END-MEMBER MORPHOLOGIES OF VOLCANIC AND SEDIMENTARY LAYERED ROCKS ON MARS FROM THE HIGH-RESOLUTION IMAGES. T. Törmänen[1], M. Ivanov[2], J. Raitala[1], J. Korteniemi[1] and V.-P. Kostama[1] [1]Astronomy, Dept. of Physics, 90014 University of Oulu, Finland (terhi.tormanen@oulu.fi), [2]V.I. Vernadsky Institute, RAS, Moscow, Russia.

Introduction: The thick stacks of layered rocks are well known on Mars since the Mariner-9 mission [e.g. 1-3]. They occur in a variety of geological settings and are exposed in scarps and crater walls that cut different terrains on Mars and provide their natural cross-sections. Two principal geological processes, effusive volcanism and sedimentation, can lead to formation of the layered sequences. Thus, the exposed layered structure of a terrain is not sufficient for the unique interpretation of the main processes that were responsible for the formation of the terrain. What is the characteristic morphology of the layers formed by volcanic processes (especially by emplacement of lava flows) and due to deposition and sedimentation? Can morphology alone be sufficient to distinguish between these modes of formation? At which spatial resolution of the images the differences in morphology can be seen? These questions are important for interpretation of the nature of materials where the modes of their formation are either not obvious or multiple. In order to address these questions we began a systematic photogeological analysis of the high-resolution images (HiRISE, MOC, HRSC, and THEMIS-vis) from the regions where the main geologic processes that formed the layered sequences are interpreted with the high degree of confidence to be either of volcanic (undoubtful volcanic regions) or sedimentary (in a broad sense) origin. The ultimate goal of this analysis is to formulate the sets of criteria that characterize the one or another type of origin of terrains and apply these sets to the regions where both the volcanic and sedimentary layered sequences may occur together, e.g., on the floor of the Hellas basin [e.g. 4-6].

Volcanic Regions: As the typical volcanic provinces, we have selected two large volcanoes, Olympus Mons and Pavonis Mons. In these regions, we inspected all available sets of images that cover walls of the calderas where the volcanic origin of the exposed materials is almost warranted. The walls of the summit calderas of Olympus Mons and Pavonis Mons are up to several kilometers high and display thick stacks of layers, which we interpret as volcanic lava flows (although the presence of interleaved layers of pyroclastic materials can not be completely ruled out). In both settings, the stacks of lava show remarkable similarities to each other. The most prominent features of the walls are their spur-and gully pattern of erosion in the upper portion and extensive talus aprons that cover about two third of the lower portions of the walls (Figure). The spurs and gullies occur at different scales from the smallest (a few meters) seen at the resolution limit of the HiRISE images to the largest (hundred meters) seen in the MOC and THEMIS images. Due to this pattern, the outer edge of the layers appears to be highly serrated. The layers are exposed within the spurs, covered by detritus within the gullies, and can be traced along the scarp for many kilometers. The HiRISE images (resolution 0.25-0.5 m/px) show that layers are highly disrupted and consist of rounded and plate-like blocks meters to tens of meters across that give the layers very rough appearance. The detritus that fills the gullies displays numerous boulders of various dimensions that obviously fell off the individual layer outcrops. The visible thickness of the layers is changed from a few to tens of meters and in places the layers are clearly not parallel to each other (e.g., Olympus Mons example). In the MOC images (resolution ~4.5 m/px) from the same sites, the fine-scale details of the layers are not seen but both the layered structure, and the spur-and-gully morphology of the walls and the debris aprons are visible. The resolution of the THEMIS-VIS images (~17.5-36 m/px) is already too rough to recognize the layers and only the spurs and gullies and the aprons are seen at the walls of the calderas.

In addition to the Olympus Mons and Pavonis Mons, we have also inspected the other volcanic regions such as Syria Planum cut by graben of Noctis Labyrinthus, Lunae Planum (walls of Kasei Valles), Elysium Mons (walls of a crater near the summit of the volcano), and Syrtis Major (walls of a crater on the surface of the plateau). In all these regions, the layered structure of their interiors is presented and it displays the same features that characterize the wall of the calderas of the large volcanoes (Table). The remarkably similar characteristics of the layered sequences from the volcanic regions reflect the basic properties of the lava flows that form brittle and coarse-grained layers of different thickness, which were emplaced episodically and locally.

We also studied locations where columnar jointing in rock layers was recently discovered from HiRISE images [7]. Columnar jointing is practically unequivocal evidence for lava flows. General morphological characteristics of the rock layers in all places where volcanic jointing is observed (Table 1 in [7]) are similar to the volcanic layers described in this study. Also the locations of the layers with columnar jointing are in or near volcanic regions, which we have looked at (Olympos Mons, Elysium Planitia, NE Hellas region S and SW from Hadriaca Patera). These observations thus support our conclusions regarding the characteristic morphologies of lava flow layers.

Sedimentary Regions: The sedimentary provinces on Mars are not as obvious as the volcanic ones and the examples of these environments should be selected with caution. As the candidates for the sedimentary sites we have chosen the interiors of Gale and Holden craters that were interpreted as regions where sedimentary rocks formed within the possible crater lakes (although other interpretations have also been presented) [e.g. 4, 8-19]. The rhythmic sequences consisting of numerous lighter and darker layers about of the same thickness (from a few meters up to a few of tens of meters) characterize the deposits on the floor of these craters (Figure). The walls of the deposits are smooth and gently winding and lack extensive talus aprons. No boulders are visible on or at the base of the walls. The deposits are heavily degraded and demonstrate cliff-and-bench pattern of erosion. The characteristics of the deposits (Table) are consistent with the horizontal emplacement of fine-grained and low-strength materials in broad regions and may be indicative for the aqueous or sub-aqueous deposition [11]. Regardless of the specific mode of origin, the layered sequences on the floor of the Gale and Holden craters are significantly different by their morphology from those related to emplacement of lava flows (Figure). The resolution of both HiRISE and MOC images is sufficient for the recognition of the basic morphologic characteristics of the presumably sedimentary deposits on the floor of the craters (Figure). In the THEMIS-VIS images these characteristics are not seen and the deposits appear as low mesas with rounded edges.

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Table. Comparison of basic morphologic characteristics of the volcanic and sedimantary layered sequences in the studied examples.

Morphologic characteristic	Lava layers in volcanic sequences	Sedimentary sequences
Layers	Yes	Yes
Spurs and gullies	Yes	No
Talus aprons	Yes	No
Boulders at the base	Yes	No
Serrated outline	Yes	No
Stair-step or cliff-bench walls	No	Yes
Rhythmic layering	No	Yes
Smooth walls	No	Yes

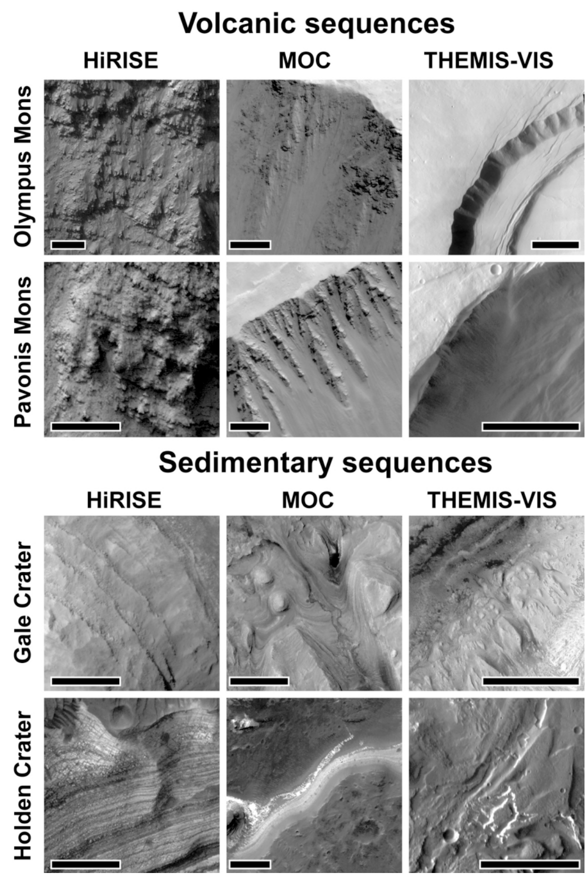

Figure. Mosaic of the HiRISE, MOC and THEMIS-VIS images showing characteristic morphology of the volcanic and sedimentary layered sequences. Scale bars for all HiRISE images are 50 m, for the MOC images - 500 m, and for THEMIS images - 5000 m.