POST-EARLY MARS FLUVIAL LANDFORMS ON MID-LATITUDE IMPACT EJECTA. N. Mangold, LPGN/CNRS, Université Nantes, 44322 Nantes, France. Nicolas.Mangold@univ-nantes.fr

Introduction: Early in Mars' history (<3.7 Gy), the climate may have been warmer than at present leading to valley networks [1], but more recent valleys formed on volcanoes [2,3,4], Valles Marineris [5,6], and glacial landforms [7,8] in conditions probably colder than in the primitive period. Rare examples of fluvial valleys over ejecta blankets have been reported for impact craters [9,10,11]. In the present study, tens of craters (12 to 110 km in diameter) with fluvial landforms on ejecta were found in the mid-latitude band (25-45°) in both hemisphere. Fluvial landforms on well-preserved craters ejecta offer a new perspective in the understanding of fluvial valleys.

Observations: A survey of hundreds of large impact craters has been done to identify fluvial landforms, especially in regions lacking ancient valleys, using images from the High Resolution Stereo Camera (HRSC) instrument onboard Mars Express and from the Context Camera (CTX) instrument onboard Mars Reconnaissance Orbiter. Only craters with fresh continuous ejecta blankets were included in this study, because ancient craters of Noachian age (<3.7 Gy) are strongly degraded by erosion and hence lack visible ejecta. Grooves, rays, terminal lobes and megabreccias formed by the impact process were identified to determine ejecta boundaries. Fluvial valleys exhibit geomorphic features distinct from ejecta, including sinuous shapes and meanders, valley junctions, braiding and local depositional fans (Fig. 1).

Observations show that valleys dissecting fresh ejecta are 50m-1km wide, and less than 65 km long (Fig. 1). Their origin as fluid flows is demonstrated by their relationship with topography: valleys always follow the main slope and do not follow radial ejecta patterns. Valleys display isolated channels and a poor connectivity. Valleys are locally sinuous, but also frequently braided suggesting a formation by episodic activity. Valley heads are often wide and isolated, without catchments or smaller tributaries suggesting local control by seepage or sudden break out. Locally, ponding inside ejecta troughs may enable a formation of channels by overflow. So, valleys mainly correspond to single channels formed episodically than valleys formed by a progressive incision of small channels.

Calculated discharge rates using both Manning and Darcy-Weisbach equations give consistent results. Results show a range of discharge rates from 500 m^3s^{-1} to 5000 m^3s^{-1} using 3 m channel depth, or 500 to 40,000 m^3s^{-1} assuming 10 m deep channels for the largest channels (>500 m wide). A comparison with a few terrestrial rivers shows that these discharge rates are very high given their length.

All examples studied were observed in regions between 25° and 42° of latitude in both hemispheres. No example of fluvial landforms on ejecta was found over 117 craters >16 km in diameter in equatorial regions (<25°N). The high proportion of craters with fresh ejecta eroded by fluvial landforms at mid-latitudes suggests that this process was common at these latitudes, and not limited to oldest periods.

Interpretation: Mid-latitudes (>25°) contain landforms such as pitted terrains or lineated fills that are interpreted as being due to shallow ice deposited by atmospheric processes [12,13]. A melting of these deposits could have provided the water required for fluvial activity. Climatic variations with, for example, high summer temperatures could have provided the energy for melting ice. Nevertheless, it may be difficult to explain such a fluvial activity in the Amazonian periods, except assuming multiple scattered episodes. Episodic variations in obliquity were proposed to explain channels inside mid-latitude crater interiors [14]. In this case, however, the oldest craters should display enhanced cumulative erosion after having crossed these multiple climatic episodes, a characteristic not observed in the studied examples.

In a second scenario, the crater itself could have provided the energy necessary for ice melting explaining the possible disconnection of fluvial episodes. Impact process may enable shallow ice melting by warm ejecta deposition. At Sinton crater, braided valleys were interpreted as being sourced from the melting of mid-latitude glaciers buried below hot ejecta [10]. In the present study, the widespread mid-latitude ice-bearing mantle could be the source of melt water. It has been shown that some of the suevite breccias (*i.e.* rocks from ejecta) around the 23 km in diameter Ries crater in Germany were deposited at a temperature of ~700°C [15]. Calculations were done to evaluate the potential role of ejecta heating on an ice-bearing substratum using classical conductive heat laws. Results show that 20 m thick ejecta heated at 700°C would create a 30 m thick zone at temperatures >0°C in 15 years. This timescale seems sufficient to form the braided and poorly connected channels observed.

Alternatively, a contribution of deep (>100 m) ground ice present at mid-latitudes and excavated by the impact is also possible, as proposed for Hale crater [11]. Snowfall on warm ejecta could also explain some fluvial landforms if it occurred massively enough to explain the high discharge rates. Indeed, an impact into an ice-bearing crust can generate temporary climate modifications leading to snow precipitation [16]. This should occur shortly after the ejecta emplacement. Nevertheless, large impacts (>100 km) into ice-bearing crust can create hydrothermal activity on crater interior and rims over duration >100,000 years [17]. Such a process may explain a prolonged fluvial activity over large crater rims, but not valleys observed on <50 km craters and valley heads far from crater rims.

Perspectives: Significant morphological differences exist between the studied landforms on fresh ejecta and ancient valley networks formed during early Mars. Nevertheless, local valleys could result of similar processes. An example north of the 150 km diameter Holden crater illustrates this conclusion. Indeed, Holden ejecta are well preserved and appears to predate the fluvial activity in Eberswalde crater [18]. Holden secondaries further away to the north are well preserved and do not show signs of fluvial erosion. The location of the impact at 25° south, is close to the boundary of the latitude mantle and at the same latitude at which valleys were observed on other craters. These observations suggest that Holden impact thermal effect should be taken into account in the understanding of the subsequent fluvial activity [18]. So, identifying fluvial activity over craters ejecta in global valley maps could be important to interpret their true climatic signature as well as their timing.

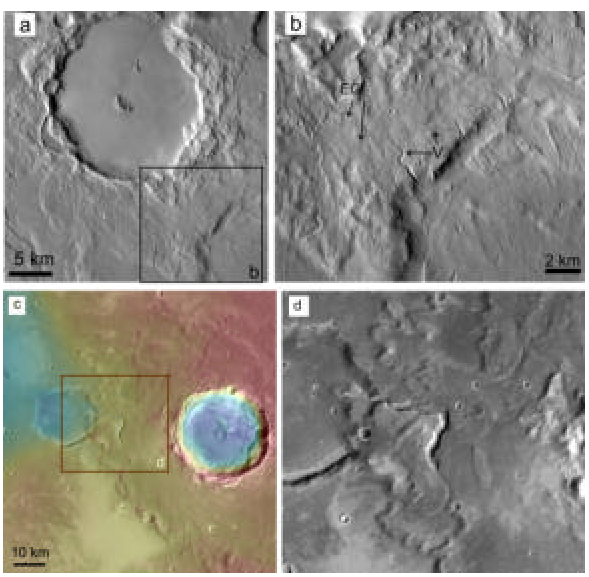

Fig. 1: Example of valleys formed on ejecta of two large craters located at 37°N and 32°N respectively. (a) and (b) CTX image of valleys cutting ejecta of a large crater visible by their rays and grooves. (c) and (d) a single valley cut ejecta well bounded by terminal lobes. This valley ends with a small depositional fan.

Conclusions: Fresh ejecta blankets studied are preserved enough to demonstrate that no long-term period of fluvial erosion occurred after their formation. While climatic variations could explain some fluvial valleys on ejecta at mid-latitude, processes associated with impact craters such as shallow ice melted by warm ejecta may better explain the occurrence of scattered fluvial activity formed inside a cold and dry period.

References [1] Craddock, R. A. Howard, A. D., *J. Geophys. Res.* 107 JE001505 (2002). [2] Gulick, V. C., Baker, V. R., , *J. Geophys. Res.* 95, 14325(1990). [3] Hauber, E. *et al.*, *Nature*, 434, 356 (2005). [4] Ansan, V., et al. AGU Fall, #EP53F-05 (2009). [5] Mangold, N. *et al.*, *Science*, 305, 78 (2004). [6] Quantin, C. *et al.*, *JGR*, 110, E12S19 (2005). [7] Fassett, C. I. et al., *Icarus*, 208, 86 (2010). [8] Dickson, J. L., et al., *Geophys. Res. Let.*, 36, L08201 (2009). [9] Mouginis-Mark, P. J., *Icarus*, 71, 268 (1987).[10] Morgan G. A., & Head, J. W., *Icarus*, 202, 39 (2009). [11] Jones, A. P. et al, *Icarus*, in press. [12] Mustard, J. F. *et al.*, *Nature*, 412, 411 (2001). [13] Byrne, S. *et al.*, *Science*, 325, 1674 (2009). [14] Berman, D. C., *et al.*, *Icarus*, 77-95 (2009). [15] Engelhardt, W. V. *et al.*, *Meteoritics*, 29, 463 (1994). [16] Segura, T. L., *et al.*, Environmental effects of large impacts on Mars, *Science*, 298, 1977 (2002). [17] Abramov, O., Kring D. A., Impact-induced hydrothermal activity on early Mars, *JGR*, 110, E12S09 (2005). [18] Mangold, N., *4th MSL Landing Site Meeting*, Monrovia, 2010.