SYSTEMATIC ROCK CLASSIFICATION IN A DATA-POOR ENVIRONMENT: APPLICATION TO MARS.

L. Keszthelyi[1], D. M. Burr[1], K. Herkenhoff, and L. Gaddis, [1]Astrogeology Team, U. S. Geological Survey, Flagstaff, AZ 86001.

The Problem: The process that a terrestrial geologist usually uses to classify a rock is analogous to a flow-chart [1]. The top-level classification (igneous, sedimentary, or metamorphic) is made first. Then further subdivisions are made until the proper rock name is determined. Further observations may lead to additional descriptors being added to the front of the rock name. Thus, a rock may be successively determined to be (1) sedimentary, (2) clastic sedimentary, and (3) sandstone. While sandstone is a proper classification of the rock, further observations lead to the addition of descriptors so the final classification could be "tan, immature, massive arkosic sandstone."

The division of rocks at the top level has produced fundamental divisions in the geological sciences. These fundamental divisions can lead to situations that must appear bizarre to a non-geologist. For example, a clast >64 mm in diameter is classified as a *bomb* if it is volcanic, but a *cobble* or *boulder* if it is sedimentary [1]. The application of terrestrial geologic techniques is predicated on being able to distinguish between the 3 main types of rocks.

Unfortunately, this most basic classification of rocks has proven to be extremely difficult with the data from (pre-MER) robotic space missions. This is because it has been impossible to make key observations remotely (e.g., whether or not a rock contains interlocked crystals). Thus, there is still debate about whether the rocks at the Pathfinder landing site included sedimentary conglomerates or only volcanic rocks (vesicular lavas). An unconventional technique is needed to provide useful rock classifications in the (relatively) data-poor environment planetary scientists must work in.

One Solution: We suggest that a technique developed for classifying lava flows seen only in drill core [2] may be an appropriate solution. Instead of a flow-chart, this classification scheme relies on the product of a matrix of classification criteria with a matrix of actual observations. The final result is a numerical score for the fit between each set of observations and each possible classification. The main benefits of this technique are (1) the clean separation of interpretation and observation, (2) a systematic procedure for compiling observations, (3) and a quantitative measure of the classification given to a rock. It also identifies the observation that is most strongly driving a specific interpretation. We describe each part of this process below:

Classification Criteria: This is a list of all the characteristics used to classify a lava flow seen in drill core. This includes features such as the nature of the flow surface, the distribution and shapes of vesicles, and the nature of the interface between the flow interior and upper and lower crusts. The criteria are each weighted by their relative importance to the classification. Criteria that are considered diagnostic are given a weight of 10 while criteria that are "common" features for each lava type were given a weight of 1. In addition, negative weights of –1 and –10 were provided for features that were expected or required to be absent, respectively. The quality of this collation of criteria is entirely dependant on the experience of the collator and is subjective.

Observations: The list of observations simply indicates the presence or absence of each classification criterion. It is important to provide some sense of the confidence of the observation. A value of 1 is given for a confident observation of a criterion, 0.5 for a tentative identification of the criterion, 0 for an inability to observe the criterion, -0.5 for a tentative absence of the criterion and –1 for a confident determination that the criterion was absent.

Product: The first step in determining a score for each classification is multiplying the weight for each criterion by the value of its observation. In this way the presence of a desired criterion and the absence of an undesired criterion both provide a positive result. Then these products are summed and then normalized by the maximum possible score. This result is the extent to which the given set of observations matches the criterion for the given classification. By comparing the scores for different classifications, the highest score provides the favored classification. The score also provides a quantitative sense of the confidence in this classification and the confidence in distinguishing it from other possibilities. Negative scores provide a sense of the strength with which certain classifications can be rejected. The results from the lava classification system were calibrated against type examples of each lava type and against previous classifications of less clear examples [2]. The type examples all scored >97% and a score of >68% corresponded to a confident classification, as long as the next highest score was at least 10% lower. In the few cases where this technique produced different results than earlier published work, it was found to provide the more objective result [2].

Application to Mars: For Mars, our initial goal is to provide a quick tool for providing rock names from the available data. For initial purposes, we selected 2 extrusive igneous rocks, an intrusive igneous rock, 2 clastic sedimentary rocks, and a chemical sedimentary rock. This covers the rock types most commonly searched for on the surface of Mars. Table 1 shows our initial list of weighted criteria for each classification.

Preliminary Application to Pathfinder Data: Table 1 includes our compilation of the observations from the Pathfinder Mission. Combining with our preliminary rock classification criteria, we would conclude that "andesite" is the most likely rock type at the Sagan Memorial Station. The andesite classification significantly outscores any of the other rock types. However, with a score of only 38%, this classification is not conclusive. This classification is driven mostly by the estimated chemical composition of the sulfur-free rocks. This result appears to be in accord with the previous (much more intensive) analysis of these data [e.g., 3, 4].

Future work: We will (1) improve the rock classification criteria, (2) apply it to the MER mission data, and (3) use it as a tool during operations to identify what observations are most needed to improve the interpretation of the Martian rocks.

References:

[1] Dietrich R. V. and Skinner B. J. (1979) *Rocks and Minerals* 319 pp. [2] Keszthelyi, L. (2002) *Sci.Res. Vol.* www-odp.tamu.edu. [3] McSween, H. Y. *et al.* (1999) *JGR, 104*, 8679-8715. [4] Basilevsky A. T. et al. (1999) *JGR, 104*, 8617-1636.

Table 1. Preliminary list of weighted rock classification criteria and observations from the Pathfinder Mission.

Criteria		Basalt	Andesite	Gabbro	Sandstone	Conglomerate	Limestone	Observation
Macro-texture	massive	1	1	1	1	1	1	1
	bedded	-10	-10	1	1	1	1	0.5
	laminated	-10	-10	-10	1	-10	1	-0.5
	patchy	1	1	-1	-1	-1	1	-0.5
	pits	1	1	-1	-1	-1	1	1
	smooth	1	1	-1	-10	-10	1	-0.5
	rough	1	1	1	10	10	1	1
Micro-texture	crystalline	10	10	10	-10	-10	1	0
grain size mode	<1/256 mm	1	-1	-10	-10	-10	1	0
	1/256 – 1/16 mm	1	-1	-10	-10	-10	1	0
	1/16 – 2 mm	1	1	-1	10	-10	1	0
	>2 mm	-10	-10	10	-10	10	1	0
grain shape	very angular	-1	-1	-1	-1	-10	1	0
	angular	1	1	1	1	-10	1	0
	subangular	1	1	1	1	-1	1	0
	subrounded	1	1	-1	1	1	1	0
	rounded	-1	-1	-10	1	10	1	0
	well-rounded	-10	-10	-10	1	10	1	0
Fractures	curvi-planar	1	1	-1	-1	-1	-1	1
	recti-planar	-1	-1	-1	1	-1	1	1
	chonchoidal	-1	-10	-10	-10	-10	-1	0
	irregular	-1	-1	1	1	1	1	1
Minerals	glass	10	1	-10	-1	-1	-10	0
	quartz	-10	-1	-10	1	1	-10	0
	olivine	1	-10	1	1	1	-10	0
	pyroxene	10	10	10	-1	1	-10	0
	plagioclase	10	10	10	-1	1	-10	0
	alkali feldspar	-10	-1	-10	1	1	-10	0
	calcite	-10	-10	-10	1	1	10	0
Bulk Chemistry	SiO_2<45%	-10	-10	-10	-1	-1	-10	-1
	SiO_2 45-52%	10	-10	10	-1	1	-10	-1
	SiO_2 57-63%	-10	10	-10	1	1	-10	1
	SiO_2 >90%	-10	-10	-10	1	1	-10	-1
	CaO>50%	-10	-10	-10	-1	1	10	-1