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First record of *Amphisauropus* and *Varanopus* in the Lower Permian Abo Formation, central New Mexico

Erster Nachweis von *Amphisauropus* und *Varanopus* in der Abo Formation, Unteres Perm von Zentral New Mexico

with 6 figures

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Abstract:
At a tracksite at Abo Pass in central New Mexico, USA, tetrapod tracks are found approximately 141 m above the base of the Abo Formation (Lower Permian, early ?Artinskian, Wolfcampian). The track-bearing stratum is a 0.3-1.3-m-thick, thinly bedded, fine-grained tabular sandstone with extensive ripple laminae that we interpret as a sheetflood deposit on a floodplain. Seven vertebrate ichnotaxa are present: *Amphisauropus latus* Haubold, *Dromopus agilis* Marsh, *Dimetropus* sp., *Batrachichnus delicatulus* Lull, *Hyloidichnus* sp., *Gilmoreichnus hermitanus* (Gilmore), and *Varanopus* sp. The track of a presumed seymouriamorph, *Amphisauropus* is widely distributed and locally common in the European Rotlöiegend but has previously been unrecorded in the United States. *Varanopus*, a captorhinomorph track known from the European Rotliegend and from the Lower Permian Choza Formation of Texas, also occurs for the first time in the Abo Formation at this site. The Abo Pass tracksite is dominated by trackways of *Amphisauropus*, which is new for Early Permian tracksites in New Mexico. This dominance by *Amphisauropus* does not reflect geologic age or facies differences among the New Mexican tracksites, but instead is probably due to idiosyncratic factors not well understood or a need for further sampling.

Zusammenfassung:
Am Abo Pass in Zentral New Mexico, USA, wurde ein Vorkommen von Tetrapodenfährten etwa 141 m über der Basis der Abo-Formation (Unteres Perm, frühes ?Artinsk, Wolfcamp) entdeckt. Die Fährten führende Lage ist ein 0,3 bis 1,3 m mächtiger dünnschichtiger, feinkörniger plattiger Sandstein mit ausgedehnter Rippellamination. Die Bildung wird als Schichtflut auf einer Überflutungsfläche gedeutet. Es liegen sieben Tetrapoden-Ichnotaxa vor: *Amphisauropus latus* HAUBOLD, *Dromopus agilis* MARSH, *Dimetropus* sp., *Batrachichnus delicatulus* LULL, *Hyloidichnus* sp., *Gilmoreichnus hermitanus* (GILMORE) und *Varanopus* sp. Die im europäischen Rotliegend weit verbreitete und lokal häufige, vermutlich seymouriamorphe Fährtenform, *Amphisauropus* war bisher in den Vereinigten Staaten noch nicht nachgewiesen worden. Die captorhinomorphe Fährtenform *Varanopus*, bekannt aus dem europäischen Rotliegend und aus der unterpermischen Choza-Formation in Texas, kann nun erstmals auch in diesem Vorkommen der Abo-Formation belegt werden. Am Abo Pass dominieren die Fährten von *Amphisauropus*, welche neu innerhalb der zahlreichen unterpermischen Vorkommen mit Tetrapodenfährten in New Mexico sind. Diese Häufigkeit von *Amphisauropus* reflektiert allerdings kein bestimmtes geologisches Alter oder eine fazielle Differenz innerhalb der Vorkommen in New Mexico, vielmehr handelt es sich um bislang unklare Besonderheiten oder allgemein um Hinweise auf bestehende Kenntnislücken und auf den Bedarf an weiteren Aufsammlungen.

1 Introduction

New Mexico’s Early Permian tetrapod ichnofauna is of global significance. Known primarily from the Robledo and Doña Ana Mountains of south-central New Mexico, study of these ichnofaunas, together with a renewed understanding of the influences of gait and substrate differences on track morphology, led to the realization that there is only a small number of valid Early Permian vertebrate ichnotaxa (HAUBOLD 2000, HAUBOLD & LUCAS 2001a). Furthermore, it became apparent that the major Early Permian ichnofaunas of North America and Europe are largely congeneric, if not conspecific (HAUBOLD 1996, 1998, HUNT & LUCAS 1998). However, one continuing problem in Early Permian tetrapod tracks concerns the distribution of *Amphisauropus*. This ichnogenus is widely recorded in Europe but seems to absent from the Permian red beds in the United States, though it has been reported from strata in Canada (MOSSMAN & PLACE 1989). The common presence in the southwestern United States of body fossils of seymouriamorphs, the presumed trackmakers of *Amphisauropus*, indicated that it is probable that this ichnotaxon would eventually be found (HUNT & LUCAS 1998).

The newly found Abo Pass tracksite, New Mexico Museum of Natural History and Science (NMMNH) locality 4394 (LERNER et al. 2000), is one in which the ichnofaunal composition is dominated by an abundance of *Amphisauropus*. *Varanopus*, a captorhinomorph track known from the Oberhof and Tambach Formations of central Germany and from the Lower Permian Choza Formation of Texas, is also found for the first time in the Abo Formation at this tracksite. The presence of *Varanopus* and *Amphisauropus* at Abo Pass extends these ichnotaxa's paleogeographic distribution and their utility for intercontinental biostratigraphic correlation of the European Lower Rotliegend.

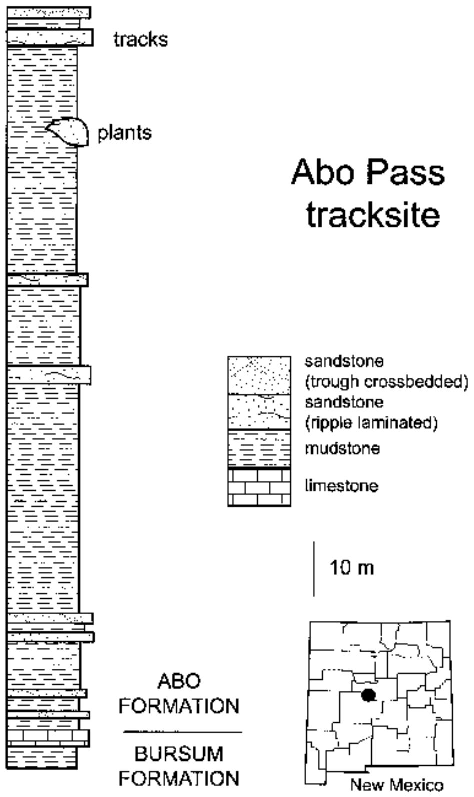

Fig. 1:
Location map and measured stratigraphic section at Abo Pass tracksite, NMMNH locality 4394.

2 Geologic Context

NMMNH locality 4394 is located at the southern end of the Manzano Mountains in central New Mexico at UTM 368454E, 3808810N, zone 13, NAD 27 (Fig. 1). The Abo Formation at this locality is a 247 m thick succession of dark reddish-brown mudstone and siltstone with subordinate beds of red arkosic sandstone and limestone-pellet conglomerate (HATCHELL et al. 1982). It lies conformably above the earliest Wolfcampian Bursum Formation and is conformably overlain by the Leonardian Yeso Formation (MYERS 1973; HATCHELL et al. 1982).

At NMMNH locality 4394, tetrapod tracks are present 141 m above the basal contact of the Abo Formation with the underlying Bursum Formation (Fig. 1). The track-bearing stratum is a 0.3-1.3 m thick, thinly bedded, fine-grained tabular sandstone bed with extensive ripple laminae. The bed is laterally extensive, with a strike on the order of hundreds of meters.

At NMMNH locality 4394 an invertebrate ichnofauna is absent, and impressions of the conifer *Walchia* are abundant a few meters stratigraphically below the tracksite (Fig. 1). Raindrop impressions and small mudcracks on some of the track-bearing surfaces indicate deposition under subaerial conditions.

At NMMNH locality 4394, the Abo Formation is mudstone dominated and contains a few, thin, tabular sandstone bodies of great lateral extent (Fig. 1). These strata are similar to part of the correlative Sangre de Cristo Formation in northern New Mexico. SOEGAARD & CALDWELL (1990) interpreted this lithofacies to indicate prolonged vertical accretion of mudstones on well-established floodplains punctuated by unconfined sheetflood events that deposited the sandstones. The sandstone bed that yields tracks at NMMNH locality 4394 corresponds well to the sheetflood sandstone lithofacies. Indeed, HUNT et al. (1990) described a tracksite in the Sangre de Cristo Formation in a lithofacies similar to that which yields locality 4394.

The Bursum Formation beneath the Abo Formation yields fusulinids of earliest Wolfcampian age, including *Triticites creekensis*, *Leptotriticites* and *Schwagerina pinosensis* (e.g., MYERS 1973). Various lines of evidence, including fossil plants, regional stratigraphic relationships and the ages of laterally equivalent marine strata, indicate the Abo-Yeso contact is close in age to the Wolfcampian-Leonardian boundary (e.g., HATCHELL et al. 1982, HUNT 1983, LUCAS et al. 1995). So, locality 4394 certainly is of Wolfcampian age, though a more precise age within the Wolfcampian is not possible.

3 Systematic Palichnology

Many of the tetrapod footprints from NMMNH locality 4394 can be assigned readily to footprint ichnotaxa already well known from other Abo tracksites: *Dromopus agilis* MARSH, *Dimetropus* sp., *Batrachichnus delicatulus* LULL, *Gilmoreichnus hermitanus* (GILMORE) and *Hyloidichnus* sp. The records of *Amphisauropus* and *Varanopus* at locality 4394, however, are new records for the Abo Formation, so we document them here.

Ichnogenus *Varanopus* MOODIE 1929

Varanopus sp.

Figs. 2B, 3D.

Referred Specimens: NMMNH locality 4394: NMMNH P-31347, 6 convex prints with counterpart (Figs. 2B, 3D); NMMNH P-33301, 2 concave prints.

Description and identification: NMMNH P-31347 consists of a series of six small tracks of varying preservation. The length and width of both the manus and pes averages 20 mm. The stride length equals 85 mm, with a pace angulation of 67°. The divarication between the axis of pes digit V and I is 155°. There is a moderate increase of length between pes digit I to digit IV. Pes digit V is as short as digit I, not well integrated and is directed outward. Based on the proportion and position of the digits, especially the length and outwardly directed position of pes digit V, we assign these tracks to *Varanopus* sp. aff. *V. curvidactylus* (cf. HAUBOLD & LUCAS 2001b). The morphology of the Abo specimens is intermediate between *V. curvidactylus* from the Choza Formation and *V. microdactylus* from the Oberhof and Tambach formations.

Discussion: MOODIE (1929) first described the ichnogenus *Varanopus*, with six ichnospecies, from material collected at Castle Peak, Texas. SARJEANT (1971) next published on the Castle Peak tracks. However, he did not restudy MOODIE'S original material and proposed a confusing reorganization of the ichnotaxa named by MOODIE. SARJEANT accepted the ichnogenus *Varanopus* in a version that did not recognize the difference between *Varanopus* and *Erpetopus*. Furthermore, SARJEANT named a new ichnogenus *Moodieichnus* for *Varanopus didactylus* MOODIE 1929. HAUBOLD (1971) reduced the number of ichnotaxa from Castle Peak and listed only *Erpetopus willistoni* MOODIE, *Dromopus palmatus* (MOODIE) and *Varanopus curvidactylus* MOODIE. These independent determinations produced confusion when applying *Varanopus* in particular V. *curvidactylus* and *Moodieichnus* to other Permian track assemblages, particularly when comparing material from North America and Europe. A restudy of the type specimens and material from the type series at Castle Peak (HAUBOLD & LUCAS 2001b, c) is the establishment of *Varanopus* as a valid ichnogenus.

SCHULT (1995a, b) assigned tracks from the Robledo Mountains mega-tracksite (NMMNH locality 846) of southern New Mexico to *Varanopus* cf. *V. microdactylus*. However, a reassessment of SCHULT'S ichnotaxonomy (HUNT et al. 1995a) resulted in the tracks identified as *Varanopus* being reassigned to *Batrachichnus delicatulus*.

Varanopus is known from the European Rotliegend (HAUBOLD 1971, 1973, 1998), including the Tambach Formation of central Germany (MÜLLER 1962, HAUBOLD 1998: Fig. 6). *Varanopus* was previously described in North America from the Choza Formation at Castle Peak, Texas and is now known from the Abo Formation at Abo Pass, New Mexico. This considerably extends the stratigraphic range of *Varanopus* in North America, from the Choza Formation, Clear Fork Group of upper Leonardian age (Castle Peak) to the Abo Formation of the Wolfcampian of early Artinskian age (Abo Pass).

Ichnogenus *Amphisauropus* HAUBOLD 1970

Amphisauropus latus HAUBOLD 1970

Figs. 2A, 3A-C, 4 and 5.

Referred Specimens: NMMNH P-31309, 1 concave track; NMMNH P-31312, 3 convex tracks; NMMNH P-31313, 3 convex tracks; NMMNH P-31316, 3 concave tracks; NMMNH P-31317, 3 concave tracks; NMMNH P-31319, 2 convex tracks; NMMNH P-31322, 2 concave tracks; NMMNH P-31323, 1 concave track; NMMNH P-31326, 1 concave track; NMMNH P-31330, 3 concave tracks; NMMNH P-31331, 2 concave tracks; NMMNH P-31333, 2 convex tracks (Fig. 3B); NMMNH P-31335, 7 convex tracks; NMMNH P-31336, 3 concave tracks; NMMNH P-31337, 1 concave track; NMMNH P-31338, 12 concave tracks; NMMNH P-31339, 2 concave tracks;

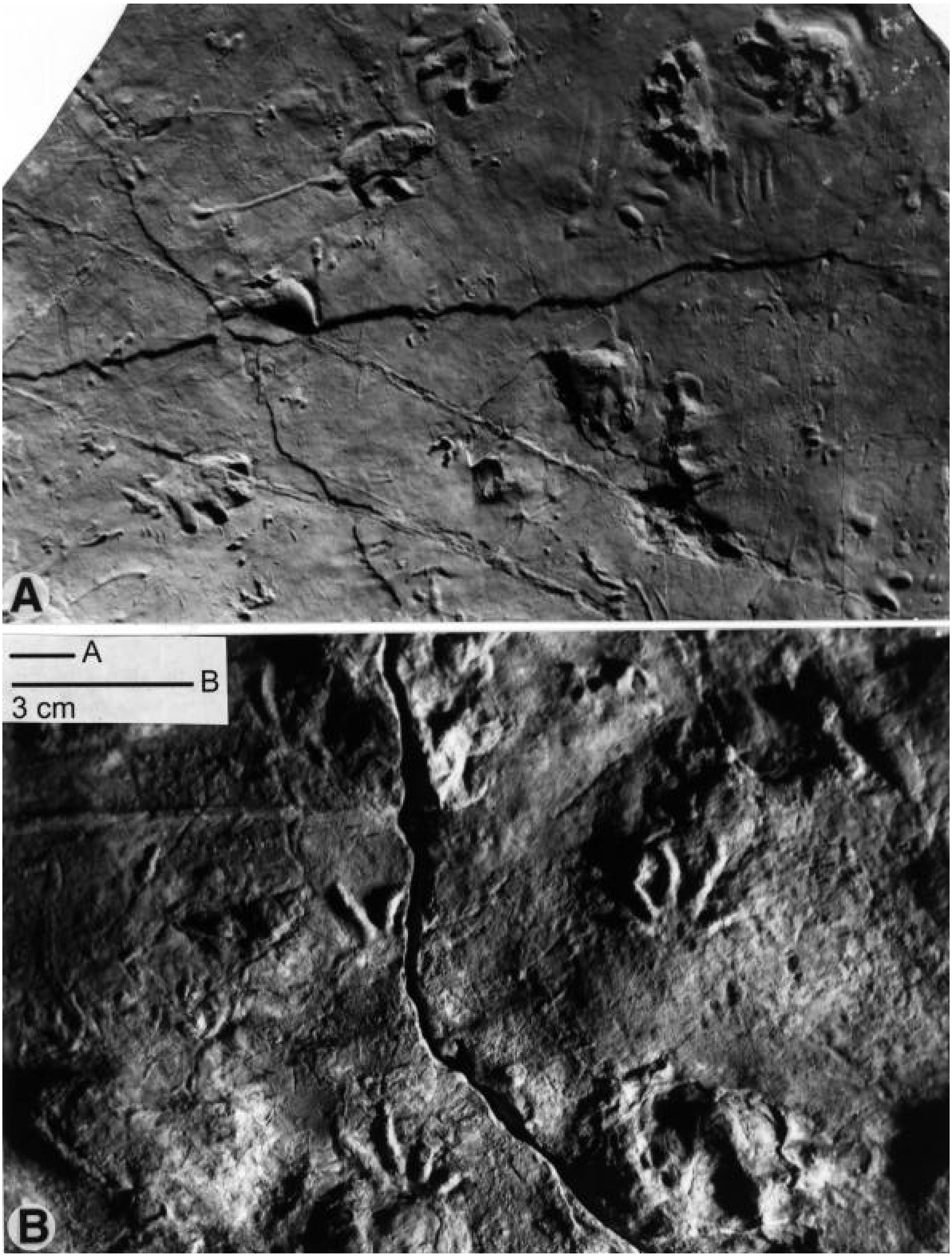

Fig. 2:
Amphisauropus latus and *Varanopus* sp. from NMMNH locality 4394.
A – *Amphisauropus latus*, NMMNH P-31343, characteristic track surface with indeterminable small tracks besides those of *A. latus*.
B – *Varanopus* sp., NMMNH P-31347, track surface.

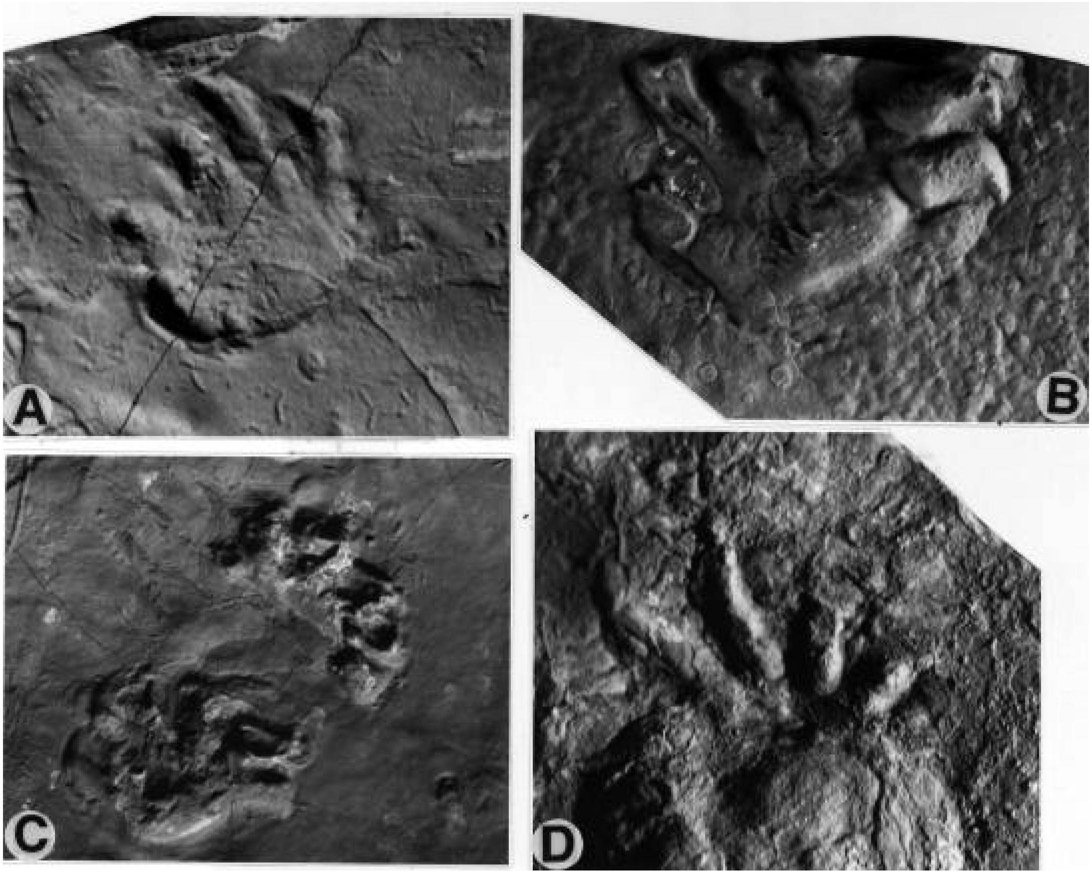

Fig. 3:
Amphisauropus latus and *Varanopus* sp. from NMMNH locality 4394.
A – *Amphisauropus latus*, NMMNH P-31343, detail of footprint. Length of the picture: 10 cm.
B - *Amphisauropus latus*, NMMNH P-31333, detail of footprint. Length of the picture: 9 cm.
C - *Amphisauropus latus*, NMMNH P-31343, detail of manus and pes tracks. Length of the picture: 15 cm.
D – *Varanopus* sp., NMMNH P-31347, detail of footprint. Length of the picture: 4 cm.

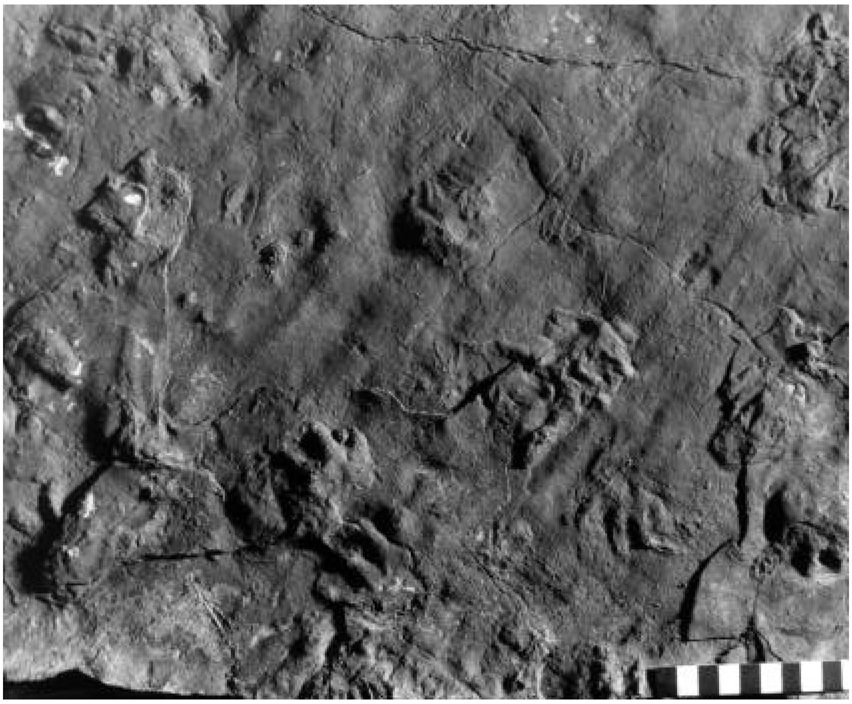

Fig. 4:
Amphisauropus latus from NMMNH locality 4394, surface with ripple lamination, NMMNH P-33301-3167, scale in cm.

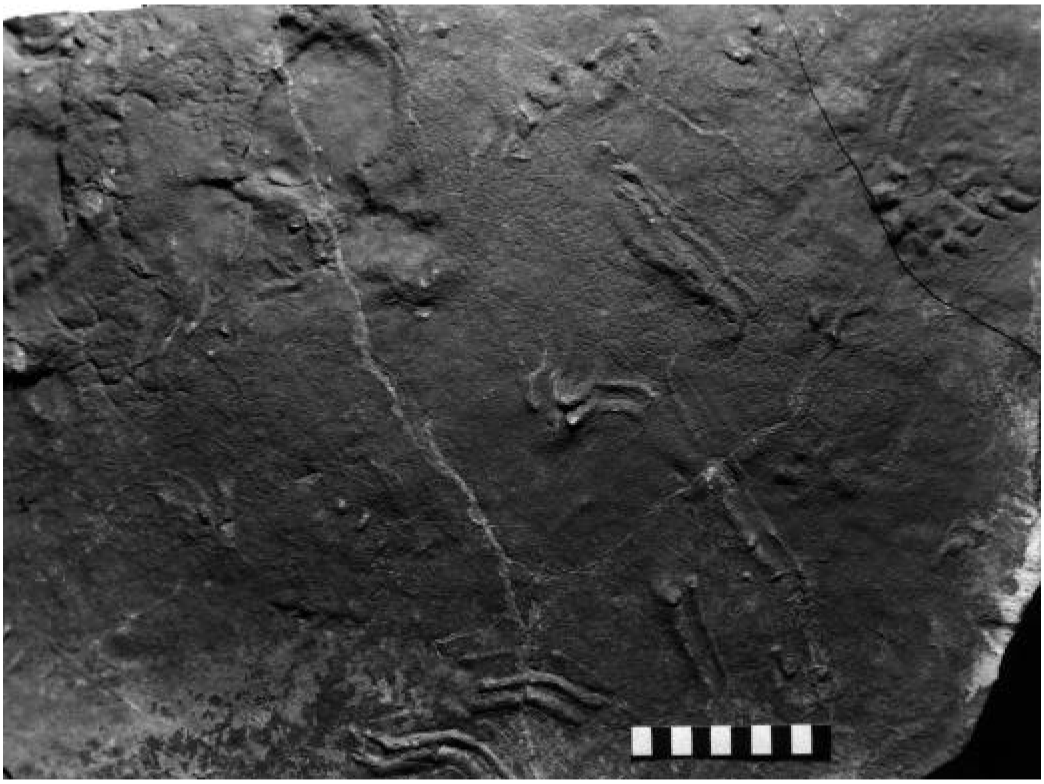

Fig. 5:
Amphisauropus latus, from NMMNH locality 4394, several tracks with digit trailing marks – one of the extramorphologic traits associated with *A. latus*, NMMNH P-31674, scale in cm.

Fig. 6:
Amphisauropus latus, segment of a trackway (left) and a manus-pes set (right) in significant preservation from the Bleichenbach Formation, Rotliegend of the Wetterau basin near Frankfurt/M. Collection HARALD STAPF, Palaeontologisches Museum Nierstein (SSN 11 OF 2 a + b), scale in cm.

NMMNM P-31342, 10 convex tracks; NMMNH P-31343, 14 concave tracks (Figs. 2A, 3A, C); NMMNH P-31345, 15 concave tracks; NMMNH P-31346, 20 convex tracks; NMMNH P-31349, 17 concave tracks; NMMNH P-31443, 1 convex track; NMMNH P-31445, 2 concave tracks; NMMNH P-31446, 3 concave tracks; NMMNH P-31663, 5 concave tracks; NMMNH P-31665, trampled surface; NMMNH P-31667, 2 convex tracks; NMMNH P-31672, 21 concave tracks; NMMNH P-31673, 7 concave tracks; NMMNH P-31674, 14 convex tracks with counterpart; NMMNH P-33299, 2 concave tracks, NMMNH P-33306, 2 concave tracks; NMMNH P-33307; 1 concave print.

Description and identification: These trackways are those of a quadruped in which both manus and pes are pentadactyl (see especially P-31342, P-31345, P-31674). Optimally preserved specimens show pes digit IV to be the longest digit. Digit tips are rounded. The manus and pes are broader than long, averaging a width of 55 mm and a length of 35 mm. The manus is slightly smaller than the pes. The divarication between the axes of pes digits V and I is 130°. Manus tracks are directed inward, whereas pes tracks are parallel to the direction of travel. Based on these features and size, we assign these tracks to *Amphisauropus latus* (cf. HAUBOLD 1970, 1971).
Discussion: *Amphisauropus* is a well known track from Lower Permian red beds in Europe. It was first named from the Thuringian Forest Basin in Germany, were it is known from the Goldlauter, Oberhof, and Rotterode formations. Common additional records have been collected since from many Rotliegend and Lower Permian basins in Central and Southern Europe (e.g., HAUBOLD 1971, 1996). One of the recent finds of *Amphisauropus* in the Rotliegend were possible in the Wetterau Basin north of Frankfurt am Main in Germany. Due to the angaged field work of Harald Stapf, Nierstein, an extended fluviatil track bearing surface has been sampled in the Bleichenbach Formation. The excellent preservation allows a new quality of information of the morphology of the tracks and the trackway pattern of *A. latus*, and is therefore included here (Fig. 6).
The Wolfcampian ichnofaunas of the American Southwest are taxonomically very similar to those found in the Rotliegend of Europe. However, until now *Amphisauropus* has not been found in the USA, though there is a Canadian Early Permian record (MOSSMAN & PLACE 1989).
After recent reinvestigations and field work of the authors in 2001 *Amphisauropus imminutus* has also been recognized in the collection from the Robledo Mountains Formation (NMMNH P-23679). *A. latus* has also been found in the Abo outcrops of the Joyita Hills east of Socorro. The records of *Amphisauropus* in the Abo Formation thus increases the similarity of Abo and Rotliegend tetrapod ichnofaunas.

4 Abo tracksite composition

In terms of numbers of specimens, the New Mexican Abo Formation is one of the richest sources of Early Permian red-bed tetrapod footprints in the world (see articles in LUCAS & HECKERT 1995). Most of the intensively collected and well studied Abo tracksites are understood as preserved in tidal flat facies in southern New Mexico (LUCAS et al. 1995). Characteristic of these sites is NMMNH locality 846 in the Robledo Mountains (HUNT et al. 1995a). From the knowledge of a first period of investigation, this site yields tracks assigned to six ichnogenera and dominated by trackways of small temnospondyls (*Batrachichnus*), araeoscelids (*Dromopus*) and large pelycosaurs (*Dimetropus*); the other track types are less common.

NMMNH locality 4394 differs from locality 846 and other Abo tracksites in ichnotaxonomic composition. Thus, about half the trackways at locality 4394 are of a seymouriamorph (*Amphisauropus*), and about one-third are araeoscelid (*Dromopus*). The other four tetrapod ichnogenera present thus comprise less than 20% of the trackways at the exposed surface. Another way to state this is to note that in comparison to locality 846, at locality 4394 the frequency of *Dimetropus* and *Batrachichnus* tracks and trackways is reduced, the abundance of *Dromopus* is somewhat increased, and *Amphisauropus* tracks are dominant on investigated surfaces.

Locality 4394 thus stands out as an important additional tracksite in yielding the first Abo records of *Amphisauropus* and *Varanopus*, but in being dominated by tracks of *Amphisauropus* as it is known from many Rotliegend track assemblages in Europe. There are several, or at least three possible explanations of this observation. It may reflect a difference in age, in lithofacies or simply be idiosyncratic.
Most of the Abo tracksites in southern New Mexico, including NMMNH locality 846, are in strata very close in age to the Wolfcampian-Leonardian boundary (LUCAS et al. 1995). Therefore, these sites could be somewhat younger than NMMNH locality 4394, which is Wolfcampian, but stratigraphically well below, and thus presumably somewhat older, than the Wolfcampian-Leonardian boundary. Thus, it could be that locality 4394 reflects a time of seymouriamorph abundance during the Early Permian, whereas locality 846 reflects a later time when seymouriamorphs were rare or absent in the Abo depositional system, and instead small temnospondyls, large pelycosaurs and araeoscelids dominated the tetrapod fauna.

This explanation, however, is not supported by the stratigraphic distribution of seymouriamorphs in Wolfcampian strata of the American Southwest. Although seymouriamorphs are present in the Abo Formation (BERMAN 1993), their precise stratigraphic distribution is not well understood. However, in the nearby Texas Permian section, seymouriamorphs range from the Wolfcampian into the Leonardian (HOOK 1989; LUCAS 1998). It, therefore, seems unlikely that age differences explain the difference in the composition of the Abo Pass and Robledo Mountains tracksites.

The second possibility is that the presence and abundance of *Amphisauropus* at Abo Pass may be related to paleoenvironmental (facies) and local factors. Early Permian tetrapod ichnofaunas occur in New Mexico along an environmental transect from alluvial fans in the north to coastal plains in the south (HUNT & LUCAS 1998). The Abo Formation in central New Mexico (area of NMMNH locality 4394) represents an inland fluvial-facies, whereas Abo tracksites in southern New Mexico are preserved in a fluviatil facies on supratidal surfaces close to tidal flats that formed along the shoreline of the Early Permian Hueco seaway. The distribution of *Amphisauropus* in central New Mexico thus might be explained if it is a facies fossil restricted to more inland fluvial environments. However, all these differences might be simply due to incomplete sample size or very local differences between the observed segments of surfaces or strata.

Neverthless, there are other Early Permian tracksites in New Mexico from inland fluvial facies were *Amphisauropus* is not yet recorded. These include sites in the Sangre de Cristo Formation near Villanueva in northern New Mexico (HUNT et al. 1990), wereas in the Abo Formation near Socorro in central New Mexico the former information (HUNT et al. 1995b) can be completed now with the record of *Amphisauropus*. The track-bearing lithofacies and the content of ichnotaxa of these sites closely resemble that at NMMNH locality 4394. Furthermore, the Socorro sites are ~ 50 km south of NMMNH locality 4394, and thus well inland of the Hueco shoreline, which was near Las Cruces, some 200 km farther south. The Sangre de Cristo Formation tracksite is even farther inland, being ~ 140 km northeast of NMMNH locality 4394. Therefore, a simple difference in overall environment or location relative to the Early Permian sea cannot explain the presence and abundance of *Amphisauropus* at NMMNH locality 4394. At all other Early Permian tracksites in New Mexico, whether in shoreline or inland facies, the former and present lack of *Amphisauropus* is mainly due to incomplete record of the surface by surface changing track content. The extended and continued, but not complete activities of the authors in collecting, recording, and understanding the track content and faunistic interpretation of the Abo and related track fauna in New Mexico points to a locally changing assemblage of *Batrachichnus-Limnopus*, *Amphisauropus*, *Dromopus*, *Dimetropus*, and *Varanopus*. We also have tracks that can be determined as *Gilmoreichnus* and *Hyloidichnus*, but the record of *Ichniotherium* in the New Mexican Abo red beds is open to question.

We conclude that the reason *Amphisauropus* is present and dominant at NMMNH locality 4394 must be ascribed to an idiosyncratic factor. This factor could be a subtle aspect of the paleoenvironment at the time of track formation at locality 4394, some peculiarity of the behavior or distribution of Early Permian seymouriamorphs or just an accident of presevation. What is clear, though, is that NMMNH locality 4394 significantly impacts our understanding of the Early Permian record of tetrapod footprints in New Mexico. It contains the first frequent record of *Amphisauropus* in association with few *Varanopus* in the New Mexican Lower Permian**,** and points to the need and potential of completing the record of ichnofaunal composition. Thus, locality 4394 strongly reminds us that even a tetrapod track record as well understood as that from the Lower Permian of New Mexico can still yield new and significant discoveries.

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