SUBCRUSTAL LID DRIVES CONTINENTAL-LIKE TECTONICS ON VENUS. R. C. Ghail[1], P. K. Byrne[2], S. Mikhail[3] and C. Gordon[3] [1]Dept Civil and Environmental Engineering, Imperial College London, London, SW7 2AZ, UK (r.ghail@imperial.ac.uk), [2]Planetary Research Group, Dept Marine, Earth, and Atmospheric Sciences, North Carolina State University, Raleigh, NC 27695, USA, [3]Dept Earth and Environmental Sciences, University of St Andrews, St Andrews, UK.

Introduction: The high surface temperature at Venus leads to the formation of a weak ductile detachment layer in the crust that partially isolates the crust from the mantle below, so that the mantle lid is able to recycle in a plate tectonic-like way below the crust. This subcrustal lid rejuvenation [1] is sufficient for steady-state heat loss and explains the global-scale geological features evident in the topography and geoid of Venus, particularly the network of rifts and wrinkle-ridged lowlands, as products of mantle convection. The surface of Venus also displays a distinctive strain partitioning at the ~1000 km scale, generating features we generically term terranes (noting that this term is used in a rather narrower sense in terrestrial geoscience), which are likely representative of crustal processes in response to stresses transmitted across the ductile lower crust. Usually terranes comprise areas of low strain (crustal blocks) outlined by relatively narrow high-strain boundaries [2], but in some cases (e.g. tesserae) the entire terrane is a high strain area. Terranes have a similar spatial scale to the spacing of impact craters and so are likely important in the resurfacing history of Venus.

Crustal Deformation: That the nature and size of terranes on Venus are comparable to continental tectonic blocks (terranes) on Earth is not surprising: the strength of dry basaltic crust on Venus is similar to continental crust and the ductile lower crust analogous to the mid-crustal detachments in many continental settings. In both cases, strain is partitioned into low strain cores and high strain boundaries that are both wider and more diffuse than their ocean plate counterparts, with a far wider variety of deformation styles contingent on past deformation history.

However, terranes on Venus differ in one important aspect: continental terranes drift across the planet in response to oceanic plate tectonics, whereas those on Venus respond only indirectly – and probably locally – to subcrustal rejuvenation.

Driving Forces: In the absence of significant erosion, regional slopes act as a good proxy for crustal strain on Venus, while the geoid broadly correlates with

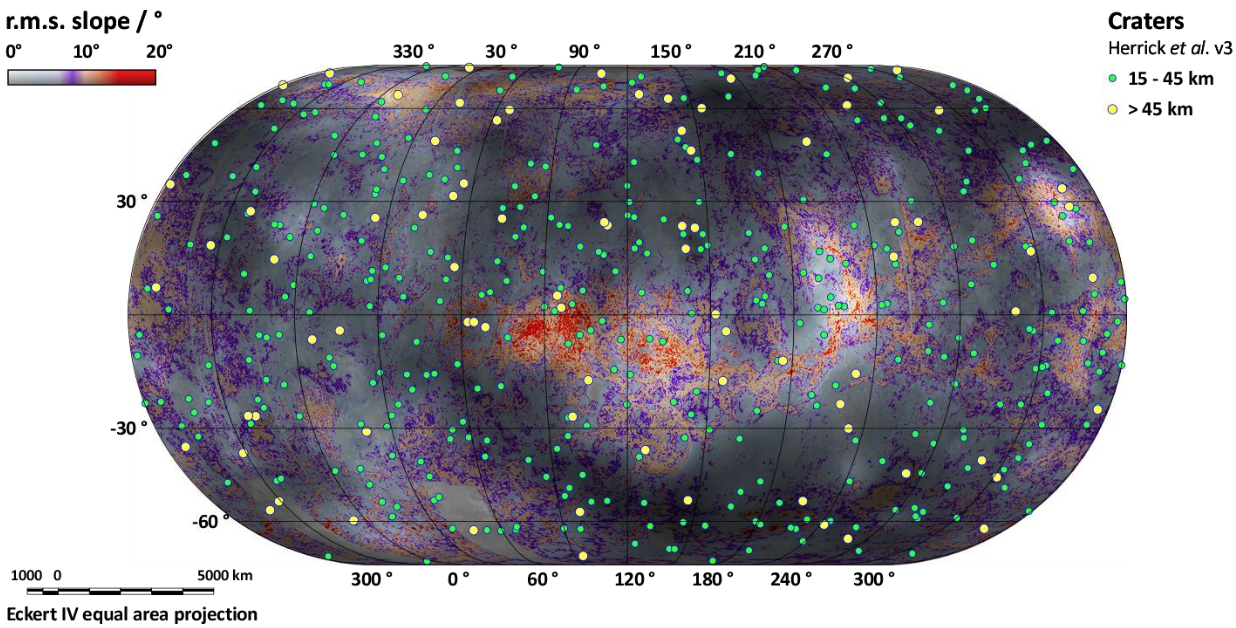

Figure 1: Altimeter-derived r.m.s. slope mapped as a proxy for crustal strain (blue = low strain, red = high strain), with the geoid as a proxy for mantle convection (dark = downwelling, light = upwelling). Strain is usually distributed into relatively narrow zones of high strain surrounding regions of low strain (terranes), but there are notable regions of high strain (tesserae), e.g. Ovda Regio. Note that high strain is often associated with upwelling, and the apparent association of craters >15 km diameter with downwelling areas.

mantle convection. Plotting these together (Fig. 1) highlights the differences in scale between crustal strain and mantle convection, but also reveals a correlation between them. The most highly strained terranes are located on geoid highs (upwelling mantle) and these terranes are also more likely to be highly deformed throughout their interior (e.g. within Parga Chasma). The reason for this is two-fold: the crust is both weaker and the detachment more pronounced above upwelling mantle, as a result of the increased heat flow (Fig. 2), and there is a net extensional traction away from the upwelling mantle swell. The East African rift system is perhaps the closest terrestrial analogue to these terranes; the east and west arms of the rift around Lake Victoria are similar to large coronae (which may in themselves be regarded as terranes) but Africa lacks the smaller coronae often associated with rifts on Venus.

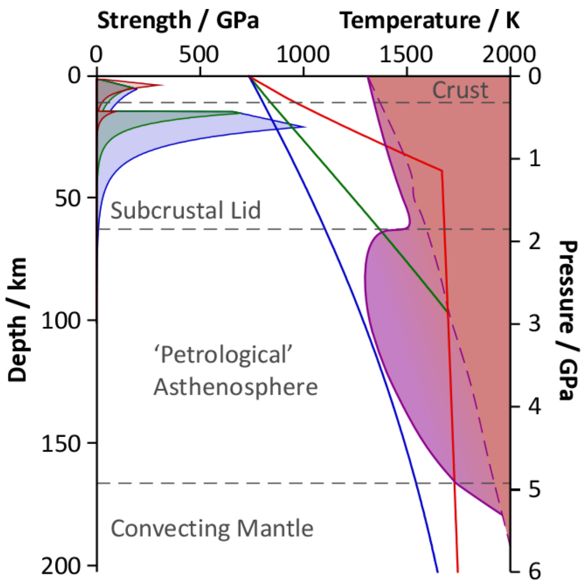

Figure 2: Crust and mantle conditions under three thermal regimes on Venus. At high heat flow (red, 36 mW m^{-2}), the crust is weak throughout and extensive melting occurs, resulting in terranes that are highly deformed throughout. At intermediate heat flows (green, 18 mW m^{-2}), a pronounced detachment forms in the lower crust and an asthenosphere in the mantle, leading to classical terranes with a low strain core bounded by high strain margins. In cold regions (blue, 12 mW m^{-2}) the detachment is less pronounced and the asthenosphere absent. Terranes appear to have experienced inversion, with interior wrinkle ridges and compressional margins.

Across most of Venus, where the mantle is neither upwelling nor downwelling, terranes appear most similar to their terrestrial counterparts with classical fold belt mountains (e.g. Lemkechen Dorsa between Tellus and Ovda) and numerous shear zones [3].

Terranes overlying downwelling mantle are stronger, have a less pronounced crustal detachment and no asthenosphere, and experience a net compressive stress. These factors result in terranes that most closely resemble typical continental basins (crustal block terranes), with wrinkle ridges formed through thin-skin inversion.

The exception to these types are tesserae terranes (e.g. Alpha Regio), which are always highly deformed regardless of location, indicating a mechanically weaker, perhaps more felsic, crustal composition.

The relationship between terranes and the geoid is consistent with an absence of global drift, or of classical (oceanic) plate movement. Subcrustal traction need only drive one crustal block into its neighbor, with only modest lateral movement (10s ~ 100 km) required to generate the range of features observed, similar in magnitude to intracontinental deformation and basin inversion. The overall effect is a local jostling of crustal blocks rather than global drift.

Implications: The jostling of crustal terranes, constantly remolding their boundaries but (usually) only rarely or less intensely deforming their interiors, may resolve the apparent paradox between the impact crater distribution and complex geology of Venus. Craters formed in the boundaries between terranes will be rendered unrecognizable, or destroyed altogether, on a geologically short timescale (10s Ma), while craters in the interiors of terranes may remain largely unaltered for 100s Ma. Thus Venus is able to maintain ~1000 impact craters in a steady-state, despite the apparently low number of partially deformed craters. Perhaps the most useful way to understand tectonic processes on Venus is to imagine what Earth would be like if it were completely covered in continental crust.

Conclusions: A fragmented, partially detached crust, drawn into constant motion by steady-state subcrustal lid rejuvenation, but able only to jostle locally with neighboring fragments, explains much of the observed geological complexity of Venus, while preserving the observed near-random distribution of impact craters. Hence, while volcanic in origin, the crust of Venus behaves much more like Earth's continents than its oceans, and is geologically far more interesting than previously thought.

References: [1] Ghail R. C. (2015) *PSS, 113*, 2–9. [2] Byrne P. K. et al. (2017) *LPS XLVIII, (this issue)*. [3] Harris, L. B. & Bédard, J. H. (2014) *GSL Sp. Pub., 401*, 327-356.