PALAEOFLOW AND SEDIMENT DELIVERY RECONSTRUCTIONS FROM MARTIAN DELTA MORPHOLOGY BY COMBINED MODELLING AND HRSC DTM ANALYSIS.

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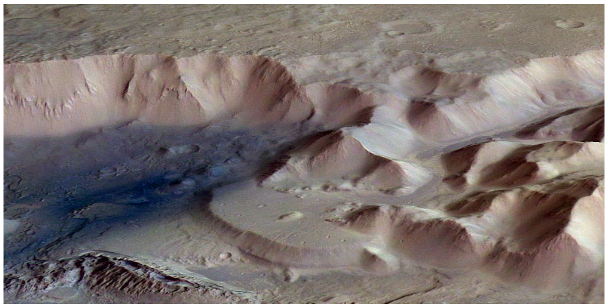

Figure 1: Gilbert-type delta in Nepenthes. The channel may have been formed by sapping. On the left of the delta there is a second lobe that may have formed as an initial drowned delta or alluvial fan.

Summary: The size and shape of alluvial fans and deltas contain information on their formative time scale, sediment supply and the amount of water involved. A new numerical morphological model is presented that allows quantitative comparison of morphological predictions and HRSC DTM-data of six deltas. As morphology is uniquely coupled to water and sediment flux, the model also discriminates between dense flows (slurries) and dilute flows (rivers). We demonstrate that two Gilbert (Fig. 1) and three stepped fan deltas may have formed by dilute flows into filling lakes in less than 10 years.

Introduction: Alluvial fans and deltas on Mars record past hydrological conditions. Until now these conditions were inferred from the morphology of the feeder channels and the deposits using images and digital terrain models (DTMs), and from calculations of the bulk fluxes of water and sediment based on the dimensions of upstream channels and catchments. Neither method can distinguish between dilute (river-like) flows and dense (sediment-laden) flows, while the formative time scales for these sediment transport modes differ orders of magnitude. Our objective is to quantitatively constrain morphological model predictions by DTM data in order to infer sediment transport mode and formative duration.

Model formulation: We built a quantitative morphological model code for fan and delta formation that assumes as little information as possible. The model calculates the growth of a sedimentary body in a (crater) lake with rising water depth h that was perhaps prefilled with sediment up to p and is flooded at most up to an overflow height o below the crater rim. The sedimentary body is represented by a low-gradient (angle α), subaerial cone on top of a high-gradient (angle β), subaqueous cone (Fig. 2). This is progressed in time numerically. Subsequent sediment flux is always deposited on top of the alluvial fan but not necessarily on the subaqueous fan delta slope. If the water level rose so fast that the newly created depositional space exceeds the input flux, then the new deposit is entirely placed on top of the subaerial fan. In this case, the deposit aggrades but regresses. The volume of the cone is constrained by the influx of sediment while the elevation of the break in slope, that is, the shoreline, is constrained by the influx of water. The water (Q) and sediment (Q_s) fluxes were calculated with physics-based predictors based on the feeder channel [1]. Evaporation could be ignored [3]. Crater diameter (D), depth (d) and shape are calculated from empirical relations. Small-scale morphology, such as crater wall irregularity, fan surface concavity and channel avulsion, is ignored. The model produces alluvial fans, stepped fan deltas and Gilbert fan deltas.

Results: The modelling demonstrates that two Gilbert fan deltas were formed by very dilute flows in overspilling crater lakes from long low-gradient upstream channels (Nanedi in Fig. 3, [2], and Nepenthes in Fig. 1). The flow was so dilute that initially only a thin drape of sediment formed on the crater wall. Only after the crater lake spilled over for some time the delta prograded. The Nanedi delta developed so long that it nearly filled the crater lake entirely with sediment.

Three stepped deltas (in Hauber et al. [2], Kraal et al. [3]) were formed by dilute flows in partially-filled crater lakes from short high-gradient upstream channels (Fig. 3). The less energetic scenario of Kraal et al. does not produce good results whereas the more energetic scenario does. A thick deposit formed on the crater wall as this more energetic flow contained more sediment. The steps were formed during the rising lake level by unsteady supply of sediment which was not resolved by the model as a constant supply was assumed.

Further modelling results demonstrate that the formative process (dilute or dense flow) and time scale of a delta are underdetermined by the final morphology if the crater lake overflowed. Two deltas, one formed by a dilute flow and the other by a dense flow, were found to have exactly the same morphol-

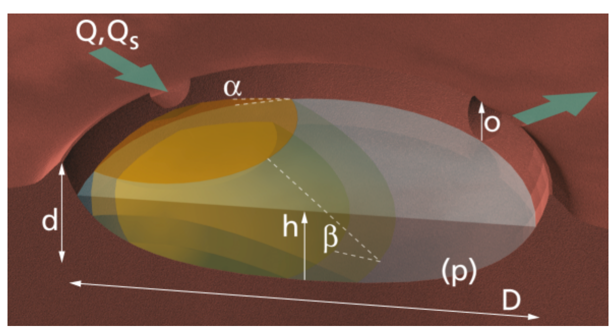

Figure 2: Principle of fan delta formation in a crater lake. Basic model parameters are indicated (see text).

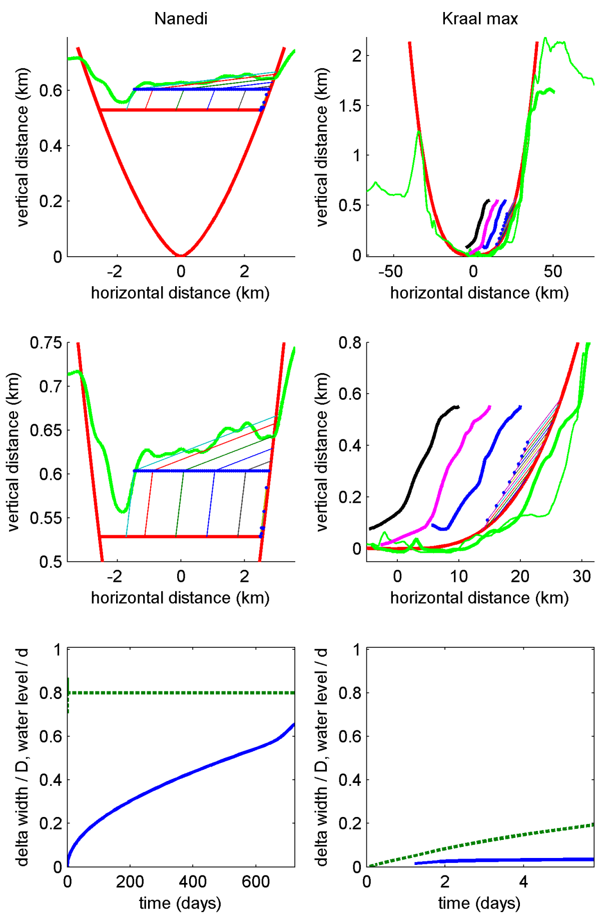

Figure 3: Results of modelling the Nanedi and Stepped fan deltas [2, 3]. Top panels: bold red line is a cross-section of the modelled crater with prefilling; bold green line is the measured profile across the crater, positioned along the delta apex; the thin green line (Kraal case) is a nearby crater profile without delta. Blue dots represent the shoreline position in each time step. Thin lines indicate the fan delta surface at various times. Middle panels magnify delta. Bottom panels: blue lines indicate relative shoreline position as a function of formative time. Dashed green lines indicate relative lake level.

ogy but a formative time scale that differs orders of magnitude (Fig. 4). The key difference is their stratification, which could be identified at eroded delta rims, and perhaps morphological details in the feeder system. Dense flows have been assumed in the past although very specific and somewhat unlikely upstream conditions and trigger mechanisms would be required.

Delta morphology appears to be related to different upstream conditions. Gilbert deltas were fed by a bed load or suspended load dominated flow from long upstream channels into a lake that overflowed for most of the formative period. Stepped fan deltas record shorter but more energetic suspension-dominated flows from steeper and shorter valleys into craters that did not overflow. There were no indications for dense flows. Ongoing image analysis combined with modelling and experiments is aimed at unravelling the formative time scale and amount of water from process-form relations for deltas and fans and detailed morphological clues [4].

Concluding remarks: A direct comparison between the cone model and HRSC DTM-data of five deltas demonstrates that single-event dilute flows of short duration (less than 10 years, order of magnitude error) can have created all these deltas. The modelling results support hypotheses with localised and short-lived periods of flowing water on Mars.

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References

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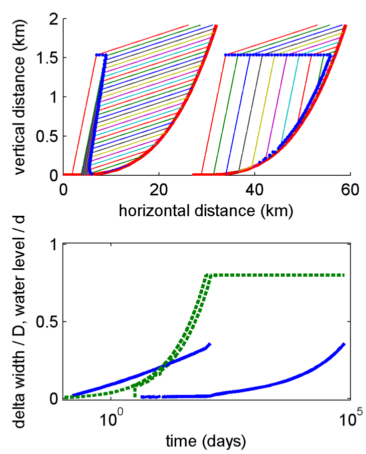

Figure 4: Dense (left) and dilute (right) cases compared. The final morphology is the same but the stratification differs and the formation time scale of the dilute case is two orders of magnitude longer.