Chapter

FLUVIAL GEOMORPHOLOGY OF MARS: BACKGROUND TO SEPARATE BIOGENIC AND ABIOGENIC EFFECTS AND TO IDENTIFY CLIMATE CHANGE RELATED FEATURES

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ABSTRACT

Biogenic effects might also influence the geomorphology of fluvial systems. An important issue in this aspect is the separation of abiogenic effects, what is quite difficult on the Earth as small level of bacterial influence is present almost at all locations. One possible solution would be the analysis of fluvial systems beyond the Earth. Here Martian fluvial structures are overviewed in this aspect, comparing the related effects and consequences on the two planets. Although our knowledge in this topic is not enough yet for firm conclusions, it is worth evaluating this question already. Based on the review presented here higher fluctuations of discharges, elevated influence of subsurface waters, and weaker bank stability is expected without biogenic effects. Beside these issues Martian

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systems also provide useful information on the connection between climate change and fluvial systems, as the range of climatic fluctuations were much larger on Mars than here on Earth.

INTRODUCTION

There are several biogenic factors that could influence fluvial produced geomorphological structures on the Earth surface [1]. To separate the biogenic and abiogenicic factors, rivers at desert and arctic terrains are used [2], while another field: the fluvial geomorphology of Mars is poorly exploited in this aspect, although several fluvial and lacustrine systems existed there [3]. In this chapter a review is given on the general properties of such ancient Martian systems, focusing on possible issues related to the lack of biogenic effects there, analyzing mainly riverbank related erosional and depositional structures. Beside abiogenic effects, the role of climate change is also important in fluvial systems' changes [4]. This later topic could also be effectively analyzed on Mars, as the range of change in climatic conditions there in the past was larger than here on Earth, and because of very low resurfacing rates on Mars, very old fluvial structures can be easily analyzed on the surface.

METHODS

During the analysis of fluvial structures on Mars various datasets, mostly from remotely recorded ones are used, including images (from HRSC [5], CTX and HiRISE detectors [6,7]) and topographic datasets (DTMs from MOLA laser altimeter [8] and from HRSC stereo images [9]).

Analog research is highly important in the field of fluvial geomorphology, as on the Earth only restricted range of factors influencing fluvial morphology could be analyzed, especially it is difficult to separate biogenicic and abiogenic effects as biogenic influence is present almost everywhere. Even in desert areas only the effect of certain parameters could be analyzed. Opposite to this, working with fluvial geomorphology on other planetary bodies (like structures produced by ancient rivers on Mars or on Titan), beside the effect of different gravity, temperature and pressure regimes, differences exist also in the litology, erodibility, liquid percolation, and chemical conditions. Although the great differences and the restricted amount of data of these extraterrestrial rivers and riverbeds make difficult such comparisons, they could provide useful inputs to better understand some aspects in fluvial geomorphology of the Earth. In this chapter no detailed description of Martian is presented, as it is out of the scope of this book, and can be red in the cited references.

FLUVIAL SYSTEMS ON MARS

Analyzing Martian surface features, there are such ones help to better understand fluvial geomorphology on the Earth, especially near to riverbanks where riparian vegetation might be present. Erosional structures at riverbanks are widespread on Mars in the case of relatively large valleys, especially at the so-called outflow channels. Morphological structures of erosion is evident but later was substantially modified in the case of smaller valley networks (age between 4.2-3.7 billion years), partly because of erosion and also late (mainly sand and dust) accumulation. Their characteristic geomorphological features in connection with the topics discussed in this book are listed below together with some examples.

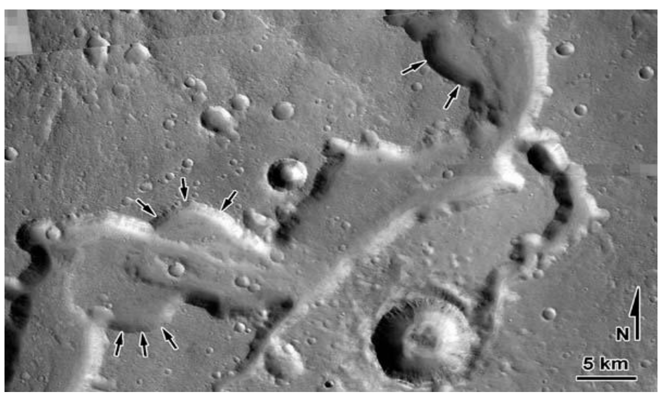

Figure 1. Signatures of laterally migrating meanders and later deeper channel incut on Mars as arc shaped structures (arrows) of Nanedi Vallis (coordinate: 311E 6N) on CTX image (NASA, JPL, MSSS).

Lateral erosion could be identified in some channels, formed partly by sapping process. Most important of them are *migrating meanders* with erosional structures that can be seen and easily inspected at Nanedi Vallis on Mars in the form of differently sized, arc shaped erosional depressions along the steep channel walls. Other type of lateral erosional features can be seen in series of overprinting channel sediments (Figure 1.).

Accumulation related structures are rare along channels, except at their termination, where fans and delta-like structures are abundant in moderately larger systems. A nice example for them is in Eberswalde crater where the probably near-shore reach of the river at the terminal crater lake produced meandering, overlapping bands with complex sedimentary strata of “Bird-foot style”. Example image can be seen in Figure 2. of this structure.

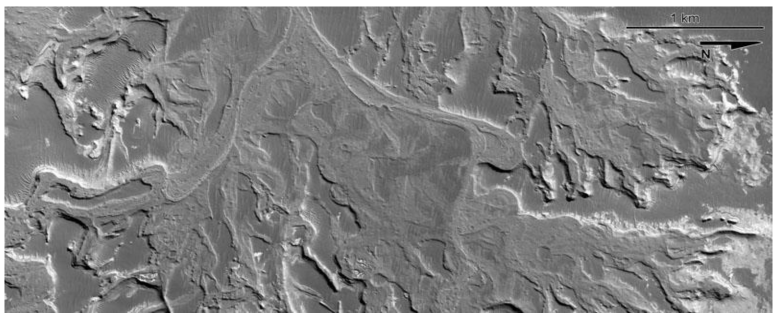

Figure 2. The fluvial sedimentary fan in the Eberswalde crater with branching, overlapping lobes (NASA/JPL/University of Arizona).

Terraced channel walls can be identified in several outflow channels that were produced by different ancient water levels, related to the temporal change in discharge and erosional incut by the flowing water. An example of such features at Reul Vallis can be seen in Figure 3.

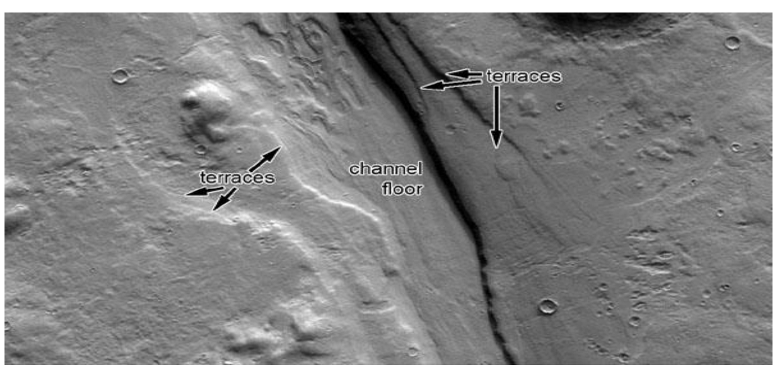

Figure 3. Image of a 70 km wide area of Reul Vallis on Mars. Note the several different terrace levels, suggesting changing water depth during the active flow, possibly accompanied with overbank flows (coordinate: 112E 37S, NASA, JPL, UA).

EFFECTS OF CLIMATE CHANGES

Analyzing Martian fluvial systems various morphological characteristics could be observed, which are indicators of changes in climatic effects. The following list provides an overview of these parameters observed on Mars, which could help to improve the interpretation of climate change related fluvial morphology on the Earth in the future:

- Meander geometry: changes mainly according to peak discharge values, but weakly also according to characteristic average discharges – both values changed temporally.
- Depth of incut: changes could be related to change in discharge, base level height, subsurface cementation change connected to permafrost.
- Shape and depth of cross-sectional profile: changes along the valley at many ancient rivers on Mars can be observed, which are probably related fo climatic fluctuations and change in the formation method.
- Shape of longitudinal profile: often show a less steep upper reach and a steeper (with deeper incut) lower reach, where the first one is more compatible with the long term erosion working under equilibrium conditions.
- Particle size and morphology of sediments: in several Martian systems sediments resembling to Gilbert-type deltas are present. These structures on Earth point to that the ancient river arrived to a standing body of water deposited relative fine fraction there, while alluvial fans and bajada fans point to dry area at the rivers' entry to plains on Earth. and probably also on Mars.
- Network structure: indicates the difference in areally distributed / confined water source, where the second became more frequent on Mars with the geological evolution of the planet.

POSSIBLE BIOGENIC EFFECTS ON MORPHOLOGY

Analyzing field and laboratory data from the Earth, candidates exist for biogenicic effects on fluvial morphology. Although this topic is difficult to analyze some important, already known points are listed below.

Strong, cemented surface might form by mineral condensation, for example such influence can be seen as calcrete formation on alluvial fans, led to fan surface induration and stabilization [10]. Microorganisms precipitated biogenicic carbonate in soils could harden the near surface material at several vegetated location in wet environments, and the occurrence of clays could be bio-mediated in many cases. This later effect could contribute in chemical changes (bonding a range of ions and molecules), could cement and harden the regolith and support the formation of aggreagates. Carbonate bioclastic material could occur at the entry of larger rivers into the sea where wave and tidal action pulverize and occasionally accumulate biogenic structures [11] on the Earth. The susceptibility of landsliding is decreased by vegetation and soil cementation [12], what might have effect not only on sediment supply but also for river track change occasionally.

Bank erodibility is influenced beside abiogenic factors like grains size, friction angle, bank slope, cementation, silt and clay content [13], while biogenic factors ranging from root cohesion, biogenic mediated cement formation could increase the stability of the river bank.

An important general biogenic effect on fluvial systems is the modified runoff that is slowed down by vegetation, and also modified by evaporation as usually slowed down by soil, but also evapotranspiration by the vegetation might occasionally increase the water loss from subsurface. With influencing the discharge and the chemistry of the inflow for the river, these factors might have an effect also on erosion and deposition, together with the formation of soil aggregates. A general comparison in these aspects between the biogenic influenced fluvial systems on the Earth and abiogenic systems on Mars can be red below in the Conclusion section.

SUMMARY AND OUTLOOK

A graphical summary of various differences in biogenic (known from the Earth) and abiogenic effects (identified at examples on Mars too) on fluvial geomorphology can be seen in the Table 1. The effects are separated into two groups: those that influence the mechanical stability of the bedrock and deposited sediments (top), and another group that influences the discharge values (bottom). Beside their background is different and separated, these two groups are partly interconnected also as the change in the erodibility might influence the extremities of discharge, and could produce enhanced erosion at elevated peak discharge. An important indirect biogenicic effect on fluvial geomorphology is the vegetation and soil cementation that slow down the runoff and produce longer duration and smaller peak discharge values even at rainy periods.

Table 1. Comparison of biogenic effects on the rivers of the Earth, and corresponding inferred abiogenic effects in Martian fluvial systems

parameters	biogenic effects	abiogenic characteristics
mechanical strength of bedrock and deposited sediments		
clay minerals	often biogenic mediated formation, chemically selective ion adsorption	only from early Noachian, no later formed by fluvial action, only re-deposited, influencing chemistry mainly under warmer climate
cementation	substantial biogenic cementation both at surface and subsurface zones	many loose structures, easy erodiblity, clayey cement from Noachian, sulfatic from Hesperian ages
trapping of fine sediment fraction	more stable banks, slowly evolving meanders	faster morphology change, larger distal deposited fine sediment fraction
grain aggregates	formation supported by clays	fewer aggregate formation supporting processes
discharge, water budget		
infiltration, subsurface seepage	lower infiltration rate, but evapotranspiration might increase water loss rate	higher infiltration and evaporation, faster subsurface seepage in general
discharge	wider and shallower maximal discharge → weaker erosion	high discharge fluctuation, wider overflow on floodplains
reaction to climate change	good biogenic reaction on the long term for even small climatic change	fast abiogenic changes if erodibility is high

Summary of the various factors is visualized in Figure 4. where simplified effects for the Earth are indicated on the left, and corresponding but abiogenic effects are indicated on the right part of the image. Note the hypothetical Martian case is for ancient rivers from the Noachian age when the conditions were not favorable for cryosphere (permafrost) yet there below the surface. The cryosphere would have changed the subsurface drainage substantially.

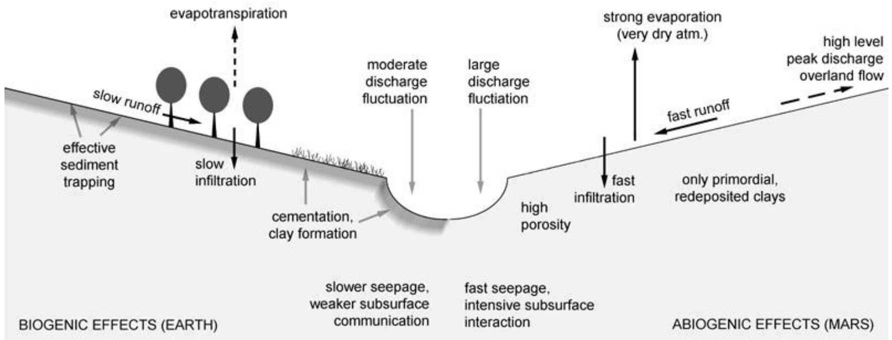

Figure 4. Comparison of several biogenic (for Earth) and corresponding abiogenic (for Mars) effects regarding the consequences on fluvial systems.

ACKNOWLEDGMENT

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