# ERASURE OF FIRST-ORDER TRIBUTARIES VIA CLIMATE CHANGE: LESSONS FOR MARS FROM EARTH.

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**Introduction:** Since Mariner 9 first imaged fluvial channels on the surface of Mars thirty years ago, one of the continuing problems of its hydrologic history has been the apparent absence of small, first-order tributaries to the large outflow channels and the larger integrated channels of the highlands [1]. Drawing on terrestrial examples from the northeast Sahara, where Quaternary climate has cycled between a savannah and hyperarid environment, the Mars-analogous landscape has been used in the past to promote the efficiency of aeolian processes [2-4] and the fluvial processes of sapping and headwall erosion [5,6]. Following up on the work of Haynes [7] more recent work on the landscape of the Sahara has emphasized the role of climate change in sculpting surface features [8]. Although we have yet to determine whether climate change on Mars was monotonic or cyclic during the late Noachian/early Hesperian, the processes may have the same end product. Discussed here are the processes of tributary obscuration based on terrestrial examples of aeolian infilling, landscape lowering and stabilization by development of a lag surface, and planation due to sand sheet formation and bedrock erosion.

**Aeolian Infilling and Drainage Integration:** The present wind regime in southern Egypt and northern Sudan is from the north, with a short reversal of monsoonal winds from the south in March and April, which does little to reverse the direction of dunes or wind streaks. Remnant tributaries affected by the active sand are located on the Gilf Kebir plateau on the border of Egypt, Sudan and Libya, and on the limestone plateau that separates the western Desert of Egypt with the Nile valley. In the Gilf Kebir, relict channels are oriented primarily north-south on the northern and western margin of the plateau, and east-west on the eastern margin. The incised, 500 m wide channels of the eastern margin are little affected by the winds that cross at 90 degrees, where only a few falling dunes extend across the channels, creating natural dams for accumulation of lacustrine sediments. Such a geologic setting on Mars would be an excellent place for investigations of paleo-environments and evidence of biotic activity. In one wadi in the Gilf Kebir, a 12 m section of lacustrine sediments has yielded artifacts and pollen from the past 9,000 years when the climate was wetter [9]. On the north end of the plateau, the wadis parallel to the wind are completely sanded up by climbing dunes, and are recognizable only through large scale patterns visible in orbital images and low scarps on the east and west sides. The heads of each of these classes of channels show different morphology. The east-west channels have abrupt headwalls, no traces of tributaries, and a planar upland lag-covered surface, whereas the north-south channels retain some low, 1-2 m deep tributary patterns that contribute to the main wadis, but in several instances drain into local pans on the surface of the plateau. Prior studies have suggested that the major wadis formed during the late Tertiary, and as evidenced by the lacustrine sediments behind the dune dam, the wadis were active at least sporadically during the pluvial periods of the Quaternary. Apparently, those same wet periods responsible for eroding and depositing meters of lacustrine sediment did not impart enough stream power to entrench the tributaries on the surface of the plateau, once that surface was protected by coarse lag. Even on the north end of the Gilf Kebir, drainage that became disintegrated prior to the Quaternary failed to re-establish itself despite an estimated 500 mm of rainfall during pluvials. The lesson for Mars is that once disrupted, tributaries are difficult to reintegrate, and local runoff, playa formation and infiltration may dominate under more clement conditions.

**Denudation, Landscape Inversion and Lag Formation:** Closer to the Nile valley the local interbedded shale, limestone and fine-grained sandstone create a different environment of erosion and sedimentation. In the Kiseiba region, orbital radar has revealed a system of drainage channels that had gone unrecognized in numerous field studies, despite the presence of fluvial sands and gravels. Here, the source regions of the channels are difficult to determine – rather than originating at a bounding scarp to the west, the first-order tributaries occur in discrete sand-sheet filled shallow basins separated by narrow, 1-2 km wide curvilinear traces of sandstone and shale bedrock exposures. Topographic cross sections of radar-detected channels indicate that the sand-choked channel centers are several meters higher than the margins. Here, it is likely that the major drainage was also formed during the late Tertiary, and climatic cycling during the Quaternary resulted in erosion of the susceptible bedrock, with sand sheet formation by redistribution of granules and sand in local depocenters. The granule armored surface of the sand sheet is more difficult to erode than the shale during the hyperarid intervals that dominate the Quaternary, resulting in sand-choked channels equal to or higher than their source tributaries. Landscape inversion here makes the paleo-hydrology difficult to interpret, but the lack of tributaries in this environment is most likely due to differential erosion.

**Sand Sheet Formation:** The ultimate end product in climatic cycling into low relief is the sand sheet, in the northeast Sahara, the Selima Sand Sheet. Here, similar processes of landscape inversion likely occurred as in Kiseiba, but the surface retains little of the bedrock margins of the channels. Instead, fluvial erosion during pluvials produced local rolling topographic relief of a few meters, which was infilled during hyperarid intervals [8]. The resulting planar surface lacks evidence of both tributaries and channels, which were recognized only through orbital radar data [10].

**Lessons for Mars:** We have not yet identified all the processes that have erased the small tributary channels on Mars, and it is still possible that in certain regions, runoff occurred in the subsurface via piping. Based on these terrestrial processes that can obscure first order tributaries, the absence of these channels does not automatically require a lack of overland flow and drainage integration, and hence, shouldn't rule out a climate involving rainfall in the martian past.

## References

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