

ANCIENT OCEANS AND MARTIAN PALEOHYDROLOGY. V.R. Baker, R.G. Strom, V.C. Gulick, J.S. Kargel, G. Komatsu, and V.S. Kale, Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721.

The concept of the hydrological cycle is one of the great achievements in the understanding of nature. Intellectual history's premier hydrologist, Leonardo da Vinci, seems to have held two simultaneous views of the cycle: (a) an external process in which evaporation from ponded areas leads to precipitation and runoff from the land (the prevailing terrestrial view), and (b) an internal process in which subsurface pressures from within the Earth force water upward, as in blood pumped through a human body. After 500 years, a very similar paradox applies to our modern view of the long-term planetary hydrological cycle on Mars. Numerous morphological features, notably the valley network systems of the heavily cratered terrains (1,2,3), imply formation by dynamical cycling of water. The sapping process responsible for most valley networks (4) requires a persistent flow of ground water that can only occur with long-term hydraulic head differentials to drive the flow in subsurface aquifers (5,6). Either endogenetic or exogenetic hydrological cycling is necessary to explain these relationships.

Endogenetic hypotheses for valley genesis on Mars maintain the necessary prolonged ground-water flows by hydrothermal circulation associated with impact cratering (7) or with volcanism (8,9,10). However, we note that the extensive volcanogenetic hydrological systems necessary to explain widespread valleys are consistent with a continuum of processes up to the megascale of Tharsis and Elysium. This observation, plus the discovery of evidence for extensive inundation of the northern plains of Mars (11,12,13,14) and the discovery of evidence for extensive glaciation in the southern hemisphere (15), led to our proposal of episodic ocean formation and related hydroclimatological change throughout Martian history (16,17). Our model was found consistent with a range of otherwise enigmatic observations, including the formation of Amazonian valley networks (5,18) and the formation of layered deposits in Valles Marineris through repeated lake filling and breaching (19). Our continuing work reveals even more detailed consistency with this conceptual scheme, including the extensive glaciation of the Hellas region (20) in Middle Amazonian time (21), further documentation of the glacial landforms used to establish southern hemisphere glaciation (22), and a coincidence of ages (within resolution capabilities) of principal elements in the late-stage global hydrological system (23).

We find it remarkable that the various Amazonian phenomena that we describe exist in temporal and spatial associations that imply a common genetic cause. Alternative hypotheses can be offered for many of the individual glacial, oceanic, fluvial, periglacial, and permafrost landforms that we have associated with a global hydrological system. If these apply, how fortuitous that the resulting landforms have been positioned to also be consistent with regional glaciation, ocean formation, and associated climatological change.

The best preserved evidence of ocean formation and related glaciation occurs late in Martian history. The ephemeral Amazonian sea in the Elysium basin, described by Chapman et al. (24), is probably a vestige of this late epoch. The associated phenomena are concentrated volcanic activity at Tharsis and Elysium, plus phases of outburst flooding. Our model of outburst through the Valles Marineris (16) is consistent with morphology there (25), but the precise volcanogenetic mechanism requires further formulation. Nevertheless, we note that the clear association of the Mangala Vallis outflow system with a local source at Memnonia Fossae (26) implies a similar connection to a Tharsis volcanogenetic source. The concentration on Mars near Tharsis of 90% of flood discharges indicated by outflow channel sizes is another fortuitous circumstance if the indicated genetic connection is denied as an "outrageous hypothesis."

Pre-Amazonian episodes of ocean formation and warm-wet climate are also indicated. Ocean development may have been more extensive, but associated landforms are degraded and not easily related to ocean size. Theoretical scenarios for ocean formation (27) and warm-wet climatic

conditions (28) are most convincingly argued for earliest Martian history, when direct landform evidence is lacking. The best evidence for these model scenarios is indirect, in the temporal sequence of valley network development (29), presumably in response to the prevailing climatic conditions. However, endogenetic mechanisms of cycling water (hydrothermal systems) complicate this relationship (30).

Modeling of small-scale volcanogenetic hydrothermal systems for typical Mars conditions (30) shows adequate discharges achieved for valley network development. Scaling upward to the immense hydrothermal system that would have to be associated with large-scale Tharsis volcanism exceeds any terrestrial experience by orders of magnitude. The cataclysmic initiation of outflow centered upon Tharsis is so remarkable as to compel a genetic association. Alternatives may be found to our hypothesis of massive volcanism triggering the water outflows (16), but these must also explain the numerous attendant phenomena that are manifested in the Martian landscape. Any alternative scheme must provide for global hydrological cycling, achieving, as in Leonardo's paradox, an overall consistency and economy of explanation.

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