WRINKLE RIDGES ON THE HELLAS BASIN FLOOR, MARS: MORPHOLOGICAL ASSESSMENT AND IMPLICATIONS H. Bernhardt[1], H. Hiesinger[1], M. Ivanov[2], J. D. Clark[1], J. H. Pasckert[1] [1]Institut für Planetologie, Westfälische Wilhelms-Universität, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany (h.bernhardt@uni-muenster.de), [2]Vernadsky Institute, Russian Academy of Sciences, Kosygin St. 19, 119991 Moscow, Russia.

Introduction: As a major sink for volcanic, glacio-fluvial and aeolian materials [e.g., 1,2], the Hellas basin on Mars is key to understanding the evolution of depositional processes on the planet. With major volcanic provinces nearby, Hellas Planitia can serve as a prime example to assess the influence of volcanic activity on this evolution, especially since the other large impact basin on the Martian southern hemisphere, Argyre Planitia, lacks any clear evidence for volcanic basin infill [3,4], e.g., wrinkle ridges on volcanic plains. Wrinkle ridges are linear topographic highs with mostly asymmetric cross-sections and have been identified on the Hellas basin floor (Fig. 1A) in previous studies [e.g., 1,5]. Although dike emplacement has been proposed as a possible formation mechanism [e.g., 6], wrinkle ridges are widely interpreted as structural features resulting from blind thrust faults (Fig. 2B) due to compression caused by a horizontal stress field [7,8,9,10]. A large number of wrinkle ridges on Mars and the other terrestrial bodies are arranged in concentric and/or (sub-)parallel patterns thought to be formed in radial or relatively uniaxial stress fields [e.g., 7,10,11].

Data: Using topographic data of the Mars Orbiter Laser Altimeter (MOLA) and the High Resolution Stereo Camera (HRSC), as well as image data obtained by the Thermal Emission Imaging System (THEMIS-IR Daytime), we conducted morphological and morphometric analyses of wrinkle ridges on the Hellas basin floor. We applied an 11 km high pass-filter to the MOLA DTM ("detrending") to improve the visibility of ridges and to identify those superposed by other materials (Fig. 1B).

Observations: The wrinkle ridges are between ~5 and ~25 km wide and vary in height between ~100 to ~300 m. The mostly pristine wrinkle ridged plains in the southeastern part of the basin (Fig. 1A, area I) lie ~300 m higher than those north of the mouths of Dao/Sungari and Harmakhis Valles (Fig. 1A, area II). In the northeast of the basin, the ridges are slightly muted by superposed material, but still clearly vsible as distinct features (Fig. 1C). In general, the wrinkle ridged plains in the eastern Hellas basin vary in brightness, i.e., temperature, in THEMIS-IR Daytime images. Ca. 460,000 km² on the eastern basin floor are characterized by ridges arranged as large-scale polygons (Ø ~100 km) and concentric rings around potential ghost craters (Fig. 1A,C), indicating their formation by a non-uniaxial stress field. Most wrinkle

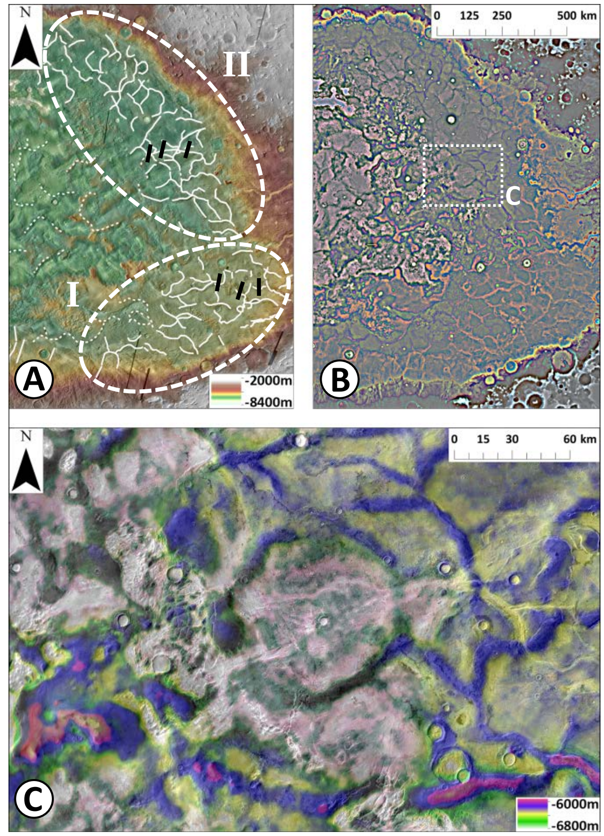

Fig. 1. *(A) MOLA DTM over THEMIS-IR Day of the eastern Hellas basin. Wrinkle ridges are marked as white lines (solid = certain, dashed = similar dimensions/geometry but superposed). We subdivided the wrinkle ridged plains in a southern (I; pristine ridges, mean elevation ca. -6200 m) and a northern (II, slightly subdued ridges, mean elevation ca. -6500 m) area. Three profiles (1-3, from west to east) of a wrinkle ridge in the north and the south, respectively, are indicated as black lines and shown in Fig. 2A.*
(B) Detrended (high-pass filter) MOLA DTM of the same area, emphasizing topography with wavelengths close to 11 km. The color change is an effect of high pass-filtering the color-coded DTM. Wrinkle ridges are visible as polygonal pattern of linear features.
(C) Detrended MOLA DTM over THEMIS-IR Day showing two concentric rings (Ø ~70 km and ~100 km) of ridges. The inner ring is probably a ghost crater. The outer ring is covered with ~200 m of more friable material in the southwest. In total, we identified 10 quasi-circular ridge-arrangements (Ø 18-85 km).

ridges on Mars are arranged either in (sub-)parallel patterns (e.g., Lunae Planum: formed in uniaxial stress field [12]), rhombic patterns (e.g., Hesperia Planum: two generations formed in different stress fields [13,14]), or zigzag patterns (e.g., Coprates Planum: single ridge generation formed in biaxial stress field

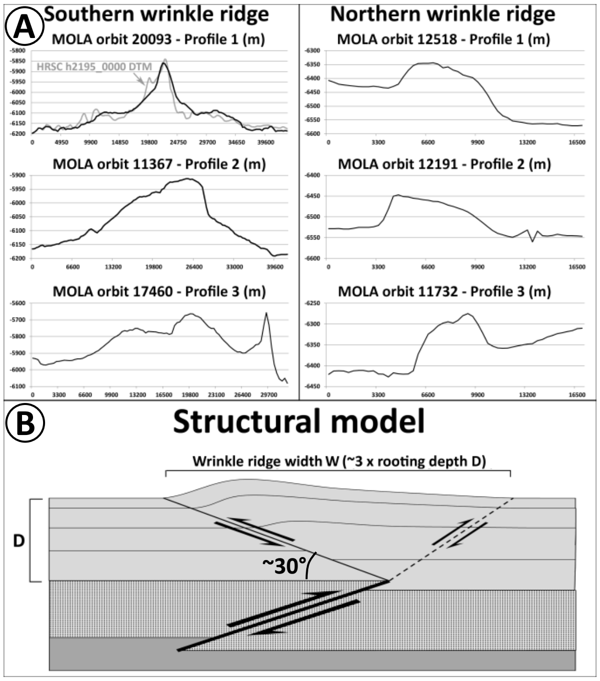

Fig. 2. *(A) MOLA PEDR profiles across two wrinkle ridges marked in Fig. 1. Profile 1 of the southern ridge overlaps an HRSC DTM whose corresponding profile is shown in grey; profile 3 shows the rim of a crater on the right. The southern and the northern wrinkle ridge have a mean width of ~25 km and ~5.5 km, and a mean height of ~250 m and ~150 m, respectively. The northern ridge clearly shows an elevation offset of up to ~120 m. (B) Structural model for the formation of wrinkle ridges [8,9,15,16]: Compressive stress causing horizontal shortening is accommodated by "blind" thrust faulting (i.e., the fault does not reach the surface) extending to depths between 100s of meters to several kilometers [7,8,9]. On the surface, the shortening results in an anticline whose width W is related to the rooting depth D according to D = W[tan(30°)]/2 [15].*

and/or strike-slipping along preexisting faults [7,13,14]). Of the two ridges we have analyzed so far, both have distinct asymmetric cross-sections whose steeper slopes may swap their directions along a single ridge (Fig. 2A). The northern wrinkle ridge shows an elevation offset with the foot of the steeper slope being up to ~120 m higher than the foot of the gentler side (Fig. 2A).

Discussion: Wrinkle ridges likely represent anticlines formed due to compression normal to a stress vector [7,8,9,10]. Generally, possible sources for compressive stress affecting the Hellas basin floor are

1) compressive tectonism caused by loading of volcanic provinces [7,11]; adjacent to Hellas Planitia are: Malea and Hesperia Planum as well as Promethei Terra and Hadriaca Patera [e.g., 17],
2) lithospheric subsidence causing basalt infill to move towards basin center; comparable to some lunar maria [7,10,11],
3) global contraction due to cooling of the planet [14].

Compressive tectonism caused by volcanic provinces and lithospheric subsidence both create radial and usually non-isotropic stress fields, and therefore dominantly concentric and (sub-)parallel ridge patterns [e.g., 7,10,11]. Global contraction, on the other hand, has repeatedly been brought forward as a model to produce isotropic stress fields [e.g., 7,13,18] and the polygonal arrangement of wrinkle ridges could be an indication that they formed in an isotropic compressive environment [11,14]. A pulse of global contraction, for instance, was suggested in a previous study to be responsible for rhombic- and zigzag-patterns of wrinkle ridges formed on Coprates and Hesperia Planum in the late Hesperian [14]. However, as the floor of the Isidis basin is the only other location on Mars where a polygonal wrinkle ridge pattern (i.e., ridges with a roughly bimodal orientation distribution or without a clear preference) has been identified besides Hellas Planitia [11], we cannot conclusively demonstrate that our observations on the eastern Hellas basin floor support a global contraction event. Nevertheless, regional processes remain problematic as sources for an isotropic stress field uniformly shortening an area of ~460,000 km². Furthermore, the scarcity of polygonal wrinkle ridge patterns elsewhere on Mars might indicate that the Hellas and Isidis basins provided unique rheological and geometric settings (quasi-circular basaltic plains superposing mega-regolith), which promoted the formation of such ridge patterns. Based on our observations and previously proposed structural formation models of wrinkle ridges [7,8,9,15] (Fig. 2B), we also estimated the thickness of the "wrinkled" layer in the Hellas basin, i.e., the minimum thickness of the entire rheologic unit (likely basalt) to be ~2 km.

Conclusions: Based on our observations, we estimated the minimum basalt thickness in the Hellas basin to be ~2 km, and, thus, the basalt volume to be at least 900,000 km³. Furthermore, the wrinkle ridges are arranged in polygons indicating their formation by a non-uniaxial, possibly isotropic, stress field. However, although global contraction appears plausible to produce an isotropic stress field, we cannot conclusively demonstrate that our observations are in favor of such an event. Nevertheless, regional processes commonly associated with wrinkle ridge formation, e.g., lithospheric subsidence or volcanically induced compression, usually cause radial or uniaxial stress fields and seem problematic as sources for isotropic stress fields over a large area like the eastern Hellas basin.

References: [1] K. L. Tanaka and G. J. Leonard (2001) *USGS Sci. Inv. Maps*, I-2694. [2] D. Wilhelms and J. Moore (2007) *USGS Sci. Inv. Maps*, I-2953. [3] H. Hiesinger and J. Head (2002) *PSS*, 50, 939-981. [4] H. Bernhardt et al. (2013) *PSS*, 85, 261-287. [5] L. F. Bleamster and D. A. Crown (2010) *USGS Sci. Inv. Maps*, I-3096. [6] R. G. Strom (1972), *IAU*, 47, 187-215. [7] T. R.Watters (1993), *JGR*, 98, 17049-17060. [8] R. A. Schultz (2000) *JGR*, 205, 12035-12052. [9] M. B. Golombek et al. (2001) *JGR-Planets*, 106, 23811-23821. [10] S. C. Solomon and J. Head (1980), *Rev. of Geoph.*., 18, 107. [11] J. Head et al. (2002), *JGR - Planets*, 107, DOI: 10.1029/2000JE001445. [12] J. Plescia (1991), *GRL.*, 18, 913-916. [13] G. E. McGill (1993) *GRL*, 20, 2407-2410. [14] N. Mangold et al. (2000), *PSS*, 48, 1201-1211. [15] N. Mangold et al (1998), *PSS*, 246, 345-356. [16] J. B. Plescia and M. B. Golombek (1986) *GSA Bull.*, 97, 1289-1299. [17] D. A. Williams et al. (2010) *EPSL*, 294, 492-505. [18] Watters et al. (1998) *Geology*, 26, 991-994.