THE LARGE THAUMASIA GRABEN, MARS – IS IT A RIFT? E. Hauber[1] and P. Kronberg[2], [1]DLR-Institute of Space Sensor Technology and Planetary Exploration, Rutherfordstr. 2, D-12489 Berlin, Germany; Ernst.Hauber@dlr.de, [2]Institute of Geology and Paleontology, TU Clausthal, Leibnizstr. 10, D-38678 Clausthal-Zellerfeld, Germany, kronberg@geologie.tu-clausthal.de.

Summary: We describe the morphology of a large and complex extensional structure in the western Thaumasia region (the "Thaumasia graben" [1] or TG). This is the first detailed description of this structure, taking into account reliable MOLA–based topographic information. We consider possible fault geometries, determine extension, and discuss the case for or against a classification as a rift.

Background: The Thaumasia region comprises an elevated plateau of mostly Hesperian high lava plains (Sinai, Solis, and Thaumasia Plana) bounded by a Noachian-Hesperian highland belt to the E, S, and W, by the long-lived Syria Planum volcanotectonic center to the NW, and by the Hesperian-Amazonian Valles Marineris to the N. The tectonics of the interior lava plains of Thaumasia are characterized by compressional wrinkle ridges. The highland belt and some of the lava plains in western Thaumasia are cut by several sets of extensional features (e.g., Claritas, Thaumasia, and Coracis Fossae) which formed during different stages of the overall Tharsis evolution [e.g., 1,2,3,4].

The TG is a prominent, ~100 km wide and ~1000 km long extensional tectonic feature striking N15°-20°W (Fig. 1). It formed during the last stage of Thaumasia tectonics, probably in Late Hesperian [5] or Early Amazonian [2]. It is superimposed on the ancient (Early Noachian) tectonic center of Claritas (27°S, 106°W; stage 1 in [4]). Several authors [e.g., 1,2,6,7] ascribe it to rifting. Roof collapse after late-stage magma withdrawal from Syria Planum has also been hypothesized [8].

Architecture: Principal morphotectonic features of the TG and adjacent areas are (Fig.1a): (i) smooth lava plains of Syria Planum, bordered to the W by (ii) an escarpment made up by an *en echelon* series of steeply W-dipping faults marking the eastern border of the TG, (iii) the graben floors of segments A and B (see Fig. 1b for location), and (iv) the curvature of steeply E-dipping faults at 18-21°S, defining the master faults of segment A and separating it from a topographical high towards NW. Between 22°S and 33°S, the western border fault system is more diffuse.

Extension across segment A has been accomodated by an asymmetric (half)graben about 150 km in length and 100 km in width. Steeply E- to SE-dipping normal faults with fault length segments of 50-80 km and displacements of 2.0 km form the master fault system (Fig. 2). The graben is characterized by step-fault platforms with displacements of up to 150 m on antithetic faults. Internal block faulting is often controlled by reactivated trends of older fractures.

At 21°S, the master fault changes over to the E-flank of the TG, and the elevation of the graben floor decreases to elevations 3500-4000 m. Segment B is about 250 km long and up to 100 km wide. As shown by profile 3 (Fig. 3), the graben floor is tilted towards the steeply W-dipping normal (planar) border fault system. Master fault lengths range from 50-80 km and observable throws from 1.5-2.2 km. MOLA data suggest limited block rotation on synthetic normal faults.

Where the TG enters more rugged Noachian terrain at 25°S (segment C, Fig. 3), its configuration becomes less evident than in segments A and B. Steeply W-dipping faults dominate the eastern border, with fault lengths of 50-90 km and observable displacements from 1.3-2.0 km. While the master faults of the eastern graben flank can be traced over >500 km along strike, the structure of the western flank is rather inconspicious. Older fault sets have a strong influence on the local rift trend and create a pattern which on Earth is often associated with oblique rifting.

South of ~24°S, the TG crosses some WNW/ESE striking topographic highs of rugged Noachian terrain, (Fig. 1b). They represent a so far undescribed continuation of the ancient highland belt toward NW, where it is successively buried under younger Tharsis lavas. Segment C is superimposed on the belt. The pre-graben relief with its NW-trending highs and lows affected local graben development of the TG.

Fault geometry – planar or listric? Normal faults in an extensional regime have planar, listric, or ramp-flat geometries. Since listric faults are characteristic of thin-skinned deformation and often involve gravitational movements on ductile layers or shallow detachments, their identification on Mars would provide important information about the planet´s lithospheric structure (thin-skinned vs. thick-skinned tectonics). On Mars, planar faults are generally assumed for larger tectonic structures like the Tempe Fossae Rift [9,10], Valles Marineris [e.g., 11], or major compressional structures like Amenthes Rupes [12]. Several profiles across the TG display features that might indicate a listric master fault, including an overall halfgraben geometry, tilted blocks, and an (albeit slight) curvature of the hanging wall which is characteristic of a rollover anticline (e.g., Fig. 2). For a listric fault, the depth D to a detachment can be determined from the dip of the master fault at the surface *(α)*, the tilt of the graben floor *(θ)*, and the vertical offset *(d)* (equation 12 in [13]). We measure a scarp height d of ~2000 m and floor tilts θ between 0.9° and 2.7°. For $\alpha = 60°$, we obtain values of D between ~33 km and ~67 km ($\theta = 2.0°$ and 1.0°, see Tab. 1). Interestingly, these values correspond very well with recent estimations of the thickness of the elastic lithosphere T_e in S-Tharsis as given by [14] (Valles Marineris: ~60 km, Solis Planum: ~35 km) or [15] (<70 km). A listric master fault might indicate gravitational gliding of an unstable part of the outward verging fold-and-thrust plateau margin [3] towards W, i.e., toward the foreland of Thaumasia. However, slip along planar faults can also produce tilted graben floors [16] and hanging wall flexure [17], so the observed morphology does not allow any firm statement about the fault geometry.

Table 1: Depths D to a detachment for a possible listric master fault geometry.

	$\theta = 1.0°$	$\theta = 1.5°$	$\theta = 2.0°$
$\alpha = 50°$	53.7 km	36.1 km	27.1 km
$\alpha = 60°$	**66.7 km**	**44.4 km**	**33.3 km**
$\alpha = 70°$	80.7 km	53.7 km	40.4 km
$\alpha = 80°$	96.1 km	64.3 km	48.2 km

Extension: The extension e along several profiles across the structure was calculated by:

$$e = D_{cum} / \tan \alpha \qquad (1)$$

where α is the dip of the fault and D_{cum} is the total or cumulated vertical offset along all the faults along the profile which belong to the structure. For all faults, a dip angle α of 60° and a planar geometry was assumed. The inspection of available imagery did not reveal significant sediment cover, which would mask the actual offset, resulting in smaller extension values. In the northern part (section A), most of the extension has occurred along a few major faults. In the southern part of the graben system, extension has been distributed among many smaller faults. Extension across the TG is 0.5 to 4.5 km, strain is 1 to 3%. Our extension values are much lower than 10 km, as estimated by [18] from scarp widths and shadows. The discrepancy might be due to our more accurate topographic data (i.e., MOLA) or to the problem that it is not straightforward – particularly in the southern segments B and C – to decide whether a given fault belongs to the TG or to an older fault set.

Discussion: While the structural geometry of the TG is more similar to classical rifts than that of Valles Marineris, there are better Martian analogues to terrestrial rifts (e.g., Tempe Fossae [9]). Rift-like features of the Thaumasia graben are the asymmetric (halfgraben) architecture, the changing polarity of the asymmetry (although it changes only once, while in terrestrial continental rifts there often are several such changes of the master fault system from one side to the other), and several characteristics of the fault systems. The overall dimensions of the TG are also in agreement with other rift on Mars (e.g., the Tempe Rift [9]) or Earth (e.g., the Kenya Rift). On the other hand, we do not observe some features which are often associated with terrestrial continental rifts: There is no distinct (narrow) rift valley, there is no rift flank uplift, and we do not see clear evidence for rift-related volcanism. So far, therefore, the geodynamic processes that led to the formation of the TG are unclear (crustal break-down due to structural uplift of Thaumasia? magma deficit near Syria Planum? a long-lived and late center of magmatectonic activity?). Geophysical data with improved lateral resolution (e.g., an improved gravity field [19]) might help in the further investigation of this region.

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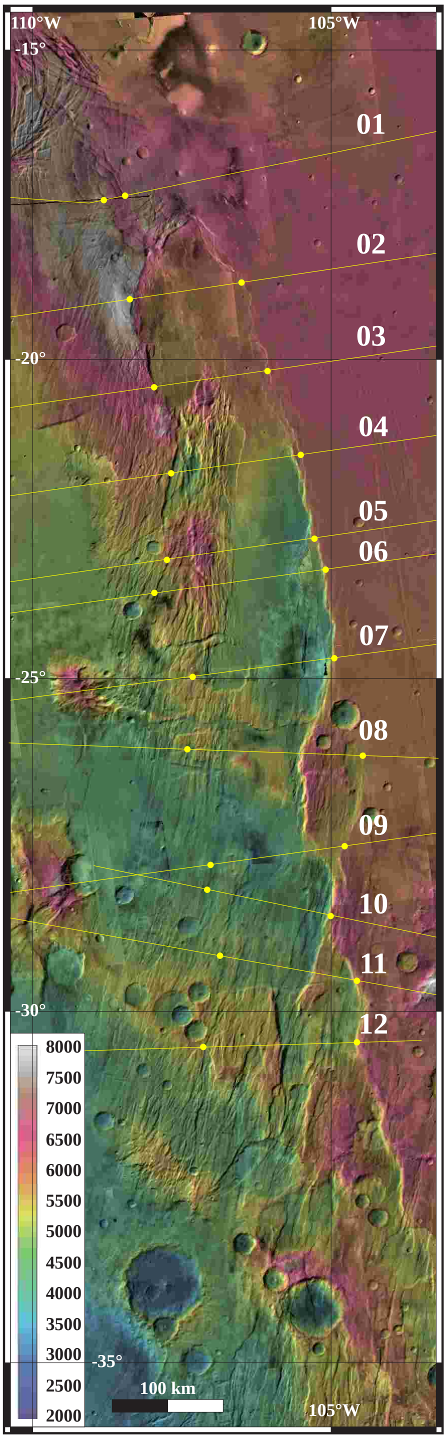
Figure 1 *(next page; **a**=left and middle)* Topographic image map (MOC-WA & MOLA) of the large Thaumasia graben (TG). Extension and strain *(middle)* were measured along several topographic profiles (derived from MOLA-based DEM´s; see text for details); *(**b**=right)* Schematic structural map, showing three segments A-C (characterized in Fig. 2-4).



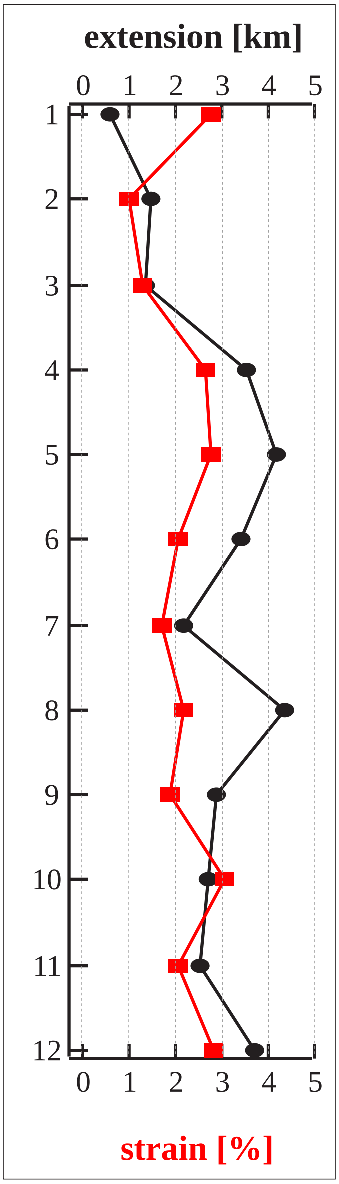


Figure 1a (left and above)

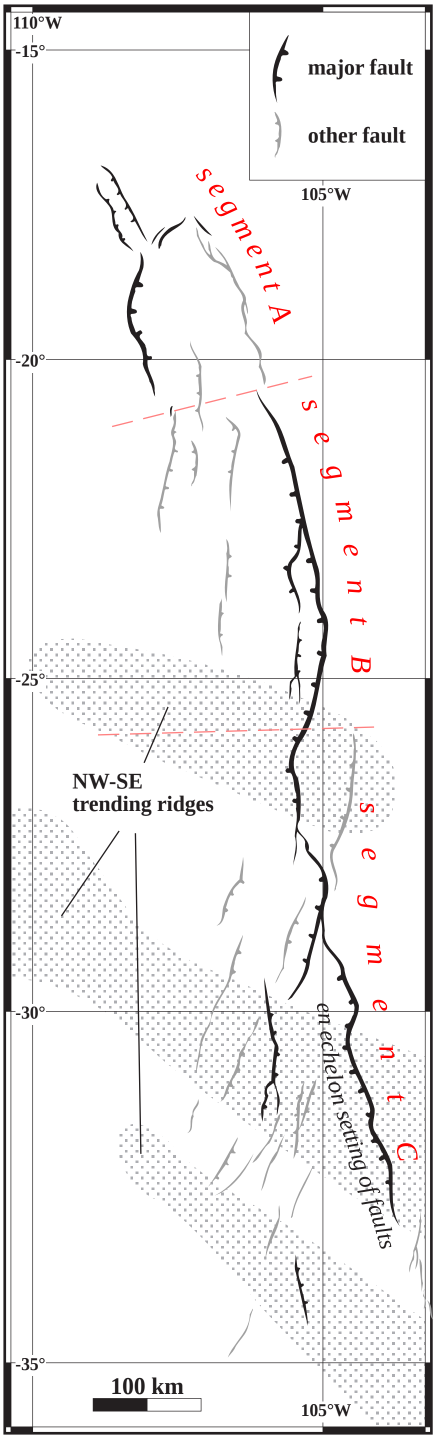
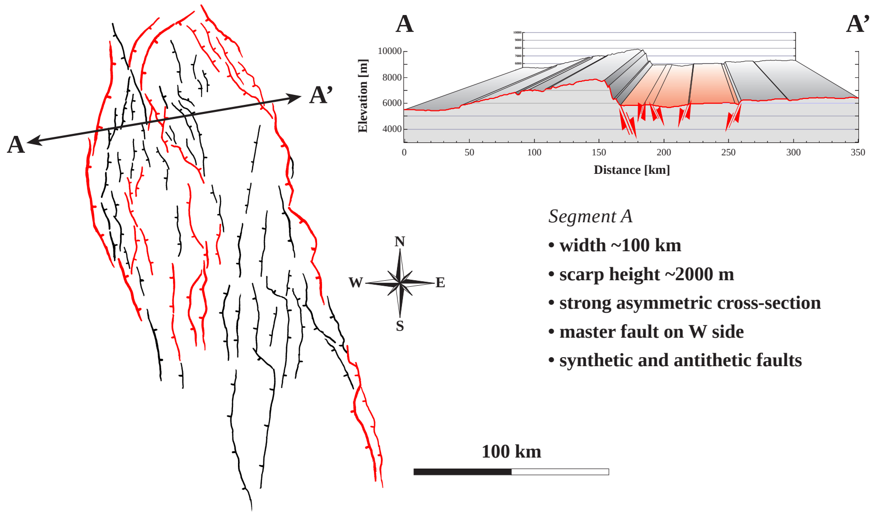


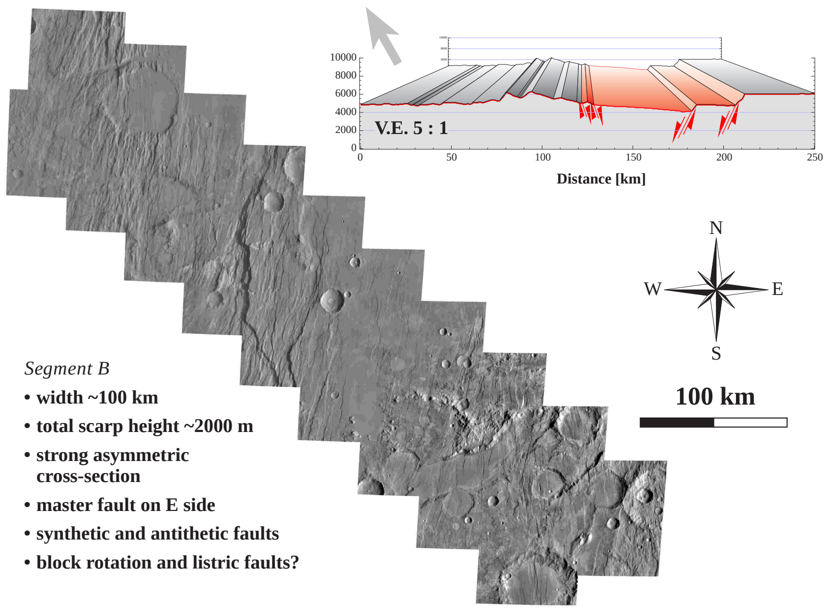
Figure 1b (right)

Figure 2 *(next page, top)*: Structural map of the northern part (segment A) of the large Thaumasia graben (TG). A topographic profile was derived from a MOLA-based digital elevation model. The inferred strucural depression related to the TG is shown in red (together with the interpretation of major faults). Key characteristics are listed as text bullets.

Figure 3 *(next page, middle)*: Viking-Orbiter image mosaic (orbit 460a, resolution ~65 m pixel^{-1}), showing details of segment B. Topographic profile as in Fig. 2. Key characteristics are listed as text bullets (note that master fault has changed to the eastern side).

Figure 4 *(next page, bottom)*: Structural map of the southern part (segment C). Topographic profile as in Fig. 2. Key characteristics are listed as text bullets (note older fault trend and similarity to terrestrial oblique rifting).


A
A'
Elevation [m]
10000
8000
6000
4000
0
50
100
150
200
250
300
350
Distance [km]
N
W
E
S
100 km
Segment A
• width ~100 km
• scarp height ~2000 m
• strong asymmetric cross-section
• master fault on W side
• synthetic and antithetic faults


10000
8000
6000
4000
2000
0
V.E. 5 : 1
0
50
100
150
200
250
Distance [km]
N
W
E
S
100 km
Segment B
• width ~100 km
• total scarp height ~2000 m
• strong asymmetric cross-section
• master fault on E side
• synthetic and antithetic faults
• block rotation and listric faults?

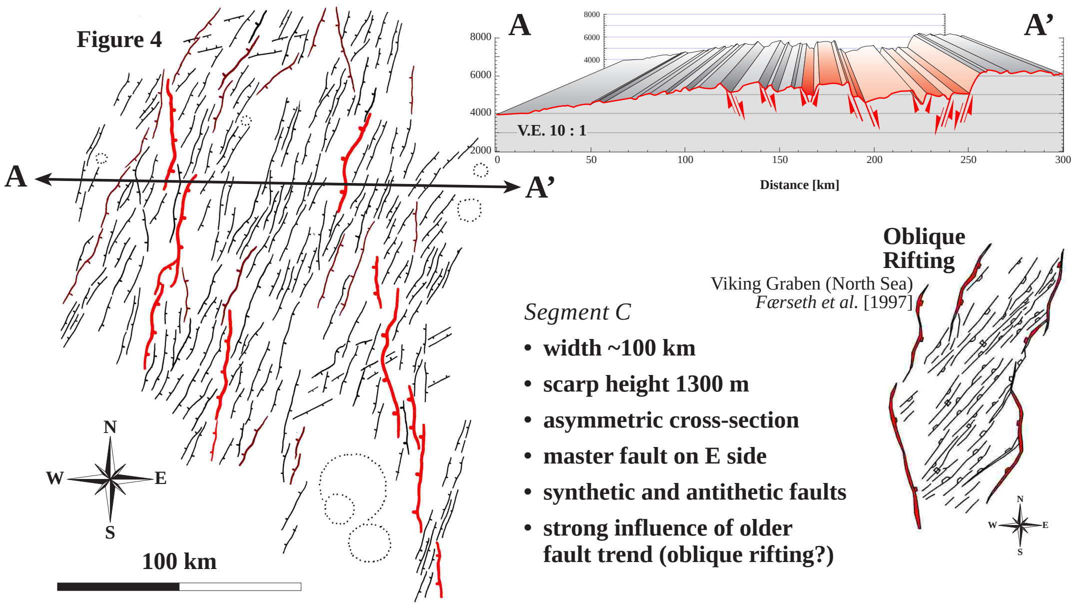


Figure 4
A
A'
8000
6000
4000
2000
V.E. 10 : 1
0
50
100
150
200
250
300
Distance [km]
Oblique Rifting
Viking Graben (North Sea)
Færseth et al. [1997]
Segment C
• width ~100 km
• scarp height 1300 m
• asymmetric cross-section
• master fault on E side
• synthetic and antithetic faults
• strong influence of older fault trend (oblique rifting?)
N
W
E
S
100 km