Ancient Ocean–Land–Atmosphere Interactions on Mars: Global Model and Geological Evidence. V.R. Baker, R.G Strom, S.K. Croft, V.C. Gulick, J.S. Kargel, and G. Komatsu, Dept. of Planetary Sciences, University of Arizona, Tucson, AZ 85721.

A great variety of geological evidence indicates that Mars has experienced past climatic epochs characterized by intense fluvial activity (1,2,3,4), glacial, periglacial and permafrost processes (5,6,7,8,22), and phases of intense degradation of impact craters (9,10). The evidence indicates planetwide causative climatological conditions very different from those prevailing today and probably generated several times during early Martian history.

The following model is consistent with a remarkable diversity of geological evidence, some of which is otherwise anomalous with regard to alternative hypotheses. Episodic cataclysmic flood discharges of immense volume emanated almost exclusively from an equatorial zone of fractures peripheral to the Tharsis Bulge, including Memnonia Fossae (Mangala Vallis) and the Valles Marineris system (Kasei and Maja Valles) extending eastward to the Chryse Trough (Shalbatana, Simud, Tiu, and Ares Valles). The huge water volume stored in the fracture system (including ponding in the Valles Marineris) may have had its release triggered by volcanism centered on the fracture system at Tharsis. Concentration of volcanism in short time spans may occur as in terrestrial rifting (11). Based on excavated channel volumes (12), total water debouched to the low-lying Northern Plains would be at least $7.5x10^6$ km^3. Allowing for drainage of extensive subsurface aquifers (13), several times this volume could have been discharged, constituting the equivalent of a planetwide layer hundreds of meters deep (14). Concentration of this water in the Northern Plains would comprise a northern hemispheric ocean (Oceanus Borealis), the relic vestiges of which are manifested as ponded sediments (15,16,35), polygonal fractures (17), and ground-ice features (6,7).

Catastrophic invasion of the plains by relatively warm flood water would have vaporized the carbon dioxide ice of the north polar cap. Subsequent evaporation of water and sublimation of the Oceanus Borealis ice cover would have occurred at atmospheric pressures elevated well above present conditions. Addition of water vapor, a greenhouse gas, to the enhanced carbon dioxide atmosphere probably would have triggered additional feedbacks, perhaps releasing adsorbed CO_2 (18) from the previously cold regolith. The warming effect would have been further enhanced and/or modulated by optimum periods of obliquity and orbital eccentricity.

The global climate associated with cataclysmic formation of Oceanus Borealis was probably relatively short-lived and analogous to terrestrial glacial climates. Valley networks formed by precipitation related to the last formation of Oceanus Borealis during early Amazonian time are limited to low permeability zones on Alba Patera (19,20). More extensive are the widespread occurrences of periglacial landforms in the cratered uplands (7,8) and along fretted terrain margins of the highlands/lowlands boundary (21). Evidence of alpine-type glaciation in areas of the southern highlands at high latitudes (22) and possible formation of ice masses in outflow channels (23,24) probably reflect this early Amazonian glacial climate. The last glacial epoch may have consisted of an ice sheet extending from the south pole to about -45 degrees latitude.

Precipitation and temperature during the maritime climatic epoch probably fluctuated with the forcing of various orbital parameters. Water from the evaporating/sublimating ocean was gradually sequestered through recharge into the heavily cratered uplands and infiltration into the sea floor. With its disappearance, the ocean could no longer contribute water vapor to the greenhouse warming. This would rapidly lead to a return of the planet to atmospheric conditions similar to those prevailing today.

Although elements of the above sequence are best evidenced during early Amazonian time, the process could have been repeated with variations throughout martian history. Water release from subsurface aquifers was probably most extensive during the Noachian when volcanic activity was widely distributed in the martian highlands. Hydrothermal cycling (25,26,27) could have been important in valley network initiation, subsequently enhanced by precipitation during the maritime climate that followed ocean formation. The global distribution of scapolite (36) may be the result of hydrothermal processes involving CO_2. Precipitated water would largely infiltrate the highly permeable martian substrates (megaregolith and lava flows), subsequently emerging as springs, thereby enlarging valleys through sapping. At least one such phase of valley development appears to be post-heavy bombardment (Hesperian) in age (28,29). At the termination of a maritime climatic epoch much of the planetary water recycled from the temporary ocean would be trapped in aquifers of the cratered highlands. There it would reside until released by subsequent temporal/areal concentration of volcanic activity. Because of atmospheric escape processes (30), the initially high endowment of martian water (31) should have been continuously declining through time. This probably contributed to the far greater component of fluvial (valley network) activity during Noachian time versus the predominance of glacial/periglacial features in the early Amazonian. The last phases of outflow channel activity (Amazonian) from Maja Vallis and Elysium eroded older ocean floor and shoreline forming a much smaller sea. This last smallest sea would be associated with the glacial activity in the southern hemisphere.

It has not escaped our attention that, given sufficient time, large standing bodies of water under a relatively mild climate could have provided conditions favorable for the inception of life.

The long-term, cyclic formation and dissipation of Oceanus Borealis and its attendant ramifications obviously have planetwide implications that will require both theoretical modeling and testing against geological constraints. As a preliminary contribution to what will need to be a broad-based interdisciplinary research effort, we note the following points of consistency with the periodic ocean formation and hydrological cycling hypothesized herein.

Basal Scarps Surrounding Volcanoes. Initiation of the Olympus Mons scarp either as a table mountain in vestigial oceanic ice (23) or as a wave-cut margin (as on Hawaiian volcanoes) is readily accommodated, with post-maritime enhancement mainly involving mass wasting. A similar basal scarp around Apollinaris may also be related to Oceanus Borealis.

Layered Terrain in Valles Marineris. This may be lacustrine deposits laid down in lakes which occupied the valley early in its history (33). In some areas, e.g., Ganges Chasma, the source of the water was probably in the subsurface (34). The canyon may have been breached more than once, eroding the sediments and supplying water to the ocean.

Shoreline. Gradational boundary materials at the margin of the southern uplands and northern lowlands are probably best interpreted as sediment deposition in an ocean (15). This boundary probably represents the shoreline of an unfrozen ocean which occupied about 25 percent of Mars' surface.

Runoff Valleys. Drainage networks on Alba Patera, Ceraunius Tholus, and Hecates Tholus could have been caused by precipitation runoff from atmospheric moisture derived from an ocean (19).

Widespread Glacial Features. Widespread glacial features such as eskers, aretes, cirques, kettles, and outwash plains southward of about -45 degrees may be the result of the final ablation of an ice sheet precipitated from water supplied by Oceanus Borealis and cold-trapped as snow in the higher elevations of the southern hemisphere (22).

Impact Crater Degradation. The impact cratering record indicates there was at least one and probably several major episodes of crater obliteration near the end of late heavy bombardment and later (9,10) which could have been caused by fluvial, glacial, and eolian erosion and deposition resulting from a denser atmosphere, at least in part, derived from Oceanus Borealis.

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