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First known fossil bird tracks (Pleistocene) on San Salvador island, Bahamas

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ABSTRACT

Two avian footprints discovered in the Grotto Beach Formation (Pleistocene) of San Salvador Island (Bahamas) are the first known vertebrate trace fossils on this well-studied island. The trace fossils, preserved as bedding-plane impressions in an oolitic-bioclastic grainstone, match the size and form of tracks made by modern gulls. The tracks are in beach facies located below a paleosol dated from Marine Isotope Substage 5e (~120,000*kya*). These tracks add to a record of Pleistocene bird tracks reported from Eleuthera Island and bode well for the recognition of more vertebrate trace fossils on San Salvador and other Bahamian islands.

KEYWORDS **Bahamas. Birds. Ichnology. Pleistocene. Trace fossils.**

INTRODUCTION

As a result of extensive coastal outcrops and intense study for the past several decades, the Holocene–Pleistocene geologic history of the Bahamas is well known. The geology of San Salvador Island in particular is the best documented of the Bahamas, which is largely attributable to its extensive coastal outcrops and the long-term presence of the Gerace Research Centre (Rothfus, 2008). Furthermore, its plant and invertebrate trace fossils are exemplary as near-equivalents to modern traces in carbonate facies and include holotypes of several ichnotaxa (Curran, 1984; Frey *et al*., 1984; Walker *et al*., 2000; Curran and Martin, 2003; Martin, 2006, 2013; Curran, 2007).

Nonetheless, vertebrate trace fossils have remained elusive on San Salvador and nearly every other Bahamian island. Thus far, the only known vertebrate traces from the Bahamas are 19 avian tracks in Pleistocene beach facies on Eleuthera Island (Kindler *et al*., 2008). Thus we are gratified to report a find of two avian tracks on San Salvador, also preserved in beach facies from the Grotto Beach Formation (Pleistocene) and approximately the same age as the Eleuthera tracks. The tracks, one well-defined and the other only partially expressed, were likely made by a medium-sized gull toward the end of Marine Isotope Substage (MIS) 5e, dating these trace fossils at ~120,000 years ago (Kindler *et al*., 2008).

LOCATION, STRATIGRAPHIC SETTING

The track locality is about 3km south of Cockburn Town, San Salvador, Bahamas (Fig. 1). At the time of their discovery, the tracks were in situ on the bedding plane of a coastal outcrop and about 0.5m above mean high tide (Fig. 2A). The trace fossils were discovered on December 30, 2013 by one of the authors (Whitten) in the presence of the other author (Martin), who confirmed their probable identity as avian tracks. The tracks were on a freshly exposed surface of 80x120cm (about a square meter), but were restricted to a smaller area (50x50cm) on the lowermost bedding plane of that surface. The very pale orange (10 YR 8/2) surface with the tracks contrasted with the surrounding weathered grey limestone. The tracks were preserved as natural depressions on the upper bedding-plane surface (Fig. 2). The lithology hosting the tracks was a medium-coarse grained oolitic-bioclastic grainstone,

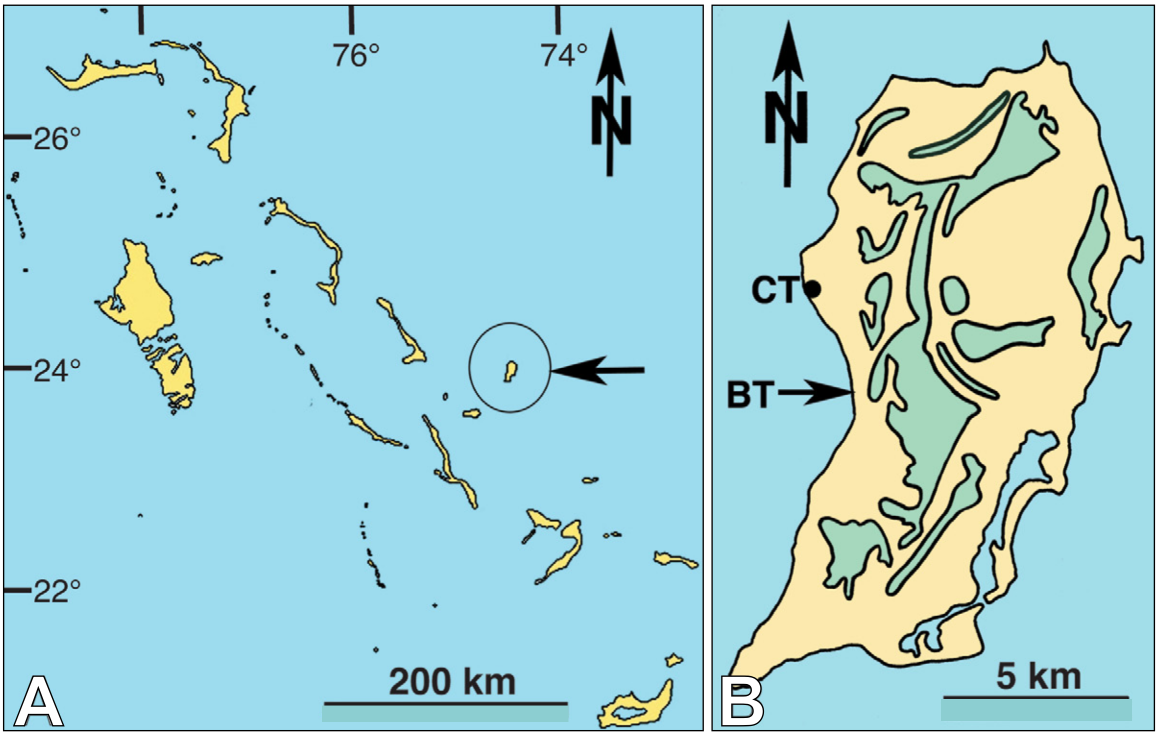

FIGURE 1. Location of fossil bird tracks in The Grotto Beach Formation, San Salvador Island, to Bahamas. A) San Salvador Island (arrow) in the Bahamas. B) Location in San Salvador 24° 01' 45.7" N, 74° 31' 28.0" W. Key, CT: cock burn town, BT: bird track locality.

with low-angle to planar cross-bedding evident in vertical section. The bedding plane also had a few circular to oblong, 4–15mm wide calcite-spar-filled structures, which are presumed cross-sections of vertical features. The bedding plane was 35–40cm stratigraphically below a prominent and well-exposed paleosol, which correlates with a paleosol about 2km north of this locality that crops out at the Cockburn Town Fossil Reef and elsewhere on San Salvador (Fig. 2; Carew and Mylroie, 1995).

METHODS AND DESCRIPTION

Track parameters were assessed in the field using a minimum-outline method, in which overall length, width, and digit widths and lengths were measured on the bottommost surface of each track. Digit widths seemed wider at the bedding-plane surface, but these apparent widths may have been from a combination of tracemaker behavior and modern erosion, thus presenting potential sources of error. Digit lengths were measured at straight-line distances from a rear-middle point of inferred metatarsal-pad impressions, and digit widths were measured perpendicular to these at the mid-length of each digit (Fig. 3). Interdigital angles (between digits II–III and III–IV) were later measured from enlarged photographs of the tracks, using lines drawn from the rear of the metatarsal pad impressions to digit ends.

Both tracks are tridactyl, and nearly symmetrical; Track 1 was 5.7cm long and 5.7cm wide, whereas Track 2 was 7.7cm long and 7.6cm wide (Table 1). Both tracks were aligned in nearly the same direction (north–northeast), separated by 39cm and offset laterally by 14cm. Track 1,

TABLE 1. Measurements of fossil avian tracks from The Grotto Beach Formation (Pleistocene), San Salvador Island, Bahamas. L: overall length, W: overall width, DII-L: digit II length, DIII-L: digit III length, DIV-L: digit IV length, DII-W: digit II width, DIII-W: digit III width, DIV-WIV-W: digit IV width, DII-IV: divarication between digits II and IV. All units in millimeters

Track	L	W	DII-L	DIII-L	DIV-L	DII-W	DIII-W	DIV-W	DII-IV
1	57	57	44	56	45	10	6	8	85
2	77	76	53	77	58	9	8	6	85

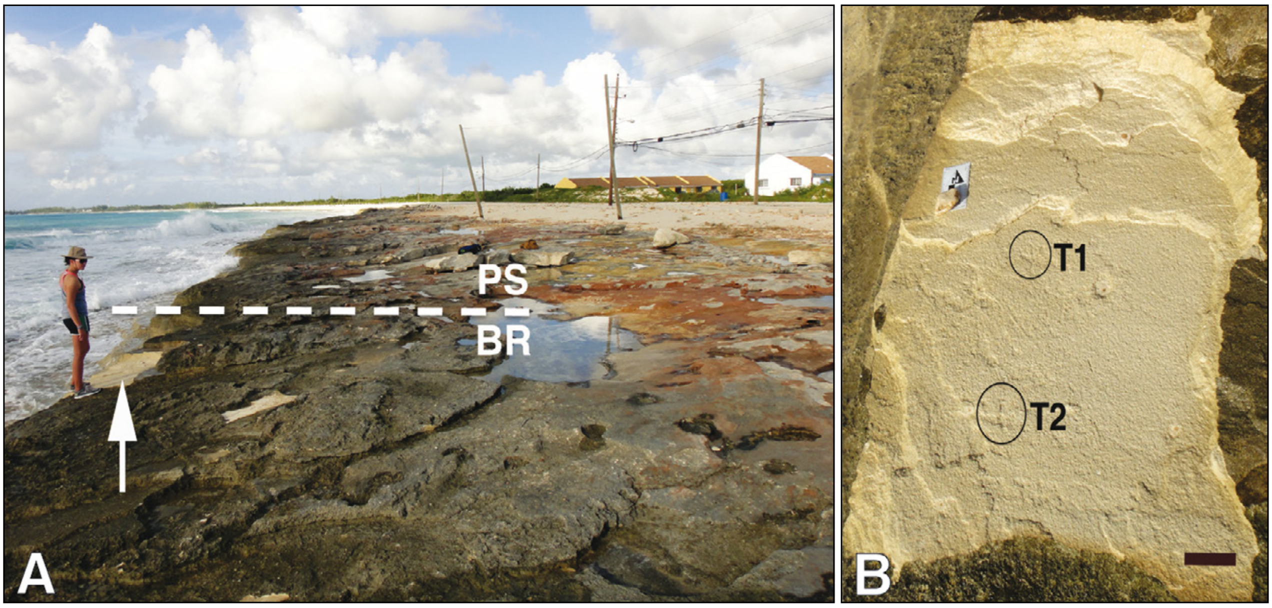

FIGURE 2. A) Stratigraphic position of the bedding plane containing the fossil bird tracks (arrow) below the paleosol (PS) that marks the top of the Grotto Beach Formation. and overlying beachrock (BR). B) Bedding-plane view, with encircled tracks (T1: Track 1, T2: Track 2). Field scale (upper left)= 15cm long.

which was at the north end of the bedding plane exposure, has thin clawmarks on the ends of all digits. Track 1 also has well-defined sand rims along the outer edge of digit II and the rear of the track, defining the proximal end of a metatarsal pad (8mm wide). Track 2 had complete digits II and IV, but digit III was only partially expressed; nonetheless, the distal end is evident. Clawmarks were apparent on all three digits, as well as a possible claw drag-mark connected to digit III. A probable metatarsal pad impression (14mm wide) is also present at the rear of the track, again defined by a sandy rim. Digit widths on both tracks were thin relative to overall track sizes, ranging from 6–10mm. Divarication angles between digits II and IV were identical, at 85° for both, although angles between digits II–III and III–IV varied (Fig. 3). Distal webbing was not evident on either track.

INTERPRETATION

Based on overall dimensions, digit lengths and widths, and divarication, the tracks were made by avian tracemakers, and probably similar species. The offset (14cm) between the outer margins of the two tracks, as well as their differing sizes, suggests that they are not connected to the same trackway, nor were they made by the same species of tracemaker. Their qualitative traits are similar to those of intermediate-sized modern gulls (Elbroch and Marks, 2001), such as a ring-billed (*Larus delawarensis*), laughing (*Leucophaeus atricilla*), or herring gull (*Larus argentatus*), or brown noddy (*Anous stolidus*), all of which live in the Bahamas today (Hallett, 2006). Track 1 overlaps in size with tracks of ring-billed gulls, laughing gulls, and brown noddies, whereas Track 2 is herring-gull sized. Gulls have fully webbed anisodactyl feet, with a reduced digit I (often absent in tracks), and metatarsal pads (Figure 4); webbing is not always present in modern tracks, either (Elbroch and Marks, 2001; Martin, 2013). Additionally, tracks made by shorebirds with fully palmate and tridactyl feet, but with variable expressions of their webbing in tracks, have been reported from Miocene strata of Spain (Doyle *et al*., 2000).

In contrast, similar-sized shorebirds, such as brown boobies (*Sula leucogaster*), are ruled out as possible tracemakers because of their totipalmate feet. Similarly, herons were excluded because of their lengthy digit I, which was absent in both tracks. The tracks overlap in size with those of American oystercatchers (*Haematopus palliates*), but these birds lack well-defined metatarsal pads in their tracks (Elbroch and Marks, 2001). Owing to slightly differing digit lengths, in which the longer outside digit is regarded as digit IV, both tracks are considered as having been made by right feet. However, subpar preservation of the trace fossils allows for the possibility that either could be from left feet.

The host lithology, a planar to low-angle cross-bedded oolitic-bioclastic grainstone, is probably beach facies, having formed in a berm just above the high-tide zone when the tracks were made. The vertical, spar-filled structures in the host lithology are likely root traces, which are common in upper-beach to eolian dune facies of the Bahamas

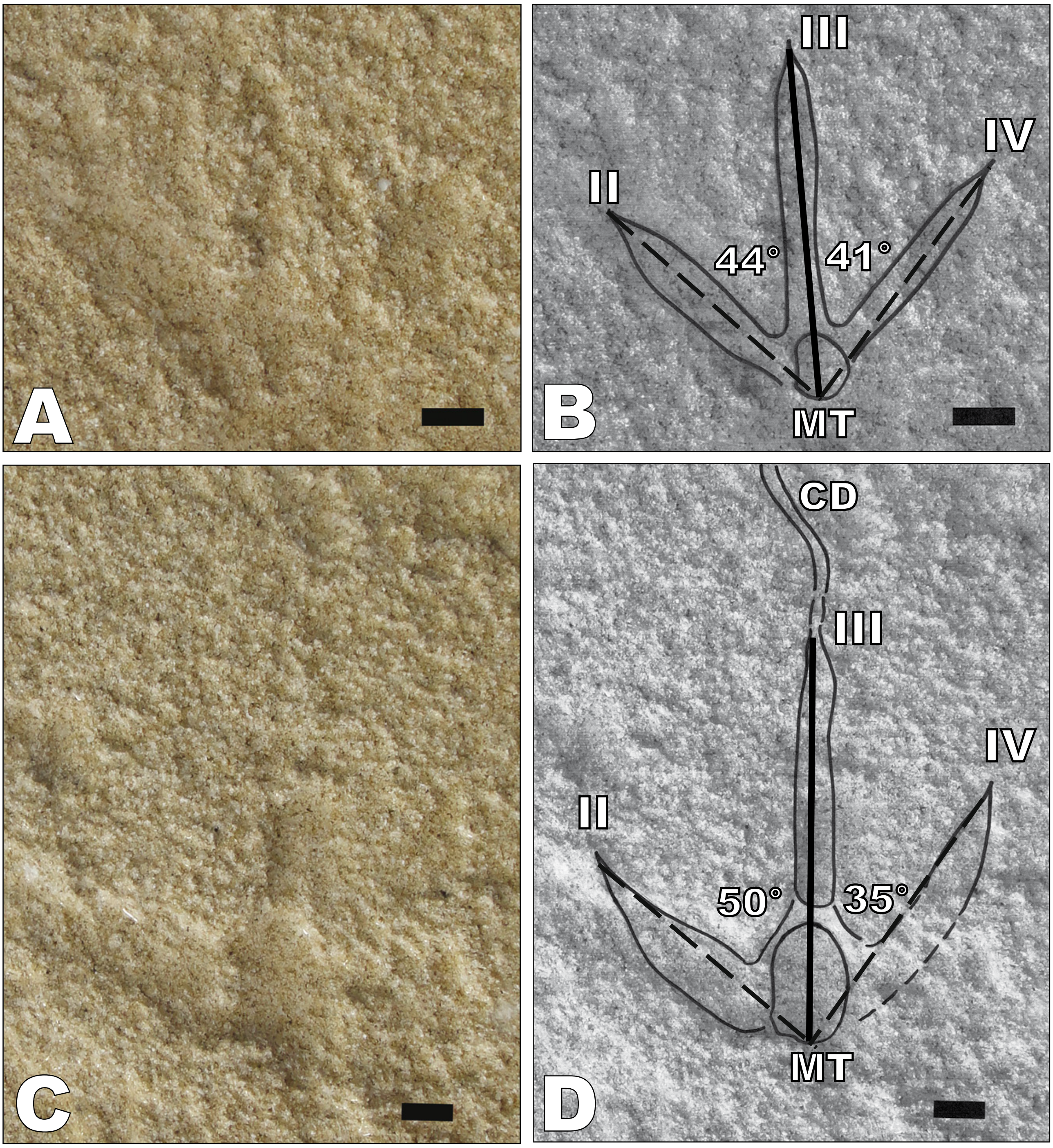

FIGURE 3. Birds tracks. A) Track 1. B) Minimum outline of Track 1, with digits indicated (II–IV), angles between digits and metatarsal impression (MT). Lines defining digit lengths and basis for interdigital angles. C) Track 2. D) Minimum outline of Track 2, with digits indicated (II–IV), angles between digits and metatarsal impression (MT); CD: central drag mark. Lines defining digit lengths and basis for interdigital angles. Scale = 1cm in all photos.

(Martin, 2006; Curran, 2007). Preservation of the tracks was most likely similar to that described by Kindler *et al.* (2008) for Pleistocene avian tracks on Eleuthera Island, in which shorebirds walked on wet sand above where waves would have reworked them.

Kindler *et al.* (2008) interpreted the Eleuthera trackmakers as those of Charadriiformes with normal anisodactyl (non-webbed) feet, such as an American oystercatcher (*Haematopus palliates*) or greater yellowlegs (*Tringa melanoleuca*). Unfortunately, the body-fossil record for shorebirds in the Bahamas is scanty, thus providing little independent verification of specific shorebirds during their geological history. For example, sooty tern (*Sterna fuscata*) and ruddy turnstone (*Arenaria interpres*) remains have been reported from San Salvador (Olson *et al*., 1990), but these were not designated as Pleistocene. The only shorebird among many well-preserved avian fossils in a subfossil (1–4.2 *kya*) blue-hole deposit on Great Abaco Island (Steadman *et al*., 2007) was an Audubon's shearwater (*Puffinus lherminieri*). A Pre-Columbian archaeological site on San Salvador yielded possible seagull remains, although their identity was uncertain (Blick and Brinson, 2007). Consequently, avian trace fossils of both Eluethera and San Salvador help to fill a gap in the fossil record of shorebirds in the Bahamas.

The well-developed and extensive paleosol stratigraphically overlying the tracks marks the top of the Cockburn Town Member, the uppermost member of the Grotto Beach Formation (Carew and Mylroie, 1995). The paleosol represents the terminal phase of a regression following Marine Isotope Substage 5e (MIS 5e), which has been dated at about 125,000 *kya*; as a result, the tracks are estimated as ~120,000 *kya*. Thus the stratigraphic position of the tracks is also remarkably similar to that of the fossil bird tracks documented from Eleuthera (Kindler *et al*., 2008). As a result, the tracks from the two islands may be close to the same geologic age.

CONCLUSIONS

These first known fossil bird tracks of San Salvador are paleontologically significant. First these are the first reported vertebrate trace fossils from an intensely studied island (San Salvador) that often serves as a world-wide model for trace fossils in tropical and semi-tropical carbonate rocks (Curran, 1984, 2007; Martin, 2006). Secondly, the stratigraphic position of the tracks match the position of other shorebird tracks reported on Eleuthera Island (Kindler *et al*., 2008), implying that track preservation in these facies may be related to Pleistocene sea-level fluctuations. Thirdly, we expect that the correspondence of both timing and depositional environments of shorebird track sites in two widely separated islands of the Bahamas will enable other researchers to look for and find more such tracks throughout the West Indies. Our study also provides an example of a "shorebird ichnofacies," such as that described by Doyle *et al*. (2000) in Miocene strata of southern Spain.

However, the exposure of these Pleistocene tracks in a coastal outcrop means these specimens will experience high-energy waves, bioerosion, and other processes that will degrade them quickly. Hence our immediate recording of their traits is meant to document them before their destruction and help future researchers establish proper search images for finding more such trace fossils on San Salvador and other islands of the Bahamas. Based on our discovery and that of Kindler *et al*. (2008), we advise that future researchers seeking fossil tracks might concentrate

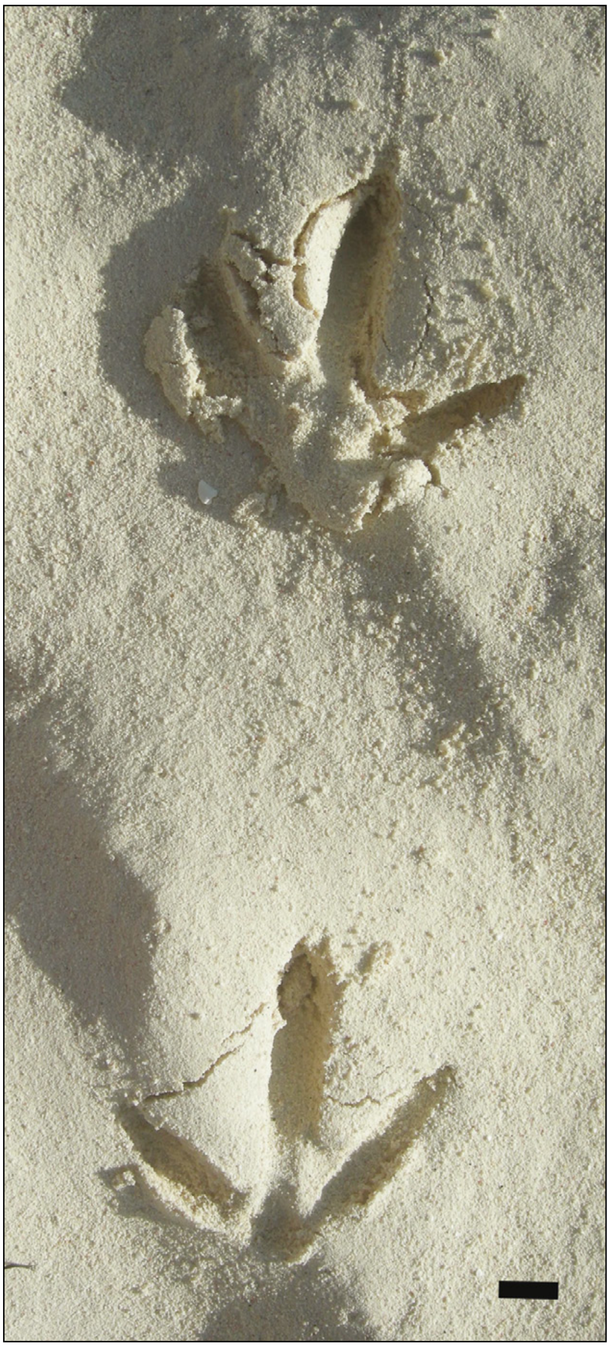

FIGURE 4. Modern tracks of ring-billed gull (*Larus delawarensis*) comparable in size, form, and sedimentary setting (carbonate-sand berm) to Pleistocene tracks in The Grotto Beach Formation. Right track (bottom) and left track (top); also note claw dragmark from digit III in the left track. Tracks observed on Graham's Harbour San Salvador Island, Bahamas. Scale= 1cm.

their efforts on beachrock facies, especially toward the top of regressive sequences. These fossil tracks, located only 1.5km northeast of the site proposed as Christopher Columbus's first landfall in 1492 (Shaklee, 2009), promise of more surprises on San Salvador that await our discovery.

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