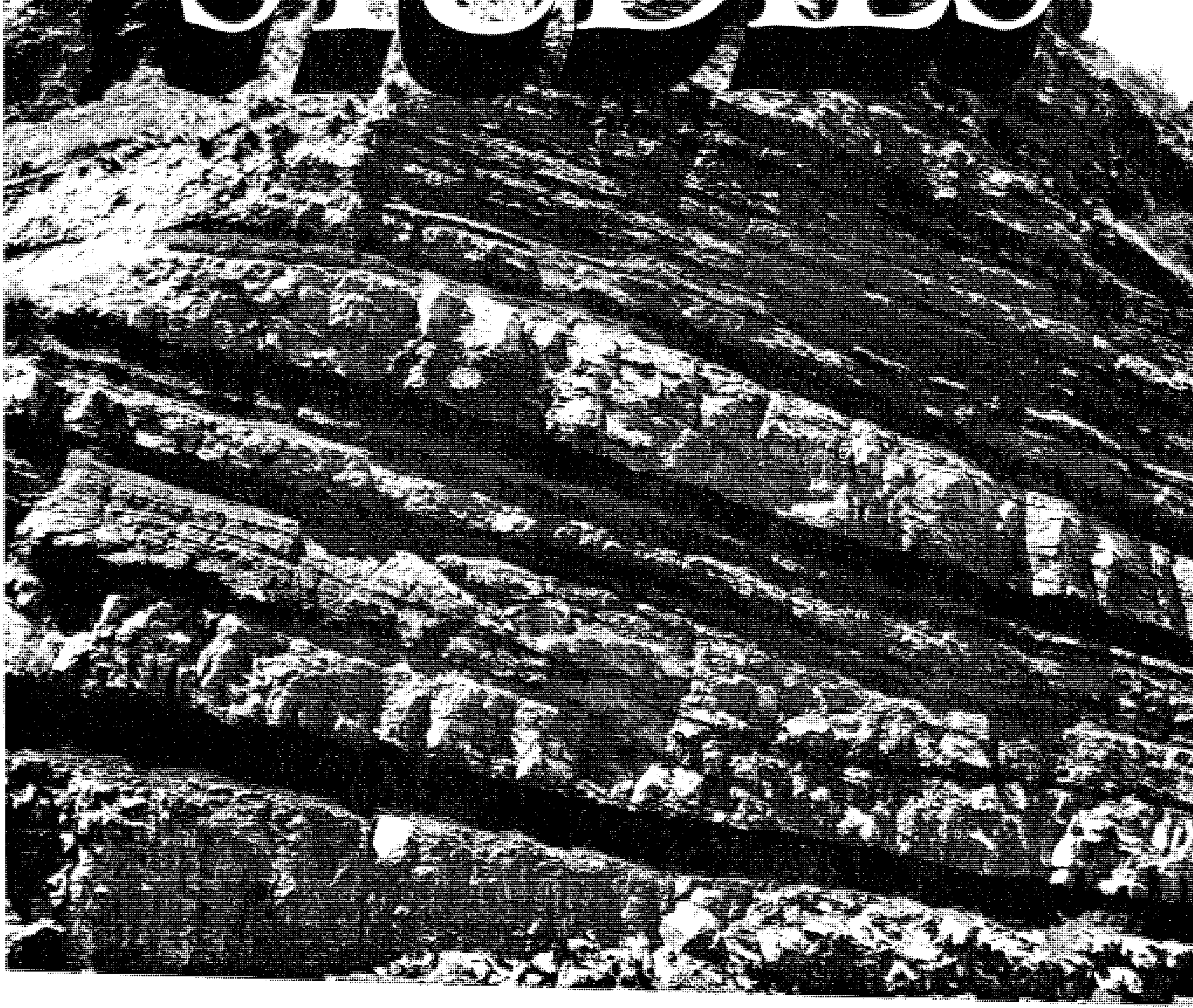
BRIGHAM YOUNG UNIVERSITY

GEOLOGY STUDIES



VOLUME 26, PART 2

JULY 1979

Brigham Young University Geology Studies

Volume 26, Part 2

CONTENTS

THE GLORY OF GOD IS INTELLIGENCE

Cover: Cretaceous coals near Castle Gate, Utah.

A publication of the

Department of Geology

Brigham Young University

Provo, Utah 84602

Editors

W. Kenneth Hamblin
Cynthia M. Gardner

Brigham Young University Geology Studies is published by the department. *Geology Studies* consists of graduate-student and staff research in the department and occasional papers from other contributors. *Studies for Students* supplements the regular issues and is intended as a series of short papers of general interest which may serve as guides to the geology of Utah for beginning students and laymen.

ISSN 0068-1016

Distributed July 1979

7-79 525 38477

CONTENTS

Environmental Significance of Pterosaur Tracks in the Navajo Sandstone (Jurassic), Grand County, Utah

WILLIAM LEE STOKES[1] AND JAMES H. MADSEN, JR.[2]
[1]*Department of Geology and Geophysics, University of Utah, Salt Lake City, Utah 84112*
[2]*Antiquities Section, Division of State History, Salt Lake City, Utah 84101*

ABSTRACT.—Well-preserved tracks of pterosaurs have been found in the Navajo Sandstone east of Moab, Utah. At least several dozen footprints are preserved on a single inclined bedding plane that is unusually smooth and flat, truncated at the upper edge at an angle of 30° by an assumed horizontal surface, and heavily stained by hematite that penetrates to a thickness of several millimeters into the sandstone. Evidently, the track-marked material is unusually resistant to erosion because cementation was facilitated by easy access of silica-bearing pore water into the layers of relatively well-sorted grains. The reworking of ordinary Navajo sand by wave action on the shores of a small water body could explain the formation of a moist shoreface and berm, the removal of fine particles, the sorting of larger grains to produce a set of well-marked beds with greater porosity, and the concentration of heavy minerals on the bedding planes. The winnowed sand, when moist, was most favorable to the formation and retention of tracks and, when solidified, produced the resistant beds and iron-stained surface on which the tracks are preserved.

INTRODUCTION

Pterosaur tracks have been discovered at two locations in the Navajo Sandstone (Jurassic?) near Moab, Utah. Lynn Ottinger, local tour guide, made the discoveries and brought them to the attention of several paleontologists including Samuel P. Wells, Robert A. Long, and the writers. At one site, designated the Sand Flats locality, almost all the tracks were confined to two large slabs of sandstone, erosional remnants detached from a nearby bedrock outcrop. To preserve them from vandalism the two slabs were removed in May 1976 under a permit issued by the Department of the Interior; they are currently stored at Brigham Young University in Provo, Utah. The field location of Ottinger's second find is not being published at this time as the specimens cannot be removed for safekeeping. These two discoveries have been discussed in a preliminary way only (Science News 1973). The present paper is intended to cover only the environmental implications of one of the localities; the tracks as such will be described in a later contribution.

NAVAJO SANDSTONE

The Navajo Sandstone is a prominent, much-studied formation best known for its part in the spectacular scenery of the central Colorado Plateau. Its age and origin have been subjects for much discussion. The formation has been variously interpreted as deep-water marine, shallow-water marine, near-shore marine, fluvial, and eolian. It has been placed entirely in the Jurassic, entirely in the Triassic, and divided between the two (Galton 1971).

A number of papers bearing on the origin of the formation have appeared recently by Freeman and Visher (1975), Folk (1977), Kamis (1977), Pacht (1977), Picard (1977a,b), Ruzyla (1977), Steidtmann (1977), and Visher and Freeman (1977).

GEOLOGIC SETTING OF THE SAND FLATS LOCALITY

The track-bearing locality in the Sand Flats drainage is in an extensive area of nearly horizontal Navajo Sandstone cut by numerous northwest-trending joints along which moderately deep, steep-sided drainage ways have been eroded. The elongate blocks between the joints have been modified into rounded, hummocky ridges alternating with narrow, sand-choked corridors of various widths. These structures are commonly called "fins."

The tracks were discovered decorating two large (1.8 m x 1.8 m) slabs lying detached in a narrow corridor between two elongate, parallel ridges (fig. 1). That the blocks were derived from the summit of the nearby outcrop about 3 m above is proven by remnants of identical structure and lithology still in place on the ridge summit immediately beyond the detached blocks (fig. 2).

The track-bearing slabs (fig. 3) are characterized by a number of unusual morphologic, petrologic, mineralogic, and sedimentary features:

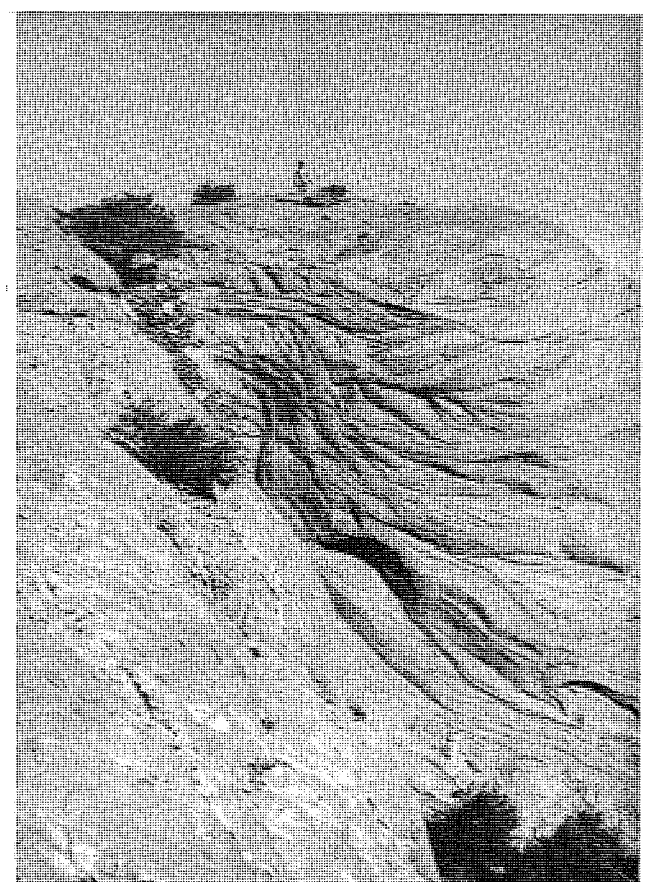


FIGURE 1.—Discovery site of pterosaur tracks. Sand Flats drainage, Grand Co., Utah. Track-marked slabs were removed from rubble below the tree; person on skyline points to a remnant of similar lithology, but with no tracks, that is considered to be in place. A closer view of this block is shown in figure 2.

1. All the tracks are on what appears to have been a single bedding plane defining one side of a thin (2.5 cm) bed. The lateral continuity of this plane has been broken by long-continued weathering so that two large, rectangular blocks have

FIGURE 2.–Near view of remnant on ridge above discovery site. Note well-marked, parallel bedding planes, thick ferruginous coating, and intersection of berm and foreshore surfaces.

been produced. Although the track-bearing bed is underlain by several similar beds that have adhered to form a tabular aggregation, no tracks can be seen on the exposed edges of the lower beds. It seems unlikely that similar beds lay over the track-marked surface, since no positive (as contrasted with negative) prints were discovered.
2. The track-bearing surface is associated with cross-bedding, but the preserved portion is geometrically smooth and flat with no perceptible curvature. Evidence is that the angle the bed made with the horizontal is that which a foreshore makes with a berm.
3. The upper edge of the track-bearing block is beveled or truncated at an angle of about 30°. The narrow shelf above the edge appears to be a continuation of the same type of material as that below the edge. This horizontal surface appears also to be parallel with formation contacts, and there is no evidence that it was formed by truncation or erosion of a preexisting stratum. In other words the entire configuration is both constructional and destructional in origin (see figs. 2 and 3).
4. The track-bearing block is unusually resistant to erosion and weathering compared to the surrounding outcrops from which it has been freed. Not only were the blocks differentially eroded until they began their downward migration due to gravity, but the track-marked surface which has been

FIGURE 3.–One of two track-marked slabs in place of discovery. Note dark ferruginous coat on surface and well-marked angular intersection on right side.

exposed to weathering for a period much longer than that affecting other surfaces in the vicinity still shows good preservation of the footprints and other primary markings.

5. The track-marked surface and others parallel with it in the same set are heavily stained with a dark ferruginous material. This surface looks like what is called desert varnish, but the discoloration penetrates into the rock between the grains and is more than a thin surficial coating (fig. 4).
6. The cement of the track-bearing slabs, except for the ferruginous crust, is almost entirely siliceous (fig. 5).

In summary, the tracks were made and preserved on a substratum of limited extent that eventually became a highly indurated, very resistant, darkly stained surface in the midst of a rock mass that is moderately indurated, moderately resistant, and unstained. It is the difference between the track-bearing rock and the great bulk of penecontemporaneous material that must be explained. The tracks are in one sense incidental to this problem.

POSTULATED SEQUENCE OF EVENTS

The postulated sequence of essential events which produced the Sand Flats pterosaur tracks may be summarized as follows:

1. Formation of a fairly deep and wide body of water, either a river or a lake, in a basin enclosed entirely by sand. Organisms indigenous to this body included wormlike burrowers and perhaps other animals.
2. Generation of periodic waves which approached the shore at an oblique angle with enough energy to shape a berm and foreshore.
3. Abrupt cessation of wave action or lowering of the water level to expose a sloping, moist surface.
4. Arrival of a number of types of vertebrate animals, chiefly pterosaurs, which traversed the yet soft and saturated face of the shore presumably in search of food (worms?) stranded, perhaps, by the lowering of the water.
5. Making of the tracks and departure of the track-makers. That the animals were not driven out by rising water is evident by the uneroded condition of the tracks.
6. Immediate burial of the still moist track-marked surface by sand of somewhat different character. The entire assemblage was buried to become part of the Navajo Sandstone.
7. Differential induration of the formation at some much later date. The wave-sorted material including the track-marked layer became more strongly cemented and hence eventually more highly resistant to erosion upon exposure.

MODERN ANALOGY

Sedimentary structures identical in general configuration to those described have been observed by the writers in process of formation along the banks of the Colorado River in Cataract Canyon, Utah, during a falling-water stage. The essential process was seen taking place in slack-water areas 30 m (100 feet)

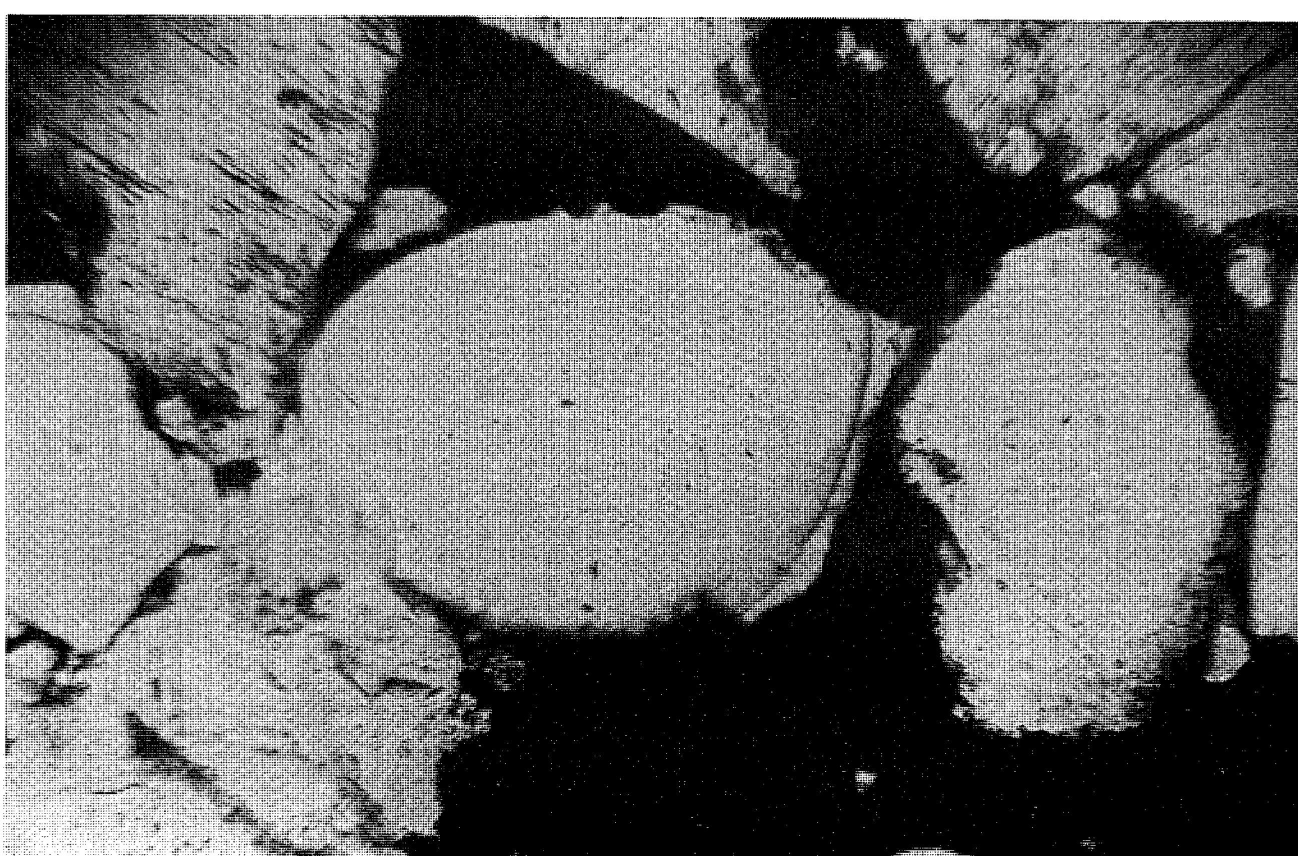


FIGURE 4.–Photomicrograph of hematite-cemented sandstone cut near and parallel to a bedding plane. Note syntectic quartz overgrowth on large central grain and later infilling hematite. Long diameter of large grain about 0.4 mm.

or more from the main current of the river. The most favorable setting is apparently that of projecting sand banks or bars alternating with indentations of shore to form small protected bays. The banks observed were composed entirely of loose sand. Periodic waves with an amplitude of 30-60 cm (1-2 feet) were being generated by the turbulence of nearby rapids and were striking the shore at an angle of about 45°. The chief result of this situation was a cutting away of the projections and a filling of the low spots by processes related directly to the forward motion and breaking of the waves. The shape of a shoreline along such stretches seems to depend on a movement of sand lifted and pushed by the waves. Since the energy of waves can carry water only to a certain average height, the sand body being built forward cannot rise above the level of the swash of the waves. Along the shores of the ocean the height reached by the waves varies with the rise and fall of the tide. In a small lake the waves might be expected to reach a more uniform height. In the observed activity of the Colorado River, once sand was built up to the maximum possible height, the wave-shaped surface departed from a rounded form to two planes intersecting at a geometrically precise angle. The surface above the break became a classical berm and was perfectly horizontal. The surface below, formed by the backwash, was likewise a very smooth plane, inclined to the horizontal at 30° (figs. 2, 3).

A second significant process related to the breaking of the waves and the formation of the berm is the winnowing of loose sand. After the passages and breaking of one wave and before the arrival of the next, water drains under the influence of gravity directly down the surface of the beach—the backwash, or backswash, of the typical wave cycle. Aside from the part the backswash plays in shaping the beach, it also has the effect of winnowing the beach material in a significant way. A concentration of heavy minerals is one visible result; in fact, it was the heavy residue of black sand on the outer slope and berm that drew attention to the process. Less obvious is a concentration of relatively large quartz grains as smaller particles are swept away.

PETROLOGY

Thin sections were made of 7 samples of sandstone directly associated with the tracks; heavy minerals were separated from two of these same samples. Data thus obtained permit comparisons with published information on the Navajo Sandstone generally. We are indebted to Arthur Trevena for the following description of the thin sections: "All are subarkoses that have a high degree of textural maturity. . . . The high degree of rounding of quartz grains and the presence of only the most stable heavy minerals suggests . . . 2nd or even 3rd cycle sand. The significant feldspar percentages, traces of metamorphic rock fragments, and a possible occurrence of kyanite suggest a metamorphic source as well."

Although strictly quantitative statements are not justified, the following observations are defensible: (1) Except for the ferruginous crust the cement is almost entirely siliceous; none of the slides shows more than traces of calcite; (2) the opaque

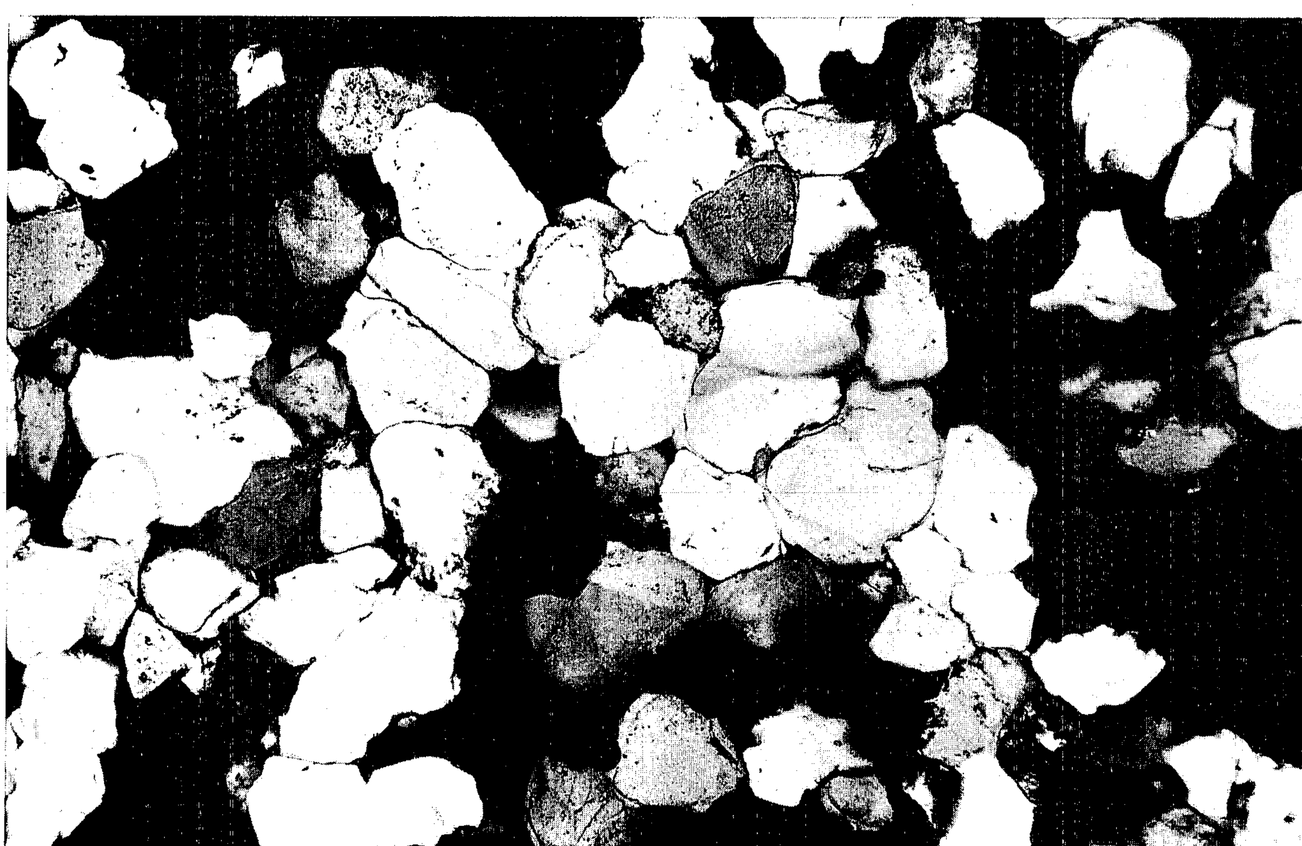


FIGURE 5.—Photomicrograph of track-bearing Navajo Sandstone cut at right angles to the bedding plane. Note solid packing and silica overgrowths which have reduced pore space and produced a highly resistant sandstone. Long dimension of view is 1.7 mm.

cement of the ferruginous crust is entirely hematite; although this mineral appears to be superficial, it does penetrate and cement a zone several grains in thickness; the hematite postdates the syntaxial overgrowths on the quartz grains (fig. 5). Magnetite is abundant in the rock beneath the ferruginous crust and is accompanied by other heavy minerals including, in order of abundance, leucoxene, ilmenite, brown tourmaline, green tourmaline, hematite, and zircon.

The petrologic data show nothing that cannot be accounted for by winnowing of ordinary preexisting Navajo Sandstone. Preferential removal of lighter and smaller mineral particles explains the concentration of heavy minerals, especially magnetite, from which the hematite staining and cementing of the bedding planes was ultimately derived. The relatively greater resistance to erosion of the track-marked material is also explainable as a result of winnowing action.

The constant reworking of the shoreface and outer berm is effective in removing finer particles and in sorting larger ones according to size and shape. Well-sorted material has relatively more pore space, which in turn facilitates percolation of solutions and eventually permits more uniform deposition of cementing material. It is exactly the same concentration of better-sorted material that favored the stability of the tracks in the unlithified sand layers.

DISCUSSION AND CONCLUSIONS

Perhaps the most meaningful deduction to be drawn from the Sand Flat tracks is that they represent a process of formation and burial that is a decided short-term phenomenon. The tracks are as delicate, well formed, and deeply indented as is possible in a sandstone matrix (fig. 6). They show no signs of having deteriorated by drying out or of being mechanically blurred by external erosion by wind or water. Such tracks could not under any circumstances have been made in dry sand. Neither could they have been made in very wet or totally saturated sand. A certain stage of saturation with just enough moisture to create the maximum degree of cohesiveness is indicated. The sand did not adhere to the feet of the animals; the grains were more cohesive to each other than they were to the skin and claws of the track-makers.

The significant point is that the sand would have lost its cohesiveness after only a brief exposure to drying with the result that the tracks would have collapsed or slumped so as to blur or distort their outlines. The evidence of the tracks seems to require either the sudden draining away of the adjacent water or, what is more likely, the subsidence of the wave action responsible for construction of the beach and berm. In any event a band of cohesive sand about 1½ m (4½ feet) wide that had been washed smooth and kept moist by wave action was laid bare and became available to the track-making animals. That this narrow strip of moist beach was visited shortly after its formation by a group of pterosaurs would strongly suggest that it had some special attraction for these birdlike reptiles. Whatever flotsam and jetsam may have been deposited by waves has left but few traces. Such bits of food as worms or fish, for example, may have been left stranded to attract scavengers. Perhaps there was little food value here, and the pterosaurs merely landed to investigate an attractive stretch of wet

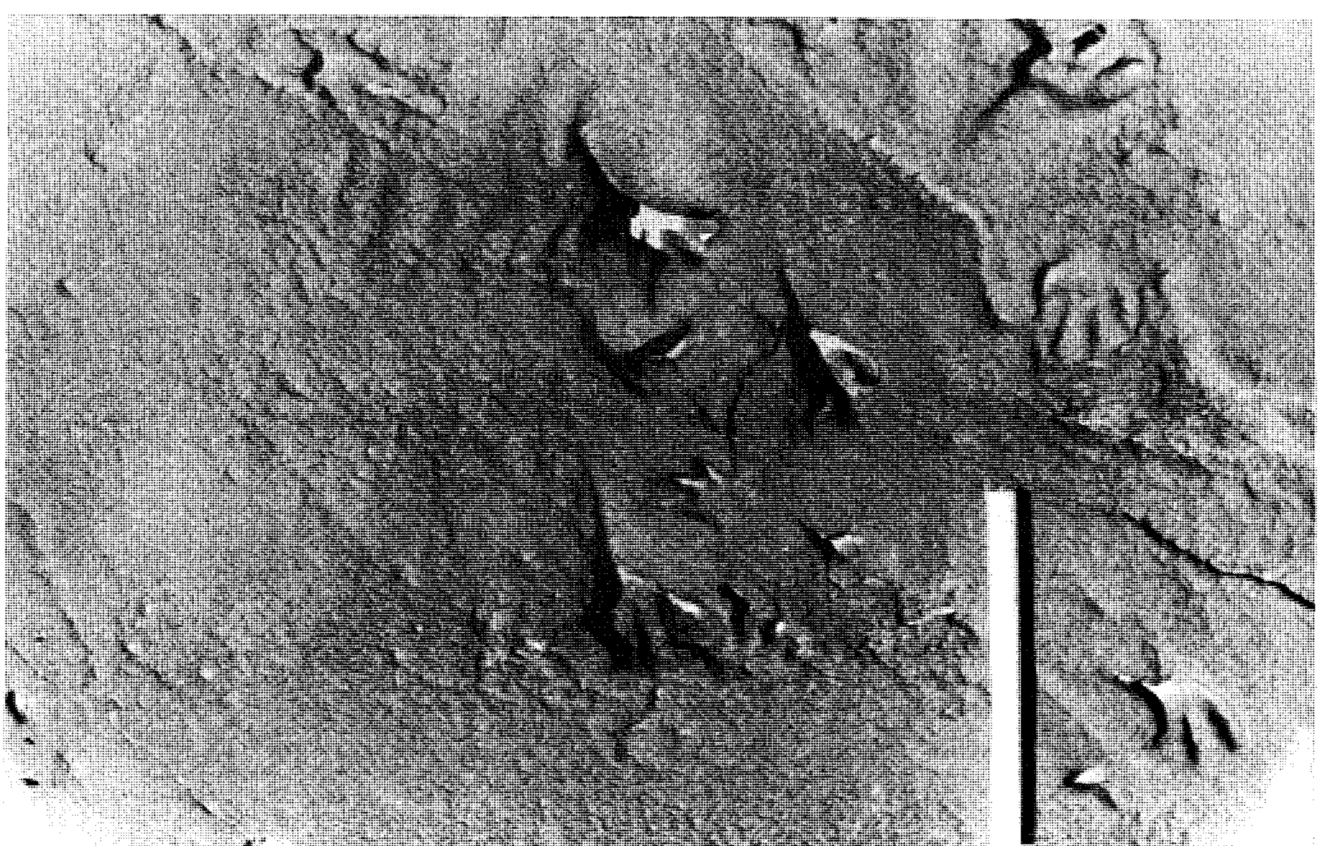


FIGURE 6.–A near view of track-marked surface, coarse-grained matrix, and deeply measured, well-defined prints. Cigarette gives scale of 10 cm.

beach. One is reminded of food-searching activities of modern shore birds.

Just as positive is the evidence that the pterosaurs deserted the scene after a brief visitation; they left the sand in virtually the same state of wetness and cohesiveness as when they arrived. The entire track-making episode may have taken only a few minutes. The preservation of clearly marked tracks of land-living animals always implies a relatively short lapse of time between their origin and burial. The condition of any such tracks, taken in connection with the nature of the sediment in which they are impressed, gives evidence as to whether burial took place in a matter of minutes, hours, or days. In the case being discussed, the tracks are fairly well-defined, small footprints less than 2 cm long are still plainly evident, and large, more deeply impressed tracks in many cases show overhanging lips and peripheral bulges. Considering that the matrix is almost pure sand, this combination would seem to imply burial of the track-marked surface within a few hours. The retention and preservation of such tracks as these is dependent mainly on the cohesiveness of the sand grains, which is in turn determined by the water content of the sand. This phenomenon is evident to anyone who crosses a shelving seaside beach to enter or leave the water. Footprints made in dry sand are nothing more than shapeless depressions, those made in wet sands at the water's edge are likewise blurred and perhaps obliterated by only a few waves. Only in an intermediate belt of moist sand will a person be able to leave distinct well-marked tracks. The physical basis for this common observation is a matter of surface tension. Maximum cohesiveness is achieved when just enough water remains to create a meniscus between adjacent grains. Under normal conditions the moment of maximum cohesiveness is short because evaporation soon removes the last columns of water, leaving the grains largely unsupported.

The covering of these tracks was not only immediate; it was also a gentle process. Aeolian action rather than water action must have delivered and deposited the final cover of sand. This positive statement is based on the fact that water, even without any energetic motion, would have saturated the sand so as to destroy its cohesiveness, thus obliterating or greatly blurring the tracks. The advance of a dune with sand falling or advancing gently down the lee slope and across the track-bearing stratum while it was still moist and cohesive would seem to be the only plausible explanation for the excellent preservation of the tracks.

The only other reported occurrence of pterosaur tracks has this in common with that being described: The imprints had to be made in a short interval between the deposition of sand and its being covered by overlying sediments (Stokes 1957). The covering materials were mud and silt, and the depositing agent was water. The tracks were delicate and vulnerable and would have been entirely or partly planed away by currents capable of picking up and removing fine unconsolidated sand. The conclusion is that after the tracks were made, the water rose gently, mud was deposited, and the trackbearing layer was not reexposed until thoroughly lithified millions of years later.

Evidence of a fairly large body of either standing or moving water may seem incompatible with the theory that the Navajo Sandstone is an aeolian desert deposit. However, the presence of a body of water among sand dunes is not impossible or even improbable. Rivers of considerable size are known to enter low-lying regions of sand where they dwindle away by seepage and evaporation. If wind action is powerful enough and a river small enough, it is entirely possible that the flow might occasionally be ponded between dunes to create sizable bodies of standing water. A river traversing moving sand dunes is almost certain to have a shifting, irregular course. The paleogeography of Navajo time is not unfavorable to this interpretation. The eroded remnants of the ancestral Rockies totaling thousands of square miles lay not far to the east, capable of giving rise to westward flowing streams that drained into the sand-covered area at a lower elevation.

ACKNOWLEDGMENTS

We thank Lynn Ottinger for bringing the pterosaur tracks to our attention; S. P. Wells and R. A. Long, for interest and encouragement; officials of the U.S. Bureau of Land Management and James A. Jensen, for aid in acquiring and preserving the specimens; M. D. Picard, for advice on petrological problems; and Arthur Trevena, for aid with thin-section identifications and photographs. The slabs were collected under permit number 74-UT-033 issued to Madsen by the United States Department of the Interior.

REFERENCES CITED

Folk, R. L., 1977, Stratigraphic analysis of the Navajo Sandstone: A discussion: Journal of Sedimentary Petrology, v. 47. p. 483–84.

Freeman, W. E., and Visher, G. S., 1975, Stratigraphic analysis of the Navajo Sandstone: Journal of Sedimentary Petrology, v. 45, p. 3–26.

Galton, P. M., 1971, The prosauropod dinosaur *Ammorsaurus,* the crocodile *Protosuchus,* and their bearing on the age of the Navajo Sandstone of northeastern Arizona: Journal of Paleontology, v. 45, p. 781–95.

Kamis, J. E., 1977, Petrology and reservoir potential of the Nugget Sandstone of southeast Idaho: In Rocky Mountain thrust belt geology and resources: Joint Wyoming-Montana-Utah Geological Associations Guidebook, p. 221–38.

Pacht, J. A., 1977, Diagenesis of the Nugget Sandstone, western Wyoming and north-central Utah: In Rocky Mountain thrust belt geology and resources, Joint Wyoming-Montana-Utah Geological Associations Guidebook, p. 207–19.

Picard, M. D., 1977a, Petrology of the Jurassic Nugget Sandstone, northeast Utah and southwest Wyoming: In Rocky Mountain thrust belt geology and resources: Joint Wyoming-Montana-Utah Geological Associations Guidebook, p. 239–58.

————, 1977b, Stratigraphic analysis of the Navajo Sandstone: A discussion: Journal of Sedimentary Petrology, v. 47, p. 475–83.

Ruzyla, K., 1977, Stratigraphic analysis of the Navajo Sandstone: A discussion: Journal of Sedimentary Petrology, v. 47, p. 490–91.

Science News, 1973, Tracks of the pterosaur: Probable oldest evidence, v. 104, p. 85.

Steidtman, J. R., 1977, Stratigraphic analysis of the Navajo Sandstone: A discussion: Journal of Sedimentary Petrology, v. 47, p. 484–90.

Stokes, W. L., 1957, Pterodactyl tracks from the Morrison Formation: Journal of Paleontology, v. 31, p. 952–55.

Visher, G. S., and Freeman, W. E., 1977, Stratigraphic analysis of the Navajo Sandstone: Reply: Journal of Sedimentary Petrology, v. 47, p. 491–97.