A test of holographic radar for detection of hidden vertebrate tracks and trackways

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***Abstract* — Previous testing has indicated that holographic radar can image surficial and shallowly-buried dinosaur tracks if the track surface presents a dielectric contrast. This paper reports on blind scanning of stratigraphic surfaces just above known, exposed trackways. Testing at Valley Quarries Fairfield operation near Gettysburg, PA yielded mixed results that could not be ground-truthed. Additional testing was conducted on the famous rock surface at Dinosaur State Park in Rocky Hill, CT, where large *Eubrontes* and *Grallator* tracks are exposed, along with filled/buried tracks whose locations are visually identifiable. The scans produced at Dinosaur State Park showed that RASCAN holographic radar was capable of clearly imaging surficial tracks based on their relief – an admittedly trivial result. For the important task of imaging subsurface/hidden tracks, the holographic radar's performance varied significantly across several tracks/conditions. The authors believe that difficulty in recognition of unexposed tracks may be related to a lack of radar detection in the absence of a clay film that both prevents easy separation of the mold from its cast (which precludes visual identification), and fails to provide a good dielectric contrast on the track surface (which hinders subsurface radar imaging). However, if radar reflectors of roughly correct dimensions are identified in rocks of suitable age and paleoenvironment, these reflectors may indicate the presence of exposable tracks.**

Keywords: dinosaur tracks, holographic radar, clay film

INTRODUCTION

Dinosaur footprints are trace fossils that are useful for studying the dinosaur's anatomy and movement [1] as well as recording paleoenvironmental data [2]. Due to their value in these endeavors, it would be beneficial if they could be located quickly and easily in exposures of rocks of the proper age and depositional environment. Fortunately, due to the mechanisms by which they are formed and preserved, GPR could be useful for detecting hidden tracks. It is common for dinosaur footprints to form and be preserved near water [3], as in lacrustine or playa environments [4] where a film of micaceous or clay-rich sediment may coat a new impression before it is later filled, buried, and lithified. The clay film creates the parting plane that facilitates visual discovery of the mold and/or cast, as well as providing the dielectric contrast for detection by GPR [5][6].

Holographic radar of the RASCAN type employs a continuous wave that is transmitted through the medium to be scanned, recording the interference pattern between a reference beam and reflections from subsurface dielectric contrasts, in a manner entirely analogous to optical holography [7]. Hence, holographic radar can be used to image an unexposed dinosaur footprint if the cast-mold surface coincides with a change in lithology; if there is sufficient lithologic contrast to preserve an underprint (see Fig. 1); or if, as previous work [6] has shown, there is a clay film on the surface between the mold and cast even if the mold and cast strata are lithologically identical.

This paper reports on tests conducted at two trackway sites, attempting to detect in-situ unexposed footprints using a RASCAN-4/2000 (2GHz) holographic radar scanner.

BACKGROUND

Several kinds of tracks have been found in Late Triassic limestone, occurring in cyclic lacustrine and playa sedimentary sequences within the Gettysburg Formation that are exposed in Valley Quarries Fairfield pit near Gettysburg, PA. These represent two kinds of small dinosaur (including footprints assigned to *Grallator tuberosus*), two aetosaurs (including footprints referred to *Brachychirotherium parvum*), a small lizard-like animal based on *Rhynchosauroides*, and tail scrapes inferred to have been made by a swimming phytosaur [8]. The tracks at Dinosaur State Park near Rocky Hill, CT occur in a fine- to medium-grained sandstone interbedded with shales of the East Berlin Formation. They are of Early Jurassic age [4] [9]. The paleoenvironments represented here shifted from an initially fluvial system to oscillation between playa and lacustrine settings [4].

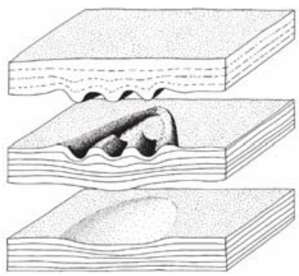

Figure 1: Sketch of a fossil footprint by Thomas Conci [10], differentiating the mold (center) from a secondary underprint, formed by loading of underlying sediment, and a cast above formed by sediment that buried the actual print.

METHODS

At the Fairfield Quarry site, a RASCAN-4/2000 was used to scan surfaces that lie stratigraphically only a few centimeters above an adjacent surface where numerous footprints are exposed (Fig. 2).

Scanning was performed by hand along parallel raster lines marked at 1cm intervals on a radar-transparent 5mm plexiglass sheet. The scanner was set to sample the interference pattern at 1cm intervals along each raster line, providing a radar image pixel size of 1cm x 1cm.

Figure 2: Trackway surface and RASCAN-4/2000 system in use at the Fairfield Quarry site. Inset shows two small surficial footprints (scale bar is 3in or ~ 8cm).

Fig. 3 shows an area with four surficial prints (highlighted), and the radar image of this same area. Note that the surficial tracks appear on the radar image, but their outlines are poorly reproduced. However, the tracks are only a few centimeters across (see inset in Fig. 2) – close to the pixel size of the image. In the radar image (Fig. 3), there are dark patches not associated with surficial tracks. These are of the proper size, approximate shape, and regularity possibly to represent tracks hidden on a buried surface. While this image is encouraging, the tracks exposed on the surface are too scientifically valuable to allow destructive testing of this hypothesis.

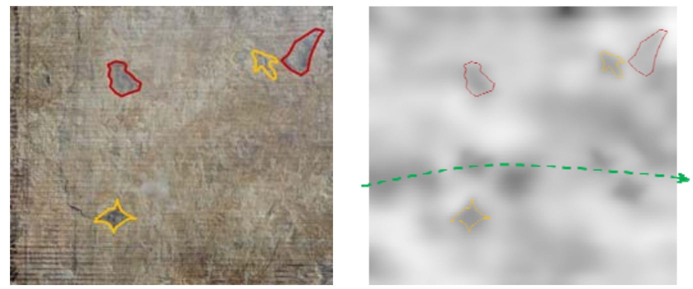

Figure 3: Photo of trackway surface (bedding plane) on the left with surficial tracks highlighted. RASCAN 4/2000 image on right, with possible trackway marked in green.

At the Dinosaur State Park site (Fig. 4), similar scanning was performed at five locations. One completely exposed track (Fig. 4 inset, Fig. 5); two locations where tracks appear to be filled (i.e. there is a rough track outline on the exposed rock surface, but the molds have not been released from the casts – see Fig. 5); one partially exposed track; and a featureless surface several cm above the main trackway stratum.

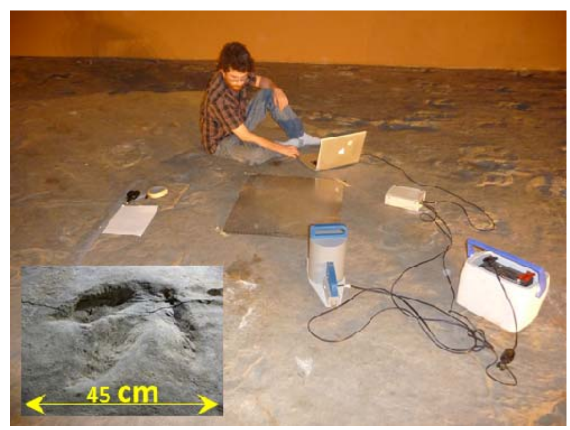

Figure 4: Trackway surface and RASCAN-4/2000 in use at Dinosaur State Park. Inset shows a typical surficial footprint.

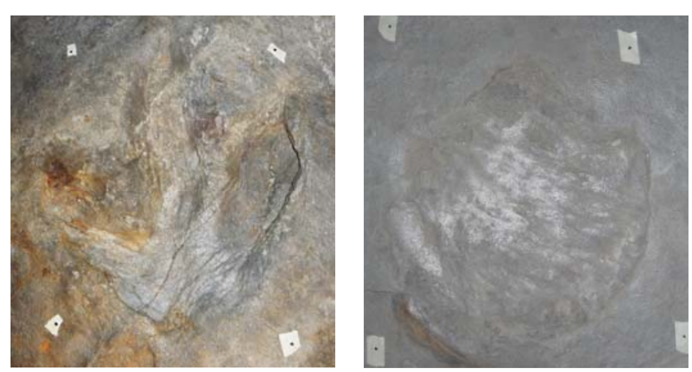

Figure 5: Exposed footprint (mold) on left, filled track on right at Dinosaur State Park. Tape marks are ~40 cm apart

Again, at the CT site, RASCAN images (overlaid on photos in Fig. 6) clearly depict the surficial tracks. However, for the filled track (on the right in Fig. 6), the radar image shows very poor correlation with the track outline suggested by the photo. Note that the scan of the featureless surface did not detect significant subsurface features, and is not considered further.

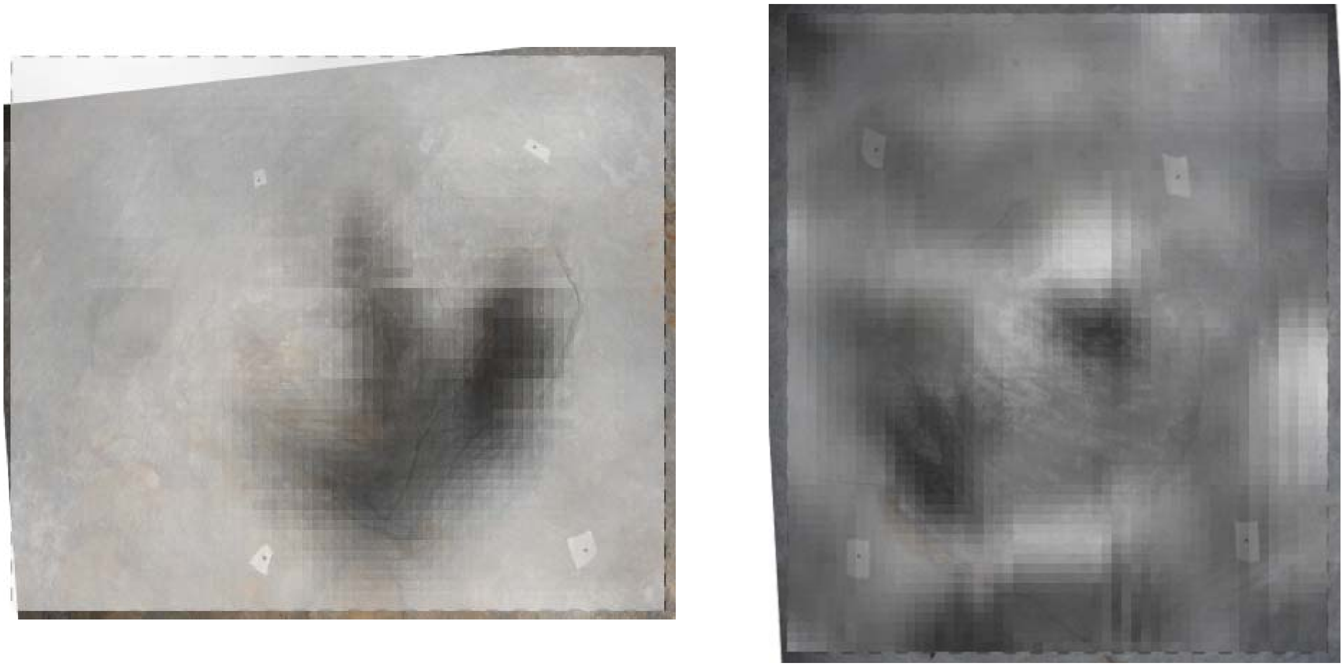

Figure 6: Radar image overlaid on photograph of exposed track (left), and filled track (right). Images are 65cm x 55cm

In an attempt to quantify how well a RASCAN image reproduces known shapes of tracks, the overlaid radar images were converted from grey scale to binary black and white (using contrast and brightness values that seemed visually to best-fit the track outline). The same tracks as in Figs. 5 and 6 are shown in Fig. 7 as transformed by this procedure.

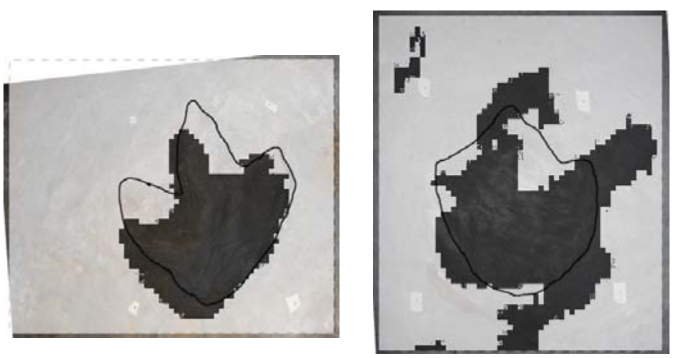

Figure 7: Binary radar image overlaid on photograph of exposed track (left), and filled track (right). Images are 65cm x 55cm. Colors are 50% transparent "white" and 100% transparent "black".

For each available RASCAN radar image (four *Eubrontes* tracks from Dinosaur State Park scanned for this study, plus a *Grallator* track from the University of Pennsylvania and an *Anamoepus* track from the collection of Franklin & Marshall College scanned for previous work [6]) a "Fit/Misfit" ratio was calculated. The Fit metric represents the total number of 1cm x 1cm "black" image pixels (depicted as transparent in Figure 7) that fell within or on the track outline, while the Misfit represents the sum of black pixels outside the outline (false positives) plus white pixels within the outline (false negatives). The Fit/Misfit ratio should be very high for a close reproduction of the print outline with no nearby radar targets, declining to zero for no recognizable image at all.

Using these metrics, for a hypothetical random (binary) image of 65cm x 55cm (3575 total pixels) containing a track with an area of 680 pixels (e.g. the exposed track in Figs. 5, 6, and 7), half of the pixels inside the track outline (680/2=340) would (accidentally) be counted as Fits. Misfits would include half of the pixels outside the track ({3575-680}/2=1447) as false positives, while half within the track (680/2=340) would be false negative, for a total of 1788. Thus, for a random image contrast pattern, the Fit/Misfit ratio would be 340/1788=0.19. Values for the track scans analyzed in this work are shown in Fig. 8.

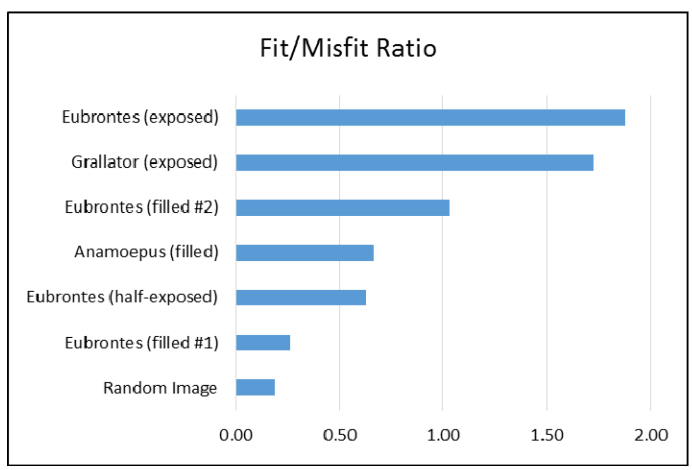

Figure 8: Fit/Misfit ratios for RASCAN images of Dinosaur tracks.

CONCLUSIONS

The exposed *Eubrontes* track provided the best-fitting RASCAN radar image (Fit Ratio = 1.88). This success is undoubtedly due to the large size of the track (680 cm^2) relative to the pixel size of the RASCAN image (1 cm^2), and the large dielectric contrast between air (~1) and the dry sandstone in which it is preserved (~2-3 [11]). The exposed *Grallator* track is much smaller (~320 cm^2), but it also presents a large dielectric contrast, and therefore yields only a slightly smaller Fit Ratio (1.72).

The filled tracks yielded a wide range of Fit ratios, from nearly indistinguishable from random (*Eubrontes* #1 at 0.26) to almost as good as an exposed track (*Eubrontes* #2 at 1.03). This is presumably due largely to variations in the dielectric contrast at the track's cast-mold interface, which may in turn be related to the presence or absence of a clay film. Dry clay has a dielectric up to 6, rising to 20-40 in the presence of even minimal moisture [11].Therefore, either dry or damp, clay provides a good dielectric contrast with sandstone or carbonate rocks with dielectric less than 3 [11].

A clay film may serve both as the parting surface that exposes tracks, as well as providing a suitable reflector for radar imaging. Despite the relatively poor visual quality of the radar images, holographic radar could provide a useful tool for prospecting for exposable trackways. "Exposable" is here used in the sense that if a track does not provide a good radar reflector, there may be no suitable parting plane in the rock to allow separation of the mold and cast. In addition, since the radar image contrast patterns do not closely reproduce track outlines, it may be difficult to differentiate buried tracks from other internal discontinuities, such as lenses of clay of purely physical origin, unrelated to footprints.

As further work, we propose testing at a site (as yet unidentified) where subsurface targets can be imaged, classified (based on visual inspection) as to whether or not they represent tracks, and then exposed to test the reliability of the method.

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