

Estimating the impact of erosion on a Carnian dinosaur footprint-bearing surface (Lerici, Northern Apennines, Italy)

**Valerio Granata, Matteo Belvedere, Alberto Collareta, Giancarlo Molli,
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ABSTRACT

Archosaur footprint sites from the Upper Triassic provide critical data for understanding the origin, early evolution, and subsequent rise of dinosaurs. Track-bearing outcrops, especially those situated within areas characterized by high hydrodynamic energy, may suffer from rapid weathering and erosion phenomena. This paper assesses the impact of erosion on the Upper Triassic (Carnian) ichnosite of Lerici (La Spezia, Italy), which is known as the type locality of *Evazoum sirigui*, as well as for featuring a small but relatively diverse ichnofauna, including both dinosaur and non-dinosaur ichnotaxa. Novel comparative analyses were carried out using digital three-dimensional models of the main trampled surface (as preserved in the field in 2024) and the original fiberglass cast stored in the former paleontological museum in Lerici (made not later than 2003 and digitized in 2023). Most tracks appear to have suffered moderate to severe weathering, and a few have been lost. Critical measures should be taken to mitigate the erosion of this important, yet progressively vanishing, track-bearing surface. The cast itself is not without its concerns: it displays a bending deformation in its central part, possibly due to the lack of proper support and/or to the slightly incorrect re-positioning of its constituent parts, which were cast separately. Our work stands as an example of how the integrated digitization of the in-situ and ex-situ ichnological heritage allows for estimating both the erosion rates that affect the actual fossil and the quality of the artificial casts. Once again, “virtual paleontology” proves to be an irreplaceable tool for modern and future geoscientists.

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INTRODUCTION

Vertebrate tracks provide an essential source of data to shed light on significant paleobiological aspects of extinct tetrapods, such as their diversity, functional morphology, behavior and ecological relationships, especially in those contexts where body fossils are not preserved. Upper Triassic tracksites have proved crucial for disclosing essential information on the origin of dinosaurs, and their early evolution and radiation (e.g., Benton, 1983; Langer et al., 2010; Bernardi et al., 2018). Tracks attributed to putative early members of the dinosaur stem lineage have been documented from several localities worldwide (Haubold, 1999; Gand and Demathieu, 2005; Marsicano et al., 2007; Bernardi et al., 2018). Often, dinosaur tracks occur alongside other tetrapod footprints (e.g., Nicosia and Loi, 2003), thus providing precious insights into the diversity of the early dinosaur-inhabited paleoecosystems.

In addition to their scientific significance, footprint sites have the potential to enhance geotourism in otherwise scarcely visited areas (Fuentes-Gutiérrez et al., 2016; Lopes et al., 2019; Antczak, 2020; Collareta et al., 2023). Thus, track sites should be regarded as extremely valuable natural resources. On the other hand, such sites are finite and -unfortunately- not perennial. Track-bearing surfaces are typically subject to the erosional action of the weather and/or vegetation (e.g., Adams et al., 2010). Wherever erosion cannot be mitigated, a different approach is required for data preservation. In the last 15 years, the application of newly crafted digital tools and technologies has allowed paleontological documentation to progress at an impressive rate, leading to the emergence of the present-day virtual paleontology paradigm (Rahman et al., 2012; Sutton et al., 2016), which has almost become a standardized approach (Davies et al., 2017; Falkingham et al., 2018). Surface scanning, digital photogrammetry, 3D modelling and sculpting are some of the tools that

enables the study of fossils through interactive digital techniques, which are useful for scientific research, knowledge dissemination, and cultural heritage preservation (Sutton et al., 2014; Lautenschlager and Rücklin, 2014; Sutton et al., 2016; Bartolini-Lucenti and Rook, 2023; Merella et al., 2023; Amzil et al., 2024; Ruella et al., 2024).

Our focus here is on the Upper Triassic (Carnian) ichnosite of Lerici (La Spezia, Italy), which features a small but relatively diverse ichnocoenosis, including both dinosaur and non-dinosaur ichnotaxa and the type material of *Evazoum sirigui* (Nicosia and Loi, 2003). The main track-bearing surface lies along a rugged sea cliff, exposed to the atmospheric agents as well as to sea spray. An attempt is made to evaluate the impact of erosion at this site by comparing the present-day (2024) outcrop with a more than 20-year-old cast through a qualitative and quantitative comparison of 3D models obtained from digital photogrammetry and surface scanning. The cast analyzed in this study can be confidently regarded as an accurate replica of the footprint-bearing surface, having been produced using polyester resin and fiberglass - a technique that has been regarded as optimal for capturing high-resolution surface detail since the beginning of the 21st century. A detailed visual inspection conducted prior to the scanning process did not reveal any significant damage or missing portions, nor any such issue emerged during the subsequent digital comparisons (see below). The authors of the original study explicitly acknowledged that "the cast of the largest footprint surface (site "a", level 3) is preserved at the Lerici Museum and allows good analysis of all the trackways" (Nicosia and Loi, 2003, p. 129).

This comparative methodology is applied here for the first time to analyzing the impact of erosion at a dinosaur footprint-bearing site, though a similar approach has been undertaken previously by relying on what might be described as "historical" photogrammetry (Falkingham et al., 2022). Some

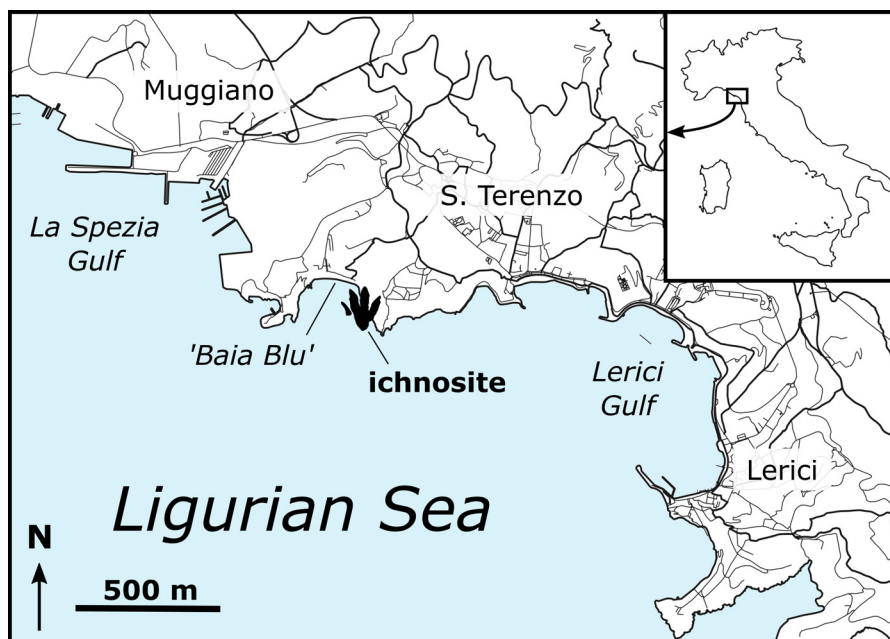


FIGURE 1. Location of the study site near Lerici (northern Italy).

issues related to the deformation of the original cast are also discussed herein.

GEOGRAPHIC AND GEOLOGICAL SETTING

The Lerici ichnosite stretches along the rocky coast between the Baia Blu, about 1 km West of the San Terenzo Village, and Punta Galera (La Spezia Province, Italy) (Figure 1). Here, a thick siliciclastic succession is exposed, belonging to the Quarziti e Filladi Formation, which is part of a Triassic sedimentary cycle that testifies to the rifting of Pangea and the subsequent opening of the Liguro-Piemontese oceanic basin (Martini et al., 1986; Abbate et al., 2005). This unit consists of fine- to medium-grained quartzites that are generally fairly sorted. Strata featuring a coarser (i.e., microconglomeratic), clearly erosive base as well as metapelitic interbeds are also present. Plane-parallel and cross-laminations (asymmetric ripples) are frequent. Overall, the Quarziti e Filladi Formation has been interpreted as testifying to a coastal plain punctuated by ephemeral ponds in the vicinity of a river delta (Abbate et al., 2005). The maximum age of the track-bearing strata may be defined by the correlation with the stratigraphic sequence exposed in the Punta Bianca area (some 10 km Southeast of the studied site) where early Ladinian conodonts (Bagnoli, 1982) and likely reworked Anisian ammonoids (Venturi and Teneroni, 1981) were discovered within deposits assigned to an earlier, Middle Triassic sedimentary cycle (Martini et al.,

1986). In turn, the mixed, carbonate-siliciclastic deposits of the Scisti di San Terenzo Formation that overlie the Quarziti and Filladi Formation, provide clues about the minimum age of the track-bearing surface. Indeed, the Scisti di San Terenzo are regarded as correlative with the Tocchi Formation of southern Tuscany (Martini et al., 1986; Abbate et al., 2005; Conti et al., 2019), which is of Carnian age (Costantini et al., 1980), as well as with other lithologically similar units of northern Tuscany (e.g., the Vinca Formation) and the southern Alps (e.g., the Travenanzes Formation), all of which have been similarly assigned to the Carnian. Consequently, the track-bearing surfaces at Lerici are considered to have formed during the Carnian (Abbate et al., 2005), specifically across the Julian–Tuvanian passage (Conti et al., 2019), well before the Carnian–Norian transition. Such a Carnian age appears to be consistent with the ichnotaxonomic composition of the vertebrate track assemblage (Nicosia and Loi, 2003; Mietto et al., 2020; Marchetti et al., 2021).

MATERIALS AND METHODS

Surface and casts

The in situ track-bearing surface investigated was referred to as level BBa3 by Nicosia and Loi (2003). It forms the top of a 60-cm-thick arenitic body. It is approximately 6 m² wide (the exposed area turned out to be larger than the one originally

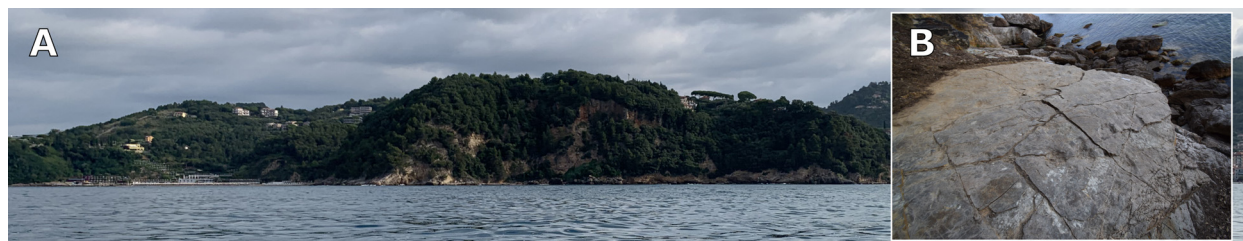


FIGURE 2. The Lerici tracksite. **A**, Panoramic overview of the coast as seen from the sea; **B**, close-up of the track-bearing surface. The exact location of the latter is intentionally kept undisclosed to prevent vandalism of the surface.

reported), and slopes towards the sea ($20^{\circ}/240^{\circ}\text{N}$), in a location that is difficult to access by land (Figure 2). This is the largest of the two main track-bearing surfaces described by Nicosia and Loi (2003), on which more than 40 tracks have been recorded; some of these tracks are organized into trackways, numbering at least 5, but no preferred direction could be identified. The ichnocoenosis includes at least five different morphotypes associated with chirotherian and dinosaurian trackways, including the type material of *Evazoum sirigui*.

The studied surface was molded in the early 2000s. A fiberglass cast copy (the one analyzed in this work) is preserved at the former “Museo Geopaleontologico” in Lerici, which has been permanently closed to the public starting from 2015. An additional fiberglass replica of the surface was made from the original rubber mold and is now housed in the Museo Universitario di Scienze della Terra, in Rome. Originally, this cast was made of

three different parts joining with each other in occurrence of the main E-W oriented fractures that affect the surface (Figure 3). Although this molding approach was likely due to the difficulty of transporting a single, large object from the barely accessible outcrop, it also led to potential accuracy issues in both replicas.

As previously mentioned, the cast exhibits a slight deformation in its central portion (Figure 4). However, said deformation is limited to a few centimeters (approximately ± 3 cm), distributed along the total length of the cast, which is over 3.5 meters. Consequently, considering the detailed scale at which subsequent comparisons were carried out on selected portions of the footprint-bearing areas, this deviation can be deemed as negligible. This bending deformation is likely attributable to insufficient physical support and/or improper storage conditions. The slightly incorrect

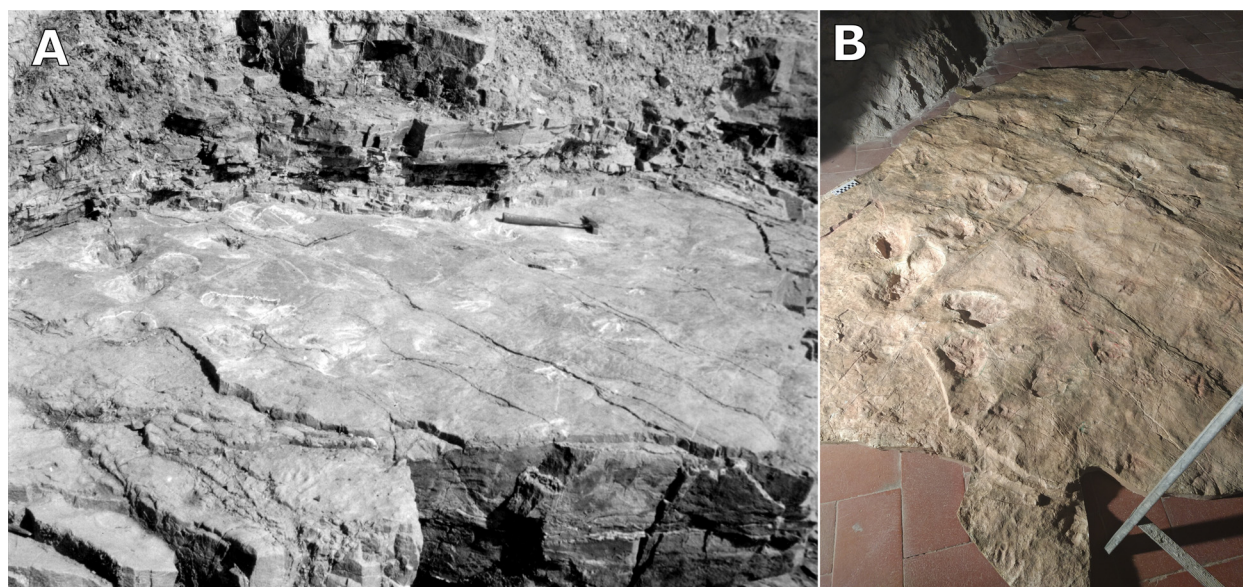


FIGURE 3. Photographs of **(A)** the original tramplage surface (after Nicosia and Loi, 2003: fig. 4) and **(B)** the fiberglass cast thereof.

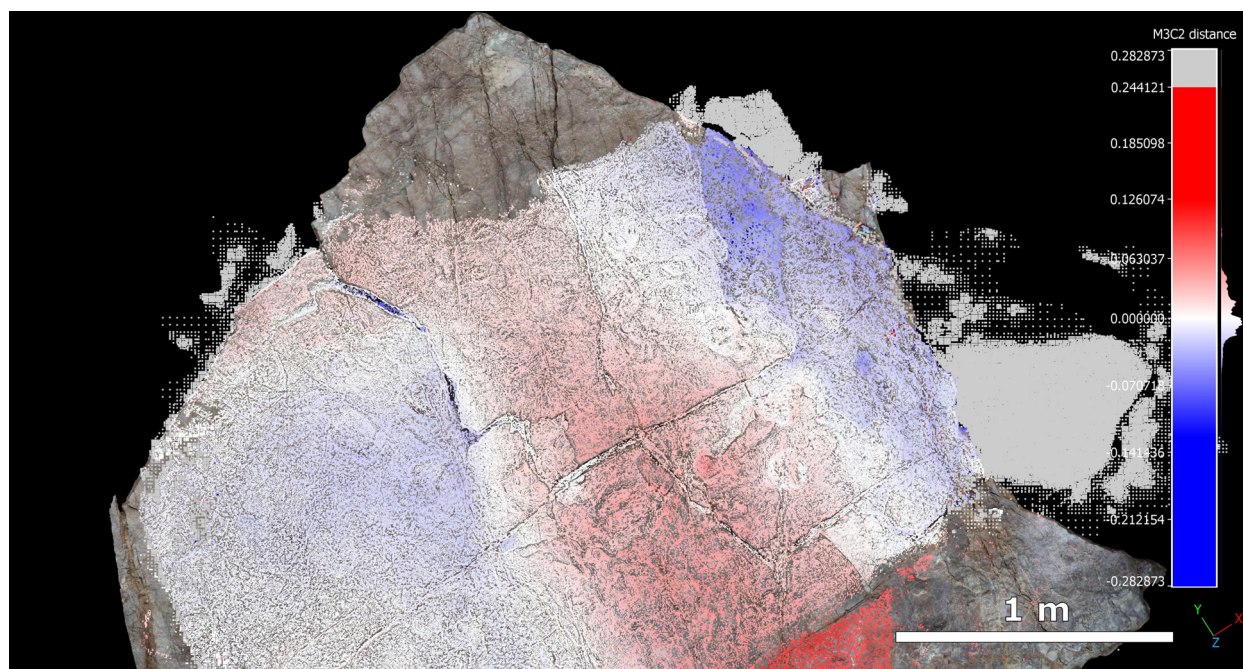


FIGURE 4. M3C2 computed surface distance between the cast and the outcrop. Note that the central portion of the cast exhibits a higher elevation, evidenced by a red color, while the blue-colored lateral parts appear to be sunken compared to the in situ surface.

re-positioning of the three parts of the cast may also be the reason for the observed deformation.

Data acquisition

The main purpose of this work is to make an initial assessment of the degree and spread of erosion at the Lerici tracksite. This was performed by digitally comparing two three-dimensional models of fiberglass cast (which was made not later than 2003) and the actual fossil-bearing surface (as it appeared in 2024).

The cast was digitized via structured light scanner and then via photogrammetry in 2023, while only photogrammetry was used for the digitization of the in situ fossiliferous surface in 2024. Following Falkingham et al. (2018), the 3D models are freely available via Figshare at the following internet address:

<https://doi.org/10.6084/m9.figshare.28105229>.

Surface scanning

An EinScan Pro HD high-definition 3D scanner, supported by the Solid Edge SHINING 3D Edition software, was used to create the structured light scanning model for the cast. Handheld HD mode was chosen, which is capable of a scanning accuracy up to 0.050 mm, a volumetric accuracy of 0.3 mm/m (using the Markers Alignment mode)

and an acquisition speed of about 3,000,000 points/s at 10 frames/s. Volumetric accuracy refers to the relationship between 3D accuracy and the object size. In this case, accuracy was reduced to about 0.3 mm per 100 cm.

Close-range photogrammetry

A 24.3-Mpixel (APS-C) Nikon D5300 camera was used to take pictures of the cast in 2023, while a 24.2-Mpixel (FF) Canon R8 camera was used for the in situ surface. Photos were then processed in Agisoft Metashape Professional (v. 2.1.0) (www.agisoft.com) to create the photogrammetric models (following Mallison and Wings 2014 and Lallensack et al., 2020). The photo series for photogrammetry were captured using the walk-around method as defined by Díez Díaz et al. (2021).

Model comparisons

The beginning of this study involved a comparative analysis of the 3D models of the cast and original surface in order to assess the extent of modification or material loss. All digital analyses were performed using CloudCompare v2.13.1 (Kharkiv) software. Several steps were necessary to set up the models and comparisons, and can be divided into 2 phases, namely, Phase 1, involving the comparison of the structured light and photo-

grammetric models of the cast and selecting the one to be used as a reference, and Phase 2, involving the comparison between the models of the cast and the actual fossil-bearing surface. These two phases are described in detail in the following paragraphs.

Phase 1:

- i.) The models had to be aligned manually by identifying pairs of points (here we used 5 pairs). This first, rough alignment was followed by a fine cloud registration (ICP).
- ii.) Two further algorithms (C2C and M3C2) were applied to the structured-light and photogrammetric models of the cast to validate the morphology of the chosen reference model, and no significant differences were observed. The C2C absolute distance was calculated between the cast model obtained by photogrammetry and that made by structured light scanning, specifically the absolute Hausdorff distance, referred to as the Pompeiu–Hausdorff distance (Oniga and Chirila, 2013; Rockafellar and Wets, 2009). The C2C distance value was subsequently mapped onto the target specimen through a heatmap visualization. In this representation (Figure 5), cooler colors indicate lower distance values, indicating a closer corre-

spondence between the target and reference items, while progressively warmer colors represent increasing divergence between the specimens. Although this method is commonly employed to detect and estimate spatial variations in the relative elevations of different targets, it has been noted elsewhere (Girardeau-Montaut et al., 2005; Fey and Wichmann, 2017) that significant coupling errors may arise from its use. In accordance with the methodology outlined by Zimmer et al. (2018), the distance between the two models was computed using the Multiscale Model-to-Model Cloud Comparison (M3C2) algorithm (Figure 6).

Unlike conventional algorithms that determine distances by identifying nearest neighbors, the M3C2 algorithm calculates distances along local normal vectors, which are derived from surface roughness. This approach reduces the influence of point position uncertainty and registration errors (Lague et al., 2013). Furthermore, recent advancements in this process, such as the M3C2-EP and Patch-based M3C2 algorithms, have been demonstrated to be highly beneficial for geosciences and their applications, due to the enhanced accuracy they provide (Ledoux et al., 2021; Winiwarter et al., 2021; Yang and Schwieger, 2023).

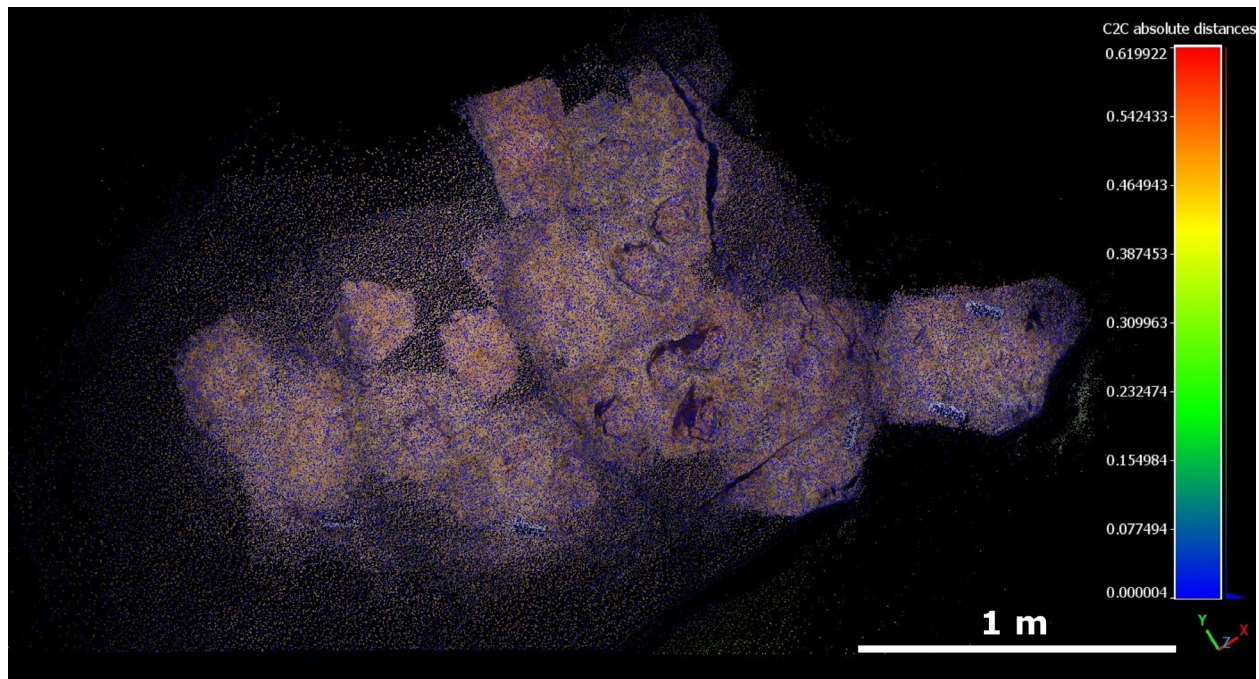


FIGURE 5. Cloud-to-Cloud (C2C) comparison algorithm between the two digital cast models, acquired through photogrammetry and structured light-scanning, respectively.

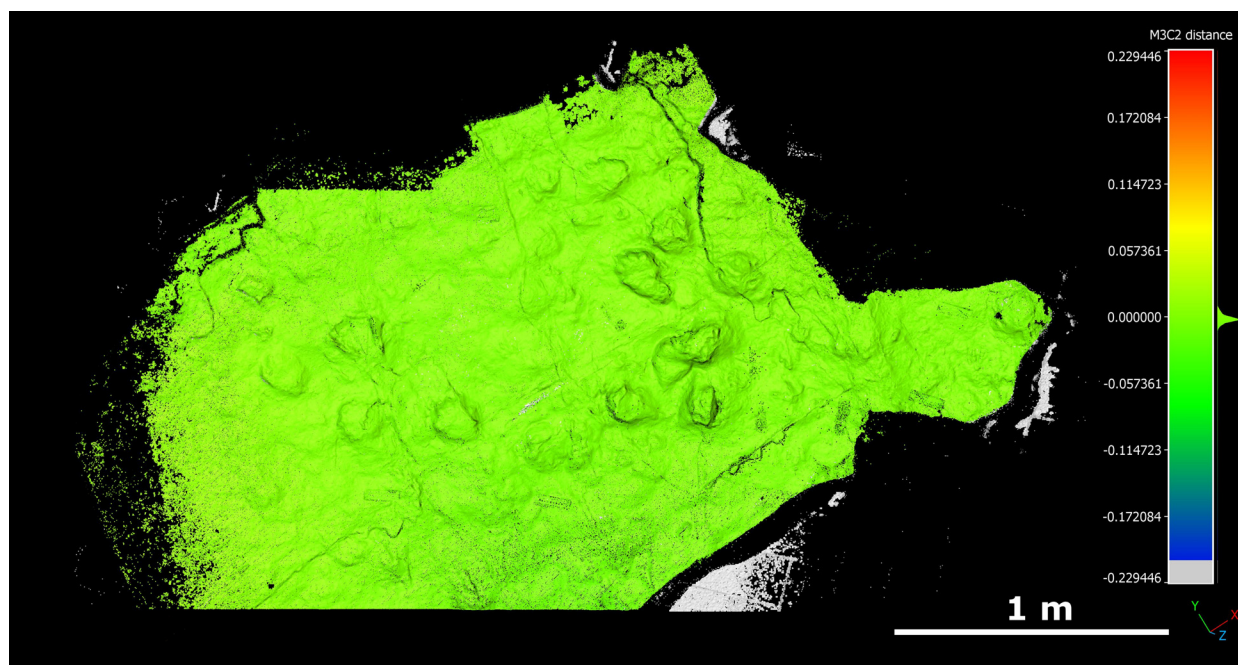


FIGURE 6. M3C2 computed distance between the two digital cast models, acquired through photogrammetry and structured light-scanning, respectively: note that the values cluster around zero. The two models obtained can therefore be regarded as comparable.

iii.) Consequently, an initial comparison using the M3C2 algorithm was carried out to confirm that there were no substantial differences between the two digital models of the cast obtained by different techniques (Figure 5). Therefore, for all subsequent comparisons, the surface model of the cast generated through photogrammetry was selected as the reference based on its higher density of points and polygons in the vicinity of the footprints, which in turn was due to the locally higher amount of available photos.

Phase 2:

The previously mentioned deformation of the cast was first observed during the M3C2 process in the form of a raised central region of the fiberglass model. Subsequently, additional comparisons through the M3C2 algorithm were conducted with a focus on specific cropped sets of footprints and areas.

The application of the M3C2 algorithm produces a surface image rendered in false colors, based on a custom Purple-Blue-White-Yellow-Red scale, where the zero value (corresponding to no alteration measured) is represented in white. This color scale reflects the absolute magnitude of erosion, with positive values indicating removal (posi-

tive erosion), and negative values indicating material deposition or accumulation (negative erosion).

It is crucial to note that by applying this methodology alone, and without appropriate rescaling of each individual three-dimensional model, obtaining the exact measurement of the material difference through the M3C2 algorithm is impossible. Additionally, it is imperative to determine and quantify the magnitude of errors at each stage, from the realization of the models in Agisoft Metashape and Solid Edge SHINING softwares to the overlap percentage of the point clouds and the application of the M3C2 algorithm in each individual comparison. The primary sources of error in M3C2 computation parameters arise from the determination of normals and the selection of the projection scale, both of which were established in accordance with the guidelines outlined by Lague et al. (2013). Based on these criteria, the uncertainty introduced by the computation of normals was deemed negligible due to the ratio between radius and surface roughness.

Accordingly, in this study, the application of this algorithm only visually returns portions of the surface where material has been removed or added, and every measurement given must be taken as an estimate. Furthermore, depositional changes, displayed by negative values on erosion

scales, do not indicate any permanent alteration to the print, but rather the temporary accumulation of debris. Thorough deeper cleaning of each footprint prior to image acquisition would likely have eliminated the majority, if not all, of the depositional artifacts.

Lastly, it should also be considered that the accuracy and precision of the surface change detection may be constrained by the quantity and quality of images used to generate the 3D models, the initial manual alignment of the meshes, or simply by the inherent non-exact reproducibility of this methodology, the results of which are determined by the aforementioned variables.

Tracks examined

The decision to crop certain sections from the complete digital models is justified by several factors: enhanced precision in the alignment of point clouds, reduced computational demands on the machine, and, as a result, accelerated processing times. Three different areas and their corresponding footprints were examined using this methodol-

ogy, and labeled as F1 ('chirotheriid'), F2 ('grallatorid') and A1 ('missing ones') (Figure 7). Note that, by indicating the aforementioned tracks as chirotheriid and grallatorid, referral is made herein to the original track interpretation provided by Nicosia and Loi 2003; a review of the ichnoassociation is currently ongoing, but beyond the purposes of this work.

F1 ('chirotheriid'). The examined area (Figure 8), measures approximately 0.34 m² and contains a putative chirotheriid footprint (Nicosia and Loi, 2003). The footprint itself has a maximum length of approximately 26.3 cm and a width of approximately 15.5 cm. What had been previously drawn as the most proximal part of the digit V metatarsal-phalangeal pad impression, appears instead to be part of a second, smaller impression with clear signs of digits pointing to the opposite direction. This may cast doubts on the original interpretation of the print, which however was not described nor discussed in detail by Nicosia and Loi (2003).

F2 ('grallatorid'). This area (Figure 9) covers a surface of 0.28 m². The footprint itself measures

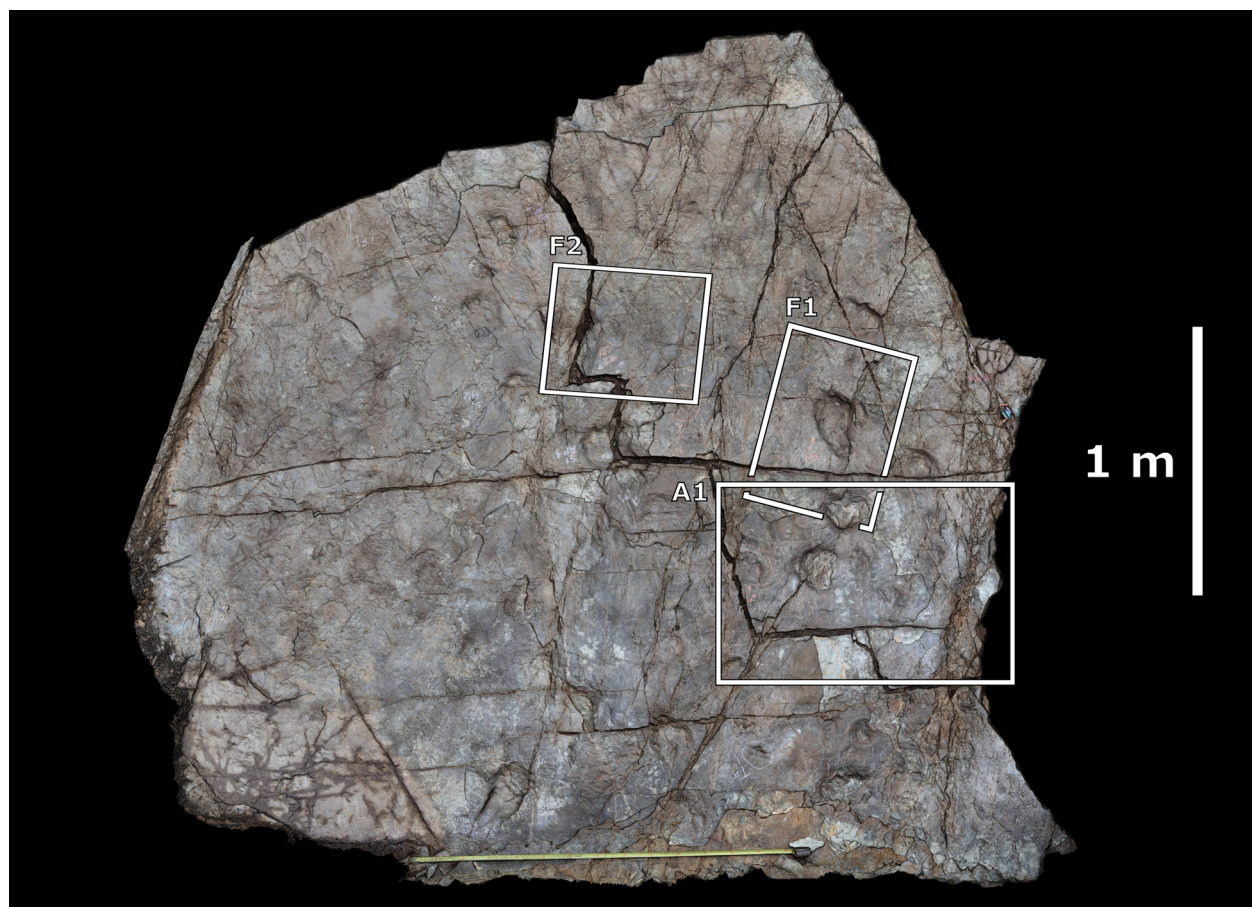


FIGURE 7. Digital rendering of the in situ surface. The boxes show the areas which the present study focuses on.

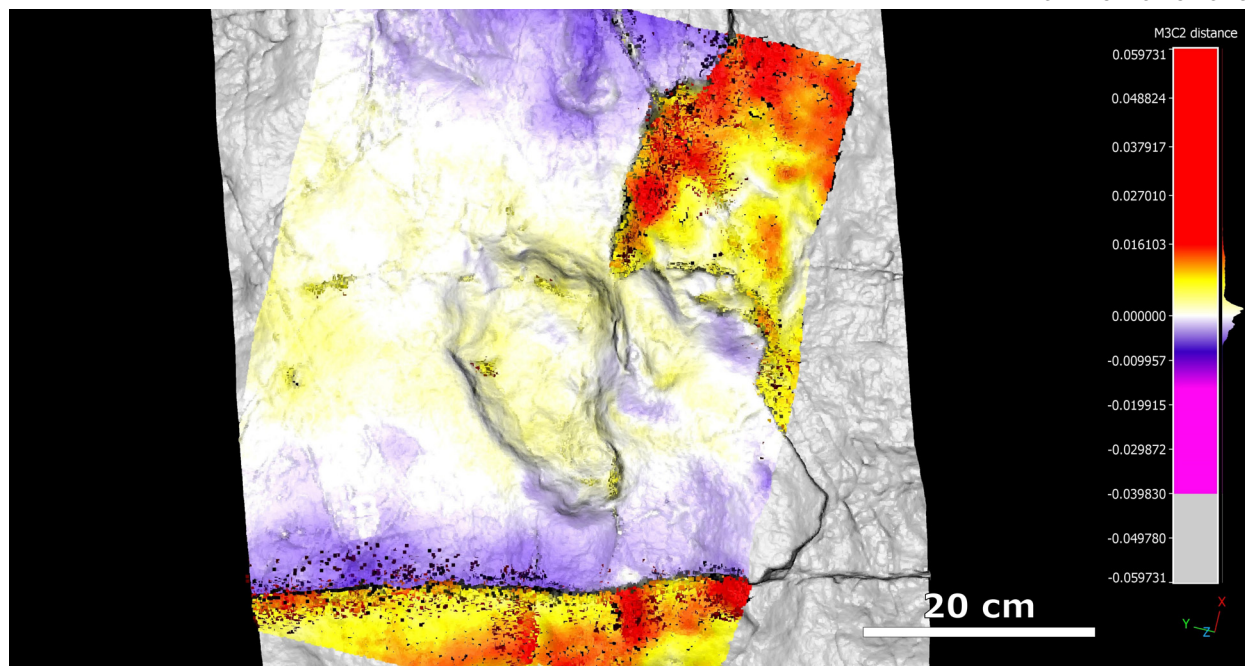


FIGURE 8. Computed M3C2 distance for the F1 ('chirotheriid') footprint. The M3C2 distance quantifies surface variations by representing them through color projections onto the pre-existing surface. The color scale illustrates the distribution of point density and the spatial (vertical) gaps between the surfaces.

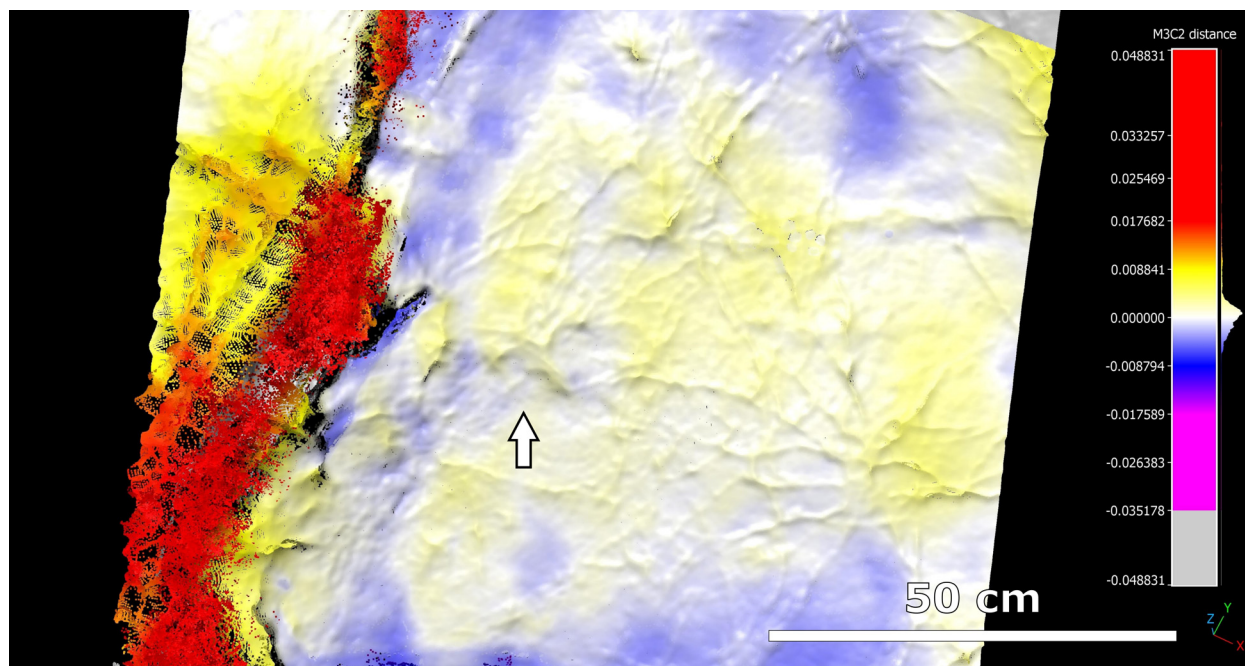


FIGURE 9. Computed M3C2 distance for the F2 ('grallatorid') footprint. The M3C2 distance quantifies surface variations by representing them through color projections onto the pre-existing surface. The color scale illustrates the distribution of point density and the spatial (vertical) gaps between the surfaces. The arrow indicates the position of the footprint, which is hardly identifiable in situ.

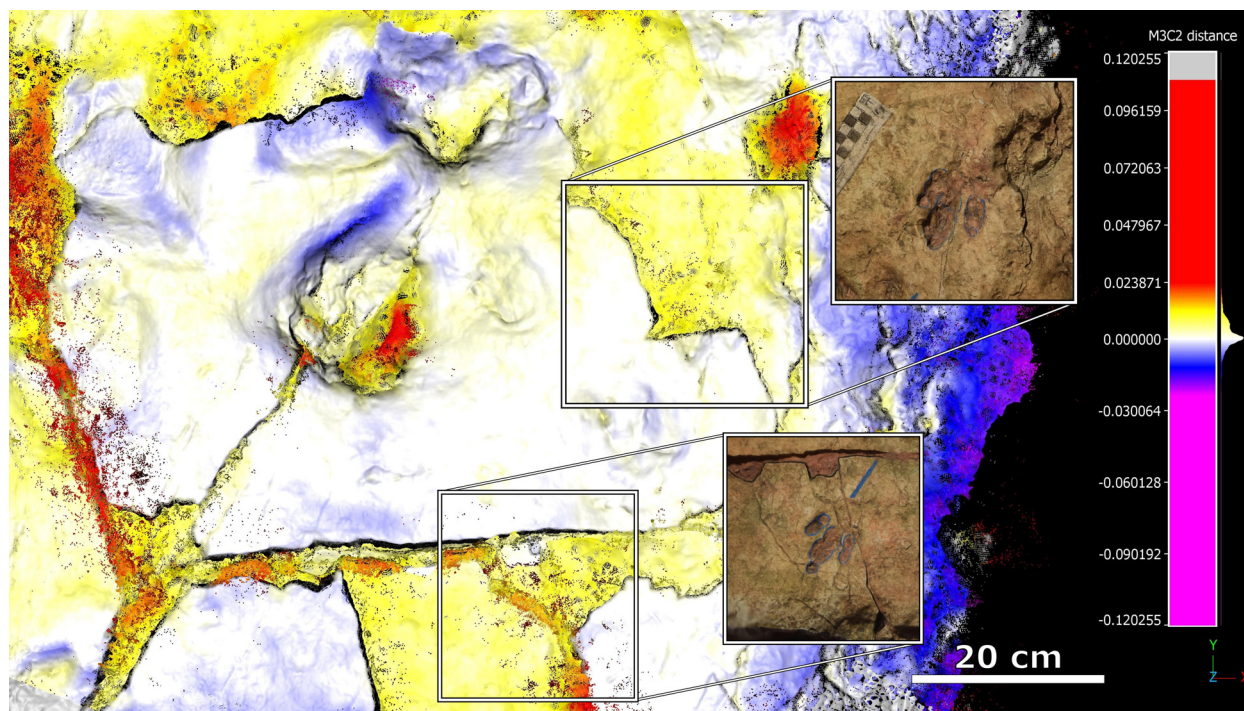


FIGURE 10. Computed M3C2 distance for the A1 ('missing ones') area. The two boxes show the missing portions of the fossiliferous layer, which in turn are present in the cast. The missing material includes two consecutive footprints, that had been provisionally assigned to *Anomoepus* by Nicosia and Loi (2003).

approximately 9.5 cm in length and 6.3 cm in width. This track is part of a trackway containing at least five impressions, likely produced by a bipedal theropod dinosaur.

A1 ('missing ones'). This area (Figure 10) has a larger surface area (0.83 m²) and contains tracks assigned to different morphotypes. The original description (Nicosia and Loi, 2003) mentions the presence of multiple chiroteriid footprints, as well as of two consecutive *Anomoepus*-like footprints. However, these footprints are no longer recognizable in outcrop, as the track-bearing stratum is locally missing.

RESULTS AND DISCUSSION

For some impressions and/or portions of the original surface, a first qualitative observation of the degree of erosion can be made by simple visual inspection. For example, some impressions that are easily identifiable on the cast were much more difficult to detect in the field in 2024, being much less pronounced, with barely noticeable morphological characters. Our digital comparisons allowed us to observe, in the three selected portions, two different types of erosion:

- 1) **Diffuse Erosion.** This type of erosion is prominent in areas F1 and F2, where one can see areas that have suffered a minimal degree of erosion (< 0.3 mm) as well as areas where the M3C2 distance exceeds 1 mm. The former areas are represented in our images with colors ranging from white to faded shadows of yellow (Figure 9); the latter in turn are represented by warmer colors which in area F2 include surface parts with M3C2 distances up to roughly 1.5 mm (Figure 8). This abrasion-type erosion, induced by various physical and chemical phenomena, is typical of the coastal environment where the site is located. The proximity of the fossiliferous outcrop to the top of the cliff results in a variety of terrigenous materials passing over the footprint-bearing stratal surface. These include falling quartzite blocks, soil and organic materials (mostly plant remains) from the slope above, which is largely covered by wood. Inspection of the studied surface is affected by such a flow, and local accumulation, of falling debris. In addition, the persistent sea spray and, possibly, the action of waves in the occur-

rence of major storms likely had a major impact on the long-term integrity of the footprints.

- 2) Concentrated Erosion (or loss of large parts). It was also possible to identify a second type of 'erosion' involving the loss of whole slabs of the track-bearing stratum, as well as the further fragmentation of the surface, especially along the edges of the studied surface and close to the original set of sub-parallel, E-W oriented vertical fractures. In this scenario, relatively large rock blocks up to 2.4 cm thick have been lost since the production of the cast (Figure 10). This kind of material loss has seemingly occurred more frequently in the proximity of the fractures, although in this case the extreme degree of erosion could be attributed to the filling of the corresponding areas of the cast during the assembly thereof. However, the photo of the main surface BBa3 provided by Nicosia and Loi (2003: figs 4, 8) apparently displays less developed fractures, so it's reasonable to say that these are also an example of surface degradation. It is important to note that Diffuse Erosion and Concentrated Erosion are present independently of each other over the studied surface, although their presence is not mutually exclusive. The examined footprints showed an erosion magnitude, intended as the distance between the two compared meshes, in the range of about 0.1 cm to 0.4 cm for Diffuse Erosion to more than 2 cm in areas of Concentrated Erosion or material detachment.

In addition to diminishing the quality and digital resolution of each individual fossil trace through Diffuse Erosion, Concentrated Erosion has led to the complete loss of part of the ichnological record. This is indeed the case of area A1, whereby the loss of two complete footprints was recorded (Figure 10). Both the footprints, which had been tentatively referred to the ornithopod related ichnogenus *Anomoepus* by Nicosia and Loi (2003), have in fact disappeared from the site. Given the high-quality of preservation of the impressions, which is evident from the cast, the two missing blocks may have been manually removed; however, no clear tool signs were detected, either in situ or through the analysis of the digital model. Due to this, it is currently not possible to state whether this pair of foot-

prints has been eroded by environmental factors or manually removed.

It is worth mentioning that, especially for Diffuse Erosion, there might be limitations intrinsic to our methodological approach. Indeed, certain areas of the surface may have undergone modifications so minimal that they would fall below the detection threshold. This limitation arises from factors such as the resolution of the photographs utilized for the 3D models; the lighting conditions of the surface during image capture; and the parameters of the software used for model reconstruction. Another factor that may potentially compromise the final quality relies in the photogrammetric acquisition method known as walk around. This technique, which is employed in situations where the object being digitized cannot be rotated, tends to favor the rendering of areas where the tracks are present over those devoid of them. Moreover, in significantly altered footprints, an insufficient percentage of overlap between two-point clouds diminish the accuracy of cloud-to-cloud alignments, potentially leading to unreliable results. One possible effect of this can be seen in Figures 6-8: in some areas where no depressions are present, such as the footprint indentation themselves, the application of the M3C2 algorithm shows nevertheless a deposition of material (bluish shaded areas).

Erosion and weathering, beyond their effects on the long-term preservation of ichnosites, have the potential to influence the interpretations of the tetrapod footprints, e.g., by altering their morphological characteristics (e.g., Marchetti et al., 2019 and references therein). This is considered, in the case dealt herein, to be of utmost relevance, since the tetrapod footprints of the Lerici site, with the exception of *Evazoum*, have not yet been formally described. The exact preservation of the ichnological record, whether physical (through the exact reproduction of material by artificial casts) or digital (through the use of scans and digital model), proves again its relevance in situations where collection and musealization of surfaces is not possible, and in the study of those sites and tracks that happen to be highly deteriorated or lost.

CONCLUSIONS

In this work, we qualified and quantified the degree of erosion affecting the Upper Triassic footprint site at Lerici (Italy), in comparison with a cast of the same surface made more than 20 years before. By employing virtual paleontological techniques, and a novel approach applied for the first time in the context of dinosaur footprints, we esti-

mated the total damage occurred in the absence of protective measures and/or preventive interventions. Through the comparison of digital reconstructions of the actual footprint-bearing surfaces and fiberglass cast we have shown the occurrence of significant alterations in various areas of the surface. These changes pose a substantial challenge for future research, as the site contains a critical ichnological record that, at present, is only partially documented.

The quality of the footprint site progressively deteriorates. This kind of degradation can be categorized into two primary types, each with distinct extents and impacts: Diffuse Erosion and Concentrated Erosion. First and foremost, we showed how the site has been eroded and depleted of some of its key ichnological features (including two undescribed footprints) in the course of some 20 years.

This case study stands as an example of how the integrating in situ and collection digitization of track-bearing surfaces allows for understanding both the erosion rates and the quality of the artificial copies. Also in these peculiar aspects, 3D digitization proves to be an irreplaceable tool for present and future paleontologists.

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