Supplementary material

1. Stratigraphic sections measured in the Dripping Spring Quartzite

The measured sections (A, B, and C; Fig. 1 in main text), correspond to the Barnes Conglomerate, the Middle Member, and the Upper Member respectively.

The Barnes Conglomerate at Horton Creek (Section A; Fig. 1c-A; GPS coordinates 34.343568°, -111.091556°). Although well known by geologists and students, the Barnes conglomerate at Horton Creek has never been formally reported. From base to top, it consists of matrix-supported conglomerates, with well rounded to sub-angular clasts (from 5 mm to 12 cm) within an arkosic to quartzitic matrix. The maximum thickness of the conglomerate at this section is ~3 m. Thin (< 50 cm) sandstone beds and lenses (often capped with finely, layered siltstone) are interbedded with conglomeratic beds. These sandstones may present eroded upper surfaces from which intraclasts were ripped and embedded in the overlying bed. Coarsening upward levels of the conglomerate may be seen overlying thin sandstone beds. Shallow (< 70 cm) channels are present at different levels of the conglomerate (Fig S1), and denote upward thinning. Sedimentary biostructures occur on sandstone surfaces, including sand folds and sand ridges.
Fining-upward, and thinning-upward (< 1 to 12 cm thick) sandstones and siltstones occur above the conglomerate where only fine textures were found. Ripple and desiccation marks are commonly found in these sandstone-siltstone levels. Wrinkle marks, mud chips, gas vesicles, and sand ridges may also be found there. These rocks are similar to those from the Upper Member, and differ from the ones from the Middle Member in color and texture. Although the contact between these two units not exposed, the drastic change in lithology and the similarity between these beds and those from the Upper Member at Coolidge Dam, may indicate a lack of Middle Member facies between the Barnes and its overlying deposits at Horton Creek.

The Barnes Conglomerate overlies the Pioneer Formation, which includes the Scanlan Conglomerate. The latter represents braided fluvial deposits (1). A same clast provenance has been proposed for both conglomerates (2, 3). It is likely that both conglomerates had a similar tectonic origin. Both conglomerates likely followed tectonic faulting of the basin boundaries (2, 4), which uplifted older Precambrian terrains that provided the clastic material for their formation. Likewise, much of the immature sandstones and siltstones of the Pioneer Fm and DSQ are compositionally similar
The deposition of the Barnes conglomerate at the studied locality displays a characteristic matrix-supported conglomerate that is not seen in all the Barnes outcrops (2). This attribute may be related to viscous flows around proximal source areas (5), and thus imply a considerable distance from the shore. The parallel bedding of the finer sandstone units, above the conglomerate, that contain abundant mud chips and occasional dewatering structures, combined

with desiccation features on bedding planes, suggest cycles of channel flooding, with the overbank deposition of fine-grained materials on floodplains, or within channels during periods of waning flow, followed by desiccation of the depositional surfaces. This upper, finer portion of section A may represent part of the Upper Member, and thus a wedge close to the northern edge of the basin.

The Middle Member at Parker Canyon (Section B; Fig. 1c-B; 33.775598°, -110.976729°). From base to top, it consists of tabular strata of arkosic sandstone (Fig. S1), that culminate with thinner and finer sediments, usually capped by laminated siltstones. This intermittence of rhythmic fining-upward sandstone is more frequent toward the top. These strata display lateral variation in less than 1-2 Km in linear distance to the East, usually exposed as steep cliffs, but maintain a more-less tabular geometry throughout the basin. Lower strata often contain channels of clast-supported conglomeratic lenses, 1-2 m in thickness. Thickness of strata is variable throughout the section (<1 to >100 cm, and typically >3 to < 80 cm). Planar and cross stratification is seen in various strata. Ripple and desiccation marks can be seen on exposed bed surfaces and become more abundant toward the top of the section, where wrinkle marks and gas vesicles also occur.

Alternation of tabular and lenticular bedded sandstones throughout the section suggests that deposition within shallow channels alternated with blanketed, shoreline deposition, perhaps due to the alternation of transgressive (high-stand) and regressive (low-stand) conditions due to either periodic marine incursions (2), or elevated lake levels. The occurrence of both trough cross-bedding and planar stratification in sandstone beds, as well as symmetrical and asymmetrical ripple marks is consistent with a variety of hydrodynamic conditions (undefined flow directions and transport velocity) during deposition. Desiccation polygons, wrinkle marks and sand ridges crowning fine-grained sandstones and siltstones on top of tabular sandstone, suggest widespread subaerial conditions, especially toward the top of the sequence. This is also consistent with well-developed gas vesicle horizons at upper levels. Intermittence of rhythmic fining-upward sandstone is more frequent toward the top, indicating less standing water and more desiccation over time, perhaps also a slight decrease in coarser materials. Overall, the fining-upward sequences at Parker Canyon imply a more distal location in relationship to the source area, or perhaps a leveling of the source area resulting in declining stream gradients and decrease of coarser input. The bedding styles and sedimentary structures of sandstones, combined with the bedding plane features seen in the fine-grained units suggest cycles of overbank flooding, followed by the desiccation of floodplain areas, consistent with deposition in a mid- to distal alluvial environment as explained by Boothroyd and Ashley (6).

The Upper Member at Coolidge Dam (Section C; Fig. 1c-C; 33.179088°, -110.530132°). From base to top, it consists of coarse to medium (but also fine) grained, cross- and planar stratified sandstone, with conglomeratic and microconglomeratic channels. At places, sandstone top-beds display erosion from overlying conglomeratic microchannels. A thick (~4-5 m) white quartzite wedge marks a distinctive change toward the middle of the section. Above the white quartzite, sandstone beds become thinner, and eventually grade into reddish to purplish siltstone-mudstone beds with planar to wavy laminations (Fig. S1). Nearly all bedding surfaces of siltstones and mudstones display desiccation features. Most of the fine grained strata contain mud chips embedded in the matrix. These strata also display parallel lamination and low-energy cross stratification. Also notable in siltstones-mudstones is the pervasiveness of Iron oxides (hematite) as part of the matrix.

This section records a more-energetic regime at the base (e.g. shallow braided channels), with a gradual transition to less energetic regimes (flooding plains). The red-purplish units indicate the establishment of mudflats that were exposed to episodic floods (given the thin bedded siltstones), frequent subaerial exposure, and further desiccation. This is interpreted here as deposition on distal alluvial systems (7).

1. Middleton LT, Trujillo AP. 1984. Sedimentology and depositional setting of the Upper Proterozoic Scanlan Conglomerate, central Arizona. In: EH Koster, RJ Steel. Canadian Society of Petroleum Geologists. Memoir 10. Calgary, Alberta. 189-201
2. Granger, H.C., and Raup, R.B., 1964, Stratigraphy of the Dipping Spring Quartzite, southeastern Arizona: U.S. Geological Survey, Bulletin Report 1068, pp. 119.
3. Shride, AF. 1967. Younger Precambrian geology in southern Arizona: USGS Prof. Paper 566, 89 p
4. Whitmeyer SJ, Karlstrom KE. 2007. Tectonic model for the Proterozoic growth of North America. Geosphere, 3 (4): 220-259.
5. Hampton, M.A., Buoyancy in debris flows. *Jour. Sed. Petrology* **49**, 753 (1979).
6. Boothroyd, J.C. and Ashley, G.M., in *Glaciofluvial and Glaciolacustrine Sedimentation*, edited by A.V. Jopling and B.C. McDonald (SEPM Special Publication, 1975), Vol. 23, pp. 193.
7. Harvey, A.M., in *Arid Zone Geomorphology; Process, Form and Change in Drylands*, edited by D.S.G. Thomas (Wiley, Chichester, 1997), pp. 231.

2. Sonoran desert sampling site.

The biogenic and biogenic-like sedimentary structures described in the main text were found in or near flood plains (not necessarily playa lake environments) of the Sonoran desert, in the SW portion of Arizona, USA. The sampling site (32.744557°, -113.639805°) is a large flood plain (San Joaquin wash) at the end of small, intertongued alluvial fans (bajadas) derived from a small volcanic range (Mohawk range). Typical facies of proximal, medial, and distal areas were observed along a transect perpendicular to the source (Fig. S2). The average annual temperature ranges from 11 to 33º C in winter and summer respectively. The average annual precipitation is around 213 mm (Data from the Western Regional Climate Center, Desert Research Institute, Reno, Nevada; http://www.wrcc.dri.edu/COMPARATIVE.html).

Biological Soil Crusts and other microbial communities here are dominated by cyanobacteria (moss and lichen being sparse or altogether absent). Adjacent to military facilities, the study sites are pristine, having been free of human or agricultural activities for many decades. A great variety of primary sedimentary structures can be seen at the surface, including abundant ripple and desiccation marks. Sedimentary biostructures are also pervasive, especially in the flooding areas, where finer sediment accumulates.

3. Supplementary figures

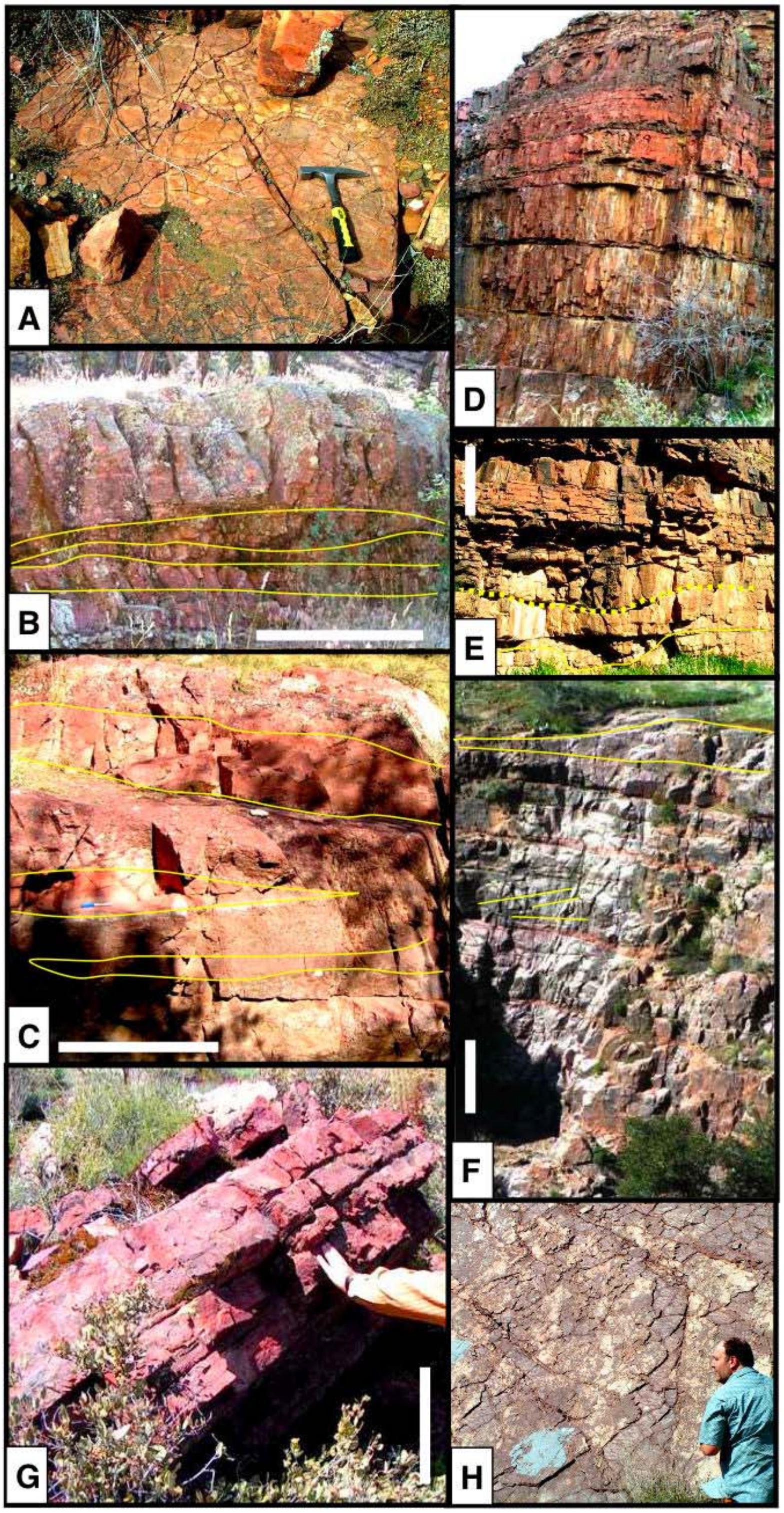


Fig. S1. Examples DSQ outcrops. A-C = Horton Creek. A) Desiccation cracks on sandstone-siltstone overlying the Barnes Conglomerate. B) Barnes conglomerate displaying channel features. Yellow lines mark the main bedding planes. Scale bar = 2 m. C) Matrix-supported Barnes conglomerate. Yellow lines delineate sandstone-conglomerate intercalations. Scale bar = 50 cm. D-F = Parker Canyon. D) Portion of the DSQ Middle member displaying tabular geometry of the strata due to rhythmic deposition. Scale bar = 2 m. E) Upper section of the Middle member showing shallow channels (yellow lines) underlying thin bedded strata. Scale bar = 50 cm. F) Lower portion of the Middle member showing wedged strata and cross stratification (yellow lines). Rhythmic deposition is well marked by differential rock coloration. Scale bar = 2 m. G) Upper Member at Coolidge Dam. Outcrop of red-purplish, finely laminated mudstone-siltstone. Scale bar = 50 cm. H) Typical bedding surface at Coolidge Dam covered with desiccation cracks (gray areas are modern graffiti).

Fig. S2. Modern Sonoran desert study site. A) Map with the location of the Mohawk Range, near Yuma, AZ, and the San Joaquin flood plain (32.744557°, -113.639805°). Scale = 5 Km. B) General view of the coarse alluvial sediments at the proximal source area (indicated as 1 in A), looking toward the range. C) Prograding sequence of non-lithified sand deposited on basement rocks, and covered by even thicker conglomeratic proximal facies (indicated as 2 in A). Scale = 1 m. D) Surface view of the less-coarse mid-alluvial facies (indicated as 3 in A). Scale = 50 cm. E) Surface view of the medial facies but closer to the distal side (indicated as 4 in A). Note the much less pebbly material and the pervasive development of earth cracks. Scale = 50 cm. F) Distal facies of the dry, muddy flood plain (indicated as 5 in A), looking toward the range. The pebbly-looking ground is due to abundant roll-ups. Scale = 50 cm.

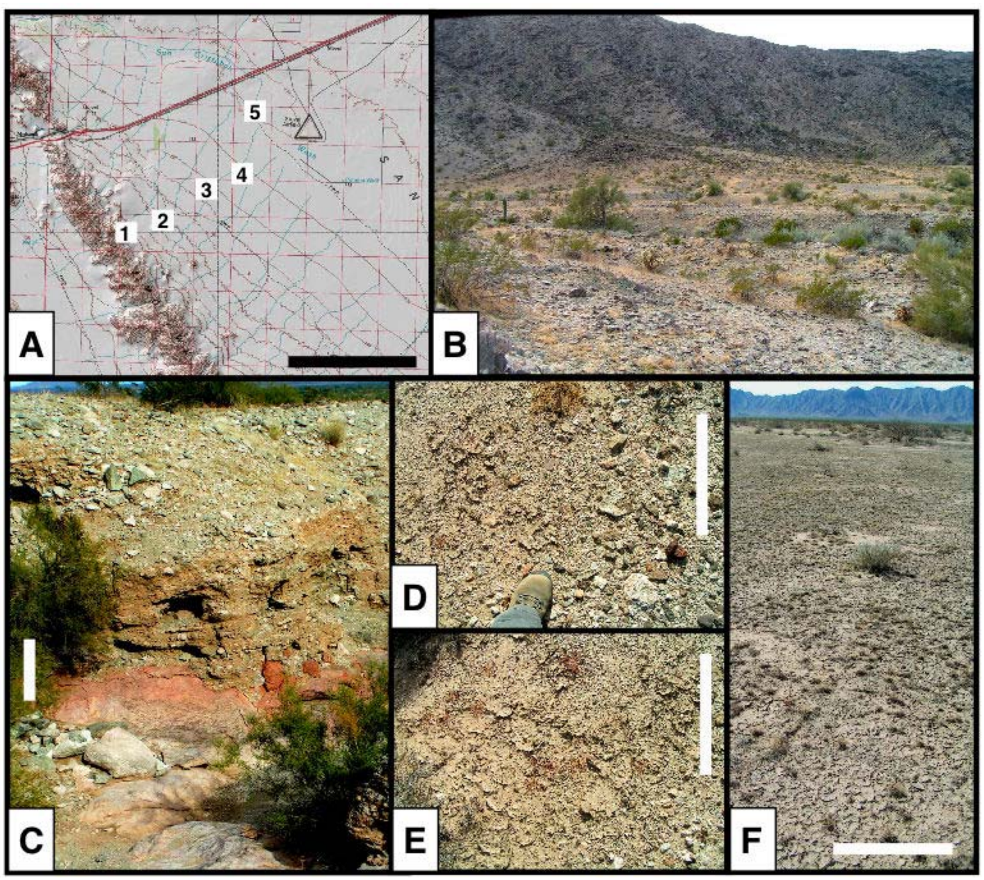
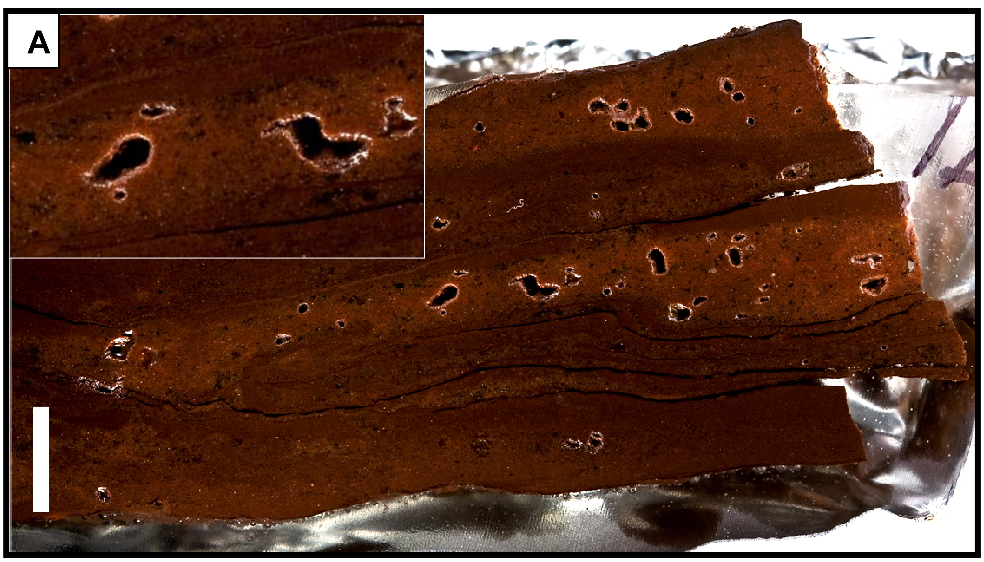
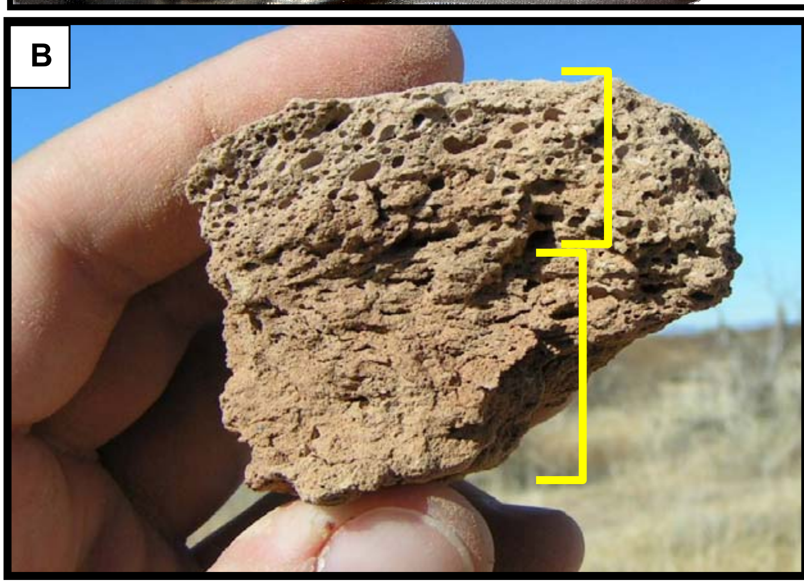
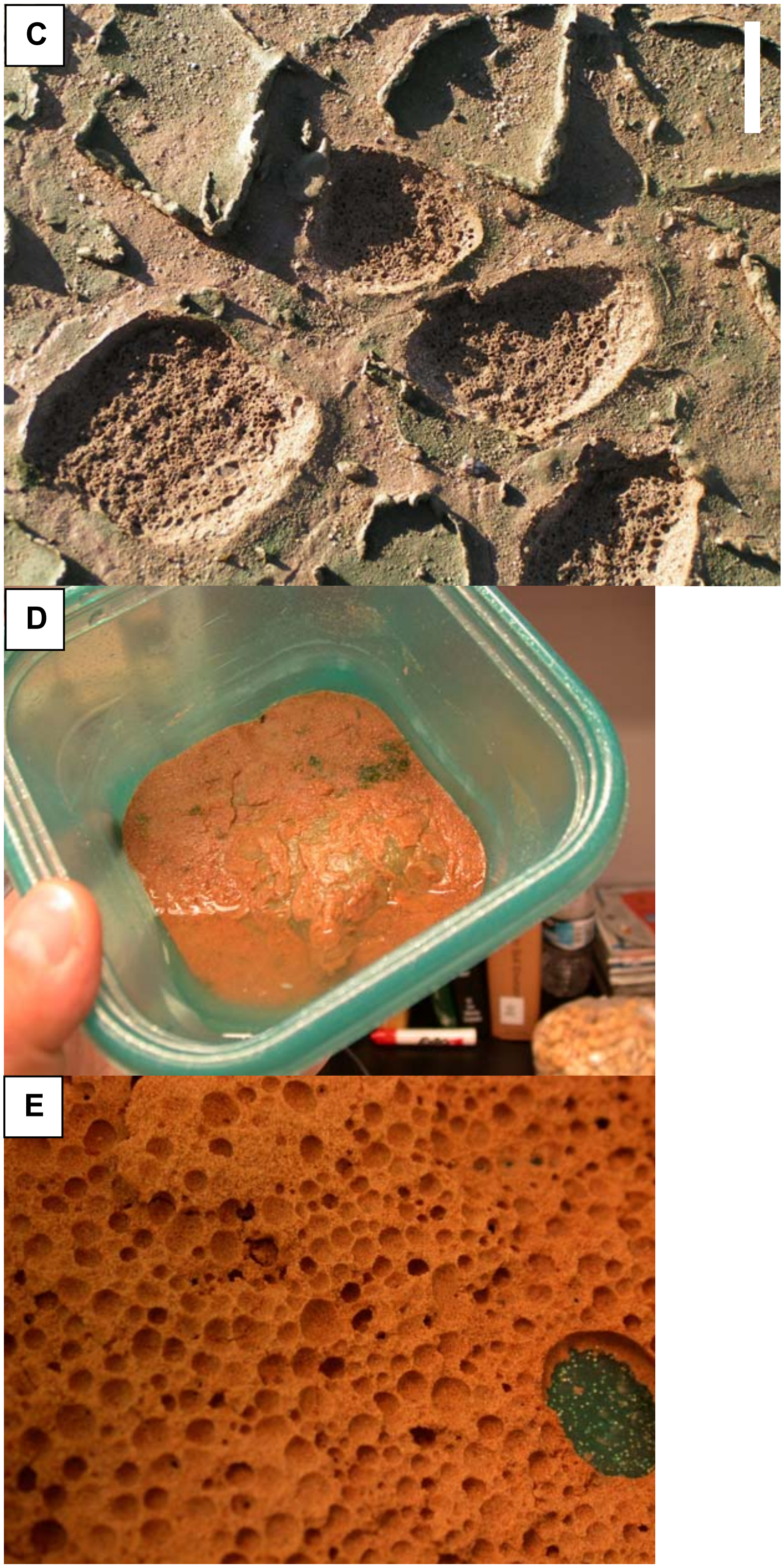


Fig. S3. Gas vesicles and vesicular horizons. A) Wet sawn rock displaying empty fenestral gas vesicles. The rock was one of many others, from different geographic and stratigraphic locations, displaying empty voids (see inset). The rock was first embedded in resin to probe for its filtration and filling of voids that could be exposed to the atmosphere by fractures, and through which the void infillings could have escaped. Dozens of sawn samples demonstrate that no voids were ever infilled. No fractures are seen associated directly with the voids, but follow the natural layering of the original deposit. Scale bar = 2 cm. B) An example of a vesicular horizon (marked upper zone) under a thin microbial crust. Elongated, subhorizontal vesicles are seen in the bottom zone (marked) along with ped formation. C) Gas vesicles forming a vesicular horizon under cyanobacteria-infested desiccation polygons. Scale bar = 10 cm. D) Water-saturated sandy substrate, previously inoculated with cyanobacteria (*Microcoleus vaginatus*), which has formed a cohesive top layer. E) The cyanobacteria layer in picture D was removed to expose well rounded gas vesicles. F) Example of fossil gas vesicles showing a thin, layered deposit on top of them (arrow), and their contribution to the irregular topography at the surface. Scale = 2 cm.






C
D
E

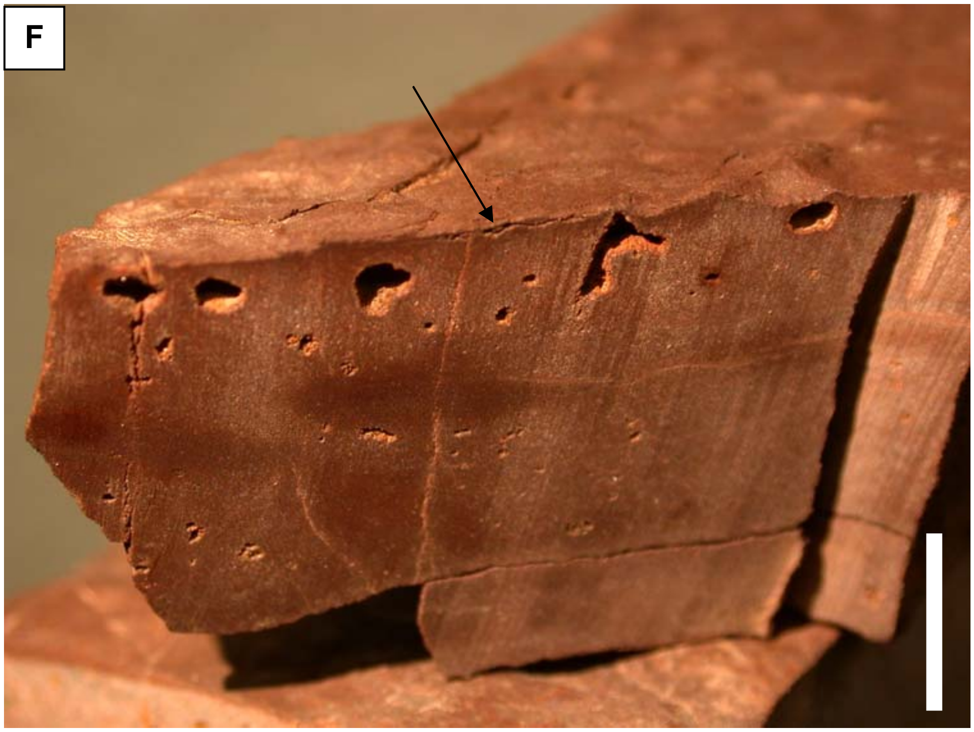
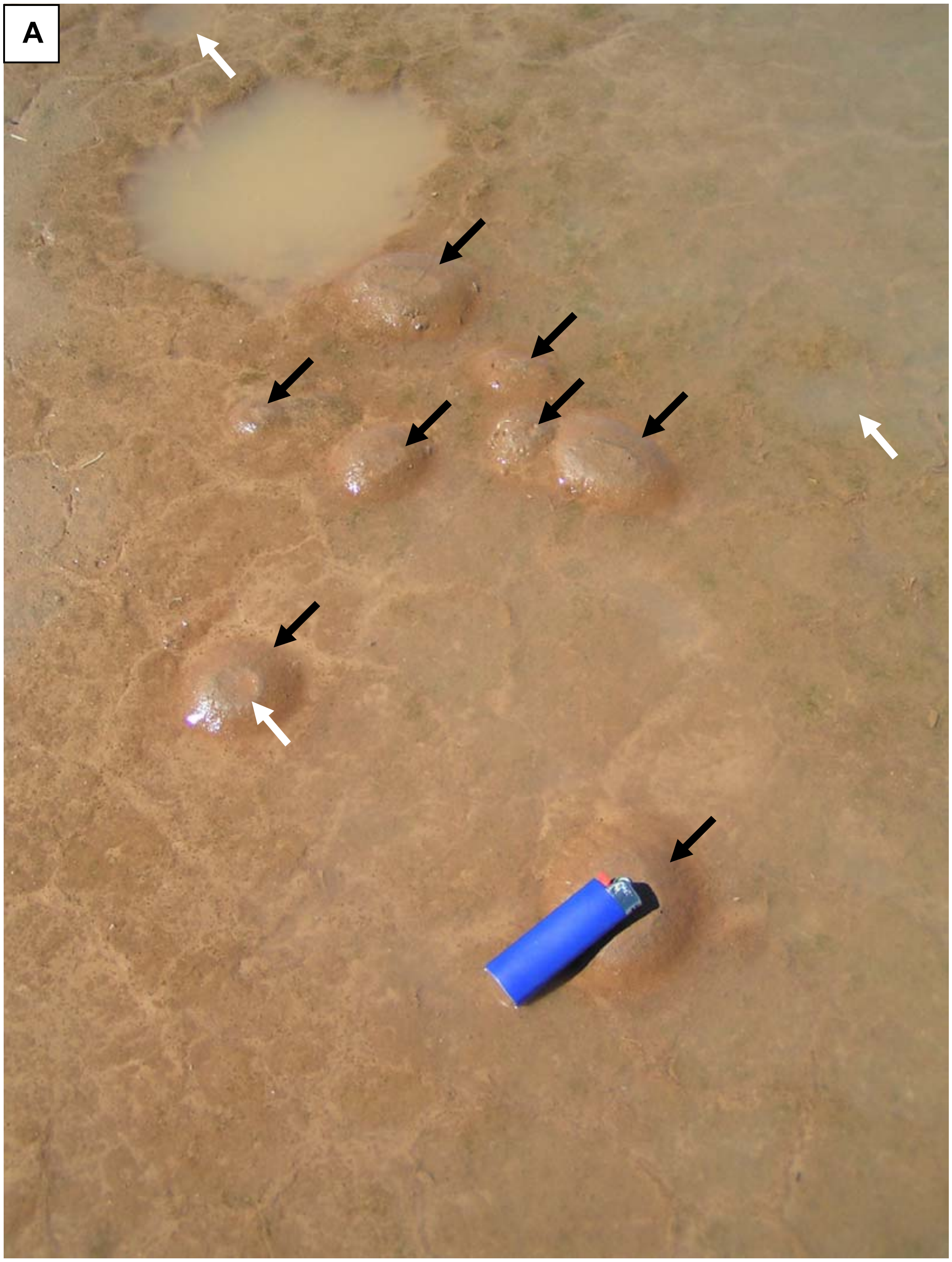
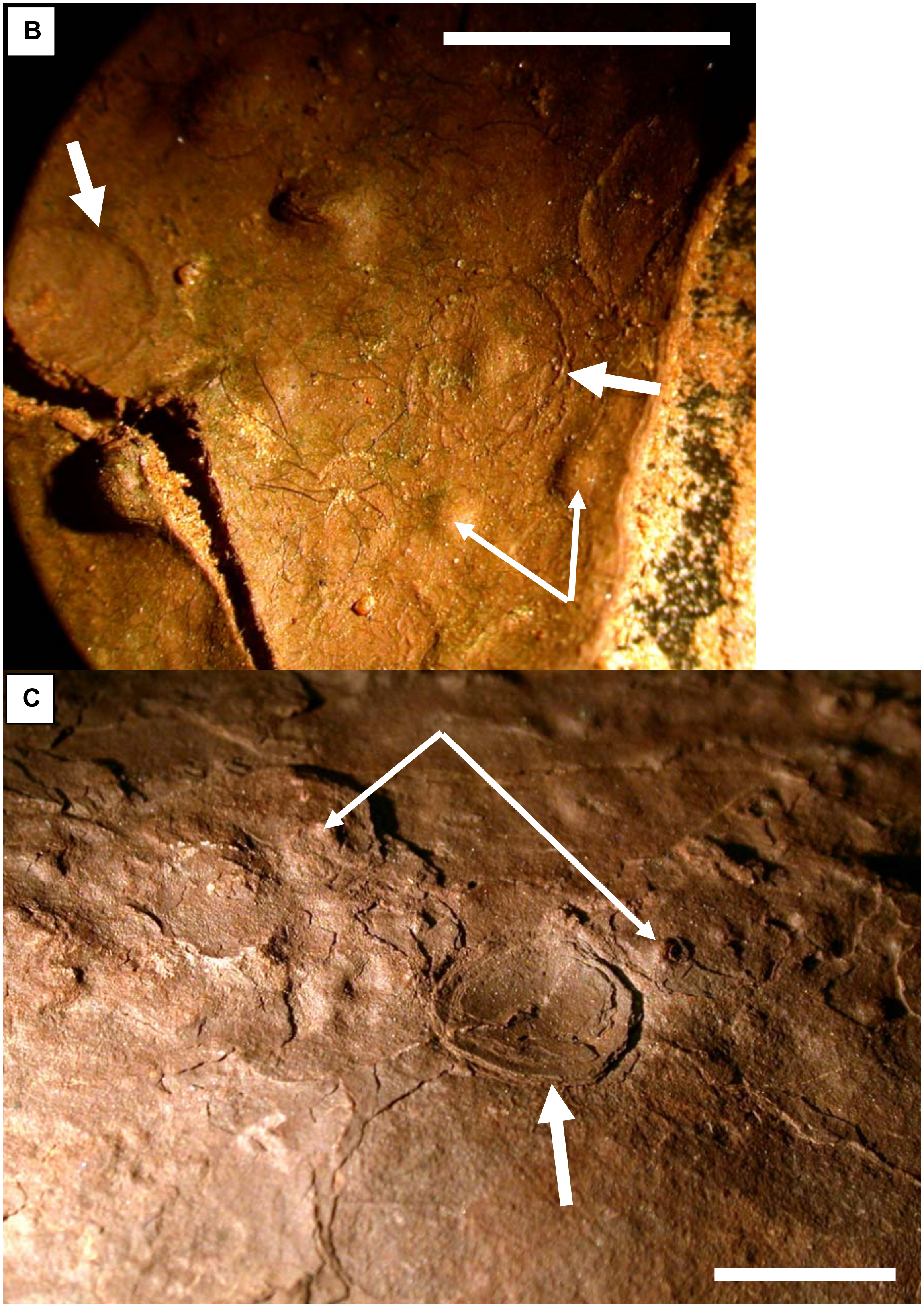

F

Fig. S4. Gas domes and collapsed gas domes in arid soil surfaces. A) Several gas domes are shown on a desert top soil colonized by cyanobacteria after a flood. Conspicuous gas domes are bound by a thin exopolysaccharide film (black arrows). Some show the initial stages of collapse (flattened tops). Several collapsed domes (white arrows) appear as round "pools". B) Delicate and thin bubbles had formed on a natural sample before collapsing (big arrows) and leaving an imprint. Bulges can also be observed (small arrow). C) Proterozoic sample showing thin siltstone layers forming a collapsed bubble-like feature (big arrow). Note bulges (small arrows) also associated to gas vesicles in the same rock sample (see Fig. S3). D) Proterozoic sample showing coarse, allochthonous grains on the bottom of a collapsed gas dome. E) This pair of collapsed gas domes (arrows) are slowly being filled with allochthonous, most notoriously coarser sediment. Scale bars = 1 cm.


A


B
C

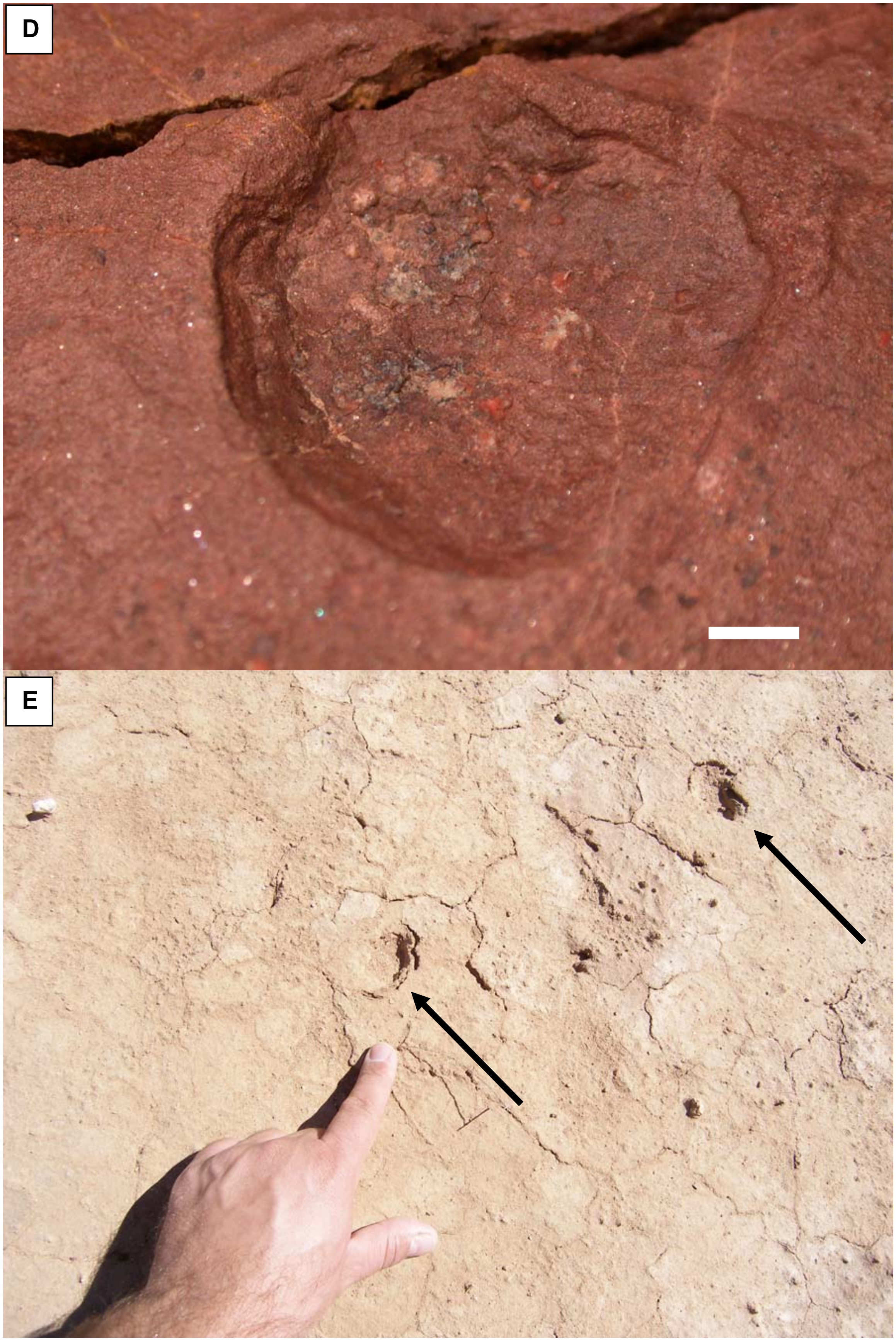

D
E

Fig. S5.