, 1921b. These tracks have been disputed later – i.e. Abel (1935) argued that they have been left by an ornithopod with severed foot, missing a toe. As Ballerstedt's descriptions were based on isolated hypichnial casts, it was also proposed that they represent incompletely preserved tridactyle tracks. Unfortunately, the original material could not be relocated yet (minor parts of the collection went lost between 1945 and 1976).

◄ **Fig. 2** Reptiles and reptile tracks from the Obernkirchen Sandstone at the Harrl hill. **(A)** Turtle manus impression, GZG.BA.0116, hypichnial cast (see Hornung, Karl & Reich 2012; this volume, p. 28). **(B)** *Pholidosaurus schaumburgensis* von Meyer, 1841, GZG.BA. 0047a, holotype. Impressions of the dorsal vertebral series of a pholidosaurid crocodile. Laterally to the transverse processes, impressions of the outer margin of the dorsal osteodermal shield are also visible *in situ*. **(C-D)** *Stenopelix valdensis* von Meyer, 1857, GZG.BA.0048a-b, holotype. Postcranial skeleton (slab and counter-slab) of a small, basal (?)ceratopsian dinosaur. **(E)** Iguanodontian ornithopod footprint, GZG.BA.0866. Natural hypichnial cast of the right pes. **(F)** *'Bueckeburgichnus' maximus* Kuhn, 1958, ichnotopotypoid GZG.BA.0930. Natural hypichnial cast of the left pes. See Hornung, Böhme & Reich 2012a (this volume, p. 27). **(G)** Ankylosaur footprint, GZG.BA.0050. Natural hypichnial cast of left pes, possibly part of the ichnoholotype of *Metatetrapous valdensis* Nopcsa, 1923. See Hornung, König & Reich 2012 (this volume, p. 29). Scale bars: 10 cm.

In 1921 Ballerstedt discovered a new type of track, left by a quadrupedal animal. He shortly described the specimen and concluded that it was left by a 'secondarily quadrupedal' dinosaur (Ballerstedt 1921a). This track was named *Metatetrapous valdensis* and correctly identified as that of an armoured ornithischian (thyreophoran) by Nopcsa (1923). Being the first thyreophoran (more precisely ankylosaurian) trackway ever identified, it was considered lost by many authorities over the decades (e.g. Haubold 1974). However, in 2007 we were able to identify two hypichnial casts of the pes imprint of an ankylosaur which may belong the original material (Hornung, König & Reich 2012; ► p. 29, this volume; Fig. 2G).

According to Grupe (1933) dinosaur tracks are confined to the section below the coal seam. A track horizon presumed by Pelzer (1998) to be present about 0.9 m below the coal seam was confirmed (pers. obs. 2011; Figs. 1A-B, 1E). The tracks (of which large-sized tridactyle pes impressions of (?)ornithopods were identified in the field) were left in an about 10 cm thick, dark-grey, silty, flasery, current-ripple cross-laminated sandstone and cast by a yellow, massive, fine-grained sandstone. This lithology is congruent with that observable on isolated hypichnial casts from the Ballerstedt collection, supporting an identification of this track-level with that described by the latter. In places the bed shows intensive internal contortion which is interpreted as dinoturbation.

Ballerstedt's material also included the manus track of a large pterosaur (*Purbeckopus* cf. *pentadactylus*), which shows close similarity to contemporaneous material from southern England, is preserved only as a plaster cast which was presented by Ballerstedt to Othenio Abel (1875–1946) in 1935. The latter left the specimen in Göttingen, when he returned to Austria for retirement in 1940. This ichnological evidence is especially important as other records of pterosaurs from the Obernkirchen Sandstone are still a bias. The size of the track indicates an animal with an wingspan of about 6 m (Hornung & Reich 2011).

(2) Invertebrates — at the Harrl hill are mostly represented by bivalves and gastropods. The bivalves belong to the family Neomiodontidae, which indicate freshwater or brachyhaline conditions (Huckriede 1967). The gastropods include Viviparidae, which are also indicative for freshwater. Several levels are strongly bioturbated by shallowly burrowing neomiodontids, leaving very abundant *Lockeia* isp. trace-fossils.

(3) Plants — The palaeoflora is mostly documented by abundant root-traces of various types (Pelzer 1998). Immediately above the coal-seam a lag of wooden trunks, preserved as flattened impressions, is present, preserved and Ballerstedt (in Grupe 1933) noted the occurrence of the tree-fern *Tempskya* in this layer. Silicified fragments of pseudo-stems of this genus are abundantly present in his collection.

Outlook

This overview on the historical outcrops at the Harrl hill is far from being complete. Research to be undertaken in the future has to include a more detailed interpretation of the facies and environment, as well as a stratigraphical correlation with other outcrops of the Obernkirchen Sandstone. The latter may be faciliated by the recognition of a major erosive boundary surface near the top of the outcrop, a similar discontinuity has been found in the Bückeberge (Dietrich 1927; pers. obs.) and in the Rehburg Mountains (Fischer 1998; Hornung, Böhme & Reich 2012d; ► p. 143-149, this volume). It is probably related to a significant drop of the lake level and can potentially serve as a cornerstone for a future sequence-stratigraphical framework of the Obernkirchen Sandstone.

References

Abel, O. (1935): *Vorzeitliche Lebensspuren.* xv + 664 pp.; Jena (Fischer).

Andrade, M. B. de & Hornung, J. J. (2011): A new look into the periorbital morphology of *Goniopholis* (Mesoeucrocodylia: Neosuchia) and related forms. *Journal of Vertebrate Paleontology* **31** (2): 352-368.

Ballerstedt, M. (1905): Über Saurierfährten der Wealdenformation Bückeburgs. *Naturwissenschaftliche Wochenschrift (Neue Folge)* **4** (31): 481-485.

Ballerstedt, M. (1914): Bemerkungen zu den älteren Berichten über Saurierfährten im Wealdensandstein und Behandlung einer neuen, aus 5 Fußabdrücken bestehenden Spur. *Centralblatt für Mineralogie, Geologie und Paläontologie* **[1914]** (2): 48-64.

Ballerstedt, M. (1921a): Zwei große, zweizehige Fährten hochbeiniger Bipeden aus dem Wealdensandstein bei Bückeburg. *Zeitschrift der Deutschen Geologischen Gesellschaft, Monatsberichte* **73B**: 76-91.

Ballerstedt, M. (1921b): Dinosaurierfährten im Wealdensandstein des Harrl bei Bückeburg und eine zur Zeit freiliegende Spur eine „vierfüßigen“ plumpen Dinosauriers. *Zeitschrift der Deutschen Geologischen Gesellschaft* **72**: 231-233.

Ballerstedt, M. (1922): Über Schreckensaurier und ihre Fußspuren. *Kosmos* **19** (3): 77-80.

Böhme, A.; Reich, M.; Hornung, J. J. & Karl, H.-V. (2012): Excursion Guide C1: Northern 'German Wealden' – the collection of the Göttingen University. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, 151-167; Göttingen (Universitäts-Verlag). [this volume]

Butler, R. J. & Sullivan, R. M. (2009): The phylogenetic position of the ornithischian dinosaur *Stenopelix valdensis* from the Lower Cretaceous of Germany and the early fossil record of Pachycephalosauria. *Acta Palaeontologica Polonica* **54** (1): 21-34.

Butler, R. J.; Liyong, L.; Jun, C. & Godefroit, P. (2011): The postcranial osteology and phylogenetic position of the small ornithischian dinosaur *Changchunsaurus parvus* from the Quantou Formation (Cretaceous: Aptian–Cenomanian) of Jilin Province, north-eastern China. *Palaeontology* **54** (3): 667-683.

Dietrich, O. W. (1927): Über Fährten ornithopodider Saurier im Oberkirchner Sandstein. *Zeitschrift der Deutschen Geologischen Gesellschaft* **78 [for 1926]** (4): 614-621.

Fischer, R. (1998): Die Saurierfährten im Naturdenkmal Münchehagen. *Mitteilungen aus dem geologischen Institut der Universität Hannover* **37**: 3-59.

Grabbe, H. (1881): Neue Funde von Saurier-Fährten im Wealdensandsteine des Bückeberges. *Verhandlungen des naturhistorischen Vereines der preussischen Rheinlande und Westfalens, Correspondenzblatt* **38** (1): 161–164. [= *Vierte Folge* **8**]

Grupe, O. (1933): Blatt Bückeburg, Nr. 2017. *Erläuterungen zur geologischen Karte von Preußen und benachbarter deutscher Länder, Lieferung* **330**: 69 pp.

Hofe, A. vom (2006): *Vier Prinzen zu Schaumburg-Lippe und das parallele Unrechtssystem.* 390 pp.; Madrid (Vierprinzen, S.L.).

Hornung, J. J.; Andrade, M. B. de & Reich, M. (2009): Are *Goniopholis crassidens* and *G. simus* different species of crocodilians? New postcranial evidence solving a taxonomic riddle. *In* 69th Annual Meeting Society of Vertebrate Paleontology and the 57th Symposium of Vertebrate Palaeontology and Comparative Anatomy (SVPCA), University of Bristol, Bristol, United Kingdom, September 23-26, 2009. *Journal of Vertebrate Paleontology* **29** (3) [suppl.]: p. 117A.

Hornung, J. J.; Böhme, A. & Reich, M. (2012): The type material of the theropod ichnotaxon *"Bueckeburgichnus" maximus* Kuhn, 1958 – reconsidered. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, p. 27; Göttingen (Universitäts-Verlag). [this volume] [2012a]

Hornung, J. J.; Böhme, A. & Reich, M. (2012): Excursion Guides A-C: The 'German Wealden' and the Obernkirchen Sandstone – an Introduction. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, 62-72; Göttingen (Universitäts-Verlag). [this volume] [2012b]

Hornung, J. J.; Böhme, A. & Reich, M. (2012): Excursion Guide B2: Wölpinghausen. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, 143-149; Göttingen (Universitäts-Verlag). [this volume] [2012d]

Hornung, J. J.; Karl, H.-V. & Reich, M. (2012): A well-preserved isolated turtle footprint from the lowermost Cretaceous (Berriasian) of northern Germany. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, p. 28; Göttingen (Universitäts-Verlag). [this volume]

Hornung, J. J.; König, J. & Reich, M. (2012): The type material of the ankylosaurian ichnospecies *Metatetrapous valdensis* Nopcsa, 1923 (Early Cretaceous, northern Germany). *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, p. 29; Göttingen (Universitäts-Verlag). [this volume]

Hornung, J. J. & Reich, M. (2006): The "Wealden" collection of Max Ballerstedt (1857-1945) – undisclosed treasures from the Early Cretaceous of northwestern Germany. *In* 76. Jahrestagung der Paläontologischen Gesellschaft. Kiel, 28.-30. August 2006. Beitragskurzfassungen. *Berichte-Reports des Instituts für Geowissenschaften, Christian-Albrechts-Universität Kiel* **22**: 40-41.

Hornung, J. J. & Reich, M. (2007): Krokodile, Schildkröten & Dinosaurier. Die „Wealden"-Sammlung der Universität Göttingen. *Fossilien* **24** (1): 32-36.

Hornung, J. J. & Reich, M. (2011): The first record of a pterosaur ichnite from the lower Bückeberg Formation (Early Cretaceous) of Bückeburg, Lower Saxony, northern Germany. *In* Nagel, D. (ed.): 82. Jahrestagung der Paläontologischen Gesellschaft in Wien, Abstract Volume. *Beiträge zur Paläontologie* **32**: 55-56.

Hornung, J. J. & Reich, M. (2012): The croc puzzle: a fairly complete specimen of *Goniopholis* (Mesoeucrocodylia: Goniopholididae) from the Bückeberg Formation (Berriasian) of Bückeburg, northern Germany. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, p. 26; Göttingen (Universitäts-Verlag). [this volume] [2012a]

Huckriede, R. (1967): Molluskenfaunen mit limnischen und brackischen Elementen aus Jura, Serpulit und Wealden NW-Deutschlands und ihre paläogeographische Bedeutung. *Beihefte zum Geologischen Jahrbuch* **67**: 263 pp.

Karl, H.-V. & Tichy, G. (2007): Zur frühen Geschichte der Paläocheloniologie von Schaumburg-Lippe. Die Rolle des Gymnasial-Professors Max Ballerstedt in der Naturwissenschaft. *Berichte zur Wissenschaftsgeschichte* **27**: 285-296.

Karl, H.-V.; Gehler, A.; Roden, V. J. & Reich, M. (2007): Die Schildkröten des nordwestdeutschen „Wealden" (Unter-Kreide: Berriasium) und ihre Paläoökologie. *In* Elicki, O. & Schneider, J. W. (eds.): Fossile Ökosysteme. 77. Jahrestagung der Paläontologischen Gesellschaft. Kurzfassungen der Vorträge und Poster. *Wissenschaftliche Mitteilungen, Institut für Geologie, TU Bergakademie Freiberg* **36**: 64-65. [2007a]

Karl, H.-V.; Gröning, E.; Brauckmann, C. & Reich, M. (2012): *Ballerstedtia bueckebergensis*, a new turtle from the Early Cretaceous Wealden facies of Germany (Testudines: Pleurosternidae). *In* Karl, H.-V. (ed.): Turtle faunal changes in Central Europe and related areas. *Studia Palaeocheloniologica* **IV**: 47-60. [= *Studia geológica Salmanticensia, Volumen especial* **9**] [2007b]

Karl, H.-V.; Staesche, U.; Tichy, G.; Lehmann, J. & Peitz, S. (2007): Systematik der Schildkröten (Anapsida: Chelonii) aus Oberjura und Unterkreide von Nordwestdeutschland. *In* Staesche, U. (coord.): Fossile Schildkröten aus vier Ländern in drei Kontinenten. *Geologisches Jahrbuch (B: Regionale Geologie Ausland)* **98**: 5-89.

Koken, E. (1886): Vorkommen fossiler Crocodiliden in den Wealdenbildungen Norddeutschlands und über die Systematik der mesozoischen Crocodiliden. *Zeitschrift der Deutschen Geologischen Gesellschaft* **38**: 664-670.

Koken, E. (1887): Die Dinosaurier, Crocodiliden und Sauropterygier des norddeutschen Wealden. *Palaeontologische Abhandlungen* **3** (5): 1-111.

Kuhn, O. (1958): *Die Fährten der vorzeitlichen Amphibien und Reptilien.* 64 pp.; Bamberg (Meisenbach).

Lockley, M. G. (2000): An amended description of the theropod footprint *Bueckeburgichnus maximus* Kuhn 1958, and its bearing on the megalosaur tracks debate. *Ichnos* **7** (3): 217-225.

Martin, A. J. (2000): Flaser and wavy bedding in ephemeral streams: a modern and an ancient example. *Sedimentary Geology* **136** (1-2): 1-5.

Meyer, H. von (1841): *Pholidosaurus schaumburgensis*, ein Saurus aus dem Sandstein der Wald-Formation Nord-Deutschlands. *Neues Jahrbuch für Mineralogie, Geognosie, Geologie und Petrefakten-Kunde* **[for 1841]**: 443-445.

Meyer, H. von (1857): Beiträge zur näheren Kenntnis fossiler Reptilien. *Neues Jahrbuch für Mineralogie, Geologie und Paläontologie* **[for 1857]**: 532-543.

Meyer, H. von (1859): *Stenopelix Valdensis*, ein Reptil aus der Wealden-Formation Deutschlands. *Palaeontographica* **7** (1): 25-34.

Nopcsa, F. (1923): Die Familien der Reptilien. *Fortschritte der Geologie und Paläontologie* **1** (2): 210 pp.

Owen, R. (1842): Report on British Fossil Reptiles, Part II. *Report of the Annual Meeting of the British Association for the Advancement of Science* **11** [1841]: 60-204.

Owen, R. (1878): Monograph on the fossil Reptilia of the Wealden and Purbeck formations – Crocodilia (*Goniopholis*, *Pterosuchus*, and *Suchosaurus*). *Monograph of the Palaeontographical Society* **7**: 1-15.

Pelzer, G. (1998): Sedimentologie und Palynologie der Wealden-Fazies im Hannoverschen Bergland. *Courier Forschungsinstitut Senckenberg* **207**: 211 pp.

Salisbury, S. W.; Willis, P. M. A.; Peitz, S. & Sander, P. M. (1999): The crocodilian *Goniopholis simus* from the Lower Cretaceous of north-western Germany. *In* Unwin, D. M. (ed.): Cretaceous fossil vertebrates. *Special Papers in Palaeontology* **60**: 121-148.

Thulborn, R. A. (2001): History and nomenclature of the theropod dinosaur tracks *Bueckeburgichnus* and *Megalosauripus*. *Ichnos* **8** (3-4): 207-222.

Van Dijk, M.; Postma, G. & Kleinhans, M. G. (2009): Autocyclic behaviour of fan-deltas: an analogue experimental study. *Sedimentology* **56** (5): 1569-1589.

Wright, L. D. (1977): Sediment transport and deposition at river mouths: A synthesis. *Geological Society of America, Bulletin* **88** (6): 857-868.

Excursion Guide B1: **The Early Cretaceous Dinosaur Trackways in Münchehagen (Lower Saxony, Germany) – The Natural Monument 'Saurierfährten Münchehagen' and the adjacent Wesling Quarry**

Oliver **Wings**[1*], Daniel **Falk**[2], Nils **Knötschke**[3] & Annette **Richter**[1]

[1]*Hannover State Museum, Hannover, Germany*

[2]*TU Bergakademie Freiberg, Geological Institute, Freiberg/Sa., Germany*

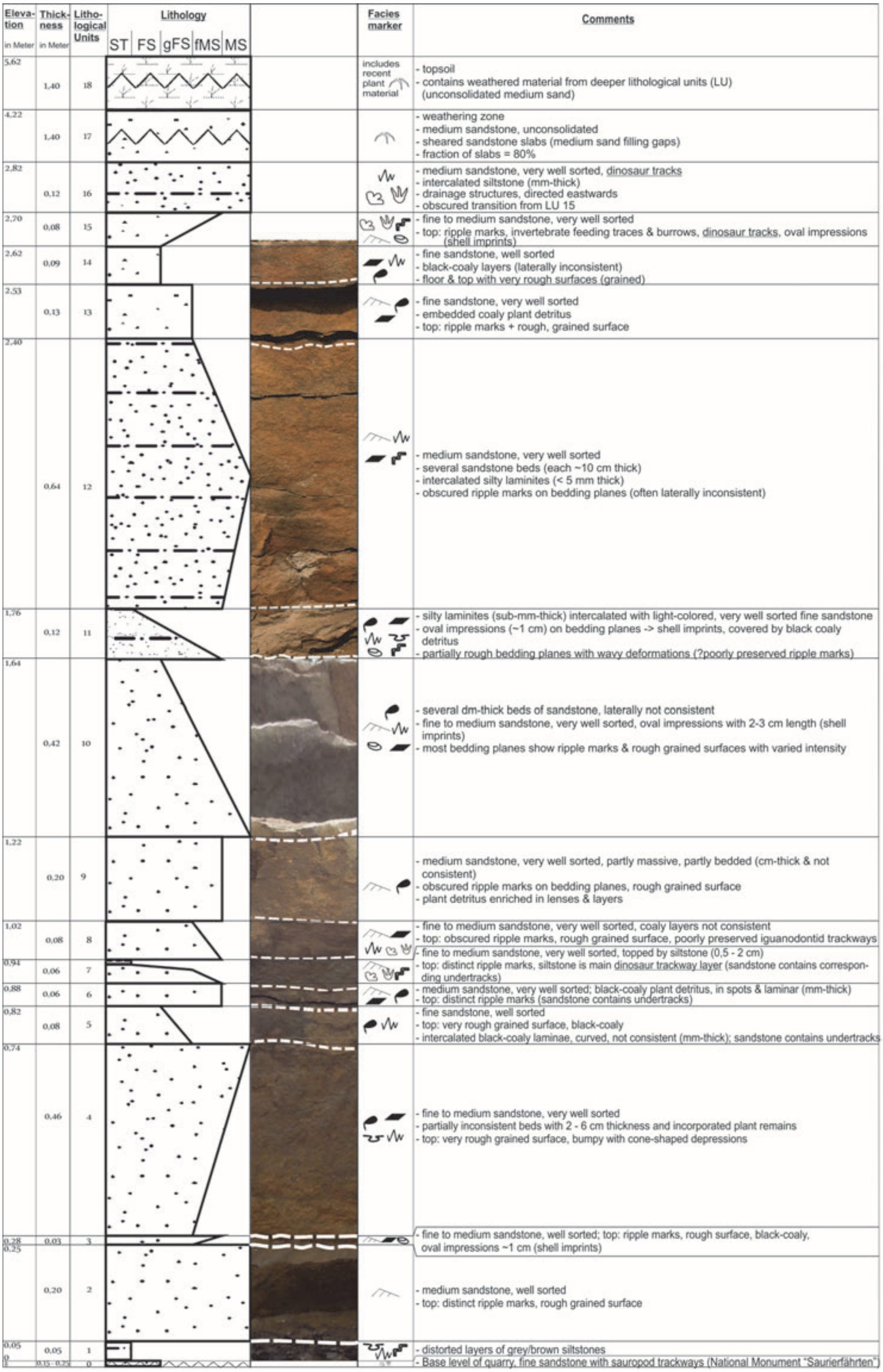
[3]*Dinosaurier-Park Münchehagen, Rehburg-Loccum, Germany*

[*]*corresponding author:* oliver.wings@web.de

Impressively large sauropod dinosaur tracks were discovered in the 1970s at the so-called 'Old Wesling-Quarry' in Münchehagen on the western flank of the Rehburg Mountains. Unique in Germany, the locality was designated as a Natural Monument by the Federal State of Lower Saxony during the following years. This marked the beginning of continuous dinosaur track research in the Rehburg-Loccum district and induced the establishment of the Dinosaur Park Münchehagen in the early 1990s. In 2004, new tridactyl dinosaur trackways were discovered in the active, new Wesling-Quarry adjacent to the Dinosaurier-Park. These discoveries led to a series of excavations by the Lower Saxon State Museum in cooperation with the Dinosaurier-Park Münchehagen and the F. Wesling Group.

The brownish to yellow-grey, fine grained quartz sandstones from the Berriasian Bückeberg Formation = 'German Wealden' are solid working stones and have been quarried in small to medium-sized quarries for many centuries. The sandstones served as massive working stones at the very influential local Cistercian monastery 'Kloster Loccum' (founded in 1163), but also for minor church buildings like the 'St.-Katharinen.-Kirche' in Bergkirchen, built by Cistercian munks. The local Rehburg sandstone was usually complemented with other Berriasian working stones from the Bückeberg area (Obernkirchen Sandstone; see Richter, Hornung et al. 2012; ► p. 73-99, this volume), although the majority derived from the direct vicinity due to transportation limitations in medieval times. While the 'Old Wesling Quarry' delivered working stones as well as road gravel, the active quarry is mainly exploited for road construction material.

Mostly covered by Cenozoic deposits, Berriasian sandstones are only exposed in several hilly areas in middle and southern Lower Saxony. The local uplifts of Jurassic and Early Cretaceous strata resulted from basin inversion since the Late Cretaceous, locally triggered by halotectonic movements of Permian salt structures (Walter et al. 1995). The most important and often fossiliferous Berriasian exposures are, aside of Münchehagen, the Harrl hill, the Rehburg Mountains, the Deister mountain, Süntel, Nesselberg and Osterwald. All of them represent overall similar depositional environments in one large palaeogeographic system at the sou-


Elevation in Meter
Thickness in Meter
Lithological Units
Lithology
ST FS gFS fMS MS
Facies marker
Comments
5,62 1,40 18
includes recent plant material
- topsoil
- contains weathered material from deeper lithological units (LU) (unconsolidated medium sand)
4,22 1,40 17
- weathering zone
- medium sandstone, unconsolidated
- sheared sandstone slabs (medium sand filling gaps)
- fraction of slabs = 80%
2,82 0,12 16
- medium sandstone, very well sorted, dinosaur tracks
- intercalated siltstone (mm-thick)
- drainage structures, directed eastwards
- obscured transition from LU 15
2,70 0,08 15
- fine to medium sandstone, very well sorted
- top: ripple marks, invertebrate feeding traces & burrows, dinosaur tracks, oval impressions (shell imprints)
2,62 0,09 14
- fine sandstone, well sorted
- black-coaly layers (laterally inconsistent)
- floor & top with very rough surfaces (grained)
2,53 0,13 13
- fine sandstone, very well sorted
- embedded coaly plant detritus
- top: ripple marks + rough, grained surface
2,40 0,64 12
- medium sandstone, very well sorted
- several sandstone beds (each ~10 cm thick)
- intercalated silty laminites (< 5 mm thick)
- obscured ripple marks on bedding planes (often laterally inconsistent)
1,76 0,12 11
- silty laminites (sub-mm-thick) intercalated with light-colored, very well sorted fine sandstone
- oval impressions (~1 cm) on bedding planes -> shell imprints, covered by black coaly detritus
- partially rough bedding planes with wavy deformations (?poorly preserved ripple marks)
1,64 0,42 10
- several dm-thick beds of sandstone, laterally not consistent
- fine to medium sandstone, very well sorted, oval impressions with 2-3 cm length (shell imprints)
- most bedding planes show ripple marks & rough grained surfaces with varied intensity
1,22 0,20 9
- medium sandstone, very well sorted, partly massive, partly bedded (cm-thick & not consistent)
- obscured ripple marks on bedding planes, rough grained surface
- plant detritus enriched in lenses & layers
1,02 0,08 8
- fine to medium sandstone, very well sorted, coaly layers not consistent
- top: obscured ripple marks, rough grained surface, poorly preserved iguanodontid trackways
0,94 0,06 7
- fine to medium sandstone, very well sorted, topped by siltstone (0,5 - 2 cm)
- top: distinct ripple marks, siltstone is main dinosaur trackway layer (sandstone contains corresponding undertracks)
0,88 0,06 6
- medium sandstone, very well sorted; black-coaly plant detritus, in spots & laminar (mm-thick)
- top: distinct ripple marks (sandstone contains undertracks)
0,82 0,08 5
- fine sandstone, well sorted
- top: very rough grained surface, black-coaly
- intercalated black-coaly laminae, curved, not consistent (mm-thick); sandstone contains undertracks
0,74 0,46 4
- fine to medium sandstone, very well sorted
- partially inconsistent beds with 2 - 6 cm thickness and incorporated plant remains
- top: very rough grained surface, bumpy with cone-shaped depressions
0,28 0,03 3
- fine to medium sandstone, well sorted; top: ripple marks, rough surface, black-coaly, oval impressions ~1 cm (shell imprints)
0,25 0,20 2
- medium sandstone, well sorted
- top: distinct ripple marks, rough grained surface
0,05 0,05 1
- distorted layers of grey/brown siltstones
0 0,15 - 0,25 0
- Base level of quarry, fine sandstone with sauropod trackways (National Monument "Saurierfährten")

thern rim of the Lower Saxony Basin, but may differ regionally in facies. For an overview of the 'German Wealden' and a general map, see Hornung, Böhme & Reich 2012b (► p. 62-72, this volume). Stratigraphically, the strata in the Münchehagen quarries belong to the Obernkirchen Sandstone which is a part of the Bückeberg Formation.

The uplift of the small diapir below the Münchehagen area caused a typical geological inversion structure. Once the weathering-resistant strata were eroded at the hilltops, the underlying soft and soluble gypsum and salt layers eroded quickly, resulting in today's landscape morphology of oval-shaped rims of Late Jurassic limestones and Early Cretaceous sandstones (Jordan 1979).

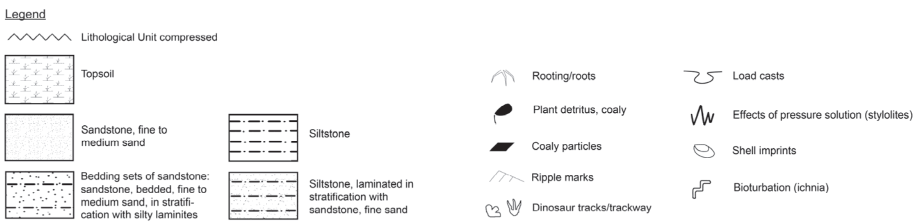
Quarrying activities and a growing interest in earth history in Europe led to the first finds of dinosaur tracks in the 19th century. Tridactyl tracks from the Rehburg Mountains were interpreted by the Lower Saxon amateur palaeontologist and collector Carl E. F. Struckmann (1833–1898) as early as 1880 (Struckmann 1880) and were correctly assigned to the then 'newly' erected group 'Dinosauria'. One of his classic finds is pictured in Hornung, Böhme et al. (2012).

Abbreviations: NLMH = Niedersächsisches Landesmuseum Hannover / Hannover State Museum; DFM = Dinosaurierfreilichtmuseum Münchehagen / Dinosaurier-Park Münchehagen, Rehburg-Loccum; MWK = Niedersächsisches Ministerium für Wissenschaft und Kultur / Lower Saxon Ministry of Science and Culture; GZG = Geowissenschaftliches Zentrum, Georg-August-Universität Göttingen / Geoscience Centre, Georg-August University of Göttingen.

Sedimentology

Both Wesling Quarries yield predominantly fine to medium quartz sandstones which are strongly siliceously cemented. The exposed geological profile (Fig. 1) has a total thickness of 5.62 m. Individual beds can be traced on a cm to dm scale, but are often laterally variable. Therefore, 19 lithological units (LU) were determined based on bedding planes with >10 m lateral extension.

◄ **Fig. 1** Geological profile in the New Wesling Quarry.



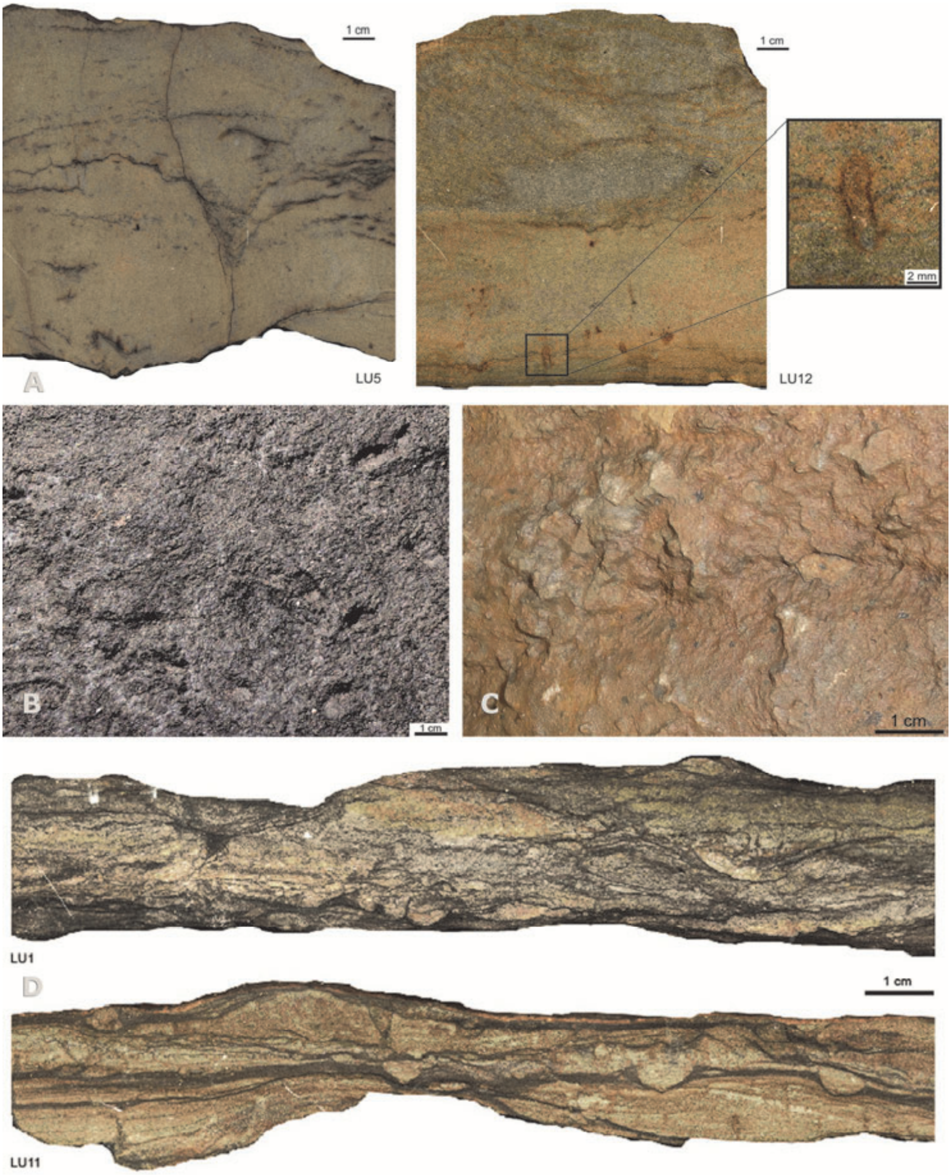


Fig. 2 **(A)** Cross-section photos of samples of LU5 and LU12. Note the local chemical discolorations ('Liesegang rings') and an invertebrate burrow (enlarged detail) in LU5 and the jagged suture caused by pressure dissolution in the central region of the LU12 sample. **(B)** Coaly bedding plane within LU10 with a rough (grained) surface and cm-sized oval shell imprints. **(C)** Rough (grained) bedding plane (LU3), possibly formed by pressure dissolution and microbial mats. **(D)** Polished samples of LU1 and LU11, illustrate their similar appearance. Note the deformed interbedded strata and the semi-circular structures (bioturbation and/or load casts).

The quarry base (LU0) is a fine grained sandstone bed with ripple marks and bioturbation by invertebrates and dinosaurs. This bed yields the well-known sauropod trackways in the DFM (Fischer 1998; Schwennicke 1998).

Colorful dark brown-grey sutures caused by grain margin dissolution are common in the sandstones (Fig. 1, 2A). The sutures often show a distorted and wavy-jagged outline (LU1–LU6; LU8–LU14; LU16). Ripple marks are often present on bedding planes (LU2; LU3; LU6–LU8; LU9; LU10; LU12; LU13; LU15; LU16) and may show a rough jagged surface (LU2–LU6; LU8–LU11; LU13; LU14). Some bedding planes are partially covered with coaly layers (Fig. 2B), others are very rough (Fig. 2C). Others have a limited lateral extension (LU3; LU6; LU8; LU10). Drainage structures are present on few bedding planes (LU10; LU16). Some lithological units yield small (1–3 cm) oval impressions (LU3; LU10; LU11; LU15), which are interpreted as shell imprints (Fig. 2B). Inhomogenously embedded coaly particles, resulting from plant detritus, and coaly layers are very common (LU4–LU6; LU9–LU11; LU13; LU14) and often coincide with pressure dissolution sutures. Chemical (dis)coloration ('Liesegang rings'; LU1; LU10–LU16, Fig. 2A) was probably caused by organic carbon and/or mineral ions.

In addition to invertebrate bioturbation (LU1; LU7; LU11; LU12; LU15; Fig. 2A, 2D), tridactyl dinosaurs tracks occur in several levels (LU7; LU8; LU15; LU16). Recent root penetration is found in the weathered zone (LU17; LU18) towards the top of the profile. In the upper zone of the profile (LU11; LU12; LU16), the sandstone beds are increasingly intercalated with mm-thick siltstone layers, representing slack water intervals. In the upper part of LU7, the sandstone is overlain from a layered 0.5–2 cm thick silty mudstone (Figs. 1, 3). This mudstone is a true dinosaur track surface and contains the best preserved tracks in the profile. Undertracks of the footprints in LU7 are clearly visible in LU6 and LU5.

Interestingly, LU1 and LU11 are very similar in general characteristics (grain size, color, bioturbation; Fig. 2D), suggesting similar depositional conditions. Slack water deposited siltstones and mudstones are intercalated with sandstones indicating temporarily higher flowing regimes (e.g. storm events).

***Ripple marks* —** Most sandstone surfaces are dominated by ripple marks and dip slightly to WSW with 3–6°. Distinct channels with a length of several meters show a paleo-flowing direction to W. The ripple marks (Fig. 3) can be classified as smallscale ripples (Allen 1968). They are symmetrical with mostly rounded crests which are mostly oriented in N–S direction. The ripple crests are mostly parallel, partly bifurcated, with a rough surface and/or are slightly eroded (plain crests). They can be determined as 'straight crested' and 'sinuous in phase' (Collinson et al. 2006) indicating wave ripples (RSI) which are generated by an unidirectional undulating water flow (foreset laminae) in shallow water offshore areas with a temporary influence of currents (drifting; RI). Minimal water depth ranged from 2.7 cm to 5.4 cm, whereas the maximum water depth cannot be determined (Schwennicke 1998). The identical orientation of crest lines on different bedding planes reveals that flow and wave direction were consistent during the deposition of several beds. The sandstone grain sizes of 0.063 mm to 0.2 mm (fine sand to medium sand) characterize current velocities of 10–30 cm/s (Allen 1968; Reineck & Singh 1980).

Fig. 3 Photograph of wide-spread smallscale ripple marks on the bedding surface of LU7. The ripple marks are sinuous in phase and straight crested. Note the dinosaur footprints of about 30 cm length and nearly 10 cm in depth.

The Natural Monument 'Dinosaurierfährten Münchehagen' – Old Wesling Quarry

The quarry base sandstone layer in the 'Steinbruch der Firma Wesling an der Alten Poststraße' (Old Wesling Quarry) in Münchehagen was exposed since 1965. When quarry work stopped completely in 1972, interested citizens under the leadership of Rolf Hulke started their care for the locality and managed to have the quarry cleaned by local fire fighters in 1980. From then on, the preserved sauropod trackways were clearly visible. These trackways present until now the first and only evidence for sauropod dinosaurs in the German Wealden.

Hulke was the first to identify the Münchehagen trackmakers as sauropod dinosaurs and informed politicians and scientists about the find. Soon after, palaeontologists from the Westphalian State Museum in Münster started to cast sauropod tracks and describe them as *Rotundichnus muenchehagensis* (Hendricks 1981). Hulke's ambitious dedication was rewarded in 1983, when the rural county of Nienburg erected a preliminary protection hall (see Look et al. 1988). The federal state of Lower Saxony put the Münchehagen locality under the protectoral status of a Natural Monument in 1987. A larger and more professional building was constructed in 1992. It opened for the public in 1993 and was also funded by the government of Lower Saxony.

To boost geo-tourism in the area, the rural county started a private-public-partnership by combining the Natural Monument with a surrounding educational theme park about 'Earth History' (Fig. 6). To date, the DFM looks back on two decades of successful education, entertainment, and research. Its chronological/stratigraphical earth history path was arranged by the palaeontologist Detlef Thies, who integrated the sauropod trackways as an authentic part of the exhibition between the Jurassic and Cretaceous sections of the path.

An excellent summary of the palaeontology and sedimentology of the Münchehagen tracksite was published in German by Rudolf Fischer and colleagues in 1998.

The gross morphology of the pes impressions of '*Rotundichnus muenchehagensis*' is an oval to elongated-oval shape, appearing slightly triangular, with the longest 'peak' pointing backwards (Figs. 4-5). The floor of the tracks is uneven; the medial side is always deeper. Also, the tip of the triangular oval is the deepest point altogether. The feet were put into the sediment in an oblique manner, the medial sides of the feet imprinting deeper and obviously bearing more weight as well as the tip of the toes I and II (Fischer 1998). Even at better preserved pes imprints, there is no impression of a claw or single, marked toes like in other sauropod tracks. The anterior margin is always smooth and rounded, lacking evidence for differentiations of the foot front (Fischer 1998).

Fig. 4 Scan from an analogous photograph from 1986, showing the first field impressions of the sauropod tracks in Münchehagen. Photo courtesy: E. Schmidt, Hannover.

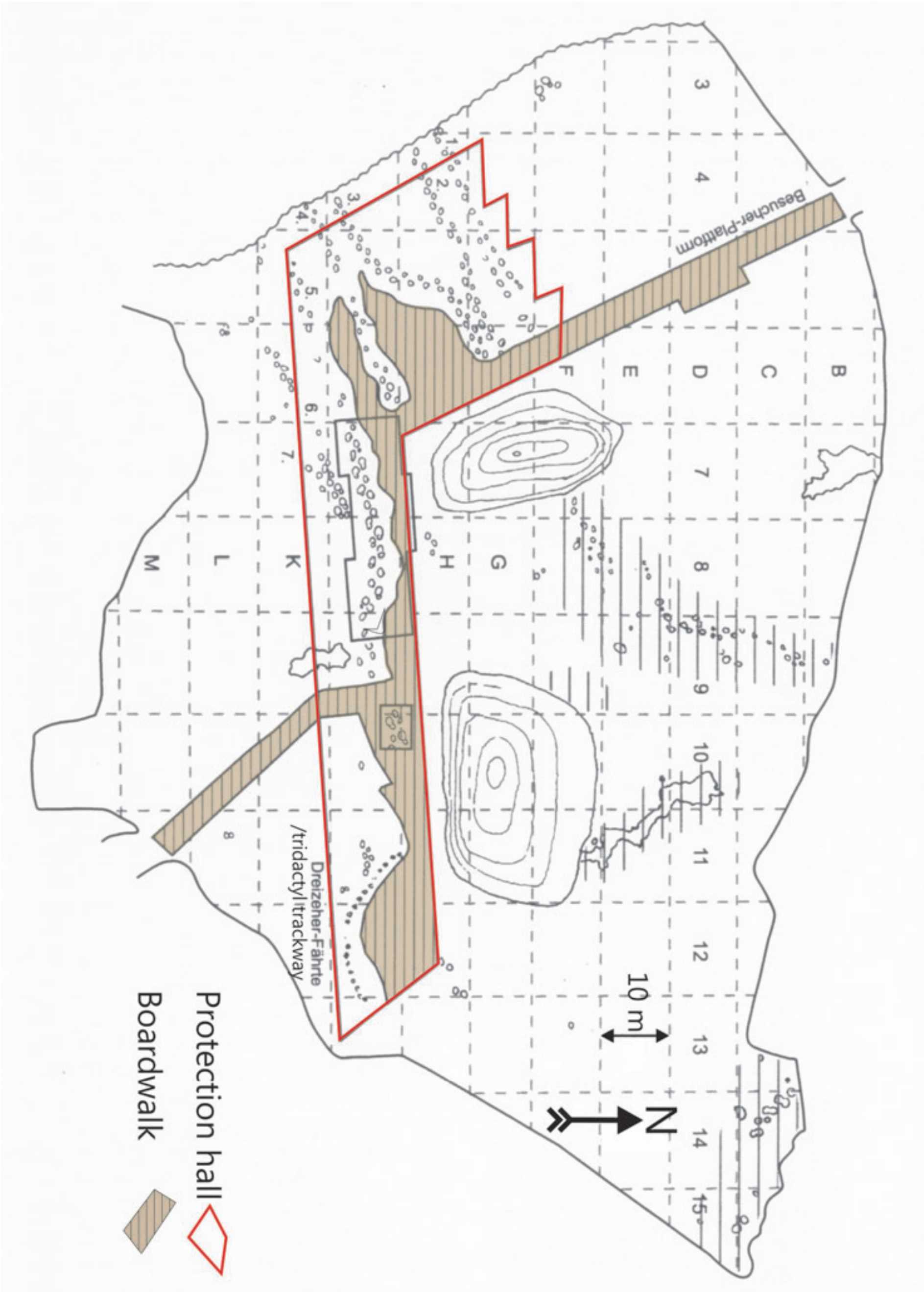


Fig. 5 Dinosaur tracks and trackways within the National Monument Site Münchehagen. Parallel lines indicate tracks currently covered with sand for protection against weathering. Slightly modified from Fischer (1998).

Manus imprints (especially trackway 5, see below) have a more or less round outline. Most of the manus impressions have been overstepped by the hind feet (see below), but some are completely preserved. Manus impressions show steep anterior margins and the deepest zones in the front area. The posterior half gradually approaches the level of the surrounding sediment (Fischer 1998), indicating that the feet had to bear most of the weight in the very front. The size of the sauropod feet varies between 0.9–1.3 cm in length and 0.85–1.0 cm in width. The manus impressions of trackway 5 have diameters of 45–75 cm. Due to the lack of claw impressions and morphological details, the tracks are considered not to be diagnostic of any particular type of sauropod or trackway (Wright 2005). The ichnotaxon '*Rotundichnus muenchehagensis*' is therefore of questionable validity.

On the approximately 15,000 m² large quarry surface, 256 unambiguous sauropod tracks have been described by Fischer (1998) (Fig. 5). Additional, poorly preserved sauropod tracks are still being found inside and outside of the hall until today. Most well-preserved tracks belong to at least 7 trackways. The trackways 1 to 4 in the western area of the protection hall are of special importance (Fischer & Thies 2000). All of them point in northeastward direction, but trackway 3 changes direction once and comes then very close to trackway 2, leading there with a leftward bow, and then turning back to the previous direction. This was interpreted as one sauropod approaching another, resulting in two individuals walking parallel to each other. Trackway 1 shows a double row of left pes impressions and, thus, must have been made by two animals walking right behind on another (Fischer & Thies 2000). All trackways from the western part of the hall show no sediment infills and no traces of manus impressions.

In contrast, the best preserved trackway 5 shows sediment infills (partially with ripple marks on the surface) as well as manus impressions. These have been overstepped by the larger pes tracks, but are still recognisable (Fischer 1998).

One special area in the protection hall must be mentioned separately and be supplemented by new, unpublished observations. Poorly preserved tridactyl dinosaur tracks can be found in the eastern part of the hall. They form a trackway out of 19 single imprints with a gap of two missing tracks after track 11. All tracks are relatively deep (4–10 cm), their length varies between 44 and 56 cm and their width between 43 and 52 cm. The poor preservation makes them typical examples for the difficulties in distinction between ornithopod and theropod tridactyl tracks. There are no marks of claws or toe pads and also no signs of anteriorly broadened 'hooves'. It even cannot be determined if the single toes are broad or rather slender. While there is no clear argument for a theropod trackmaker, the tracks do not resemble all other known ornithopod tracks in the German Wealden (Fischer 1998).

New work on the sandstone surface of the National Monument around the protection hall (Knötschke & Richter, pers. obs. 2010 and 2011), revealed the presence of more tridactyl tracks, most of them clearly ornithopods. It is plausible that they had been covered by sediment during the Münchehagen pioneer years in the 1980s and have only been eroded and exposed recently. The new tracks are shallow and not well preserved, but they proof the presence of sauropods and iguanodontid ornithopods in the same habitat and have great importance for the understanding of the Early Cretaceous in Northwestern Germany. The quarry base layer appears to be the only stratigraphic zone in Münchehagen with sauropod tracks and yields additionally some ornithopod tracks. The latter dominate from this level upwards in Münchehagen and within the entire comparable locality of Obernkirchen (see Richter, Hornung et al. 2012; ► p. 73-99, this volume), where only iguanodontid ornithopod tracks appear together with theropods.

This may imply that sauropods were migrating while ornithopods had more stable habitats. Another hypothesis is that the Münchehagen tracks represent a transitional period in Lower Saxony, when sauropods, which dominate the Jurassic herbivore dinosaur track record, emigrated elsewhere, and ornithopods, whose tracks are unknown from Jurassic deposits in Lower Saxony, arrived and settled in the region. These hypotheses should be tested in future studies.

Fig. 6 Overview of the new quarry (upper left, with overburden dumps) and the old one (lower right), rebuilt into the DFM, with the elongated main sauropod track hall. Helicopter photograph, 2005, NLMH.

Fischer (1998) provides a detailed account of the sedimentological history of the sauropod trackway layer. Deposition in shallow water led to the preservation of the tracks and their sediment infillings, followed by minor background erosion. However, a strong storm event can be reconstructed from different erosional angles of cut tracks in the main layer (Fischer 1998). The following interruption in the sedimentation led to a very rich endobenthonic life (Fischer 1998) causing heavy bioturbation within the top layer of the pre-storm sediments and burrow structures in the zones below. These can be assigned to the *Cruziana* ichnofacies group and contain mainly *Thalassinoides* and *Planolites* (Schwennicke 1998).

The active Wesling Quarry – Lower Level

***The new track findings in 2004* —** In summer 2004, quarrying activity revealed on the bedding surface of LU7 abundant and excellently preserved tridactyl dinosaur footprints, preserved as true tracks. Approximately 80 m² of the new tracksite (Fig. 6) were uncovered in an emergency campaign (Figs. 7-8) which was solely financed by the NLMH. Documentation was done by the classic manual way, creating 1 m x 1 m – frames and drawing by hand (Fig. 9), corrected with photographs. The small area yielded at least three trackways belonging to the ichnotaxon *Iguanodontipus* and two 'allosauroid' theropod trackways (Figs. 10-11). All trackways show bipedal gaits.

The iguanodontid ornithopod tracks (Fig. 9; all data from 2004: n=37; longest trackway: n=18) measure 24–44 cm in length and width, thus corresponding to small-sized, plausibly subadult animals. Especially interesting are very deep tracks with prominent displacement rims which may represent 'gliding' structures where the deep mud was possibly squeezed around and between the toes and hoofs during movement. These structures together with the short pace (49–77 cm; mean: 69 cm) and stride length (104–156 cm; mean=134 cm) indicate that the iguanodontids walked carefully in the unstable sediment. All *Iguanodontipus* trackways extend in different directions, three of them crossing each other, and none of them represents a straight line of walking.

One of the theropod trackways consists of five tracks, the other of two tracks. The width of the tracks is 23–27 cm (mean=24 cm), the length is 28–40 cm (mean=35 cm). The pace of the longer trackway is 102–113 cm (mean=107 cm), the stride is 210–220 cm (mean=216 cm), indicating a fast moving animal.

Overviews were given at the EAVP-meeting in Darmstadt/Germany in 2005 (Wings et al. 2005) and at the SVP-meeting at Austin/Texas in 2007 (Richter et al. 2007).

In 2006 and 2007, three more small 'bands' of the Lower Level (LU7) have been gradually uncovered. Quarrying of the massive overlying sandstones (LU9– LU10) with a wheel loader resulted in temporary exposures with a length of approximately 20 m and a width of 1.5–2 m. These additional areas of the Lower Level were cleaned and documented via photogrammetry by an NLMH-team.

Fig. 7 The massive sandstone layers above the Lower Level trackway layer can only be removed with an excavator.

Fig. 8 The complete excavation area at the Lower Level in 2004/2005. The tracks are protected with white plastic sheets.

The best section of several trackways exposed in 2004 was casted with silicone and polyester (by the company Wolter Design, Loccum), and is housed in the NLMH. The best part of the original track surface was removed by quarry workers and colleagues from the University of Göttingen early in 2005. During excavation, the brittle siltstones and sandstones broke into bits and pieces. After transport to the Göttingen Geoscience Museum, the parts were reassembled by technical staff of the Museum (M. Sosnitza & H. Schwanke). The resulting block (see Fig. 9), which is housed at the GZG, has a size of ~20 m² and contains nearly two dozens tracks.

Also in 2004, large resting traces of unionid bivalves were found by quarry workers somewhere in the quarry. The traces are in the repository of the NLMH and are pictured in Hornung, Böhme et al. (2012).

Fig. 9 Very deep iguanodontid ornithopod tracks preserved together with ripple marks.

Fig. 10 Striking light enhances the excellent preservation of the 2004/2005 track.

Recent excavations (2009–2011) — The DFM and the affiliated Association for the Advancement of Lower Saxon Paleontology ('Verein zur Förderung der Niedersächsischen Paläontologie') funded and carried out several months of fieldwork in the Lower Level in each of the years 2009 to 2011. During these years, a total area of approximately 1100 m² was uncovered, documented, and excavated (Fig. 12). Almost all of the tracks and their natural casts were excavated and are currently awaiting preparation in the DFM. Unfortunately, due to undocumented quarry activities, it was not possible to correlate the uncovered trackways with data from all former excavations in the Lower Level.

Interestingly, only one iguanodontid ornithopod trackway, but five theropd trackways and several additional poorly preserved theropod tracks were discovered on this large area (Fig. 13). All trackways were found in an NW–SE-oriented, approximately 20 m wide band which also bears very prominent ripple marks, indicating the variable preservation potential during deposition of LU7. Detailed data about the tracks will be published elsewhere.

The very long trackway (I1, currently consisting of 53 consecutive tracks) of a slow-walking, medium-sized iguanodontid ornithopod (*Iguanodontipus*) extends from NW to SE and changes direction to ENE after about the half of the excavated area.

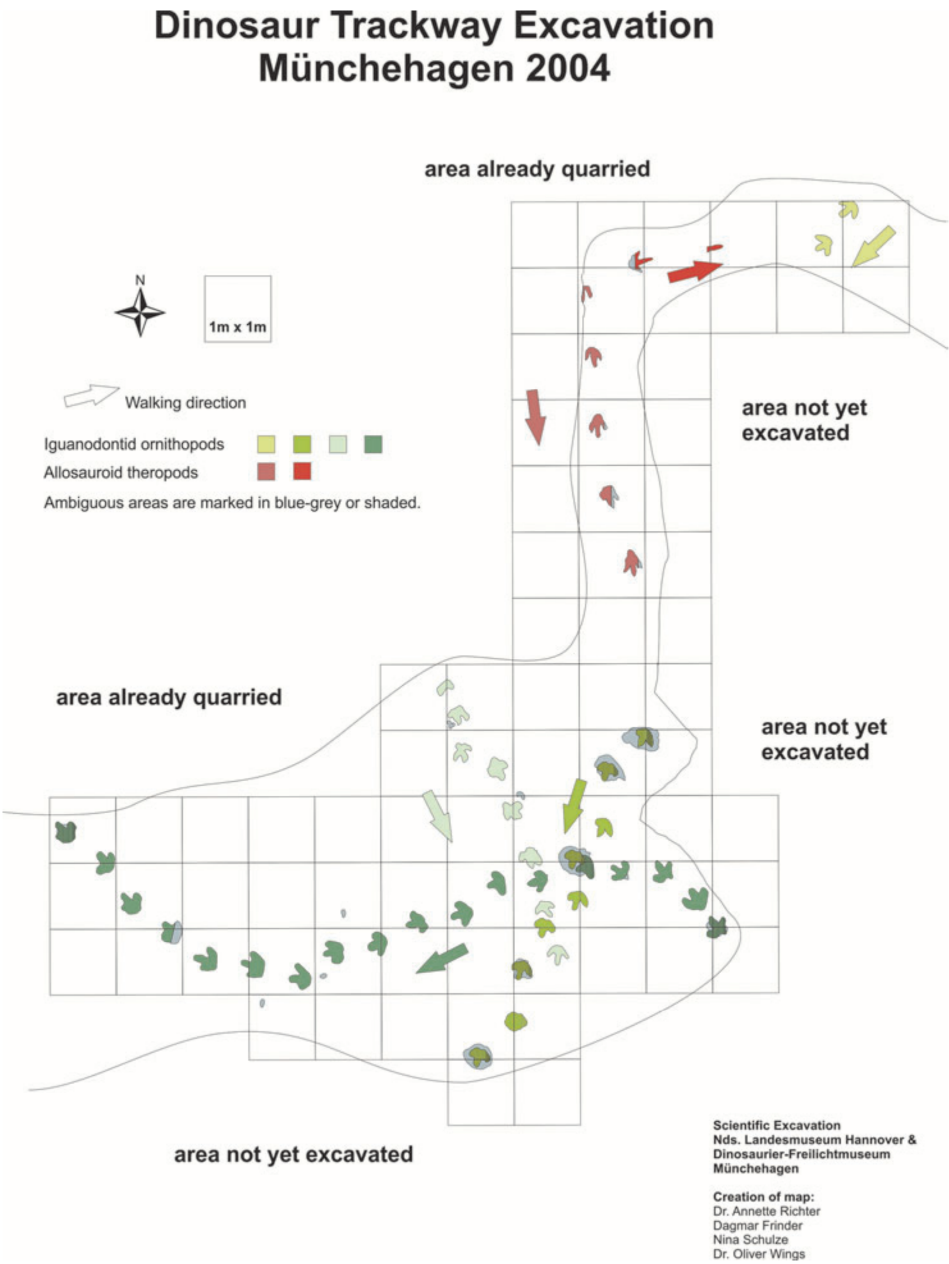


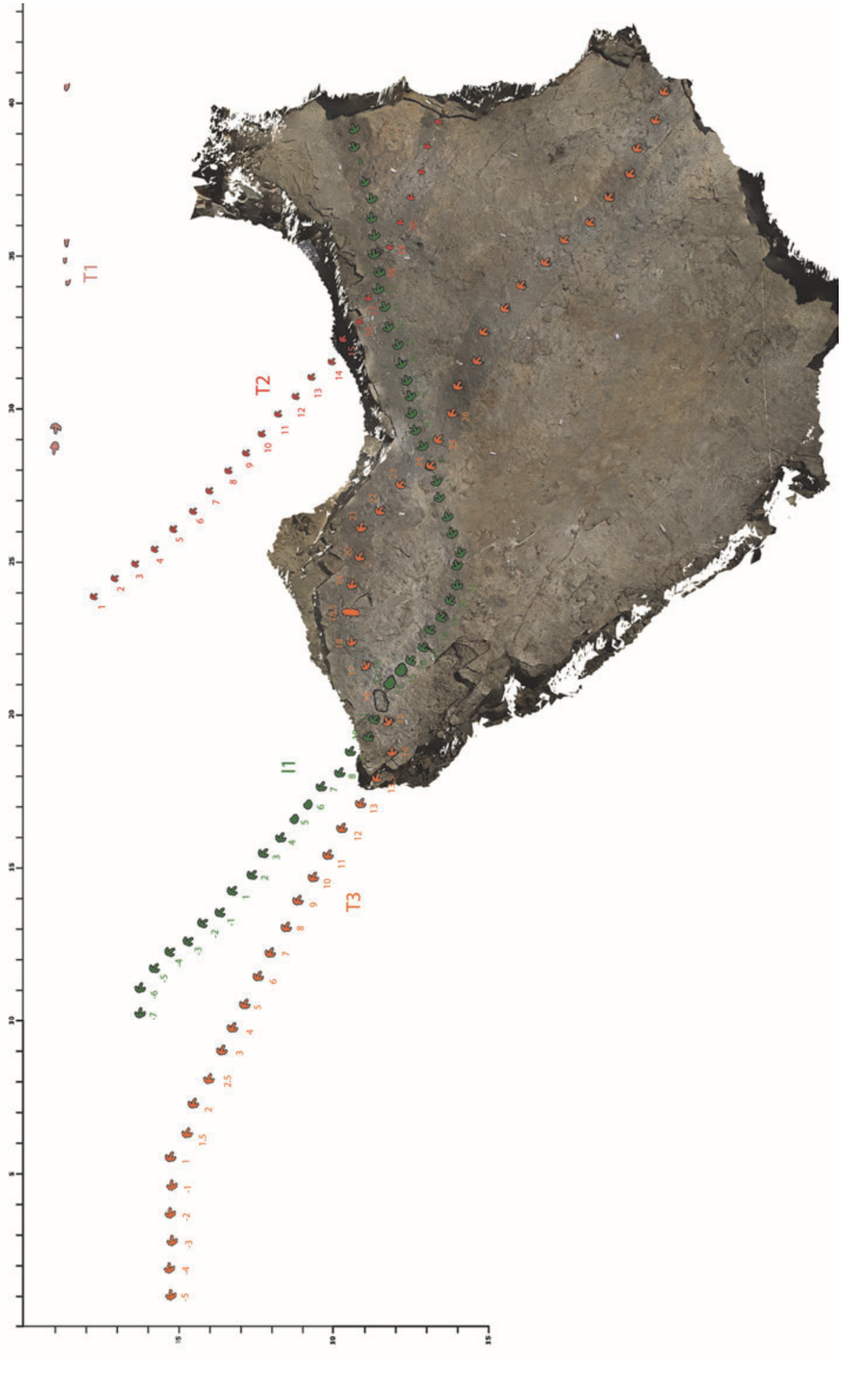
Fig. 11 Excavation map 2004.

Fig. 12 The extended Lower Layer excavation areas in September 2009 **(A)** and September 2010 **(B)**.

The theropod trackways represent two size classes: T1, T2, T4, and T5 were medium-sized trackmakers, but T3 provides evidence for a larger theropod (footprint length >35 cm) in the Münchehagen area. T1 is poorly preserved at the northern edge of the well-preserved band of LU7. Beside one well-preserved track, 5 impressions of digit III only were found. T2 represent to date 24 consecutive footprints of a fast moving animal, running almost straight from NW–SE. The first 15 excavated tracks of T2 have already been prepared and are now exhibited in the eastern part of the protection hall in the DFM (Figs. 14-15).

The large T3 theropod was also walking in SE direction. The trackway currently consists of 48 consecutive footprints, starting with five poorly preserved tracks in the NW. The tracks can be clearly assigned to a theropod dinosaur, although the morphology of the tracks and the preservation of the claw impressions vary to some extent despite of the great preservation potential of LU7. T4 and T5 are currently only known from some poorly preserved, but consecutive tracks near the last uncovered tracks of T3.

Fig. 13 Excavation map 2009–2011. The drawn track outlines are partially superimposing a photogrammetric orthophoto. T4 and T5 are not included in this map. ►


T1
T2
I1
T3

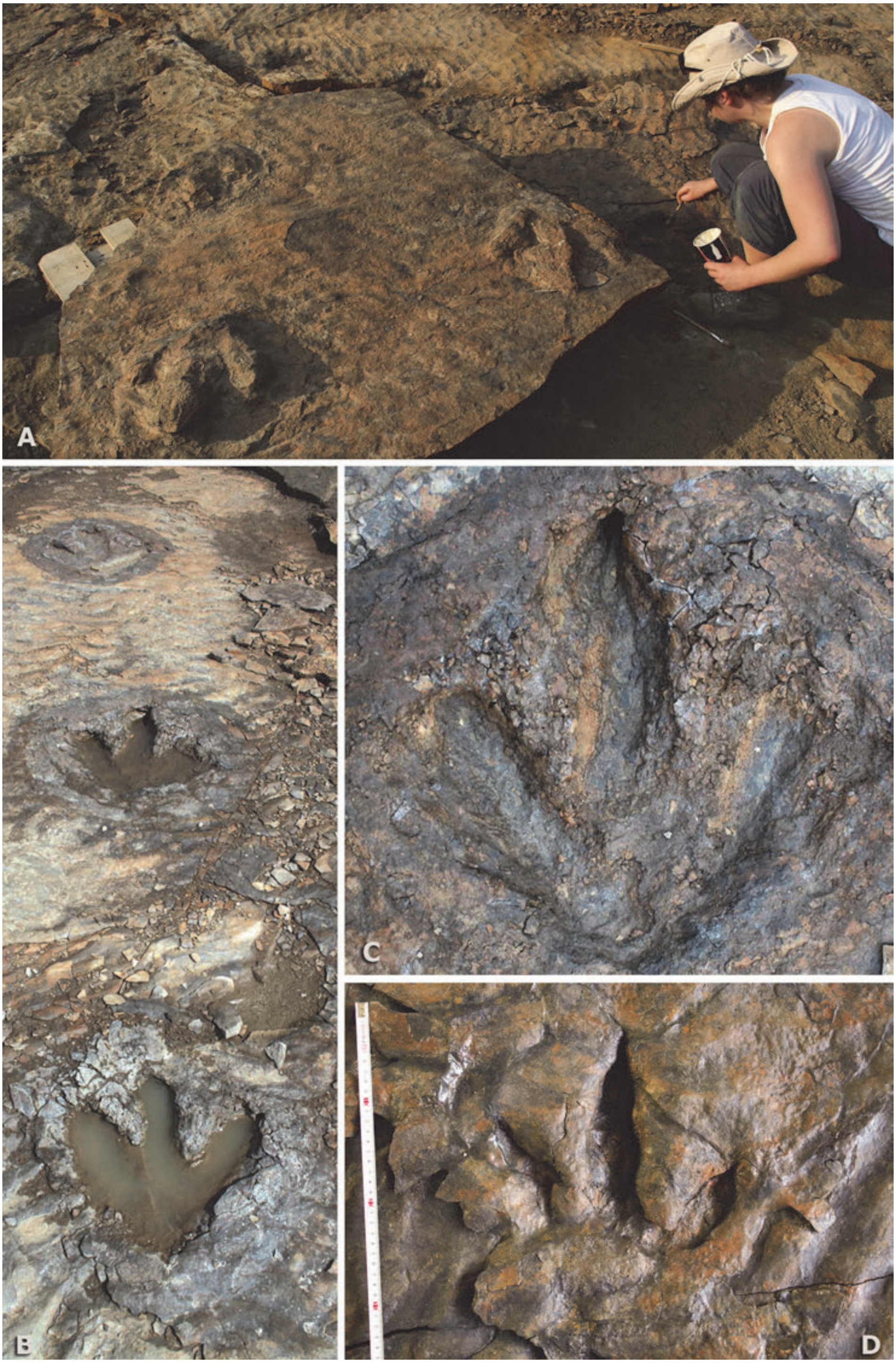

A
B
C
D

Fig. 15 The reconstructed T2 theropod trackway in the Natural Monument Hall in DFM. The natural cast will be displayed next to the imprints. For a detailed view of the first track see Fig. 14D.

The large uncovered area and the high number of tracks required to protect the fragile, water-susceptible silty mudstone layer of the LU7 from weathering for several months, but also from frost during winter. Immediate protection of the freshly exposed tracks with a mix of water and special white glue (a PVA glue which becomes water-resistant once dried) turned out to be the best preservation of the original trackway layer. Several more layers of glue were subsequently applied when necessary. To prevent frost riving during winter, all tracks were first filled with plastic sheets and sand, then covered by tarps and about 20–30 cm of sand. This arrangement provided a good protection during the strong German winters. The last exposed tracks were excavated during spring 2011.

◄ **Fig. 14** **(A)** Large slab with natural casts of ornithopod tracks (left) and a theropod track (right). Note the brittle silty mudstone layer with imprints behind the slab. **(B)** Part of the large theropod (T3) trackway. The tracks are filled with rain water. Impregnation with white glue made the tracks water proof. **(C)** T3 track with large claw impression. **(D)** Detailed view of a very well preserved deep small theropod (T2) track with claw marks. Cracks in the brittle mudstone were partly filled for exhibition purposes in DFM.

The active Wesling Quarry – Upper Level

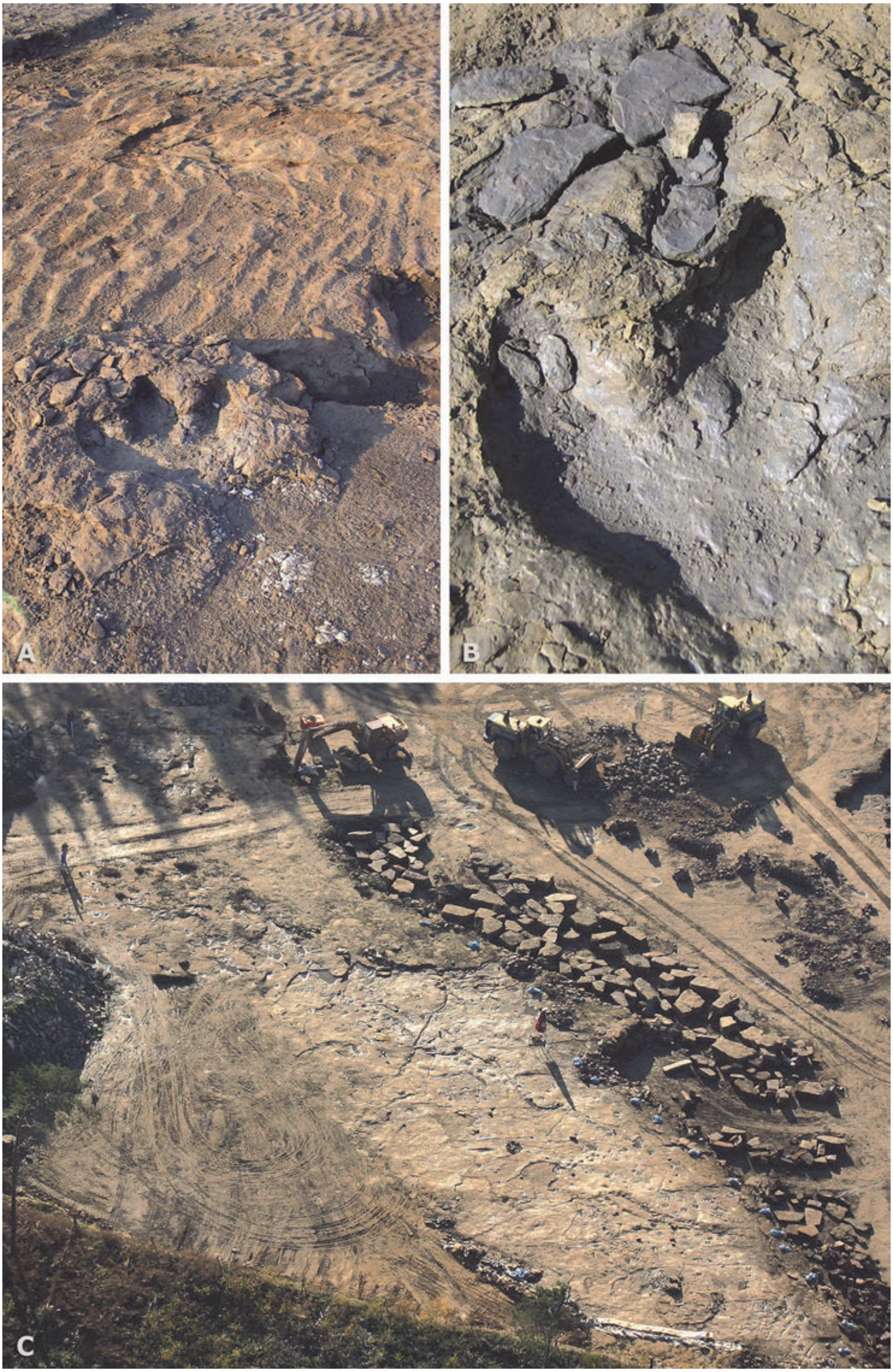
When documentation of the exposed true tracks on the Lower Level was almost finished in early summer 2005, another dinosaur track layer was discovered by the zoological preparator of the NLMH, Christophe Houlgatte. This layer (LU16) was completely covered by shallow ripple marks and yielded a very track-rich area, stratigraphically higher than the Lower Level (app. 1.88 m). This Upper Level represents another type of track preservation with almost all tracks preserved as rather shallow undertracks. Nonetheless, all tracks possessed clear margins and rather sharp outlines. At one occasion, the brittle siltstone covering the undertrack surface could be excavated and photographed (see Lehmann 2006 and Fig. 16A-B) before it dried out and eroded away.

The 2005-campaign — When the MWK funded the excavation and documentation of the first large area with the majority of the tracks, the field work was conducted by the NLMH. Most of the cleaning was done by volunteers during weekends, though. An area of approximately 1,200 m^2 with an abundance of tracks had been cleaned of loose sediment by the helpers. Documentation was done by an external geodetic company, using long-range photos made from a car hoist. Results are not yet fully published, but will be briefly introduced here. Almost all tracks on that surface resemble pes imprints of *Iguanodontipus* and thus will be referred as 'iguanodontids' *sensu lato* here. The trackmaker supposedly may have been an animal similar to *Mantellisaurus* (Norman 2011) or a closely related taxon. Only one theropod trackway was identified.

The Upper Level showed one extremely long trackway from an adult 'iguanodontid' (on the map: trackway 'A'), consisting of 57 well-preserved and another two only weakly preserved imprints.

This is the longest individual trackway ever discovered in the German Berriasian (Richter et al. 2007). The single imprints were rather large, having widths of 42–43 cm and lengths of 43–44 cm and paces of approximately 90 cm. The trackway extended in a slight bow from the furthermost northern corner of the quarry to a southwest/southeastern ending point where the lithofacies changed abruptly. The animal walked in a sinuous line, but then changed direction to a more pronounced left bow, finally turning southeastward.

Fig. 16 **(A-B)** The unstable mudstone track layer. **(A)** overview within the Upper Level of Münchehagen, **(B)** detail of the situation, showing a large track without and a small track with infilling. **(C)** Overview of the Upper Level from the new Münchehagen Quarry north of the Dinosaur Park. Helicopter photograph, 2005, NLMH. ►


A
B
C

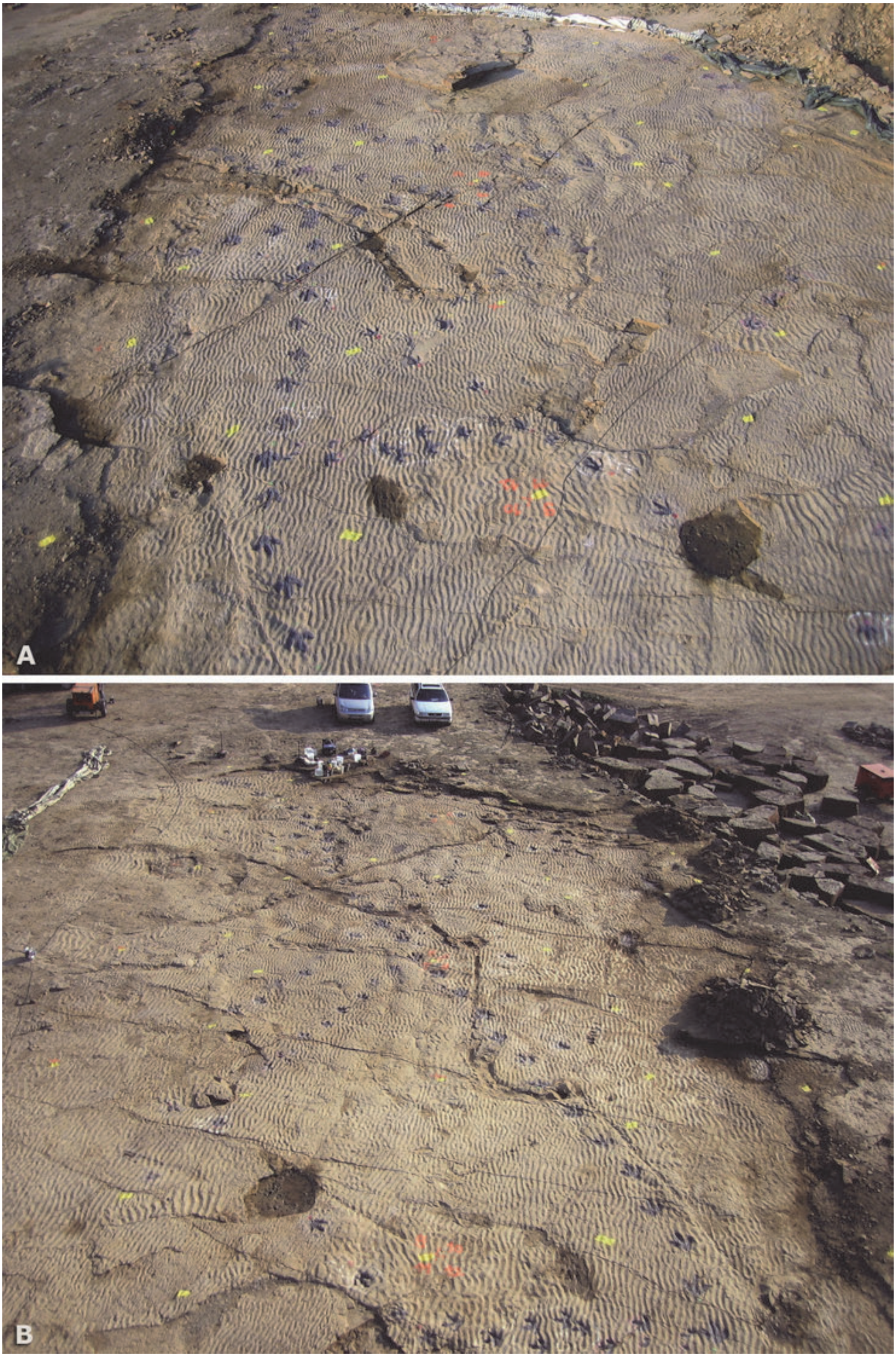
The A-trackway is also distinctive because of very well preserved manus imprints at the tracks A 40 to A 44 and A 51 to A 53. After the first identification of manus tracks by M. Lockley on an isolated sandstone slab from that quarry (2002; unpublished data sheet from the DFM), no *in-situ* find was reported again from Lower Saxony. The 'A-individual' is the first record for manus track morphology of an '*Iguanodontipus*-like' trackway from northwestern Germany. The manus imprints all showed a pronounced crescent, kidney-shaped outline, with their long axis being steeply angled inward to the walking direction axis. A field photo was published by Lehmann (2006).

The long A-trackway crosses several times with other iguanodontid trackways. Larger individuals (C, E, G and P-trackways) crossed mostly in western or northwestern direction, all of those almost parallel to each other, but occasionally with proof of overstepping with the individual A: The other large individuals (track widths of 40–46 cm) must have been walking through the coastal environment shortly after the A-iguanodontid. E and G tracks are even larger than the A-track. Additionally, small tracks were found with track widths of 26–27 cm, with the L-trackway being best preserved. This trackmaker could be a smaller taxon or a juvenile to subadult individual of the same taxon. The first two tracks showing merely the toe tips pressed deeply into the substrate. There are hints that this small iguanodontid was accompanied by at least one large iguanodontid, as it is located directly next to the M-trackway. Both trackways run absolutely parallel. The iguanodontid trackways F and K are parallel to C and E, but proceed in the opposite direction. The K-tracks are difficult to interpret. They are situated very close to each other and probably represent two individuals of the same size.

The only theropod trackway (J) consisted of 9 measurable tracks with track widths of 32–33 cm and lengths of 31–34 cm, some with preserved claw impressions. The SE to NW walking direction is parallel to one iguanodontid crossing the A-trackway, although no interaction is apparent.

After documentation, most trackways were casted, especially around the long A-trackway. Again, large groups of volunteers from the museum helped, and the final polyester work was done at Wolter Design in Loccum. The resulting large polyester slabs are housed at the NLMH. Original surfaces could not be preserved *in situ* but were excavated right after documentation. Only few original tracks from the A-trackway could be preserved and are also housed at the NLMH. Two abstracts of the results of the campaigns from 2004 to 2006 have been published (Wings et al. 2005; Richter et al. 2007).

Fig. 17 Part of trackway 'A', the longest 'iguanodontid' trackway of the Upper Level Münchehagen and as well of the Lower Cretaceous of Germany, consisting of 57 well preserved and two more doubtful tracks. All tracks darkened with graphite for photographic contrast, **(A)** view to the north, **(B)** view to the south. Photograph courtesy: NLMH. ►


A
B

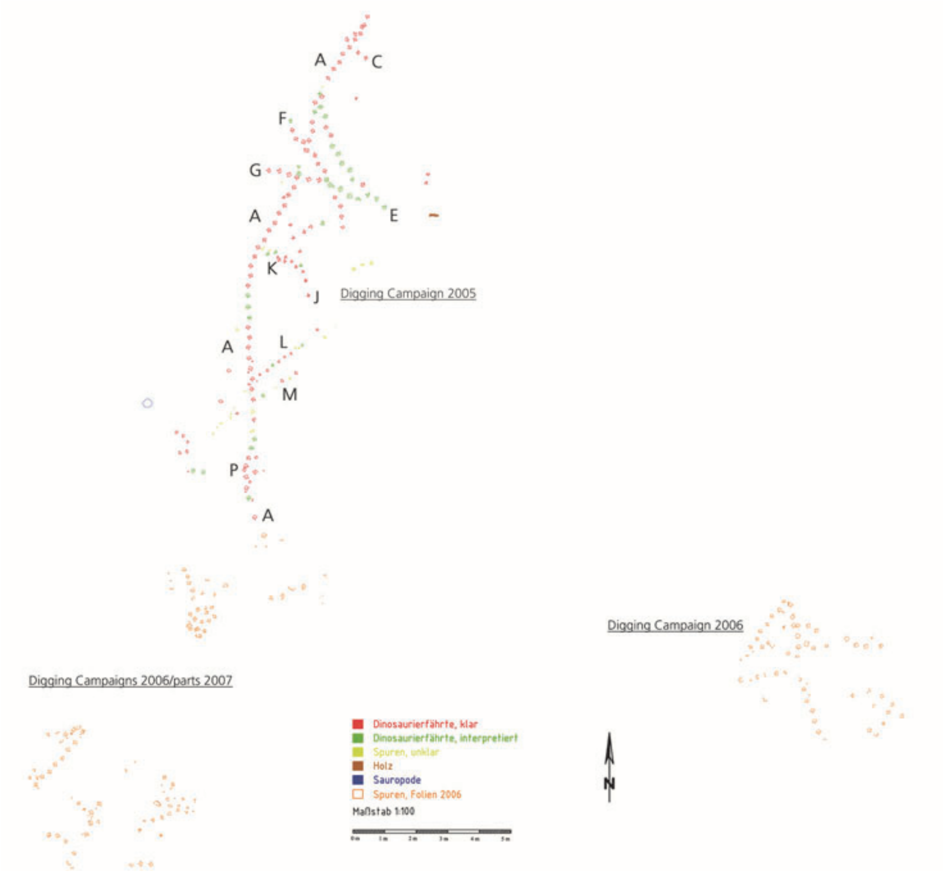


Fig. 18 Preliminary track map from the new Münchehagen Wesling Quarry and the NLMH- and DFM-excavation campaigns in the Upper Level from 2005 to 2007. Overview of the main areas, including the very rich northern area ('2005'). Tracks and trackways in red: well preserved; in green: slightly interpreted and reconstructed; in yellow: doubtful and/or badly preserved; brown: fossil wood.

***The 2006/2007-campaign* —** The MWK supported the entire excavation campaign once more together with the NLMH, hiring an additional scientist (Dr Ute Richter) for the season of 2006/parts of 2007. Final and detailed results of the 2006/2007-season are planned to been submitted for publication in the near future. A part of the documentation was aided by the geodetic bureau, but all tracks were drawn on transparent, thick foils and carried to the museum, where they were photographed and digitally assembled.

Dinosaur tracks became increasingly less abundant on the Upper Level as the lithofacies changed laterally following the quarry-work in SSW and SE direction. The resulting, rather 'patchy' track map depicts the limited preservation potential of the specific environment at the Münchehagen shoreside.

An uninterrupted continuation of the 2005 track area was not found in 2006. Instead, three smaller areas with tracks were unveiled, one at least shortly below/ southward of the area with the long A-trackway. This first area can be divided into a left and a right spot, the latter one consisting of 4 poorly preserved tracks. The southern part of the left area was nick-named 'Theropod Ballroom'. It yields theropod and few ornithopod tracks in at least 4 to 5 different directions, forming the only trampled area at Münchehagen, in contrast to the heavily trampled dinoturbation at the Obernkirchen Chicken Yard (Richter, Hornung et al. 2012; ► p. 73-99, this volume).

One trackway of consecutive tracks in SE direction marked the northern half of the first area. The second area with several more straight-aligned tracks, forming true trackways, was discovered about 20 m SW. The SE walking direction in at least one trackway correlates with the walking directions of the juvenile 'L' and the adult 'M' of the northern 2005-area and may have been formed by individuals of the same group. Beside undertracks, at least two original (theropod) tracks were identified in the second area.

A third area with tracks was situated more eastward within the quarry. It consisted of several iguanodontid trackways with 8 to 13 consecutive tracks together with obscured short trackways. All are preserved as average quality undertracks with no continuations to the 2005-area. Around the early 2006-zones, the direction of the ripple marks had changed and showed clear crossing structures.

Without external financial support, the NLMH continued a much smaller campaign into 2007. Some additions to the two western areas of the 2006-campaign uncovered, for example, another trackway (7 tracks) correlating with the 'L' and 'M' trackway from 2005 and several isolated tracks. The documentation foils were still being used, but they finally proved not to be the right solution for the boreal North German climate, generating opaque layers of water of condensation below the foils, so that tracks or sedimentological structures were not clearly visible. On the remaining rest of the surface, dinosaur tracks became extremely rare as the lithofacies changed once more, in large parts having smooth surfaces, in other parts being covered only by ripple marks from different flow regimes, completely lacking dinosaur tracks. Within the track-free zones of the surface, some tree logs and a fragment of a horse-tail could be identified. Unfortunately, they could neither be taken out of the sandstone nor be mapped.

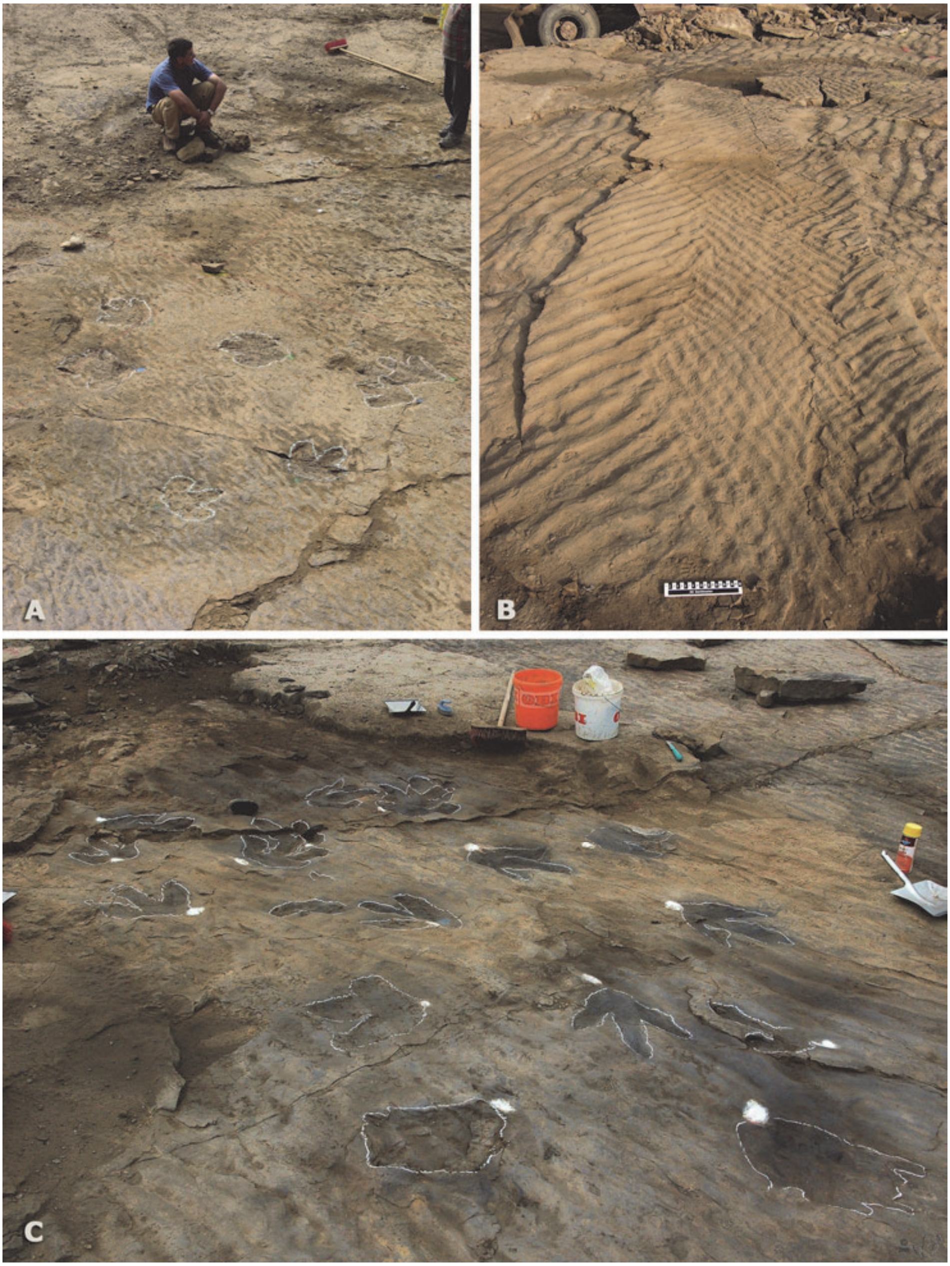


Fig. 19 (A) An excavated area with well-preserved ornithopod pes tracks during the campaign 2006. **(B)** Crossing ripple mark systems indicate different flow regimes; Upper Level, excavation campaign 2006, northern part. **(C)** The 'Theropod Ballroom' area in 2006. Photograph courtesy: O. Schirmer.

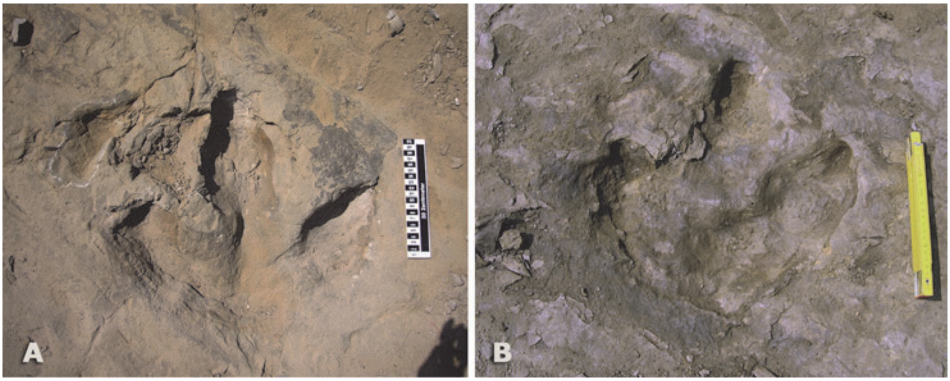


Fig. 20 (A) Iguanodontid ornithopod pes and manus tracks from the area 2006. (B) One pes track from an ornithopod/iguanodontid from the Münchehagen excavation area 2007.

Summary and Epilogue

The Münchehagen tracksites in the active Wesling quarry are highly significant because of (1) their excellent preservation of theropod and ornithopod tracks (2) the general scarcity of longer trackways in the Early Cretaceous of northern Germany (3) unusual walking directions of the track-producers.

In 2006, the historical part of the sauropod track area in Münchehagen was declared a 'National Geotope'. New dinosaur tracks continue to appear in the Münchehagen area every year. Münchehagen thus has an unbroken high potential for wide-ranging trackways. Several thousand square meters of the tracksite layers could still be excavated. Due to the partially rapid progress of quarry works, not all of them can be excavated and/or studied with the desired accuracy. However, due to the rising public interest in the Münchehagen dinosaur tracks, an agreement was set concerning future finds within the active quarry. When the quarry work reaches the forest path between the quarry and the DFM, a combination of both areas is considered. It is most desirable to get more information about the southern extent of the 'sauropod trackway layer' and the northwestern continuation into the Wesling quarry, which already yields iguanodontid and theropod tracks. A further expansion of the vertebrate track record at Münchehagen could even launch new DFM park activities, such as public excavation campaigns for park visitors. Finally, the southern parts of the quarry should be united with the park area and form a larger, common national geotope or a future monument zone.

Acknowledgements

We wish to express our sincerest gratitude to Mr. Ferdinand Wesling senior, owner of the F. Wesling Group, for his generous support during all these years. Also, Bernd Wolter, former manager of the DFM, greatly and continuously supported the excavation teams. The famous 'Dino Schnitzel' from the DFM restaurant will always be remembered as one of the crucial pillars of the excavation campaigns!

We thank the MWK of Lower Saxony, Hannover, for financial support to the field work in 2005 and 2006, to research in Münchehagen and Obernkirchen, and to parts of the symposium.

Marco Mastroianni, palaeontological preparator at DFM, provided tremendous help during many years. Florian Stuckert (formerly DFM) also helped with the project. Dr Michael Schmitz, former head of the Department of Natural History at the NLMH, recognized the significance of the Münchehagen locality and fought many battles; first to make this project possible and then to keep it running smoothly over the years. The rural county of Nienburg must be thanked for its support concerning the early research as well as the development of the Natural Monument and the Dinosaurier-Park.

Also, we would like to thank our sponsors of the Dinosaur Track Symposium Obernkirchen 2011, and, within them, first of all Sigmund Graf Adelmann and Irene Neumann, Bückeburg (Schaumburger Landschaft), Dr Joachim Werren, Hannover (Stiftung Niedersachsen) and Dr Stephan Lüttich, Hannover (Stiftung Klosterkammer).

Dr Mike Reich has our highest gratitude for providing the opportunity to publish this volume within the Göttingen University series and also his organisational and editorial work.

And last but not least, we want to give our warmest thank you to all of our many, many busy volunteers and earth sciences students, without whom this big project would never have been possible at all. Staffs at the NLMH – on regular positions like two scientific trainees and other collaborators as well as project-based like Dr Ute Richter and Torsten van der Lubbe – helped intensively. We would like to mention Andreas 'Andy' Basse, whose endless help with field work and photographing the foil drawings and whose wonderful landscape reconstructions accompanied the project for years. During all these years, Ole Schirmer turned out to be the 'good spirit' of the Münchehagen digging-group, always reliable and constantly providing all of his power and skills to the project. Beside different collectors' groups like the 'Arbeitskreis Paläontologie Hannover' under Udo Frerichs or especially the phenomenal and inexhaustible 'Interessengemeinschaft Paläontologie & Geologie Norderstedt' led by Klaus Vöge, several private groups and families helped full of enthusiasm, some of them for many years even under less rewarding working conditions. We would like to mention especially our younger helpers, who helped from the very beginning and regularly during weekends: Julian Picht and Lena Weimann were wonderful permanent field workers – we thank you and your families! During the last years, the excavation was mainly carried out by DFM staffs, but only the participation of dozens of dedicated helpers and sedulous students kept the dig running. We would to like to thank all of them, but especially Rico Schellhorn and Klaus Schwermann for their persistence. Jens Lallensack created the digital excavation map for the last years and Daniela Schwarz-Wings commented on a draft of the manuscript.

References

Allen, J. R. L. (1968): *Current Ripples. Their relation to patterns of water and sediment motion.* xiii + 433 pp.; Amsterdam (North Holland Publishing Company).

Collinson, J. D.; Thompson, D. B. & Mountney, N. P. (2006): Sedimentary structures. *Classic geology in Europe* **13**: x + 292 pp.

Elstner, F. & Mutterlose, J. (1996): The Lower Cretaceous (Berriasian and Valanginian) in NW Germany. *Cretaceous Research* **17** (1): 119-133.

Fischer, R. (1998): Die Saurierfährten im Naturdenkmal Münchehagen. *In* Fischer, R. (ed.): Das Naturdenkmal „Saurierfährten Münchehagen". *Mitteilungen aus dem Institut für Geologie und Paläontologie der Universität Hannover* **37**: 3-59.

Fischer, R. & Thies, D. (2000): *Das Dinosaurier-Freilichtmuseum Münchehagen und das Naturdenkmal "Saurierfährten Münchehagen", 2nd ed.* 125 pp.; Stolzenau (Weserdruckerei).

Hendricks, A. (1981): Die Saurierfährte von Münchehagen bei Rehburg-Loccum (NW-Deutschland). *Abhandlungen aus dem Landesmuseum für Naturkunde zu Münster in Westfalen* **43**: 1-22.

Hornung, J. J.; Böhme, A., Lubbe, T. van der; 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. *Paläontologische Zeitschrift* **86** (3): 231-267.

Hornung, J. J.; Böhme, A. & Reich, M. (2012): Excursion Guides A-C: The 'German Wealden' and the Obernkirchen Sandstone – an Introduction. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, 62-72; Göttingen (Universitäts-Verlag). [this volume] [2012b]

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).

Kemper, E. (1973): Das Berrias (tiefe Unterkreide) in NW-Deutschland. *Geologisches Jahrbuch (A: Allgemeine und regionale Geologie BR Deutschland und Nachbargebiete, Tektonik, Stratigraphie, Paläontologie)* **9**: 47-67.

Lehmann, J. (2006): *Dinosaurier – Spuren einer vergangenen Welt: Münchehagen, der Bremer Stein und die Saurierfährten.* 91 pp.; Bremen (Haus der Wissenschaft).

Look, E. R.; Kulle-Battermann, S. & Töneböhn, R. (1988): *Die Dinosaurierfährten von Münchehagen (Landkreis Nienburg/Weser) im Naturpark „Steinhuder Meer".* 21 pp.; Hannover (Naturhistorische Gesellschaft).

Raddatz, M. (2010): Geologische Kartierung der Bückeberg-Formation (Unterkreide) am Bückeberg bei Obernkirchen (Niedersachsen), TK 1 : 25.000 Blatt Kathrinhagen 3721. *Unpublished Diploma mapping, Martin-Luther University Halle-Wittenberg,* 125 pp.; Halle/S.

Reineck, H.-E. & Singh, I. B. (1980): *Depositional Sedimentary Environments, 2nd rev. and upd. ed.* xix + 549 pp.; Berlin etc. (Springer).

Richter, A.; Hornung, J. J.; Böhme, A. & Stratmann, U. (2012): Excursion Guide A1: Obernkirchen sandstone Quarries – A Natural Workstone Lagerstaette and a Dinosaur Tracksite. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, 73-99; Göttingen (Universitäts-Verlag). [this volume]

Richter, A.; Wings, O.; Richter, U. & Knötschke, N. (2007): "Happy Feet": A new Lower Cretaceous dinosaur tracksite from Münchehagen, Germany. *Journal of Vertebrate Paleontology* **27** (3) [suppl.]: p. 134A.

Schwennicke, T. (1998): Sedimenttexturen und Lebensspuren der Sohlbank des Naturdenkmals „Saurierfährten Münchehagen". *In* Fischer, R. (ed.): Das Naturdenkmal „Saurierfährten Münchehagen". *Mitteilungen aus dem Institut für Geologie und Paläontologie der Universität Hannover* **37**: 61-102.

Struckmann, C. (1880): Vorläufige Nachricht über das Vorkommen großer, vogelähnlicher Thierfährten (*Ornithoidichnites*) im Hastingssandsteine von Bad Rehburg bei Hannover. *Neues Jahrbuch für Mineralogie, Geologie und Paläontologie* **[1880]** (1): 125-128.

Walter, R.; Dorn, P.; Giese, P.; Walther, H. W. & Dill, H. (1995): *Geologie von Mitteleuropa, 6th ed.* ix + 566 pp.; Stuttgart (Schweizerbart).

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 Beiträge zur Naturgeschichte* **14**: p. 105.

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

Excursion Guide B2: **Wölpinghausen**

Jahn J. **Hornung**[1*], Annina **Böhme**[1,3] & Mike **Reich**[1,2]

[1]*Department of Geobiology, Geoscience Centre of the University of Göttingen, Göttingen, Germany*

[2]*Geoscience Museum of the University of Göttingen, Göttingen, Germany*

[3]*Hannover State Museum, Hannover, Germany*

[*]*corresponding author:* jhornun@gwdg.de

In the summer of 1879, the small village of Wölpinghausen, located c. 35 km WNW of Hannover, became the place where dinosaur tracks in Germany were scientifically investigated for the first time. During the summer of this year, the geologist Carl F. Struckmann (1833–1898, Fig. 1A) from Hannover undertook extensive excavations of dinosaur tracks in a nearby quarry.

Struckmann's detailed reports were published in 1880 (Fig. 1B), but they were predated by a short protocol notice from a meeting of the 'Deutsche Geologische Gesellschaft', in which a sketch of giant footprints from the 'Rehburg area', sent by the mining engineer Fritz F. von Dücker, was presented. It is not clear, if von Dücker referred to the same material than Struckmann, but the latter was not mentioned in the note. The sketch led Wilhelm Dames to the assumption that the tracks were left by a dinosaur (Hauchecorne in Beyrich et al. 1879; Dames in Beyrich et al. 1879; see Hornung et al. 2012). However, Struckmann was definitely the first to substantiate these conclusions by a scientific description (Struckmann 1880a, 1880b). In autumn of 1879, the excavation of these giant tracks had already spawned strong public curiosity, and Struckmann met this interest with public talks and various newspaper articles. Referring to the pioneering works of Beckles (1852, 1854) from the English Wealden, Struckmann finally assigned the tracks to the ornithopod *Iguanodon*. This was further substantiated when he sent a plaster cast to Louis Dollo (1857–1931) in Brussels, who at this time investigated the famous *Iguanodon* assemblage from Bernissart, Belgium. Dollo (1883) noticed the perfect fit between the pedal skeleton of *Iguanodon* and the track cast and confirmed Struckmann's observations. The tracks also supported Dollo's new reconstruction of this animal as having a bipedal stance. Unfortunately, the exact geographical and geological context of the tracksite was only described in short by Struckmann.

Old Quarries

The area between Wölpinghausen and Münchehagen (Fig. 2) is densely spotted with old, abandoned sandstone quarries; however, no significant outcrops are preserved today. The tracksite quarry belonged to the property of A. Spörl. The exact site of this quarry is currently unknown, but it was described as located 'below the Wilhelmsthurm', the latter being a touristical look-out on top of the Wölpinghäuser Berg, c. 1.5 km NW of Wölpinghausen. Therefore, a location between the small settlement of Berghol and the Wilhelmsturm is most probable. Struckmann recovered c. 40 dinosaur footprints from two horizons near the base of a c. 6 m thick succession in 40–60 cm thick sandstone beds. The tridactyle tracks reached footlengths of 60 cm. They were preserved as hypichnial casts as well as epichnial reliefs. Struckmann did not provide further descriptions or measurements of trackways. He collected an unknown number of the tracks as isolated slabs; the largest specimens contained two consecutive footsteps (Fig. 1B). At least two single hypichnial casts are still preserved at the Lower Saxony State Museum (NLMH 105.746, NLMH 105.747; see Hornung et al. 2012), representing the oldest historically published find of a dinosaur track from Germany still preserved in a public collection. A large slab of sandstone with many dinosaur tracks (at the Göttingen Geoscience Museum, GZG.IF.00100, see Hornung & Reich 2012b; ► p. 169-187, this volume) also originates from Wölpinghausen, and was a donation of the Principality of Schaumburg-Lippe to the Georg-August University in 1880.

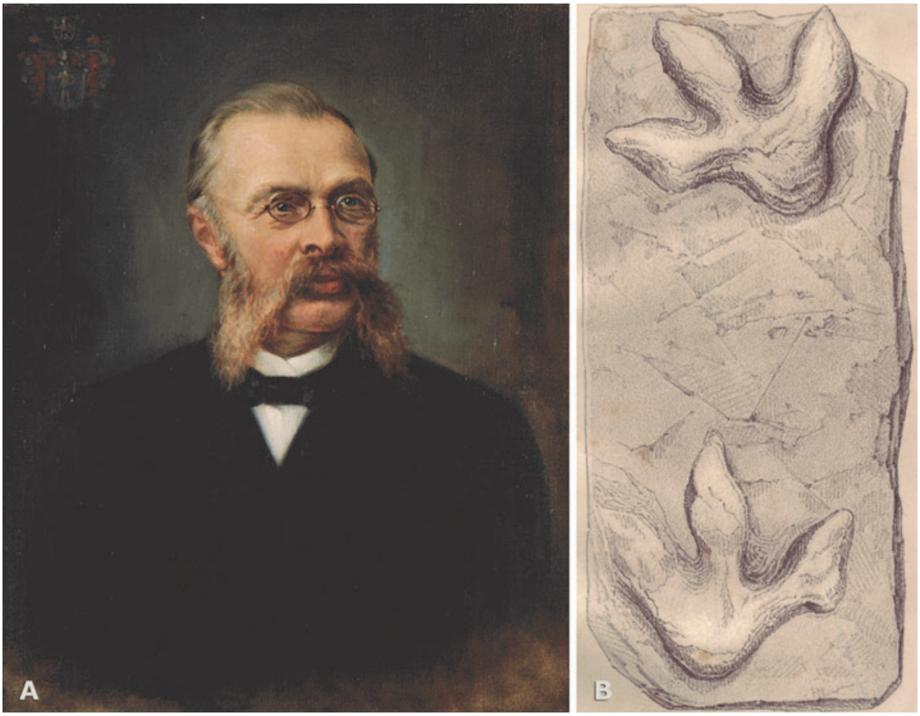


Fig. 1 **(A)** Carl E. F. Struckmann (1833–1898), discoverer of the first dinosaur tracks in Germany (courtesy of the Naturhistorische Gesellschaft Hannover). **(B)** Slab with two pes impressions (natural hypichnial cast) of an iguanodontian ornithopod from the Obernkirchen Sandstone near Wölpinghausen as figured by Struckmann (1880b: pl. IV, fig. 1). The collection of Struckmann was donated in part to the Göttingen University (GZG) as well as purchased after his death by the Hannover Provincial Museum (today NLMH). Unfortunately, this specimen cannot longer be traced in any of both collections.

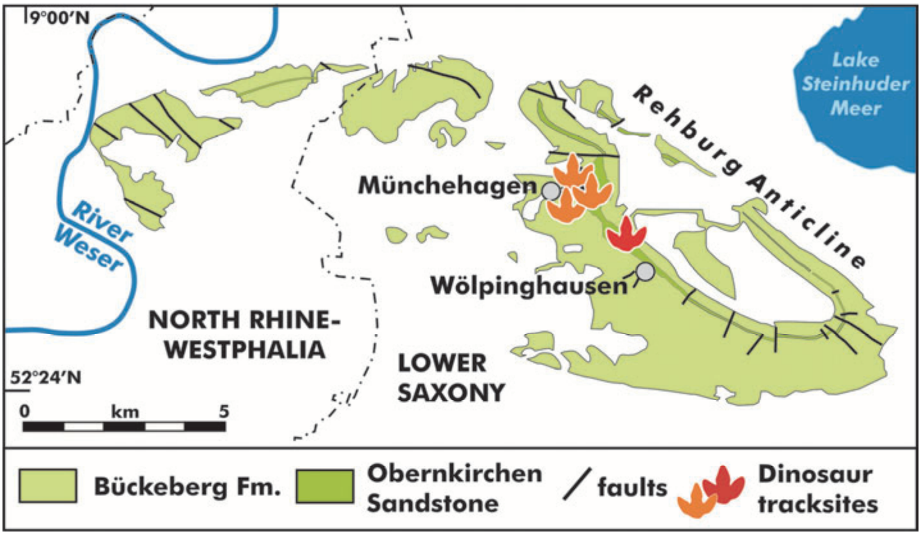


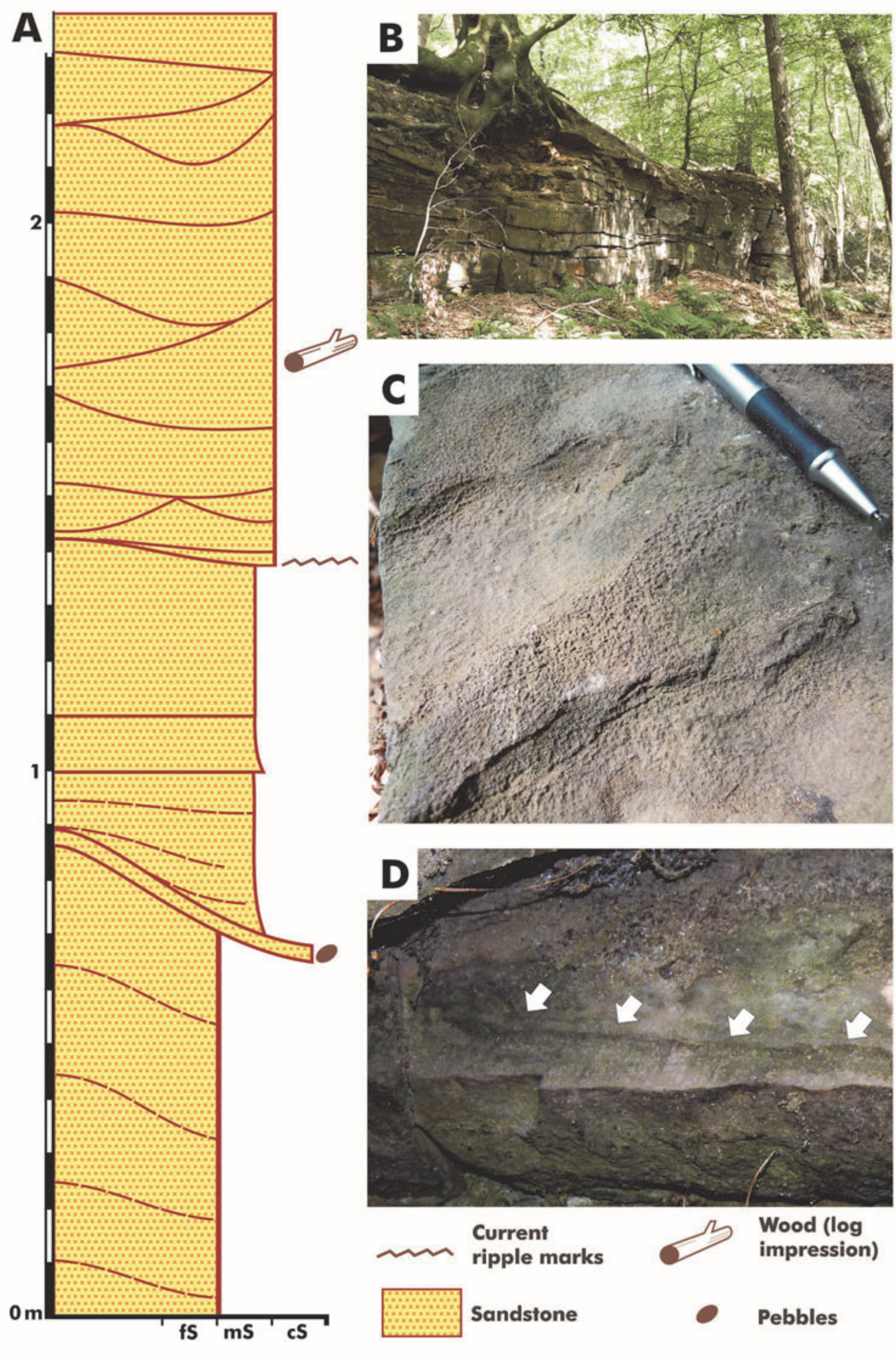
Fig. 2 Simplified geological map of the Rehburg Anticline with outcrop of the Bückeberg Formation (after LBEG 2009, modified). The tracksites near Münchehagen (orange, see Wings et al. 2012; ► p. 113-142, this volume) and the historical site close to Wölpinghausen (red) are marked.

Lithofacies and Cretaceous Environments

The small quarries around Wölpinghausen exploited the local equivalent of the Obernkirchen Sandstone, locally also known as Rehburg Sandstone or 'Hauptsandstein' ('main sandstone'). The sandstone, embedded between older and younger lacustrine shales is exposed on the southern flank of the Rehburg Anticline (Fig. 2). This c. 7 km long, SE–NW striking saddle structure on the southern side of the Steinhuder Meer lake was probably formed by halotectonic uplift triggered by evaporites of the earliest Cretaceous Münder Formation (Jordan 1979). The hard, erosion-resistant, quartzose sandstone, reaching a thickness of 10 to 12 m, forms a topographic ridge around most of the western, southern and southeastern perimeter of the anticline, protecting the softer sediments of the saddle core (Kaufmann et al. 1980). Between Münchehagen and Wölpinghausen, the strata have a dip of c. 25 degrees in southwesterly direction.

Today, solely a 2–3 m high ledge is exposed for >60 m in SE–NW direction immediately below the Wilhelmsturm (Fig. 3). This exposure apparently represents what remains of a largely infilled quarry.

As Struckmann's track horizons occurred in the lower part of the sandstone succession, the strata exposed today below the Wilhelmsturm cannot be correlated with these. They are also more thinly bedded, slightly younger and represent the uppermost layers of the sandstone preserved in the area. The lithofacies consists of thin- to medium-bedded, coarse- to fine-grained, mostly moderately to well-sorted sandstones with lenticular to sheet-like bedding-geometry.


A
B
C
D
2
1
0 m
fS
mS
cS
Current ripple marks
Wood (log impression)
Sandstone
Pebbles

The succession comprises at least three fining-upward cycles (Fig. 3A). The best preserved cycle starts with a 2–3 cm thick basal lag consisting of a coarse-grained sandstone with isolated small (3–4 mm) quartz pebbles. This lag overlies an irregular bounding surface and is overlain by thin- to medium bedded, fining-upward, medium- to fine-grained, structureless sandstone, deposited in convex-down, lenticular (up to 8 m wide, 0.4 m thick), concordant bedsets, passing up-wards into laterally thinning sheet-like beds (Fig. 3B). This cycle terminates with a surface covered by unidirectional current ripple marks. The ripple crests show truncation, collapsed flanks, and a reticular, irregular surface pattern, while the ripple troughs are smooth and well preserved (Fig. 3C). The next cycle starts with a c. 1 m thick coset of structureless, medium-grained sandstone. The single beds were deposited in convex-down, lenticular beds (0.3–>5 m wide, 0.05–0.15 m thick). This unit contains a c. 40 cm long wood log impression (Fig. 3D), the only fossil encountered in this outcrop.

The irregular bounding surfaces, coarse basal lag and lenticular bed-geometry indicate cyclical erosive events, which resulted in the formation of shallow channels, subsequently filled by deposits from sediment-laden stream flows (e.g. Mutti et al. 2000). Following the filling of the channels, unconfined flows formed small mouth bars. The apparent lack of internal textures within the sandstone may be a secondary effect due to a poor granulometric contrast or result from very quick deposition from hyperconcentrated flows during rapid deceleration. The formation of current ripples at the top indicates a decrease of sediment concentration during waning flow stage. Crest degradation and collapse evidences a partial emergence of the ripple-marked surfaces. The reticulated pattern on top of the ripple crests is similar to that formed by emerged and dried-up microbial mats (Schieber et al. 2007; Bose & Chafetz 2009).

The lithofacies indicates an environmental setting in a river terminal channel mouth with a very shallow basinward depth gradient, resulting in the formation of extensive shallow-water mouth bar sandflats (e.g. Wright 1977). Fluctuating discharge, e.g. due to seasonal floods, resulted in rapid erosion and remobilization of matured sands. The direction of the channels and ripple marks on laterally unconfined beds indicate northwesterly to northeasterly flow directions. During falling flood stages and flow stagnation, ripple marked surfaces were colonized and stabilized by mat-building microbes. Local emergence is evidenced by degraded ripple crests and dried-up microbial mats with a few mm of water still covering the ripple grooves.

◄ **Fig. 3** Wölpinghausen, quarry below the Wilhelmsturm. Obernkirchen Sandstone, Obernkirchen Member, Bückeberg Formation. **(A)** Lithological log. **(B)** Outcrop, looking towards NE. **(C)** Current ripple-marks with degraded crest tops and reticulate structures probably related to desiccation of emergent microbial mats. **(D)** Wood fragment (log impression, arrows), c. 40 cm long. *Abbreviations:* **fS** fine-grained sandstone, **mS** medium-grained sandstone, **cS** coarse-grained sandstone.

Summary

From the data currently available, it appears that the dinosaur tracks from the southern flank of the Rehburg Anticline (including those from the Münchehagen sites, Wings et al. 2012; ► p. 113-142, this volume) were exclusively found in the lower part of the main sandstone succession. The facies of these deposits were interpreted as shallow-water lagoonal and barrier sand deposits which were mobilized by storm events (Pelzer 1998; Hornung et al. 2012). The upper part exposed below the Wilhelmsturm preserves a distalmost fluvial facies and shows a change of environment throughout the deposition of the sandstone unit. At Münchehagen, the uppermost deposits have not been studied in detail yet. However, at least the base of one isolated channel incised into the lower track-bearing sandstone and filled with large-scale cross-stratified sandstone was reported from the Dino-Park tracksite (Fischer 1998). This might represent a fluvial channel deeply incised from the base of the upper unit.

The outcrop below the Wilhelmsturm shows once again that the Obernkirchen Sandstone and its lateral equivalents have to be considered polygenetic, with rapid lateral and vertical facies changes (see Pelzer 1998; Hornung et al. 2012), though they represent only a relatively thin interval within the up to 700 m thick pelite-dominated Bückeberg Formation. A detailed study of this variability will provide insight into the various environments which were roamed by the late Berriasian dinosaur communities.

Acknowledgements

We thank V. J. Roden, Darmstadt, for checking the English spelling of a first draft.

References

Beckles, S. H. (1852): On the *Ornithoidichnites* of the Wealden. *Quarterly Journal of the Geological Society of London* **8** (1-2): 396-397.

Beckles, S. H. (1854): On the *Ornithoidichnites* of the Wealden. *Quarterly Journal of the Geological Society of London* **10** (1-2): 456-464.

Beyrich, H. E.; Websky, W. & Speyer, O. (1879): 2. Protokoll der December-Sitzung. *Zeitschrift der Deutschen Geologischen Gesellschaft* **31**: 798-804.

Bose, S. & Chafetz, H. S. (2009): Topographic control on distribution of modern microbially induced sedimentary structures (MISS): A case study from Texas coast. *Sedimentary Geology* **213** (3-4): 136-149.

Dollo, L. (1883): Troisième note sur les dinosauriens de Bernissart. *Bulletin du Musée Royal de d'Histoire Naturelle de Belgique* **2**: 85-126.

Fischer, R. (1998): Die Saurierfährten im Naturdenkmal Münchehagen. *Mitteilungen aus dem geologischen Institut der Universität Hannover* **37**: 3-59.

Hornung, J. J.; Böhme, A., Lubbe, T. van der; 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. *Paläontologische Zeitschrift* **86** (3): 231-267.

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).

Kaufmann, R.; Oppermann, H.-U. & Petsch, K. (1980): Zur Entwicklung der tiefen Unterkreide (Berrias/Valangin) im Süden des Rehburger Sattels unter besonderer Berücksichtigung der Tongrube Sachsenhagen. *Ballerstedtiana* **3**: 5-27.

LBEG [Landesamt für Bergbau, Energie und Geologie Niedersachsen] (2009): Cardomap server. http://memas01.lbeg.de/lucidamap/index.asp [last accessed 02 July 2009]

Mutti, E.; Tinterri, R.; di Biase, D:; Fava, L.; Mavilla, N.; Angella, S. & Calabrese, L. (2000): Delta-front facies associations of ancient flood-dominated fluvio-deltaic systems. *Revista de la Sociedad Geológica de España* **12** (2): 165-190.

Pelzer, G. (1998): Sedimentologie und Palynologie der Wealden-Fazies im Hannoverschen Bergland. *Courier Forschungsinstitut Senckenberg* **207**: 211 pp.

Schieber, J.; Bose, P.; Eriksson, P. G.; Banerjee, S.; Sarkar, S.; Altermann, W. & Catuneanu, O. (eds., 2007): *Atlas of Microbial Mat Features Preserved within the Siliciclastic Rock Record.* 324 pp.; Amsterdam (Elsevier).

Struckmann, C. (1880a): *Die Wealden-Bildungen der Umgebung von Hannover. Eine geognostisch-paläontologisch-statistische Darstellung.* viii + 122 pp.; Hannover (Hahn).

Struckmann, C. (1880b): Vorläufige Nachricht über das Vorkommen großer, vogelähnlicher Thierfährten (*Ornithoidichnites*) im Hastingssandsteine von Bad Rehburg bei Hannover. *Neues Jahrbuch für Mineralogie, Geologie und Paläontologie* **[1880]** (1): 125-128.

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. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, 113-142; Göttingen (Universitäts-Verlag). [this volume]

Wright, L. D. (1977): Sediment transport and deposition at river mouths: A synthesis. *Geological Society of America, Bulletin* **88** (6): 857-868.

Excursion Guide C1: **Northern 'German Wealden' – the collection of the Göttingen University**

Annina **Böhme**[1,3*], Mike **Reich**[1,2*], Jahn J. **Hornung**[1] & Hans-Volker **Karl**[4]

[1]*Department of Geobiology, Geoscience Centre of the University of Göttingen, Göttingen, Germany*

[2]*Geoscience Museum of the University of Göttingen, Göttingen, Germany*

[3]*Hannover State Museum, Hannover, Germany*

[4]*Friedrich-Schiller University Jena, Department of Prehistory and Early History, Jena, Germany*

[*]*corresponding authors:* Annina.Boehme@nlm-h.niedersachsen.de & mreich@gwdg.de

The 'Wealden' collection of the University of Göttingen is part of the Georgia Augusta Geoscience Collections, which range among the four largest geoscientific collections in Germany, comprising over 4.5 million objects and series, and existing since almost 300 years (Reich 2008, 2012; Reich et al. 2009; herein).

History of the 'Wealden' collection at Göttingen University

The earliest collection work on 'German Wealden' fossils in Göttingen can be traced back to Johann Friedrich Blumenbach (1752–1840; Fig. 1A, 2). Over the following years, more than 50 persons (professional and amateur palaeontologists and geologists) collected, provided and donated material, with a peak of activity during the second half of the 19th and the first half of the 20th century. Additionally numerous larger fossils were purchased by the University of Göttingen. Major parts of the collection were acquired by geological mapping campaigns under the supervision of the former chair of geology and palaeontology at the Göttingen University, Adolf von Koenen (1837–1915; Fig. 1C), between 1881 and 1907, as well as by the long-term loan of the geological collection of the 'Gymnasium Adolfinum' school in Bückeburg in 1976. The latter includes the private collection of Max[imilian Wilhelm Carl] Ballerstedt (1857–1945; Fig. 1D), together with his personal library, notes, pictures and correspondence, and comprises more than 1000 fossil objects. The latest important acquisition was achieved by a smaller collection (approximately 300 objects, some of which were also previously in the possession of M. Ballerstedt) from the Schaumburg-Lippesches Landesmuseum in Bückeburg in 2010 (long-term loan).

Among the most significant personalities concerning the expansion of the 'Wealden' collection were Friedrich E. Witte (1804–1887), Carl E. F. Struckmann (1833–1898; Fig. 1B; see Hornung, Böhme & Reich 2012d; ► p. 143-149, this volume), Carl A. L. von Seebach (1839–1880), Heinrich F. W. Grabbe (1858–18??), Erich Meyer (1874–1915), Erich Harbort (1879–1929), Karl Andrée (1880–1959) and many others (Reich 2008, 2012; Reich et al. 2009; Hornung, Böhme et al. 2012; herein).

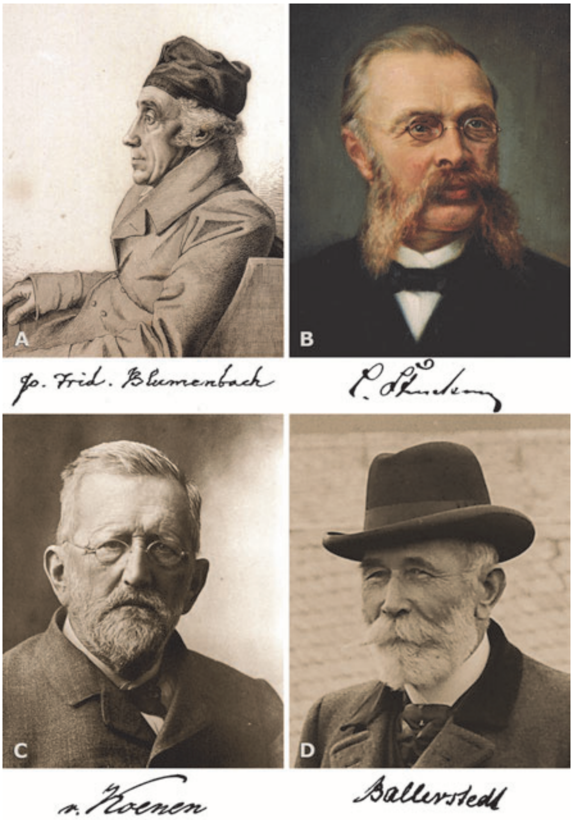


Fig. 1 Portraits and signatures of 'Wealden' researchers related to Göttingen. **(A)** Johann Friedrich Blumenbach (1752–1840). **(B)** Carl E. F. Struckmann (1833–1898). **(C)** Adolf von Koenen (1837–1915). **(D)** Max Ballerstedt (1857–1945). Photograph / picture: GZG Archive (A, C-D); Naturhistorische Gesellschaft Hannover (B).

The 'Wealden' material provided the bases for research on the 'German Wealden' fauna and flora since the 18th century (e.g. by von Meyer 1841, 1857, 1859; Dunker 1844, 1846; Schenk 1871; Grabbe 1881, 1883, 1884; Koken 1883, 1886, 1887, 1896; Branco 1887; Ballerstedt 1905, 1914, 1921b, 1922; Michael 1936; Huckriede 1967; Schmidt 1969; Schultze 1970; Sues & Galton 1982; Butler & Sullivan 2009; Andrade & Hornung 2011 etc.). To the most important type material among these belongs the postcranial skeleton of the small dinosaur *Stenopelix valdensis* von Meyer, 1857 from the Harrl hill (see Hornung, Böhme & Reich 2012c; ► p. 101-112, this volume), since it is the most complete dinosaur from the 'German Wealden'. However, its systematic position is still under discussion. It was found in 1855 (Bernhards 1948) and donated to the 'Gymnasium Adolfinum' school in Bückeburg, housed at Göttingen University since 1976. The Adolfinum's collection was founded as a private natural sciences collection by Prince Georg Wilhelm zu Schaumburg-Lippe (1784–1860) and curated at the school since 1840 (Bernhards 1948). Hermann von Meyer (1801–1869) – an early doyen of vertebrate palaeontology in Germany – described two new genera from the material of the Adolfinum, *Stenopelix* (von Meyer 1857, 1859) and the crocodilian *Pholidosaurus* (von Meyer 1841).

Fig. 2 Johann Friedrich Blumenbach published one of the earliest descriptions of German 'Wealden' fossils: "Strombiten" [= mass occurrences of the gastropod *Paraglauconia strombiformis*] in 1780. Reference specimen from Neustadt am Rübenberge, Lower Saxony [coll. Blumenbach]. The first German 'Wealden' fossil description was probably given by Friedrich Lachmund (1635–1676) in his 'Oryctographia Hildesheimensis', published in 1669.

Due to the incompleteness and the morphological peculiarities of both, von Meyer hesitated to refer both reptiles to higher taxa and referred to them by the rather general term 'saurians'. Impressed by the fossils he studied, von Meyer proposed in a letter to school principal Wilhelm Burchard (1804–1887) to establish a "... local collection adequate to land and people..." in 1857 (Bernhards 1948).

It was M. Ballerstedt, who addicted himself to this mission in the first half of the 20th century. Max Ballerstedt (1857–1945), born in Bückeburg, was a teacher, collector and amateur palaeontologist. After a traineeship from 1883–1887, he finally began his work as full-time teacher at the Adolfinum in 1898 and supervised its natural sciences collection since 1900. Additionally he endeavoured own excavations of dinosaur tracks at the Harrl hill near Bückeburg (Hornung, Böhme & Reich 2012c; ► p. 101-112, this volume), together with the Schaumburg-Lippische Heimatverein (local history society). His efforts were recognised well by the aristocratic government, and in 1907 he was appointed as a high school professor ('Gymnasialprofessor') by Prince Stephan Albrecht Georg zu Schaumburg-Lippe (1846–1911) on honorary causes (Ballerstedt never received a doctoral degree; a proposal from the 1930s years concerning granting of a honorary doctorate of the University of Göttingen was not successful). In 1912, at the age of only 55, he was retired from school service due to increasing deafness and was granted a special pension to further supervise and increase the fossil collections. In the course of time, he collected about 1500 objects (mainly 'Wealden' and Pleistocene vertebrate fossils) and finally in 1940, he donated his collection to the 'Schaumburg-Lippesche Landesregierung' (government of Schaumburg-Lippe, being know an administrative district of Lower Saxony). The collection remained at the Adolfinum but suffered from a lack of attendance after Ballerstedt's death in December 1945 and in the wake of World War II. After some efforts of preservation by the teacher Hilrich Bernhards since 1948, most of the collection found a new home in Göttingen in 1976 (Hornung & Reich 2006, 2007).

One of Ballerstedt's main interests were dinosaur tracks (e.g. Ballerstedt 1905, 1914, 1921a, 1921b, 1922) and he communicated with many outstanding palaeontologists of his time by letters and personally, including Othenio Abel (1875–1946), Louis Dollo (1857–1931) and Franz Baron Nopcsa (1877–1933).

Additional highlights of the Ballerstedt/Adolfinum collection are the possible type material of the ankylosaurian ichnospecies *Metatetrapous valdensis* Nopsca, 1923 and the theropod ichnotaxon '*Bueckeburgichnus*' *maximus* Kuhn, 1958 (see Hornung, Böhme & Reich 2012c; ► p. 101-112, this volume).

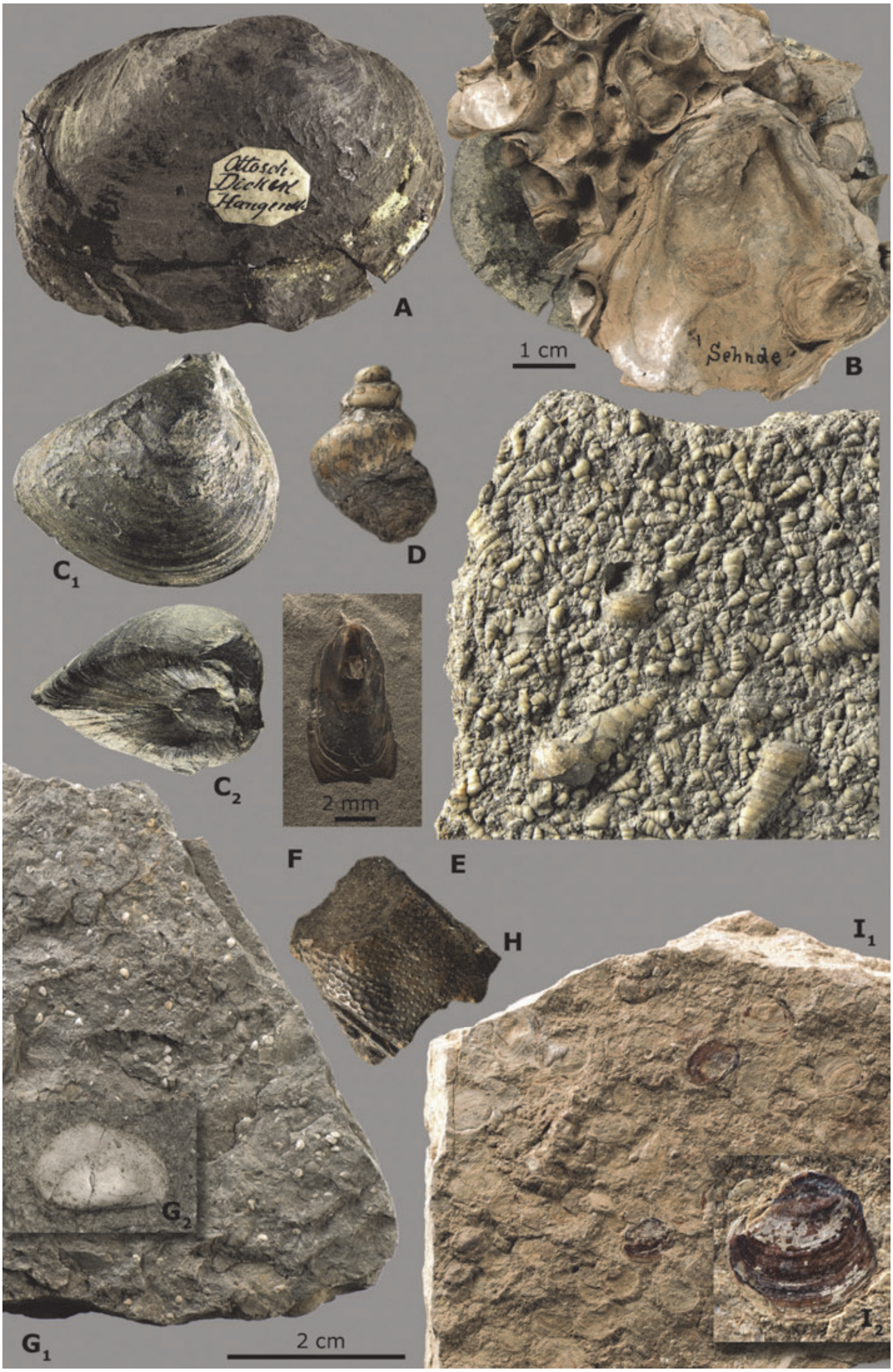
Faunal and floral successions

The 'Wealden' (Bückeberg Formation, Early Cretaceous) of northern Germany (Lower Saxony and Westphalia) is not only known for its dinosaur tracks. At least in the collections of the University of Göttingen, there are far more than 3000 objects and series from over 100 localities (including material from outcrops no longer in existence), comprising a wide spectrum of organisms:

***Molluscs (Fig. 3A-E)* —** The invertebrate macrofauna is dominated by mollusc assemblages. Bivalves are represented mainly by unionids and neomiodontids. Some oysters and rare mytilids and trigoniids are present, too. Gastropods are dominated by viviparids and *Paraglauconia* spp. (e.g. Blumenbach 1780; Dunker 1846; Huckriede 1967). The fauna displays virtually exclusive non-marin conditions. In Valanginian times, the marine input increased, as can for example be seen by the repeated appearance of oysters at Sehnde near Hannover (e.g. Struckmann 1891). Up to date, there is still a lack of detailed taxonomic and diversity studies of these groups.

***Arthropods (Fig. 3G-I)* —** Non-marine ostracods are common elements of the microfauna in the pelitic basinal 'Wealden Shale' deposits (e.g. *Cypridea* spp.) and represent one of the most biostratigraphically useful groups within the 'Wealden' fossils (e.g. Wolburg 1949, 1959, 1962, 1971; Schudack & Schudack 2009). Spinicaudatans (conchostracans), already identified, collected and described by Dunker in 1846 and later on by Jones (1862), are rare. Additionally, malacostracans, insects (mostly coleopterans) and arachnids were reported but not well studied yet.

Fig. 3 Molluscs, arthropods and a brachiopod from the German 'Wealden'. ► **(A)** Bivalve *'Unio menkei'*, argillaceous facies – pit 'Otto', Kloster Oesede near Osnabrück. **(B)** Oyster ?*Aetostreon* sp., argillaceous facies – Sehnde near Hannover. **(C_{1-2})** Bivalve *Neomiodon latoovatus*, argillaceous facies – Sülbeck near Northeim. **(D)** *Viviparus* sp. – Neustadt am Rübenberge. **(E)** Slab with the gastropod *Paraglauconia strombiformis* – Neustadt am Rübenberge. **(F)** Chitino-phosphate brachiopod *Lingula* sp. – Vorhagen. **(G_{1-2})** Slab with various ostracod specimens of *Cypridea laevigata* including an enlarged single specimen – Bredenbeck. **(H)** Carapace fragment of an indet. decapod – Deister. **(I_{1-2})** Slab with conchostracans including a detailed view on a single specimen – south of Lagemann. From the Berriasian (A, C-G), the Berriasian–Valanginian (H), and the early Valanginian ('Wealden' 5-6) (B) of Lower Saxony, as well as the Berriasian–Valanginian of Westphalia (I) (GZG coll.). Scale bars: 2 cm = A, C-E, G-I; 1 cm = B; 2 mm = F.


Ottosch.
Dickeh
Hangend
A
1 cm
Sehnde
B
C1
D
C2
2 mm
F
E
H
I1
G2
I2
G1
2 cm

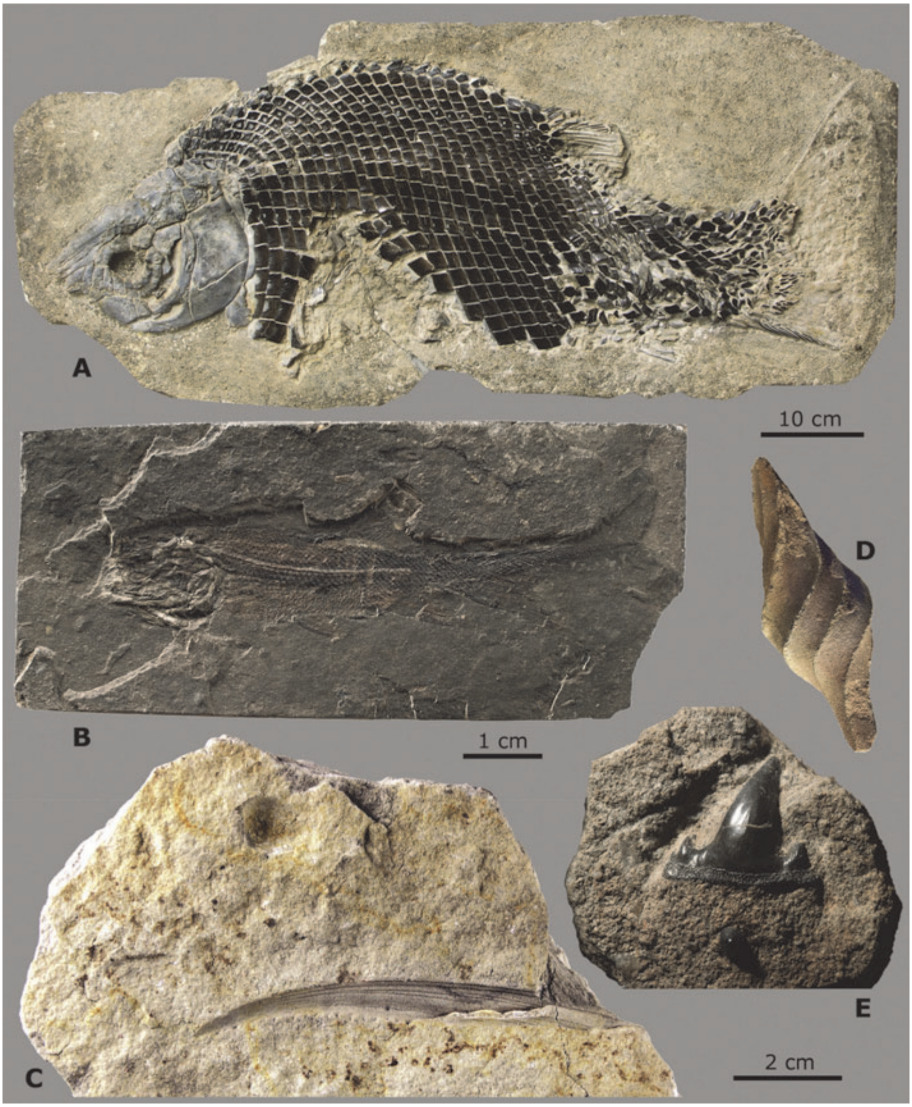


Fig. 4 Actinopterygians **(A-B)** and sharks **(C-E)** from the German 'Wealden'. **(A)** *Scheenstia mantelli* (syn. *Lepidotes mantelli*) – Obernkirchen. **(B)** *Indaginilepis rhombifera* (holotype) – Stadthagen. **(C)** Fin spine of a hybodontid shark, preserved as mould, sandy facies – (?)Bückeberg. **(D)** 3D-preserved hybodontid shark egg capsule, sandy facies – Harrl. **(E)** Hybodontid shark tooth *Hybodus* sp. and crushing tooth (Semionotiformes) – Sehnde near Hannover. From the Berriasian (A-D) and early Valanginian ('Wealden' 5-6) (E)of Lower Saxony (GZG coll.). Scale bars: 10 cm = A; 2 cm = C-E; 1 cm = B.

Brachiopods (Fig. 3F) — Are at least represented by *Lingula* sp. (which is known for tolerating brackish conditions) from the pelitic basinal 'Wealden' succession.

Selachians (Fig. 4C-E) — The presence of hybodont sharks is proven mainly by teeth, bony fin spines, some egg capsules (*Palaeoxyris* spp.) and rare head spines of Hybodontiformes (see also Fischer & Kogan 2008), that lived in fresh and brackish waters.

Actinopterygians (Fig. 4A-B) — Bony fishes are represented by scales, teeth and up to complete specimens, including spectacular specimens of lepidotid fish (e.g. Branco 1887; López-Arbarello et al. 2007) like *Scheenstia* (López-Arbarello 2012; López-Arbarello & Sferco 2011). In 1970, H.-P. Schultze described a new palaeoniscoid fish (*Indaginilepis rhombifera*) from Stadthagen. Otoliths are rare (Martin & Weiler 1954).

Turtles (Fig. 5) — At least six species of aquatic turtles are known from the Bückeberg Formation represented mainly by hypo- and epireliefs from the carapace and plastron, some isolated bones and one natural cast of an isolated manus track. Several different ecotypes of turtles can be reconstructed, such as large river turtles of the estuary areas (*Pleurosternon bullockii*, *Hylaeochelys menkei*), medium sized flat-water turtles (*Desmemys bertelsmanni*), Matamata-like bottom-dwelling turtle (*Chitracephalus dumonii*) and the ancestor of the soft-shelled turtles (*Peltochelys duchastelli*), like the recent pig-nosed turtle (*Carettochelys insculpta*) of Northern Territory of Australia and New Guinea (Karl, Gröning et al. 2012b). *Pleurosternon bullockii*, *Hylaeochelys menkei* and rather medium-sized specimens of *Ballerstedtia bueckebergensis* are common finds in the Obernkirchen Sandstone (e.g. Grabbe 1884; Peitz 1998; Karl et al. 2007a, 2007b; Hornung et al. 2008; Karl, Gröning et al. 2012a; see Hornung, Böhme & Reich 2012c; ► p. 101-112, this volume). Furthermore, the turtle ichnospecies *Emydhipus cameroi*, was recently be identified (Karl et al. 2012c). The German 'Wealden' turtle fauna includes elements also known in part from contemporaneous or slightly younger Cretaceous strata of Belgium, Spain and England.

Plesiosaurs (Fig. 7A) — Apparently entered the Lower Saxony Basin during times of marine incursion, but may have prevailed there also in brackish and lacustrine waters. The collections of the Göttingen University house some isolated fossil remains (vertebrae, limb elements) which probably allow an assignment to *Brancasaurus brancai*. Based on at least one fairly complete, 3 m long skeleton, this plesiosaur was first described from the upper Bückeberg Formation near Gronau in Westphalia by Wegner in 1914.

Pterosaurs — Are so far known only by a single manus imprint of a very large specimen (wingspan ca. 6 m), which is nearly indistinguishable from the contemporaneous ichnotaxon *Purbeckopus* from southern England. The specimen survived as a plaster cast which was originally presented by Max Ballerstedt to Othenio Abel in 1935 (Hornung & Reich 2011).

Fig. 5 Turtles from the German 'Wealden'. **(A)** Steinkern (internal cast) of a turtle shell of *Hylaeochelys menkei*, sandy facies – Harrl hill. **(B)** Scapula of the small turtle *Chitracephalus dumonii*, argillaceous facies – Wendthagen. **(C)** Internal impression of a turtle shell of *Ballerstedtia bueckebergensis*, sandy facies – Bückeberg ('new quarry', 1912). All from the Berriasian of Lower Saxony (GZG coll.). Scale bars: 10 cm = A; 1 cm = B; 5 cm = C.

Fig. 6 Crocodilian fossils from the German 'Wealden'. **(A_{1-2})** Skull roof and palate of the broad-snouted crocodile *Goniopholis simus* (preserved as mould), sandy facies – Harrl hill. **(B-C)** Osteoderms of *Goniopholis* sp., argillaceous (B) and sandy (C) facies – Sehnde/ Gretenberg near Hannover (B) and Harrl hill (C). **(D)** Tooth of *Goniopholis* sp., argillaceous facies – Sehnde/Gretenberg near Hannover. From the Berriasian (A, C) and early Valanginian ('Wealden' 5-6) (B, D) of Lower Saxony (GZG coll.). Scale bars: 10 cm = A; 5 cm = B-C; 1 cm = D.

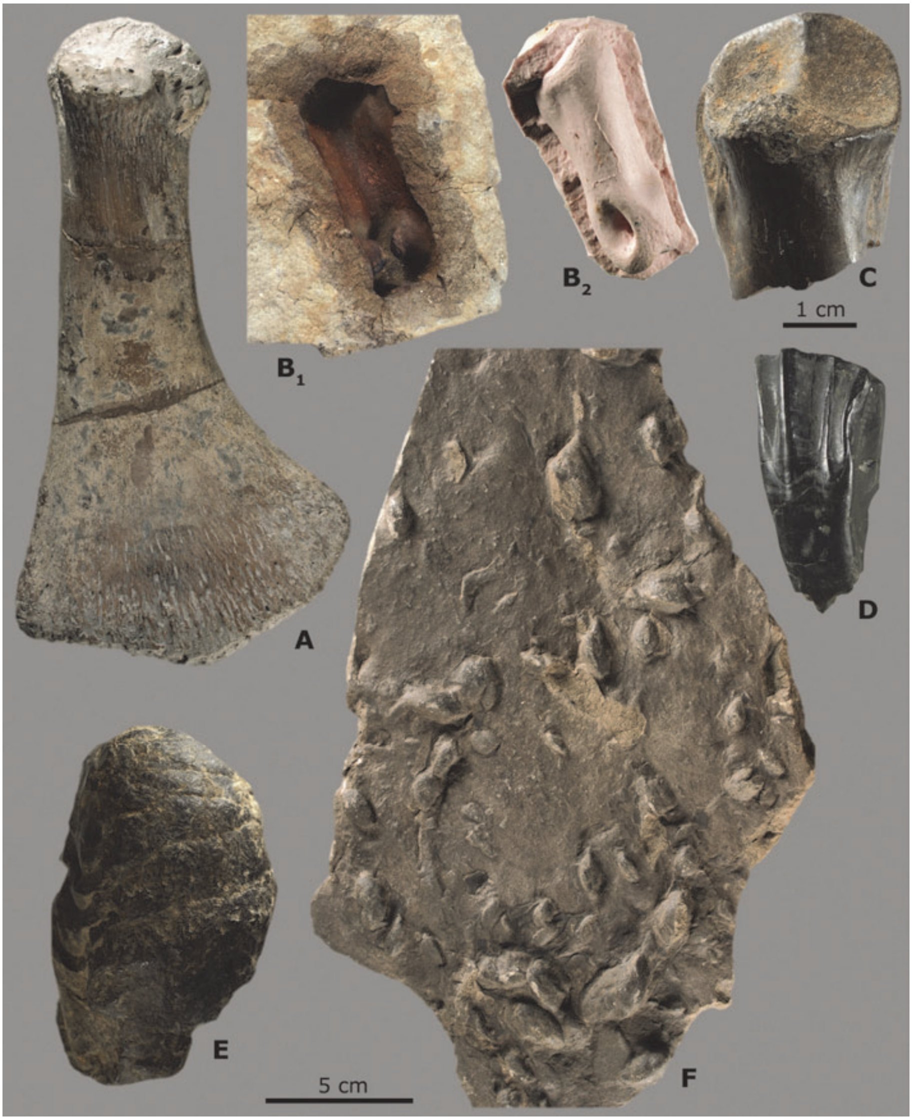


Fig. 7 Plesiosaur and dinosaur fossils as well as ichnofossils from the German 'Wealden'. **(A)** Propodial of the plesiosaur *Brancasaurus brancai*, argillaceous facies – Gronau. **($B_{1\text{-}2}$)** ?Finger phalange of a medium-sized theropod, preserved as mould (B_1) and corresponding silicone rubber cast (B_2), sandy facies – Harrl hill. **(C)** Presumably pedal phalange fragment of a small ornithopod, argillaceous facies – Kniggenbrink, Deister. **(D)** Worn tooth of an iguanodontian dinosaur, argillaceous facies – Sehnde/Gretenberg near Hannover. **(E)** Phosphatic coprolite, argillaceous facies – Salzbergen. **(F)** Bivalve resting trace *Lockeia* isp. – (?)Harrl. From the Berriasian (B, E-F), early Valanginian ('Wealden' 5-6) (D) and Berriasian–Valanginian (or Hauterivian) (C) of Lower Saxony, as well as from the early Valanginian ('Wealden 6') (A) of Westphalia (GZG coll.). Scale bars: 5 cm = A-B, E-F; 1 cm = C-D.

Crocodilians (Fig. 6) — Are present with several skulls, partial skeletons, individual bones and teeth of at least two species. Best known are the basal neosuchian, broad-snouted crocodile *Goniopholis simus* (see also Salisbury et al. 1999; Andrade & Hornung 2011), probably being comparable to the present-day nile crocodile (*Crocodylus niloticus*) in its ecology, and the slender-snouted *Pholidosaurus schaumburgensis* (see Hornung, Böhme & Reich 2012c; ► p. 101-112, Fig. 2B, this volume), resembling the present-day Malayan gharial *Tomistoma schlegelii* in morphology (e.g. Koken 1886, 1887).

Dinosaurs (Fig. 7B-D) — The mostly complete but enigmatic ornithischian *Stenopelix valdensis* von Meyer, 1857 (see Hornung, Böhme & Reich 2012c; ► p. 101-112, this volume) was controversially referred to Ornithopoda ('Hypsilophodontidae'), Pachycephalosauria and basal Ceratopsia (e.g. Schmidt 1969; Sues & Galton 1982; Butler & Sullivan 2009), latest research suggests a close relationship to very basal ceratopsians (Butler et al. 2011). Ornithopods are represented mainly by tracks (natural casts and epireliefs), isolated bones and teeth of basal iguanodontians. Ankylosaurs are present with two isolated natural casts of a left pes track – *Metatetrapous valdensis* Nopcsa, 1923 (e.g. Ballerstedt 1921b; Hornung et al 2007; see Hornung, Böhme & Reich 2012c; ► p. 101-112, this volume). The track record suggests a high diversity of theropods in the Bückeberg Formation. Mainly tridactyl tracks (natural casts and epireliefs) of middle sized theropods – including also natural casts and epireliefs from '*Bueckeburgichnus*' *maximus* Kuhn, 1958 (e.g. Lockley 2000; Thulborn 2001; see Hornung, Böhme & Reich 2012c; ► p. 101-112, this volume) – and very rare isolated bone fragments of theropods are preserved in the Göttingen collection. From the Obernkirchen 'chicken yard', we even know didactyl tracks of Troodontidae (see Richter, van der Lubbe et al. 2012; ► p. 52, this volume).

Invertebrate and undetermined trace fossils (Fig. 7E-F) — In the 'Wealden' sandstones, *Lockeia* isp., a resting trace of bivalves, is one of the most abundant invertebrate ichnofossils. Coprolites of vertebrates and burrows of unknown origin are also present.

Charophytes, palynomorphs and other plants (Fig. 8) — In addition to charophytes (e.g. Schudack 1996) and palynomorphs (e.g. Dörhöfer 1977; Pelzer 1998), plants (e.g. Riegel et al. 1986) are represented by stems, rhizomes, leaves and rootlets mainly of tree ferns (e.g. *Tempskya* sp., *Onchiopsis* sp.) and ferns *s. str.* (e.g. *Matonidium* sp.), horsetails (*Equisetites* sp.), gingkoes (*Baiera* sp.), conifers (araucarians, cypress) and other gymnosperms (e.g. *Pseudotorellia* sp.), bennettitales and cycads (e.g. *Zamites* sp., *Dioonites* sp.).

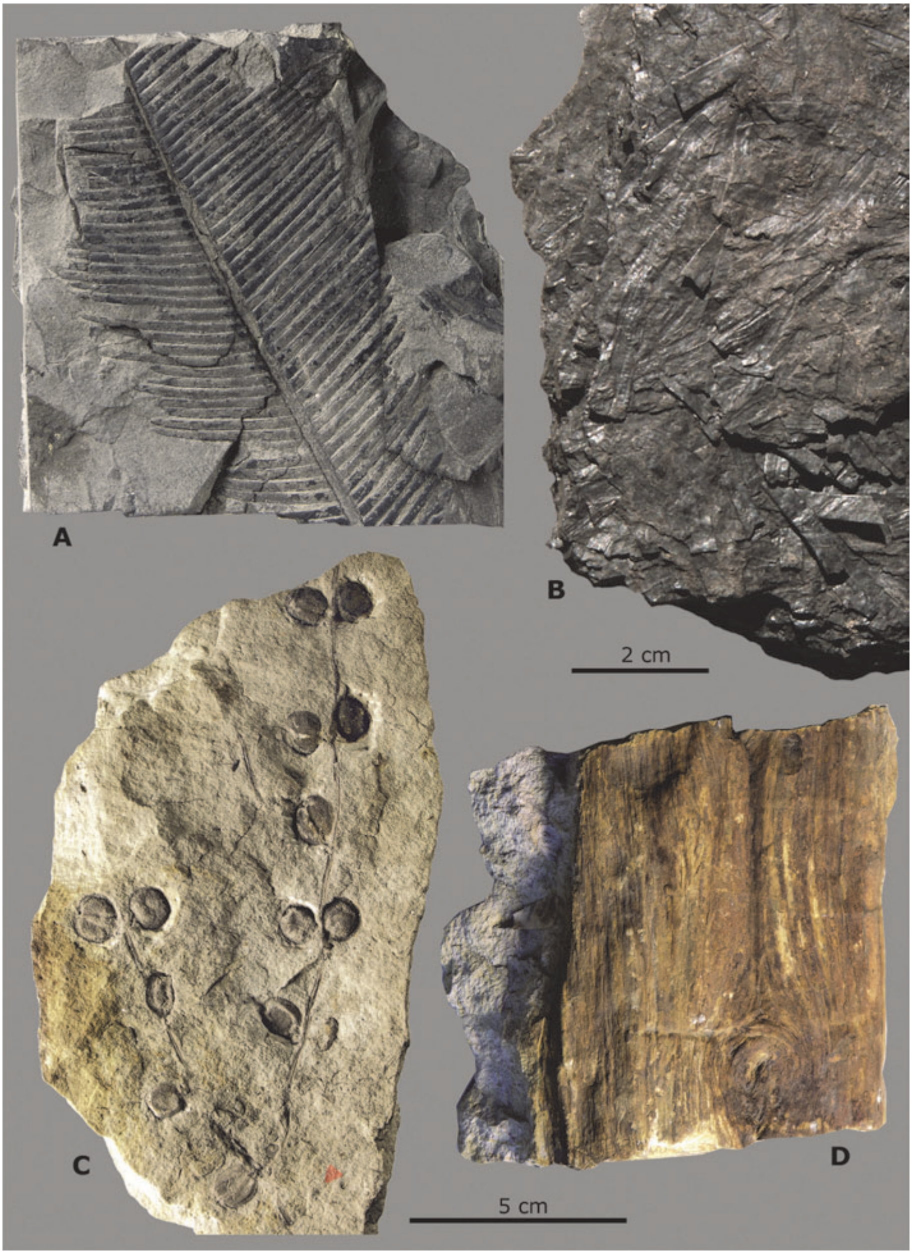


Fig. 8 Plant remains from the German 'Wealden'. **(A)** Cycad *Dioonites* sp., argillaceous facies – Borgloh, south of Osnabrück. **(B)** '*Abietites* leaf coal' with the gymnosperm *Pseudotorellia linkii* – Duingen. **(C)** Horsetail *Equisetites burchardti*, sandy facies – Wennigsen, Deister. **(D)** Small ?conifer tree trunk, sandy facies – Harrl. All from the Berriasian of Lower Saxony (GZG coll.). Scale bars: 2 cm = A-B; 5 cm = C-D.

Discussion and summary

Fossils from the Bückeberg Formation occur in sandstones, claystones, limestones (partly sideritic) and coals. Therefore, the preservation ranges from cavities and casts (after the artificial removal of the very soft residue of the altered skeletal substance, see Hornung, Böhme & Reich 2012b; ► p. 62-72, this volume) in sandstones to fully permineralised fossils.

In general, the 'German Wealden' localities, being represented by the material of the collections of the Göttingen University, can be merged in 11 main regions: (1) Rehburg Mountains (Münchehagen, Wölpinghausen etc.), (2) Bückeberge mountains (Obernkirchen, Liekwegen, etc.), (3-7) Harrl hill, Deister, Süntel, Osterwald, and Hils mountains, (8) Hannover (Sehnde, Gretenberg, etc.) area, (9) Braunschweig area, (10) Osnabrück area and (11) Westphalia (Gronau). By numbers of specimens, bivalves dominate by far. Within the invertebrates, bivalves and gastropods dominate the macrofauna and ostracods the microfauna. The bulk of vertebrate fossils in the collection originate from the Bückeberge, Harrl hill and Sehnde/Gretenberg (eastern Hannover area). The Bückeberg and Harrl hill fossils are typical sandstone moulds and the Sehnde/Gretenberg fossils (claystones and limestones) are bodily preserved.

The analysis of the entirety of those fossils in relation to their localities will bring more light to the 'German Wealden' biodiversity and palaeoecology in the near future. Finally, we have to bear in mind, that there is a lot of hidden diversity in the 'German Wealden'. Many organisms and their remains, like otoliths, mammals, lizards and lissamphibians, still have to be verified.

Acknowledgements

We thank V. J. Roden, Darmstadt, for checking the English spelling of our first draft, as well as T. R. Stegemann for technical assistance.

References

Andrade, M. B. de & Hornung, J. J. (2011): A new look into the periorbital morphology of *Goniopholis* (Mesoeucrocodylia: Neosuchia) and related forms. *Journal of Vertebrate Paleontology* **31** (2): 352-368.

Ballerstedt, M. (1905): Über Saurierfährten der Wealdenformation Bückeburgs. *Naturwissenschaftliche Wochenschrift (Neue Folge)* **4** (31): 481-485.

Ballerstedt, M. (1914): Bemerkungen zu den älteren Berichten über Saurierfährten im Wealdensandstein und Behandlung einer neuen, aus 5 Fußabdrücken bestehenden Spur. *Centralblatt für Mineralogie, Geologie und Paläontologie* **[1914]** (2): 48-64.

Ballerstedt, M. (1921a): Zwei große, zweizehige Fährten hochbeiniger Bipeden aus dem Wealdensandstein bei Bückeburg. *Zeitschrift der Deutschen Geologischen Gesellschaft, Monatsberichte* **73B**: 76-91.

Ballerstedt, M. (1921b): Dinosaurierfährten im Wealdensandstein des Harrl bei Bückeburg und eine zur Zeit freiliegende Spur eine „vierfüßigen" plumpen Dinosauriers. *Zeitschrift der Deutschen Geologischen Gesellschaft* **72**: 231-233.

Ballerstedt, M. (1922): Über Schreckensaurier und ihre Fußspuren. *Kosmos* **19** (3): 77-80.

Bernhards, H. (1948): Bericht des Studienrats Dr. H. Bernhards, Bückeburg, über Entstehung, Bestand und Bedeutung der paläontologischen Sammlung des Adolfinums in Bückeburg. *Unpublished manuscript*: 21 pp. [GZG Archives]

Blumenbach, J. F. (1780): *Handbuch der Naturgeschichte. Zweyter Teil:* 559 pp.; Göttingen (J. C. Dieterich).

Branco, W. (1887): Beiträge zur Kenntnis der Gattung *Lepidotus. Abhandlungen zur geologischen Specialkarte von Preußen und den thüringischen Staaten* **7** (4): 84 pp.

Butler, R. J.; Jin Li-yong; Chen Jun & Godefroit, P. (2011): The postcranial osteology and phylogenetic position of the small ornithischian dinosaur *Changchunsaurus parvus* from the Quantou Formation (Cretaceous: Aptian-Cenomanian) of Jilin Province, north-eastern China. *Palaeontology* **54** (3): 667-683.

Butler, R. J. & Sullivan, R. M. (2009): The phylogenetic position of the ornithischian dinosaur *Stenopelix valdensis* from the Lower Cretaceous of Germany and the early fossil record of Pachycephalosauria. *Acta Palaeontologica Polonica* **54** (1): 21-34.

Dörhöfer, G. (1977): Palynologie und Stratigraphie der Bückeberg-Formation (Berriasium, Valanginium) in der Hilsmulde (Nordwest-Deutschland). *Geologisches Jahrbuch (A: Allgemeine und regionale Geologie BR Deutschland und Nachbargebiete, Tektonik, Stratigraphie, Paläontologie)* **42**: 3-122.

Dunker, W. (1844): Ueber den norddeutschen Wälderthon und dessen Versteinerungen. *Studien des Göttingischen Vereins bergmännischer Freunde* **V**: 105-185.

Dunker, W. (1846): *Monographie der Norddeutschen Wealdenbildungen: ein Beitrag zur Geognosie und Naturgeschichte der Vorwelt.* 83 pp.; Braunschweig (Oehme & Müller).

Fischer, J. & Kogan, I. (2008): Elasmobranch egg capsules *Palaeoxyris*, *Fayolia* and *Vetacapsula* as subject of palaeontological research – an annotated bibliography. *Freiberger Forschungshefte (C: Paläontologie, Stratigraphie, Fazies)* **528**: 75-91.

Grabbe, H. (1881): Neue Funde von Saurier-Fährten im Wealdensandsteine des Bückeberges. *Verhandlungen des naturhistorischen Vereines der preussischen Rheinlande und Westfalens, Correspondenzblatt* **38** (1): 161-164. [= *Vierte Folge* **8**]

Grabbe, H. (1883): Die Schaumburg-Lippe'sche Wealden-Mulde. *Doctoral thesis, University of Göttingen:* 61 pp.; Bückeburg (Grimme).

Grabbe, H. (1884): Beitrag zur Kenntniss der Schildkröten des deutschen Wealden. *Zeitschrift der Deutschen Geologischen Gesellschaft* **36**: 17-28.

Hornung, J. J.; Böhme, A., Lubbe, T. van der; 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. *Paläontologische Zeitschrift* **86** (3): 231-267.

Hornung, J. J.; Böhme, A. & Reich, M. (2012): Excursion Guides A-C: The 'German Wealden' and the Obernkirchen Sandstone – an Introduction. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, 62-72; Göttingen (Universitäts-Verlag). [this volume] [2012b]

Hornung, J. J.; Böhme, A. & Reich, M. (2012): Excursion Guide A2: Harrl hill near Bückeburg. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, 101-112; Göttingen (Universitäts-Verlag). [this volume] [2012c]

Hornung, J. J.; Böhme, A. & Reich, M. (2012): Excursion Guide B2: Wölpinghausen. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, 143-149; Göttingen (Universitäts-Verlag). [this volume] [2012d]

Hornung, J. J.; Karl, H.-V. & Reich, M. (2008): An exquisitely preserved turtle footprint from the Berriasian (lowermost Cretaceous) of northwestern Germany. *In* Löffler, S. B. & Freiwald, A. (eds.): Jahrestagung der Paläontologischen Gesellschaft. 8.-10. September 2008, Erlangen. *Erlanger geologische Abhandlungen, Sonderband* **6**: 91-92.

Hornung, J. J.; König, J. & Reich, M. (2007): Rediscovered type material of the ankylosaurian ichnospecies *Metatetrapous valdensis* Nopcsa, 1923 (Early Cretaceous, NW Germany). *In* Elicki, O. & Schneider, J. W. (eds.): Fossile Ökosysteme. 77. Jahrestagung der Paläontologischen Gesellschaft. Kurzfassungen der Vorträge und Poster. *Wissenschaftliche Mitteilungen, Institut für Geologie, TU Bergakademie Freiberg* **36**: 59-60.

Hornung, J. J. & Reich, M. (2006): The "Wealden" collection of Max Ballerstedt (1857-1945) – undisclosed treasures from the Early Cretaceous of northwestern Germany. *In* 76. Jahrestagung der Paläontologischen Gesellschaft. Kiel, 28.-30. August 2006. Beitragskurzfassungen. *Berichte-Reports des Instituts für Geowissenschaften, Christian-Albrechts-Universität Kiel* **22**: 40-41.

Hornung, J. J. & Reich, M. (2007): Krokodile, Schildkröten & Dinosaurier. Die „Wealden"-Sammlung der Universität Göttingen. *Fossilien* **24** (1): 32-36.

Hornung, J. J. & Reich, M. (2011): The first record of a pterosaur ichnite from the lower Bückeberg Formation (Early Cretaceous) of Bückeburg, Lower Saxony, northern Germany. *In* Nagel, D. (ed.): 82. Jahrestagung der Paläontologischen Gesellschaft in Wien, Abstract Volume. *Beiträge zur Paläontologie* **32**: 55-56.

Huckriede, R. (1967): Molluskenfaunen mit limnischen und brackischen Elementen aus Jura, Serpulit und Wealden NW-Deutschlands und ihre paläogeographische Bedeutung. *Beihefte zum Geologischen Jahrbuch* **67**: 263 pp.

Jones, R. T. (1862): A monograph oft he fossil Estheriae. *Monograph of the Palaeontographical Society* **14** (5): 134 pp.

Karl, H.-V.; Gehler, A.; Roden, V. J. & Reich, M. (2007): Die Schildkröten des nordwestdeutschen „Wealden" (Unter-Kreide: Berriasium) und ihre Paläoökologie. *In* Elicki, O. & Schneider, J. W. (eds.): Fossile Ökosysteme. 77. Jahrestagung der Paläontologischen Gesellschaft. Kurzfassungen der Vorträge und Poster. *Wissenschaftliche Mitteilungen, Institut für Geologie, TU Bergakademie Freiberg* **36**: 64-65. [2007a]

Karl, H.-V.; Gröning, E.; Brauckmann, C. & Reich, M. (2012): *Ballerstedtia bueckebergensis*, a new turtle from the Early Cretaceous Wealden facies of Germany (Testudines: Pleurosternidae). *In* Karl, H.-V. (ed.): Turtle faunal changes in Central Europe and related areas. *Studia Palaeocheloniologica* **IV**: 47-60. [= *Studia geológica Salmanticensia, Volumen especial* **9**] [2012a]

Karl, H.-V.; Gröning, E.; Brauckmann, C. & Reich, M. (2012): First record of *Chitracephalus dumonii* (Testudines: Pleurodira; Early Cretaceous) in Central Europe and the rise of Matamata-like turtles. *In* Karl, H.-V. (ed.): Turtle faunal changes in Central Europe and related areas. *Studia Palaeocheloniologica* **IV**: 73-86. [= *Studia geológica Salmanticensia, Volumen especial* **9**] [2012b]

Karl, H.-V.; Valdiserri, D. & Tichy, G. (2012): New material of the chelonian ichnotaxon *Emydhipus cameroi* Fuentes Vidarte et al., 2003 from the Berriasian (lowermost Cretaceous) of northern Germany. *In* Karl, H.-V. (ed.): Turtle faunal changes in Central Europe and related areas. *Studia Palaeocheloniologica* **IV**: 61-72. [= *Studia geológica Salmanticensia, Volumen especial* **9**] [2012c]

Karl, H.-V.; Staesche, U.; Tichy, G.; Lehmann, J. & Peitz, S. (2007): Systematik der Schildkröten (Anapsida: Chelonii) aus Oberjura und Unterkreide von Nordwestdeutschland. *In* Staesche, U. (coord.): Fossile Schildkröten aus vier Ländern in drei Kontinenten. *Geologisches Jahrbuch (B: Regionale Geologie Ausland)* **98**: 5-89. [2007b]

Koken, E. (1883): Die Reptilien der norddeutschen unteren Kreide. *Zeitschrift der Deutschen Geologischen Gesellschaft* **35**: 735-827.

Koken, E. (1886): Vorkommen fossiler Crocodiliden in den Wealdenbildungen Norddeutschlands und über die Systematik der mesozoischen Crocodiliden. *Zeitschrift der Deutschen Geologischen Gesellschaft* **38**: 664-670.

Koken, E. (1887): Die Dinosaurier, Crocodiliden und Sauropterygier des norddeutschen Wealden. *Palaeontologische Abhandlungen* **3** (5): 1-111.

Koken, E. (1896): Die Reptilien des norddeutschen Wealden. Nachtrag. *Palaeontologische Abhandlungen* **7**: 119-126. [*Palaeontologische Abhandlungen, N.F.* **3** (2)]

Kuhn, O. (1958): *Die Fährten der vorzeitlichen Amphibien und Reptilien.* 64 pp.; Bamberg (Meisenbach).

Lockley, M. G. (2000): An amended description of the theropod footprint *Bueckeburgichnus maximus* Kuhn 1958, and its bearing on the megalosaur tracks debate. *Ichnos* **7** (3): 217-225.

López-Arbarello, A. M. (2012): Phylogenetic Interrelationships of Ginglymodian Fishes (Actinopterygii: Neopterygii). *PLoS ONE* **7** (7): 1-44. [e39370]

López-Arbarello, A. M.; Reich, M. & Gehler, A. (2007): New specimen of *"Lepidotes" mantelli* Agassiz, 1833 from the German "Wealden" and the taxonomy of the giant *"Lepidotes"* of Europe. *In* Elicki, O. & Schneider, J. W. (eds.): Fossile Ökosysteme. 77. Jahrestagung der Paläontologischen Gesellschaft. Kurzfassungen der Vorträge und Poster. *Wissenschaftliche Mitteilungen, Institut für Geologie, TU Bergakademie Freiberg* **36**: p. 92.

López-Arbarello, A. M. & Sferco, E. (2011): New semionotiform (Actinopterygii: Neopterygii) from the Late Jurassic of southern Germany. *Journal of Systematic Palaeontology* **9** (2): 197-215.

Martin, G. P. R. & Weiler, W. (1954): Fisch-Otolithen aus dem deutschen Mesozoikum (Dogger bis Wealden). *Senckenbergiana Lethaea* **35** (3-4): 119-192.

Meyer, H. von (1841): *Pholidosaurus schaumburgensis*, ein Saurus aus dem Sandstein der Wald-Formation Nord-Deutschlands. *Neues Jahrbuch für Mineralogie, Geognosie, Geologie und Petrefakten-Kunde* **[for 1841]**: 443-445.

Meyer, H. von (1857): Beiträge zur näheren Kenntnis fossiler Reptilien. *Neues Jahrbuch für Mineralogie, Geologie und Paläontologie* **[for 1857]**: 532-543.

Meyer, H. von (1859): *Stenopelix Valdensis*, ein Reptil aus der Wealden-Formation Deutschlands. *Palaeontographica* **7** (1): 25-34.

Michael, F. (1936): Paläobotanische und kohlenpetrographische Studien in der nordwestdeutschen Wealdenformation. *Abhandlungen der Preußisch-Geologischen Landesanstalt (Neue Folge)* **166**: 79 pp.

Nopcsa, F. (1923): Die Familien der Reptilien. *Fortschritte der Geologie und Paläontologie* **1** (2): 210 pp.

Peitz, S. (1998): Schildkröten der deutschen Wealden-Fazies – Ein Einblick in die Ballerstedtsche Sammlung. *In* Maisch, M. W. & Matzke, A. T. (eds.): *2. Treffen der deutschsprachigen Paläoherpetologen, Tübingen 27.02.-01.03.1998. Extended Abstracts*: 12-18; Tübingen.

Pelzer, G. (1998): Sedimentologie und Palynologie der Wealden-Fazies im Hannoverschen Bergland. *Courier Forschungsinstitut Senckenberg* **207**: 211 pp.

Reich, M. (2008): The Value of the Göttingen Geoscientific Collections for Biodiversity and Palaeobiodiversity Research. *GCBE Bulletin. Nachrichtenheft des Göttinger Zentrums für Biodiversitätsforschung und Ökologie* **1/2007**: 31-36.

Reich, M. (2012): Zur frühen Geschichte der Göttinger Universitätssammlungen. *In* Georg-August-Universität Göttingen (ed.): *Dinge des Wissens. Die Sammlungen, Museen und Gärten der Universität Göttingen*: 79-88; Göttingen (Wallstein-Verlag).

Reich, M.; Reitner, J.; Roden, V. J. & Stegemann, T. (2009): *The Geoscientific Collections oft he Göttingen University*: 24 pp.; Göttingen (Geowiss. Museum).

Richter, A.; Lubbe, T. van der; Böhme, A. & Stratmann, U. (2012): Obernkirchen – an old becomes a new dinotrack locality. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, p. 52; Göttingen (Universitäts-Verlag). [this volume]

Riegel, W.; Pelzer, G. & Wilde, V. (1986): Erste Ergebnisse einer paläobotanischen Grabung in der fluviatilen Wealden-Fazies des Osterwaldes bei Hannover. *Courier Forschungsinstitut Senckenberg* **86**: 137-170.

Salisbury, S. W.; Willis, P. M. A.; Peitz, S. & Sander, P. M. (1999): The crocodilian *Goniopholis simus* from the Lower Cretaceous of north-western Germany. *In* Unwin, D. M. (ed.): Cretaceous fossil vertebrates. *Special Papers in Palaeontology* **60**: 121-148.

Schenk, A. (1871): *Die Fossile Flora der nordwestdeutschen Wealdenformation*: 65 pp.; Cassel (T. Fischer).

Schmidt, H. (1969): *Stenopelix valdensis* H. v. Meyer, der kleine Dinosaurier des norddeutschen Wealden. *Paläontologische Zeitschrift* **43** (3-4): 194-198.

Schudack, M. (1996): Die Charophyten des Niedersächsischen Beckens (Oberjura – Berriasium): Lokalzonierung, überregionale Korrelation und Palökologie. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen* **200** (1/2): 27-52.

Schudack, U. & Schudack, M. (2009): On the taxonomy of the species *Cypridea setina* Anderson, 1939 and *Cypridea laevigata* Dunker, 1846 (Ostracoda, Crustacea) from the Early Cretaceous of Europe – a special note on systematical inconsistencies. *Berliner paläobiologische Abhandlungen* **10**: 311-320.

Schultze, H.-P. (1970): *Indaginilepis rhombifera* n. gen. et n. sp., ein altertümlicher Palaeoniscoide (Pisces, Actinopterygii) aus dem Wealden von Norddeutschland. *Paläontologische Zeitschrift* **44** (1-2): 10-24.

Struckmann, C. (1891): Die Wealdenbildungen von Sehnde bei Lehrte. *Neues Jahrbuch für Mineralogie, Geologie und Paläontologie* **[1891]** (1): 117-131.

Sues, H.-D. & Galton, P. M. (1982): The systematic position of *Stenopelix valdensis* (Reptilia: Ornithischia) from the Wealden of north-western Germany. *Palaeontographica (A: Paläozoologie, Stratigraphie)* **178**: 183-190.

Thulborn, R. A. (2001): History and nomenclature of the theropod dinosaur tracks *Bueckeburgichnus* and *Megalosauripus*. *Ichnos* **8** (3-4): 207-222.

Wegner, T. (1914): *Brancasaurus brancai* n. gen. n. sp., ein Elasmosauride aus dem Wealden Westfalens. *In* Schöndorf, F. (ed.): *Wilhelm Branca zum siebzigsten Geburtstage, 9. Sept. 1914. Eine Festschrift seiner Schüler*: 235-305; Leipzig (Borntraeger).

Wolburg, J. (1949): Ergebnisse der Biostratigraphie nach Ostracoden im nordwestdeutschen Wealden. *In* Bentz, A. (ed.): *Erdöl und Tektonik in Nordwestdeutschland*, 349-360; Hannover (Amt für Bodenforschung).

Wolburg, J. (1959): Die Cyprideen des NW-deutschen Wealden. *Senckenbergiana Lethaea* **40** (3/4): 223-315.

Wolburg, J. (1962): Zur Taxionomie und Nomenklatur einiger im Handbuch „Leitfossilien der Mikropalaeontologie" (1962) dargestellten Wealden-Ostracoden. *Senckenbergiana Lethaea* **43** (6): 529-532.

Wolburg, J. (1971): Zur Taxonomie und Nomenklatur einiger Wealden-Ostracoden. *Senckenbergiana Lethaea* **52** (1): 39-46.

Excursion Guide C2: **Dinosaur tracks from the Berriasian Obernkirchen Sandstone on exhibit at the Göttingen University Geopark**

Jahn J. **Hornung**[1*] & Mike **Reich**[1,2*]

[1]*Department of Geobiology, Geoscience Centre of the University of Göttingen, Göttingen, Germany*

[2]*Geoscience Museum of the University of Göttingen, Göttingen, Germany*

[*]*corresponding authors:* jhornun@gwdg.de & mreich@gwdg.de

The collections of the Geoscience Centre at the University of Göttingen (GZG) includes two large blocks derived from the Obernkirchen Sandstone, both displaying a number of dinosaur tracks. The larger specimen is on public exhibit in the Geopark (Reich et al. 2009; Reich 2012) outside the GZG building. The smaller one is presently stored in a courtyard and not accessible to the public.

Data on the provenance of the blocks are scarce. The larger slab (GZG.IF.00100) was a donation by the Prince of Schaumburg-Lippe to the Georg-August University of Göttingen in 1880 (July 27; Fig. 1). It originates from Wölpinghausen and is one of the few specimens still preserved from the area from which Struckmann (1880a, 1880b) described the first dinosaur tracks from the Obernkirchen Sandstone (Hornung, Böhme & Reich 2012d; ► p. 143-149, this volume). It was shortly mentioned, but not described, by Schmidt (1959).

The origin of the second specimen is entirely unknown. The yellowish colour of the sandstone is similar to material from the Bückeberg (Obernkirchen area) but this cannot be regarded unambiguous.

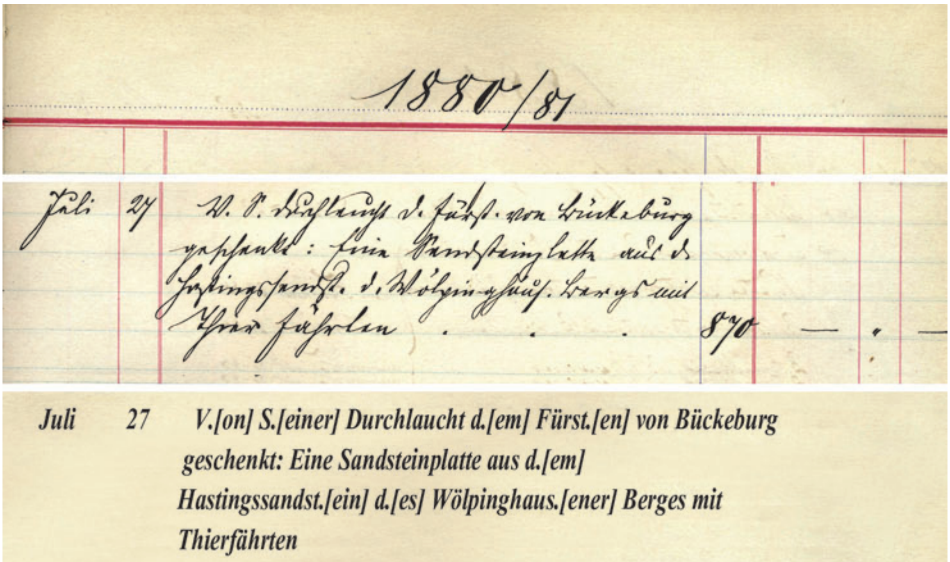
The large block – GZG.IF.00100 (Figs. 2-6, Table 1)

The block is 178 cm long, 150 cm wide, and consists of a 28–32 cm thick, massive, fine-grained sandstone layer (Fig. 2). On the underside the tracks are preserved as hypichnial casts (reliefs). The tracks, preserved as undertracks, were impressed in a thin, sandy-clayey mudstone layer which is preserved in some patches. Its thickness varies slightly and thins in some areas to 1–2 mm. Sandfilled mudcracks in this layer evidence desiccation of the muddy bed. In one corner patches of a 1–2 cm thick layer of sandstone, casting current ripple marks, underlie the mudstone layer, representing the oldest preserved stratum. The asymmetrical ripple marks had sinusoidal crests. The palaeo-flow direction indicated by the ripple-marks is shown in Fig. 2B. The top also contains the impression of a c. 5 cm long wood fragment.

At least 19 individual tracks are recognisable on the slab, ranging in preservation quality from good to vague. Many tracks show terrace-like lineation on the lower surface which can be interpreted as microfaults, formed due to the strain exerted by the foot to the substrate and/or subsequent track margin collapse after removal of the foot. There is also evidence of multiple overstepping and faintly preserved irregularities that suggest originally an even higher abundance of tracks. Due to the size of the trackmakers and partial overstepping, a maximum of two consecutive footprints are recorded in individual trackways. For most of the tracks no preceding or succeeding steps can be identified.

The block presents an unusual abundance and diversity of different morphotypes, referable to ornithopods as well as to theropods. The broad range of preservation quality suggests a certain time-span and history of the substrate condition (water content, e.g. Manning 2004) for the accumulation of the tracks. However, the interplay of trackmaker size, substrate condition and track preservation is complex and not easy to decipher without tight control of the relevant parameters (‘goldilocks’ effect’, Falkingham et al. 2011). At least the track surface records a spot of activity of a number of different dinosaur taxa. The tracks have two main directions, juxtaposed by about 180° of heading to each other (Fig. 3B).

For the purpose of description the individual tracks are numbered 1 to 19 according to Figure 2B. Trackways are additionally marked I and II. Other remarkable features discussed below are labeled A to C.


1880/81

Juli 27 V.[on] S.[einer] Durchlaucht d.[em] Fürst.[en] von Bückeburg geschenkt: Eine Sandsteinplatte aus d.[em] Hastingssandst.[ein] d.[es] Wölpinghaus.[ener] Berges mit Thierfährten 870

Fig. 1 Inventory entry concerning the Obernkirchen Sandstone slab GZG.IF.00100 donated to the Göttingen University: *“July 27th, 1880, donated by His Serenity Prince of Bückeburg [Principality of Schaumburg-Lippe]. A sandstone slab from the Hastings sandstone of the Wölpinghausen mountain with animal tracks”* [loose translation].

Systematic ichnology I

Basic measurements were taken according to Figure 3A and summarised in Table 1 and Figure 5. All described specimens originate from the Obernkirchen Member, Bückeberg Formation (late Berriasian) of Lower Saxony.

Dinosauria Owen, 1842
Ornithischia Seeley, 1887
Ornithopoda Marsh, 1881

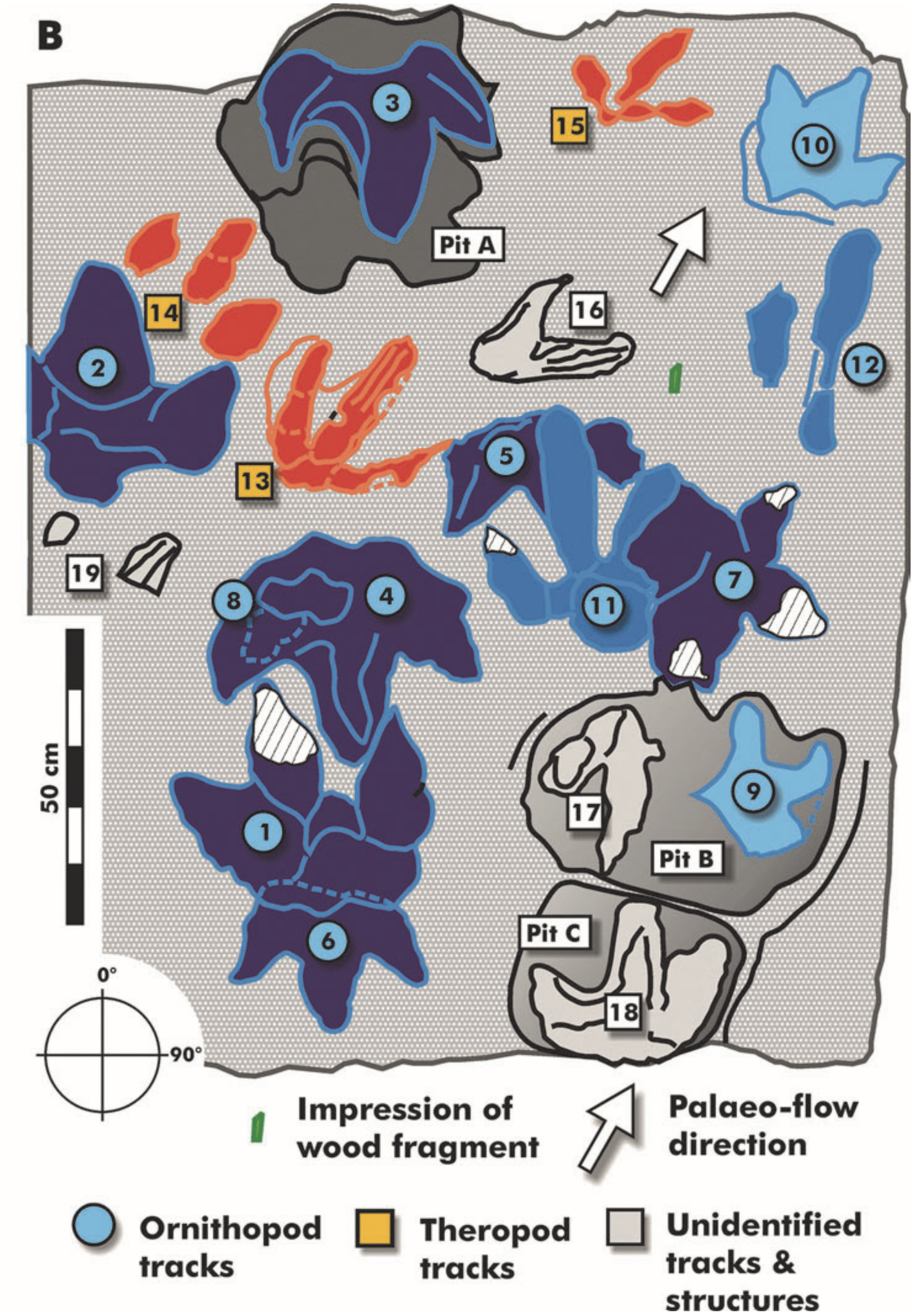
Ichnogenus ***Dinehichnus*** **Lockley, dos Santos, Meyer & Hunt, 1998**
Dinehichnus isp.
Figs. 2, 6B

Material **–** left pes impression: track 11, right pes impression: track 12.

Description and remarks **–** Two pes impressions of markedly different preservation quality. Track 11 is the cast of a deeply impressed tridactyle left pes, showing no trace of a hallux. The pes is symmetrically mesaxonic with a moderate toe divarication (Fig. 4). There are no claw-marks. Digit II is represented by a single, triangular pad impression. Digit III, being distinctly longer than II and IV, forms a subcylindrical impression, which is slightly broadening towards its rounded apex. Very indistinct indentions may indicate the presence of three interphalangeal pads. Digit IV is largely overstepped by track 7. However, it can be observed, that it is slightly longer than digit I and has a broad, rounded apex similar to digit III. At the base of the digits, and well separated from them, a centrally located, ovate metatarsophalangeal pad is deeply impressed. Track 12 consists only of the weak impresssions of digit III and IV, but they are very similar in shape, divarication and size to track 11. According to their relative position and size it seems possible that tracks 11 and 12 belong to a single trackway. However the strong differences in the deepness of impression suggest that their arrangement is either coincidentally and they have been formed at different occasions under different substrate conditions, or that the substrate characteristics were markedly different in short distance.

The symmetrical shape, quadripartite appearance with very prominent metatarsophalangeal pad, and the blunt, subtriangular to subcylindrical digits, are in good accordance to the characteristics of *Dinehichnus socialis* Lockley, dos Santos, Meyer & Hunt, 1998 from the Upper Jurassic of Utah, U.S.A. (Lockley et al. 1998a). However, the size is markedly larger than in *D. socialis* which has average foot lengths between 10 and 20 centimeters. On the other hand, the size range in *D. socialis* was considered quite large, with the largest specimen from Utah measuring 28 cm (Lockley et al. 1998a, Lockley & Wright 2001), approaching therefore the size of the Wölpinghausen tracks. The latter can therefore be attributed to this ichnogenus. Similar tracks have also been reported from the Upper Jurassic and Lower Cretaceous of Spain and the Upper Jurassic of Poland (e.g. Gierliński et al. 2009).

Fig. 2 Large block (GZG.IF.00100) with numerous dinosaur tracks from the Obernkirchen Sandstone near Wölpinghausen, donated by the Principality of Schaumburg-Lippe in 1880 to the Göttingen University, and on exhibit at the Göttingen University Geopark. ▲ **(A)** Photograph. ► **(B)** Interpretative drawing (p. 173). The polar grid provides the reference for the directional measurements in Fig. 3B.


B
3
Pit A
15
10
14
2
16
12
13
5
7
11
19
8
4
50 cm
17
9
Pit B
1
6
Pit C
18
0°
90°
Impression of wood fragment
Palaeo-flow direction
Ornithopod tracks
Theropod tracks
Unidentified tracks & structures

Dinehichnus is commonly attributed to a basal iguanodontian (i.e. dryosaurid for small specimens, 'camptosaurian' for larger examples) trackmaker. In some occurrences of tentatively referred specimens a short hallux is impressed, which is in closer compliance to the pes morphology in *Camptosaurus* than in dryosaurids (Gierliński et al. 2009). The deeply impressed track 11 lacking a hallux suggests that digit I was strongly reduced or absent in the trackmaker. However, it is by far too large to have been left by a dryosaurid. It is therefore hypothesised that the Wölpinghausen tracks have been left by a relatively large-bodied basal iguanodontian, which is morphologically intermediate between the relatively narrow- and long-footed 'camptosaurs' and more derived, broad-footed, tridactyle ankylopollexians. The Wölpinghausen slab seems to indicate that taxa representing both phylogenetic grades (see below for advanced ankylopollexians) lived sympatrically during the Berriasian in Central Europe.

The evidence of a missing hallux even in deeply impressed specimens of large *Dinehichnus*, in conjunction with the tridactyly of the type material, evokes the question, whether tetradactyle specimens should be definitly excluded from the ichnogenus. However, a deeper investigation on this topic is beyond the scope of this contribution.

Ichnogenus ***Iguanodontipus*** **Sarjeant, Delair & Lockley, 1998**

Iguanodontipus isp.

Figs. 2, 6A

***Material* –** pes impressions: tracks 9, 10.

***Description and remarks* –** Two isolated, moderately to poorly preserved pes impressions. Tridactyle, digits short, straight, stubby and resembling an isosceles triangle in outline. Distal metapodophalangeal pad impression ('heel') long (nearly as long as free digit III in track 8) and with posteriorly rounded margin.

Sarjeant et al. (1998) introduced the ichnogenus *Iguanodontipus* for tracks from the Berriasian Purbeck Group of southern England. This was an attempt to formalise the previously rather informally termed track morphotype associated with the ornithopod *Iguanodon*. However, the authors explicitly stated, that the new taxon was not intended as a kind of waste-basked ichnotaxon for the abundant '*Iguanodon*-tracks' in England and elsewhere but to embrace only tracks of the defined morphology. The diagnosis of the type ichnospecies *Iguanodontipus burreyi* Sarjeant, Delair & Lockley, 1998 was based upon a trackway left by a rather small individual with stubby digits and a broad and long metapodophalangeal pad impression. Its morphology closely approaches that of the two tracks here under discussion but not that of the more common, much larger tracks which are often also summarised under this ichnotaxon (e.g. Diedrich 2004, Pollard & Radley 2011: text-fig. 34.6d, and see below).

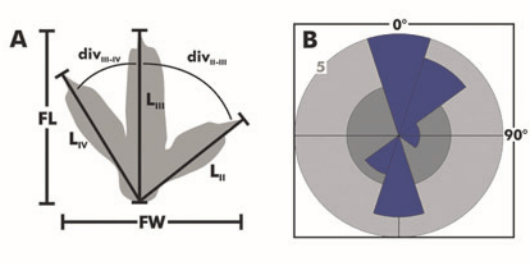


Fig. 3 **(A)** Measurements as in Table 1. **(B)** Diagram of orientation of the tracks on GZG.IF.00100. Two juxtaposed main directions are evident. Note that the directions are relative to the polar grid in Fig. 2B, as the original orientation of the track block is unknown.

Herein we follow the original concept of *Iguanodontipus* as established by Sarjeant et al. (1998) and expanded by Meyer & Thüring (2003) and restrict the identification of this ichnotaxon to tracks 9 and 10 on GZG.IF.00100. These are also similar to tracks identified as *Iguanodontipus* isp. from the Oncala Group (Berriasian) of Soria (Spain; Pascual-Arribas et al. 2009) and from the Late Jurassic of Porto Escada (Portugal, Antunes & Mateus 2003).

Table 1 GZG.IF.00100, measurements of tracks. The heading refers to the polar grid in Fig. 2B, see Fig. 3A for explanation of morphometric indices.

Track-way	Step length [cm]	Track no.	Determination	Auto-podium	FL [cm]	FW [cm]	L-II [cm]	L-III [cm]	L-IV [cm]	div_{II-III} [°]	div_{III-IV} [°]	Head-ing [°]
I	80	1	Ornithopod isp. 1	pes, l	40	41	35	40	34	42	40	344
		2	Ornithopod isp. 1	pes, r	39	41	35	39	?	?55	55	5
II	82	3	Ornithopod isp. 1	pes, r	34	36	23	29	21	40	35	177
		4	Ornithopod isp. 1	pes, l	41	42	38	41	36	37	43	183
		5	Ornithopod isp. 1	pes	?	?	?	?	?	?	?	172
		6	Ornithopod isp. 1	pes, r	31	32	26	31	23	47	50	185
		7	Ornithopod isp. 1	pes	35	36	?	35	?	68	90	120
I		8	Ornithopod isp. 1	manus, l	8	15	n/a	n/a	n/a	n/a	n/a	n/a
		9	*Iguanodontipus* isp.	pes, ?r	30	>22	24	30	?	25	?	357
		10	*Iguanodontipus* isp.	pes, ?l	22.5	>19	18.5	22.5	?	30	?	45
		11	*Dinehichnus* isp.	pes, r	39	32.5	31	39	>28	35	35	347
		12	*Dinehichnus* isp.	pes	32	>28	?	32	29	?	?	20
		13	Theropod isp. 2	pes, l	30	27.5	22	30	27	27	35	32
		14	Theropod isp. 2	pes, ?r	?	~26	?	?	?	?	?	36
		15	?Theropod isp. 2	pes, ?r	>18	?22	>10	>18	>15	42	?	215
		16	indet.	pes, ?r	27	?	?	22	17	?	?	80
		17	indet.	pes	>30	?	?	?	?	35	?	200
		18	indet.	pes	31	>34	?	?	?	?	?	5
		19	indet.	pes	?	?	?	?	?	?	?	?

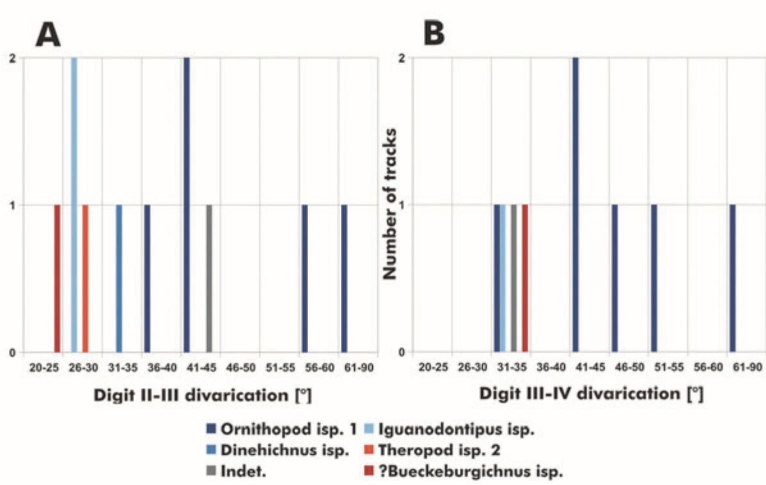


Fig. 4 Histograms of digit divarications of tracks preserved on GZG.IF.00100 and GZG.IF.0010. **(A)** Digit II/III-divarication, **(B)** digit III/IV-divarication.

ichnogen. et ichnosp. indet. 1

Figs. 2, 5

Material **–** left and right pes impressions (consecutive steps): tracks 1 + 2 (trackway I) and 3 + 4 (trackway II), left pes impressions: tracks 5, 6, 7, (?) manus impression: track 8 (probably to trackway I).

Description and remarks **–** At least seven, good to poorly preserved pes impressions, four represent two pairs of consecutive left and right steps (trackways I, II). The trackways show a placement of the pedes nearly in a straight line (exact pace angulations cannot be measured). The pes seem to have been oriented slightly laterally but this is not sure as both trackways seem to have been left during a change of walking direction. If it is referable to trackway I, the manus impression is located anteriorly and slightly laterally to the pes. Tridactyle, large and massive, digit III longer than digits I and II, digits 'fleshy', cone- to pear-shaped, often constricted at the base of the free digits. Digits pointed but without distinct claws, and moderately to strongly splayed (Fig. 3). Metapodophalangeal pad short (except in very deeply impressed tracks, e.g. 2, 7) and posteriorly squared-off. In trackways the feet are placed almost in line with the digits being slightly turned medially. Track 8 is a sharply and deeply impressed transversally subtriangular, peanut-shaped structure, c. 15 cm wide. In comparison with other occurrences (e.g. Lockley & Wright 2001) it can be interpreted as a manus impression. It slightly overlaps a similar imprint, which is interpreted to result from a first attempt of the animal to place its manus on the ground, which was followed immediately by the second and final attempt, located slightly anterolaterally to the first. The manus imprints are superimposed to the older and less well preserved pes track 4. Their position suggest, that they were made by the left manus and belong to trackway I.

This morphotype is the most common large ornithopod track from the Obernkirchen Sandstone and known in great abundance from many localities (Hornung, Böhme et al. 2012). This includes the pioneering finds by Struckmann (1880a, 1880b) from Wölpinghausen. Though it has been identified as being referable to *Iguanodontipus* in some publications it does not match the original diagnosis of this ichnogenus as stated above. Its ichnotaxonomic placement must be kept open, as there is a yet unresolved plexus of ichnogenera defining often very similar track morphotypes, including e.g. *Amblydactylus* Sternberg, 1932, *Wealdenichnites* Kuhn, 1958, *Caririchnium* Leonardi, 1984 among others. Its producer was probably a heavily built basal iguanodontian reaching a body length of up to 8 m.

Saurischia Seeley, 1887

Theropoda Marsh, 1881

ichnogen. et ichnosp. indet. 2

Figs. 2, 6B

Material **–** Isolated pes impressions: tracks 13, 14, ?15.

Description and remarks **–** The two tracks attributable to this theropod morphotype are moderately to poorly preserved. In both tridactyle, mesaxonic tracks the digits are much stronger impressed than the metatarsal region, suggesting a fast locomotion.

Track 13, a right pes impression, which is the best preserved one, clearly shows the clear asymmetry in the 'heel' region typical for theropod footprints. The digits are splayed moderately (Fig. 4). Interphalangeal pads are nearly indistiguishable, though this condition is clearly the result of preservation and not of pes anatomy. Digit IV probably possessed four interphalangeal pads, their number on the other digits cannot be assessed. All digits taper apically but only on digit II a faint claw-mark can be identified. Digits II and IV are subequal in length but distinctly shorter than digit III.

Track 14 consists only of the impressions of the distal digits of a (?)left pes. This specimen shows a claw-mark on digit IV. Track 15 is very poorly preserved but its asymmetry suggests a theropod trackmaker, too.

This morphotype is similar in size and proportions to well preserved theropod tracks from the same formation at Obernkirchen by Diedrich (2004, on exhibit in the Doberg Museum, Bünde). They also show the overall morphology of the complex of track morphotypes often referred to as *Megalosauripus sensu* Lockley et al. (1998b). In the light of only mediocre preservation, a twisted theropod track taxonomy and evidently high diversity of theropod ichnotaxa in the Obernkirchen Member (e.g. van der Lubbe et al. 2009; Richter et al. 2009; Richter, van der Lubbe et al. 2012; ► p. 52, this volume), the Wölpinghausen examples are kept here in open nomenclature.

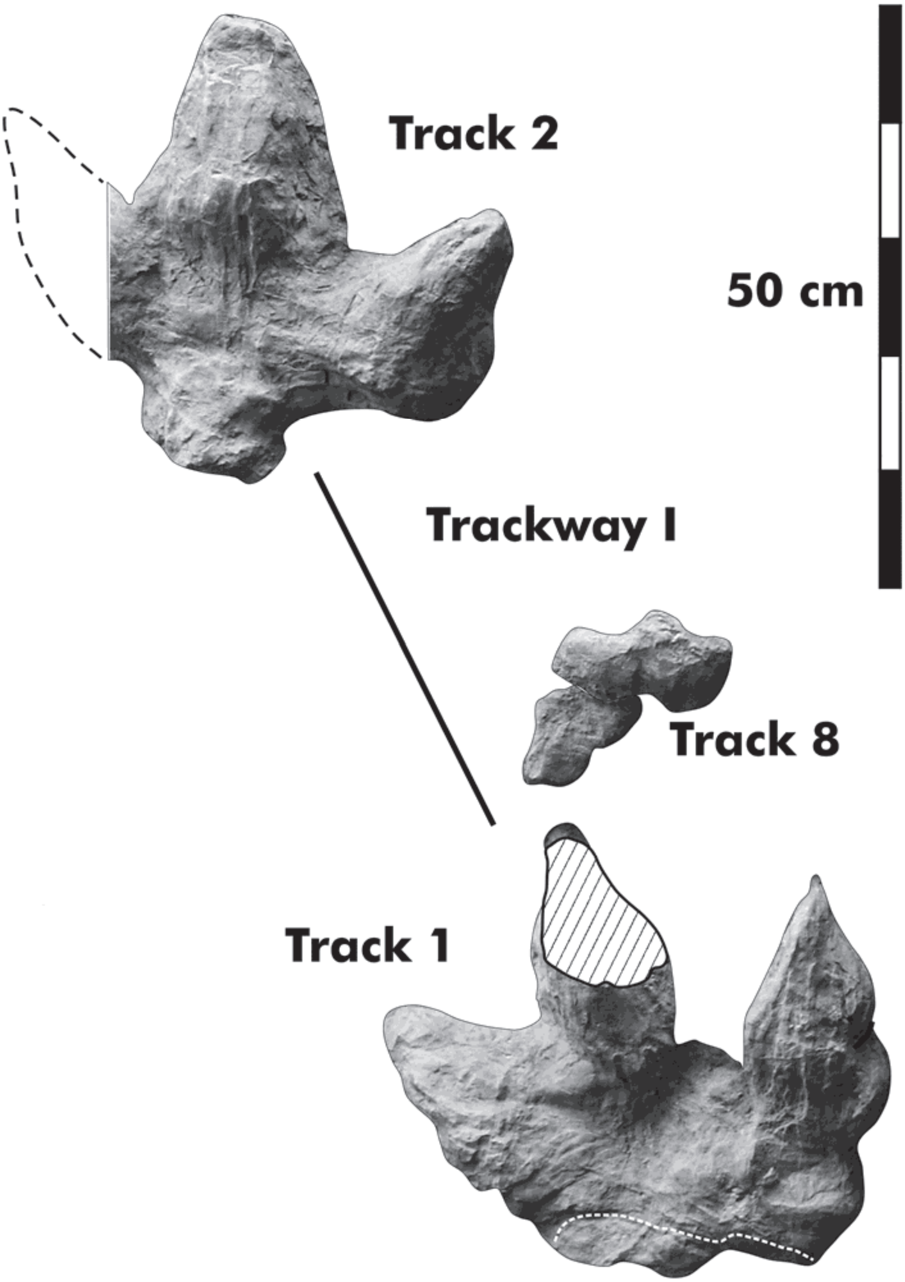


Fig. 5 Ornithopod ichnospecies 1, trackway I (hypichnia), tracks 1 (left pes), 2 (right pes), 8 (left manus), GZG.IF.00100. Note that the manus (track 8) was apparently impressed two times, the upper right impression is deeper and more pronounced.

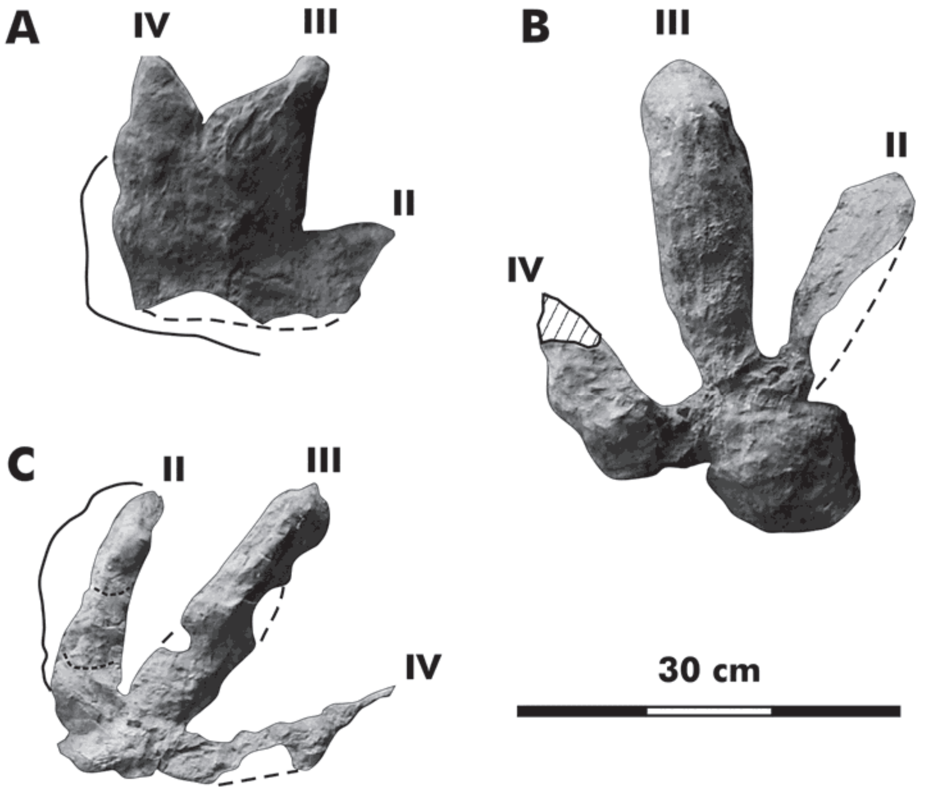


Fig. 6 Ornithopod and theropod tracks (hypichnia) from GZG.IF.00100. **(A)** *Iguanodontipus* isp., track 10 (right pes), **(B)** *Dinehichnus* isp., track 11 (right pes), **(C)** theropod ichnospecies 2, track 13 (left pes).

Dinosauria Owen, 1842

ichnogen. et ichnosp. indet. ('tridactyle tracks')

Fig. 2

Material **–** Isolated pes impressions: tracks 16, 17, 18, 19.

Remarks **–** At least three tracks of parts of tracks cannot be determined safely as they are deformed or otherwise extramorphologically damaged.

Other morphological features on GZG.IF.00100

Fig. 2

***Material* –** Three 'pits' (preserved as hypichnial bulges): A, B, C.

***Remarks* –** Aside of the unequivocal dinosaur tracks on the underside of the slab, three large, rounded bulges occur, which represent the cast of pit-like structures on the original surface. Pit/bulge A can be most easily explained as a multiple over-stepping of tridactyle tracks. The casts of digits are clearly visible, sticking out from the periphery of the bulge. The youngest track (track 3) is reasonably well pre-served.

The origins of structures B and C are less obvious. They consist of two transver-sally elliptical, rather shallow depressions, which are sharply delimited. The larger structure B partly indents structure C. On one side the bulges are delimited by a broad groove, which branches between both bulges. This most probably represent a displacement rim. Tridactyle tracks located within the pits/bulges (tracks 9, 16, 18) show various amounts of deformation, increasing towards the middle of the structures. These deformations suggest that the pits were formed after the tri-dactyle tracks and were deformed largely by vertical compression (local shear failure, Manning 2004).

A possible explanation of these structures would be an interpretation as sauropod manus/pes tracks. Sauropod tracks are known from one site at Münchehagen (Hendricks 1981; Fischer 1998; Lockley et al. 2004). However the lack of more detailed features and the presence of other, possibly anorganic, pit-like features in the Obernkirchen Sandstone ('Hauptsandstein') (Kaufmann et al. 1980; Fischer 1998) leave open alternative interpretations.

The small block – GZG.IF.00101 (Figs. 4, 7, Table 2)

The smaller track slab from an unknown locality (in Lower Saxony) consists of a block of massive, fine-grained sandstone, 120 cm high, 86 cm wide, and 26 to 29 cm thick. Its lower surface preserves an (inverted) relief, which records an inter-esting history of deposition.

The oldest layer (which is not longer preserved) formed a surface with a slight slope towards a gentle depression on the right side of the slab (as on Fig. 7). This surface emerged and desiccation cracks were formed on it. The next phase was dominated by the cut of a shallow, 4–5 cm deep channel into this surface which opened towards the right into the depression. The steep bank of this channel is preserved on the lower left area of the slab and shows failure and collapse due to over-steepening. The bottom of the channel was covered by an apparently thin sheet of sand which formed current ripple marks that confirm a flow from the left to the right, and are preserved as cast on the lower surface of the subsequent bed. This phase of deposition ended with a new thin layer of fine-grained sediment, which dried-up and formed desiccation cracks. The well-preserved mudcrack casts on the underside of track 22 suggests that it has been left on the mud layer before its final emersion and cracking, and is therefore older than tracks 20 and 21. Another c. 1 cm thick sandstone sheet covered this layer and cast the ripple-marks and desiccation-cracks. Tracks 20 and 21 have been originally formed on top of the thin sandstone layer and were transmitted as undertracks. Finally the tracks, channel and any other relief were filled-up by deposition of the main c. 25 cm thick sandstone layer, which is massive at its base and ripple cross-laminated a few cm below its top.

Table 2 GZG.IF.00101, measurements of tracks. See Fig. 3A for explanation of morphometric indices.

Track no.	Determination	Auto-podium	FL [cm]	FW [cm]	L-II [cm]	L-III [cm]	L-IV [cm]	div_{II-III} [°]	div_{III-IV} [°]
20	? *'Bueckeburgichnus'* isp.	pes, r	25	>22	?	25	26	?	35
21	? *'Bueckeburgichnus'* isp.	pes, ?l	?	?	?	?	?	?	?
22	? *'Bueckeburgichnus'* isp.	pes, l	35	33	25	34	27	25	35

Systematic ichnology II

Dinosauria Owen, 1842

Ornithischia Seeley, 1887

Theropoda Marsh, 1881

Ichnogenus **'*Bueckeburgichnus*' Kuhn, 1958**

?**'*Bueckeburgichnus*'** isp.

Fig. 7

***Material* –** Two consecutive pes impressions (both incomplete, trackway III): tracks 20, 21, one complete, isolated pes impression: track 22.

***Description and remarks* –** The block preserves the hypichnia of three tracks, apparently left by the same species of trackmaker. Track 22 is the best preserved and provides most information on morphology. The tracks are tridactyle and mesaxonic with moderate digital divarication. Digit III shows three indistinct interphalangeal pads. Three interdigital pads can also be discerned on digit IV. Digit II is broader than the other digits and conically shaped; separate interphalangeal pads cannot be discerned. The metatarsal region shows an asymmetry at the base of digits II and IV. The digits are pointed apically and bear a claw-mark at least in digit IV (track 20), less distinct in digit III (tracks 20 and 22), and possibly digit II (track 22).

Tracks 20 and 21 form a trackway, consisting of a right pes impression (track 20) and the posteromedial part of the subsequent left pes impression (track 21). The tracks are arranged in a straight line and the feet were slightly turned inwardly. The short step length (c. 45 cm) indicates slow locomotion speed.

Track 22 shows a short slip-face in its 'heel'-region.

The morphology of the tracks, including the claw-marks and metatarsal asymmetry, clearly indicate a theropod trackmaker. Some characteristics are congruent with the problematic ichnogenus '*Bueckeburgichnus*' (Lockley 2000, Thulborn 2001, Hornung, Böhme & Reich 2012a; ► p. 27, this volume), most important the broad, triangular, fleshy digit II. The lack of a hallux impression, reported from the type ichnospecies '*B.*' *maximus* Kuhn, 1958, is explainable by the shallow impression depth of the tracks in GZG.IF.00101. Another difference is the size, which is considerably smaller than in the '*B.*' *maximus* type material. It seems reasonable that the trackmaker of tracks 20 to 22 was closely related to or an ontogenetically younger specimen of the producer of '*B.*' *maximus*. Aside of the occurrences in the Berriasian Obernkirchen Member, '*Bueckeburgichnus*' has so far only been reported from the Berriasian–Valanginian and Aptian of Spain (e.g. Canudo et al. 2005).

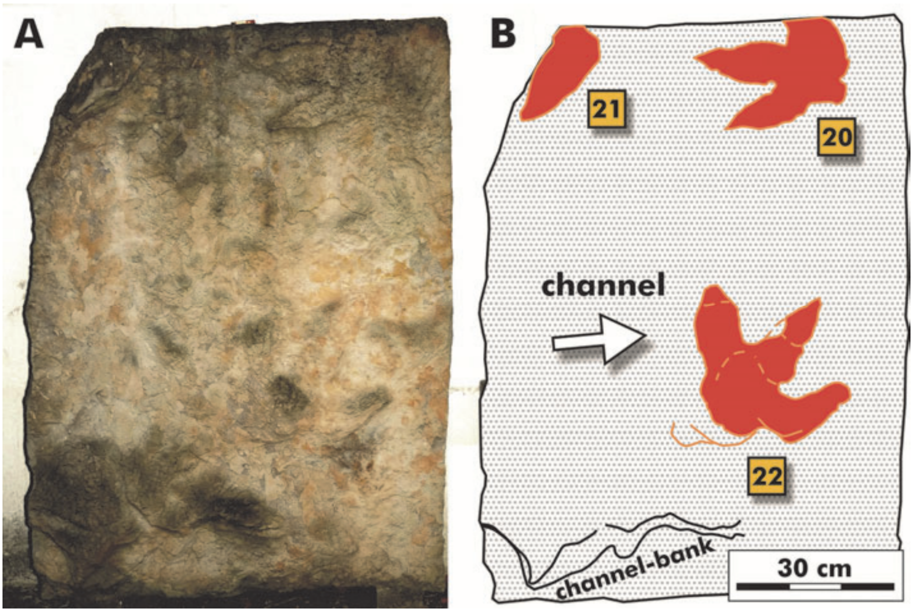


Fig. 7 Block with three theropod tracks (?'*Bueckeburgichnus*' isp.) from the Obernkirchen Sandstone from an unknown locality in Lower Saxony, GZG.IF.00101. Symbols and colour-coding as in Fig. 2B.

Discussion

Especially the abundance and diversity of tracks on GZG.IF.00100 provide a very valuable insight in the dinosaur fauna of the Obernkirchen Member. *Iguanodontipus* isp. and ornithopod ichnospecies 1 represent morphotypes common to the local ichnofauna (e.g. Struckmann 1880a, 1880b; Dietrich 1927; Lehmann 1978; Lockley & Wright 2001; Hornung, Böhme et al. 2012). As far as known at present, typical *Iguanodontipus* tracks occur exclusively associated to the larger morphotype (e.g. Lehmann 1978), and it will require further investigations whether both morphotypes may represent different ontogenetic stages of the same orthotaxon. As evidenced by the manus morphology, the trackmaker of ichnospecies 1 was a member of the Styracosterna Sereno, 1986. This clade is characterised by a specialised manus, in which only digits II to IV are used for quadrupedal locomotion and were conjoined in a single skin envelope. Digit I was reduced to a defensive 'thumb spine' and digit V was specialised as a grasping organ and both did normally not contact the ground. The structure formed by digits II to IV left the subtriangular impressions (Wright 1999). Recent analysis has shown that earliest members of Styracosterna occurred in the Late Jurassic [*Cumnoria prestwichii* (Hulke, 1880) from the Kimmeridgian; McDonald et al. 2010], however these are rather gracile animals. In contrast, the Berriasian tracks from the Bückeberg Formation and elsewhere clearly show that an evolution towards massive, large-bodied forms have taken place as early as the Jurassic–Cretaceous boundary – an intervall very poorly represented by osteological remains.

Such an important transition in the iguanodontian bauplan during the Berriasian is additionally underscored by the occurrence of large-sized *Dinehichnus* isp. This type of track is commonly associated with very basal, 'camptosaur'-grade iguanodontians, though the lack of a hallux impression indicates some advancement in pes morphology towards more derived iguanodontians. These tracks document the sympatric co-occurrence of very basal and more advanced iguanodontians in the Berriasian of Central Europe.

The theropod track record supports a considerable diversity of this clade, as has shown in other localities. Whether even sauropods can be added to the ichnocoenosis cannot be decided finally. The ichnological and sedimentological record of GZG.IF.00100 documents the formation of tracks over a considerable amount of time under changing substrate conditions. The sedimentary record commences with a thin sand layer, deposited under unidirectional flow conditions (current ripple marks). Flow-direction was about 45° respective to the baseline of the slab and subparallel to one of the main directions of the tracks. The flow waned subsequently and a thin layer of fine-grained material settled subaqueously. Dinosaurs crossed the site through this quite and shallow water-body which increasingly dried-up. Finally the tracks were covered by a new sand deposit.

The heading of the tracks is not random, most tracks follow a main direction or its juxtaposed heading. This orientation, together with the taxonomical diversity and the apparent accumulation of tracks over a considerable time-span indicates, that the slab represents an area of 'dinosaur crossing' and probably a bypass region suited well for passage.

Unfortunately the preserved material does not allow a certain conclusion on the exact stratigraphic origin of the specimen. However, the still existent outcrops at Wölpinghausen expose only the uppermost parts of the local equivalent of the Obernkirchen Sandstone (Hornung, Böhme & Reich 2012d; ► p. 143-149, this volume). The lithofacies at these outcrops is mostly represented by medium to thinly bedded, partly channelised, fluvial sandstones. It seems more reasonable that the slab originates from the deeper (today inaccessible) parts of the section, where also the first tracks have been found by Struckmann (1880a).

Acknowledgements

We thank V. J. Roden, Darmstadt, for checking the English spelling of an first draft, as well as T. R. Stegemann and A. Gehler (both Göttingen) for technical assistance.

References

Antunes, M. T. & Mateus, O. (2003): Dinosaurs of Portugal. *Comptes Rendus Palevol* **2** (1): 77-95.

Canudo, J. I.; Barco, J. L.; Cuenca-Bescós, G. & Ruiz-Omeñaca, J. I. (2005): Presence of two different theropod footprints in the Valanginian – Hauterivian (Lower Cretaceous) of Villanueva de Huerva (Zaragoza, Aragón, Spain). *In International Symposium on Dinosaur and other Vertebrates Palaeoichnology (2005), Fumanya, Barcelona – Abstract book*: 38-39.

Diedrich, C. (2004): New important iguanodontid and theropod trackways of the tracksite Obernkrichen in the Berriasian of NW Germany and megatracksite concept of Central Europe. *Ichnos* **11** (3): 215-228.

Dietrich, O. W. (1927): Über Fährten ornithopodider Saurier im Oberkirchner Sandstein. *Zeitschrift der Deutschen Geologischen Gesellschaft* **78 [for 1926]** (4): 614-621.

Falkingham, P. L.; Bates, K. T.; Margetts, L. & Manning, P. L. (2011): The 'Goldilocks' effect: preservation bias in vertebrate track assemblages. *Journal of the Royal Society Interface* **8** (61): 1142-1154.

Fischer, R. (1998): Die Saurierfährten im Naturdenkmal Münchehagen. *In* Fischer, R. (ed.): Das Naturdenkmal „Saurierfährten Münchehagen". *Mitteilungen aus dem Institut für Geologie und Paläontologie der Universität Hannover* **37**: 3-59.

Gierliński, G. D.; Niedźwiedzki, G. & Nowacki, P. (2009): Small theropod and ornithopod footprints in the Late Jurassic of Poland. *Acta Geologica Polonica* **59** (2): 221-234.

Hendricks, A. (1981): Die Saurierfährte von Münchehagen bei Rehburg-Loccum (NW-Deutschland). *Abhandlungen aus dem Landesmuseum für Naturkunde zu Münster in Westfalen* **43**: 1-22.

Hornung, J. J.; Böhme, A., Lubbe, T. van der; 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. *Paläontologische Zeitschrift* **86** (3): 231-267.

Hornung, J. J.; Böhme, A. & Reich, M. (2012): The type material of the theropod ichnotaxon *"Bueckeburgichnus" maximus* Kuhn, 1958 – reconsidered. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, p. 27; Göttingen (Universitäts-Verlag). [this volume] [2012a]

Hornung, J. J.; Böhme, A. & Reich, M. (2012): Excursion Guide B2: Wölpinghausen. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, 143-149; Göttingen (Universitäts-Verlag). [this volume] [2012d]

Hulke, J. W. (1880): *Iguanodon prestwichii*, a new species from the Kimmeridge Clay, distinguished from *I. mantelli* of the Wealden Formation in the S.E. of England and the Isle of Wight by differences in the shape of the vertebral centra, by fewer than five sacral vertebrae, by the simpler character of its tooth-serrature, etc., founded on numerous fossil remains lately discovered at Cumnor, near Oxford. *Quarterly Journal of the Geological Society of London* **36**: 433-456.

Kaufmann, R.; Oppermann, H.-U. & Petsch, K. (1980): Zur Entwicklung der tiefen Unterkreide (Berrias/Valangin) im Süden des Rehburger Sattels unter besonderer Berücksichtigung der Tongrube Sachsenhagen. *Ballerstedtiana* **3**: 5-27.

Kuhn, O. (1958): *Die Fährten der vorzeitlichen Amphibien und Reptilien.* 64 pp.; Bamberg (Meisenbach).

Lehmann, U. (1978): Eine Platte mit Fährten von *Iguanodon* aus dem Obernkirchener Sandstein (Wealden). *Mitteilungen aus dem Geologisch-Paläontologischen Institut der Universität Hamburg* **48**: 101-114.

Leonardi, G. (1984): Le impronte fossili di dinosauri. *In* Bonaparte, J. F. (ed.): Sulle orme dei dinosaur. *Esplorazioni ricerche* **IX**: 161-186; Venezia (Erizzo).

Lockley, M. G. (2000): An amended description of the theropod footprint *Bueckeburgichnus maximus* Kuhn 1958, and its bearing on the megalosaur tracks debate. *Ichnos* **7** (3): 217-225.

Lockley, M. G.; dos Santos, V. F.; Meyer, C. A. & Hunt, A. P. (1998): A new dinosaur tracksite in the Morrison Formation, Boundary Butte, Southeastern Utah. *In* Carpenter, K.; Chure, D. J. & Kirkland, J. I. (eds.): The Upper Jurassic Morrison Formation – an interdisciplinary study. *Modern Geology* **23** (1): 317-330. [1998a]

Lockley, M. G.; Meyer, C. A. & dos Santos, V. F. (1998): *Megalosauripus* and the problematic concept of megalosaur footprints. *In* Pélaez-Moreno, B. P.; Holtz, T. jr.; Sanz, J. L. & Moratalla, J. (eds.): Aspects of Theropod Paleobiology. *Gaia* **15**: 313-337. [1998b]

Lockley, M. G. & Wright, J. L. (2001): Trackways of large quadrupedal ornithopods from the Cretaceous: a review. *In* Tanke, D. H. & Carpenter, K. (eds.): *Mesozoic Vertebrate Life*: 428-442; Bloomington (Indiana University Press).

Lockley, M. G.; Wright, J. L. & Thies, D. (2004): Some Observations on the Dinosaur Tracks at Münchehagen (Lower Cretaceous), Germany. *Ichnos* **11** (3-4): 261-274.

Lubbe, T. van der; Richter, A. & Böhme, A. (2009): *Velociraptor's* sisters: First report of troodontid tracks from the Lower Cretaceous of northern Germany. *Journal of Vertebrate Paleontology* **29** (3) [suppl.]: p. 194A.

Manning, P. L. (2004): A new approach to the analysis and interpretation of tracks: examples from the dinosaurian. *In* McIlroy, D. (ed.): The Application of Ichnology to Palaeoenvironmental and stratigraphic analysis. *Geological Society of London, Special Publication* **228**: 93-123.

Marsh, O. C. (1881): Principal characters of American Jurassic dinosaurs. Part V. *The American Journal of Science and Arts (series 3)* **21**: 417-423.

McDonald, A. T.; Kirkland, J. I.; DeBlieux, D. D.; Madsen, S. K.; Cavin, J.; Milner, R. C. & Panzarin, L. (2010): New Basal Iguanodonts from the Cedar Mountain Formation of Utah and the Evolution of Thumb-Spiked Dinosaurs. *PLoS ONE* **5** (11): [e14075]

Meyer, C. A. & Thüring, B. (2003): The First Iguanodontid Dinosaur Tracks from the Swiss Alps (Schrattenkalk Formation, Aptian). *Ichnos* **10** (2-4): 221-228.

Owen, R. (1842): Report on British Fossil Reptiles, Part II. *Report of the Annual Meeting of the British Association for the Advancement of Science* **11** [1841]: 60-204.

Pascual-Arribas, C.; Hernández-Medrano, N.; Latorre-Macarrón, P. & Sanz-Pérez, E. (2009): El icnogénero *Iguanodontipus* en el yacimento de "las Cuestas I" (Santa Cruz de Yanguas, Soria, España). *Studia geológica Salmanticensia* **45**: 105-128.

Pollard, J. E. & Radley, J. D. (2011): Trace Fossils. *In* Batten, D. J. (ed.): English Wealden Fossils. *Palaeontological Association Field Guide to Fossils* **14**: 653-676.

Reich, M. (2012): Zur frühen Geschichte der Göttinger Universitätssammlungen. *In* Georg-August-Universität Göttingen (ed.): *Dinge des Wissens. Die Sammlungen, Museen und Gärten der Universität Göttingen*: 79-88; Göttingen (Wallstein-Verlag).

Reich, M.; Reitner, J.; Roden, V. J. & Stegemann, T. (2009): *The Geoscientific Collections oft he Göttingen University*: 24 pp.; Göttingen (Geowiss. Museum).

Richter, A.; Böhme, A. & Lubbe, T. van der (2009): "Chicken Run": A new unusual, heavily dinoturbated tracksite from the Lower Cretaceous sandstones of Obernkirchen, northern Germany. *In* 69th Annual Meeting Society of Vertebrate Paleontology and the 57th Symposium of Vertebrate Palaeontology and Comparative Anatomy (SVPCA), University of Bristol, Bristol, United Kingdom, September 23-26, 2009. *Journal of Vertebrate Paleontology* **29** (3) [suppl.]: p. 171A.

Richter, A.; Hornung, J. J.; Böhme, A. & Stratmann, U. (2012): Excursion Guide A1: Obernkirchen sandstone Quarries – A Natural Workstone Lagerstaette and a Dinosaur Tracksite. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, 73-99; Göttingen (Universitäts-Verlag). [this volume]

Richter, A.; Lubbe, T. van der; Böhme, A. & Stratmann, U. (2012): Obernkirchen – an old becomes a new dinotrack locality. *In* Richter, A.; Hübner, T. R. & Reich, M. (eds.): *Dinosaur Tracks 2011. An International Symposium, Obernkirchen, April 14–17, 2011. Abstract Volume and Field Guide to Excursions*, p. 52; Göttingen (Universitäts-Verlag). [this volume]

Sarjeant, W. A. S.; Delair, J. B. & Lockley, M. G. (1998): The footprints of *Iguanodon*: a History and Taxonomic Study. *Ichnos* **6** (3): 183-202.

Schmidt, H. (1959): Die Cornberger Fährten im Rahmen der Vierfüßler-Entwicklung. *Abhandlungen des Hessischen Landesamtes für Bodenforschung* **28**: 137 pp.

Seeley, H. G. (1887): On the classification of the fossil animals commonly called Dinosauria. *Proceedings of the Royal Society of London* **43**: 165-171.

Sereno, P. C. (1986): Phylogeny of the bird-hipped dinosaurs (Order Ornithischia). *National Geographic Research* **2**: 234-256.

Sternberg, C. M. (1932): Dinosaur tracks from Peace River, British Columbia. *Annals and Reports of the National Museum of Canada* **[1930]**: 59-85.

Struckmann, C. (1880a): *Die Wealden-Bildungen der Umgebung von Hannover. Eine geognostisch-paläontologisch-statistische Darstellung.* viii + 122 pp.; Hannover (Hahn).

Struckmann, C. (1880b): Vorläufige Nachricht über das Vorkommen großer, vogelähnlicher Thierfährten (*Ornithoidichnites*) im Hastingssandsteine von Bad Rehburg bei Hannover. *Neues Jahrbuch für Mineralogie, Geologie und Paläontologie* **[1880]** (1): 125-128.

Thulborn, R. A. (2001): History and nomenclature of the theropod dinosaur tracks *Bueckeburgichnus* and *Megalosauripus*. *Ichnos* **8** (3-4): 207-222.

Wright, J. L. (1999): Ichnological evidence for the use of the forelimb in iguanodontians. *In* Unwin, D. M. (ed.): Cretaceous Fossil Vertebrates. *Special Papers in Palaeontology* **60**: 209-219.

The Early Cretaceous (late Berriasian) Bückeberg Formation in the southern Lower Saxony Basin, to the west and to the south of Hannover, yields abundant and diverse dinosaur tracks, known since the late 1870s. After a few decades of pioneering and discovery, this area was scientifically neglected for a long time concerning dinosaur tracks and tracksites, and only single sporadic finds were reported in the second half of the 20th century. During 2007 and 2008, a new tracksite was discovered in Obernkirchen, yielding an astonishing amount of new and well-preserved dinosaur tracks, cared for by the Hannover State Museum and its cooperational partners. The present volume contains the abstracts of lectures and posters presented during the Dinosaur Track Symposium 2011 as well as excursion and collection guides. On behalf of the Schaumburger Landschaft, this symposium was held at the medieval Stift Obernkirchen, Germany, from April 14th to 17th, 2011. Nearly one hundred palaeontologists, biologists, geologists and other scientists from sixteen countries participated.

GEORG-AUGUST-UNIVERSITÄT
GÖTTINGEN

ISBN: 978-3-86395-105-4

Universitätsdrucke Göttingen