MAGMATIC DIKES AND MEGAFLOODS: A PROTRACTED HISTORY OF INTERACTIONS BETWEEN MAGMA AND SUBSURFACE ICE, CERBERUS FOSSAE, MARS. S. A. Kattenhorn and J. A. Meyer, Department of Geological Sciences, University of Idaho, Moscow, ID 83844-3022, simkat@uidaho.edu, meye0750@vandals.uidaho.edu.

Introduction: The Cerberus Fossae region of Mars is located southeast of the volcanic bulge Elysium Mons, between 154-174°E and 6-12°N. The region is dominated by a cluster of four sets of SE-trending parallel fractures, the longest of which extends a distance of ~1200 km (Fig. 1). The fracture sets are spaced 40-45 km apart and each set is distinctly segmented (Fig. 2). A second cluster of fractures occurs parallel to, and 350 km north of Cerberus Fossae (Fig. 1). Each of these fractures is approximately radial to Elysium Mons, and ostensibly reflect magmatic intrusions (dikes) that propagated away from Elysium driven by magma pressures in the central volcanic complex.

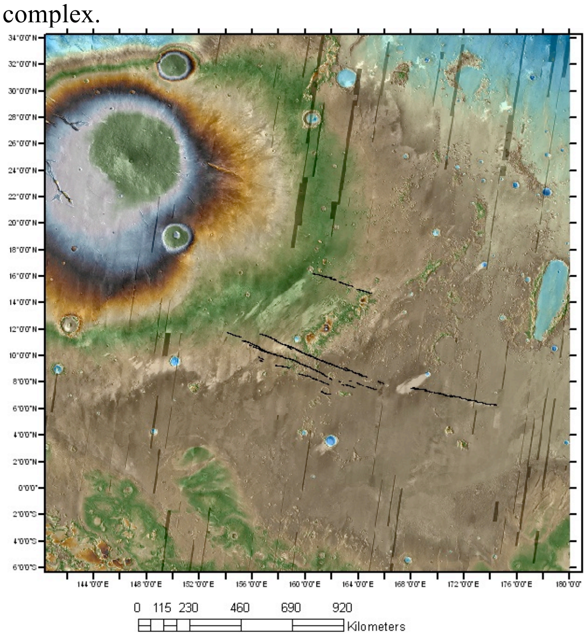

Figure 1: Regional view of Cerberus Fossae (black lines) and its relationship to Elysium Mons (top left). The dike system intruded radially away from the volcano. Colors represent MOLA elevations superimposed on THEMIS images.

The Cerberus Fossae fractures have been attributed to dike intrusions in previous work [1-2], as they appear to act as a source region for the Athabasca Valles megafloods that flowed southward from the western end of Cerberus [1-4]. In this work, we explore the relationship between Cerberus Fossae and megafloods, characterize the geometries and topographic signatures of where the megaflood erosional valleys intersect the fracture zones, discuss mechanical models for the surface manifestation of fracturing related to dike intrusion, and promote the case for a protracted history of megaflood events related to a long-lived dike intrusion history during the construction of Elysium Mons.

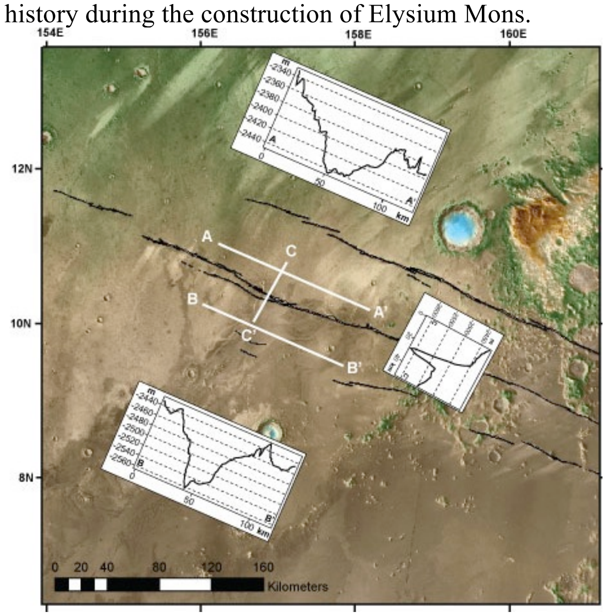

Figure 2: Segmented geometry of Cerberus Fossae fractures, analogous to terrestrial dikes. The western edge of Cerberus served as the source of the Athabasca floods, which emanated in the vicinity of profile C-C' and flowed SW. An erosional valley is evident both NE (A-A'; 60m deep) and SW (B-B'; 120 m deep) of the central crack. The higher elevation of the valley on the NE side (see C-C') suggests an abandoned valley from an earlier dike-related flood from the NE.

Cerberus Fossae: The term fossa (plural, fossae) refers to a long, narrow trough or depression on the surface of planetary body. The term has no explicit genetic affinity, with fossae potentially forming in response to graben faulting, dike intrusion, eruptive fissures, pit chains, and even geomorphic modification by surface processes. Cerberus Fossae is spatially related to Elysium Mons volcano and forms a radial pattern away from volcano typical of dike patterns on both Earth and Mars [6]. The SE-trending dike system curves toward a more easterly orientation with increasing distance from Elysium, implying intrusion into a regional stress field in which the maximum compression, σ_1, was oriented approximately E-W. A pressurized magma body with a circular shape in map view preferentially forms fractures facing the σ_1 direction. Accordingly, Elysium Mons only shows a pattern of radial fractures emanating from its E and W sides.

The Cerberus Fossae fractures are young relative to other geological features in the area in that they cross-cut the topography and all craters along their lengths. The dike affinity is further evidenced by the existence of effusive products along the edges of the fractures, implying that they are eruptive fissures [4, 6-7]. The detailed fracture geometry (Fig. 2) reveals a highly segmented system that is typical of terrestrial dike systems [8]. The segmentation is evident at a range of scales, implying fracture growth through the mechanical interaction and linkage of smaller segments to form longer segments. The smallest segments have lengths in the range 3-10 km. Linkages of these segments create a second tier of segment lengths in the 20-50 km range. Linkages between these segments create a third tier in the 90-120 km range. Dikes are well approximated as dilating cracks within an elastic body [9]. As such, they should show an approximately elliptical distribution of dike opening from tip to tip along the dike length. Many of the Cerberus Fossae fractures show rounded ends and somewhat consistent widths along their lengths, although exact width versus length patterns have not yet been quantified. Part of this morphology is the result of geomorphic modification through collapse along the fissure margins; however, it is also possible that the surface manifestation of the fractures is caused by normal fault graben as opposed to a large eruptive fissure (see Discussion).

Athabasca Valles Megafloods: The region south of Cerberus Fossae hosted a Late Amazonian megaflood system in Athabasca Valles [1-4]. Aqueous erosional products of the Athabasca floods are liberally exposed along a prominent erosional valley that can be traced upstream to a source at Cerberus Fossae. The conventional model for these floods invokes magmatic interaction with a subsurface layer of ice, such as a frozen groundwater system. Melting of the ice layer by magma as dikes propagated upward through the martian crust resulted in copious water release, causing a megaflood that moved down the regional slope towards the south, and creating the prominent erosional channel Athabasca Valles. Such a model makes a strong case for the presence of a subsurface cryosphere that may hold vast quantities of H_2O. The possible existence of such a layer has motivated numerous studies and Mars missions, and is now borne out by numerous lines of evidence such as the findings of the recent Phoenix mission [10], evidence of ejecta of icy materials during recent impacts [11], and clues to water signatures in epithermal neutron data [12].

Our analysis of surface topography along the Cerberus Fossae cracks suggests that Athabasca Valles may have formed through numerous superposed megaflood events, each related to a dike intrusion event at Cerberus. Although the main erosional channel (120 m deep) is associated with the longest, center fracture (Fig. 2 inset), a 60 m deep channel upslope of this fracture suggest earlier flood events related to dikes further north. Hence, Athabasca Valles may represent the cumulative result of a protracted period of megafloods during the progressive development of the dike system from Elysium, which is consistent with geomorphic evidence of multiple floods in Athabasca [5]. It is possible then that there were lower per-flood-event discharges than the 1-2 million m^3/s estimate of [1, 5].

Discussion: Our analysis of Cerberus Fossae confirms a magmatic origin for these features, but with some caveats. Although effusive volcanic products are visible in some locations along the fissures, highlighted by prominent SW-directed wind streaks from the fracture margins, many portions of the fracture system are distinctly graben-like. Detailed views of the fissures in HiRISE images reveal that the margins of the fossae consist of multiple, parallel, vertical cracks. Hence, the fissures do not represent a single dilated dike, but rather a discrete zone of deformation. Although such a geometry is not inconsistent with dike intrusion (dikes commonly propagate through a tight cluster of cracks that formed in the process zone ahead of the propagating dike; [9]), it is also possible that these cracks are associated with the upward propagation of normal faults. Vertical, dilational normal faults are common in the rift zones of Iceland [13] as well as on Mars [14]. They create dilational space along vertical cracks during ongoing extension, offering a pathway for magma. A normal fault model is not inconsistent with dikes being responsible for the fossae as normal fault graben commonly form above the upper tip of a subsurface dike in terrestrial rift zones [15]. Through ongoing detailed mapping of the fractures, we will determine which of these mechanisms provides the better mechanical model for the surface manifestation of Cerberus Fossae.

References: [1] Burr et al. (2002) *GRL 29,* 10.1029/2001GL013345. [2] Berman & Hartmann (2002) *Icarus* 159, 1-17. [3] Burr et al. (2002) *Icarus* 159, 53-73. [4] Jaeger et al. (2007) Science 317, 1709-1711. [5] Mège & Masson (1996) *Planet. Space Sci.* 44, 1499-1546. [6] Plescia (2003) *Icarus* 164, 79-95. [7] Keszthelyi et al. (2000) *JGR-Planets* 105, 15,027-15,049. [8] Delaney et al. (1986) *JGR* 91, 4920-4938. [9] Pollard (1987) *Geol. Assoc. Can. Spec. Pap.* 34, 5-24. [10] Smith et al. (2009) *Science* 325, 58-61. [11] Byrne et al. (2009) *Science* 325, 1674-1676. [12] Clevy et al. (2005) *Eos, Trans. AGU* 86, P31C-0220. [13] Grant & Kattenhorn (2004) *J. Struct. Geol.* 26, 537-557. [14] Ferrill et al. (2004) *GSA Today* 14, 4-12. [15] Rubin & Pollard (1998) *Geology* 16, 413-417.