A HUMAN LANDING SITE AT APOLLINARIS SULCI: LIFE INSIDE A YARDANG. L. Kerber[1], R.P.Mueller[2], L. Sibille[2], A. Abbud-Madrid[3], T. Bertrand[4], K.M. Stack[1], A.K. Nicholas[1], C.E. Parcheta[1], S. Piqueux[1], I. J. Daubar[1], M.J. Malaska[1], J.W. Ashley[1], S. Diniega[1] J.L. Dickson[5], C.I., Fassett[6], [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109 (kerber@jpl.nasa.gov), [2]Swamp Works, Exploration Research and Technology Programs, NASA, Kennedy Space Center, FL 32899 [3]Center for Space Resources, Colorado School of Mines Golden, CO 80401 [4]Laboratoire de Météologie Dynamique, 4 Place Jussieu, Paris, France [5]Brown University, 324 Brook St., Providence RI 02912. [6]Department of Astronomy, Mount Holyoke College, South Hadley, MA.

Introduction: Human explorers on Mars will conduct investigations and collect samples that will have enormous and enduring scientific value. For this reason, any human landing site must provide access to a variety of geologic terrains of different ages and origins, ensuring continuous scientific return over many years. In addition, the site must offer resources that will allow future astronauts to reduce their logistical reliance on Earth and establish a stable and sustainable presence on Mars.

Apollinaris Sulci is a region located on the dichotomy boundary of Mars between the 4-km-tall volcano Apollinaris Mons and the ~150 km diameter Gusev Crater (**Fig. 1**). Its position at low latitudes, on the boundaries of diverse terrain types, and adjacent to a unique combination of useful resources, makes it an ideal candidate for a future human landing site.

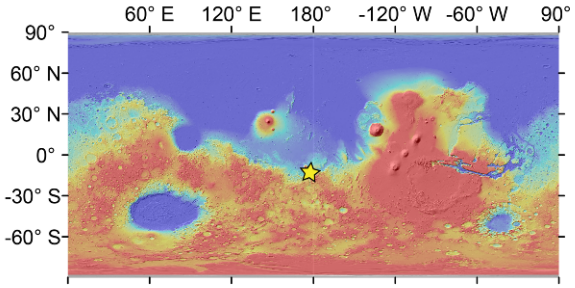

Figure 1. Location of the candidate human landing site at Apollinaris Sulci (12˚40' S, 176˚40' E). Global Mars Orbiting Laser Altimeter (MOLA) data and hillshade.

Science Targets: A 100-km radius exploration zone (EZ) centered on the flat, open plains of southern Apollinaris Sulci contains numerous scientific regions of interest that span across several periods of Martian history (**Fig. 2**). To the south, the landing site is bordered by Noachian highlands with two types of valley networks (**Fig. 2b**). To the southwest is Gusev crater, host to a vast Hesperian basaltic plain useful for calibrating crater counting ages. This region also has numerous kipukas that are similar to the Columbia Hills explored by the Spirit rover futher south and good conditions for observing dust devils. Towards the northwestern part of the EZ is a region of "chaos", a type of terrain which is hypothesized to be related to catastrophic water release [1-3]. In the northern part of the exploration zone is the terminus of the giant volcanic fan of Apollinaris Mons, a volcano that was last active near the boundary between the Hesperian and Amazonian periods [4]. Apollinaris Mons is thought to have formed through explosive volcanic eruptions with significant volcano-ice interactions [5]. Apollinaris Mons is also associated with a gravity anomaly, a magnetic anomaly [6], and unexplained hydrogen and chlorine anomalies [7]. Directly to the north of the landing site are yardangs (wind-eroded ridges) of the Medusae Fossae Formation (**Fig. 2b**), a voluminous fine-grained deposit stretching for thousands of kilometers along the Martian equator [8-9].

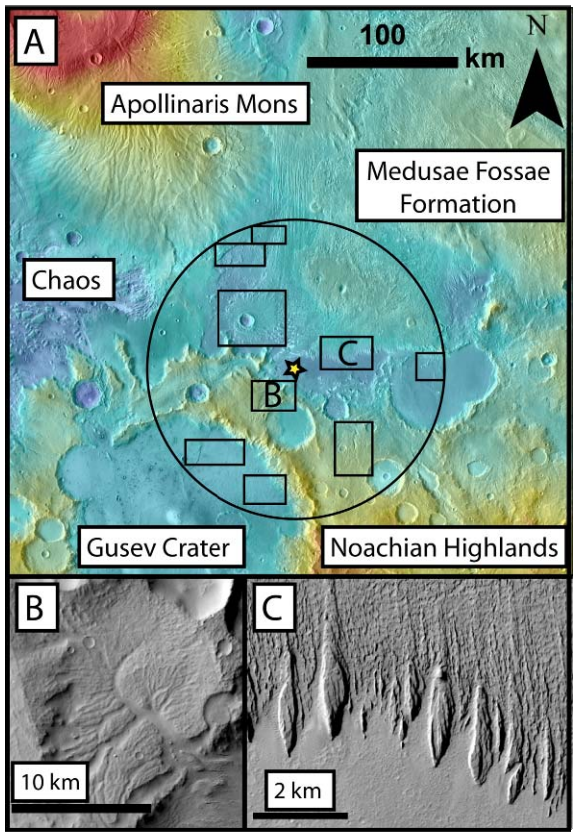

Figure 2. A) The location of the proposed Exploration Zone and scientific regions of interest. B) Dendritic valley network. C) Yardangs of the Medusae Fossae Formation. A from MOLA data, B and C from global CTX mosaic accessed via Google Mars.

This deposit is thought to be an ignimbrite (formed from volcanic ash flow deposits [8]), or a tuff (formed

from volcanic ash fall deposits [9]). In most places the Medusae Fossae Formation is characterized by a gentle emplacement that preserves underlying geological features [10]. Later erosion exposes these buried strata in a nearly pristine state. Where it is exposed in Apollinaris Sulci, the Medusae Fossae Formation has fine-scale, non-uniform, and discontinuous layering. The presence of yardangs provides natural roadcuts into the Medusae Fossae Formation, allowing ready access to its depositional history and those of underlying units.

Possibilities for In-Situ Resource Utilization: While water ice appears to be common at high Martian latitudes, the Martian low latitudes are markedly depleted in hydrogen [7]. The region surrounding Apollinaris Mons and Lucus Planum is a notable exception to this trend: here gamma ray data reveal up to 7.5 wt% water-equivalent hydrogen within the first tens of centimeters [7]. This enhancement has been attributed to the phreatomagmatic nature of the Apollinaris eruptions [7], but the idea that water could still remain close to the surface at low latitudes for several billion years remains speculative.

A major advantage to landing a human mission near the Medusae Fossae is the potential to use the formation itself as a source of feedstock for civil engineering projects. The Medusae Fossae represents a vast source of fine-grained, easily mineable material that could be used to build landing pads, berms, roads, habitations, emergency shelters, equipment shelters, etc. [11]. In addition, dwellings could be dug directly into the side of yardangs, providing natural protection from temperature extremes, radiation, and small meteors. Volcanic tuff deposits have served as building material for human beings for milennia [11]. Cities such as Rome and Naples sit above extensive tuff quarries and underground tunnels, cisterns, storerooms. In the Cappadocia region of modern Turkey, early Christians built and enlarged underground cities, some of which were capable of housing more than 20,000 people and their livestock during times of war [12] (**Fig 3**). Some of these cave houses are still in use today as residences, storerooms, stables, and hotels.

The geography of Apollinaris Sulci is conducive to extended human habitation, as it includes a flat plain (for landing spacecraft, transporting materials, and eventual farming) coupled with the yardang cliffs of the Medusae Fossae Formation, which would provide raw construction material and a place to dig protective habitations. In-situ additive construction using basalt-based materials and sulfur compounds as binders would also be possible [13]. The exploration zone is close to the Spirit rover, which could eventually be retrieved and studied. At 12 S, the landing site is close enough to the equator to take advantage of solar power and the increased equatorial velocity of Mars for Mars Ascent Vehicles. In summary, the Apollinaris Sulci region provides a compelling target for scientific exploration, resource utilization, and human habitation.

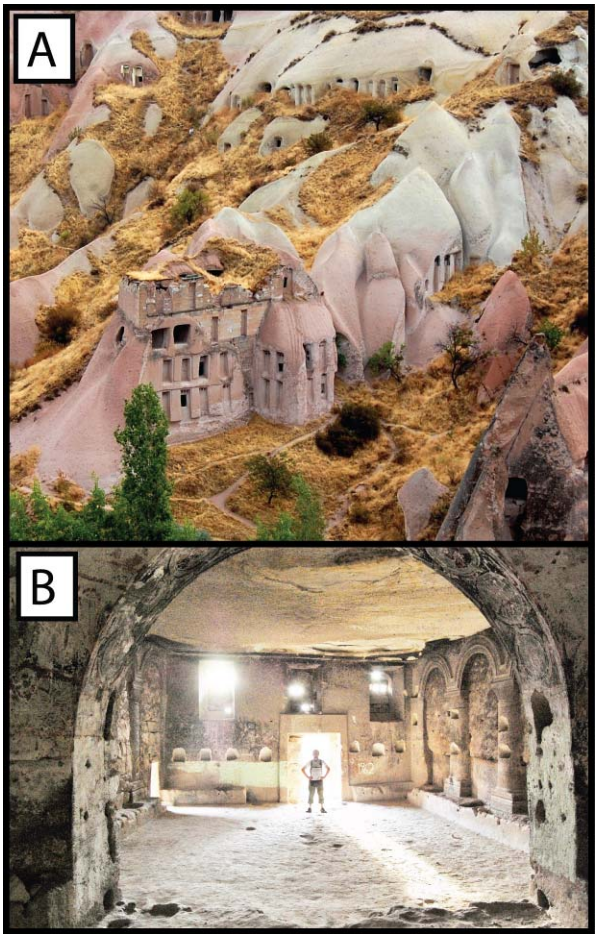

Figure 3. Ancient tuff dwellings in Cappadocia, Turkey from the outside (A) and inside (B). Photos by author.

References: [1] Sharp, R.P. (1973) *J. Geophys. Res. 78*, 4073–4083. [2] Chapman, M.G., Tanaka, K.L. (2002) *Icarus 155,* 324–339. [3] Meresse, S., et al. (2008) *Icarus 194*, 487–500. *JGR 90,* 1151–1154. [4] Greeley, R., Guest, J., 1987. *USGS Misc. Inv. Series Map I-1802*-B [5] Robinson, M.S. (1993) *Icarus 194*, 487–500. [6] Hood, L.L., et al. (2010) Icarus 208, 118-131. [7] Boynton, W.V. et al. (2007) *JGR 112*, E12S99. [8] Scott, D.H., Tanaka, K.L. (1982) *JGR 87*, B2, 1179–1190. [9] Kerber, L. et al. (2011) *Icarus 216*, 212–220. [10] Kerber, L., Head, J.W. (2010) *Icarus 206*, 669–684. [11] Funiciello, R. et al. (2006) GSA Special Papers 408, 119–126. [12] http://www.cappadociaturkey.net/derinkuyu_undergrouun_city.htm. [13] Mueller, R.P., et al. (2014) *Proc. of ASCE Earth and Space 2014*: pp. 394-403.