VENUS' HIGHLAND TESSERAE ARE TECTONIC COUNTERPARTS TO EARTH'S CRATONS.

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Introduction: The term "tessera" (pl. "tesserae") describes a major terrain type on the surface of Venus characterized by tectonic complexity and high radar backscatter [1] (**Figure 1**). Most highland regions on Venus are surfaced by tessera terrain [2] and underlain by thicker than average crust [3]. A long-held view has been that tesserae mark the oldest preserved crust on Venus [2,4], largely on the basis of their superposition by younger and more widespread radar-smooth plains that are generally interpreted as volcanic in origin [e.g., 2].

The term "tessera" is not a descriptor of lithology but of surface morphology, and information regarding the rocks that comprise tesserae is limited [e.g., 5]. Further, tessera deformation was not necessarily everywhere simultaneous [6], and the tesserae preserved today need not have originally been the same rock type, nor emplaced in the same way, nor deformed by the same process(es). Different tessera exposures, and even different regions within a single tessera, may have different mineralogies and, by implication, different precursor rock types [7].

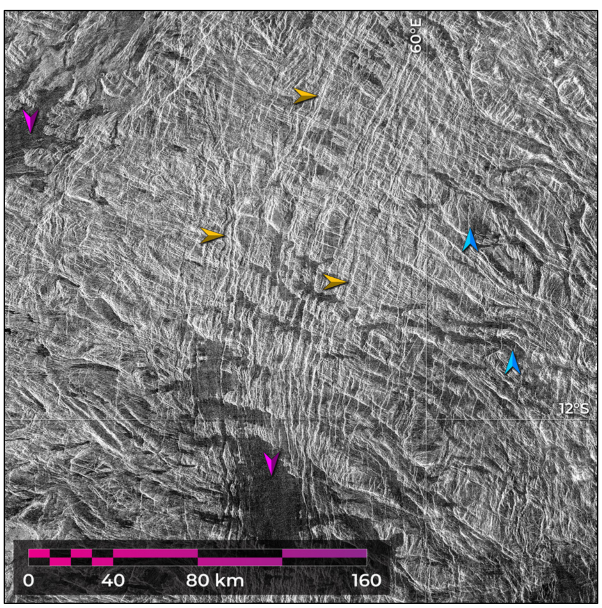

Figure 1. A region of tessera along the western margin of Ovda Regio, Venus. This terrain is riven with extensional structures (gold arrows); locally low-lying areas are filled with radar-dark material (magenta arrows), presumably some combination of lavas and sediments. Lenticular and arcuate features in the tessera may be folds (blue arrows). This is a portion of the left-look Magellan global radar image mosaic, centered at 11.5°S, 59.4°E.

Highland tesserae share several important traits with cratons on Earth. Both physiographic feature types are associated with relatively thick crust; both show extensive tectonic deformation; and both are typically the locally oldest material where they occur. Here, we explore the possibility that highland tesserae are the tectonic counterpart on Venus to cratons on Earth.

Terran Cratons: In the broadest sense, a craton is a piece of continental lithosphere isolated from the convecting mantle and resistant to continued, penetrating deformation [8]. Indeed, there is no *a priori* requirement that a craton be of a particular composition or have formed in a single eon, be composed of rocks of a specific metamorphic grade, or have undergone a prescribed amount of erosion—only an absence of new interior deformation even when the margins continue to be sites of considerable strain accumulation [8].

Earth's cratons today formed in the late Proterozoic to early Cambrian, although they feature components that were originally cratons in their own right that formed in the Archean and early Proterozoic [8]. Indeed, a key characteristic of Terran cratons is their formation via accretion and incorporation of adjacent materials (principally island arcs and other components from the ocean floor) [e.g., 9].

Of course, there are important differences between highland tesserae and cratons. For instance, cratonic rocks on Earth are dominantly felsic or their metamorphic products. There is no direct evidence for continental crust on Venus, although on the basis of morphology, gravity anomaly signature, and thermal emissivity, tesserae *have* been proposed to be similar to continental materials on Earth [10,11]. In addition, the sub-cratonic upper mantle must be depleted by partial melt extraction so as to be more buoyant than the oceanic mantle [12], and have relatively low abundances of heat-producing elements such that heat production at the base of the craton is low [13]. On Venus, neither the state of the upper mantle beneath tesserae nor the thermal gradient there is known.

Nonetheless, cratons on Earth have been shaped by plate tectonic processes and represent the collision and accretion of different tectonic units such as island arcs, slices of oceanic plateaux, continental blocks, and accretionary complexes [8]. The formation of cratons results in substantial deformation of the constituent rocks, typically manifest by multiple, crosscutting sets of tectonic structures—such as the joints, normal faults, and folds that deform the Archean–Paleoproterozoic rocks of the Rae province in the North American craton [8] (**Figure 2**).

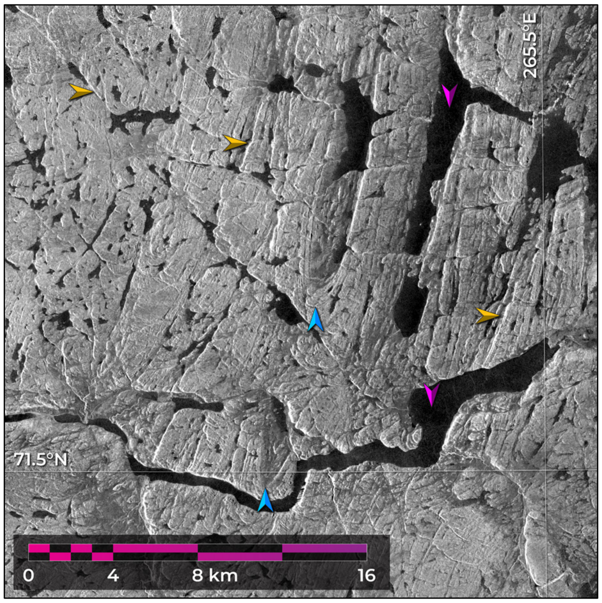

Figure 2. A portion of the Rae province in Nunavut, part of the North American craton [8]. Sets of extensional structures striking north–northeast and southeast are abundant (gold arrows); low-lying, radar-dark areas are water (magenta arrows). Lenticular and arcuate features may be eroded, periclinal folds (blue arrows). This view is part of Sentinel-1 radar image frame E083N070T1, centered at 71.6°N, 59.4°E.

Tessera Accretion: We recently documented that, in some regions on Venus, stratigraphically younger volcanic plains have been tectonically deformed so as to acquire the morphological characteristics of adjacent tessera units [14]. For example, along the Sogolon Planitia boundary with Aphrodite Terra, plains become progressively more folded with proximity to, and share the same general strike directions, as the dominant fabrics within, the tessera terrain there (**Figure 3**). These observations indicate that, in places, tessera terrain has expanded both in area and volume by the deformation and incorporation of younger smooth plains and the associated uplift and thickening of the crust [14]—the very kinematic manner by which cratons on Earth form.

There are other examples of lateral motions having taken place on Venus. For instance, there is structural evidence that Lakshmi Planum collided as a block with Ishtar Terra [15], and that the Tellus Regio tessera was assembled from smaller, antecedent pieces of originally spatially separated tesserated terrain [16]. Large-scale horizontal mobility of terrain on Venus, including portions of present tesserae, may at one time have been more widespread than has generally been assumed in models for the geological evolution of Venus.

Implications: Crustal thickness, local stratigraphic order, morphological similarity, and even manner of formation suggest that highland tesserae may be Venus' counterparts to cratons on Earth. If so, then tessera need no longer be an orphaned morphology type, since kinematically similar rock units are present on the other large, rocky world in the Solar System. Cratons on Earth reflect the actions of plate tectonics. It is unclear if this process is responsible for the formation of Venus' tesserae on Venus—but climate evolution models support the presence of surface water in Venus' past [17], an environmental condition thought to be key to plate recycling on Earth [18]. New, high-resolution radar image and topographic data for detailed morphological analysis [19,20], together with noble gas isotope abundances for constraining paleoclimate models [21], will be crucial to answering the question of whether cratons are present on the second planet.

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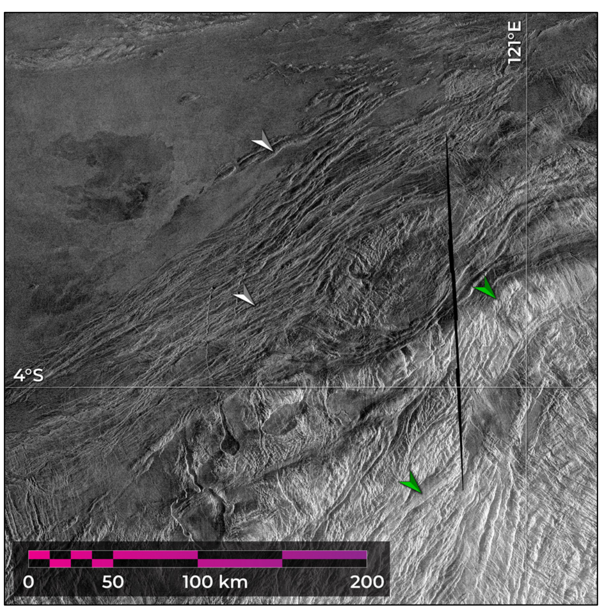

Figure 3. At the Sogolon Planitia–Aphrodite Terra margin, northeast-trending folds in the plains (white arrows) have the same strike direction as more open tessera folds (green arrows). Right-look Magellan radar data, centered at 3.5°N, 112.0°E.