GEOLOGIC EVOLUTION OF EASTERN HELLAS, MARS: STYLES AND TIMING OF VOLATILE-DRIVEN ACTIVITY.
David A. Crown[1], Leslie F. Bleamaster III[1], and Scott C. Mest[2], [1]Planetary Science Institute, 1700 E. Ft. Lowell Rd., Suite 106, Tucson, AZ 85719, crown@psi.edu, [2]Geodynamics, NASA Goddard Space Flight Center, Greenbelt, MD, 20771.

Introduction. The east rim of the Hellas basin and the surrounding highlands comprise a geologically significant region for evaluating volatile abundance, volatile distribution and cycling, and potential changes in Martian environmental conditions. This region of the Martian surface exhibits landforms shaped by a diversity of geologic processes and has a well-preserved geologic record, with exposures of Noachian, Hesperian, and Amazonian units, as well as spans a wide range in both latitude and elevation due to the magnitude of Hellas basin. In addition, geologically contemporaneous volcanism and volatile-driven activity in the circum-Hellas highlands provide important ingredients for creating habitats for potential Martian life.

Previous Work. The eastern Hellas region includes the highland terrains of Tyrrhena Terra and Promethei Terra, extensive ridged plains of Hesperia Planum, the highland volcanoes Tyrrhena and Hadriaca Paterae, the Dao, Harmakhis, and Reull Valles canyon systems, and the basin floor deposits of Hellas Planitia. Geologic mapping studies and geomorphic analyses of landforms characteristic of the region have employed Viking Orbiter, Mars Global Surveyor (MOC and MOLA), and Mars Odyssey (THEMIS) datasets to examine the geologic processes operating in the region and its surface evolution. Specific areas of interest include: highland degradation styles and regional stratigraphy [1-5], explosive volcanism associated with the highland paterae [6-8], emplacement of Tyrrhena Patera lava flows [6, 9-10], the timing and nature of fluvial systems [2, 11], formation of valles and relationships to associated sedimentary plains [2, 12-16], geomorphology of lobate debris aprons [17], and the morphologies and population characteristics of impact craters [18-19].

Geologic History of Eastern Hellas. A generalized geologic history for eastern Hellas has been derived by synthesizing results from numerous studies of the region. The Noachian Period included the formation of Hellas basin and numerous other large impact events that formed the adjacent rugged highlands. Degradation of cratered terrains by a combination of processes was initiated; extensive, well-integrated valley networks formed in some areas and many highland crater rims show numerous, parallel troughs. The Late Noachian and Early Hesperian Epochs were marked by continued modification of older surfaces, volcanism forming the main structures of Tyrrhena and Hadriaca Paterae (subsequently eroded by fluvial processes), and the emplacement of Hesperia Planum. In the Late Hesperian Epoch, channeled and smooth varieties of sedimentary plains filled low-lying areas within the highlands and were dissected by the extensive canyons of Dao, Harmakhis, and Reull Valles, which presumably contributed sediment and volatiles to Hellas Planitia. A complicated sequence of erosional and depositional events at the east rim and on the basin floor may have included lacustrine and glacial activity [20-21]. In the Amazonian Period, volatile-driven activity is represented by the later stages of canyon development, prominent lobate debris aprons associated with highland massifs, potentially ice-rich debris flows, and gully systems on crater and canyon walls [22-23]. Ice-cemented mantling deposits, as have been described for Martian mid-latitude regions [24-25], are variably preserved throughout the region and show interesting spatial and temporal relationships with recent flow features.

Fluvial Valleys. Cratered terrain and intercrater plains surfaces, crater rims, and flanks of the highland paterae exhibit valley systems interpreted to results from a combination of groundwater sapping and surface runoff. Integrated valley networks with sub-parallel, rectilinear, or dendritic patterns are found within Tyrrhena Terra and Promethei Terra. Drainage basins in Promethei Terra are significantly smaller in areal extent but more numerous than those in Promethei Terra, reflecting differences in the topographic characteristics of these two highly cratered regions. Mapping studies suggest that Tyrrhena Terra fluvial systems are ancient, whereas those in Promethei Terra are Hesperian in age and dissect an intermontane basin unit that accumulates in low-lying regions of the highlands. The apparent age difference between valley networks in the two regions is consistent with the more pronounced and long-lived presence of volatile-driven activity near Promethei Terra. The highland paterae exhibit radial valley systems dissecting their flank materials. Deeply incised valleys within the wider, flatter-floored troughs along the flanks of Hadriaca Patera suggest a greater component of surface runoff than at

Tyrrhena Patera. Recent analyses of THEMIS images show fine-scale parallel troughs perpendicular to the larger radial valleys, consistent with friable pyroclastic deposits and sustained fluvial erosion of the highland paterae. The interior crater rims of many large impact craters in the region also have numerous parallel troughs, although good constraints for the timing of the erosion are not available.

Vallis Systems. Dao, Harmakhis, and Reull Valles extend through the cratered highlands and sedimentary plains of eastern Hellas toward Hellas Planitia. Dao and Harmakhis Valles are characterized by steep-walled depressions, zones of subsided plains, and prominent central canyons whose walls display gullies with associated depositional aprons covering parts of canyon floors. Reull Vallis' distal regions are similar, but its upper reaches exhibit streamlined islands, scour marks, narrow, sinuous channels, and lateral terraces or benches, evidence for a fluvial stage or zone. The emplacement and erosion of a sequence of plains adjacent to Reull Vallis may be directly tied to flooding associated with this channel system Recent studies suggest that the lateral and vertical growth of Dao and Harmakhis Valles are dominated by collapse and sapping. Surface runoff may only have occurred locally. The prominent role of collapse and sapping at both small and large scales as well as sequences of finely layered deposits at the margin of Hellas Planitia suggest a volatile-rich substrate in eastern Hellas that denotes an accumulation zone for atmospheric volatiles and/or the edge of a volatile-rich deposit associated with the basin floor.

Recent Ice-related Features. The regional geology of eastern Hellas is overprinted with a suite of more recent feature indicative of contained ice, melting of ice, or its release to the atmosphere. Lobate debris aprons with lineated surfaces showing viscous flow are observed extending from canyon walls, highland massifs, and crater rims. These features may be analogous to rock glaciers or debris-covered glaciers. A variety of smaller ice-rich flow features have also been recognized in similar settings. These are often found in association with the ice-cemented mantling deposits characteristic of the Martian mid-latitudes and prominent gully systems. Geologically recent volatile-driven activity occurs in select localities over much of eastern Hellas and appears to be intense but concentrated on steeper slopes of interior crater rims and canyon walls.

Conclusions. The eastern Hellas region of Mars is clearly characterized by an extensive history of volatile-driven activity, although the style, spatial extent, and magnitude may have varied considerably over the time represented by the preserved geologic record. The general progression from widespread and spatially distinct valley development across the region in the Noachian Period to concentrated activity associated with large canyon systems in the Hesperian Period and finally to smaller-scale, more localized flow features in the Amazonian Period may represent a transition from a water- to an ice-dominated surface environment due to changes in climatic conditions. The consistent representation of volatile-driven activity in the geologic record suggest that eastern Hellas was always "wet" to some degree. The transition may have been gradual, occurring at different times and rates in different parts of the region due to the local effects of geology, topography, and climate. Hesperian and Amazonian activity, though still influencing large areas of the Martian surface, appear to have been restricted to a narrower band in latitude than the older valley networks. Sedimentary plains and layered deposits both within Hellas Planitia and on the east Hellas rim may indicate periods of enhanced volatile deposition in low-lying regions of the highlands. Remobilization of volatiles deposited earlier and/or subsequent, more localized deposition/preservation may account for the distribution and form of younger ice-rich flow features.

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