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Supporting Information for

Geometry and segmentation of Cerberus Fossae, Mars: implications for marsquake properties

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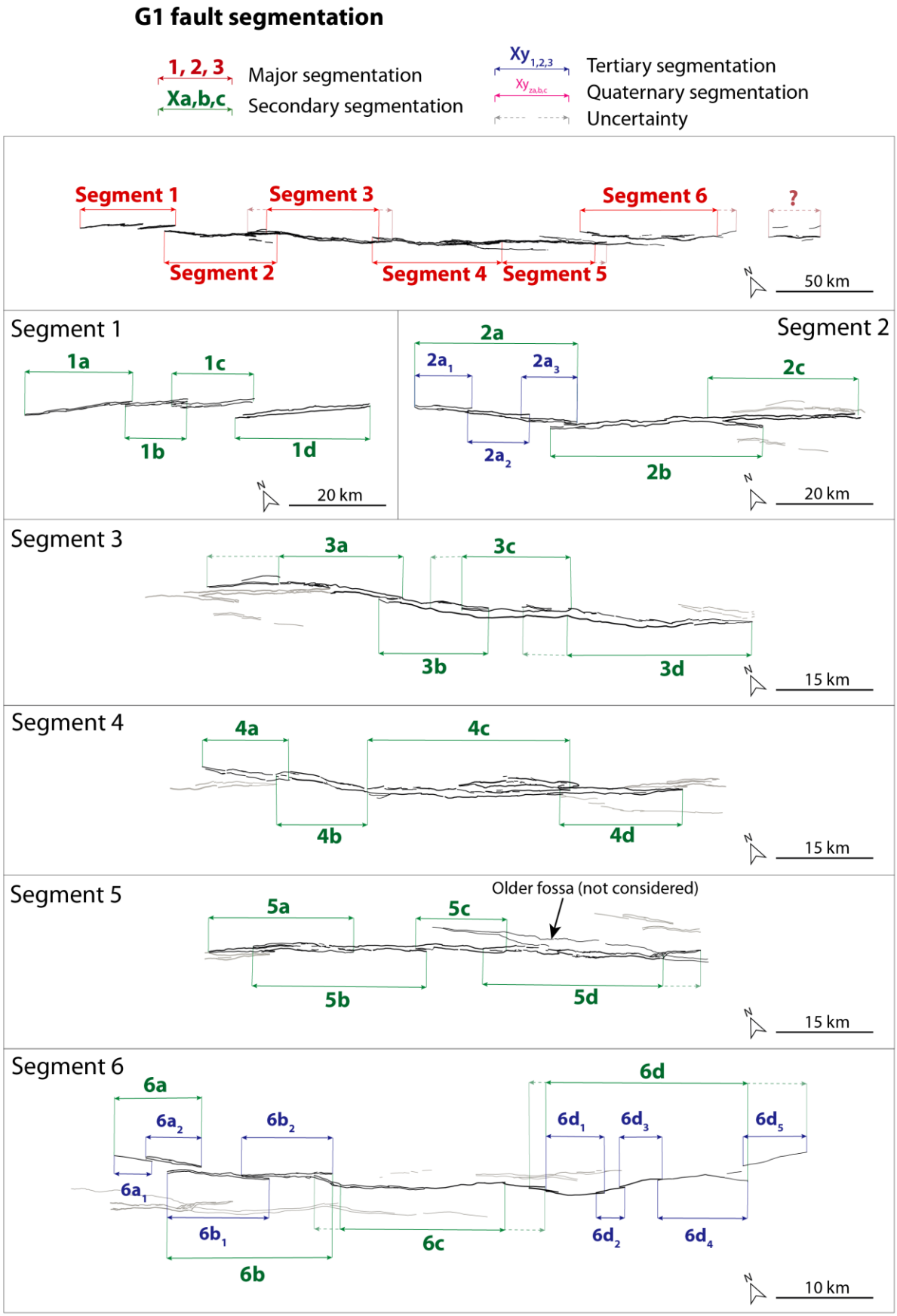
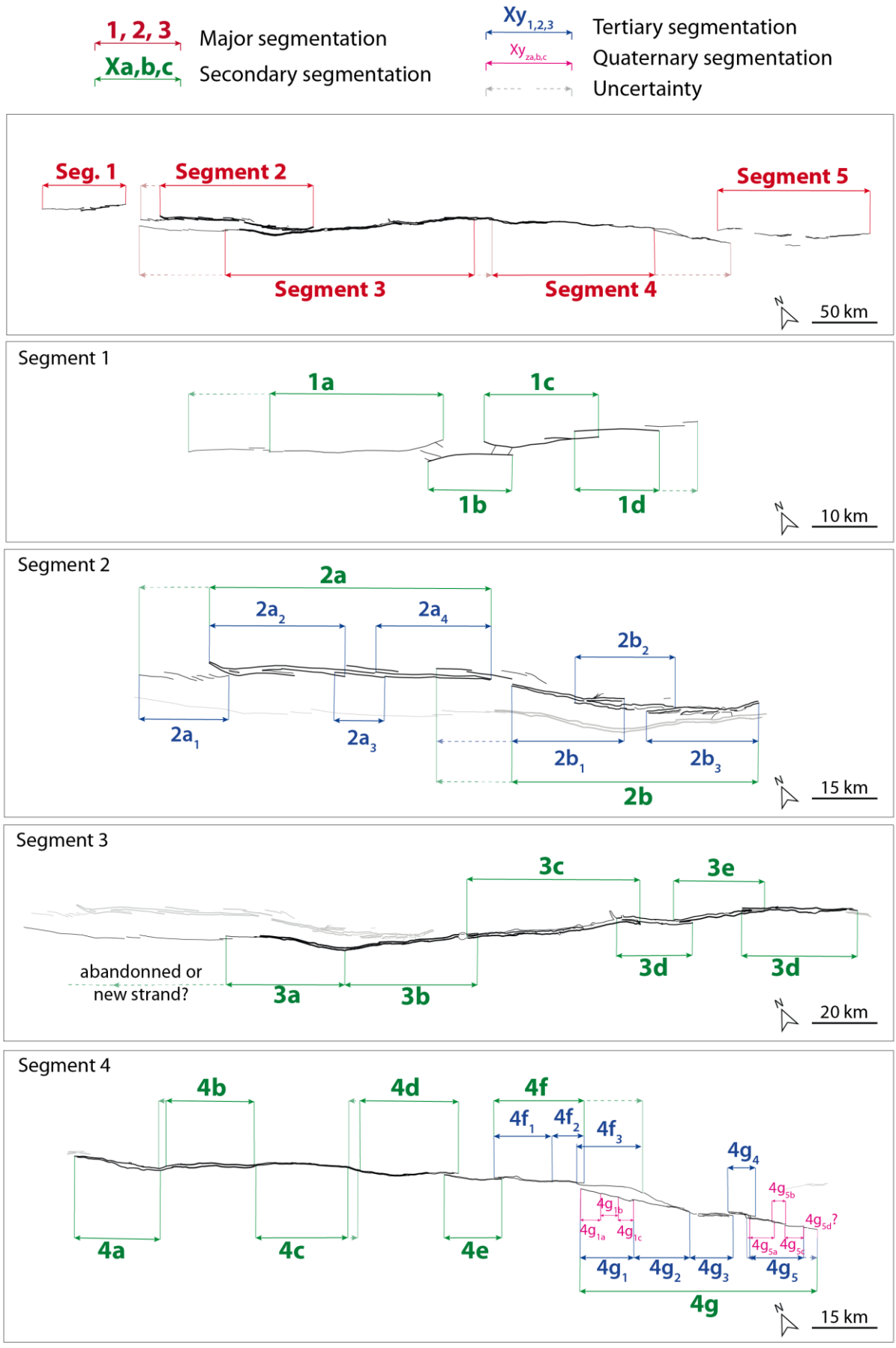
Introduction

The Supporting Information includes one figure denoted Supplementary Figure S1 associated with Supplementary Text S1, that shows a detailed fault map of the Cerberus Fossae system and a description of the lateral segmentation we identified in this study. Supplementary Figure S2 shows in detail the topographic profiles determined along each calculated DEMs presented in Fig. 5, associated with the mean topographic profile.

Perrin et al.; Supplementary Figure S1



Perrin et al.; Supplementary Figure S1 (following)



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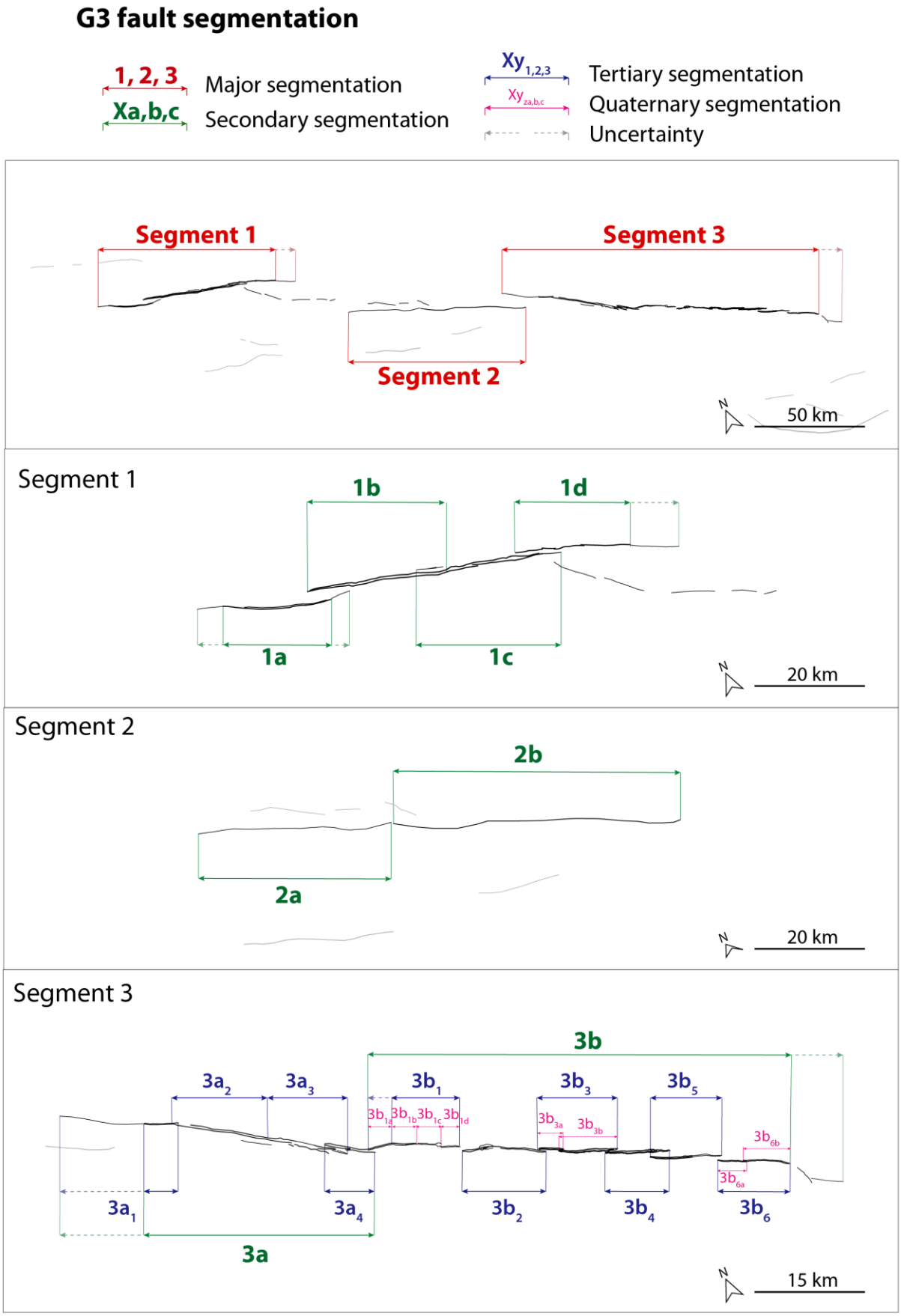
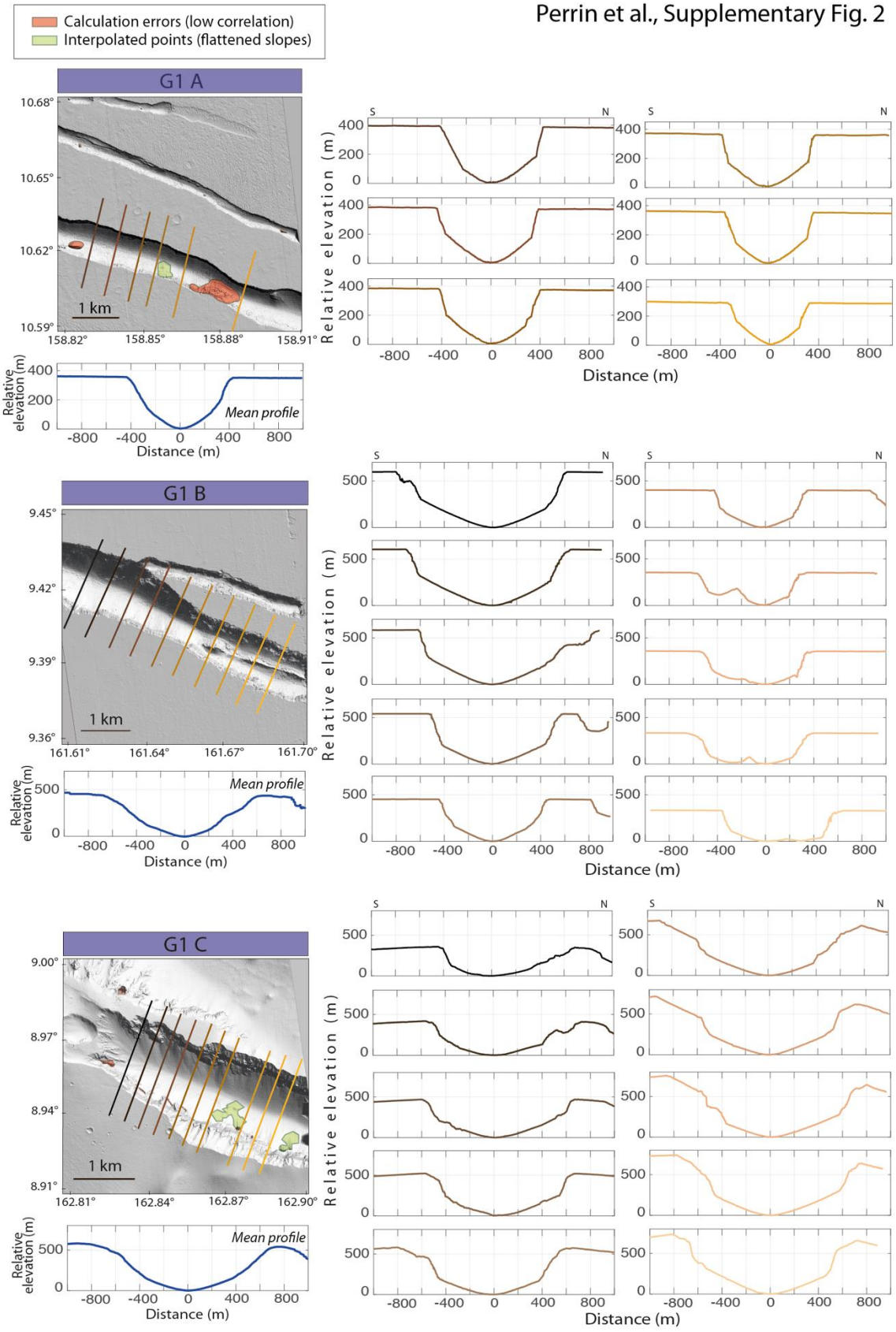
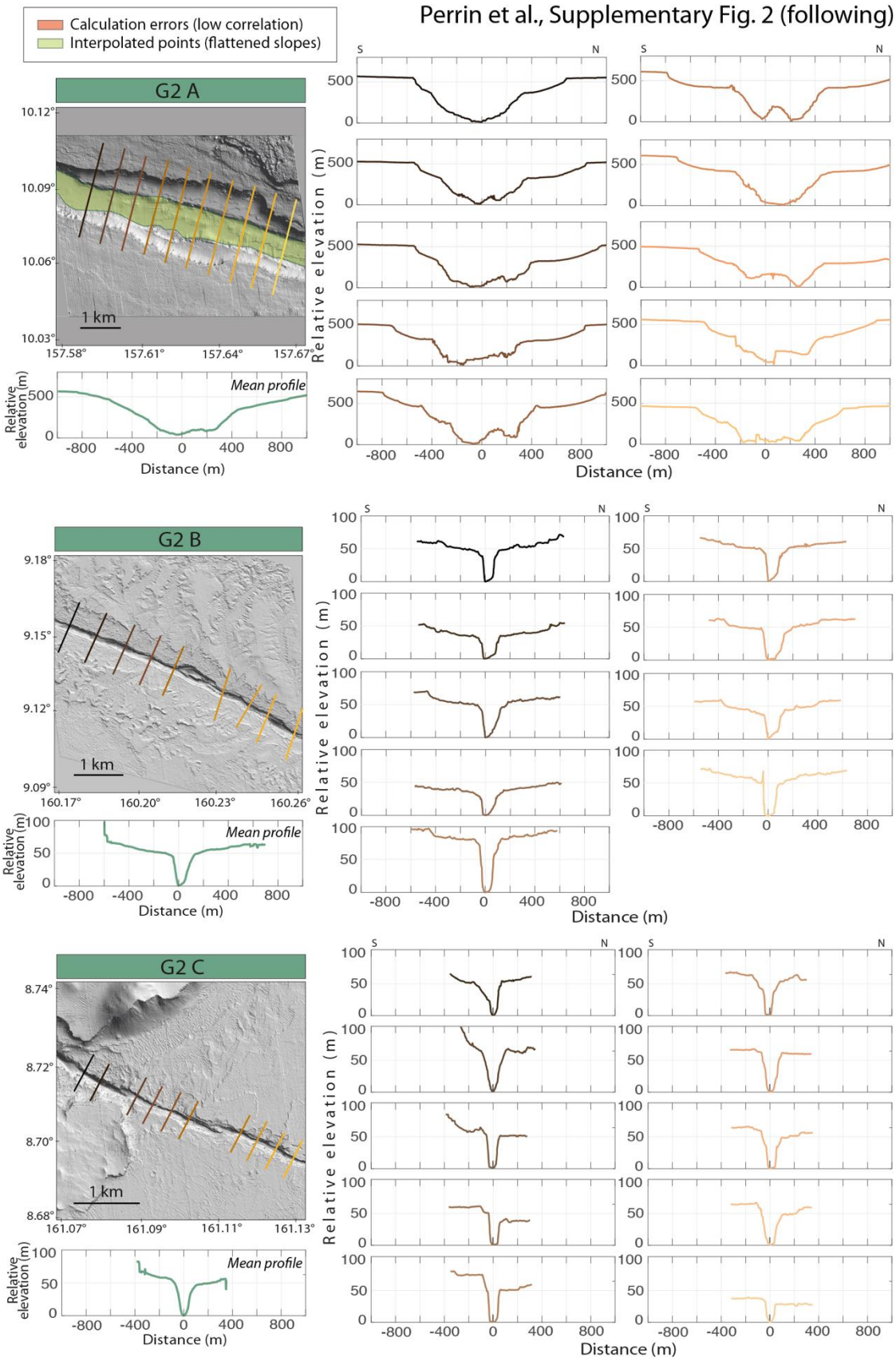
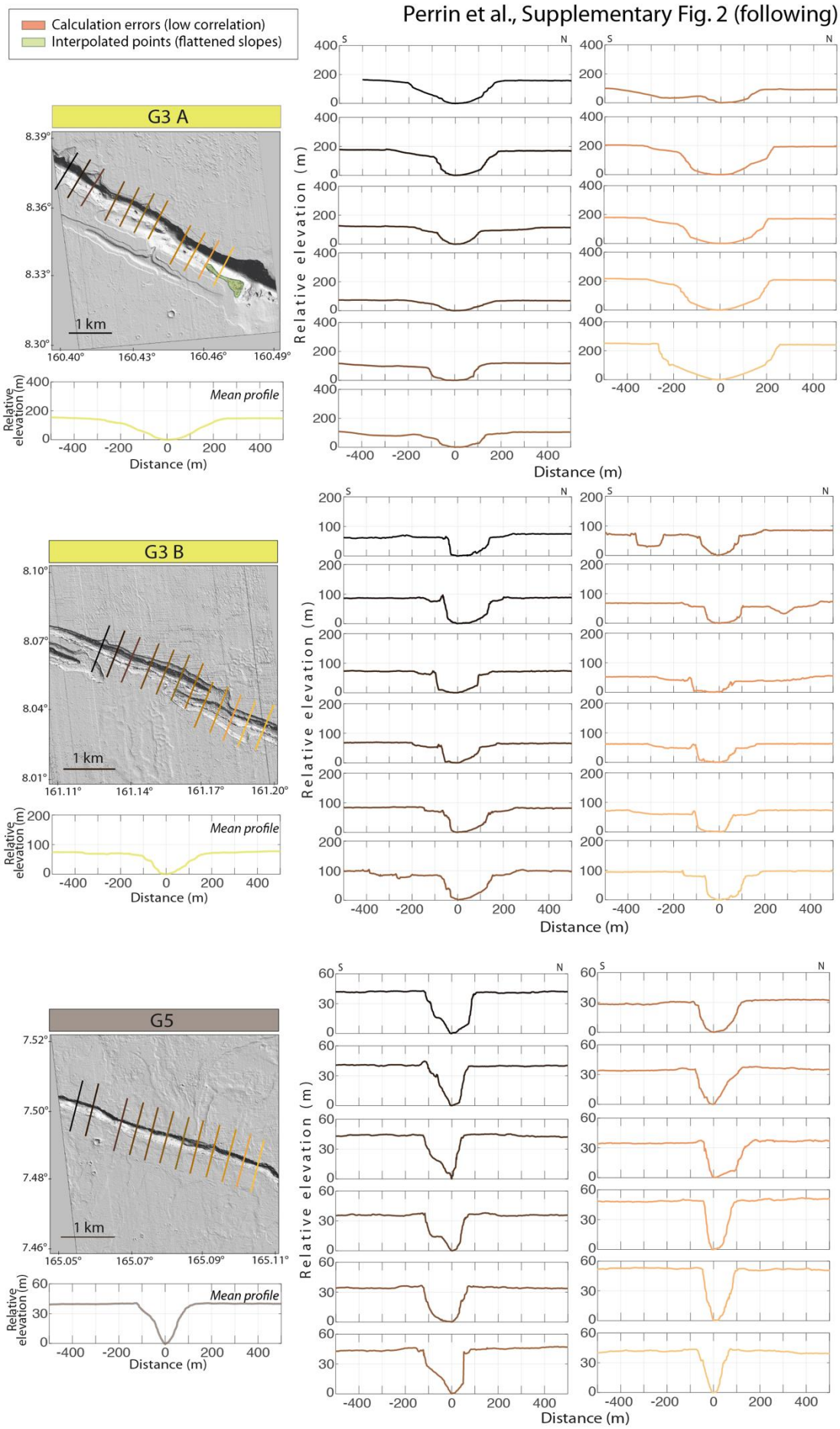


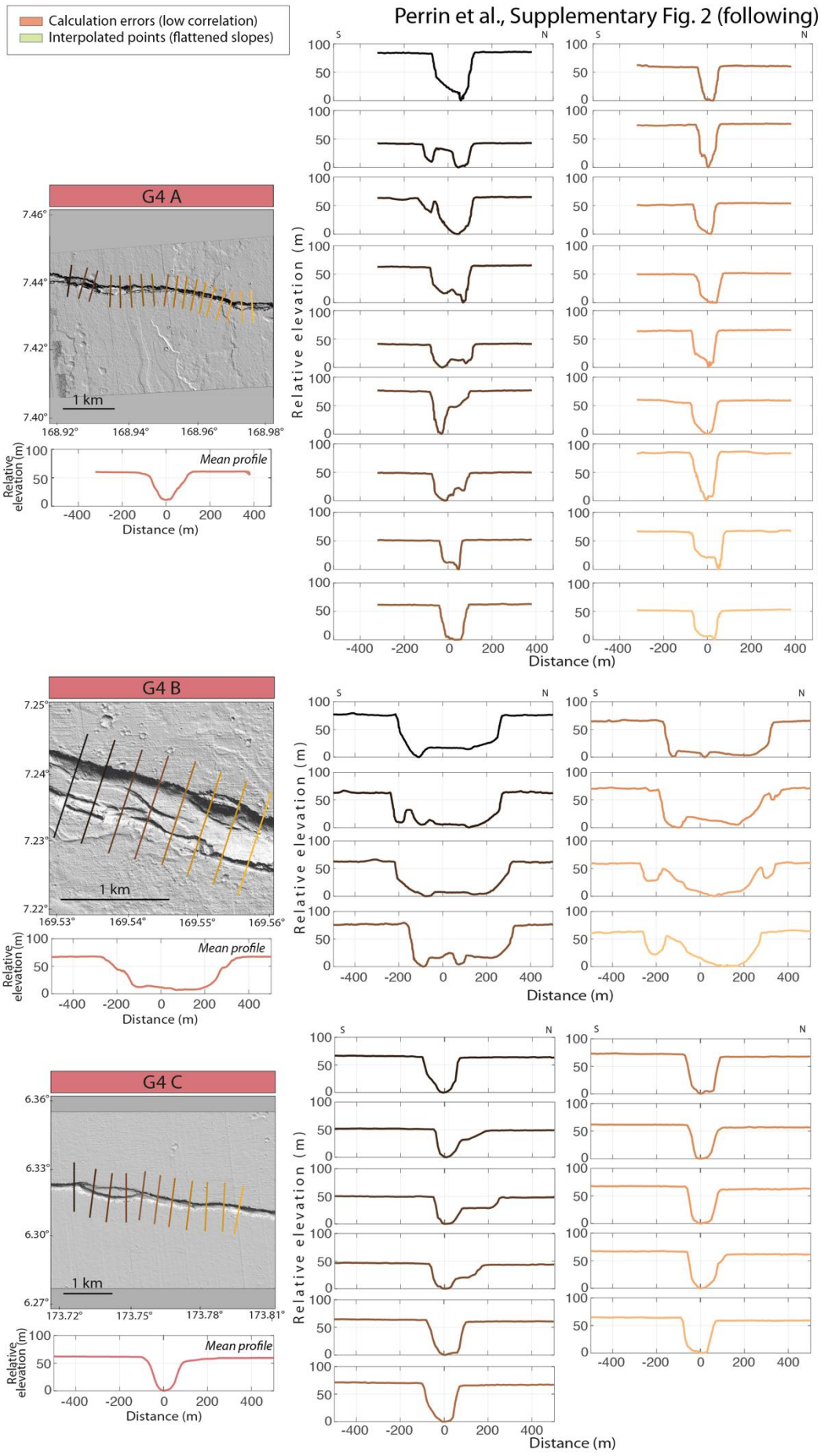
Supplementary Figure S1: Fault traces of G1, G2 and G3 of Cerberus Fossae and their associated segmentation (see G4 in Fig. 3). The trace lines thickness is related to its surface expression: the thicker is the line, the more evolved and well-established is the scarp. A closer view of the sub-segments in each major segment is shown. Grey traces depict the neighbor major segments, or unconsidered fossa parts. Up to four orders of segmentation have been identified. The major segments are indicated in red, the secondary segments in green, the tertiary segments in blue and the quaternary segments in magenta, and uncertainties are in dotted arrows. The detailed description of the segmentation is in Supplementary Text S1.

Perrin et al., Supplementary Fig. 2




Perrin et al., Supplementary Fig. 2 (following)
Calculation errors (low correlation)
Interpolated points (flattened slopes)
G2 A
G2 B
G2 C
1 km
Mean profile
Relative elevation (m)
Distance (m)
S
N


Perrin et al., Supplementary Fig. 2 (following)
Calculation errors (low correlation)
Interpolated points (flattened slopes)
G3 A
G3 B
G5
1 km
Mean profile
Relative elevation (m)
Distance (m)
S
N


Calculation errors (low correlation)
Interpolated points (flattened slopes)
Perrin et al., Supplementary Fig. 2 (following)
G4 A
G4 B
G4 C
1 km
Mean profile
Relative elevation (m)
Distance (m)
S
N

Supplementary Figure S2: Digital Elevation Models (1m/pixel) built from HiRISE stereo pairs along the five main fossae (G1, G2, G3, G4 and G5) of Cerberus Fossae (see locations on Fig. 1). Associated mean across strike topographic profiles are shown below each DEM. To the right of each image, successive topographic profiles are shown from West (black) to East (orange), showing the local lateral variation of throw and width of the fossae.

Supplementary Text S1: description of G1, G2, G3 and G4 segmentation. This text is associated with Supplementary Fig. 1.

Fossa G1:

G1 is about 520 km long and divided into six major colinear segments of 75 to 120 km in length. Major segment 1 is a short segment which corresponds to the NW tip of the Cerberus Fossae system. It is divided into four secondary segments (1a to 1d) of ~20 km long on average, separated by right-stepping jogs < 3km wide.

Major segment 2 is isolated from segment 1 by a >4 km wide step-over. Major segments 1 and 2 are connected through an oblique fault section that we consider as a splay fault of major segment 2 (secondary segment 2a). This section is oblique by ~10° compared to the main direction of major segments 1 and 2. Major segment 2 is thus divided into three secondary segments (2a, 2b and 2c) of 37 km long on average. Secondary segments 2a and 2b are connected through a small jog where the azimuth changes (~10°). Secondary segments 2b and 2c are well connected and are overlapping through a left-stepping jog. It is possible to observe tertiary segments in segment 2a (i.e., $2a_1$, $2a_2$ and $2a_3$). They are 10 km long and separated by <1 km right-stepping jogs.

Segment 3 is connected to segment 2 through a complex 10 km wide zone where sub-parallel secondary faults are observed, associated with a local change in the azimuth (~9°). Both segments are overlapping over a distance of 25 km. Four secondary segments are visible along major segment 3 (i.e., 3a to 3d), but the location of their tips is uncertain since they are well connected to each other. Still, it is possible to highlight trends inside the widened fossa. Thus, as for major segments 1 and 2, secondary segment 3a makes the connection between major segments 2 and 3 and is slightly oblique to the main fossa trend. Secondary segments 3a and 3b are well connected through a right-lateral jog and segment 3b is slightly oblique compared to the main fossa strike (~7°). This obliquity allows its eastern boundary with secondary segment 3c to be highlighted. A change of azimuth (~10°) and possibly a small, well connected, jog are then observed between secondary segments 3c and 3d. A small change in the azimuth is observed at the eastern tip of secondary segment 3d, possibly due to the connection with major segment 4.

Major segments 3 and 4 are separated by a left-stepping jog of 3 km wide and an 8° change in the fossa strike. Four secondary segments (4a to 4d) are identified into major segment 4. They are ~26 km long on average. Secondary segments 4a and 4b are separated by a left-stepping jog; 4b and 4c are well connected but a slight bend of ~10° is observed. Secondary segment 4c could be considered to be two secondary segments but it is hard to distinguish them since the fossa morphology does not show discontinuities, with the exception of a sub-parallel fossa in the north. This secondary structure seems to connect at the eastern tip of secondary segment 4c, where a small jog is also observed in the main fossa trace. This zone corresponds to the transition between secondary segments 4c and 4d.

The transition between major segments 4 and 5 is formed by a series of sub-parallel narrow fossae that are overlapping in a 12 km long and 3 km wide (total) zone. Secondary segment 5a marks this transition and overlaps with secondary segment 5b over almost half of its length. They are <1 km apart before merging in a wider fossa toward the East. Still the eastern tip of secondary segment 5a is distinguishable when both segments separate. A small change in the fossa strike (~13°) is observed between

secondary segments 5b and 5c, associated with a small (<1 km) left stepping jog. We consider the rest of the major segment as part of secondary segment 5d, since the fossa is so wide that is hard to distinguish clear structural discontinuities. The eastern tip of segment 5c shows a left-stepping jog of 1km wide, which seems to have reactivated an older fossa structure. This wide shallow fossa, labeled segment 9.1 in Vetterlein and Roberts (2010), is not considered in this study since its trace is less clear in the ground surface (older?) and cross-cut by the current fossa (segment 5d and see fig. 2a in the main text).

A large step-over of 5 to 8.5 km wide is separating major segments 5 and 6. Major segment 6 is ~125 km long, and its width is much narrower than the other major segments (i.e., segment 6 would correspond to a less evolved fossa). Thus, it is possible to distinguish up to three scales of segmentation. Secondary segments 6a and 6b are separated by a 1.5 km wide right-stepping jog associated with a change in the fossa strike (10°). Secondary segment 6a might correspond to a splay fault of major segment 6. Two tertiary segments are observed along secondary segments 6a and 6b, both separated by small left-stepping jogs. Secondary segments 6b and 6c are well connected through a two successive bends of 20°. A similar structure, associated with smaller scale fault segments, is observed between secondary segments 6c and 6d. Small left- and right-stepping jogs of <300m wide separate tertiary segments of secondary segment 6d (i.e., $6d_1$ to $6d_5$). The eastern tip of major segment 6 bends and is associated with secondary splay faults that form a fan shape toward the east (20°).

A small segment is situated in the eastern continuity of fossa G1, but 25 km away (labeled '?' on thop panel of figure S1). We do not consider this segment as part of G1, but it might correspond to a new fault segment of G1 (i.e. recent volcanic activity, Horvath et al., 2021; Moitra et al., 2021), indicating the eastward direction of long-term propagation of the deformation.

Fossa G2:

G2 is ~610 km long, divided into four or five major segments. The uncertainty concerns major segment 1, which we consider as part of the fossa system, even if it is a short segment (~60 km) isolated from major segment 2 (underlap of 12 km long and 12 km wide). Its narrow trace is segmented into four secondary segments (1a to 1d), separated by right- and left-stepping jogs of ~1 km wide.

Major segment 2 is the main northern branch of fossa G2. Major segment 2 is ~125 km long and composed of two secondary segments (2a and 2b), separated by a small gap in the main fossa trace (4 km) where small secondary faults associated with a small bend of the fossa trace (10°) are observed. Secondary segments 2a and 2b are divided into four and three tertiary segments, respectively. Tertiary segment $2a_1$ corresponds to the western tip of major segment 2 and is formed by small left-stepping en-échelon fractures. Tertiary segments $2a_2$, $2a_3$ and $2a_4$ are fairly well connected via left-stepping jogs, that are distinguishable on each of the fossa shoulders. Tertiary segments $2b_1$, $2b_2$ and $2b_3$ are overlapping and have begun to connect each other through right-stepping jogs.

Major segment 2 is oblique to major segment 3 and to the main fossa G2 trace (15°). They are separated by a small step-over of 1.5 km wide. Major segment 3 is 160 to 200 km long. Its trace could be longer since a shallow discontinuous trace is sub-parallel to major segment 2 and is continuing to the West. This strand might correspond either to

an ancient structure that was active before the main activity 'jumped' and concentrated on major segment 2, or it shows the southern migration of the deformation from major segment 2. In either case, we do not consider this minor strand in the segmentation, since it is sub-parallel to major segment 2 (not colinear) and its trace is difficult to analyze. The main trace of major segment 3 is divided into six secondary segments (3a to 3f) separated either by bends of 15-20° or by small well-connected step-overs.

The boundary between major segment 3 and major segment 4 cannot be clearly delineated. We based our choices on two main observations: i) the average strike of the fossa, since major segment 3 strikes N105°E over 150 km before slightly changing to N115°E along major segment 4 and the eastern part of the fossa (>200 km long); ii) the width of the fossa decreases significantly along major segment 4 and the eastern part of the fossa. Also, a small step over of 1.5 km wide is observed at the transition between both major segments.

Major segment 4 is 135 to 180 km long. Its width decreases progressively toward the East, allowing small scale segmentation in the less evolved part of the fossa to be observed. It is divided into 7 secondary segments which are connected through bends (4a-4b, 4b-4c, 4c-4d; 5-10°) or separated by small jogs (4d-4e, 4e-4f, 4f-4g; <1km wide). Also, the azimuth changes between secondary segments 4f and 4g (10°). Secondary segments 4e and 4f are possibly one single secondary segment, but we separated them based the definition of other secondary segments (step-over width between 4d-4e has a similar dimension to the step-over between 4e-4f). Secondary segment 4f is sub-divided into three tertiary segments of 7-15 km long ($4f_1$, $4f_2$ and $4f_3$). They are connected through small bends and jogs (<500 m). Secondary segment 4g is sub-divided into five tertiary segments of 12 km long on average ($4g_1$ to $4g_5$), separated by small right- and left-stepping jogs of ~500m and small bends (<10°). At both tips, tertiary segments $4g_1$ and $4g_5$ are divided into three and three to four quaternary segments, respectively (i.e., $4g_{1a}$ to $4g_{1c}$ and $4g_{5a}$ to $4g_{5d}$). They are separated by 100-200m wide jogs and local bends in the fossa trace (10-12°).

An 8 to 10 km wide step-over separates major segments 4 and 5. Major segment 5 is ~110 km long. Its surface trace is tenuous and discontinuous, thus we did not analyze its sub-segmentation.

Fossa G3:

G3 is ~260 km long and is divided into three isolated major segments, separated by large step-overs (5 to 10 km wide). The inter-segment zone between major segments 1 and 2 is 6 to 10 km wide and 18 km long, where shallow surface traces are present. These traces might correspond to secondary splay faults at the eastern and western tips of major segments 1 and 2 respectively. However, these strands were not taken into account because they are discontinuous and uncertain.

Major segment 1 is ~70 km long, sub-divided into four secondary segments of 21 km long on average (1a to 1c). They are separated by 1-2 km left-stepping wide more or less connected jog.

Major segment 2 is ~60 km long, and its trace is very shallow. It is possibly divided into two secondary segments 2a and 2b, that are defined based on their trace: secondary segment 2a is discontinuous, associated with an aligned pit chain, while secondary segment 2b is a more evolved fossa.

Major segment 3 is ~110 km long, and is sub-divided into two secondary segments that are striking N120°E (3a) and N110°E (3b), connected through two successive bends in the fossa trace (~20°). Secondary segment 3a is sub-divided into five tertiary segments ($3a_1$ to $3a_5$) connected through a small bend (10°; 3a1-3a2) associated with a structural discontinuity in the fault trace (hill), a well-connected jog (3a2-3a3) and a not well-connected jog of 300 m wide (3a3-3a4). Secondary segment 3b is sub-divided into six tertiary segments of 12 km long ($3b_1$ to $3b_6$), separated by <700 m wide step-overs. It is possible to identify four quaternary segments in tertiary segment 3b1 (i.e., $3b_{1a}$ to $3b_{1d}$), and two quaternary segments in both tertiary segments 3b3 ($3b_{3a}$ and $3b_{3b}$) and 3b6 ($3b_{6a}$ and $3b_{6b}$). They are separated by ~100 m wide step-over and a small bend (10°). Minor oblique splay faults are observed at the eastern tip of major segment 3 and G3.

Fossa G4:

G4 is ~435 km long and is divided into three main segments of 100 to 180 km long, separated by step overs >3 km wide. Major segment 1 is ~100 km long, and is divided into three secondary segments, connected by major bends in the fossa trace (20° 1a-1b; 15° 1b-1c). Secondary segment 1a is subdivided into four tertiary segments ($1a_1$ to $1a_4$), which have slightly different fault strikes (5 to 10°), and are linked by fairly well-connected jogs with local bends up to 20°. Secondary segment 1b is divided into three tertiary segments ($1b_1$, $1b_2$ and $1b_3$), connected similarly to secondary segment 1a (bends and well-connected jogs). The trace of secondary segment 1c is less pronounced toward the East. It is divided into three tertiary segments separated by small jog (1c1-1c2; 200 m wide) and a change in the azimuth (1c2-1c3; ~10°). Tertiary segment 1c3 might correspond to a minor splay of secondary segment 1c.

Major segment 2 is ~135 km long and is divided into two isolated secondary segments 2a and 2b, separated by a left-stepping jog of 2 km wide. Tertiary segments $2a_1$, $2a_2$, $2a_3$ and $2a_4$ are well connected along secondary segment 2a (slight bends up to 10° and <500m wide relay zones), while tertiary segments $2b_1$, $2b_2$, $2b_3$ and $2b_4$ are not well connected along secondary segment 2b (step-overs of 500 m to 1 km wide). Quaternary segments are thus observed along tertiary segments $2b_1$ ($2b_{1a}$ and $2b_{1b}$), $2b_2$ ($2b_{2a,}$ $2b_{2b}$ and $2b_{2c}$), $2b_3$ ($2b_{3a,}$ $2b_{3b}$ and $2b_{3c}$) and $2b_4$ ($2b_{4a,}$ $2b_{4b}$ and $2b_{4c}$). They are 7 km long on average, and separated by small <300 m wide step-overs and slight azimuth changes < 10°.

Major segment 3 is about 180 km long, but its total length is uncertain. Indeed, its trace is mainly formed by right-stepping jogs, while its eastern tip is formed by left-stepping en échelon fractures with an average azimuth slightly oblique compared to major segment 3. We consider this section as part of major segment 3 (secondary segment 3e), but it might correspond to a future new major segment. Major segment 3 is thus divided into five secondary segments 3a to 3e, separated by step-overs of <3 km wide, except between 3d-3e (~4 km wide). Tertiary segments are observed along all secondary segments (four along 3a, three along 3b, 3c and 3e, two along 3d). They are all separated by small step-over of <1 km wide or connected through slight bends (<10°). Quaternary segments are observed in most parts of major segment 3, especially in the eastern and less evolved part of the fossa (i.e., in secondary segments 3c, 3d and 3e). They are separated by small step overs <300m wide and azimuth changes <10°.

Fossa G5:

G5 is at least 200 km long and is situated about 20 and 35 km away from G2 and G1, respectively. Its trace is very discontinuous. Thus, we did not analyze its segmentation.

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