Introduction: The prominent canyons of Dao, Niger, Harmarkhis, and Reull Valles extend through cratered highlands and younger sedimentary plains east of the Hellas basin [1-3]. Geologic mapping studies place the formation of these outflow channel systems into the context of a multi-stage sequence of erosional and depositional events extending from Noachian to Amazonian time [2-7]. Viking image-based geometric analyses indicate that surface and subsurface flow as well as collapse were involved in their formation [8,9]. Surface releases of water [10] and groundwater flow [2,3] may have been driven by heat associated with adjacent volcanic centers. These earlier indications for migration of subsurface fluids are supported by evidence for a recent groundwater system associated with Dao Vallis [11]. High resolution Mars Orbiter Camera (MOC) images and Mars Orbiter Laser Altimeter (MOLA) profiles are being used to refine models for the formation and evolution of the channel systems and to assess fluvial and potential lacustrine sedimentary environments that may be related to outflow channel development.

Outflow Channel Source Regions: The inferred valles source regions hold critical clues to the geologic processes central to their formation and the role of water in their evolution and modification. Dao and Niger Valles are parallel canyons that join together south of Hadriaca Patera. Both have steep-walled closed depressions as apparent source regions; these have smooth floors with small knobs that are either remnants of collapsed plains or accumulations of sedimentary material. In Viking images no layering in canyon walls or interior layered deposits are observed. Harmarkhis Vallis has a similar scarp-bounded source depression whose floor is mostly covered by debris aprons shed from adjacent highland massifs. Source depressions of these three systems are separated from their main canyons by zones of subsided plains; these suggest subsurface connections and provide evidence for groundwater flow systems in the region [2,8].

MOLA topographic profiles show that the depressions at Dao and Niger Valles are 958 and 1230 m deep, respectively; the source depression of Harmarkhis Vallis is 1600-1900 m deep, even though it exhibits evidence for significant infilling by debris. In all three cases, the deepest parts of the depressions are toward their centers. Their concave upward shapes in profile suggest enlargement by wall collapse with material shed onto their floors, although for Dao and Niger Valles no distinct lobes of material are apparent. MOLA profiles show that those areas interpreted to be subsided plains lie up to 500 m or more below their surroundings, indicating significant quantities of subsurface materials (rock and/or ice) have been removed (potentially into the open canyon areas of the channel systems and eventually deposited in Hellas Planitia).

The irregular depression in the source area of Reull Vallis and adjacent parts of the channel system have surfaces that lie ~300 m below the surrounding ridged plains of Hesperia Planum. Due to infilling and the apparently complex history of Reull Vallis, it is not clear whether the topography is due to collapse or merely surface erosion. Reull Vallis consists of three morphologically different segments. The upper two segments exhibit streamlined features, layering or terraces in canyon walls, and in parts contain a lined floor deposit [3]. The third segment is a wide, open canyon that is most similar to the other outflow channels. A prominent tributary side canyon occurs at the junction of segments 2 and 3. This tributary canyon exhibits layering in its walls and is considered a secondary source of fluids for Reull Vallis [3]. MOLA profiles show that this canyon is up to 1562 m deep with relief of 1000 m or more along both the northern and southern walls. The cross-sectional shape is similar to that of the source depressions at Dao, Niger, and Harmarkhis Vallis with materials shed from the walls presumably creating a concave upward shape. The elevation of the tributary canyon floor is between -1900 and -2200 m. The elevation of the floor of Reull Vallis at the start of segment 3 is -2232 m suggesting a common base level. The end of segment 2 of Reull Vallis is at an elevation of -1703 m; it is unclear whether the floor deposits in segment 2 are ~500 m thick or if this topographic change reflects a major difference in the development of the different channel segments.

The available MOC narrow-angle images for the source regions show a diversity of surface textures. Floor deposits for Dao and Niger source depressions (images M07-01301 and M03-06711) have smooth, knobby, and hummocky surfaces. Duneforms are present and concentrated in local low-lying regions. Both well-defined and degraded pits and/or craterforms are evident. The upper parts of the walls are layered. In the Niger Vallis source depression, small layered and rounded hills are observed on the northern gullied wall; these are presumably slump blocks of plains materials. Small irregular hills are found on the depression floor; in one case a possible terrace is observed surrounding a hill on all sides. In addition, faint banding parallel to the northern wall that crosses topographic obstacles is apparent. MOC image M10-01978 of the Harmarkhis Vallis source shows debris draped over a gullied canyon wall with a hummocky floor presumably dominated by mass-wasted material.

The tributary canyon to Reull Vallis has floor deposits with smooth, hummocky, knobby, and pitted surfaces. Very few craters are apparent, and transverse...
dunes occur in local low-lying areas. At the base of the north wall (image M09-06385) two mesas are observed that show at least three distinct layers. These could be slumped from the plains above or remnants of an interior layered deposit. On the floor of the canyon in its center, arcuate to polygonal scarps are evident; some are isolated, some occur in groups, and others are nested. These appear to be due to deflation of the floor materials. At the south wall (image M00-01794) a gully extends across the plains toward Reull Vallis. Parallel ridges and talus slopes suggest significant downslope transport of material. At the base of the south wall, a bench or terrace separated from the floor materials by a scarp is seen. Dark lineations on the canyon floor occur parallel to the scarp. MOC image M02-01602 of the floor of a large crater adjacent to the canyon shows layered mesas on its floor.

**Characteristics of Surrounding Plains:** On the basis of 1:2M-scale [3,6] and 1:500K-scale [4,5] geologic mapping, a sequence of sedimentary plains units have been defined in the eastern Hellas region. The channeled plains are interpreted to be a relatively young depositional unit resulting from local redistribution and scouring of older plains by surface flow as water moved toward Hellas Planitia [see also 1,7]. Smooth plains dominate the region between Reull Vallis and the highlands of Promethei Terra to the north, and their emplacement may be associated with flooding from Reull Vallis. At least part of the channeled plains appears to have been covered by smooth plains in the past, as mesas of smooth plains occur to the southwest of Reull Vallis. Between Dao/Niger and Harmakhis Valles and to the south of Harmakhis Vallis, channeled plains are dominated by small scour marks and runoff channels. Large craters present on the surface are relicts of older plains surfaces. Near Dao and Harmakhis Valles, many of these craters have eroded ejecta blankets and smooth floors. To the south of Reull Vallis and near its tributary canyon, craters appear to be filled, in some cases almost completely. This region is thought to have been exhumed as smooth plains were eroded.

Analysis of MOLA profiles of the channeled plains shows an irregular surface consistent with local dissection and transport of material. Most channeled plains surfaces lie below those of the smooth plains from which some of the material may have been derived. Smooth plains surfaces show less small-medium scale topographic variability than the channeled plains. The maximum change in elevation within a given MOLA profile for the channeled plains is greater (300-1200 m) than that for the smooth plains (100-400). For the channeled plains, the profiles showing smaller changes in elevation are from the area that appears to have been exhumed. Here, the rims of filled craters are the highest points. This is consistent with the idea that the smooth plains at one time extended to the south of Reull Vallis [3]. Prominent massifs up to 4 km high are observed in the region. Massif peak elevations and edifice heights show no particular correlation to geologic units or with respect to the Hellas Basin. These preliminary results suggest that the large-scale topography of the region was established prior to emplacement of the plains units and formation of Reull Vallis.

**Conclusions:** Several styles of mass-wasting appear to dominate the recent geologic history of outflow channel source regions. Prominent talus slopes are observed, and blocks and hills are evident on canyon wall slopes and depression floors. Debris aprons extend from adjacent highland terrains and are draped over canyon walls; these exhibit ridged and knobby morphologies suggestive of viscous flow. Layered blocks and mesas could be slumped from upper canyon walls or are interior layered deposits which may reflect a period of localized sedimentary activity, perhaps in confined lacustrine settings as the fluvial stage of outflow channel development waned. Preliminary regional analyses of the topographic characteristics of plains that contain outflow channels are consistent with widespread deposition and subsequent erosion of sedimentary materials in association with flooding events, particularly from Reull Vallis. Further analysis of Mars Global Surveyor datasets will continue to unravel the complex geologic history of the eastern Hellas region and to identify sites for future exploration where long-lived fluvial systems may have operated.

**References:**