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Anomalous Impressions in Tapeats Sandstone (Cambrian), Grand Canyon

W. R. Barnhart*

Abstract

A group of 32 impressions is documented in the top of the Tapeats Sandstone at Plateau Point, Grand Canyon. These may be biological in origin, and a brief history of relevant local research is reviewed. This analysis assumes the rapid deposition shown in earlier work, and the implications of that model are explored. One is that thixotropic mobility in the sand when the impressions were formed adversely affected their clarity. Evidence of an original, thin, clay-sheet substrate is explored, as are its implications for preservation. This clay diminished the details of the impressions but served as a mold to faithfully preserve forms in the more mobile sand. Organic and inorganic explanations are considered, and the recognition of regular, linear groups suggests a possible biogenic origin.

Introduction

Plateau Point is a common destination along the Bright Angel Trail in Grand Canyon National Park and a popular side trip from Indian Gardens (Figure 1). Situated on the Tonto Platform of the South Rim, it provides majestic views of the geological succession to both rims (Figure 2). This detached promontory of upper Tapeats Sandstone (Figure 3) has been a popular overlook of the Colorado River below since the arrival of tourism. Decades ago, loose rubble was removed from the northwestern section of the promontory to provide a safe path to a section of pipe railing. The lesser eroded sandstone exposed in this pathway (Figure 1 insert and Figure 3) contains trackways left by a multitude of invertebrates on many layers, and one sandstone layer contains 32 larger impressions this paper will explore.

The impressions may be biogenic, or they may be inorganic features such as percussion marks, erosional marks, or tool marks. Unique sedimentary conditions add to difficulties in identification. However, the location is public and accessible, and the author encourages others to examine the evidence and add to the conversation.

Tapeats Sandstone

Barnhart (2012b) described the Tapeats as a vast sand plain of rapidly depositing sediment. From Plateau Point on the Tonto Platform, isolated outcroppings of the Tapeats can be examined for tens of km in all directions and show little change in the depositional structure. Outside of the canyon, exposures of the Tapeats in central, western, and eastern

* W. R. Barnhart, Birmingham, AL, shinumonow@gmail.com
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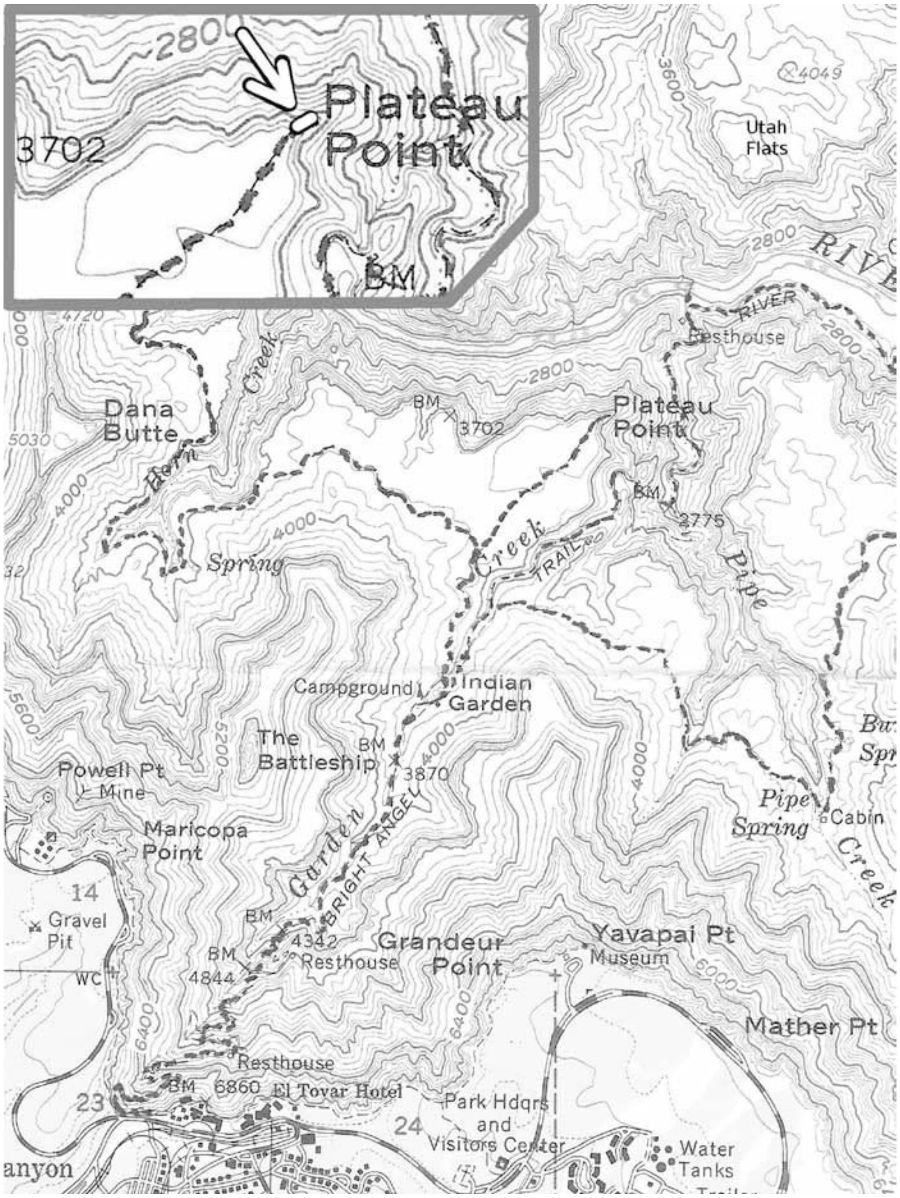


Figure 1. Bright Angel Trail from Grand Canyon village to the Colorado River. Plateau Point is on the southern edge of the Tonto Platform (the relatively flat eroded top of the Tapeats) between Indian Garden's campground and the river. Insert shows the location of Layer 21 on Plateau Point, giving its approximate orientation NE to SW. (U.S. Geological Survey, 1964).

Arizona (Barnhart 2012a) extend the same depositional model several hundred km.

Monadnocks would have provided the only high ground during deposition. They served as sources for loose rubble and potential refuges for animals. But they are sparse; there are few protruding above the Tapeats northwest of Plateau Point. Chadwick and Kennedy (2001) documented one in Ninety-One Mile Canyon (Figure 1) that rises 250 m above the contact with the Precambrian basement and 34 m (112 ft) above the top of the Tapeats into the Bright Angel Shale.

Monadnocks are isolated, rounded hillocks, remnants of the erosional surface of the Great Unconformity. Known examples in the area form a roughly linear arrangement that crosses the area around Plateau Point. Rather than representing ancient receding highlands, they are simply erosional remnants of a massive sheet erosion event (Barnhart 2012a, 2012b). Rubble from these mounds is found in the Tapeats, primarily at its base. Ninety-One Mile Canyon is 2 to 3 km northwest of Plateau Point. At the time the impressions were formed, the top of the Tapeats was a relatively flat sheet of rapidly accumulating sand, broken only by the 34-m-tall hill about 2 to 3 km away.

The layer containing the impressions is just over a meter below the contact between the Tapeats and overlying Bright Angel Shale. Both are dated by trilobites (McKee and Resser, 1945) as "late Early Cambrian age for the upper parts of the Tapeats Sandstone in the Grand Wash Cliffs in the western part of the canyon and an early Middle Cambrian age for the formation in the eastern canyon" (Middleton et al., 2003, p. 94). Thus, the top of the Tapeats is considered progressively younger from west to east; Plateau Point is midway between in location, and presumably in age, about the transition from early to middle Cambrian. The base of the middle Cambrian is placed at about 500 Ma by Beuss and Morales (2003) and 509 Ma by Gradstein et al. (2012).

History of the Find

The impressions were first reported by Mackay (1985). He described five impressions (numbers 2, 3, 4, 6 [or 8], and 9 in this paper). While he did not recognize their groupings, he did propose a biogenic origin based on their size and association with invertebrate ichnofossils. At least one—number 9—he suggested was produced by a three-toed foot. This author visited the site

Figure 2. Plateau Point seen from the Kaibab Trail as a detached promontory of rock situated in the center of the Canyon.

on numerous occasions, spending more than three days there on at least three occasions between 1986 and 1995. Field photos were taken using a 12-in-square string grid for scale. In addition, latex molds were made of impressions 2, 3, 4, 5, and 9, which were used to produce plaster casts.

Local Trace Fossils

Ichnofossils are common throughout Grand Canyon, both vertebrate footprints and invertebrate traces. Gilmore (1926, 1927, 1928) documented tetrapodal trackways in the Coconino Sandstone, Hermit Formation, and Supai Group (Figure 4). McKee (1982, p. 100, as cited in Blakely, 2003, p.150) noted that vertebrate trackways and ac-

Figure 3. Trail across Plateau Point as seen from the approach. Surface of Layer 21 is indicated by the arrow.

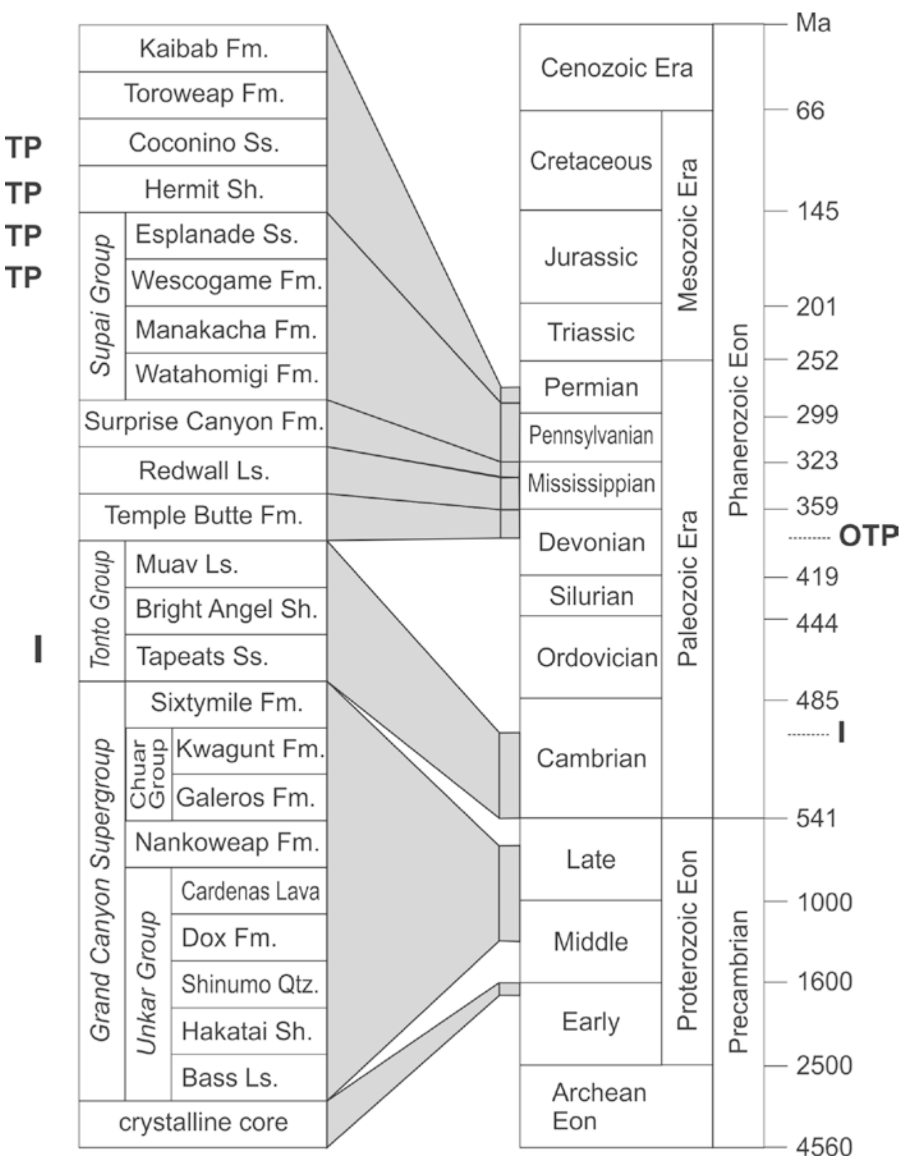


Figure 4. Comparison of the Layers of the Grand Canyon and the geological timescale modified from Beuss and Morales (2003, p. 7). Dates from Gradstein et al. (2012). Placement of tetrapodal prints (TP), oldest tetrapodal prints (OTP), and the impressions described in this paper (I) are shown in the margins.

companying plant debris “suggest the presence of broad floodplains developed during times of regressing seas and semiarid-to-arid climates” in the Supai. In the Coconino, segments of trackways generally move up lee faces of dunes and are ascribed to heat-tolerant vertebrates moving over “Sahara-like dunes [that] were part of an enormous desert that once extended north into Montana” (Middleton et al., 2003, p. 163). Brand and Tang (1991), however, attributed these tracks to aquatic vertebrates because the trackways “exhibited several features that imply that these trackways were not made in subaerial conditions. The animals were swimming in the water part of the time and at other times were walking on the substrate” (Brand and Tang, 1991, p. 1201).

Invertebrate traces are common in many local formations, especially the Bright Angel Shale. In Layers 21 to 28 of the Tapeats (terminology of this study), invertebrate traces are ubiquitous and varied (Figure 5) but appear to form a pattern. Invertebrate traces occur both within the sand and at the sand-clay interface. Some trails that appear to begin and end abruptly may simply represent vertical migration between clay and sand. Some appear to be escape structures, burrowing down into the already-deposited sand. There is a shallow depression in the middle of the study area that may have been a small channel. This is supported by the decreasing number of traces approaching it, suggesting the creatures may have reacted to differences in hydrostatic pressure or moving water. Careful observation in Layer 21 shows that invertebrate traces are not found in the channel, possibly due to increased thixotropy there.

Invertebrate traces are found in association with the other impressions, sometimes overprinting them (#9 and #10) or sometimes being overprinted by them (#24). In short, the invertebrate traces and larger impressions were produced at the same time, both in the clay portion of a sand-clay couplet. This helps us reconstruct a sequence of deposition and trace making.

The varying distribution of invertebrate traces, relative to both the channel and impressions, suggests a rapid response to changing conditions, and effort to cope with a hostile environment. Similar patterns found in Layers 22 to 28, suggest a single population of these invertebrates were restricted to single couplets. If the couplets represent individual waves of a wave train, then each one would bring a new population reacting to a harsh environment, rather than representing multigenerational communities that developed and grew in situ.

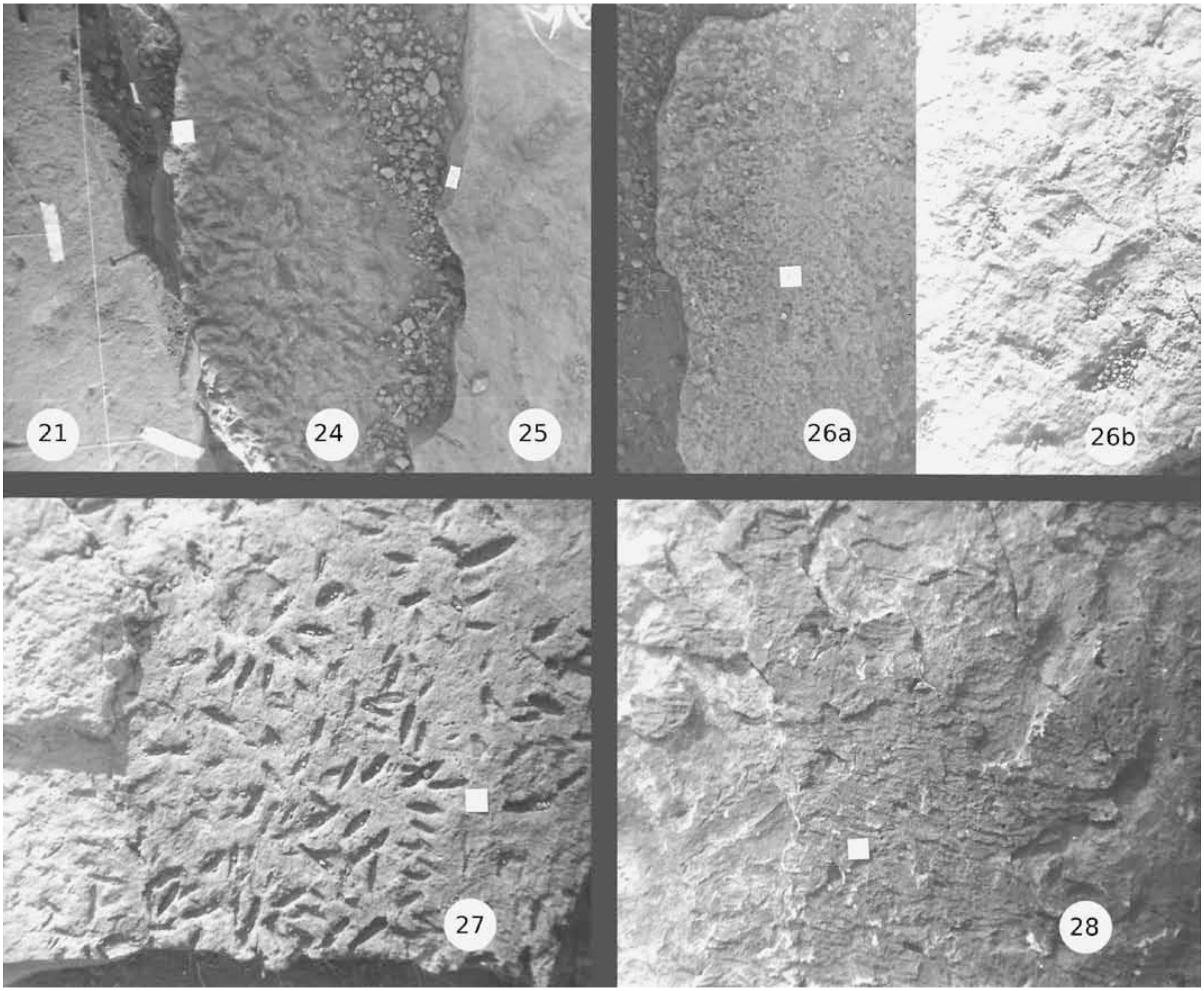


Figure 5. Layers above Layer 21, showing typical invertebrate traces for each layer. Traces are not uniform over entire layer. Layer 26 shows some of the differences that can be seen over short distances. Small white squares for scale are one inch square.

The Impressions

All identified impressions were measured in the field along their greatest diameter. As no lines of impressions had been established at that time, no standardized pattern was used. That was corrected by using the photographs as surrogates and remeasuring the impressions, using the string grid for scale (Table I). These measurements, taken from the photos, are considered more closely associated with the original size of impressions and will be used as the standards for further analysis of these lines. A conversion factor of 185 pixels per inch was used. Significant size differences exist in lines of impressions. If this represents initial conditions, then it would be an argument against the groupings representing trackways. If they are trackways, then a reason for the size discrepancies must be feasible in the sedimentary context.

Sedimentary Setting

The layer containing the impressions is named Layer 21 for this study and is one of a series of alternating shale and sand couplets. Layer 21 is 18 to 25 cm (7–10 in) thick in the study area. The pattern

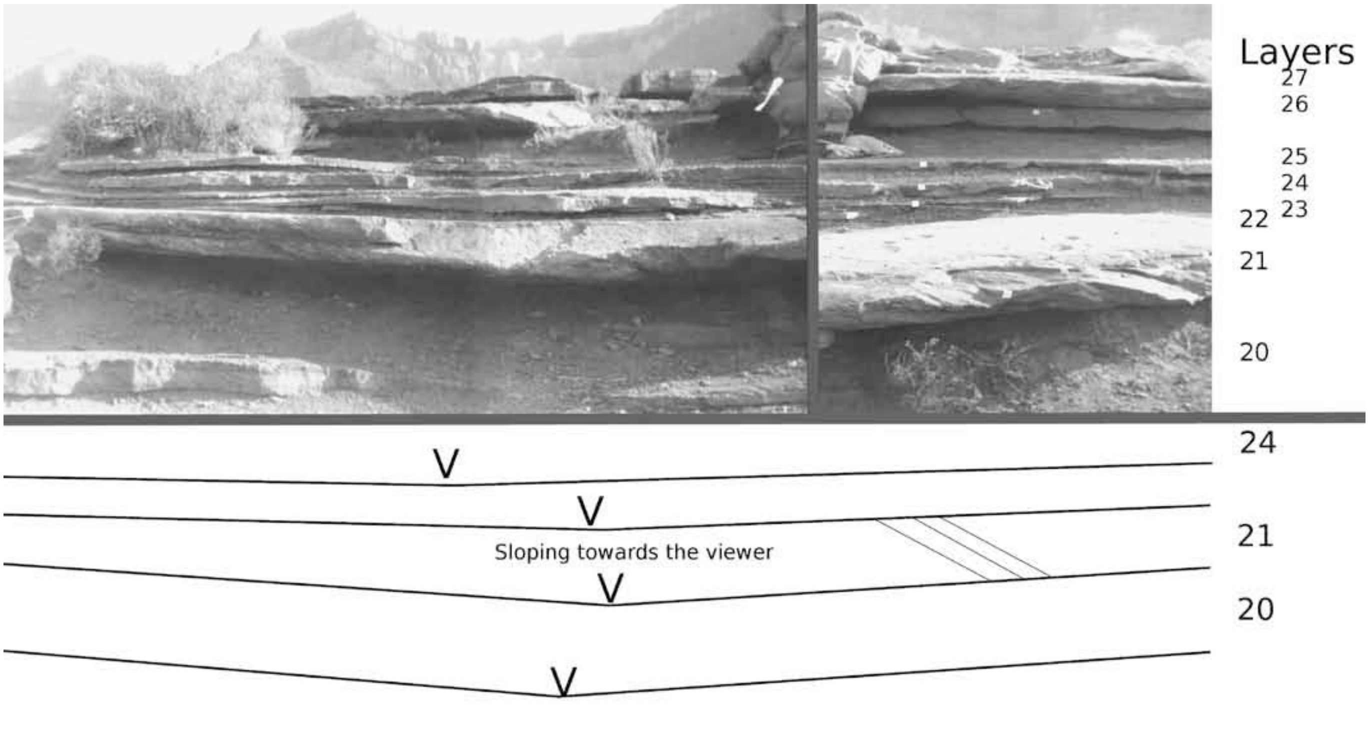


Figure 6. Composite view of Tapeats layers described here. Camera angle in the far right photo was shifted to show above layers more distinctly. Numbering of layers and location of thalweg (V) in each layer is indicated. Lee slope depositional direction is visible in several locations in photo and indicated in diagram.

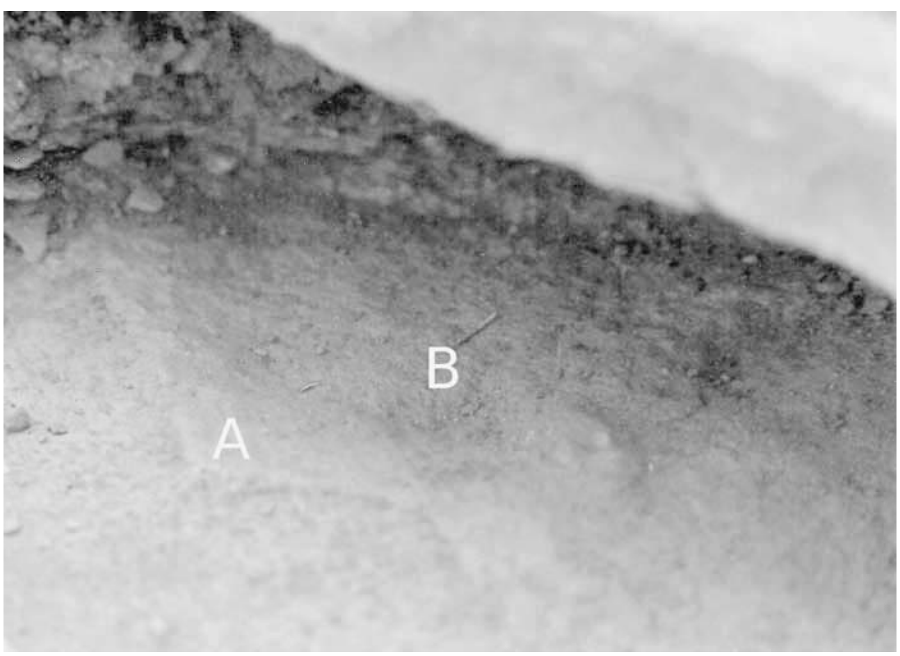


Figure 7. Impression 22, showing the thin layers between Layer 21 and Layer 22, as well as the consistent association of (A) push-up and (B) depression with most impressions.

of bedding planes suggests relatively narrow tongues of sediment were deposited from the east (Barnhart, 2012b), centering on a continuing shallow channel, or thalweg. The presence of the thalweg up into the overlying layers suggests the continuing presence of a channel, which emphasizes the rapidity of sedimentation. Figure 6 is a view of the lee slope depositional surface retained in the lithified stone in both the far right of the photograph, where fracture and spalling have exposed it, and in Layer 21 of the sketch. The alternating sand and shale continues at a finer level, seen in the details of Impression 22 (Figure 7). The impression is only partly visible, with overburden still covering the remaining portion.

Alternating layers of sand and clay is often called *flaser bedding* and is attributed to fluvial or tidal deposition. But

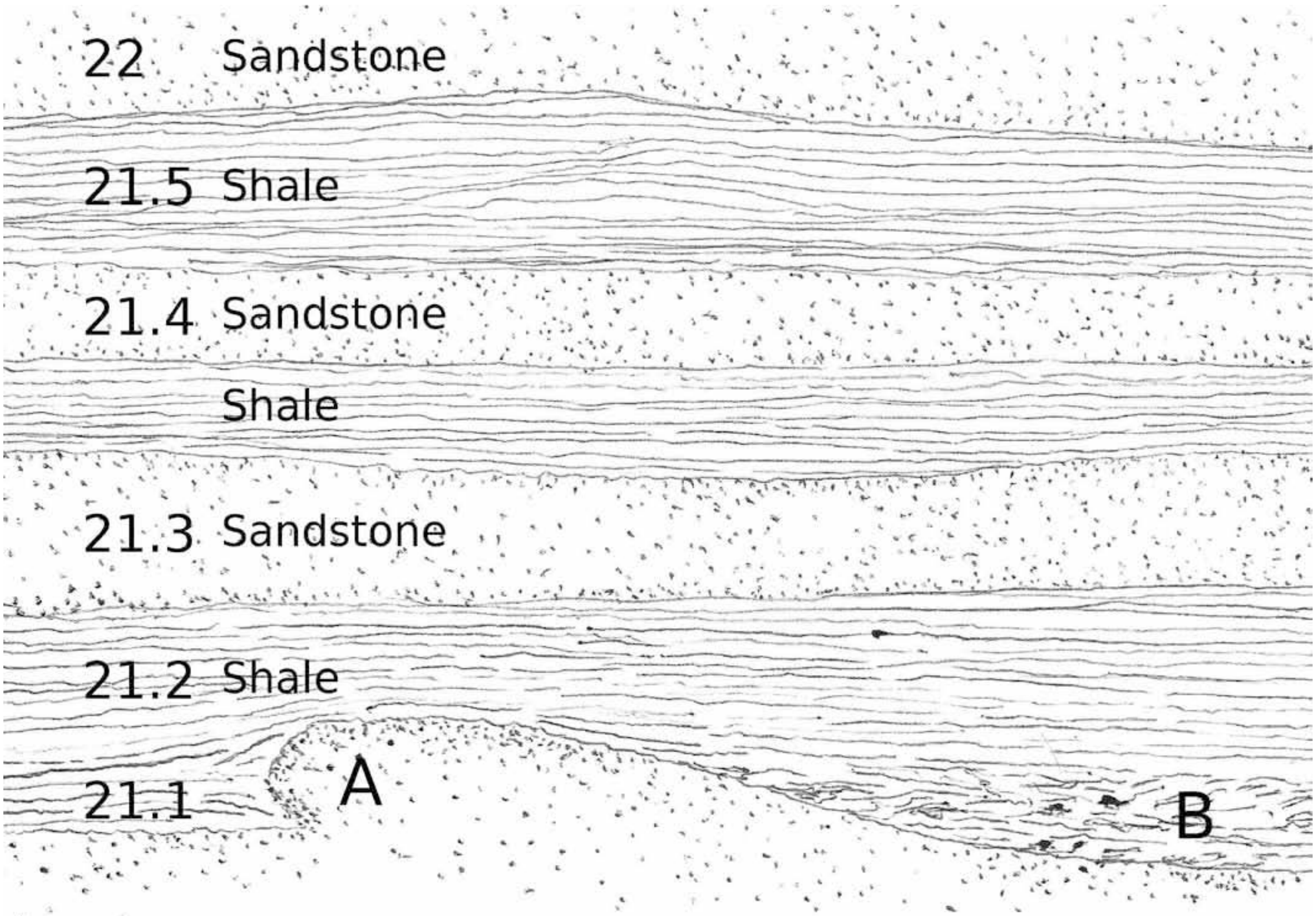


Figure 8. Cross section of small lamina between Layer 21 and Layer 22 through Impression 22, showing (A) the overhanging push-up and (B) distortion of shale layers in the impression and around the push-up. Thin lamina of sandstone, 21.3 and 21.5, 5–7 mm and 3.5 mm thick, respectively, show impressions were made prior to the smaller follow-on waves.

this style of bedding, even with clay, also can be formed at higher flow velocities, a weakness of facies models. Barnhart (2012a) suggested that deposition in the Tapeats occurred in a succession of waves. Each wave deposited a layer of sand in its more turbulent front and clay in the rheologically smoother train. Schieber et al. (2007), in the lab, and Barnhart (2011), in the field, showed that clay can be laid down in higher flow velocities because of its tendency to clump together into sheets. A sedimentary approach is needed to explain flaser bedding that accounts for grain size, flow velocity, depth, bed thickness, wave height, and current direction and continuity.

The timing of the impressions is constrained by the irregular fracturing and displacement of the shale of Layer 22.1 (Figure 8) relative to the continuous sheets above it (Layer 22.2). This suggests that sheets of flocculated clay were broken up by whatever made the impressions after deposition by the front part of the wave. The impression was made after the passage of the initial larger wave (cf. Barnhart, 2012a) but before the passage of the following wave train that deposited thinning couplets of sand and clay (Figure 8). In other words, given the depositional model of Barnhart (2012a), the impression was formed, buried, and preserved in a matter of seconds.

Based on that model, Layer 21 would have been deposited by a single wave 1.6 to 2.0 m (5–6 ft) high, based on a ratio of deposition-to-flow depth of 1:6 to 1:8 (Allen, 1976; Rubin and McCulloch, 1980). The thickness of Layers 22 through 26 indicates a succeeding, shallower wave train. Then the next sequence of a larger wave and follow-on train deposited Layer 27, 1.0 to 1.4 m (3–4 ft) high (Figure 6). The lesser thickness of couplet 21.3 and 21.4, but with the same ratios of sand to shale laminae, suggest the smaller waves were a few cm to tens of cm high (Figure 8). The shale layers are lenticular, not continuous. Layers 22 and 23, while separated by shale in the study area, merge to a single layer to the east (Figure 6). This is consistent with deposition upward continuing in lenses by merging patterns of smaller waves.

The impressions in Layer 21 are unique to Plateau Point to date. Layer 20 contains abundant oxidized iron nodules and can be traced west as far as Horn Creek and as far east as the South Kaibab Trail (Figure 1). No similar impressions have been found in Layer 21 outside the study area. Nor were any observed north of the Colorado River in the Phantom Creek Drainage area of Utah Flats at the same approximate level.

Inferred Conditions at the Time of Deposition

Impressions 1 through 22 were best identified in the field by an associated push-up. Figure 8 shows how the clay layers were fractured and displaced by the push-up (A) but continued above it unbroken. This suggests that the clay layer, approximately 0.25 to 0.5 cm (0.125–0.25 in) thick, had already covered the sand when the impression was made, creating a space between the sand layer and the source of the impressions that was originally occupied by clay (Figures 8 and 9). This sedimentological inference explains the poor detail of the impressions in the sand—that detail was lost when the thin clay layer was removed (Figure 10).

Figure 9. Impression 9 in an orthographic view showing relative depth of impression and height of push-up. Rollover edge of push-up is visible as shadow around outer right hand edge. Push-up is about 0.8 cm high, and impression is measured as 19.5 cm in width, upper left to lower right (dime for scale). Note sloughing along the edge of Layer 21 to the upper right is at the angle of deposition of strata, showing tangential contacts at both top and bottom of strata.

While the absence of the clay obscures some details, much information is preserved in the sand. Small round marks in the sandstone of Impression 9 appear to be air bubbles, perhaps generated by impact and trapped in the clay. Afterwards, the more mobile sand migrated into the bubbles. This suggests that the clay was sufficiently rigid to act as a mold for the impressions, which the relatively mobile sand filled and then lithified. If so, this sand mobility indicates thixotropy.

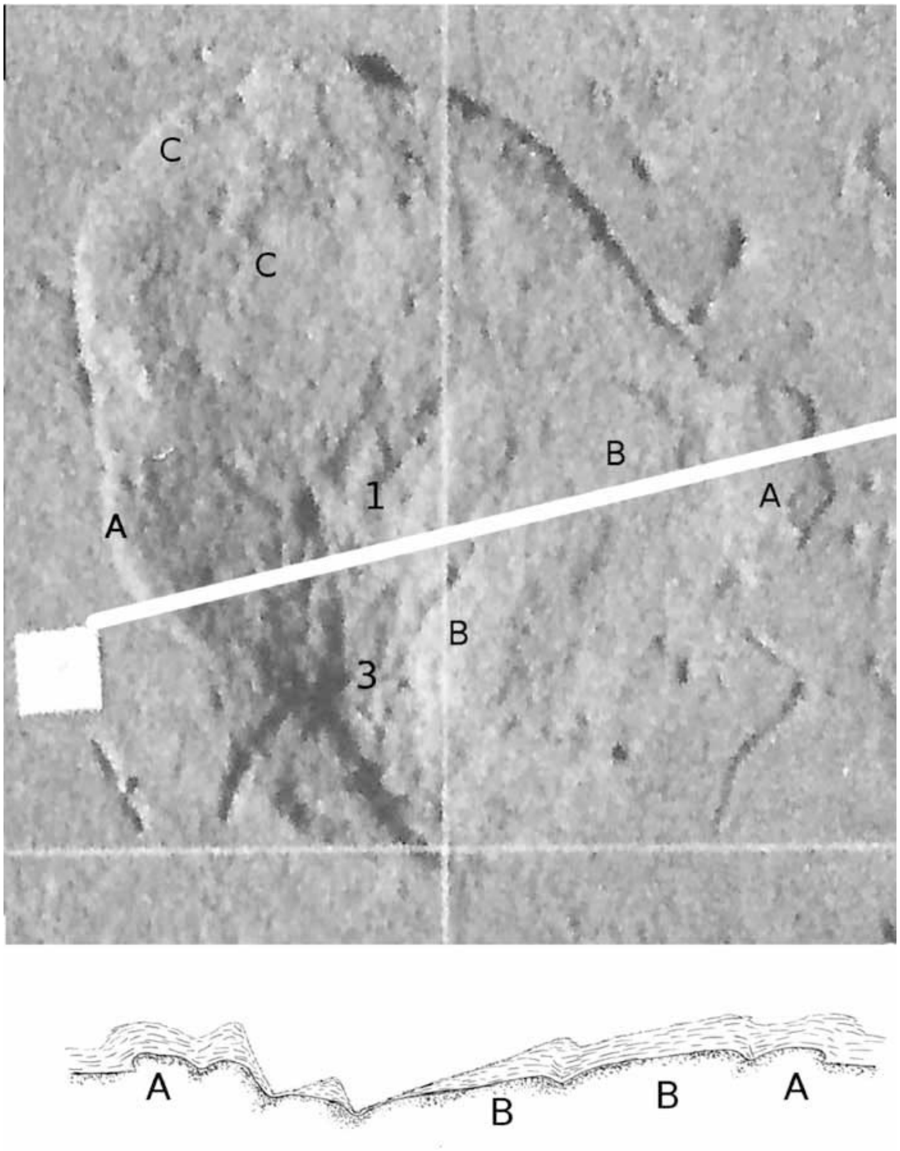


Figure 10. Cross section of Impression 9, showing (A) original push-ups produced by shear, (B) secondary push-ups, and (C) push-up suspended and relocated by moving water.

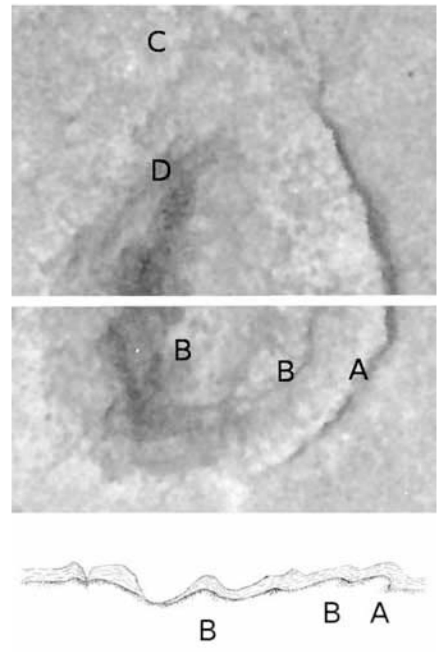


Figure 11. Impression 2 with cross section, showing (A) original push-up produced by shear action, (B) secondary push-up, (C) push-up relocated by moving water, and (D) the multiple layers affected.

Most impressions show a sand push-up to one or more sides (Figure 10A). These border push-ups were likely produced by the original downward impact on the clay-covered sand. Additional push-ups inside the impressions (Figure 10B) lack the overhangs and may show the effect of shear forces originating from the impressions' centers. Impression 9 contains two distinct interior push-ups. They are not aligned and may therefore represent separate impact events. Both are to the left of crescent impressions (Figure 10, 1 and 3), which are the deepest part of the impression. The push-up shown by Figure 10C appears to have been realigned by water flow. The sketch under Figure 10 shows how the clay could have blurred details when the impression formed.

Impression 2 (Figure 11) shows similar features, yet in this impression, the two internal push-ups (B) are aligned to the left of the deepest point. This suggests pressure from two points in a line. Impression 2 consists of the impression, a primary push-up, a secondary push-up, and slumping sand back into the depression. The slumped area increased the diameter at the top of the track; the deeper part probably reflects the original size. Slumping may help explain the variation in impression diameters shown in Table I.

Thixotropy and Clarity

The facies-model style of interpretation can often mask uniformitarian bias,

Impression	Measured in field: Max Dimension cm	Measured in field: Max Dimension in	Measured from photos: Max Dimension pixels	Measured from photos: Max Dimension cm	Measured from photos: Max Dimension in
1	12.0	4.7	135.0	11.3	4.4
2	10.5	4.1	93.3	7.8	3.1
3	9.5	3.7	84.2	7.0	2.8
4	7.8	3.1	87.5	7.3	2.9
5	7.5	3.0	76.2	6.4	2.5
6	7.5	3.0	84.4	7.0	2.8
7	17.8	7.0	178.2	14.9	5.9
8	5.0	2.0	62.8	5.2	2.1
9	19.5	7.7	193.0	16.1	6.3
10	9.0	3.5	113.0	9.4	3.7
11	8.5	3.3	105.2	8.8	3.5
12	7.5	3.0	76.0	6.3	2.5
13	4.5	1.8	50.2	4.2	1.7
14	5.0	2.0	50.0	4.2	1.6
15	11.5	4.5	100.8	8.4	3.3
16	6.3	2.5	77.2	6.4	2.5
17	11.8	4.6	177.0	14.8	5.8
18	13.5	5.3	136.1	11.4	4.5
19	9.3	3.7	96.0	8.0	3.2
20	8.5	3.3	99.5	8.3	3.3
21	7.0	2.8	88.5	7.4	2.9
22	7.0	2.8			
23	7.0	2.8	83.7	7.0	2.8
24	5.8	2.3	71.1	5.9	2.3
25	6.5	2.6	58.9	4.9	1.9
26			88.2	7.4	2.9
27			62.2	5.2	2.0
28			46.7	3.9	1.5
29			50.0	4.2	1.6
30			70.3	5.9	2.3

Table I. Maximum width of prints taken in the field and from photographs using 12 in. string grid as a standard.

and sedimentary rocks are often better understood by a hydraulic interpretation (Barnhart, 2011). When rapidly deposited sediments of a rare event are assumed to have formed slowly, comparison to a modern depositional environment will probably miss the point. This is true of the Tapeats, which is often interpreted by uniformitarian geologists as a shore or nearshore environment, when sedimentary features suggest rapid, catastrophic deposition (Barnhart 2012a, 2012b). Understanding the actual depositional situation points to implications of the event. For the Tapeats, deposition by large waves, depositing sand at a rate of as much as 15 m per hour (Barnhart 2012b), implies several consequences. One pertinent to this study would be the presence of thixotropic conditions.

Thixotropy occurs when an impermeable layer is deposited over sand with a high volume of interstitial water. Increasing overburden pressure causes the hydrostatic pressure of the water in the sand to also increase and migrate toward low-pressure zones. Under the right conditions, sand grains will be suspended in the water, not supporting each other. A break in the overlying layer will cause the release of water and the compaction of the sand. If that were the case where the impressions were made, water moving up into the fractured clay would further diminish details, and the sand would be forced into the overlying mold of the fractured clay.

The rapid deposition of Layer 21.1 atop Layer 21 (Figure 8) could have created this condition. When the impressions were made, excess water could have moved laterally and then upward to relieve the increasing pressure in the sand. Hydrostatic pressure would have been high, allowing the shock of impact that made each impression to also break the clay, resulting in localized liquefaction.

This laterally moving water flowed across the top of the sand and eroded some shallow invertebrate traces. Im-

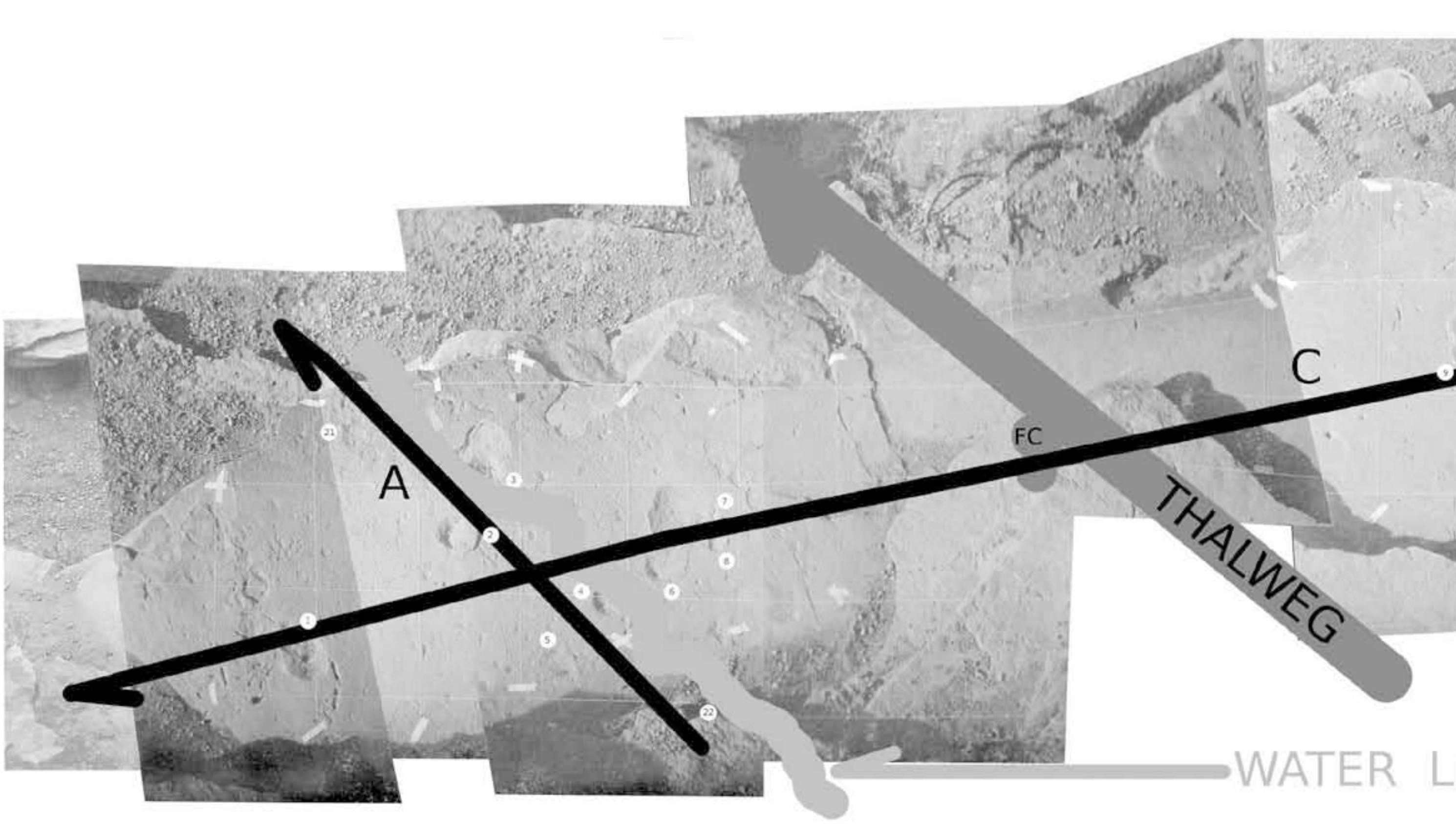


Figure 12. The Plateau Point impressions associated into 6 lines of similar shape and size.

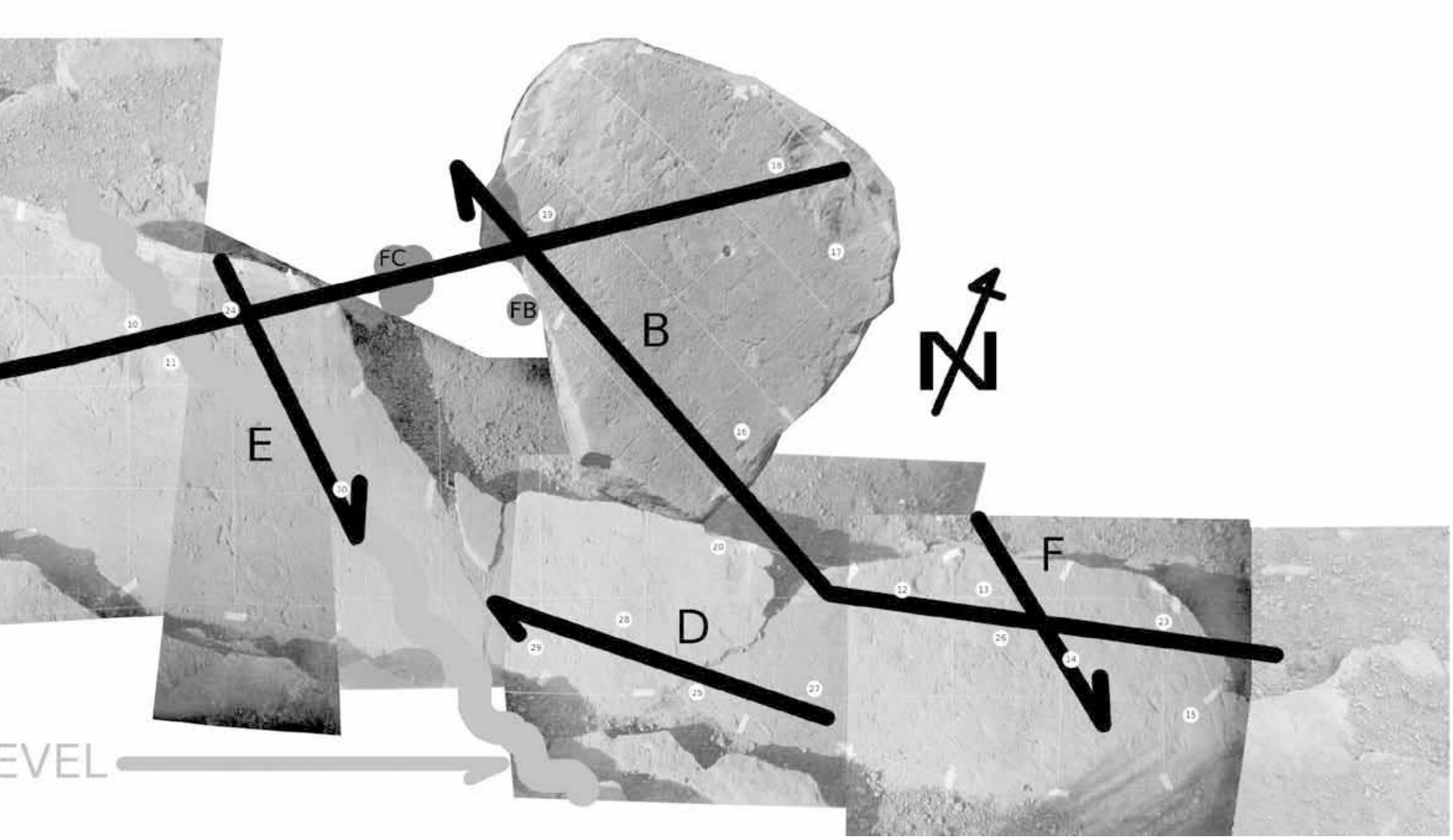
pressions 4 and 5 also appear to have been affected; they are shallower and less distinct than others. Impression 26, on the other hand, is surrounded by invertebrate traces. But it was nearly obliterated before the invertebrate traces, although after the deposition of the original clay sheet. It is so shallow that it was identified in photos only because of its position relative to a line of other impressions. However, Impressions 6, 7, and 8 have few invertebrate traces around them, suggesting the impression disturbed the sand after the tracemakers and that water released from the sand actively obliterated them.

Another reason the impressions are shallow and unclear could have been the firmness of the sand substrate, like walking on wet versus dry sand. Might it be possible to distinguish the relative contribution to the lack of clarity of the impressions to these causes? Thixotropy would preserve detail, but the depth would be shallow. A firm substrate would capture less detail. Impression 26 is a good example of a very shallow but detailed impression. This, along with the evidence from the loss of invertebrate traces, supports a thixotropic explanation for loss of details.

Possible Causes of the Impressions: Arguments for a Biogenic Origin

There are several possible causes for impressions in sedimentary rock, both organic (tracks) and inorganic (e.g., tool marks, erosion marks). To confirm biogenic trackways, Sarjeant (1975) felt a minimum of at least three sequential impressions should be found. Frey (1975) noted that quadrupeds regularly show an alternation of right and left feet and this should be reflected in the impression pattern. Loope (1986), in discussing Holocene hoof impressions from the Nebraska Sand Hills, confirmed them as biogenic based on a linear arrangement of 3 to 5 prints that showed an alignment indicating alternation between front and back or left and right.

With the Plateau Point impressions, one indication of a biogenic origin is the ability to group them into linear series, based on similarities in size and shape (Figure 12). While there is considerable size variation between impressions (5–19.5 cm), none of them are too small or too large to fit within the size range of known taxa, especially if some impressions reflect multiple impacts. The grouping in Figure 12 and Table II combines impressions of similar, but not exact, sizes. Disparities in size are



Line A			Line B			Line C			Line D			Line E			Line F		
Imp.	cm	in	Imp.	cm	in	Imp.	cm	in	Imp.	cm	in	Imp.	cm	in	Imp.	cm	in
2	7.8	3.1	12	6.3	2.5	all avg.	10.0	3.9	29	4.2	1.7	24	5.9	2.3	13	4.2	1.7
3	7.0	2.8	15	8.4	3.3				28	3.9	1.5	30	5.9	2.3	14	4.2	1.7
4	7.3	2.9	16	6.4	2.5				25	4.9	1.9						
5	6.4	2.5	19	8.0	3.1				27	5.2	2.0	avg.	5.9	2.3	avg.	4.2	1.7
21	7.4	2.9	20	8.3	3.3												
22	7.0	2.8	23	7.0	2.8				avg.	4.6	1.8						
			26	7.4	2.9												
avg.	7.2	2.8															
			avg.	7.4	2.9												

Table II. Maximum width of prints grouped by lines as taken from photo measurements.

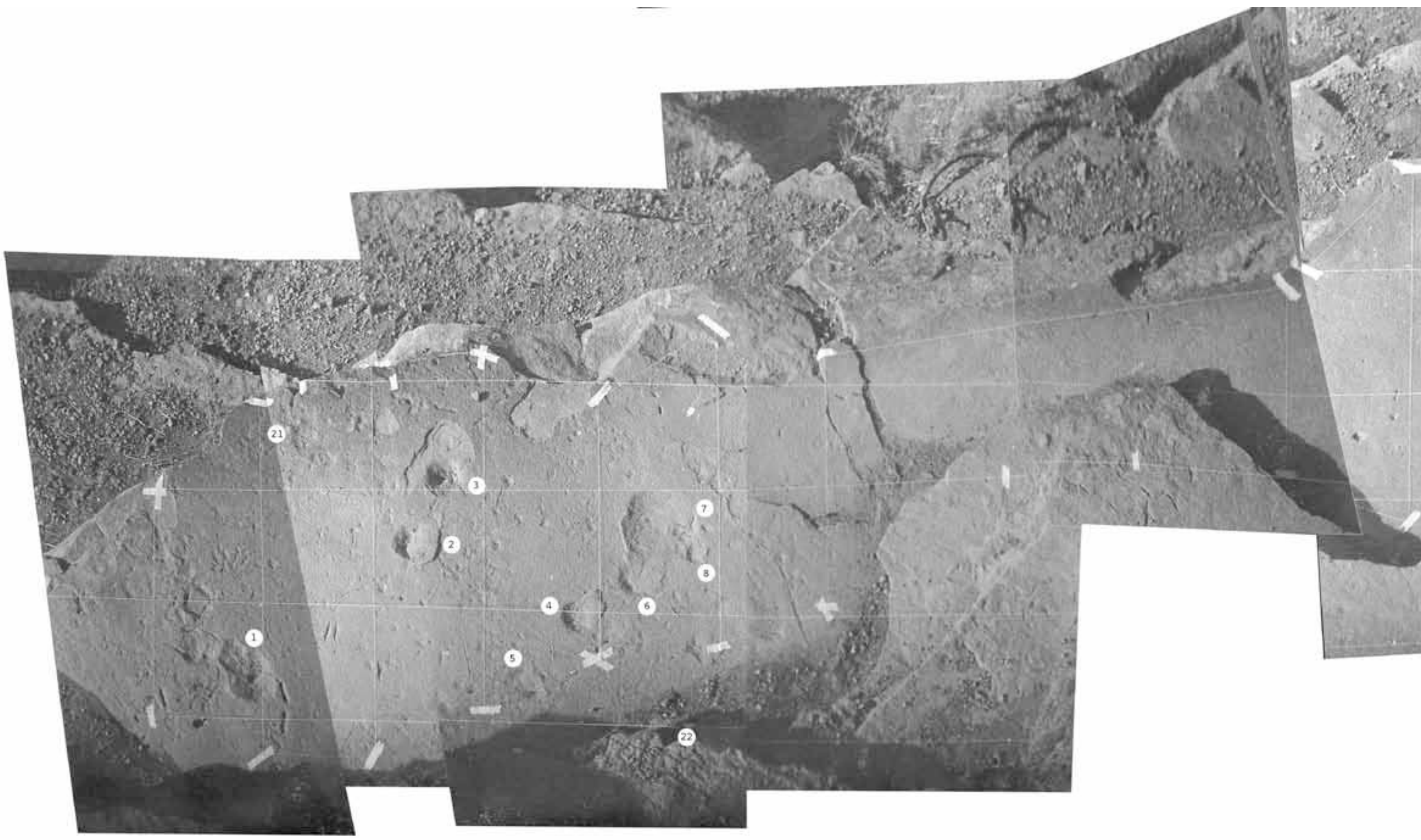


Figure 13. Montage of impressions found in Layer 21 in the study area. String grid was laid out at 12 in (30.5 cm) intervals in both directions, and images were processed to remove keystone affect prior to assembly. Picture of loose rock (Figure 14) with impressions 16–19 was moved and rotated to likely original position.

attributed to multiple impacts and post-impression slumping of the perimeter.

Another indication is the internal geometry, particularly the sediment push-up associated with many impressions. Although percussion marks would also involve the downward pressure of an object on the sediment substrate, that would not be expected for tool marks or erosional features.

Possible Inorganic Causes

There are several possible inorganic causes, including erosional remnants, percussion marks, currents marks, tool marks, and overburden compaction. If the Plateau Point impressions were erosional remnants, their origin should be visible in the three-dimensional framework shown at the outcrop. Figure 9 shows erosion of the outer edge of the layer to the upper right. This is a fracture surface aligned with the depositional lee-slope surface that fractured across the surface toward the viewer. The transition between layers is easily recognized. Invertebrate traces are common over much of the top of Layer 21 and in overlying layers but are largely absent on surfaces of the lee slopes. The ability to see this level of detail of later erosion suggests that if the impressions were erosional, their nature would be visible in the field. If they were erosional remnants, the entire surface probably would show evidence of erosion, including the removal of the invertebrate traces. More important, the "push-ups" could not be erosional features because they then would belong to the overlying layers, not Layer 21.

Another possibility is that they are random percussion marks, caused by larger cobbles or boulders bouncing off the sand substrate during catastrophic deposition or dropped from rafts of ice or vegetation in lower energy conditions. Neither seems likely. There is no evidence of cobbles or boulders in the surrounding sediment above the Lower Tapeats (100+ m below). There are no

other percussion marks in the surrounding sediments.

Finally, Barnhart's (2012b) model of the Tapeats would preclude the presence of such cobbles. the entire area shown in Figure 1 was a broad sand plain, except for a single monadnock several km to the northwest. Given this model, we would not expect percussion marks to be associated with smaller waves but only with the larger waves at the front of the wave train. Evidence around Impression 22 (Figures 7 and 8) indicates deposition by smaller waves carrying sand and clay.

Another possibility is tool marks. These are typically caused by debris carried in currents or eddies that impact the substrate and leave marks. But there is no evidence of tools or tool marks in the surrounding sediments. Furthermore, the depositional model proposed and continued singular location of the small channel indicates sediments deposited by currents and waves moving west without currents or eddies in this area. Several of the lines of impressions are aligned in other directions.

Another inorganic cause might be diagenetic changes after deposition, including differential compaction. This would require localized pressure points. Again, the impressions are extremely rare for this area; a process like differential compaction would be expected to leave more widespread evidence. Furthermore, the layers of overburden shown in Figure 6 show it to be just as flat as Layer 21, just as the underlying layer, Layer 20, is also.

Although McKey et al. (1971) were able to produce pseudomorph concavities at the bottom of the lee slopes of prograding sediments that appear to mimic a biogenic origin, Sarjeant (1975) recognized that those occurring on bedding planes are more likely to be biogenic. Since Layer 21 is a bedding plane, not the base of a lee slope, McKey et al.'s (1971) pseudomorphs are not a likely explanation either.

Implications of a Biogenic Origin

Tracks and trackways in the Tapeats Sandstone would be of significant interest. Footprints and trackways are definitive time stamps in a rock and are useful in discerning animal behavior and geographic range (Lockley and Hunt, 1995), even in the absence of corresponding body fossils (Brand and Florence, 1982). Some have questioned how tracks and trackways could have been left during the Flood (e.g., Aufdemberge, 2004; Whitmore, 2009). Others have used footprints to help define its progress (Froede, 2010; Oard, 2001, 2011; Snelling, 2010).

The main reason prints would be of interest is that the oldest documented tetrapod footprints occur in Devonian strata in Poland (Niedzwiedzki et al., 2010), dated between 391.8 and 397.5 million years ago (Ma). Other Devonian tetrapod prints have been documented in Australia, Brazil, Greenland, Scotland, and Ireland (Murphy, 2006). Prints in the Cambrian Tapeats would call for a fundamental reassessment of our understanding of evolutionary history. For that same reason, great caution must be used in the further study and conclusions from these impressions at Plateau Point.

Figure 14. The loose rock in Figure 13B as it now lies. Gap is approximately 0.5 m (about 18 in) and 2 m (6 ft) west of its original position.

Extent and Characteristics of the Plateau Point Impressions

Their occurrence in "Cambrian" strata argues against a biogenic origin within the standard uniformitarian/evolutionary history. But that limitation is not as severe in a biblical history. It seems unlikely, as noted above, that inanimate objects or physical processes could have produced six lines of such similar but diverse impressions at such regular intervals. To better assess their origin, we must understand the nature of these impressions carefully.

A montage of Layer 21 (Figure 13) provides a photographic replication of Plateau Point at the time the fieldwork was originally done in the late 1980s. The only change was the photographic relocation of a single rock slab to its position prior to its breaking off and sliding a short way downhill when the trail was constructed (Figure 14). The shape and position of the slab make the relocation relatively simple. Figure 13 shows 30 identified impressions. Another two were found just outside the study area and are shown in Figure 15.

The ability to group these impressions into the aligned segments (Figure 12) suggests a biogenic origin. Further work is needed. Will the patterns stand up to mathematical analysis and compare with recognized biogenic causes? These are questions for further research.

Discussion

Invertebrate traces and body fossils in the lower Paleozoic sequence at Grand Canyon show better preservation in the clays rather than in the sands like the Tapeats. The overlying Bright Angel Shale has abundant *Cruziana* trackways, although their body fossils are found only on separate parting surfaces. This makes more sense in a catastrophic model; invertebrate trace makers would have begun creating traces wherever they were carried by waves.

Associated body fossils would also be helpful in confirming a biogenic origin, but tracks and trackways are commonly accepted as viable fossil evidence by paleontologists. Woolfe (1990) recognized that traces alone were enough evidence to redefine an entire facies attribution, and Froede and Cowart (1996) used trace fossils to evaluate differing depositional environments between uniformitarian and young-earth Flood interpretations of the Dougherty Gap. In the case of these impressions at Plateau Point, further research is encouraged.

Conclusions

Based on fieldwork done between 1986 and 1990 and subsequent examination of field photographs, the 32 impressions at Plateau Point can be logically grouped into six tentative trackways, A to F (Figure 12 and Table II). Inorganic causes

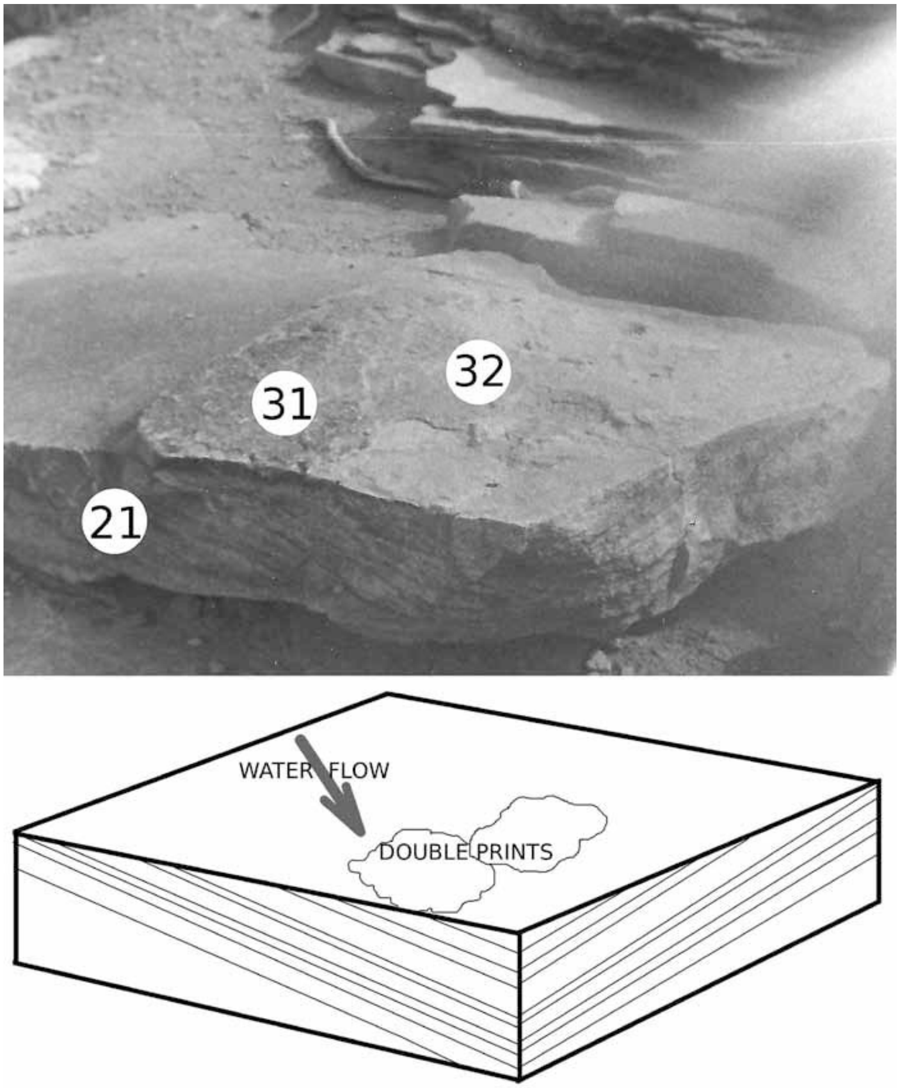


Figure 15. Impressions 31 and 32 are approximately 30 feet west from Figure 13. Block diagram (below) shows sedimentary layers and direction of current (parallel to thalweg, Figure 13). These are the only two impressions not found in Layer 21 but in the overlying layer. However, they appear associated with one of the potential lines, C, indicating a high rate of deposition.

for these features do not appear to fit the existing evidence, given the depositional model of Barnhart (2012b). Further fieldwork should be carried out at Plateau Point, especially if the Park Service ever excavates additional overburden to improve the trail. However, sufficient data exist here for more detailed quantitative analyses that may strengthen or weaken hypotheses regarding origin. The impressions are quite anomalous, in any case, simply because of their rarity in the region and their stratigraphic location and deserve further study.

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