Exploring Newly Discovered Dinosaur Trackways in the Messak Formation, Sebha Region, Southwest Libya

Mustafa A. Abdullah*[1], Alsharef A. Albaghdady[2] and Alsedik Abousif[1]
[1]University of Sebha -Libya
[2]Libyan Academy-Libya
*Corresponding author: mustafaabdullah72@yahoo.com

Abstract

New footprints of theropod dinosaurs were discovered near Sebha city, southwestern Libya. It is the only known dinosaur record from the Jurassic to Lower Cretaceous period within the Messak Formation. The dinosaur footprints have been examined, counted, measured, photographed, and described to deduce the type of dinosaur, its size, shape, walking style, potential diet, and, if possible, its social interactions with other individuals. A total of 183 clear dinosaur footprints were found and documented, and at least two main sizes of footprints have been defined, characterized, and categorized into two groups: large footprints and small ones. The examined footprints made by an upright dinosaur stood and walked on its two hind feet on a humid layer composed of clay, silt, and fine sand. These footprints suggest they may belong to the theropod group of dinosaurs. The size of these footprints ranges from 20 to 60 cm, and the most common type is characterized by an angle of 50 to 70 degrees between the outermost digits. The foot size suggests that the trace makers' height at the pelvis ranged from 0.8 to 2.4 m, while the overall length of the creature reached 9 m from head to tail. A close examination of the footprints reveals almost equal distances between each footprint, indicating that the animals were moving with coordinated, normal steps and walking in their typical gait. Consequently, they were not in a state of chase or escape from any potential dangers. Based on the current state of knowledge, we believe there are two possible interpretations regarding the preservation of these footprints. Physical and chemical processes, such as consolidation, cementation, and the formation of a crust of iron oxides, played a crucial role in preserving the dinosaur footprints within fragile sediments primarily composed of silt and mudstone beds, which are covered by thin layers of sandstone.

Keywords: Murzuq Basin, Messak Formation, dinosaur footprints.

1. Introduction

1.1 Dinosaurs in Libya

Dinosaurs are a diverse group of reptiles within the clade Dinosauria. They first emerged during the Triassic period, approximately 243 to 233 Ma. The exact origin and timing of the evolution of these extinct creatures have remained subjects of ongoing research. Dinosaurs were the dominant terrestrial vertebrates from the Jurassic through the entire Cretaceous periods. Fossil records indicate that all birds are feathered dinosaurs that evolved from earlier theropods during the Late Jurassic epoch. Thus, they are the only dinosaur lineage known to have survived the Cretaceous-Tertiary extinction event around 66 Ma (Stephen et al., 2015).

The first scientific recognition of dinosaur footprints in Libya was recorded in Nalut city at Jabal Nafusah (Dalla Vecchia, 1995). Scattered remains of dinosaur skeletons have been found in the Nalut area at the top of the Kabaw Sandstone Formation and near the Kiklah Formation (Weishample, 1990 and others). Both formations are stratigraphically equivalent to the Messak Formation in southern Libya (Klitzsch 1963 & 1972). The Nalut dinosaur skeleton remains include dorsal vertebrae and a complete right tibia (Lapparent, 1960 and Weishample, 1990). The age of the Nalut dinosaur skeleton remains has been determined through investigations, dating them back to the Aptian (Upper Cretaceous) period (Dalla Vecchia, 1995). Additionally, other studies suggest that they are taxonomically classified under the subfamily *Abelisauroidea*, which was prevalent in Gondwana before its separation from South America. Recently, several dinosaur footprints and tracks have been discovered at a local farm approximately 8 km northeast of Sebha city (Fig. 1).

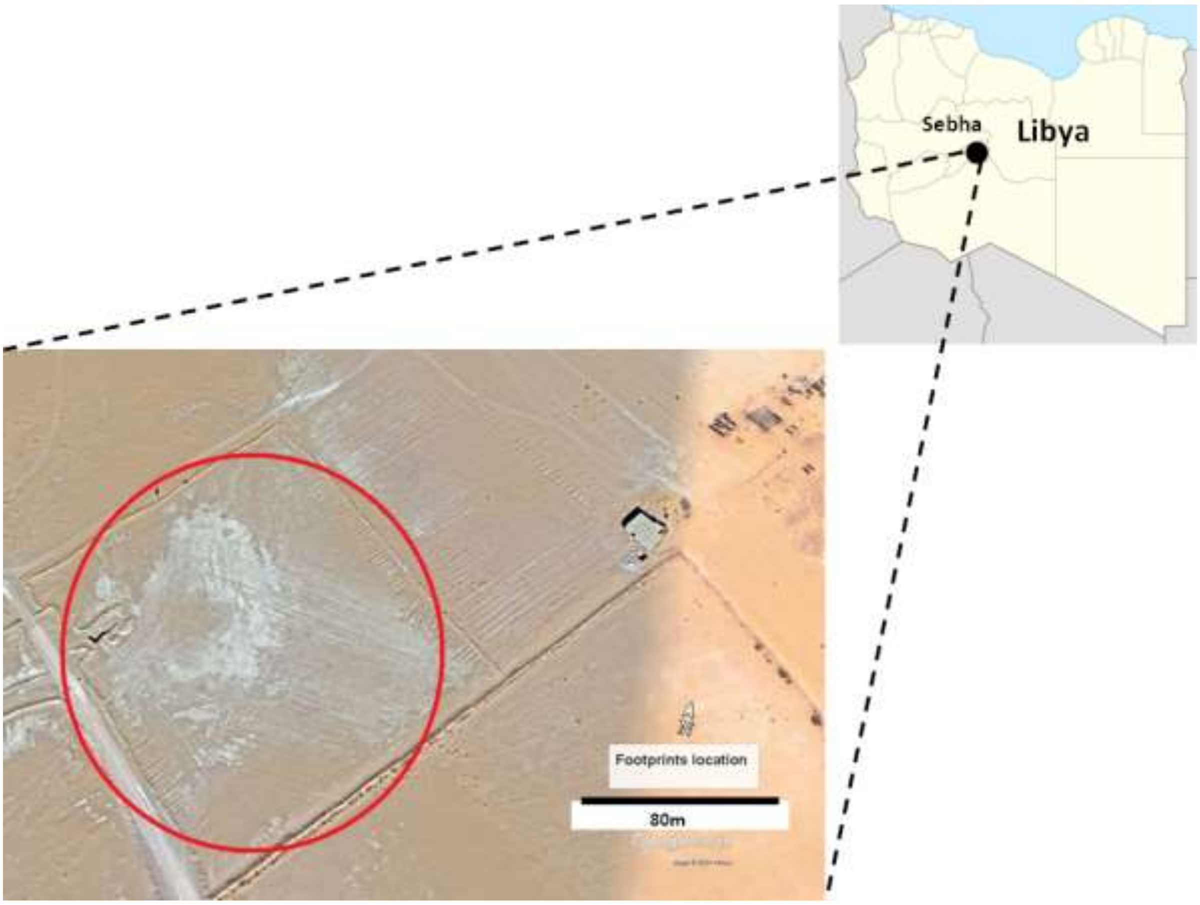

Fig. (1). shows a location map of Libya, indicating the position of the new dinosaur footprint location approximately 8 km northeast of the Sebha site.

1.2 The Discovery

The dinosaur footprints were first discovered on December 18th, 2006, at the coordinates 27° 05' 45" N and 14° 51' 41" E. These footprints are arranged in several paths, which are either parallel or sometimes oriented in opposite directions (Fig. 4). The discoverer of these dinosaur footprints was Dr. Haj Mahmoud Al-Sayyed Abdullah. He noticed them while walking around an area near his farm. Initially, he thought they might belong to a large bird, such as an ostrich, but the considerable size of the footprints led him to question whether they were from an ostrich or other unknown birds. Despite his keen observation, he could not see all the traces and footprints that may have been obscured by a layer of sand, which were later uncovered by a team of geological professors from Sebha University and the University of Hamburg in Germany.

Upon receiving information about the discovery of these footprints, Dr. Mustafa Abdullah was examined upon exposure, revealed that they belonged to a dinosaur species that went extinct around 70 million years ago. In response, the geology department of Sebha University organized a scientific expedition led by Dr. M. El-Chair, Dr. A. El-Hodairi, Dr. M. Abdullah, .and Dr. A. Albaghdady, along with Dr. C. Betzler and Dr. F. Thiedig from the University of Hamburg, Germany. The German professors happened to be in the city of Sebha while accompanying Dr. Mustafa on a scientific trip to the Murzuq Basin to supervise doctoral research. During this trip, dinosaur footprints and tracks were examined, described, photographed, and documented. The findings were promptly communicated to the university administration, and a detailed report was prepared and submitted to Sebha University. This report includes a comprehensive description of the dinosaur footprints, their location, and precise coordinates.

In addition, urgent suggestions have been issued for immediate action to maintain and safeguard these tracts against tampering, sabotage, and erosion. It was proposed that paleontologist specialists from Germany be brought in to assist with the investigation and give the finest scientific technique for preserving these valuable dinosaur footprints. On the other hand, the administration of Sebha University should tell the country's competent and accountable authorities so that they may assist and support our study through communication and finance. The university agrees to cover all costs associated with bringing in German specialists, as well as transportation and preservation of these dinosaur tracks.

Later on, the Arab Spring revolutions broke out in February 2011, and the scientific search activity was entirely frozen for an indefinite period. In the year 2019, the university administration became more cooperative and has a better understanding of the importance of scientific research. It welcomes and appreciates the cooperation with other institutions, such as the Heritage Authority, in the southern region of Libya in order to protect the dinosaur footprints and create public awareness of the importance of these footprints from a scientific, economic, and tourism perspective.

Finally, on Tuesday, June 4, 2024, the geological department of the University Sebha conducted a one-day rapid trip with a chosen team from the National Oil Corporation and Zallaf Oil Exploration Company. The purpose of this journey was to see the dinosaur footprints and check that they were still intact and had not been disturbed. It was an excellent chance for Dr. Mustafa to join the team, participate in scientific debates, and give some suggestions that may help to preserve and maintain these monuments for future generations.

Based on the report submitted to the University of Sebha and the Heritage Authority in December 2019, as well as the first meeting of some of the University of Sebha's geology department faculty members and the National Oil Corporation's exploration cabinet officials with Zallaf Oil Operations, several recommendations for immediate action were considered as part of the united effort to protect and save this important discovery.

1.3 Geological setting of the area

The area with newly discovered dinosaur footprints (tracks) is situated on the northeastern edge of the Messak Plateau, around Sebha city (Fig. 1). The nature of the rocks on which the tracks were made indicates continental deposits. These deposits are composed of silty-sandstone rock alternating with kaolinitic mudstone. They have a fluvial origin and are arranged in layers with fine sand lamination in between. The superficial mud kaolintic layer is characterized by its bright white color, which is almost unmistakable to the eye. It is revealed in the form of small spots and is sometimes covered by a layer of sandstone, sandy aeolian sediments, or valley sediments at other times. The dinosaur footprints are placed in agriculture fields (Fig. 1).

The field is located deep on a valley bottom where Jurassic and Cretaceous claystone and sandstones are present. They are exposed and topped irregularly by Pleistocene water and wind deposits. Small, isolated flat hills, such as Quweirat al-Mal hill near Wadi al-Shati road, are scattered in the valley. Intermittent streams pass close to the tracks, exposing them to erosion. The geological features show alternating sandstone rocks alternated with kaolinitic mudstone beds of the Messak Formation (Fig. 2).

The term Messak Formation was proposed by Klitzsch (1972). The lower contact of this formation is not exposed everywhere in the Murzuq Basin, while its upper contact is eroded in the entire investigated area, being locally covered with continental Tertiary to Quaternary sediments. The Messak Formation dates back to the Upper Jurassic to Lower Cretaceous periods (Klitzsch 1963). According to Seidl and Rölich (1984), the Messak Formation is subdivided into two lithologically distinct members: the Germa Member, representing the lower part (Upper Jurassic), and the Awbari Member, comprising the upper part (Lower Cretaceous; Fig. 2). The Germa Member is characterized by kaolinitic claystone and siltstone layers interbedded argillaceous, fine-grained sandstones. Notably, carbonized leaf impressions of *Phlebopteris sp*. ferns are present within this member. The thickness of the Germa Member varies from 0 to 80 m in the Sebha area. The Awbari Member consists of medium- to coarse-grained, pebbly sandstones that are light in color, displaying tabular and trough cross-bedding structures. These sandstones are often interbedded with conglomerates and various siltstone fragments. The thickness of the Awbari Member ranges from 0 to 20 m in the Sebha region (Fig. 2).

Overall, the Messak Formation in the Sebha sheet reaches a total thickness of approximately 100 m (Seidl and Rölich, 1984). While no vertebrate fossils have been identified, scattered and poorly preserved plant fossils have been found (Fig. 2). The presence of these plant fossils suggests a Cretaceous age for the formation. These fossils have been traced to several surface exposures in the Messak cliffs near the village of Jarma (El-Chair et al., 1995). The lithological characteristics of the formation indicate a range of continental sedimentary environments, including fluvial and alluvial conditions.

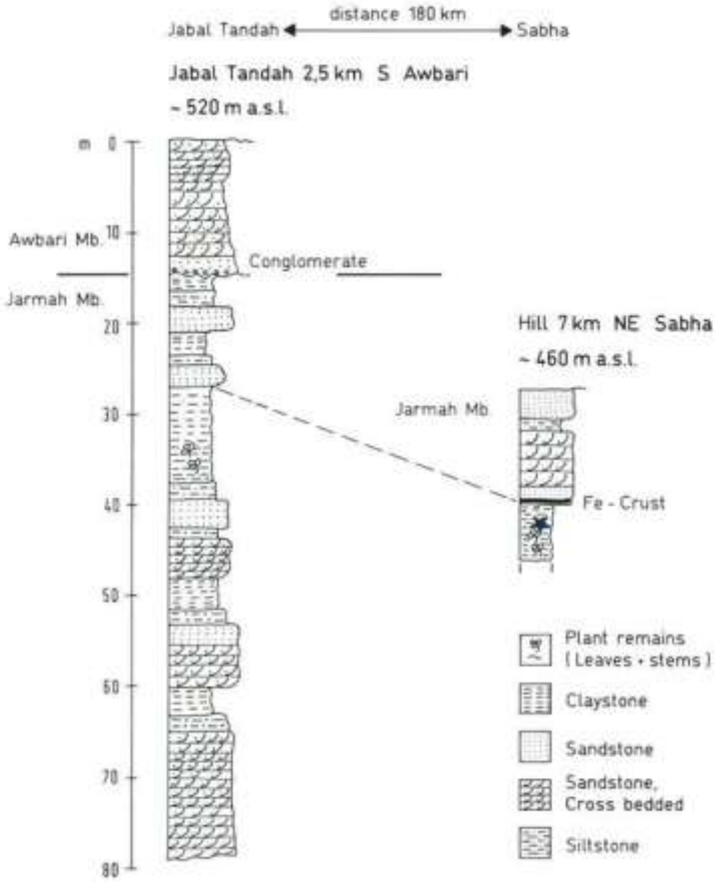

Fig. (2). A measured geological section of the Messak formation in the Awbari and Sebha area. The star pointed to the location of dinosaur footprints. Modified after El Chair, et al., 1995

2. The Aim

In this paper we will try to introduce this site of dinosaur footprints in the Sebha area and present the preliminary results of what we have achieved so far. Our efforts have been focused on these new dinosaur footprints in order to study the different shapes of footprints, taking their measurements, lengths, spacing, and directions. Hence we will be able to compare them with other similar footprints in available literature. Finally we hope to deduce the type of dinosaur, its shape, size, height and way of walking.

3. Methodology

The footprints were methodically studied, counted, measured, photographed, and precisely recorded in order to determine the dinosaurs that generated them as well as their size and movement. Taxonomic identification of the tracks and their trace producers was used to back up these findings. Furthermore, stratigraphic analysis, including division, description, and correlation, was used to precisely describe the geological strata containing the footprint traces.

4. Results and Discussion

4.1 Jurassic - Lower Cretaceous North African theropods

Dinosaur skeletons, bone fragments, eggs, and footprints have been discovered on every continent. During the Early Jurassic and Cretaceous periods, North Africa was home to a diverse range of dinosaur species. The vast, arid expanse of the Sahara Desert is particularly rich in dinosaur fossils, footprints, and other remains. Recent studies have documented significant quantities of these fossils and footprints across several North African countries, including Egypt, Tunisia, Algeria, and Morocco (Anderson et al., 2007; Smith et al., 2006; Weishampel, 1990).

In Libya, several distinct dinosaur footprints have been discovered and reported for the first time in the Fezzan region. This article marks the first scientific documentation and description of these trace fossils from southern Libyan territories. Notably, dinosaur skeletons have been unearthed in the Nalut area, specifically at the top of the Kabaw Sandstone Formation and the Kiklah Formation (Dalla Vecchia, 1995; Duffin, 2001). These formations, located in the Jabal Nafusah region, are stratigraphically equivalent to the Messak Formation in southern Libya (El-Zouki, 1980). The Nalut fossils, which include dorsal vertebrae and a complete right tibia, date back to the Aptian stage of the Lower Cretaceous period. Moreover, these fossils have been tentatively classified within the subfamily Abelisauroidea, a group that thrived in Gondwana before its separation from South America. Lapparent (1960) conducted a significant study on African dinosaurs, where he identified the genus *Elaphrosaurus iguidiensis* based on findings in Algeria and Tunisia. However, challenges arose due to the uncertain origins of the dinosaur bones discovered at that time, which may have come from the Kabaw, Kiklah, or Sidi as Sid Formations.

4.2 Track description

A total of 183 fossilized dinosaur footprints have been discovered embedded in a mudstone silty-sandstone substrate, surrounded by a thin crust of dark iron oxides (Fig. 3B). Additionally, an ambiguous, rounded area was identified in the same field (Fig. 5A & B). Upon closer examination, this semi-circular area appears to consist of several overlapping dinosaur footprints, though the individual shapes are not as clearly defined as others found nearby.

Multiple tracks of footprints can be distinguished, suggesting they may belong to the same species of dinosaur. While the shapes of the footprints are generally similar, there is significant variation in size (Fig. 4A & B). Some footprints are exceptionally large, while others are of medium or small size. The length of these footprints ranges from 18 to 60 cm. Each footprint displays an impression of a foot with three toes, each featuring a claw at the front, characteristic of a predatory dinosaur (Fig. 3B).

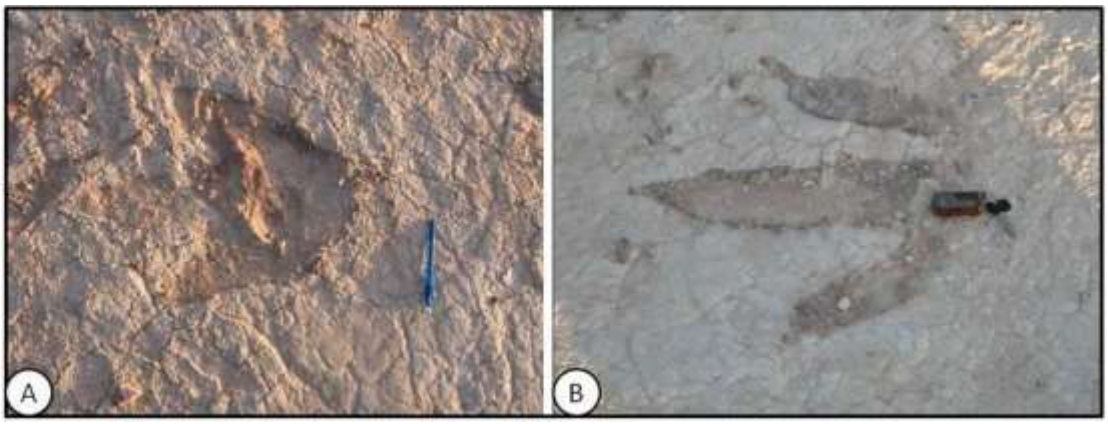

Fig. (3).Two separated f dinosaur footprints resulting from the movement of dinosaurs on a wet clay and silt floor. (A) Displays a small, short-toed foot while (B) shows a single, large long-toed foot embedded in clay with a thin layer of sand and dark crust of iron oxides

Based on the sequence, shape, and arrangement of the footprints and tracks, it can be concluded that they were made by upright dinosaurs. These dinosaurs were capable of standing and walking on their hind feet across a wet and humid surface composed of clay, silt, and fine sand. The footprints likely belong to a theropod group of dinosaurs, possibly with a saber-toothed hip structure. The size of these footprints ranges from 18 to 60 cm (Fig. 3A & B). The most common type features an angle of 50 to 70 degrees between the outermost digits (Fig. 3B). The stride length which is spacing between each to successive footprint was 2.0 ± 0.1 m and 1 ± 0.06 m for the largest and smallest footprints, respectively.

According to Therrien et al., (2007) estimations, we estimate that the biggest trace makers had a height ranging from 2.4 to 3 m up to the pelvis, while their overall length may have reached from 6 to 9 m from head to tail. Meanwhile, the smallest is 0.8 to 1 m up to the pelvis and 3 to 3 total length. Upon closer inspection, the footprints appear to be evenly spaced, suggesting that the animals were moving with coordinated, regular steps, and about 2 m stride length indicating a normal walking gait. This regularity in stride length implies that the animals were not being chased, nor were they under the influence of panic or fear from a predator (Hutchinson, J. R., & Garcia, M., 2002; Carrier, D. R., 1987; Baker, J. R., & Thomas, R., 2008).

4.3 Track preservation

Footprint fossils are formed through several stages and under specific conditions. The process begins with the trace makers moving across very soft and wet, unconsolidated sediments, leaving impressions of their presence. To preserve these footprints, rapid burial is essential to protect them from erosion. This burial is followed by petrifaction, physical changes, and chemical diagenesis, which enhance the chances of preserving the footprints over geological time until they are eventually discovered. Ideal conditions for footprint preservation include ancient swamps, lake edges, and riverbanks. In such environments, mudstone and siltstone layers alternate with thin beds of unconsolidated sand during flooding episodes. This results in the accumulation of mixed sandy, muddy, and silty deposits around river channels.

According to Seidl and Rölich (1984), the Jarmah Member of the Messak Formation was deposited in a meandering river environment. Mud deposits are expected on riverbanks and floodplains, while sand accumulates as point bar facies or within river channels. Additionally, mud on riverbanks may be covered by fine to medium sand from crevasse splay events, and the presence of oxbow lakes associated with meandering channels is also anticipated. These scenarios support our interpretation of the environment where the footprints were found. In contrast, the Awbari Member is attributed to a braided river environment (Seidl and Rölich, 1984). Braided river deposits generally lack significant mud due to steep slopes and high hydrodynamic flow conditions. These conditions result in the scarcity of mud and fine deposits, which are carried away by fast-moving currents, while sand accumulates as channel fills or point bars.

The geological description of the area adjacent to the footprint site reveals a substantial layer of white mudstone, primarily composed of kaolin. This layer is followed by medium to coarse-grained reddish-brown sandstone with a basal conglomerate consisting of pebbles from water bodies during sedimentation. Additionally, cross-bedding in the sandstone indicates the presence of a small stream-like water body, potentially a tributary of a larger river channel, situated on a floodplain dominated by clay.

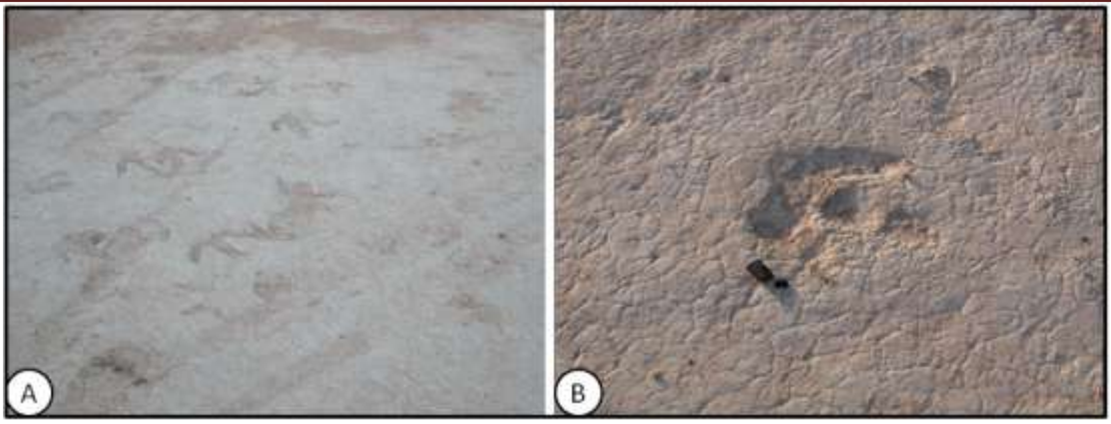

Fig. (4). Shows dense dinosaur tracks resulting from the movement of dinosaurs on a wet muddy floor or partially covered with water with different tracts directions (A). A close view of one single footprint occurs embedded in clay with a thin layer of sand; see the deep prints of hone holes and dark crust of iron oxides (B)

Based on current knowledge, two main explanations are proposed for the preservation of the footprints. First, it is suggested that the trace makers walked over a wet claystone and siltstone bed. Due to the animals' considerable weight, their lower feet sank into the mud as they moved in search of food, leaving deep impressions in the soft sediments. These footprints were subsequently filled with fine sand transported by small river channels. The sandy infill helped preserve the footprints' impressions, especially after the surrounding clay materials had been eroded (Holland, S. M., & Reaves, K. D. 1999). Second, the creatures may have walked on a thin layer of loose sand that covered underlying mudstone and siltstone layers. The weight of the moving animals caused the sandstone layer to sink into the underlying claystone, preserving the footprints in the process (Miall, A. D., 1996). Additionally, any further traces might be found at the boundary between the kaolinite clay and sandstone layers. Subsequent iron oxide cementation and the formation of a thin iron oxide layer between the kaolinite and sandstone played a crucial role in the preservation of these sediments (Friedman, G. M., & Sanders, J. E., 1978).

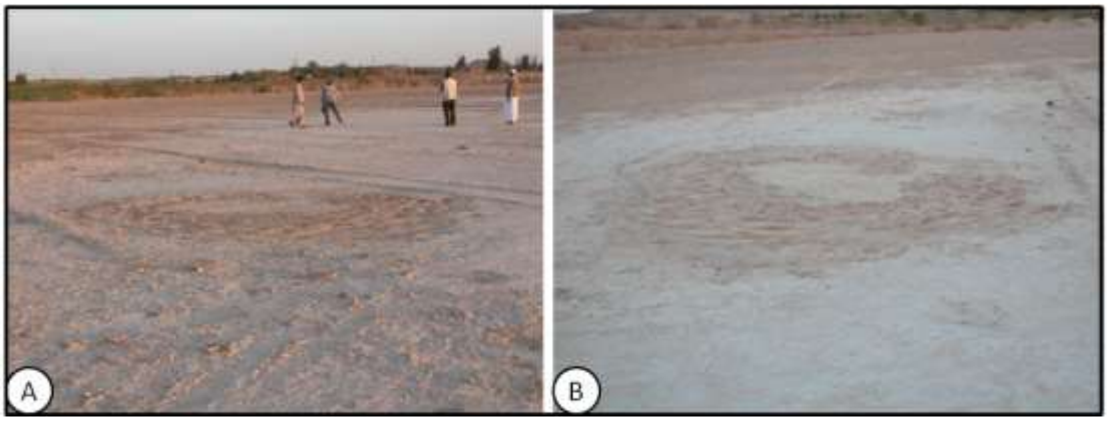

Fig. (5). Dinosaur tracks in a circular position that were interpreted as resulting from the movement of dinosaurs on a wet muddy floor or partially covered with water.

4.4 Ichnological significant and classification of the tracks

Ichnological methods provide valuable insights into the behavior and activity of their trace makers. The new dinosaur footprints discovered in the Messak Formation at the Sebha Site were made by tetrapod vertebrates. These trace fossils were created when dinosaurs walked across soft, wet deposits of mixed mud and sand. The sand eventually hardened enough to preserve the impressions before additional sediment was deposited on top. While footprints alone cannot identify the specific dinosaur species, they offer significant information about the animal's speed, weight, and behavior. Additionally, they can reveal details about the moisture levels of the sand at the time the footprints were made. Footprint fossils can serve as local index fossils, helping to date the rocks in which they are found. For instance, the footprints in the Messak Formation are confined to the superficial layer of the Jarma Member in the southern part of Libya.

5. Recommendations to save the trace fossils

Based on the report submitted to the Heritage Authority and the University of Sebha in December 2019, and following the initial onsite meeting with faculty members from the University of Sebha's Geology Department and officials from the National Oil Corporation and Zallaf Oil Operations, several immediate actions were recommended:

1. Coordinate with Hamburg University: Engage with the team from Hamburg University, led by Dr. M. Abdullah, who are working on the preservation of dinosaur tracks at the Sebha site.

2. Designate Excavation Sites: Identify and officially designate excavation sites as protected under the Heritage Law. This will safeguard them from destruction and facilitate fundraising for the acquisition of well-preserved artifacts.

3. Expand Fossil Exploration: Conduct further exploration and excavation of fossil sites based on evidence from preserved tracks found along the kaolin-sandstone border.

4. Perform Ground-Penetrating Radar (GPR) Surveys: Use GPR to scan the surface and identify the boundaries between clay, sand, and surface soil. The target area for these shallow geophysical surveys is between 5 to 7 square kilometers.

5. Support the Southern Antiquities Monitoring Team: Provide geologists to assist the Southern Antiquities Monitoring Team, offering them training as restorers and guides.

6. Develop Museums and Parks: Complete the Libyan Natural History Museum and Geological Park, and establish branches in regional museums.

7. Establish Local Museums or Parks: For excavation sites that cannot be relocated, create open museums or geological parks at their current locations, especially in accessible areas. Form a team from a scientific university to conduct further investigations following site authorization.

6. Conclusion

Dinosaur footprints discovered and described herein represents the first confirmed ichnofossils from Messak Formation in Sebha city area, establishing them as the oldest definitive of this theropod clade from Libya. The new Dinosaur footprints demonstrate the wide geographical distribution of these ichnofossils across Libya during Jurasic and Cretaceous time.

The footprints are suggesting that they may be attributed to the theropod group of dinosaurs with a saber-toothed hip and the size of these footprints varies from 20 to 50 cm. The most frequent type is characterized by an angle of 50 to 70 degrees between the outermost digits.

The foot size suggests that the tracemakers' height up to the pelvis ranged from 0.8 to 2 m, while the overall length of the creature reached 8 m from head to tail.

Based on the current stand of knowledge, two possible explanations for the preservation of the footprints were presented and interpreted.

As a result of the animal's huge weight, its lower feet sank into the mud as the animal moved in its search for food, leaving deep marks in those soft layers.

The deep holes of footprints have been quickly filled with fine sand, which is derived by small river channels. Sandy filling has preserved the trace's sandy matrix, especially after the clay materials have been eroded. Iron oxide cementation played the most crucial role in sediment preservation.

Messak Formation holds considerable untapped potential to better characterize the still engimatic avian theropod and indeed other continental vertebrates that inhabited southern Libya during Jurasic and Cretaceous periods.

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