If a meteorite of Martian sandstone hit you on the head would you recognize it?

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Introduction: Have you thrown away a 'meteorwrong' that was really a Martian meteorite? All thirteen Martian meteorites recognized are igneous rocks but Mars is a very Earthlike planet with exposed igneous rocks, deposit of sediments and almost certainly sedimentary rocks. Sedimentary rocks of Martian origin have NOT been recognized as meteorites. Sedimentary meteorites should be sampled on Earth in proportion to the fraction of Mars covered by sedimentary rock. They should not be entirely absent. Such meteorites are seldom seriously considered. As a result, Martian sedimentary meteorites may have been collected, not recognized and thrown away. Meteorites of sedimentary rock from Mars would, contribute significantly to elucidating the climatic history of the planet and to the search for possible life forms.

Context: The controversy about the origin of organics and other features, in Martian meteorite ALH84001[1-4], and the suggestion that Mars supported life in its wetter early history suggest that a search for Martian life in samples with the highest probability of preserving such traces would be useful. The most likely sites for preservation of traces of Martian life are in Martian sedimentary rocks. Only a true Martian sedimentary rock containing fossils can provide unequivocal evidence of life prior to a detailed surface mapping and sampling program on Mars. The ultrabasic igneous rock, ALH84001, is by comparison an extremely poor candidate in which to search for Martian life as it is more likely to show terrestrial contamination signatures than Martian biogenic signatures[3]. Nannofossils of definite terrestrial origin are known in 4 Antarctic chondrites indicating the pervasiveness of terrestrial invasion[4]. The ability to recognize Martian sedimentary rocks (and any fossils that they may contain) should they arrive on earth as meteorites is, therefore, critical to both the search for evidence of life on Mars, and for detailed understanding of the Mars climate.. Knowledge of Martian paleoclimate, has fundamental implications for understanding the evolution of both Mars and Earth.

The presence of eolian bedforms and ubiguitous red dust, demonstrate the movement of unconsolidated sediments by Martian winds[5]. Evidence for the role of water as a sculptor of the Marscape and as an agent of erosion, transportation and deposition increases almost daily[6]. Sediment deposits are likely to occur in topographic lows and flood plains of various drainage systems that cover significant fractions of the planet surface. Impact processes that ejected Mars samples for delivery to Earth as meteorites cannot have been biased to sample only igneous rocks, so a fraction of the sedimentary rock on the surface should have been ejected. The assumption that meteorites have mafic or ultramafic compositions dominates the meteorite identification process and could lead to an erroneous rejection of a sedimentary rock meteorite. We suggest that this bias needs to be corrected.

The feature by which many meteorites are recognized to be of extraterrestrial origin is fusion crust, the product of its transit through the Earth's atmosphere. Most descriptions of fusion crust on meteorites fail to discuss comprehensively the range of appearance seen. A telling example is the fusion crust on lunar anorthosite meteorites that is quite unlike the crust on other achondrites or chondrites. Anorthosite fusion crust sometimes looks green and 'greasy' and superficially resembles chlorite or serpentine minerals. The appearance of fusion crust formed on a carbonate or evaporite substrate rather than a mafic or ultramafic igneous rock is simply unknown but both are potential Martian surface rocks. Similarly if a consolidated siliciclastic sediment were ejected from Mars, the fusion crust formed during its deceleration and descent to Earth could be quite unlike anything that previous meteoritic experience defines as true fusion crust. Therefore, sedimentary rock samples displaying evidence of a transit through the Earth's atmosphere (fusion crust) are unlikely to be recognized as meteorites and would be thrown away as "meteorwrongs". Such material must be reexamined at every opportunity. Without comprehensive knowledge of the expected appearance of fusion crust on a variety of rock types the rejection, as 'meteorwrongs', of very rare meteorite types such as the proposed Martian sedimentary rocks is very likely.

Martian meteorites are a very small fraction of the global collections of meteorites representing perhaps 0.1% of the total. Since the proposed sedimentary meteorites would probably represent less than 50% of all Martian meteorites if they could be collected in an unbiased manner, the total number of samples that could have been collected at present remains very small (1-5 meteorites). The low probability of locating such rare materials requires that the best sites for collecting sedimentary meteorites are in the areas of active meteorite concentration i.e. Antarctica and other desert sites.

What should we look for in a Martian sedimentary meteorite? New constraints on the morphology and lithological character of the Martian surface are developing on a daily basis as a result of recent and current missions to Mars (Pathfinder and MGS)[7]. Detailed prediction of the petrography and composition of Martian sediments would therefore be premature. However, it is possible to make *a priori* assumptions that may provide guidelines to identifying a Martian sedimentary rock if collected as a meteorite here on Earth. The best evidence for the appearance and characteristics of Martian sedimentary rocks must come from the landers on Mars, Viking and Pathfinder[7]. Were sedimentary rocks detected at either the Viking or the Pathfinder sites? Possibly yes. While the Pathfinder site cannot be assumed to be representative of the surface of Mars, it provides hints that sedimentary rocks occur on Mars.

The fact that all recognized Martian meteorites are igneous may have affected interpretation of the Alpha Proton X-ray spectrometer data from Mars Pathfinder. We offer an alternate interpretation of chemical and imaging data from the Pathfinder site and suggest that some of the boulders studied may be interpreted as sedimentary rocks rather than the andesitic compositions presently favored. The x-ray data are “force fit” into an igneous context when they can just as realistically be interpreted in a sedimentary context. The bulk compositions of typical terrestrial sedimentary rocks[8-11] are plotted on Fig 1. Note that the primary classification of sedimentary rocks is by texture and not by chemical composition so that individual sedimentary rock types can show as much variation as all igneous rocks. The Sojourner measurements of the boulders Barnacle Bill and Yogi while interpretable as andesites or more specifically icelandites, may also be considered in terms of their sedimentary equivalents. Lithic arenites/wackes, and mudrocks from Earth overlap completely the andesite and basaltic andesite fields and share this composition space with the bulk compositions of Barnacle Bill, Yogi and Wedge. The great range of composition seen in terrestrial sedimentary rocks generally reflects the composition of the source rocks from which the sediments were originally eroded, the degree of both physical and chemical weathering and amount recycling of the sediment that makes up the rock. Silicate rocks that have seen little transformation from their original (igneous and metamorphic) source rocks are in their first cycle while repeatedly reprocessed earth materials are considered to be in second or third cycles. A consequence of this recycling is the transformation of easily weathered igneous minerals into clay minerals and oxides. As the proportion of easily weathered material decreases, the proportion of more resistent minerals increases (i.e. mineralogical maturity increases). Pure quartz rocks with essentially no felsic or mafic components are the most mature product. Pure quartz sediments have not yet been positively identified on Mars but would provide strong evidence that Martian sedimentology can be studied using parallel techniques to terrestrial sedimentary geology.

A notable feature of the composition of Barnacle Bill is its similarity to terrestrial lithic arenites and shales/mudstones. In particular, lithic arenites provide a reasonable sedimentary rock type for the inferred geology of the Ares Valles site with infrequent flooding and high energy available during the sediment transport and deposition phases. From the imaging results of Pathfinder, planar features, pits and pronounced relief on Half Dome, as well as “bump and socket” textures [12] on individual boulders suggests that layering is present that may be of sedimentary origin. Several boulders contain pebble to cobble-sized inclusions. Compositional analogues from earth and the textural features seen at Pathfinder provide a reasonable basis for assuming that sedimentary rocks have been seen on Mars and indeed may provide as viable a model for the geology of the Ares Valles as one based on andesitic regolith. The absence of a pyroxene-like absorption band within the IR spectroscopic results from some Martian sites is not a problem if the rocks are sedimentary[13].

Sedimentary rocks are formed on the surface of the planet and provide information on Martian surface conditions and processes throughout time that will simply not be recorded by igneous rocks. Sediments can be formed

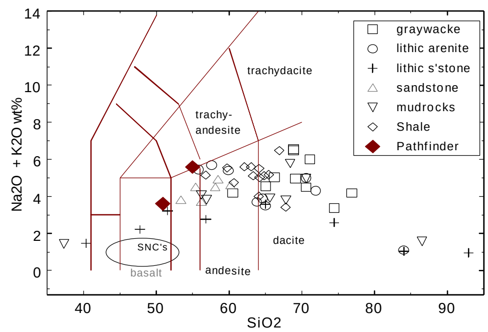

Figure 1: Compositions of Barnacle Bill and Yogi from Sagan. Sta., Mars on classification diagram for igneous rocks with composition ranges of typical sedimentary rocks[8-11] superimposed

in situ (authochthonous) by chemical and biochemical processes, thereby reflecting physical (temperature, pressure and presence of water) and chemical (eh, pH, elemental concentrations) conditions. Sedimentary rocks can also be formed of particles derived from a wide catchment area (allochthonous) thereby sampling adjacent terrain and potentially a wide variety of bedrock types. Compositional data for such samples provide constraints on larger areas of the Martian surface than a single igneous rock Age dates for Martian sediments would provide chronological constraints on the climatic and near surface evolution of the planet. Finally, if life were ever present on Mars, the most likely site for preservation of fossil traces would be in sedimentary rocks. Since the total number of Martian meteorites is small, the number of potential sedimentary rock meteorites is even smaller. Sampling statistics for small numbers are obviously a critical part of this problem. It is, therefore, important that we start now to try and correct the possible collecting bias in the global meteorite collections. The positive identification of Martian sedimentary meteorites will be difficult, but the potential benefits of identifying such materials are great.

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