EFFECT OF THE HELLAS IMPACT ON REGIONAL TECTONISM: A CASE STUDY FROM THE NOACHIS-SABAEA REGION, SOUTHERN HIGHLANDS OF MARS. T. Ruj[1, 2], G. Komatsu[1, 2], J. M. Dohm[3], H. Miyamoto[3], and F. Salese[1, 2], [1] International Research School of Planetary Sciences, Università d'Annunzio, Viale Pindaro 42, 65127 Pescara, Italy, (trishit@irsps.unich.it), [2] Dipartimento di Ingegneria e Geologia, Università d'Annunzio, Viale Pindaro 42, 65127 Pescara, Italy, [3] The University Museum, University of Tokyo, Hongo 7-3-1, Bunkyo-ku, Tokyo 113-0033, Japan.

Introduction: Extemely ancient (~ > 4.0 Ga) Martian geologic provinces of the southern highlands of Mars preserve the Early Noachian elements of crustal activity [1-3]. Our study region, Noachis-Sabaea (the eastern part of Noachis Terra and mostly the southern part of Terra Sabaea), is one such geologic provinces with significant paleotectonic record [4]. Noachis-Sabaea (Fig. 1) is surrounded by Arabia Terra to the north, Syrtis Major and Tyrrhena Terra to the east-northeast, Hellas to the southeast, and Argyre to the west [5]. In our preliminary work [4], we classified differently oriented grabens into three sets (sets 1, 2, 3), with set 1 being attributed to the Hellas impact, while others interpreted to have originated mainly from extensional tectonic stresses prior to the giant impact event (though there likely was an interplay between the pre-Hellas structures, which includes reactivation, and Hellas-induced structures). In this work, we discuss possible modes of formation of the mapped tectonic structures, including responsible stresses and geological processes.

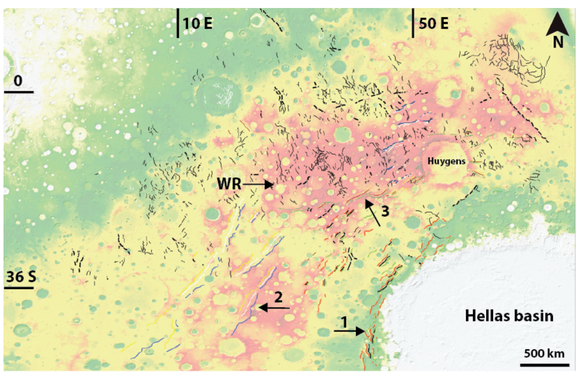

Fig. 1. MOLA map of the Noachis-Sabaea study region with mapped tectonic structures. Structures include: graben sets 1 (red, green, and black lines respectively mark the western wall, eastern wall, and graben trace), 2 (similar to 1 but yellow, blue, and white), and 3 (yellow, green, and red respectively mark the northern wall, the southern wall, and graben trace), and wrinkle ridges (WR) in black.

Data and structure dating: We have prepared a detailed Arc-GIS-based structural map of the Noachis-Sabaea region using HRSC (High Resolution Strereo Camera) and CTX (ConTeXt) camera images, as well as MOLA (Mars Orbital Laser Altimeter) and HRSC DEMs (Digital Elevation Model). In addition, the digital geologic map of Mars [5] serves as a reference for our investigation. We determined the relative age of formation of the grabens by their orientations and cross-cutting relationships among rock materials and other tectonic structures.

Structural details and interpretation: The Noachis-Sabaea province is dominated by tectonic structures formed by both extensional (grabens and half grabens) and compressional (wrinkle ridges, circular wrinkle ridges) stresses. The northeastern part of the Noachis-Sabaea ((Fig. 1)) study region is primarily composed of flood basalts resulting from the development of the Syrtis Major volcanic province, which are deformed mainly by wrinkle ridges and normal faults. Wrinkle ridges occur both within and outside impact crater basins. Many structures in the Noachis-Sabaea province are mapped and interpreted as normal faults having been produced by the Hellas and Isidis impacts. The western margin of the Hellas basin, which includes highly degraded rim materials, for example, is dominated by extensional structures including half grabens, mapped as set 1.

Set 2 grabens have been mapped to the west of the set 1 grabens, along the western margin of the highly degraded Hellas rim materials. Consistent with NE-SW trending structuress inferred from remanent magnetic anomalies [6]. Set 3 grabens, which trend mostly east-west and generally have lengths ranging from 100 to 250 km, form a long graben chain nearing 2800 km [4]. We interpret set 2 and 3 have also begun to form prior to the Hellas impact. A concentration of circular wrinkle ridges (interpreted to be the product of concentric compressional stresses [7]) have been mapped near the junction of set 2 and set 3 grabens.

Sequence of the events: The relative age of formation of the Hellas and Huygens impact basins have been estimated to be Early Noachian (Huygens ~4 Ga, Hellas ~4 Ga) based on crater statistics [8]. Set 1 grabens are interpreted here to be the result of the Hellas impact. Though there is no direct cross-cutting relationships among the set 2 grabens and other structural entities in the study region, the circular wrinkle ridges which concentrate mostly at the junction of sets 2 and 3, might indicate a genetic (incuding temporal) link among all three types. The eastern boundary of set 3 grabens occurs at the Huygens impact crater including rim materials, possibly indicating tectonism prior to the Huygen impact event, with extensional stresses likely occuring following the event (including possible impact-related reactivation).

The compressional events that produced the mostly NNW-SSE-trending wrinkle ridges are the latest events coeval with the proposed Hesperian global contraction of Mars [9]. Several type 1 (no visible ejecta and central peak and estimated to be > 3.7 Ga) and type 2 (visible ejecta and central peak estimated to be < 3.7 Ga) crater [10] floors, which are interpreted to have been partly infilled by sedimentary deposits and/or flooded by basaltic lavas, contain wrinkle ridges.

Our proposed sequence of events includes:

- Pre-Hellas extensional tectonism results in the formation of graben sets 2 and 3
- Hellas impact event results in the formation of set 1 graben and the emplacement of rim materials and ejecta deposits
- Hellas impact disrupts the extensional settings, while the attempted continuation during the centers' demise results in Hellas' deformed shape

• The Huygen impact around the time of the Hellas impact truncates the graben chain of set 3
• The Isidis impact contributes to the structural complexity of the Noachis-Sabaea province [11]
• Crustal extension ceases
• Flood basalt emplacement related to the development of the Syrtis Major volcanic field occurs
• Compressional tectonism possibly related to planetary cooling contributes to the formation of wrinkle ridges.

Possible tectonic setting: Taking into account the orientations, morphology, relative ages, spatial and temporal relationships among tectonic structures, as well as the rock types identified through orbital-based spectroscopy, the Noachis-Sabaea region appears to comprise charecteristics of a terrestrial tectonic extensional zone. Characteristics include varying directions of extension, which resulted in the formation of set 2 and set 3 grabens, as well as rock materials that have been interpreted to include flood basalts [12] and feldspathic rocks of possible granitic composition [13]. The trend of set 2 grabens, in particular, roughly parallel to the hypothesized traces of spreading centers drawn based on the interpretation of the Mars Global Surveyor-based remanent magnetic anomalies [6]. Our structural investigation of the Noachis-Sabaea province thus may provide corroborating evidence for the activity proposed by Connerney et al. [6].

More work is necessary to determine the extent of the extensional zone, including how such a zone fits into an ancient, more global crustal configuration. This includes exploring whether the zone is representative of a triple point junction typical of Earth, with a hypothesized scenario schematically shown in Fig. 2. In our hypothesized scenario, an early phase of plate tectonism [14] includes a pre-Hellas spreading center like tectonism in the Noachis-Sabaea province with associated emplacement of flood basalt and felsic rocks; the later rock type being a signature of recrystallized crustal melt or primordial (Hadean-age equivalent) crustal materials including anorthosite.

In our hypothesized scenario, the Earth-like spreading center, with the lithosphere being pulled apart while maintaining a constant crust/mantle ratio in a typical rift, shuts down sometime following the Hellas impact event. The Hellas impact was significantly large, such that it could have contributed to major changes in the planetary conditions of Mars including plate tectonism and the hypothesized spreading center. In addition to major deformation of the target crustal/litohospheric materials (possibly tapping into the mantle at the time of the impact as well as generating voluminous impact crater melt), the giant impact could have completely disrupted a tectonic system that involved divergent plate boundaries. We propose that the impact would have generated significant melt, mantle materials would have moved closer to the Martian surface through isostatic compensation following the giant impact, and eventual cooling of the melt would have produced a barrier to continue spreading. The upwelling and related spreading center could have modified the shape of the Hellas impact basin, as the eastern part of the system would have forced its way into the region of impact deformation/modification during its demise and the cooling of the impact melt.

If there was a spreading center, then there must have been the presence of a subduction zone(s) and associated orogenic complexes to consume the extented crustal material. A candidate orogenic complex [2] has been proposed to the northwest of Argyre associated with the development of the Thaumasia highlands and possibly Coprates Rise mountain ranges.

Implications: Extremely ancient geologic provinces such as Noachis-Sabaea merit further detailed geologic investigation as they have significant potential to inform on the early evolution (Hadean-age-equivalent) of both Mars and the solar system.

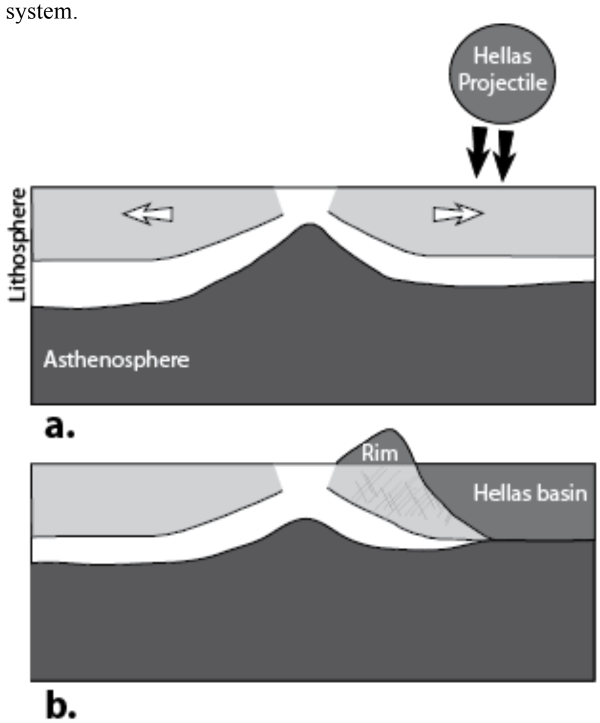

Fig. 2. Steps of the crustal activity of the Noachis-Sabaea region schematically portrayed, including (a) tectonic scenario during Hellas impact event, (b) resulting activity from the Hellas impact including impact-driven formation of structures such as graben set 1 shown in Fig. 1, emplacement of rim and ejecta deposits, and disruption of both target crustal/lithospheric materials and possibly a plate-tectonic-driven system. Fractures developed, ejecta formed. Lithosphere, asthenosphere and mantle thickness ratio changed and the major tectonic forces such as plate dragging, slab pull, slab push were not able to keep the lithoshphere in movement.

References: [1] Dohm, J. M. et al. (2013) *in "Mars Evolution, Geology, and Exploration" (A.G. Fairén, Ed.), Nova Science Publishers, Inc.*, pgs. 1-34. [2] Dohm, J. M. et al. (2015) *LPSC,* Abstract #1741. [3] Salese, F. et al. (2015) *EPSC*, Abstract #431. [4] Ruj, T. et al. (2015) *EPSC,* Abstract #255. [5] Tanaka, K. L. et al. (2014) *U.S.G.S. Scientific Investigations Map* 3292. [6] Connerney, J. E. P. et al. (2005) *PNAS, 102*, 14970–14975. [7] Mangold, N. et al. (1997) *Platnt. Space Sci.*, 46, n 4, 345-356. [8] Robbins, S. J. and Hynek, B. M. (2012) *JGR,* v 117, E05004. [9] Head, J. W. et al. (2002) *JGR Planets* v 107, E1, 3/1-3/29. [10] Mangold, N. et al. (2012) *JGR*, *117*, E04003. [11] Anderson, R.C. et al. (2008) *Icarus*, doi:10.1016/j.icarus.2007.12.027. [12] Rogers, A. D. and Nazarian, A. H. (2013) *JGR, 118*, 1094-1113. [13] Wray, J. J. et al. (2013) *Nature Geoscience, 6*, 1013-1017. [14] Baker, V. R. et al. (2007) In Yuen, D. A., Maruyama, S., Karato, S. I. and Windley, B. F., eds., Superplumes: Beyond plate tectonics: Springer, p. 507–523.