PROCESS-RESPONSE SEDIMENTARY MODELING OF ANCIENT MARTIAN DELTAS 2: OFF-SHORE SEDIMENTATION AND FORMATION TIMESCALES M. R. T. Hoke[1], B. M. Hynek[1], G. Di Achille[2], E. Hutton[3], [1]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, Colorado (monica.hoke@colorado.edu), [2]Istituto Nazionale di Astrofisica, Osservatorio Astronomico di Capodimonte, Napoli, Italy, [3]Institute of Arctic and Alpine Research, University of Colorado, Boulder, Colorado.

Over the past decade many researchers have described the Late Noachian and Early Hesperian surface environment on Mars as being characterized by precipitation and surface runoff, forming the densest distribution of valley networks [e.g. 1-4] and hundreds of paleolakes [e.g. 5]. Despite the evidence for widespread fluvial activity and sediment transport on Mars, delta deposits are relatively rare. This may be in part due to resurfacing by impact gardening and eolian processes that limit the preservation of these features [e.g. 5-7]. It may also be that many deltas did not form as a result of various conditions, such as short flow events that finish before a lake filled the basin [8] and fluctuating lake levels and/or offshore sedimentation [7].

We use a comprehensive morphodynamical model (*Sedflux 2.0*) to explore the effects of changing hydrologic and sedimentary conditions on delta formation under Martian conditions [9]. River and sediment discharge were calculated using the Darcy-Weisbach equation for width- and depth-averaged flow velocity and well known and tested terrestrial sediment transport predictors modified for application to Martian flows. The river was assumed to discharge into an initially-empty idealized impact crater 40 km in diameter. The river was set to enter the crater 1 km above the crater floor. A lake was assumed to fill the crater at a rate determined by the river discharge until the lake was 1 km deep, or level with the river, at which point the water level was held steady for the remainder of the model run. A range of sediment grain sizes transported by the river to the basin were determined from both landers and orbiting spacecraft data in order to include grain sizes typical of Mars and yet representative of the Martian deltas. Several different scenarios of seasonal river change were explored to encompass a range of possible formation conditions.

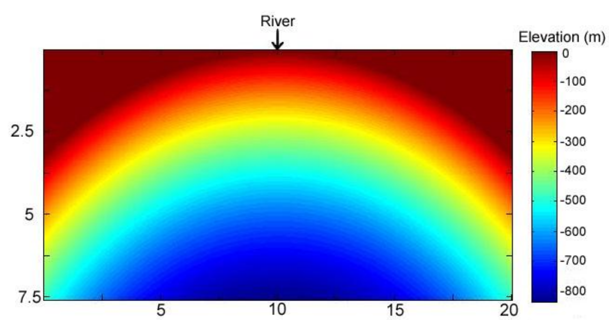

Figure 1. The elevation (m) below the rim within the initial bathymetry of the receiving basin is shown in 0.5 m/pixel vertical resolution with spatial resolutions in the x- and y-axes of 25 m. The river entered the basin at the center of the x-axis, as indicated by the arrow. Distances along the x- and y-axes are given in km.

Effects of river discharge on grain distribution

As river depth and discharge were increased, the faster flows transported more suspended sediment further into the basin beyond the delta-forming region. The slower settling rates of the smaller grains allowed them to reach greater distances before being deposited onto the crater floor. Indeed, most of the modeled deltas had topset material that consists of larger grain sizes transported primarily by bedload, while significant amounts of fine-grained, suspended-load material was deposited further into the basin beyond the delta. The fine-grained material transported beyond the deltas in our results may represent the thinly layered deposits seen beyond some deltas on Mars as well as represent thicker offshore sedimentation that hypothetically make many deltas difficult to identify [7]. The difference between thinly layered distal deposits and thicker offshore sedimentation lies in the discharge rates and concentrations of the supply-river.

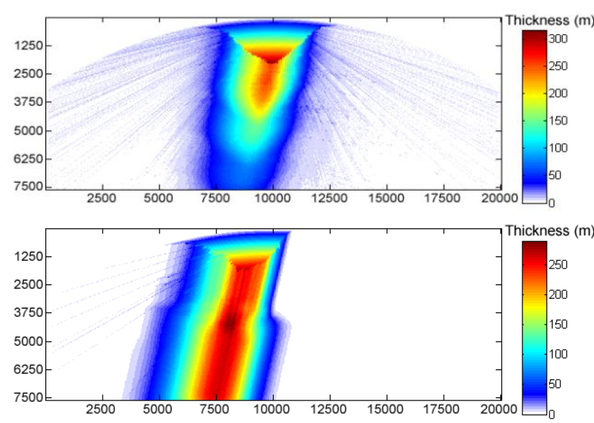

Figure 2. Deposite thicknesses (meters) that correspond to total delta volumes of 1 km^3 are formed in 45 years by a 5m-deep continuous river (top figure) and in only 0.8 years by a 40m-deep continuous river (bottom figure). The deeper flows transport material further into the crater basin, producing significant off-shore sedimentation.

The off shore sedimentation is an important consideration for Martian deltas that have been interpreted to have rapid formation timescales as a result of high discharge rates [e.g. 8, 10, 11]. Although the rivers in those scenarios are capable of supplying the delta-forming zones with sediment at a rapid rate, much of that sediment may be transported past the delta forming zones, as was seen in our results. If the Martian deltas were composed primarily of larger-grained bedload material, their formation would fit with continuous high discharge scenarios. However, most of the deltas on Mars were characterized by finer sediment [e.g. 10, 12], suggesting the flows had to have been of low enough energy to allow deposition in the coastal region.

Implications on delta formation timescales

Continuous formation scenarios of Martian deltas within Sedflux are capable of producing rapid formation timescales, even with the loss of smaller sediment beyond the delta. A continuous 40-m deep deluge emptying into a basin would form a 1 km^3 delta in 0.8 years. This timescale is 10 times longer than was calculated based on sediment supply to the basin. The difference is due to the loss of sediment beyond the delta-forming region.

However, the continuous deluge conditions for Martian delta formation that have been suggested [e.g. 8, 10, 11] are much more extreme than the conditions required for the formation of the contemporaneous valley networks. The large valley networks formed as a result of precipitation and surface runoff during the Late Noachian and Early Hesperian over periods of 10^5 to 10^7 years with runoff rates similar to intense storms in arid regions on Earth [e.g. 13, 14]. The deltas that formed during this time in Martian history were likely exposed to the same climatic conditions and formation scenarios. Therefore, intermittent formation conditions requiring smaller flows are likely more realistic scenarios for many of the Martian deltas. On that end of the spectrum, a 1-m deep continuous river would form a 1 km^3 delta in 4750 years, compared with a calculated formation timescale of 3780 years. If the river was ephemeral, formation timescales could approach 500,000 years, placing it within the duration of clement conditions in the Late Noachian and Early Hesperian on Mars.

Conclusions

By adding more detail into Martian delta formation modeling through the use of increased grain size distributions and various process-response modules that Sedflux offers, we see different results than if we used bulk flow and transport calculations. With the ability to track sediment as it is transported throughout the basin, it is apparent that non-negligible amounts are moved beyond the delta-forming region. These results have important implications for the formation timescales of the deltas and the lack of identifiable deltas on Mars today.

First, the offshore sedimentation increased with greater river discharges, increasing the gap between the calculated and modeled formation timescales. Therefore, formation timescales that consider only the supply of sediment to the system and don't take into account factors affecting deposition and delta formation are underestimates of the actual amount of time needed to form the deposits.

Second, the lack of identifiable deltas in many locations that would have supported their formation [e.g. 5] may be a result of significant sediment transport beyond the coastal delta-forming region [7]. With significant offshore sedimentation, the elevation of a delta above the basin floor becomes less recognizable [7]. Combined with reworking of deposits during fluctuating lake levels associated with an arid- to semi-arid environment [14] and post-formation resurfacing by impact and eolian processes [e.g. 7], these results could explain the lack of deltas seen on Mars.

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