ANALYSIS OF THE ELYSIUM REGION, MARS. J. Nußbaumer, Johannes Gutenberg University, Mainz, Germany.

Introduction: The (former) presence of liquid water on the surface of planet Mars is one of the most central topics in the study of Mars specifically as well as in the planetology of the terrestrial planets. The observation of fluvial morphology in southern Elysium Planitia,Mars, already proved the existence and action/effect of water in this region in the past. However, only speculation on standing bodies of water has been made. The discovery of very rare specific features provides more insight into the fate and origin of water in this region. Positive relief zig-zag features within the Medusae Fossae Formation resemble similar structures on Earth observed at shorelines on Earth.

Elysium Planitia: The Elysium region near the Martian equator is thought to be an area associated with the youngest volcanic, fluvial and glacial activity seen on Mars so far [1]. The relevant geological units include Aeolis [A], the Cerberus Plains [CP] and the Medusae Fossae Formation [MFF]. Areas in Elysium Planitia were examined by numerous persons. Volcanic heating melted the ice in the permafrost ground near the volcanoes [2] and formed larger lakes or seas. Common opinion is, that a Hot Spot heated a large area beneath the Elysium volcanoes and induced eruptive phases, the first occurred in the late Noachian and the second in the middle Amazonian [3, 4]. [5] described widespread ground ice in Elysium by means of variations of crater morphologies, which are an expression of a changing deepness of volatile layers. Evidence of groundwater or ground ice within the CP exists as impact crater ejecta morphologies, where a significant number of ejecta have fluidized ejecta morphologies. Another result was, that the distribution of the ice in the ground depends strongly on latitude [6]. Ice near the surface is situated in the higher latitudes, and larger, deeper concentrations of frozen ice is distributed in the southern highlands, that show a high abundance of crater lakes [7]. A repository for massive amounts of Noachian water is the deep impactgardened southern highlands that also show a magnetic field [8]. Current opinion is that in the northern areas, a muddy sea was formed [9]. This observation is based on linear features resembling coastlines. Investigations showed, that altimeter data agrees with this hypothesis [10]. The fact, that MOLA shows equal values and the same heights along the proposed coastlines and their terraces indicates, that an ocean could have been formed during the middle Amazonian. Mapping of the Elysium Basin has revealed that this area experienced a complex geologic history, including volcanism, impact cratering, cryospheric melting, subsurface outflow, and potential surface runoff. In Elysium Planitia, numerous examples of volcano/ground ice interactions have been identified [11]. The depositional sequences of Elysium deposits were described in 5 stages. First, the Vastitas Borealis Formation covered the majority of the terrain. After fan deposition, debris and/or lava flows, highly mobilized mud-flows and channel networks, volcanic debris and lava flows were emplaced [12]. Fluvial sources are possibly attributed to punctuated periodic outflows [13]. Water from southern Elysium Planitia would have flowed through Marte Vallis into Amazonis Planitia [15]. Shorelines in Elysium were portrayed by [16]. [17] presented evidence in support of shore morphology to an embayment of a northern plains ocean into the southern Elysium region. Shoreline features in Cydonia, Tempe, Utopia/Isidis, and South Elysium can not be correlated to global ocean shorelines. Valleys debouch into many of the basins, indicating that they may include alluvial and lacustrine sediments [18] and a proposed ice sheet NW from the Elysium volcanoes. The height of ridges and hills can be used as a minimum value for the thickness of an ice cover. If these ridges are sub-ice volcanoes, then an ice sheet must have been present at both the Elysium and Isidis sites, water likely was involved in removing subsurface material and eroding and transporting ancient clastic debris. Environmental conditions may have been rather clement at times if fluvial, debris-flow, or marine activity occurred at or near Elysium Planitia [20]. Hypotheses for the origin of the dichotomy include excavation by one or more large impacts [21]. In Elysium Planitia, three volcanoes raise about ~4000 m around the surrounding terrain. The area around the volcanoes was formed in the lower Amazonian and is 2,5-3 Mrd years old [23]. Lithologically, the geologic units seem to be flood basalts from the volcano area [24]. Southwest of the Elysium volca-noes, a lower Amazonian unit may have formed lacustrine or marine [25, 26]. [27] described a Paleolake with a 180 m thick ice layer northwest of the Elysium volcanoes. Granicus Valles is supposed to have been covered by ice. This conclusion is supported by other workers on local to regional water bodies apparently active in the same period, such as the Elysium Basin [28]. Terrace formations in the valley system Granicus Valles indicate several fluvial episodes. The lake formation is related to the drainage of the surrounding aquifer in the Aeolis Mensae region [29]. In Elysium, there are signs for volcano-ground ice interactions, rootless cones or pseudocraters [30, 31]. These are formed by phreatomagmatic explosions due to the emplacement of a lava flow over a volatile-rich substrate. Pseudo-craters indicate a volatile layer in the subsoil. The heat of the Elysium volcanoes may have melted the ice in the ground and triggered lahar-like mud-flows [32]. Melt water deposits have been described, (Jokulhlaups) from subglacial lakes formed through volcanic activity. Volcanoes in the cratered uplands have been described [34] that could have induced floods to the northern lowlands.

The **Medusae Fossae Formation** [MFF] is an extensive, wind-scoured deposit stretching from 130 to 240 E near Mars' equator [35]. The MFF has been interpreted as volcanic airfall deposits [35]. The MFF is superposed on the CP.

Widespread fluvial flow within the western part of the MFF is present. The western MFF are deposits, that extend from the dichotomy boundary northwest into the western CP. The western MFF has a maximum elevation of -1400 m and a thickness of up to 1200m [36]. The MFF forms sequences along the highland-lowland boundary between the Elysium rise and Olympus Mons. The MFF is Amazonian in age [37]. In many places, the MFF shows systems of linear ridges and grooves. Much of the surface of MFF is eroded into sets of streamlined ridges or yardangs, carved by wind [38, 39]. The yardangs have varying orientations among different beds possibly because of climate controlled changes in wind direction [40, 41]. Various origins for the MFF have been proposed, including volcanic ash or aeolian sediment. [42]. The stratigraphy of the area can be simplified into three main units. Npl2, the oldest, was heavily channeled to form a series of resistant peaks in the lowlands that were later surrounded by Aps. Finally MFF was deposited on top of both Npl2 and Aps and has subsequently been eroded, forming sets of parallel yardangs and exhumed craters. Stratigraphically, MFF units appear to be coeval with members 4 and 5 of the Tharsis Montes Formation. [43] found that the upper, lower, and middle member designations made from Viking images often conflict with the stratigraphy apparent in MOLA data, for example, in several places Aml, the lower member, is above Amu, the upper member. Associated pyroclastic activity has been proposed to be a major source of fine grained material forming the Medusae Fossae Formation [44]. [45] has outlined a scenario in which at least part of the Medusae Fossae Formation may be due to fluvial channel emplacement. In this scenario, evaporation and sublimation of these fluvial channel effluents is followed by condensation of the volatiles and their redeposition at the orographic rise represented by the lowland- upland scarp. It appears that some faulting and folding was synchronous with deposition of eastern MFF components [46]. Also it was proposed, that the MFF formed from airborne ice-rich material emplaced during periods of high obliquity [47]. The complex stratigraphy of the MFF suggests that periods of emplacement were interrupted by periods of erosion. The lower member [Aml] is smooth to rough and highly eroded and interpreted to be lava flows interbedded with pyro-clastic rocks or eolian deposits. The middle member [Amm] is similar to the upper member but the surface appears rougher and more deeply eroded in places; it is cut by scarps and transected by intersecting joint sets and interpreted to be welded and nonwelded pyroclastic rocks or layers of eolian deposits. The upper member [Amu] consists of widespread deposits that are smooth, flat and sculpted into ridges and grooves in places, with broadly curved, locally serrated margins. Finally, the MFF has also been interpreted to be remnants of ancient polar deposits, when Mars' rotation axis moved [50]. [52] interprets the MFF as an old carbonate platform. Other hypotheses are, that palagonite-rich mud rivers induced through eruptions in the ice-rich subsoil were initated. He mentions, that one volcanic mudflow, that poured from the Upland-Lowland Boundary, washed the former surface away, and removed the entire material, and formed drumlin fields and ice sheets. Formation period of the MFF was middle to late Amazonian. Large concentrations of yardangs are found in the MFF [56], with smaller assemblages found in Aeolis, and within craters. The paleochannels are the youngest fluvial paleochannels yet observed. Easily erodible materials such as pyroclastic deposits, mudflows, and lacustrine sediments have been proposed as components. Young lavas are interwoven with the MFF with multiple-layers, after lava was flowing, vulcanic dust has formed the MFF with a high water content. Measurements of radar backscattering show low density and high porosity of the MFF. Reason for ice deposition could be the raised heat transfer radiation of deposits with high porosity. The layered ice formations may have melted after warming of the MFF, which partly bursted, and formed chaotic terrain and lakes. Many examples of layering are evident in western MFF. Mesa-like remains of an old geological unit are part of the MFF. On these mesas, streamlined hills formed, that resemble terrestrial drumlins. Ridges with flat tops may be Mobergs. Mobergs are eruptions in the permafrost, consisting of palagonite tuff and palagonitic Breccie.

References: [1] Tanaka, K. L., and D. H. Scott (1986) *Lunar Planet. Sci. 17*, 865–866. [2] Mouginis-Mark, P. J. (1985), *Icarus 64*, 265–284. [3] Tanaka, K. L, et al. (1992), *U.S., Geol Surv. Misc. Invest. Ser. Map*, I-2147. [4] Frey, H. V., and R. A. Schultz (1990), *J. Geophys. Res. 95*, 14203–14213.[5] Cave, J. A. (1993), , *J. Geophys. Res*. 98, E6, 11,079-11,097.[6] Squyres, S. W., et al. (1992), *In Mars*, pp. 523–554. Univ. of Arizona Press, Tucson. [7] Cabrol, N. and E. Grin (1999), *Icarus, 142*, 160-172. [8] Connerney, J. et al. (2001), *Geophys. Res. Lett., 28*, Issue 21, p.4015. [9] Parker, T. J., et al. (1993), *J. Geophys. Res., 98*(E6), 11061-11078. [10] Scott, D. H., and M. G. Chapman (1995), *U. S. Geol Survey Geol Series Map I-2397*, scale 1: 5,000,000. [11] Mouginis-Mark, P. J. (1985), *Icarus 64*, 265–284. [12] Skinner, J. A., and K. L. Tanaka (2001), Proc. *Lunar Planet. Sci.. 32*, 2154. [14] Nelson, D. M., et al. (2001), *Lunar Planet. Sci., 32*, 2069.[15] Carr, M. H., and J. W. Head (2003), *J. Geophys. Res., 108*, E5, 5042, doi:10.1029/2002JE001963. [16] Clifford, S. M., and T. J. Parker (2001), *Icarus, 154*, 40–79. [17] Parker, T. J. and P. M. Schenk (1995), *Lunar Planet. Sci. 26*, 1105–1106. [18] Tanaka, K. L., et al. (2003), *J. Geophys. Res., 108*[E12], 8079, doi:10.1029/ 2003JE002054. [20] Tanaka, K. L. et al. (2003), J. *Geophys. Res., 108*[E4], 8043, doi:10.1029/2002JE001908. [21] Wilhelms, D. E. and S. W Squyres (1984), *Nature 309*, 138–140. [23] Greeley, R., and J. E. Guest (1987), *U.S. Geol Surv. Misc. Invest. Ser., Map* I-1802-B. [24] Plescia, J. B. (1990), *Icarus, 88*, 465–490. [25] Scott, D. H., et al. (1987), *U.S. Geol Surv. Misc. Invest. Ser., Map I-1802*-A, B, C. [26] Tanaka, K. L, et al., Geologic map of the Elysium region of Mars, scale 1:5,000,000, *U.S., Geol Surv. Misc. Invest. Ser. Map*, I-2147, (1992). [27] Chapman, M. G. (1994), *Icarus 109*, 393-406. [28] Scott, D. H., and M. G. Chapman (1995), *U. S. Geol Survey Geol Series Map I-2397*, scale 1: 5,000,000. [29] Clifford, S. M., and T. J. Parker (2001), *Icarus, 154*, 40–79. [30] Lanagan, P. D., A.S. McEwen, L. P. Keszthelyi, and T. Thorvaldur (2001), *Geophys. Res. Lett*., 28, 2365. [31] Mouginis-Mark, P. J. (1985), *Icarus 64*, 265–284. [32] Christiansen, E. H. (1989), *Geology, 17*, 203–206. [34] Stewart, E. M., and J. W. Head (2001), *J. Geophys. Res., 106*(15), 17505–17514. [35] Bradley, B. A. et al (2000), *Lunar Planet. Sci. 31*, 2055. [36] Bradley, B. A., et al. (2002), *J. Geophys. Res., 107*, E8, 5058, doi:10.1029/2001JE001537. [37] Scott, D. H., et al. (1978), *U.S. Geol Surv. Misc. Inv. In Series Map* I-1111. [38] Ward, A. W. (1979), *J. Geophys. Res. 84*, 8147–8166. [39] Scott, D. H., and K. L. Tanaka (1982), *J. Geophys. Res., 87*, 1179– 1190. [40] Zimbelman, J. R., et al. (1998), *Lunar Planet. Sci. 29*, 1085. [41] Zimbelman, J. R., et al. (1997), *Lunar Planet. Sci.*, 1623– 1624. [42] Scott, D. H., et al. (1978), *U.S. Geol Surv. Misc. Inv. In Series Map* I-1111. [43] Sakimoto, S. E. et al. (1999), *J. Geophys. Res.*, 104, 24,141– 24,154. [44] Keszthelyi, L., et al. (2000), *J. Geophys. Res., 105*, 15,027– 15,049. [45] Head, J. W., and M. A. Kreslavsky (2001), *Lunar Planet. Sci., 32*, 7053. [46] Shockey, M.,et al. (2004), *Lunar Planet. Sci*. [CD-ROM], XXXII, abstract #1539. [47] Head, J. and M. Kreslavsky (2004), *Lunar Planet. Sci., 32*, 1635. [50] Schultz, P. H., and A. B. Lutz (1988), *Icarus, 73*[1], 91– 141. [56] 1986 Scott, D. H., and K. L. Tanaka (1986), *U.S. Geol. Surv. Map, I-1802*–A.