KEY OBSERVATIONS FOR A BETTER DETERMINATION OF NOACHIAN AND HESPERIAN CLIMATES FROM FLUVIAL LANDFORMS. N. Mangold, Laboratoire Planétologie Géodynamique Nantes, CNRS/Universite Nantes, 2 rue de la Houssinière, 44322 Nantes, France, nicolas.mangold@univ-nantes.fr

Introduction: Valley networks on Mars are known since Mariner and Viking missions. Their presence in highlands suggested that the ancient period (>3.5 Gy) experienced climatic conditions different from present ones, but these landforms have also be interpreted as the result of stronger geothermal and/or impact fluxes [1-3]. Impact crater degradation provides another tool to analyze past evolution. Studies using Viking data concluded that large impact craters were strongly degraded during early Martian history, whereas younger craters were only weakly degraded [4]. In the following, we summarize several new results related to fluvial landforms and crater degradation in order to extract the consistency of these results and link these interpretations to climate evolution.

Fluvial landforms age and preservation: Valley networks usually interpreted as formed under warmer climate than the current one are dated mainly from the Late Noachian, extending slightly into the Early Hesperian period [e.g., 5]. The valleys usually occupies basins of several hundreds of km apart with main valleys being several hundreds of meters deep. Nevertheless, recent imagery allowed scientists to identify the occurrence of fluvial valleys of Late Hesperian and Early Amazonian ages [e.g., 6-9], formed well after the classical Late Noachian valley networks [e.g., 5]. In addition, several landforms expected to be of the Noachian era were recently determined to represent regional episodes in the Hesperian period. For example, the famous Eberswalde delta fan was initially proposed as a smoking gun for a wet and warm early Mars [10]. This landform appears to be superimposed over the widespread ejecta of the Holden crater (Fig. 1) [11]. A detailed analysis of valleys geometry and crater counts on ejecta suggests that Eberswalde fan formed in a relative short-term episode from limited fluvial activity in the Late Hesperian. The origin of fluvial activity could be due to transient climatic episodes or Holden impact warming. Hale (150 km in diameter) and Lyot (250 km in diameter) craters represent other examples identified as potential impact-related fluvial activity [12-13]. Alluvial fans, as those present inside Holden crater, were initially interpreted as being the markor of an optimum of erosion at the end of the Noachian [14], but local imagery shows that they affect impact craters that are for most of them of Hesperian age, too. For example, Jones crater displays an alluvial fan, but its ejecta cover the widespread Samara and Loire valley networks and crater counts give a retention age in the Late Hesperian [15]. Lastly, a series of mid-latitudes impact craters displays local fluvial incision on ejecta blankets that may be due to local warming such as due to the warm impact ejecta likely inside a cold climate as present one [16]. In summary, the various ages of the recently discovered Hesperian/Amazonian fluvial activity compared to Late Noachian valleys plead for non-global processes. The amplitude of erosion and limited extent of these Hesperian/Amazonian examples compared to Noachian example plead for much limited erosion [17]. Hesperian age landforms figure out a cold Hesperian period with transient or regional processes.

Crater degradation: Global altimetry and recent high resolution imagery enabled us to revisit previous work [4] about crater degradation in two large regions [15]. We distinguished three classes, using two main parameters, i.e. the presence of preserved ejecta and of fluvial activity: (i) Craters with fluvial erosion on walls and rim but lacking an ejecta blanket. (ii) Craters with fluvial erosion on walls and rim and a preserved ejecta blanket. (iii) Fresh craters lacking any fluvial erosion on rim with a preserved ejecta blanket. Alluvial fans are observed mainly in the intermediate craters, that display preserved ejecta. This is a surprising result, because the presence of alluvial fans suggests an enhanced fluvial activity [14] that we would have expected more for older craters than fresher craters with preserved ejecta. Depth-to-diameter and slope rim-to-diameter plots confirm quantitatively what is observed qualitatively. The chronology of all the craters in this region can be performed using classical isochrons [18-20]. All the craters together gives an isochron at 4.00±0.03 Gy, which corresponds to the age of the basement [19]. The transition between type I and type II craters occurs at 3.70±0.06 Gy, in the Early Hesperian [20]. This age pinpoints the period during which the strong fluvial degradation of Early Mars stopped. Subsequent fluvial activity occurred at a time erosion was globally limited, confirming results from individual examples above, that these landforms may have formed from regional processes rather than global ones, including alluvial fans in craters identified by [14].

Key observations deduced from observations:

(1) Impact ejecta vs fluvial valleys: The identification of fluvial valleys incising ejecta allow us a better determination of the timing of the fluvial activity, thus enable a better chronology of all episodes. Large Hesperian craters (i.e., Holden, Lyot [13,15]) were suspected to have generated fluvial erosion by impact warming. With regards to the size of these craters, not smaller than those in the Late Noachian, and the limited amount of fluvial erosion associated, these observations suggest that impact processes cannot explain more developed fluvial activity in the Noachian.

(2) Preservation of landforms: Last decades discoveries have generated studies on well-developed depositional landforms. These landforms appear preserved because they formed from relative recent episodes usually unrelated to the Noachian period. Their setting could correspond to short-term episodes, as shown by fluvial discharge calculations [21, 13]. Only few of these deposits are linked to Noachian valleys or more ancient periods. For example, the crater Terby displays an old stack of sediments that was likely an ancient deltaic system, with much less preservation of its feeding valleys [22]. In general, fresh pristine landforms should be taken with care, i.e. a Noachian age is usually unlikely.

(3) Impact degradation: The depth, slope rims and preservation of ejecta are parameters of main importance for estimating the degradation of a crater. Whereas some craters were initially attributed to Noachian period (e.g., Holden), their characteristics do not fit with other craters of Noachian age. On the other hand, the strong degradation of the Noachian craters, compared to Hesperian ones, is difficult to explain by processes that would not be global and widespread as would be by climatic processes, i.e. volcanism and impact warming occurred in the Hesperian but had limited effect on crater shapes.

Conclusions: While several datasets already concluded to a strong shift in climate at the end of the Noachian [e.g., 5], recent interpretations and models favour the Noachian as being as cold as other periods with geothermal and impact effects being predominant [e.g., 1-3]. We have shown that the Hesperian/Early Amazonian periods display many landforms (alluvial fans, deltaic deposits and valley networks) that are pristine, well-preserved and related to such type of regional activity (impact, volcanism) or transient climatic episodes (obliquity?). However, the distinct impact degradation in the Noachian shows that the latter experienced much stronger erosion suggesting not only regional processes. Any cold early Mars model should take into account that the Hesperian processes were unable to degrade craters significantly. Cold early Mars model should explain why the crater degradation and valley networks were so different in the Noachian compared to the Hesperian. A recent study focused on 250-800-km impact craters and on Hesperian volcanoes showed that the dynamo stopped likely between 3.75 and 3.79 Gy, well after the Hellas impact [23]. This event may have caused a sudden climatic shift, which provoked the sharp shift in crater degradation conditions that we have detected, while subsequent conditions became colder.

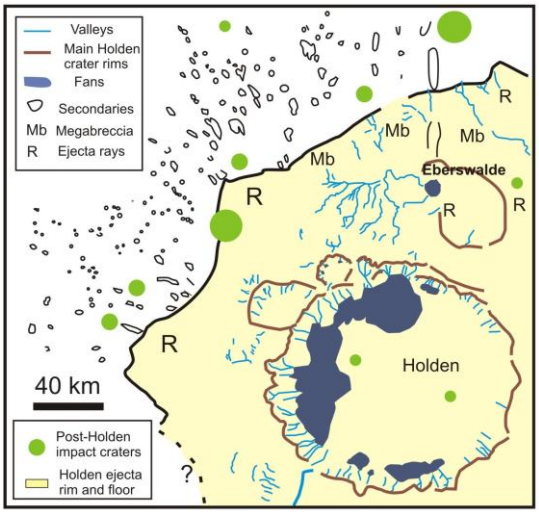

Fig. 1 : From [11]. Geomorphic map of North Holden area showing the depositional fan in Eberswalde and feeding valleys superimposed over the Holden ejecta blanket (in yellow). The age of Holden crater is mid- to late Hesperian from crater counts on ejecta.

References: [1] Segura et al Science, 298, 1977-1980 [2] Segura et al J. Geophys. Res. 113:E11007 [3] Gulick, Geomorphology, 2001 [4] Craddock and Maxwell (1997) *JGR*, 102(E6), 13321-13340 [5] Fassett and Head, JGR-Planets, 2008 [6] Mangold et al., *Science*, *305*(5680), 78-81 [7] Fassett *et al.*, *Icarus*, 2010 [8] Howard and Moore, Geology, 2011 [9] Grant and Wilson, GRL, 2011 [10] Malin and Edgett, Science, 2003 [11] Mangold et al., in review at Icarus [12] Harrison et al., GRL, 2010 [13] Jones et al., Icarus, 2011 [14] Moore and Howard (2005) *JGR*, *110* (E4), E04005, [15] Mangold et al., JGR-Planets, in press. [16] Mangold, Planet Spa. Sci., 2012 [17] Ansan et al., this meeting [18] Michael and Neukum (2010) *Earth Planet. Sci. Lett.*, *294*(3-4), 223-229 [19] Werner (2008) *Icarus*, *195*(1), 45-60, [20] Werner and Tanaka Icarus, doi: 10.1016/j.icarus.2011.07.024. [21] Kleinhans et al., EPSL, 2010 [22] Ansan et al., Icarus, 2011. [23] Langlais et al EPSC/DPS meeting, Nantes, 2011-773.