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THE DIVERSITY AND STRATIGRAPHIC DISTRIBUTION OF PRE-DINOSAURIAN COMMUNITIES FROM THE TRIASSIC MOENKOPI FORMATION

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Abstract—Recent discoveries of tetrapod tracks in the Moenkopi Formation (Early Triassic) of Capitol Reef National Park (CARE), and Glen Canyon National Recreation Area (GLCA), Utah have revealed important new terrestrial and subaqueous vertebrate track localities on multiple stratigraphic horizons. The San Rafael Swell area to the north has also yielded important footprint horizons. These well-preserved track horizons are the oldest and most laterally extensive track-bearing horizons documented in the Western U.S. Ichnogenera (*Chirotherium*), *(Rhynchosauroides*), and *(Rotodactylus),* are the dominant forms. Rare fish fin drag marks *(Undichna)* relate to fish skeletal remains identified in the Torrey Member of the Moenkopi Formation.

Tracks are preserved either as positive relief "casts" filling impressions in the underlying mudstones or on plane bed surfaces as negative relief "impressions". Exposed traces occur on the undersides of resistant sandstone ledges where the mudstone has eroded away and in finer grained sediments such as mudstones and siltstones. The Torrey Member represents deposition on a broad, flat-lying coastal delta plain (Blakey, 1973 and 1977). Both nonmarine (fluvial) and marine (principally tidal) processes influenced deposition. Even-bedded mudstones, siltstones, claystones, and fine grained sandstones, containing abundant ripple marks and parallel laminations dominate lithologic types. Ichnites indicating swimming/floating behavior of quadruped tetrapods are associated with the walking trackways. The water depth was sufficiently shallow to permit the vertebrates to touch the substrate with both manus and pedes when moving through the water.

Vertebrate tracks form locally dense concentrations of toe scrape marks which sometimes occur with complete plantigrade manus and pes impressions. Well preserved, skin, claw, and pad, impressions are common. Rare, well developed, tail-drag marks frequently occur in certain trackway sequences. Fish fin drag marks and fish skeletal material are preserved with tetrapod swim tracks. Vertebrate ichnites occur with fossil invertebrate traces *Arenicolites*, *Paleophycus*, *Fuersichnus*, and *Kouphichnium* (horseshoe crabs). Traces of unique millipede body fossils, and complete 3-dimensional plant molds of *Equisetum* plants are present.

Lateral correlations of stratigraphic units with recognizable ichnites occur in the Moenkopi Formation throughout Utah's national parks will aid interpretations of the paleoecology, and diversity of ichnofauna in the North American Western Interior during the Early Triassic known as "the dawn of the dinosaurs".

INTRODUCTION

Important discoveries have been made during the course of GLCA history. The tracksways in the Torrey Member of the Moenkopi Formation were first described in detail from this stratigraphic unit and suggest a great potential for finding other sites in this widely exposed unit in Capitol Reef, Glen Canyon National Recreation Area, and San Rafael Swell (Fig. 1). Extensive track bearing horizons in the Moenkopi provide correlation through the entire region.

Fossil footprints are a non-renewable resource on public land, and provide an opportunity for public education, scientific research, and an administrative opportunity and challenge for both scientists and land management authorities.

GEOLOGY

The Torrey Member of the Moenkopi Formation has been the subject of broad-based stratigraphic investigation for 50 years (McKee, 1954; Smith et. al., 1963; Blakey, 1973 and 1977; Stokes, 1980; Hintze, 1988; Morris et. al., 2000). Recently the Torrey Member has been studied in stratigraphic detail with emphasis on the extensive tetrapod track-bearing surfaces of pre-dinosaurian communities (Mickelson, et. al., 2000, 2001, and 2005; Mickelson, 2003) (Fig. 2). The Torrey Member vertebrate tracks are the oldest and most laterally extensive megatracksite horizons yet recorded and are known to extend throughout Utah.

Following the deposition of the Sinbad Member in a clear shallow sea, a change in tectonic and/or climatic conditions caused the progradation of a major delta succession into Utah. This delta complex is preserved as the Torrey Member. A threefold lithofacies classification model produced by Smith (1987) was adapted to describe depositional environments of the Torrey Member delta-plain channels. Outcrop measured sections (a west to east trend) are similar to Smith's (1987) lithofacies classification for meandering river estuarine systems (Fig. 3).

Basal deposits of the Torrey Member include interbedded siltstones, dolomites, and very fine-grained sandstones that were laid down in advance of the prograding delta. This sequence grades upwards into ledge-forming coarser grained sandstones and interbedded siltstones. The facies includes channel deposits of large-scale trough cross bedded fine to medium grained sandstone that was deposited within the fluvial-dominated reaches of the upperdelta-plain. Channel bodies dominated by ripple to large-scale trough cross bedded sandstones and interbedded mudstones are organized into inclined heterolithic packages (Fig. 2). Also present within these sandstone and mudstone-dominated channels are large-scale soft sediment deformational features and clay-draped ripple- and dune-scale bedforms. These inclined bar-forms are likely point-bar deposits that experienced tidal influence and may represent the more seaward lower delta-plain expression of the sandstone-domi-

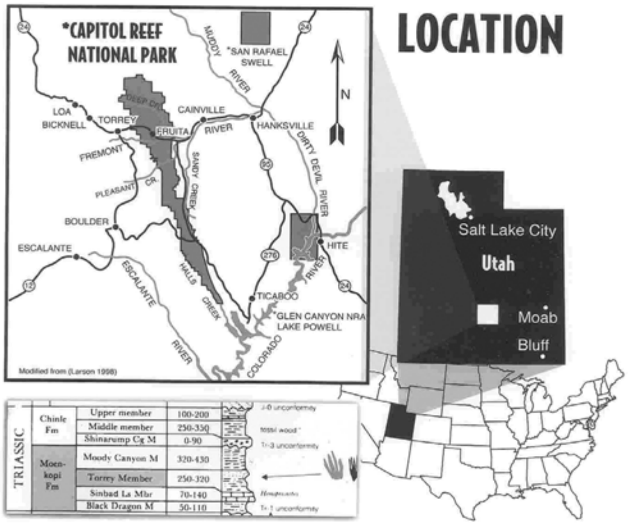

FIGURE 1. Location map and stratigraphic nomenclature of multiple localities from the Early Triassic Moenkopi Formation southeastern and central Utah. The Moenkopi Formation is composed of the following members in ascending order, Black Dragon, Sinbad Limestone, Torrey and the Moody Canyon.

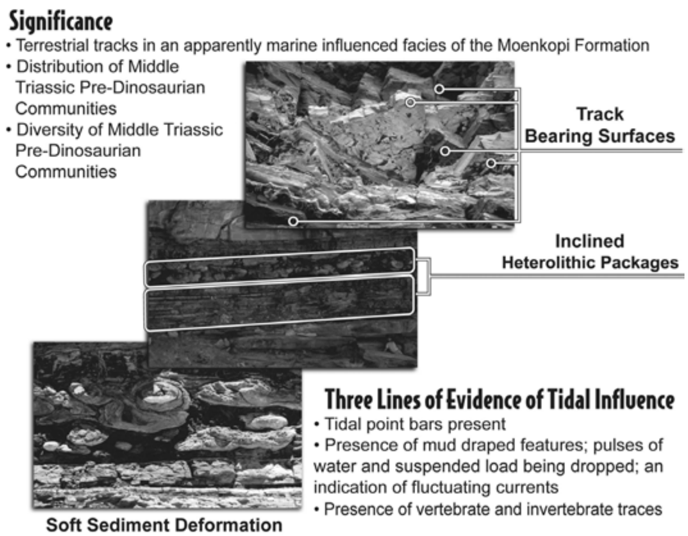

FIGURE 2. The significance of vertebrate footprints and evidence of environmental implications in the Torrey Member, Moenkopi Formation.

nated fluvial channels.

Several track-bearing horizons are present within this delta-plain facies. Multiple tetrapod track horizons have been identified within the fluvial-dominated reaches of the upperdelta-plain. Tetrapod tracks and fish-fin drag marks are typically associated within the upper sandstone and mudstone-dominated channels.

VERTEBRATE ICHNOLOGY

Chirotherium Tracks

Chirotherium tracks have been previously described from continental North America, Europe and South America continents (Peabody, 1948; Leonardi, 1987; Tresise and Sargeant, 1997). The Moenkopi tracks are herein described as relatively narrow, quadrupedal trackways indicating the normal tetrapod walking gait. In the walking gait a small pentadactyl manus impression regularly occurs immediately in front of, but never overlapped by, a much larger, pentadactyl pes which generally resembles a reversed human hand. Manus and pes tends to be plantigrade; digits I-IV point more or less forward; manus digit IV is always shorter than III which is the largest; the footprints may or may not show specialized metatarsal pads. Clear impressions often show a granular or beaded skin surface (skin impressions). Associated swim tracks are common and often indicate current flow directions (Fig. 4) (Mickelson, et. al., 2000, 2001 and 2005; Mickelson, 2003)

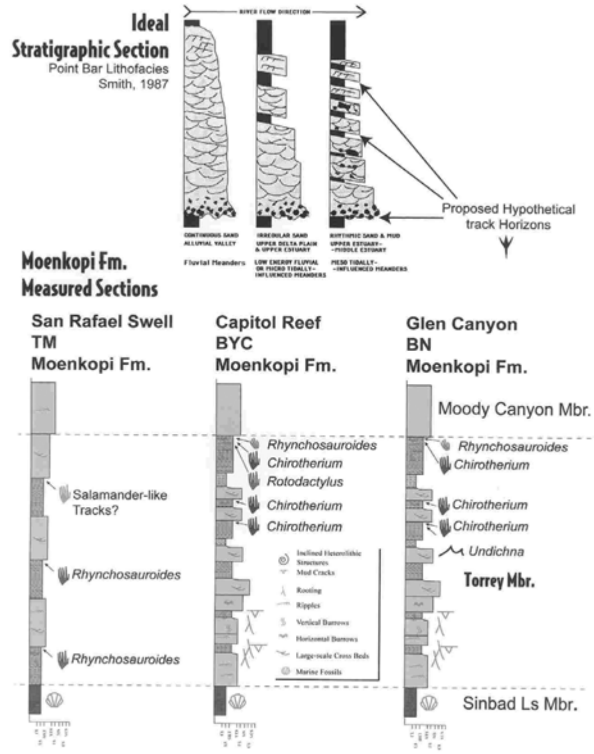

FIGURE 3. A comparison of Smith's 1987 ideal stratigraphic section of point bar lithofacies, to measured sections of the track-bearing units of the Moenkopi Formation.

Rotodactylus Tracks

Long-striding, pentadactyl trackways of a medium-sized reptile are well preserved with rare skin and claw impressions. These tracks commonly occur with smaller *Rhynchosauroides* footprints. The manus is always closer to the midline than the pes, and in some cases overstepped even in the walking gait by the much larger pes in a moderately narrow trackway pattern; pace angulation (of the pes) is as high as 146 degrees in a running trackway and as low as 93 degrees in a walking trackway. The pes impression indicates a foot with an advanced digiti-

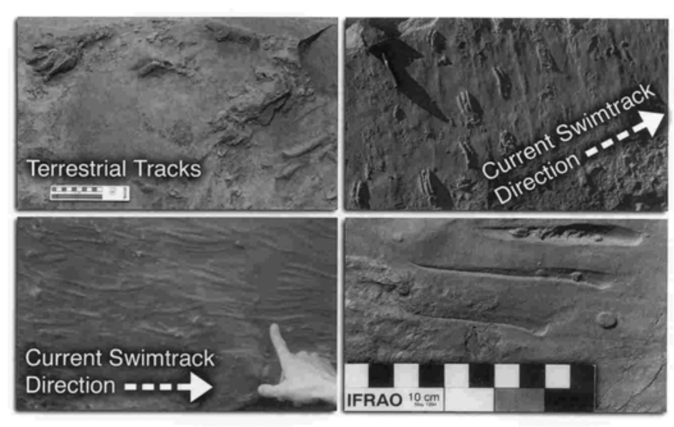

FIGURE 4. An example of terrestrial and swim tracks of *Chirotherium*.

grade posture (Peabody, 1948) and with a strongly developed but slender digit V rotated to the rear where it functioned as a prop. Manus digit V may or may not be rotated backward but it too had a propping function. Digit IV on both manus and pes is longer than III; digit I may fail to impress; claws are evident and distinct on digits I-IV. Well defined skin impressions, often preserved in exquisite detail, have a scaly plantar surface characterized by transversely elongate scales on the digit axis bordered by granular scales (Fig. 5).

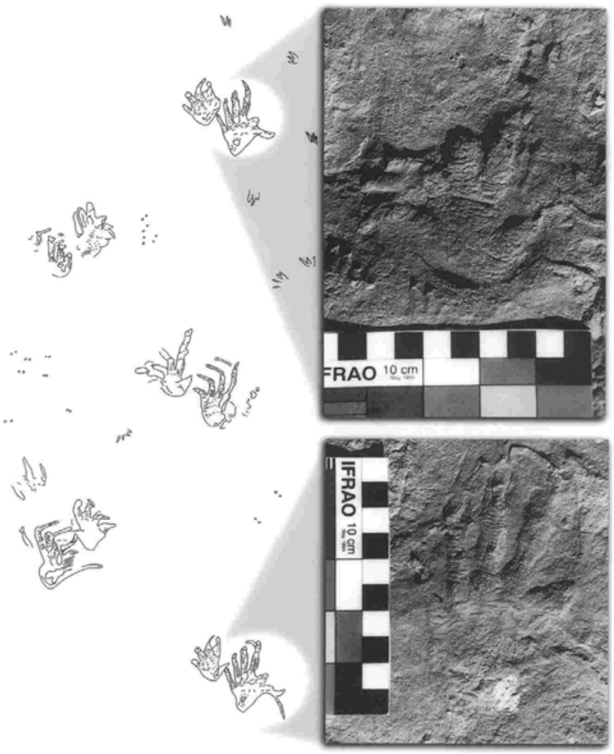

FIGURE 5. An example of *Rotodactylus* tracks preserved with rare skin impressions. Several consecutive manus and pes tracks are preserved in a trackway and illustrated by Susan J. Lutz.

Rhynchosauroides Tracks

Dense concentrations of *Rhynchosauroides* tracks are commonly associated with the trackways of *Chirotherium* and *Rotodactylus*. These small lacertoid footprints are generally characterized by deeply impressed manus and a faintly impressed pes. Trackways exhibit a relatively wide pattern with pentadactyl footprint relatively distant from the midline. The pace angulation is low, below 90 degrees (100 to120 degrees if figured from the manus pattern). Most often only 3 to 4 digits are preserved with occasional tail drag marks (Fig. 6). The digits are slender and relatively longer in the pes than in the manus and both sometimes exhibit distinct claw impressions. Swim tracks are common.

Undichna Fish Trails

The Moenkopi Formation is known for its exceptional vertebrate fossil record. Fish are rare and have not been studied in detail, and fish trails (fish fin drag marks) have never been recorded in the Early Triassic (Mickelon, et. al., 2000, 2001, 2005; Mickelson, 2003). This study describes the first known occurrence of fish trails (fish fin drag marks), *Undichna* from the Early Triassic Torrey Member of the Moenkopi Formation (Fig. 7). This ichnogenus has been reported in abundance from the Late Paleozoic, Permian, Cretaceous, and more recently from the Eocene (Loewen, 1999). *Undichna* from the Torrey Member of the Moenkopi Formation represents the first and only known occurrence of fish trace fossils in the Triassic in the Western U.S.

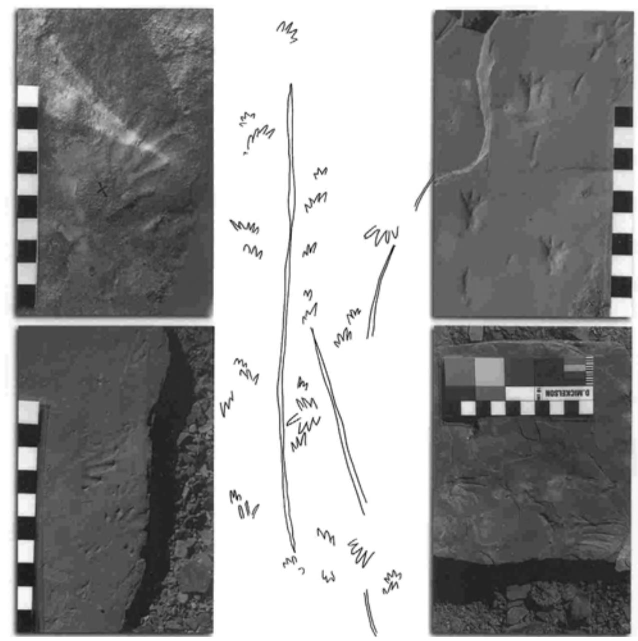

FIGURE 6. Dense concentrations of individual tracks and trackways of *Rhynchosauroides* are the dominant forms within the Moenkopi Formation. Illustrated trackway by Dan Channey and Susan J. Lutz.

FIGURE 7. *Undichna* (fish fin drag marks).

The fish fin trace fossils are preserved as convex hyporelief sandstone casts filling imprints preserved in underlying mudstone. Exposed traces occur on the undersides of resistant sandstone ledges where the mudstone eroded away. *Undichna* commonly occur with locally dense concentrations of swim traces of *Chirotherium*. *Undichna* usually occur in clusters. One isolated fish fin trace consists of a single, slightly-asymmetrical, sinusoidal trail. The trace is 56 cm. long and includes 6.5 cycles with wavelengths varying from 9 to 10 cm and amplitudes of 3.5 to 4.5 cm. The trails were most likely produced by a fish with a large caudal or anal fin able to reach the sediment without any other fin doing so. The low wavelength to amplitude ratio is most consistent with a caudal fin. This occurrence of *Undichna* is similar to other previous descriptions made by (Loewen, 1999) and it supports that the preservation of these trails being favored in fine-grained sediments (Loewen, 1999).

Swim Tracks

Peabody (1948) first described swim tracks from the Moenkopi Formation from several locations in Arizona. Recently, (Pienkowski and Gierlinski, 1987, McAllister (1989), McAllister and Kirby (1998), Mickelson, et. al., 2000, 2001, 2005, Mickelson, 2003 and Kvale, et. al., 2001), criteria have been introduced for identifying and describing tetrapod swim traces that indicate trackmaker buoyancy. Swim traces in the Moenkopi Formation are characterized primarily by posterior overhangs and reflectures of the individual digit impression; and secondarily by striations and claw marks along digit impression length, and the often incomplete nature of the trails (Figs. 4 and 6). These swim tracks grade into subaqueous traces formed by more typical terrestrial propulsion and demonstrate less buoyancy as the water became more shallow, disappearing as the trackmaker becomes fully buoyant. When interpreting the environment of deposition, the sedimentary substrate should be consistent with the presence of the swim traces.

Bouyancy creates important differences between locomotion on land and in water. In a floating animal the digits can extend farther posteriorly in the propulsive phase without unbalancing (losing the necessary support to maintain posture) the organism. This allows the propulsive force to be on a more horizontal plane and produce a scrape mark instead of compressing downward into the sediment.

The Moenkopi tracks were originally impressed into a muddy matrix and later filled in with fine sand. The swim tracks are elongated, striated scratch marks (produced by scales and nails) preserved in the substrate. The propulsive phase leaves "kick-off scours" (Thulborn and Wade, 1989) which occur immediately posterior to the traces. The sandstone cast is unfilled, and the scour is seen as the irregular positive relief behind the digit scrapes. The scrapes represent the action of the water eddies created behind the digits as they pass close over the sediment at the end of the propulsive phase.

INVERTEBRATE AND PLANT ICHNOLOGY

Fuersichnus, *Palaeophycus*, and *Arenicolites*: The Torrey Member of the Moenkopi Formation assemblage studied is considered herein as an example of the *Glossifungites* ichnofacies and commonly contains vertebrate swim tracks. This ichnofacies is restricted to firm but unlithified nonmarine and marine surfaces. Tracks and traces in the *Glossifungites* ichnofacies are characterized by low diversity and high density assemblages which include *Fuerichnus*, *Palaeophycus*, *Arenicolites*, and *Skolithos*.

Fuersichnus

The ichnogenus *Fuersichnus* (Fig. 8) is a relatively rare trace fossil that has been documented from Triassic and Jurassic nonmarine deposits and only recently documented in marine deposits from the Upper Cretaceous (Buatois, 1995). The ichnogenus consits of horizontal to subhorizontal, isolated or loosely clustered, U-shaped, curved to banana-like burrows, characterized by distinctive striations parallel to the trace axis. It is interpreted as a dwelling structure probably produced by crustaceans or polychaetes (Hantzschel, 1975).

Palaeophycus

The ichnogenus *Palaeophycus* (Fig. 8) is a common trace fossil that has been documented from Precambrian to Holocene nonmarine and marine deposits (Pemberton and Frey, 1982). Galleries are branched, and irregularly winding, cylindric or subcylindric tubes, that sometimes cross-cut one another. Horizontal galleries most often have vertically striated lined burrows or rarely nearly smooth surface textures. *Palaeophycus* represents passive sedimentation within an open dwelling burrow constructed by a predaceous or suspension-feeding animal.

Arenicolites

The ichnogenus *Arenicolites* (Fig. 8) consists of simple U-tubes (paired tubes) without spereite, perpendicular to the bedding plane; usually varying in size, tube diameter, distance of limbs, and depth of burrows; limbs are rarely somewhat branched, some with funnel-shaped opening; walls are commonly smooth. This is a common trace fossil documented from Triassic to Cretaceous from marine and nonmarine deposits. The Torrey *Arenicolites* are very consistent in size, shape, and

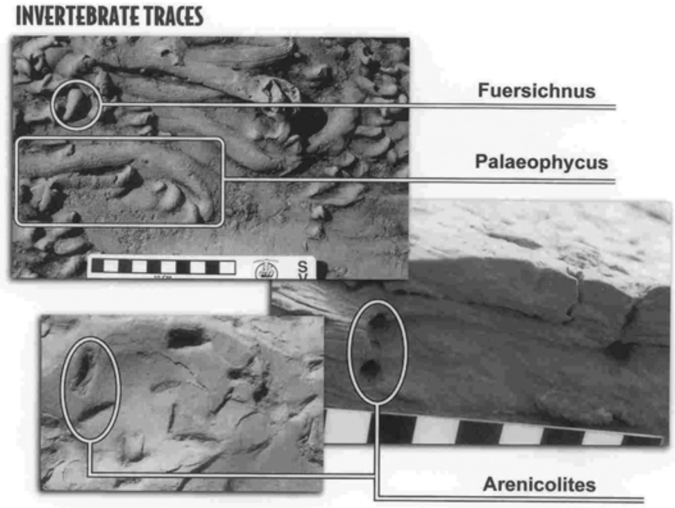

FIGURE 8. An example of invertebrate trace fossils found with associated vertebrate tracks.

distance apart from each other. *Arenicolites* are interpreted as being made by annelid worms (Hantzschel, 1975).

Kouphichnium

The ichnogenus *Kouphichnium* (Fig. 9) (horseshoe crab) tracks occur as several types of morphologies. Heterpodous tracks of great variety with either two chevron-like series of four oval or round holes or bifid v-shaped impressions or scratches that are forwardly directed. Imprints most often exhibit median drag-marks. These traces are found in both marine and terrestrial environments; horseshoe crabs have been extinct in terrestrial fresh water settings since the end of the Jurassic (Hantzschel, 1975). They are indicators of shallow, subaqueous to semi aquatic environments in firm substrates.

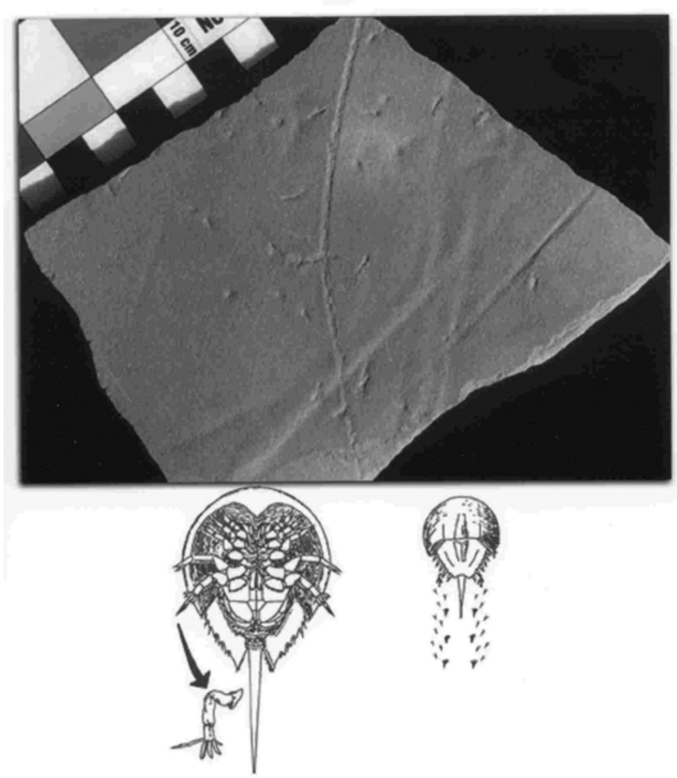

FIGURE 9. Horseshoe crab traces-*Kouphichnium*. These trails also occur as composite and over-lapping patterns associated with specific behaviors.

Millipede

A rare, well preserved body fossil trace portrays morphologies of a large millipede (arthropod) (Fig. 10). This diploplodid arthropod has a reconstructed length approaching 7cm, it is elongate, tapering front to back, with up to 53 body segments. Millipedes are generally rare in the fossil record due to their terrestrial habitats. This is the first occurrence of this type of arthropod from the Early Triassic in western North America.

FIGURE 10. A single millipede preserved with associated plant and terrestrial vertebrate footprints.

Equisetum

Sphenopsids (*Equisetum*) decreased in diversity and became increasingly restricted to herbaceous forms during the Triassic. Early Triassic *Equisetum* fossils in the Moenkopi are particularly rare, and are often preserved in situ and in 3-dimensional molds, probably because they tended to grow on freshly deposited substrates that are common in active depositional settings (Fig. 11).

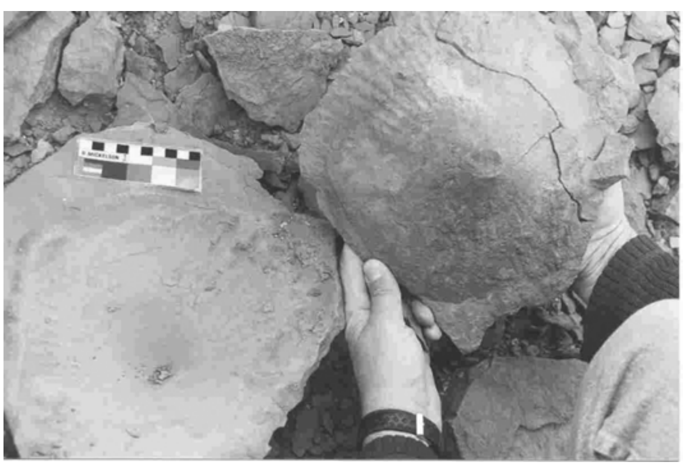

FIGURE 11. An example of a 3-dimensional mold of a fossilized horsetail plant (*Equisetum*).

All Mesozoic sphenopsids were based on the same basic body plan as the present-day *Equisetum*, having unbranched central axes bearing whorls of leaves. Large *Equisetum* (30 cm thick) may have attained heights of 10m. and grew along the banks of fluvial-tidal channels during deposition of the Moenkopi Formation. During the early Mesozoic, the anatomy and distribution of Mesozoic sphenopsids is consistent with primary colonization of open or disturbed damp habitats where their rhizomatous growth and moderate size may have allowed them to form dense thickets.

SUMMARY

Significance

- Terrestrial tracks in an apparently marine influenced facies of the Moenkopi Formation
- Distribution of Middle Triassic Pre-Dinosaurian Communities
- Diversity of Middle Triassic Pre-Dinosaurian Communities

Evidence

- Tidal point bars present
- Presence of mud draped features; pulses of water and suspended load being dropped; an indication of fluctuating cur rents
- Presence of vertebrate and invertebrate traces

Conclusion

- Occurrence of terrestrial and sub-aqueous tracks in the Moenkopi Formation.
- Tracks occur in marine influenced environments.
- Implication is that these animals may have tolerated brackish water conditions.

DISCUSSION

Several important discoveries have been made during the course of GLCA and CARE history the last ten years. Trackways are first described in detail from the Torrey Member of the Moenkopi Formation. Their abundance suggests a great potential for finding other sites in this unit, which is widely exposed in Capitol Reef, Glen Canyon National Recreation Area, Zion, Canyonlands and Arches National Parks. Extensive track bearing horizons in the Moenkopi Formation provide a good basis for biostratigraphic correlation throughout the entire region.

Lateral correlations of the ichnostratigraphic units identified in the Moenkopi Formation throughout Utah's national parks will aid interpretations about the paleoecology, and ichnospecies diversity of the Western Interior during the Early Triassic-"The Dawn of the Dinosaurs".

As a non-renewable resource on public land, fossil footprints provide an opportunity for public education, scientific research, and an administrative opportunity and challenge for both scientists and land management authorities.

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