THE SEARCH FOR POSSIBLE SOURCE CRATERS FOR MARTIAN METEORITE ALH84001

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ABSTRACT: ALH84001 is the only martian meteorite currently known with a crystallization age of 4.5 Ga. This ancient age indicates the meteorite must come from the ancient crust of Mars, located primarily in the southern hemisphere of the planet. The 4.56 Ga crystallization age, the 16 Ma ejection, and theoretical models of how material is ejected off Mars were used to identify possible source craters for ALH84001. Eight craters remain from the initial search and subsequent photogeologic analysis, with two craters being the best candidates. One crater is 11.3 x 9.0 km in size and located east of Hesperia Planitia at 11.7°S 243.3°W. The second crater is 22.9 x 14.6 km, located south of the Schiaparelli impact basin at 14.0°S 343.5°W.

INTRODUCTION:The martian meteorite ALH84001 has attracted much attention since the August 1996 announcement of possible biogenic evidence and microfossils within entrained carbonates [1]. ALH84001 is an igneous orthopyroxenite which crystallized 4.5 Ga ago [2]. The meteorite records a shock event (Ar-Ar analysis) at about 4.0 Ga ago (likely from a near-by impact) [3] and has a cosmic ray exposure age of about 14-16 Ma, suggesting ejection from the planet about 16 Ma ago [4]. Unlike the other SNC meteorites which contain only traces of carbonates, ALH84001 contains relatively large carbonate globules that formed by interaction of atmospheric carbon dioxide with water. The temperature of formation for these carbonates is still hottly debated [5, 6, 7], as is the formation age of the carbonates (ranging from 1.39 Ga [8] to 3.84 Ga [1]).

A major question with any of the martian meteorites is where on the planet did they come from. For the 11 younger SNC meteorites, a number of sites in the young Amazonian-aged regions of the planet have been proposed [9]. Using similar reasoning based on the meteorite's formation age, its ejection age, and current ideas of how material is ejected off Mars, possible source craters for ALH84001 can be identified.

TERRAIN CONSTRAINTS: Sm-Nd analysis indicates a crystallization age of 4.56 Ga for ALH84001 [2], indicating that the rock comes from the ancient terrain on Mars. Only the heavily cratered Noachian-aged terrain dates from this time period, specifically the Middle and Early Noachian units which are estimated to have ages greater than 4.3 Ga based on the Neukum and Wise chronology [10]. These units cover about 20% of the surface of Mars, primarily in the heavily cratered southern hemisphere. The search for possible source craters of ALH84001 is thus limited to these units.

CRATER CONSTRAINTS: The cosmic ray exposure age suggests that ALH84001 was ejected off Mars about 16 Ma ago, thus constraining the age of the source crater. The erosional environment on Mars over the past 20 million years is expected to have been similar to that of today, with no surface fluvial activity and only minor amounts of volcanism and eolian and impact erosion. Thus the source crater for ALH84001 is expected to still retain features of a fresh impact crater: sharp rim, pristine ejecta blanket, and little evidence of subsequent geologic activity. The search for possible source craters of ALH84001 is limited to such fresh-appearing craters.

THEORETICAL CONSTRAINTS: Acceleration of material to martian escape velocity without pulverizing the material is a problem which has been studied in considerable detail since a martian origin was first proposed for the SNC meteorites. Acceleration of spallation products produced during the formation of large impact structures is one mechanism which has been proposed [11], which other studies have found that ejected material can be accelerated to the necessary speeds during oblique impacts [12, 13]. Vapor plumes created during impact into the volatile-rich substrate of Mars may help to gently accelerate the material to the martian escape velocity of about 5 km/sec. Based on these dynamical studies, a near-vertical impact producing a crater >100-km-diameter, or a low angle impact producing an elliptical crater >10-km-diameter could eject the necessary quantity of material from Mars. Thus, this search for possible source craters of ALH84001 has been limited to craters larger than 100-km-diameter and to elliptical craters with a major axis larger than 10-km in diameter.

OTHER CONSIDERATIONS: ALH84001 contains additional information which may help identify possible source craters. The meteorite contains evidence of a major pre-ejection shock event around 4.0 Ga [3]. This event is believed to represent shock from a near-by impact. Thus any potential source crater for ALH84001 should be located near another, more ancient impact. In addition, the presence of carbonates within the meteorite suggest a water-rich environment. Geochemical and geological evidence suggests that large quantities of water/ice exist in the martian substrate, so surface evidence of fluvial activity near any potential source crater, while supportive of the evidence, is not necessary. Harvey and McSween, arguing for a high-temperature origin of the carbonates, suggest that the carbonates could be formed by reactions between the host rock and a hot carbon dioxide rich fluid produced during impact. This scenario would also support evidence of a near-by impact, but the controversial age of the carbonates prevents using such a scenario as a major constraint in identifying possible source craters for the meteorite.

THE SEARCH: *The Catalog of Large Martian Impact Craters*, a compilation of 42,283 martian impact craters larger than 5-km-diameter and including characteristics of each crater such as its location, underlying terrain, preservational state, and degree of ellipticity, was used to search for possible source craters of ALH84001. The search was constrained to terrain units which formed during the Middle and Early Noachian periods since these are the only units which could possibly date from the 4.56 Ga time period during which the rock crystallized. The 16 Ma ejection age of the meteorite constrained the search for possible source craters to those craters still displaying pristine morphologies. The theoretical constraints on what size and shape crater can eject material from Mars were used to constrain the search to craters >100-km-diameter (any shape) and to elliptical craters >10-km-diameter. These were the only constraints used in the initial search for possible source craters.

THE RESULTS: Twenty-three impact craters were identified as possible source craters for ALH84001 based on the above criteria. Thirteen of these craters were of the large (>100-km-diameter) type while the other 10 were of the smaller elliptical crater type. Once these thirteen craters were identified, we used Viking Orbiter imagery to take a closer look at each crater. All of the large (>100-km-diameter) craters were eliminated from further consideration due to evidence of geologic activity which likely makes the crater older than 16 Ma (large numbers of superposed craters, rims breached by tectonic or fluvial processes, degradation of ejecta blanket, etc.). Two of the smaller elliptical craters were eliminated by this same analysis for similar geologic reasons. Of the remaining eight craters, six are surrounded by ejecta blankets which have undergone some degradation. Two craters, however, meet all the criteria established above and display little evidence of subsequent erosion. These two craters are the strongest candidates for possible source craters of ALH84001. The first is a slightly elliptical 11.3 x 9.0 km crater with an asymmetric ejecta blanket located east of Hesperia Planitia on the Noachian-aged cratered unit of the plateau sequence at 11.7°S 243.3°W. A 25-km-diameter rimless, flat-floored crater is located less than 25-km away from the crater and some scouring of the surrounding terrain, suggested by some to be the result of fluvial activity, is seen. The second crater is 22.9 x 14.6 km elliptical crater located south of the Schiaparelli impact basin at 14.0°S 343.5°W, within Noachian-aged dissected plateau unit. This crater displays a prominent "butterfly" ejecta pattern and is located on the rim of a degraded 60-km-diameter crater. The small valley network channel Evros Valley is located to the north of this crater and evidence of fluvial erosion of the region is seen directly to the east of the crater, indicating that fluvial activity has been a major process in this area at least during some period in the martian past.

FUTURE WORK: Work is continuing to better characterize the areas of the possible source craters of ALH84001. Although most of the current work is directly at the two best sites discussed above, the six small "runner-up" craters are also being re-evaluated. New data from the Mars Global Surveyor Mission should provide additional information that will be useful in this analysis.

REFERENCES: [1] McKay, D.S. et al. (1996) *Science*, *273*, 924-930. [2] Jagoutz, E. et al. (1994) *Meteoritics*, *29*, 478-479. [3] Ash, R. D. et al. (1996) *Nature*, *380*, 57-59. [4] Swindle, T. D. et al. (1995) *Geochem. Cosmochem. Acta*, *59*, 793-801. [5] Romanek, C. S. et al (1994) *Nature*, *382*, 655-657. [6] Harvey R. P. and H. Y. McSween (1996) *Nature*, *382*, 49-51. [7] Hutchins, K. S. and B. M. Jakosky (1996) *Bull. Amer. Astron. Soc.*, *28*, 1058. [8] Wadhwa, M. and G. W. Lugmair (1996) *Meteoritics*, *31*, A145. [9] Mouginis-Mark, P. J. et al (1992) *J. Geophys. Res.*, *97*, 10213-10225. [10] Tanaka, K. L. et al (1992) in *Mars*, 345-382. [11] Vickery, A.M. and H. J. Melosh (1987) *Science*, *237*, 738-743. [12] Nyquist, L. E. (1984) *Proc. Lunar Planet. Sci. Conf. 14th*, B631-B640. [13] O'Keefe, J. D. and T. J. Ahrens (1986) *Science*, *324*, 346-349.