CALDERAS ON VENUS: TECTONICS, VOLCANISM AND RELATIONSHIP WITH REGIONAL PLAINS.

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Introduction. Calderas on Venus, after *"Magellan"*, were described as *"circular to elongate depressions not associated with a well-defined edifice and are characterized mainly by concentric patterns of enveloping fractures"* [1]. They are most common between 40 and 80 km in diameter, preferentially clustering in the Atla-Beta area [1,2]. The "*Catalog of Volcanic structures of Venus*" [2] includes 97 calderas, which may have formed by similar processes that have been modeled by the well-studied terrestrial calderas [3,4]. ***Goals of the study:*** **1)** To study the global distribution of all calderas from the catalog [2]. **2)** To study topography and geology of calderas and their surroundings. **3)** To study the period of caldera-forming activity. ***Methods:*** We used *"Magellan"* C1 and F-MIDRs and GTDR data for our analysis. Our study included the following points: **1)** Topography of the calderas. We exclude from this analysis calderas with diameters less than 50 km because of GTDR data resolution. **2)** Distribution and kinematics of caldera-dependent tectonic structures. We analyzed the relationship of stratigraphic units and tectonic structures of calderas and their local environment. **3)** Style of caldera-related volcanism – is the caldera a source of radar bright lava flows (hereafter lava flows) and/or shield volcanoes (hereafter shields). **4)** Relationship of calderas with rifts zones – is the caldera located in chasmata and/or fracture belts, which are interpreted as rifts [5,6,7], or not. **5)** Relationship of calderas with regional plains with wrinkle ridges (hereafter Pwr), which can be used as a stratigraphic marker [8,9]. If Pwr embay all structures and caldera-related volcanic edifices – the caldera predates Pwr (hereafter *pre Pwr CA*). If Pwr embay some tectonic structures of the caldera, but a portion of them deform Pwr, and caldera-related volcanic edifices overlay Pwr – this caldera started before and finished after Pwr (hereafter *pre & post Pwr CA*). If there are no traces of caldera tectonic and volcanic activity before formation of Pwr – this caldera postdates Pwr (hereafter *post Pwr CA*).

Results. ***Global distribution*** shows that calderas are clustered in Atla-Beta-Themis triangle (fig. 1) [1,2].

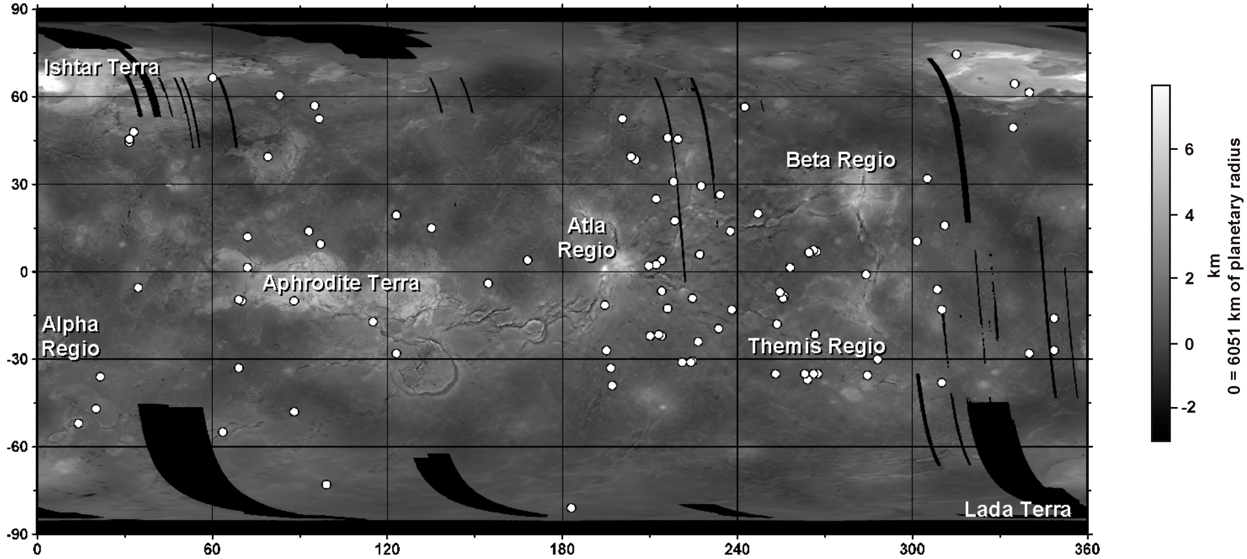

Fig. 1. Location of calderas according to the *"Catalog of volcanic structures of Venus"* [*2*], overlain on a topographic map of Venus.

Topography. Fifty one calderas are represented by depressions (53%), 11 (11%) have an irregular flat shape, 6 (6%) are depressions with a very low rim, 1 (1%) is dome-like, and 28 (29%) have a diameter that is less than 50 km.

Tectonic structures. Four sets of tectonic features in calderas are observed. **1)** Concentric extensional structures (graben, normal faults and fractures) are observed in 61 calderas (63%). **2)** Concentric extensional fracturing and radial compressional structures (ridges) inside and/or outside of the concentric fracturing are observed in 28 (29%). In some cases, concentric ridges inside calderas are observed. This type has the same set of tectonic structures as arachnoids [2,10]. **3)** Seven calderas (7%) have concentric and radial extensional fracturing. **4)** One caldera (1%) has radial fracturing only. Types 3 and 4 have the same sets of tectonic structures as novae [1,2,11].

Style of volcanism. Shields are associated with 46 calderas (47%), lava flows with 23 (24%), both shields and lava flows are associated with 16 (17%), and 12 (12%) show no volcanic activity. Nine calderas have features which can be interpreted as related pit craters and canali [12,13].

Relationship with rifts. Eighty onr calderas are located outside of rifts (83%), and 16 (17%) are located inside rifts.

Relationship with regional plains (Pwr). Thirty-five (36%) *pre Pwr CA*, 31 (32%) *pre & post Pwr CA* and 24 (25%) *post Pwr CA* are identified (fig. 2). In 7 calderas (7%) it is impossible to compare the period of their activity with the position of Pwr. Distribution of tectonic structures, style of volcanism and association with rifts in caldera age populations are shown in fig. 3.

Interpretation. To understand the place of calderas in the history of the planet we should clearly define their ages relative to a stratigraphic marker – Pwr [8,9]. Therefore, in our interpretation are calderas for which periods of activity were able to be defined, thus 7 calderas were excluded from this analysis (fig. 2). Hereafter % are shown relative to each age population.

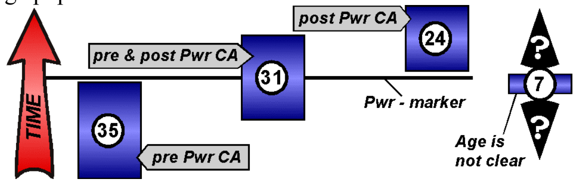

Fig. 2. Period of caldera-forming activity. 35,31,24,7 – numbers of calderas.

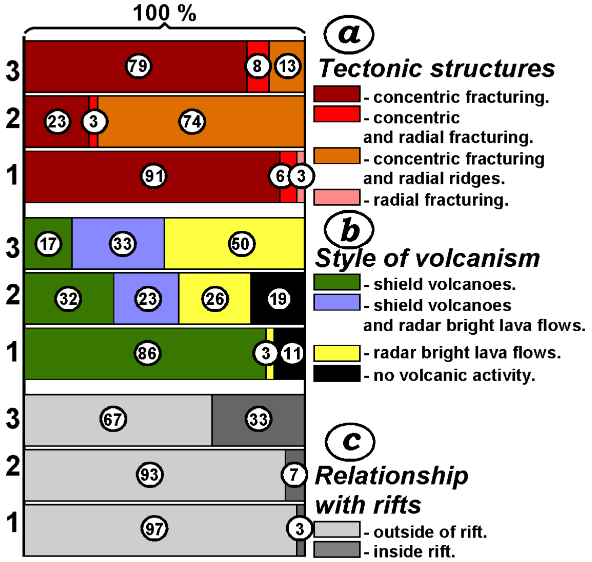

Fig. 3. Distribution of tectonic structures (a), styles of volcanism (b) and association with rift zones (c) in age populations of calderas. **1** – *pre Pwr CA*, **2** – *pre & post Pwr CA*, **3** – *post Pwr CA*. Numbers show % in each age population.

Tectonics (fig. 3a). Most of *pre Pwr CA* (91%) and *post Pwr CA* (79%) have concentric extensional fracturing only. Most of *pre & post Pwr CA* (74%) are arachnoid-like and have concentric extensional fracturing and radial (sometimes concentric) compressional ridges. These are connected with a regional network of wrinkle ridges, that change their strikes to a radial orientation relative to the calderas in their local environment. Based on this, the formation of most *pre & post Pwr CA* approximately took place on the background of regional stress. Some of the *post Pwr CA* (13%) also have the same set of tectonic structures, but without traces of regional stress influence. This is in agreement with models of arachnoid formation [14]. Therefore, most of the *post Pwr CA* and *pre Pwr CA* were formed in the same manner as terrestrial calderas with concentric fracturing only [3,4], while most of the *pre & post Pwr CA* and a small amount of the *post Pwr CA* were formed by the same conditions as arachnoids [10,14].

Volcanism (fig. 3b). <u>*Pre Pwr CA*</u> – 86% show shield activity only, and 3% - lava flows only. <u>*Pre & post Pwr CA*</u> – 55% show shield activity, 49% - lava flows, and 23% show both styles of volcanism. <u>*Post Pwr CA*</u> – 50% show shields activity, 83% - lava flows, 33% show both style of volcanism. Relative to Pwr, shield activity is decreasing and lava flow emplacement is increasing with time. This is in agreement with the model of regional and global stratigraphy [8,9], which predicts the evolution of the style and rate of volcanism with time (called "directional" [15]). An increasing of number of lava flows with time may be explained by the overburdening of possible existing lava flows by Pwr in *Pre Pwr CA,* but the decreasing of shield activity with time can't be explained by this reason.

Relationship with rifts (fig. 3c). <u>*Pre Pwr CA*</u> – 97% are outside of the rifts, and 3% are in the rifts. <u>*Pre & post Pwr CA*</u> – 93% are outside of the rifts, and 7% are in the rifts. <u>*Post Pwr CA* – 67%</u> are outside of the rifts, and 33% are in the rifts. Most of the rift-related calderas are *Post Pwr CA*. Relative to Pwr, increasing numbers of rift-associated calderas with time may evidence the displacement of volcanism with time to the rift zones due to an increasing of the lithosphere thickness [16,17].

Summary. 1) We have studied all calderas of the list [2] (97 structures). **2)** The calderas are clustered in Atla-Beta-Themis triangle (fig. 1) [1]. **3)** Most calderas are represented by depressions, sometimes surrounded with a very low rim. **4)** We classified them (4 classes) on the basis of tectonic sets that are characteristic of each class. Most of the calderas (63%) have the same set as terrestrial calderas, some of the calderas (37%) have a set of tectonic structures that are common for venusian arachnoids and novae [1,2,10,11]. Therefore, part of the calderas (29%) should be described as arachnoids, another part (8%) as novae. **5)** Most of the calderas show no association with rift zones. **6)** Similar numbers of *pre Pwr CA, pre & post Pwr CA* and *post Pwr CA* were observed (fig. 2). **7)** Appropriateness of changing in formation of sets of calderas-related tectonic structures, style of volcanism and association of calderas with rift zones relative to stratigraphic position of Pwr are exposed (fig. 3). The evolution of the sets of tectonic structures by caldera formation shows that most of the *pre Pwr CA* and *post Pwr CA* were apparently formed due to mechanisms proposed for terrestrial caldera formation [3,4], while most of the *pre & post Pwr CA* were approximately formed due to mechanisms proposed for arachnoid formation [10,14]. Changes in the style of volcanism through time supports a "directional" model of Venus evolution [8,9]. The character of the association of calderas with rifts supports models demonstrating an increase of lithosphere thickness with time [16,17].

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