RECENT AND POSSIBLY ONGOING FORMATION OF TESSERATED ROCKS ON VENUS.
Paul K. Byrne¹, Richard C. Ghail², Peter B. James¹, Christian Klimczak⁴, A. M. Celâl Şengör⁵, and Sean C. Solomon⁶, ¹Department of Earth and Planetary Sciences, Washington University in St. Louis, St. Louis, MO 63130, USA; ²Department of Earth Sciences, Royal Holloway, University of London, Surrey TW20 0EX, UK; ³Department of Geosciences, Baylor University, Waco, TX 76798, USA; ⁴Department of Geology, University of Georgia, Athens, GA 30602, USA; ⁵Department of Geology, Faculty of Mines, Istanbul Technical University, 34469 Ayazağa, Istanbul, Turkey; ⁶Lamont–Doherty Earth Observatory, Columbia University, Palisades, NY 10964, USA.

Introduction: The term “tessera” (pl. “tesserae”) is given to a major terrain type of Venus characterized by tectonic complexity and locally high radar backscatter [1]. Tesserae occupy about 7% of the planet’s surface [2]. The prevailing view is that tesserae mark the oldest preserved crust on Venus, mainly on the basis of their common superposition by younger, radar-smooth plains that are generally interpreted as volcanic [e.g., 2]. Tesserae also have a greater average crater-retention age than the smooth plains, on the basis of the areal density of impact craters >16 km in diameter [3]. And the recognition of relatively small exposures of tessera far from larger instances of this terrain type led to the hypothesis of a regional or even global tessera basement beneath the planet’s widespread plains [4].

Here, on the basis of detailed structural analysis, we argue to the contrary that the formation of rocks we recognize as tesserae in several areas has taken place geologically recently—and may even be ongoing.

Tessera Properties: Areas mapped as tesserae, originally termed “parquet” terrain, features two or more sets of cross-cutting ridges and/or grooves, indicative of several periods of deformation [1]. Most instances of this terrain type are topographically elevated, and tessera constitutes much of the planet’s two major highlands, Ishtar and Aphrodite Terrae. On the basis of gravity anomaly, morphology, and inferred composition, tesserae have even been proposed to be the Venus counterparts to continents on Earth [e.g., 5].

Yet “tessera” as a descriptor term relates to morphology rather than lithology, and information regarding the rocks that comprise tesserae is limited. Thermal emissivity data from the Venus Express spacecraft suggest that the Alpha Regio tessera differs in lithology from the surrounding plains [6], and the presence of layering within some tessera exposures is consistent with this terrain type being in part composed of stacks of lava flows [7]. Nonetheless, it is important to recognize tesserae only as deformed rocks, rather than a distinct rock type, and there is no requirement that the tectonics that formed tesserae—what we term “tesseration”—was everywhere simultaneous, nor that all tesserae preserved today were originally the same rock type, were emplaced the same way, or were deformed by the same process(es).

Recent Tessera-Style Deformation: We identify several areas on Venus where the narrative of tesserae as ancient is challenged. In those areas, lowland plains show progressively greater shortening deformation with proximity to the margins of higher-standing tesserae, such that the structures formed in the plains become indistinguishable from the dominant tectonic fabric of the tesserae themselves.

For example, along the northern margin of Ovda Regio, notably at about 4°N, 85°E, radar-smooth plains show a series of laterally extensive anticlinal folds that strike approximately northeast–southwest, a direction generally parallel to that of the dominant tectonic fabric within the tessera unit that makes up Ovda Regio here (Figure 1). Indeed, these folded plains assume the morphological and radar characteristics of the tessera without any distinct boundary, implying a continuum of increasing shortening strain from north to south across this margin—even though radar-smooth plains, ridged plains, and tesserae are assigned to different time-stratigraphic systems in current global geological maps of Venus [e.g., 2].

The concept of tesseration of smooth plains was earlier proposed for southeast Thetis Regio [8]. In addition to that area and the Ovda Regio example above, we have also found transitions from plains to tesserae at the boundary between Sogolon Planitia and Aphrodite Terra at 3°N, 112°E, and along the Semuni Dorsa–Ishtar Terra boundary at 70°–75°N, 5°E. In all such cases, the dominant and secondary tectonic fabrics of deformed plains matches those within adjacent tesserae, with no clear demarcation between these major terrain types.

Tesseration Driven by Interior Flow: In an earlier study [9], we calculated the magnitudes and directions of mantle flow from a recent global crustal thickness model [10]. This model, in turn, was derived from long-wavelength gravity and topography measurements acquired by the Pioneer Venus and Magellan missions [11]. Importantly, the inferred interior flow directions we calculate for each site given here (e.g., the cyan arrow in Figure 1) are approximately aligned with the principal shortening axes, orthogonal to the strikes of the shortening structures—which suggests that, since the flow directions are contemporary, so, too, is at least a portion of the deformation we document.
Implications for Venus Geology: Our observations indicate that, at least in some places on Venus, the formation and expansion of tesserated rocks by the incorporation of apparently stratigraphically younger smooth plains has taken place geologically recently, and may even be continuing today. Accordingly, the areal extent (and, presumably, total volume) of tesserated rock on Venus has increased in the relatively recent past.

An enduring question regarding tesserae has been the nature of their precursor rocks [e.g., 4]. Per our interpretation, at least some tessera units are highly deformed plains units, which themselves are effusively emplaced lavas and/or igneous-derived sediments. Moreover, the concept of plains becoming tesserated is consistent with observations of layering within some tesserae [7]: those layers may be the component flows or flow units that originally formed smooth plains. That such internal layering is visible today necessitates some amount of erosion of the tesserated rocks, which in turn implies that at least some of the “intratessera” radar-smooth units [e.g., 4] comprise debris sourced from local highs [7]. Further, the shortening of plains units could help account for the observation of folds of differing wavelengths within tesserae [e.g., 12], with those wavelengths a consequence, at least partly, of the thickness of plains lavas being folded.

Interior viscous flow drives modest but widespread lateral motions of discrete crustal blocks in the lowlands, via tractive stresses transferred through a low-strength crustal layer [9]. That same mechanism may be responsible for the progressive deformation of plains into tesserated rocks we describe here, although it is only the relative convergence that can be documented, and not the motions of plains or highlands relative to any mantle reference frame.

Outlook: On the basis of the observations we describe here, some portions of tesserae may reflect ongoing, sustained shortening deformation and erosion of originally smooth plains units. The spatial scale of plains tesseration is considerable: this pattern of deformation is present for thousands of kilometers along much of the northwestern boundary of Aphrodite Terra and the southern margin of Ishtar Terra. This shortening may balance, to at least some extent, regional-scale extension elsewhere on Venus, such as across the rift zones to the southeast of Aphrodite and elsewhere.

Our finding of geologically recent tesseration does not mean that all portions of all tesserae are young; the central portions of those units may well be quite old (as indicated by the crater spatial densities there). Moreover, there is evidence that some large tessera exposures have been assembled from smaller, antecedent pieces of tesserated terrain [8, 13]. Yet, by attributing seemingly disparate units on Venus—conventionally assigned to different periods in the planet’s geological history—to different kinematic stages of the same process, we suggest that tesserae as a terrain type have little value as global stratigraphic markers. If so, then prevailing ideas for the geological history and level of recent tectonic activity on Venus require substantial revision.