

INFERRING EARLY MARS CLIMATE FROM COMPARISON OF DRAINAGE BASINS' MORPHOLOGIES ON MARS AND EARTH. T. F. Stepinski, *Lunar and Planetary Institute, Houston TX 77058-1113, USA, (tom@lpi.usra.edu)*, A. P. Stepinski, *Rice University, Houston, TX 77005, USA, (adamstep@rice.edu)*.

Abstract. Morphologies of Martian and terrestrial drainage basins are encapsulated by their circularity functions enabling objective and quantitative comparison. A neural net technique is used to construct a geomorphic similarity map for a population of basins. First, we study a control population of terrestrial basins for which climate data is available. We establish a correlation between basin's morphology and climate. Second, we study a sizable population of terrestrial and Martian basins. We find a systematic difference between morphologies of basins on the two planets. By extrapolating morphology-climate correlation to Martian basins, this difference could be understood in terms of climatic differences with Martian basins developing in extremely dry climate.

Introduction. Valley networks are remnants from early Mars that suggest a possibility of warmer and wetter climate in this epoch. Recently [1], we have proposed that a fluvial environment responsible for valleys creation can be assessed by analytically studying a morphology of their underlying drainage basins. The morphology of a basin reflects the large-scale geology of its site, as well as its total fluvial degradation. Factoring out the effects of geological setting reveals the pattern of basin degradation that points to a mechanism of that degradation. The basins are computationally extracted [2] from the digital topography data. Using methods of integral-geometry we represent each basin by a circularity function. This function provides a compact representation of basin's morphology and it is a good indicator of basin's degradation mechanism. A neural net technique called self-organizing map is used to construct a similarity graph for different basins. In [1] we have constructed such similarity graph for 53 basins, 26 of them were Noachian basins underlying prominent valley networks and 27 of them were typical terrestrial basins in US and South America. This graph has revealed systematic differences between morphologies of basins on the two planets indicating that terrestrial and Martian surfaces eroded differently.

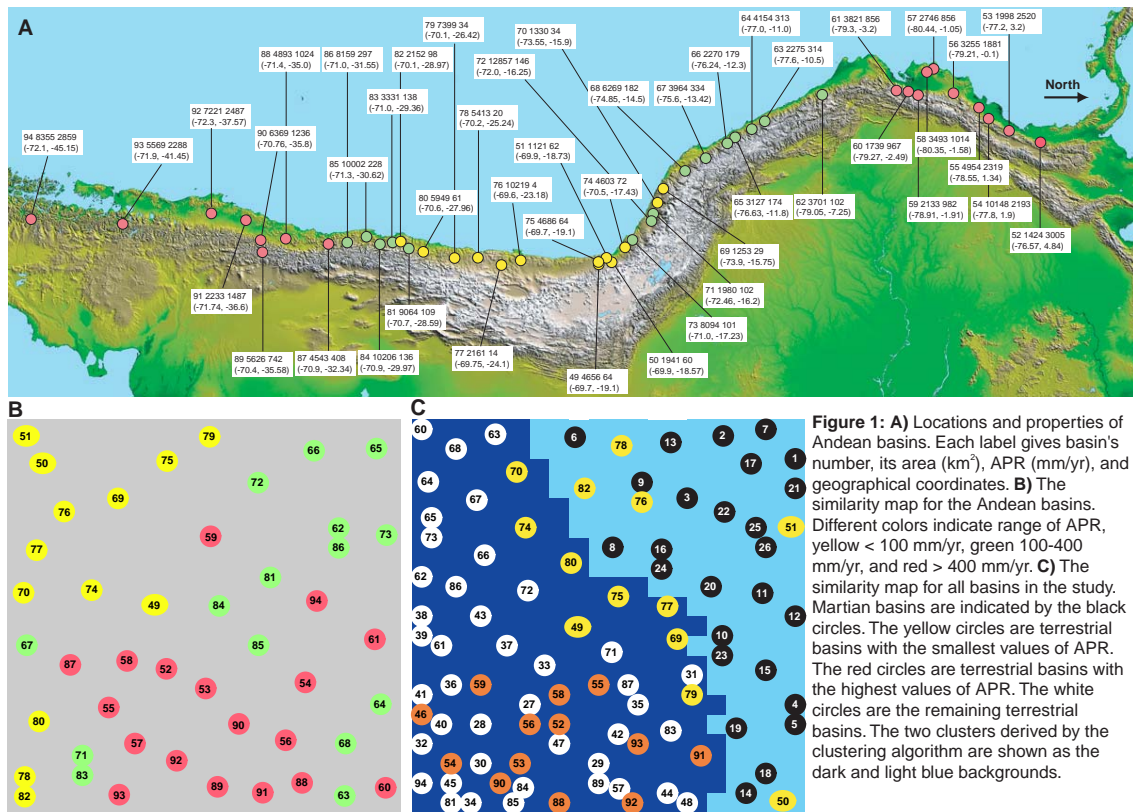
In the present study we focus on understanding the reason for the dichotomy in basins' morphologies on the two planets. In particular, we investigate a role of climate (restricted to the amount of rainfall) on basin's morphology. To this end we first study the population of 46 terrestrial basins extracted from the western slopes of Andes between 5°N and 45°S. The spatially-averaged annual precipitation rate (APR) for these basins is in the range of 3–3000 mm/yr reflecting a highly variable climate of the Andes. Andean orogen is particularly well-suited [3] to study a correlation between climate and landscape morphology because it is a hemisphere-scale range with highly variable rainfall across a single convergent margin. These climatic differences are not dependent upon orographic effects, but are robust features of the general circulation pattern in the Southern hemisphere, and therefore may be considered a priori conditions under which the mountain range developed. Using a technique introduced in [1] for the Andean basins, we show

that basin's morphology correlates with climate. Then, we combine the population of Andean basins with 26 Martian and 22 terrestrial basins from our previous study and construct a similarity graph for all 94 basins. We infer the climate on early Mars from the location of Martian basins on this final graph.

Data and Methods. The Martian basins are extracted from digital elevation models (DEMs) with resolution of 128 pixels/degree constructed using the MOLA Mission Experiment Gridded Data Record (MEGDR) data. The terrestrial basins are extracted from DEMs with the 450-meter resolution for compatibility with Martian DEMs. Both, Martian and terrestrial basins have areas of the order of 10^4 km². The Andean basins are extracted from DEMs with the 180-meter resolution and have areas of the order of 10^3 km². Terrestrial and Andean DEMs are constructed using Shuttle Radar Topography Mission (SRTM) data with 90-meter resolution. Precipitation data [4] has a resolution of 2 pixels/degree. The APR for the Andean basins is calculated as an average APR over the entire basin. Martian basins are labeled 1 to 26, terrestrial basins are labeled 27 to 48, and Andean basins are labeled 49 to 94 (north to south) for use on Fig. 1. For each basin we calculate the circularity function. We use these circularity functions to construct the similarity graph. Methods for calculating a circularity function and constructing a similarity graph are described in [1].

Results and Conclusions. Fig. 1A shows the locations of the Andean basins. The labels give the area, the APR, and the location for each basin. Fig 1B shows the basin morphologies similarity map for the Andean basins, basins (represented by labeled circles) with similar morphologies are located close to each other on the map. The map was constructed using basins without indicating their APRs, it reflects only geomorphic similarity. After the map has been constructed we have indicated the APR by coloring the circles representing basins. The major result is a correlation between basin morphology and the APR. Despite some scatter, the circles with the same color tend to be located in the same area of the graph. That indicates that basins in similar climates tend to have similar morphologies. For example, the 13 basins with the APR < 100 mm/yr (yellow circles) cluster in the upper-left corner of the graph thus having common geomorphic features. The 18 basins with the high values of APR (red circles) cluster in the lower part of the graph indicating that they too have common geomorphic features which, however, are different from the features characterizing the low APR basins.

Fig. 1C shows the basin morphologies similarity map for all 94 basins in our study. Again, basins with similar morphologies are located close to each other on the map. The map was constructed using basins without indicating their planet of origin. Afterwards we have marked the Martian basins as black circles. The yellow circles indicate the 13 terrestrial basins with the lowest values of the APR. These basins are all



located between 16°S and 29°S in the Atacama Desert, which is a region that has been subject to long-term aridity and today is among the driest places on Earth. The red circles indicate the 13 terrestrial basins with the highest values of the APR. The white circles indicate the remaining terrestrial basins. The graph reveals a clear morphologic dichotomy between Martian and terrestrial drainage basins. This dichotomy is further supported by the clustering [5] of unlabeled basins into just two clusters indicated on Fig. 1C by the dark and light blue backgrounds. With few exceptions, a natural binarity in the data corresponds to planet affiliation. Thus, we have confirmed our previous finding [1] using a larger sample of data.

The addition of climatic data offers a possible explanation for an observed dichotomy. We have already demonstrated (Fig. 1B) a correlation between basin's morphology and climate for basins in the Andes. Embedding the Andean basins into a larger population of terrestrial and Martian basins preserves this correlation. Fig. 1C indicates a spread in locations of both wet climate and dry climate basins. This spread reflects variations due to the local environment. Transcending these variations is the overall ordering of basins by the APR. Such ordering is best seen by anchoring an imaginary ruler in the lower-right corner of the map and rotating it clockwise from the bottom edge to the diagonal of the map. At small angles of rotation the basins along the ruler are mostly from wet climates, at intermediate angles of rotation the basins along

the ruler are mostly from moderate climates, and at angles approaching 45° the basins along the ruler are predominantly from dry climates. Continuing the rotation beyond the diagonal of the map, the ruler intercepts mostly Martian basins, although some Atacama basins are also found there. Extrapolating this terrestrial morphology-climate correlation to Mars points to an extraordinarily dry climate on early Mars. APRs similar to or lower than those encountered at the Atacama desert are inferred for Noachian sites during the formation of the valley networks. Like in the Atacama, this precipitation is likely to come in the form of rare storms rather than being continuous. Such storms could be induced by impacts [6] instead of being the result of the terrestrial-style large-scale circulation pattern.

References

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