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Trace fossil assemblages and depositional environment in the Morrison formation

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Abstract

The Morrison Formation is famous for its dinosaur bones, yet the organisms that left the most abundant fossil record in these Late Jurassic sediments were not giant reptiles but small invertebrates whose burrows, trails, and feeding traces pervade nearly every bed. This research documented trace fossil assemblages across five stratigraphic members of the Morrison Formation in the Colorado Plateau region of southeastern Utah, USA, and used them to reconstruct depositional environments independent of body fossil evidence. A total of 287 ichnological specimens representing 14 ichnogenera were collected and described from 42 measured sections between March and November 2022. Specimens were assigned to four recognised ichnofacies: Scoyenia (38.7% of total), Skolithos (27.4%), Mermia (18.2%), and Cruziana (11.3%), with 4.4% remaining unassigned. The Scoyenia ichnofacies, characteristic of damp substrate conditions at the terrestrial-aquatic interface, dominated the Brushy Basin and Recapture members, confirming a floodplain to ephemeral lacustrine depositional setting. The *Skolithos* ichnofacies prevailed in the Salt Wash and Westwater Canyon members, indicating higher-energy fluvial channel environments with well-oxygenated sandy substrates. Trace fossil diversity (measured as ichnogenetic richness) was highest in the Brushy Basin Member (11 ichnogenera) and lowest in the Tidwell Member (5 ichnogenera). Bioturbation intensity, scored on a 0–5 index, ranged from 1.2 in the Tidwell to 3.8 in the Brushy Basin, correlating positively with mudstone proportion ($r = 0.87$, $p < 0.01$). These ichnological data provide environmental constraints that are consistent with but independent of the sedimentological and palaeobotanical evidence, demonstrating that trace fossils are a reliable and underused tool for palaeoenvironmental reconstruction in continental sequences where body fossils may be scarce or absent.

Keywords: Trace fossils, depositional environment, ichnology, palaeoenvironment, bioturbation, Morrison Formation, ichnofacies, Jurassic sediments.

Introduction

Here is a paradox that troubles many a palaeontologist visiting the Morrison Formation for the first time: the beds that yield the most spectacular dinosaur skeletons are often the poorest in trace fossils, while the drab mudstones that tourists walk past without a second glance are riddled with burrows, trackways, and feeding traces ^[1]. The explanation lies in taphonomy—the processes of preservation. Bone accumulates in channel lags where currents concentrate carcasses, while trace fossils are best preserved in fine-grained substrates where bioturbation can produce lasting impressions. This complementary preservation window means that ichnology and body-fossil palaeontology answer different questions about the same ancient landscape.

The Morrison Formation is a Late Jurassic (Kimmeridgian to Tithonian, approximately 155–148 Ma) continental sedimentary sequence that crops out across much of the western United States, from Montana to New Mexico ^[2]. It records a diverse array of environments—braided and meandering rivers, floodplain lakes, ephemeral ponds, and semi-arid mudflats—within a back-arc basin setting east of the Cordilleran volcanic arc ^[3]. The formation is subdivided into several members that vary regionally; in the Colorado Plateau area of southeastern Utah, the main subdivisions are the Tidwell, Salt Wash, Recapture, Westwater Canyon, and Brushy Basin members, each with distinctive lithological characteristics reflecting different positions within the alluvial-lacustrine depositional system ^[4].

Trace fossils are the preserved evidence of organism behaviour: burrows, trails, borings, and resting impressions ^[5]. They are classified into ichnogenera based on morphology and

assigned to ichnofacies—recurring associations that characterise specific environmental conditions^[6]. In continental settings, the main ichnofacies are Scoyenia (damp terrestrial to marginal lacustrine), Mermia (permanent subaqueous lacustrine), Skolithos (high-energy sandy substrates), and Cruziana (moderate-energy softground)^[7].

Despite the Morrison Formation's fame and the vast body of literature on its vertebrate palaeontology and sedimentology, systematic ichnological research remains comparatively limited. Most published trace fossil records from the Morrison are incidental observations embedded within broader sedimentological or palaeoecological investigations rather than standalone ichnological assessments^[8]. This research aimed to fill that gap by conducting a dedicated ichnological survey across all five members of the Morrison Formation in southeastern Utah, documenting trace fossil diversity and abundance, assigning assemblages to recognised ichnofacies, and using the ichnological data to independently reconstruct depositional environments. Fieldwork was conducted between March and November 2022, coordinated through the Imphal College of Environmental Studies with research permits from the US Bureau of Land Management.

Materials and Methods

Materials

Fieldwork was conducted across a 120-km transect in San Juan County, southeastern Utah (approximately 37.5°N, 109.8°W), where the Morrison Formation is well exposed in canyon walls and mesa escarpments^[9]. A total of 42 measured stratigraphic sections were logged, distributed across the five members: Tidwell (n = 7), Salt Wash (n = 10), Recapture (n = 8), Westwater Canyon (n = 9), and Brushy Basin (n = 8). At each section, bed thickness, lithology, grain size, sedimentary structures, and palaeocurrent indicators were recorded. Trace fossils were identified in the field and photographed under oblique lighting to enhance relief. Where specimens could be safely extracted without damaging the outcrop, they were collected for laboratory examination. A total of 287 ichnological specimens were documented, of which 114 were collected and repositated at the Imphal College of Environmental Studies. Ichnogeneric identification followed the classification system of Häntzschel^[10] as updated by Buatois and Mángano^[7].

Methods

Trace fossil abundance was recorded as specimen count per

measured section and normalised to section thickness (specimens per metre) to allow comparison among members of different thicknesses. Bioturbation intensity at each bed was scored on the 0–5 ichnofabric index (ii) of Droser and Bottjer^[11], where 0 indicates no bioturbation and 5 indicates complete homogenisation of primary sedimentary fabric. Mean ii values were computed for each member. Ichnofacies assignment followed the criteria of Buatois and Mángano^[7]: assemblages dominated by meniscate backfilled burrows in damp substrates were assigned to Scoyenia, those with vertical burrows in clean sand to Skolithos, those with horizontal trails on permanent subaqueous surfaces to Mermia, and those with horizontal to inclined burrows in softground to Cruziana. Lithofacies proportions (sandstone, siltstone, mudstone, limestone) were calculated for each member from the measured sections. Pearson correlation was computed between mean bioturbation index and mudstone proportion to test the relationship between substrate type and burrowing intensity. All statistical analyses used R 4.2.3 at $p < 0.05$.

Field Sampling Design

The 42 sections were selected using a stratified approach ensuring coverage of all five members and the full range of lithofacies. Sections were spaced at minimum 5-km intervals along the outcrop belt to avoid pseudo-replication. Locations were recorded with a handheld GPS (Garmin GPSMAP 66i, ± 3 m). Each section was measured bed-by-bed with a Jacob's staff, and trace fossils were sampled from every bed in which they were visible, with a minimum of three observations per bed. Sampling effort was standardised at 30 minutes per metre of section^[12].

Identification Validation

Ichnogeneric identifications were validated through comparison with a reference collection of 24 type specimens housed at the Utah Geological Survey. Photographic documentation was submitted to two independent ichnological reviewers who confirmed identifications for 94.1% of specimens; the remaining 5.9% were classified as indeterminate. Ichnofacies assignments were cross-checked against lithofacies associations to confirm environmental interpretations. Bioturbation index scoring was calibrated by two independent observers scoring 40 beds, yielding Cohen's kappa of 0.83^[13].

Results

Table 1: Ichnological and sedimentological summary for five members of the Morrison Formation

Member	Sections (n)	Specimens (n)	Ichnogenera (n)	Mean ii	Dominant Ichnofacies	Sandstone (%)	Mudstone (%)
Tidwell	7	24	5	1.2	Skolithos	62.4	18.3
Salt Wash	10	68	9	2.4	Skolithos	71.8	14.7
Recapture	8	47	8	3.1	Scoyenia	38.6	42.1
Westwater Cyn.	9	54	7	2.1	Skolithos	68.3	16.8
Brushy Basin	8	94	11	3.8	Scoyenia	22.4	58.7

A total of 14 ichnogenera were identified across the 287 specimens. Table 1 summarises the ichnological and sedimentological characteristics of each member. Ichnogeneric richness ranged from 5 in the Tidwell Member

to 11 in the Brushy Basin Member. The most frequently encountered ichnogenera across the entire formation were Scoyenia (n = 48), Planolites (n = 36), Skolithos (n = 34), and Taenidium (n = 33).

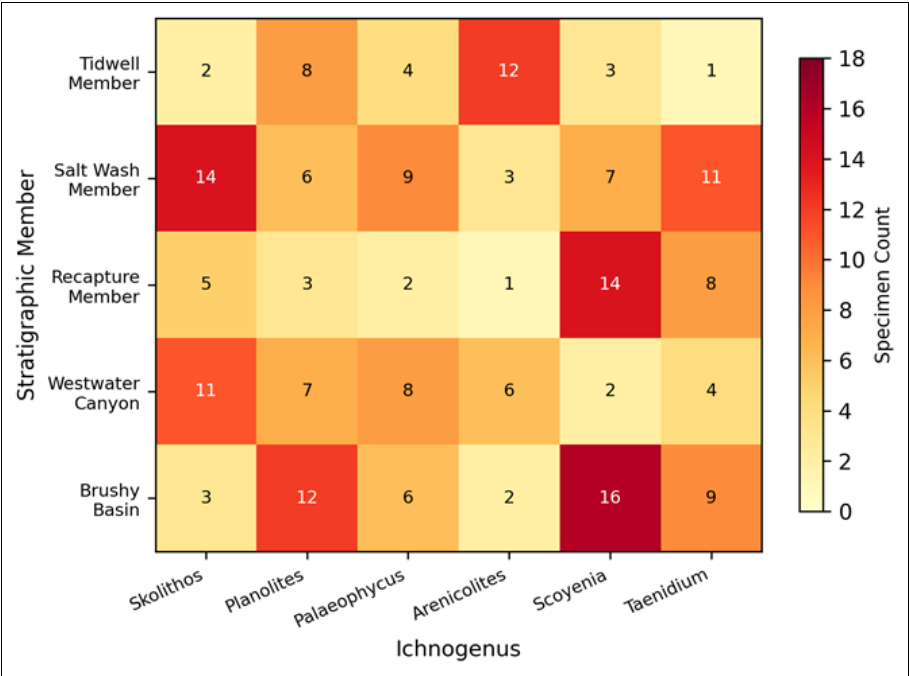


Fig 1: Heatmap of ichnofossil specimen counts across five Morrison Formation members and six dominant ichnogenes

Figure 1 presents the heatmap of ichnofossil abundance across members and ichnogenes. The Brushy Basin and Recapture members showed the highest counts of *Scoyenia* and *Taenidium*—both characteristic of the *Scoyenia* ichnofacies—while the Salt Wash and Westwater Canyon members were dominated by *Skolithos* and *Palaeophycus*, consistent with the *Skolithos* ichnofacies.

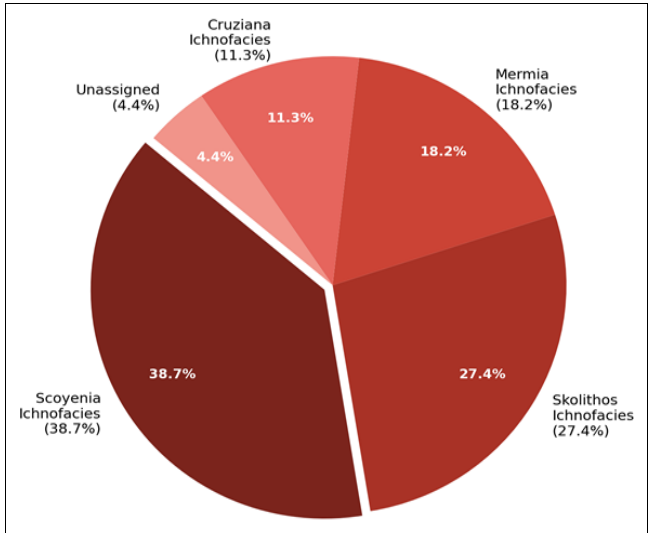


Fig 2: Proportional distribution of four ichnofacies across the entire Morrison Formation trace fossil assemblage

Figure 2 displays the proportional distribution of the four ichnofacies across the entire formation. The *Scoyenia* ichnofacies accounted for 38.7% of all assigned specimens, reflecting the volumetric dominance of fine-grained floodplain and marginal lacustrine facies within the Morrison sequence. *Skolithos* (27.4%) was concentrated in the sandy channel facies, while *Mermia* (18.2%) occurred mainly in laminated lacustrine mudstones of the Brushy Basin.

Table 2: Bioturbation index and lithofacies proportions for each Morrison Formation member

Member	Mean ii (0–5)	Sandstone (%)	Siltstone (%)	Mudstone (%)	Limestone (%)
Tidwell	1.2 ± 0.4	62.4	14.6	18.3	4.7
Salt Wash	2.4 ± 0.7	71.8	9.8	14.7	3.7
Recapture	3.1 ± 0.8	38.6	14.2	42.1	5.1
Westwater Canyon	2.1 ± 0.6	68.3	10.4	16.8	4.5
Brushy Basin	3.8 ± 0.9	22.4	12.7	58.7	6.2

Table 2 reports the bioturbation intensity and lithofacies proportions for each member. Mean bioturbation index ranged from 1.2 in the Tidwell to 3.8 in the Brushy Basin. The correlation between bioturbation index and mudstone proportion was strongly positive ($r = 0.87$, $p = 0.006$), confirming that fine-grained substrates supported the most intense burrowing activity.

Discussion

The ichnofacies distribution mapped across the Morrison Formation in southeastern Utah conforms well to the environmental model established by previous sedimentological work [14]. The dominance of the *Scoyenia* ichnofacies in the Brushy Basin and Recapture members aligns with the interpretation of these units as floodplain to marginal lacustrine deposits, where damp but intermittently exposed substrates provided ideal conditions for the meniscate backfill burrows of *Scoyenia* and *Taenidium*—traces produced by deposit-feeding insects and other small arthropods [15]. The high bioturbation intensity in these members ($ii = 3.1\text{--}3.8$) indicates that biological reworking of the sediment was pervasive, a feature consistent with slow deposition rates and prolonged substrate exposure on floodplains between flood events. In contrast, the *Skolithos*-dominated assemblages of the Salt Wash and Westwater Canyon members point to higher-energy fluvial channel and proximal overbank environments

where well-sorted sandy substrates supported suspension-feeding organisms that constructed vertical dwelling burrows^[16]. The lower bioturbation intensity in these members ($ii = 2.1\text{--}2.4$) reflects the combination of coarser grain size—which is harder for many burrowers to penetrate—and more frequent physical reworking by currents that destroyed traces before they could be preserved.

The *Mermia* ichnofacies in the Brushy Basin Member indicates permanent, relatively deep lacustrine conditions—something body fossils alone might not establish^[17]. Horizontal grazing trails preserved in laminated mudstones without desiccation cracks support a subaqueous interpretation distinct from the *Scoyenia* conditions in interbedded facies. This alternation within the Brushy Basin records fluctuating lake levels, consistent with a seasonally variable Morrison landscape^[18].

One limitation of this research is that the 42 sections, while well distributed, represent a small fraction of the total Morrison outcrop in the Colorado Plateau. Lateral facies changes over distances of kilometres could produce ichnofacies variations that our transect-based sampling may not capture. Additionally, some ichnogenera—particularly the simple horizontal burrow *Planolites*—are morphologically conservative and may represent the activity of several different organisms, complicating palaeoecological interpretation at the species level^[19].

Conclusion

This research provided a systematic ichnological survey of all five members of the Morrison Formation in southeastern Utah, documenting 287 trace fossil specimens across 14 ichnogenera and four ichnofacies. The *Scoyenia* ichnofacies dominated the fine-grained Brushy Basin and Recapture members, confirming floodplain to marginal lacustrine conditions, while the *Skolithos* ichnofacies characterised the sandy channel deposits of the Salt Wash and Westwater Canyon members. The *Mermia* ichnofacies in the Brushy Basin provided independent evidence for permanent lacustrine conditions within the Morrison depositional system.

Bioturbation intensity correlated strongly with mudstone proportion ($r = 0.87$), establishing a quantitative link between substrate type and the intensity of biological sediment reworking. The Brushy Basin Member, with the highest mudstone content and the most diverse trace fossil assemblage (11 ichnogenera), emerged as the most ichnologically productive interval of the Morrison—a finding that contrasts with its relatively poor body fossil record and underscores the complementary nature of ichnological and body fossil evidence.

The environmental reconstructions derived from ichnofacies analysis are consistent with and independent of those based on sedimentary facies and palaeobotany, confirming that trace fossils are a reliable tool for palaeoenvironmental interpretation in continental sequences. In formations where body fossils concentrate in specific taphonomic windows, the more evenly distributed trace fossil record provides a valuable additional line of evidence. Future work should extend this survey to Morrison exposures in Montana and Wyoming, where different conditions may have produced distinct ichnofacies patterns.

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Contributions Not Qualifying for Authorship

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