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Geological and hydrological histories of the Argyre province, Mars

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ABSTRACT

The geologic history of the multi-ringed Argyre impact basin and surroundings has been reconstructed on the basis of geologic mapping and relative-age dating of rock materials and structures. The impact formed a primary basin, rim materials, and a complex basement structural fabric including faults and valleys that are radial and concentric about the primary basin, as well as structurally-controlled local basins. Since its formation, the basin has been a regional catchment for volatiles and sedimentary materials as well as a dominant influence on the flow of surface ice, debris flows, and groundwater through and over its basement structures. The basin is interpreted to have been occupied by lakes, including a possible Mediterranean-sized sea that formed in the aftermath of the Argyre impact event. The hypothesized lakes froze and diminished through time, though liquid water may have remained beneath the ice cover and sedimentation may have continued for some time. At its deepest, the main Argyre lake may have taken more than a hundred thousand years to freeze to the bottom even absent any heat source besides the Sun, but with impact-induced hydrothermal heat, geothermal heat flow due to long-lived radioactivities in early martian history, and concentration of solutes in sub-ice brine, liquid water may have persisted beneath thick ice for many millions of years. Existence of an ice-covered sea perhaps was long enough for life to originate and evolve with gradually colder and more hypersaline conditions. The Argyre rock materials, diverse in origin and emplacement mechanisms, have been modified by impact, magmatic, eolian, fluvial, lacustrine, glacial, periglacial, alluvial, colluvial, and tectonic processes.

Post-impact adjustment of part of the impact-generated basement structural fabric such as concentric faults is apparent. Distinct basin-stratigraphic units are interpreted to be linked to large-scale geologic

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activity far from the basin, including growth of the Tharsis magmatic–tectonic complex and the growth into southern middle latitudes of south polar ice sheets. Along with the migration of surface and sub-surface volatiles towards the central part of the primary basin, the substantial difference in elevation with respect to the surrounding highlands and Tharsis and the Thaumasia highlands result in the trapping of atmospheric volatiles within the basin in the form of fog and regional or local precipitation, even today. In addition, the impact event caused long-term (millions of years) hydrothermal activity, as well as deep-seated basement structures that have tapped the internal heat of Mars, as conduits, for far greater time, possibly even today. This possibility is raised by the observation of putative open-system pingos and nearby gullies that occur in linear depressions with accompanying systems of faults and fractures. Long-term water and heat energy enrichment, complemented by the interaction of the nutrient-enriched primordial crustal and mantle materials favorable to life excavated to the surface and near-surface environs through the Argyre impact event, has not only resulted in distinct geomorphology, but also makes the Argyre basin a potential site of exceptional astrobiological significance.

1. Introduction

A detailed reconstruction of the geologic history of the Argyre impact basin and surroundings (30–65°S, 290–340.0°E; Figs. 1 and 2), referred to hereafter as the Argyre province, is presented through a preliminary United States Geological Survey (USGS) map based on stratigraphic, structural, and geomorphic mapping using Viking Orbiter, Mars Global Surveyor (MGS), Mars Odyssey (ODY), and Mars Reconnaissance Orbiter (MRO) data (Fig. 3). The Argyre province includes the primary impact basin, basin floor and rim materials, the transition zone (region between the Thaumasia highlands mountain range and the Argyre basin and rim materials), and the southeastern margin of the Thaumasia plateau (Figs. 1 and 2). The large impact event resulted in the construction of the primary Argyre basin and the uplift of a mountainous rim. It also produced deep-seated and shallow basement structures such as radial structurally-controlled valleys and concentric ring scarps, as well as local (i.e., secondary) basins occurring among the rim materials and away from the primary basin and rim materials; impact-related deformation occurred as much as 2000 km away from the impact site (Dohm et al., 2001a) (Fig. 2).

Since the formation of the impact basin, erosional and depositional processes have substantially modified the Argyre basin and rim materials, including the emplacement of five major and distinct basin-stratigraphic units (units NAb1, NAb2, NAb3, ANb4b, HAb4a, which are detailed in Section 3.1 and in Fig. 3 and Tables 1–3). As shown below, the Argye impact event has been a significant influence on the geologic and hydrologic history of the region

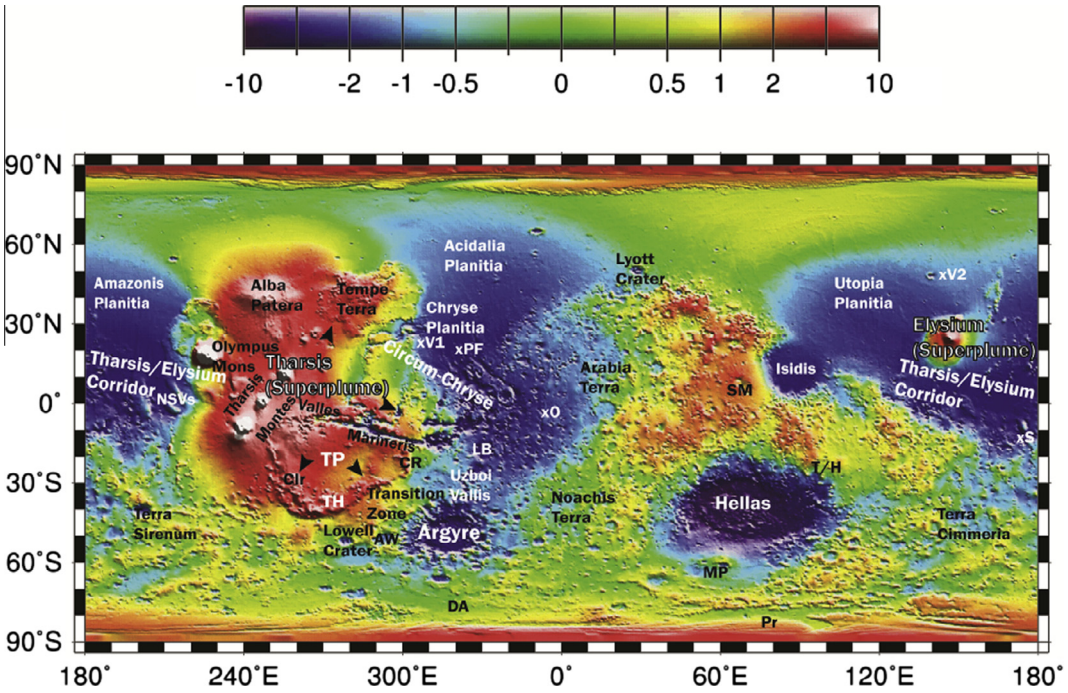

Fig. 1. Mars Orbiter Laser Altimeter Map showing the planet shape with the zonal spherical harmonic degree 1 removed (Smith et al., 1999) and nomenclature and general locations of features of interest, including Argyre basin, Tharsis and Elysium, both interpreted here as superplumes, Uzboi Vallis, the Argyre western-margin-paleolake basin (AW), Thaumasia plateau (TP), Thaumasia highlands mountain range (TH), Coprates rise mountain range (CR), Claritas Rise (Clr), Prometheus crater (Pr), Dorsa Argentea (DA), Ladon basin (LB), the northwestern slope valleys (NSVs), the ancient Europe-size drainage basin which may have contributed floodwaters to the circum-Chryse outflow channel system (black arrowheads pointing to the northern, eastern, southern, and western margins), Malea Planum volcanic province (MP), Tyrrhenus/Hadriacus volcanic province (T/H), Syrtis Major volcanic province (SM), Pathfinder landing site (xPF), Viking 1 landing site (xV1), Viking 2 landing site (xV2), Spirit landing site (xS), and Opportunity landing site (xO). Note that this geologic investigation points to the dark blue patches in the Argyre province (see Fig. 2 for outline of province), representative of relatively low topography, being inundated by water directly following the Argyre impact event (please also compare with Fig. 9). Also note the southeastern margin of the Thaumasia plateau paralleling the multi-ring structure of the Agyre impact, and as such, one of the many pieces of evidence of the influence that Tharsis and Argyre had on one another (also see Fig. 2). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)