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The crowns, spiders and stars of Venus

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Abstract

Venus surface has been studied extensively using SAR (synthetic aperture radar) –imagery provided by the NASA Magellan mission in 1990 - 1994. The radar images with ~98% coverage and resolution of ~100 m may be used in order to understand the global suite of surface structures, and to analyze single features and their formation processes using photogeological approaches and methods.

This study recognizes and catalogues four Venusian surface structure types, the *coronae, arachnoids, novae and corona-novae*. The study goals are:

a) To provide a thorough survey of the four Venusian volcano-tectonic feature groups (characteristics, distribution, measurements of size and location), and to defend the recognization of the feature groups,
    a. 596 coronae, 139 arachnoids, 74 novae and 35 corona-novae
b) To present a characterization method that is based on the generalized governing geological units: I - deformation zones, II - plains, III - tessera, and IV - regions with volcanic concentration,
c) To present results on the observations of formational processes:
    a. Arachnoids display implications for at least three different formational origin
    b. Model of corona-novae formation provides theoretical explanations to meet the observations of the individual features
    c. Observations of young arcuate tectonic features on the flanks of some of the volcano-tectonic features located in the rift zone –region

All gathered information supply to the goal of understanding Venus. As a single plate planet without plate tectonics, an alternate heat flow mechanism is in effect. The volcano-tectonic features may be part of the solution.

Keywords: Venus, volcano-tectonics, Coronae, Arachnoids, Novae, Corona-novae

Preface

It was some nine years ago, when I first started tackling with the oddities of Venusian surface features. The many legged arachnoids were the first, and now, another chapter of the story with them and several other structures is finally closing. The journey has been part exhausting, part invigorating, but altogether exciting. Particularly the last few months have once again turned on the interest that I had for this veiled celestial body before the red one caught my attention at the arrival of the Mars Express. With the new Venus missions, I hope this renewal of interest will not wear of, and I will have time to experiment with some of the new ideas that came along with this process.

Many people helped during my journey and for that, I owe them my gratitude. First, I want to thank my supervisor, docent Jouko Raitala for all his work and efforts for me and our research group during these past nine years – Jouko, the group has come a long way. Also my colleague, doctor Marko Aittola has been a vital part of my work – our work, and I hope there will still be many challenges to tackle together. As for the rest of the bunch – Terhi, Teemu, Hanna, Jarmo, Toni and Matias – keep up the good work!

The life outside the uni has been for every bit as important as my research and study, serving as the counter weight to keep my scale in balance. Mom, dad, sisters and brothers, I love you all. Friends, I would not change a day!

Last but not least, the very foundation of my every day life, my family. My beloved wife, Virpi, my daughter, the little princess Emma and the furry friend (and faithful companion through the long nights of endless writing) Killi – I could not have done it without you.

Oulu, 1.12.2006
Petri Kostama

Original publications

This thesis consists of an introduction and five original papers.

I **Kostama, V.-P., M. Aittola, T. Törmänen and J. Raitala:** Characterization of coronae and corona-like features of Venus (Manuscript).

II **Aittola, M. and V.-P. Kostama*:** Venusian novae and arachnoids: Characteristics, differences and the effect of the geological environment. Planetary and Space Science, Volume 48, pp. 1479 – 1489, 2000.

III **Kostama, V.-P.* and M. Aittola:** Arcuate graben of Venusian volcano-tectonic structures: The last phase of tectonic activity? Astronomy and Astrophysics, v.428, pp.235-240, DOI: 10.1051/0004-6361:200400061, 2004.

IV **Aittola, M. and V.-P. Kostama*:** Chronology of the formation process of Venusian novae and the associated coronae. Journal of Geophysical Research (Planets), Volume 107, Issue E11, pp. 22 – 1, CiteID 5112, DOI 10.1029/2001JE001528, 2002.

V **Kostama, V.-P., T. Törmänen and J. Raitala:** Venusian arachnoids: the geological aspect (Submitted to Icarus).

- Equally distributed share of responsibility to both writers.

Original publications are not included in the electronic version of the dissertation.

CONTENTS

1. Introduction

For the past few years, the world has shown increasing interest in the planetary bodies, a sort of a new age of discovery with new planetary missions launching every year. Particularly, Mars is seen as a very important target for studies because of its water-rich past, indications of which was proposed after the Viking missions (i.e. Baker 1982; Jöns 1983, 1984; and many others). However, the volcanic as well as tectonic structures and features of the early Mars, formed during the planets active phase, are in most cases covered and modified by later geological events. Besides Mars (and other "terrestrial" objects), Venus may also be used for comparative planetological studies. Like Mars, it is thought to be a planet with only one continuous plate, with a different heat-loss mechanism compared to Earth (e.g. Solomon and Head 1982; Morgan and Phillips 1983; Schubert at al. 1997). As Venus also has a very thick atmosphere, and water does not exist on its surface, we can quite easily identify and study the different units and features modifying the planetary surface (Arvidson et al. 1991), if we can get past the thick atmospheric cover (Fig. 1). Venus is also very comparable to Earth by its size and density, providing therefore a secondary view of a similar size planet without effective erosional processes.

The contemporary Venus research employs the Magellan mission (1990-1994) as its primary source of surface data. The used data is in the form of SAR (synthetic radar aperture) images, topographic maps and measurements (GTDR; global topographic data record). Information on slopes, reflectivity, emissivity, and magnetic anomalies is also readily available. The mission covered (with SAR) ~98% of Venusian surface with spatial resolution of ~100-250 m/pixel, which was resampled to a common scale of 75 m/pixel. The incidence angle differed from ~15-45° (c.f. Campbell 2002). The resolution of the radar images is enough for global as well as local geologic observations. Topographic data has a resolution of ~5 km/pixel which is high enough for geological studies of larger regions as well as the prominent volcano-tectonic structures covered by this study.

The greatest expectations for discoveries from the Magellan mission concerned the possibility of global plate tectonics. Based on the available data and research, we have been able to conclude that a similar system of plate-tectonics that affects our planet does not exist on Venus (e.g. Solomon and Head, 1982). The "one-plate"-system of our sister planet is probably due to the lesser rigidity and smaller horizontal movements compared to Earth (e.g. Solomon et al. 1992; Hansen et al. 1997). The lack of plate tectonics does, however, have a considerable impact on the heat flow budget of Venus. There are several different models that try to offer some realistic values, and also explanations for the heat flow (e.g. Solomatov and Moresi 1996; Leitner and Firneis 2005; Turcotte 1993; Solomon and Head 1982).

All the models explicitly show that we still know very little of the inside structure of Venus. The size, mean density and internal heat budget are similar to Earth, but the interior probably differs to great extent. Despite the apparent absence of water, the bulk composition should also be similar (Kaula 1999). The present day absence of water on Venus also precludes the effective development of an astenosphere (Phillips 1986; 1990). Also the observations of gravity anomalies coincide quite well with surface structures, implying that Venus does not have an astenosphere that would separate lithosphere from the movements of the mantle. One other observation stands out: the surface distribution of Venusian volcanic and tectonic structures. On Earth the volcanoes are found usually in chains, while on Venus the distribution seems quite uniform, almost random (e.g. Head et al. 1992; Crumpler and Aubele 2000). But, in more careful analysis, this randomness disappears: the structures are not randomly located, as the analysis of areal distribution based on structure types and their geological environments shows (e.g. Papers I, II and V). There are also extensive linear fractures occurring along the equatorial region. These features are called *chasmata* and they expand over 55 000 km (Jurdy and Stefanick 1999). They have been interpreted to represent some of the youngest formations on Venusian surface (e.g. Grimm and Phillips 1992; Head et al. 1992; Herrick 1994). They seem to have a connection to at last some of the volcano-tectonic structures: novae (Aittola 2001), coronae (Krassilnikov et al. 2005), and corona-novae (Paper IV).

Lacking the direct means to access the details of the inside structure of Venus, we must use secondary ways to get some of the needed information: Analysis of Venusian volcanic structures may be used, comparing them to the tectonically more prominent rift zones (e.g. Krassilnikov et al. 2005) and somewhat smaller ridge belts, and to the centers of both volcanism and tectonism. This work on the volcano-tectonic structures (Papers I-V) therefore supplies to the goals of understanding of: a) how Venus works, how it substitutes for the lack of global tectonics, and b) what do the different singular structures and structure groups tell us what is happening inside the planet, and c) what is the effect of the areal geology to the formation processes of the surface structures.

In my research the main tools used are the Magellan SAR-database (C-MIDR, F-MIDR, and FMAP -images) and topographic information of Venus. Analysis of volcano-tectonic structures with these datasets has revealed information on the structures and their environment (Papers I and II), their development and evolution (Papers II-V), and their implications for the effect of local geology (Papers I, II and V). Emphasis of the study has been particularly on the systematic comparison of structure types and the environmental settings, which has resulted in characterization and typing of the volcano-tectonic features in a global scale, based on local governing geology (Paper I).

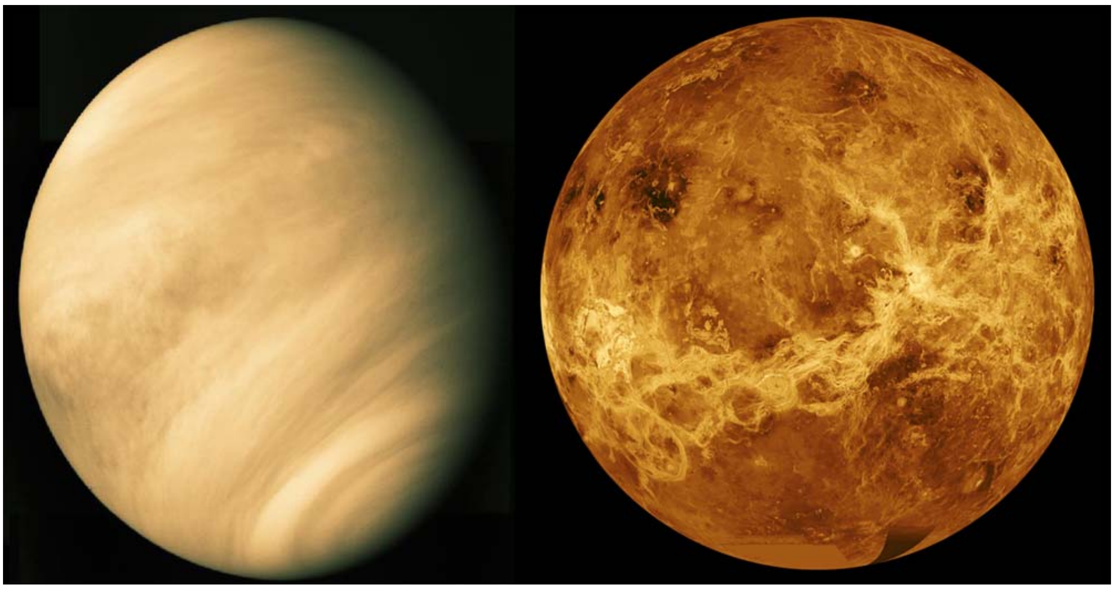

Figure 1. The thick and cloudy atmosphere of Venus veils its surface from visual observations. On the left is a spherical view of the Venusian surface centred at 180°E.

2. Venus – beneath the veil

2.1. Atmosphere

Venus has a very thick atmosphere with surface pressure of around 95 bar. The main component is CO_2 (~96.5%) with some N_2 (~3.5%) and other elements. Venus is very hot due to a "runaway" greenhouse effect. Carbon dioxide or water vapors in the atmosphere prevent heat energy in the form of infrared light from leaking out to space. Due to this, the average temperature for this veiled planet is a continuous ~740 K on the surface (around mean planetary radius, MPR=6051.84 km; Schaber et al. 1992; Baer et al. 1994; Lodders and Fegley 1998).

The atmosphere is currently very dry (~30 ppm) but it has been suggested that water was more abundant during the earlier phases of the planet's evolution. Due to the high temperatures, the existing water has probably been always in gaseous form, and therefore been able to reach the higher parts of the atmosphere. From the upper parts of the atmosphere, the hydrogen was able to escape to space and oxygen combined with other atoms, after water molecules were broken apart by UV-light. We cannot be certain of the origin or the correct amount of water, but some estimations do exist. The origin of the water may have been endogenic (volcanic outgassing) or exogenic (cometary or meteoritic bombardment), while the "global water layer" may have been between 4 to 525 m thick (Donahue and Russell 1997).

The atmosphere and surface do not probably interact much due to the slow wind speeds near the surface (V_{winds} <0.5 m/s). However, the velocities of the winds pick up with altitudes, up to 100 m/s at 60 km, so winds may have more influence on surfaces in higher locations (such as the Maxwell Montes) (Counselman et al. 1979, 1980; Kerzhanovich and Marov 1983). For the photogeological studies, the existence of the atmosphere is a hindrance as it limits our possibilities to view the surface, and forces us to use other means, such as radar images.

2.2. Surface, crust and lithosphere

It is imperative to note that the surface environment of Venus is very hot and dry. The lack of water does influence directly the formation and evolution of the surface structures as there are no water related processes.

Venus seems to have one other very important difference when compared to Earth: it is in fact a single-plate planet with only one hypsometric peak around its MPR (Fig. 2). Venus displays a monotone elevation distribution with ~80% of its surface and surface features are within ±1km of the MPR. There are also *tessera* highlands, domical areas and mountain belts, which rise from a few to several kilometers above the MPR. The Venera lander panoramas revealed layered surface rocks which may consist of lithified sediments, lava flows or exfoliated lavas (e.g. Florensky et al. 1977, 1983; Basilevsky et al. 1983, 1985; Garvin et al. 1984). By their composition, all the analyzed rock types from the landing sites are close to basalts (e.g. Vinogradov et al. 1973; Surkov et al. 1977, 1983, 1984, 1987;

Barsukov et al. 1992). The vast lava plains cover the lowlands and highland depressions, and indicate, together with numerous dome fields, larger volcanic edifices, rift zones and ridge belts, that volcanism and tectonics have played a major role on Venus. Its exogenic geological processes include eolian erosion, transportation and deposition, atmosphere- and temperature-related chemical weathering, and impact crater formation. Random distribution and relative pristine morphology of craters seem to indicate a global resurfacing event or events, but does not require that the whole Venusian crust was generated in a short time period (e.g. Bond and Warner 2006; Ghail 2006).

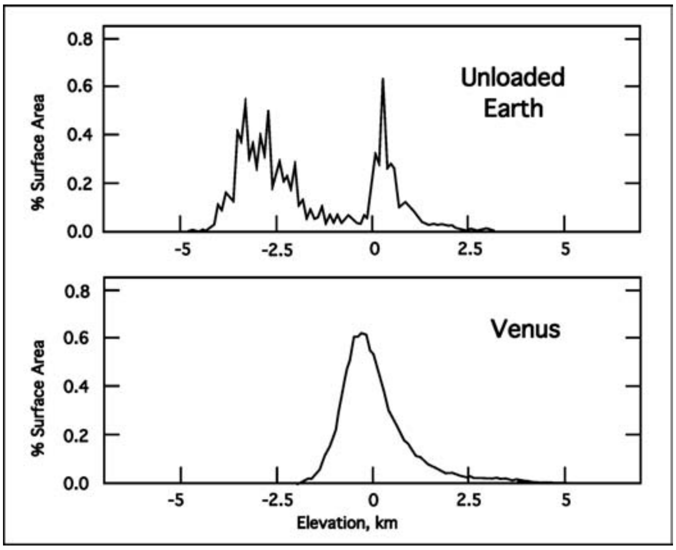

Figure 2. The hypsometric diagrams of the crusts of Earth and Venus. The two peaks for our continental and oceanic surface show up clearly, while Venus exhibits just a single peak.

The properties of the Venusian crust are mainly unknown. Some estimates have been drawn from theoretical limits, geodynamic models, isostatic rebound of impact craters and spacing of the tectonic structures. Main problem is to isolate the part of the gravity signal due to crustal thickness variations from other contributions to compensation. The values for the crust range from 5 up to 50 km (c.f. Zuber 1987; Grimm and Solomon 1988; Banerdt and Golombek 1988; Grimm and Hess 1997), with a mean value of 30 km (20-50 km) derived from Magellan gravity data (Grimm 1994).

2.3. Internal structure and Venusian heat flow

As we do not have any seismic data from Venus, the internal structure or even the proportions of lithosphere, mantle and core are not exactly known. This affects the understanding of Venusian heat flow; its mechanism and amount of the flow. We also do not know why Venus does not have a magnetic field. Temperature on the surface exceeds the level where most common minerals would be magnetized. Therefore, we do not have even remnants of the field that possibly/probably once existed.

On Earth, the mean heat flow is 87±2 mW/m^{-2}. The value changes drastically on depending where we measure it. Continental mean is 65±1.6 mW/m^{-2} whereas seafloor values are around 101±2.2 mW/m^{-2}. Middle ocean ridge (MOR) exhibits even higher values, ~400 mW/m^{-2}. For Venus, we do not have any direct measurements, but we may propose different models in order to set constraints for the Venusian heat flow.

Global scaling of the heat flow: As Venus is very similar in general respects to Earth, we may derive one end member for the heat flow using the values measured from our planet. Solomon and Head (1982) proposed a direct scaling from the Earth value, which sets the Venusian mean heat flow at 78 mW/m^{-2}. This has been calculated using the simple formula based on the mass ratio of the two planets:

$$q_{Venus} = 0.815\ q_{Earth}$$

This value is of course not very elaborate, and implies that Venus has just one type crust. Leitner and Firneis (2005) proposed the use of two types of crusts (similar to Earth oceanic and continental crusts). The Venusian low- and uplands are considered as oceanic crust (~92%) and highlands continental crust (~8%). Using this and the measured values from Earth, the flow value is ~80 mW/m^{-2}. However, this model would imply active plate tectonics on Venus, so it is not really realistic (Leitner and Firneis 2005), as we do not observe any evidence supporting it on the surface.

Catastrophic or episodic resurfacing: This model explains the transport of the heat from the interior by proposing a series of global resurfacing events (Turcotte 1992, 1993). The model is based on the assumption of continuous heat production within the planets interior which heats the mantle and results in unstable lithosphere, and at some point, a new global resurfacing event. The estimated mean heat flow for this model is 12±3.0 mW/m^2, which is too low for a planet with a surface filled with features of mainly volcanic origin.

Parameterized convection models: As we do not have any seismic information and therefore no hard data on the internal structure of Venus, these models are based on the "as best as possible" exploration of the thermal history. A good example is the work of Solomatov and Moresi (1996) where they propose a switch between plate tectonics and no plate tectonics occurring around the ~500 Myr. In the non-stagnant lid phase the heat flow is ~50 mW/m^2, while with the stagnant lid the heat flow is around ~15 mW/m^2. There is one drawback to this model: it can't explain the formation of the widely spread coronae/corona-like structures, although it has been proposed that in a typical parameterized solution where the heat flow is around 35-50 mW/m^2 (Phillips et al. 1997), the coronae could account for 15-28% of the heat loss (Stofan et al. 2001).

Estimating the capabilities of the heat transport: More plausible values for Venusian heat flow are derived using this method. A mean value of 39.5±1.5 mW/m^{-2} (Leitner and Firneis 2005) may be considered as a minimum value, as this model does not take into account the volcanoes and their impact on the values. This model may be revised and calibrated by using the catalogues of surface impressions of the volcano-tectonic activity (such as the one presented by Kostama and Aittola 2001; Paper I; Appendix I).

The considerations for the heat flow of Venus and therefore also the evolution of the activity of Venus is beyond the scope of this work. However, this work does add new insight and detail to the ongoing work of understanding Venusian internal activity and heat flow by analysing the volcano-tectonics in a regional and global sense (Papers I, II, IV and V).

3. Methods

3.1. Photogeological approach

The work is mainly based on interpretation of radar images from the Magellan spacecraft SAR-instrument. In the process, several things are important: the direction of the view in each radar image (left or right), incidence angle, surface roughness (Fig. 3), emissivity and slope and scale of the analysed structures and their details. All these must be considered during the photogeological analysis process. Detailed coverage of these items in question can be found in Ford and others (1993).

3.2. Magellan data: SAR-images and GTDR

The highest resolution "image" data of Venus, Magellan synthetic aperture radar images were produced from raw data first as ribbon-like BIDR (basic image data record) and F-BIDR (Full resolution BIDR) which are not usable for mapping. Venus mapping utilizes the MIDR (Mosaicked IDR) images of various resolution and coverage (Table 1, Fig. 4).

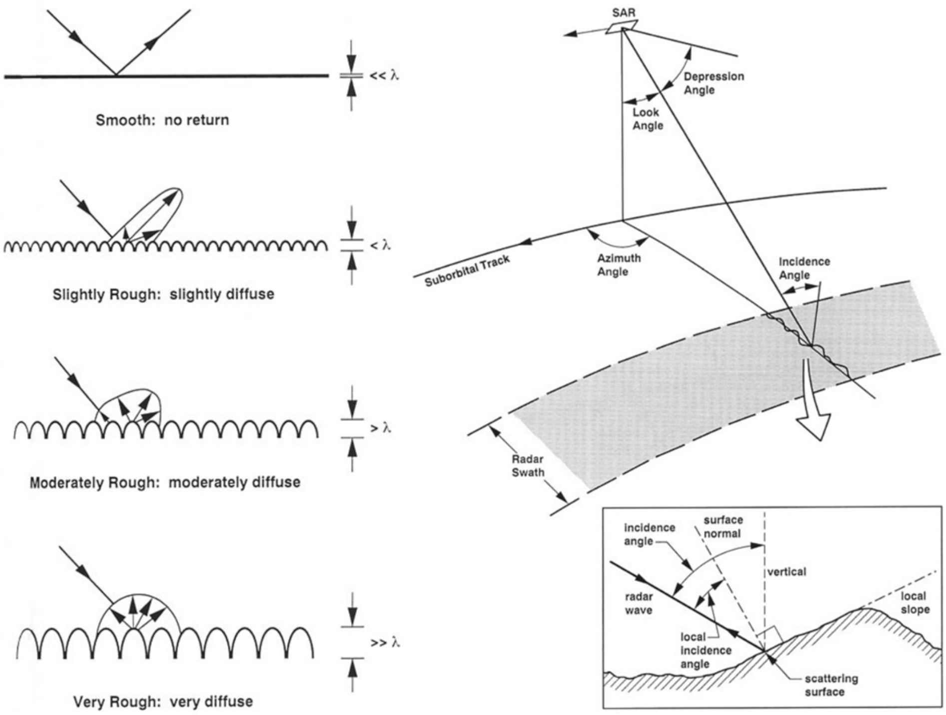

Figure 3. The effect of surface roughness, incidence angle and surface topography in SAR observations.

Dataset		Resolution	Coverage
F-MIDR	Full resolution Mosaicked Image Data Record	75 m/pix	5° x 5° region
C1-MIDR	Compressed Mosaicked Image Data Record	225 m/pix	15° x 15° region
C2-MIDR	Compressed Mosaicked Image Data Record	675 m/pix	45° x 45° region
C3-MIDR	Compressed Mosaicked Image Data Record	2025 m/pix	120° x 80° region

Table 1: From the available MIDR data, F-MAPs (75 m/pix) were also produced covering large regions with highest possible resolution.

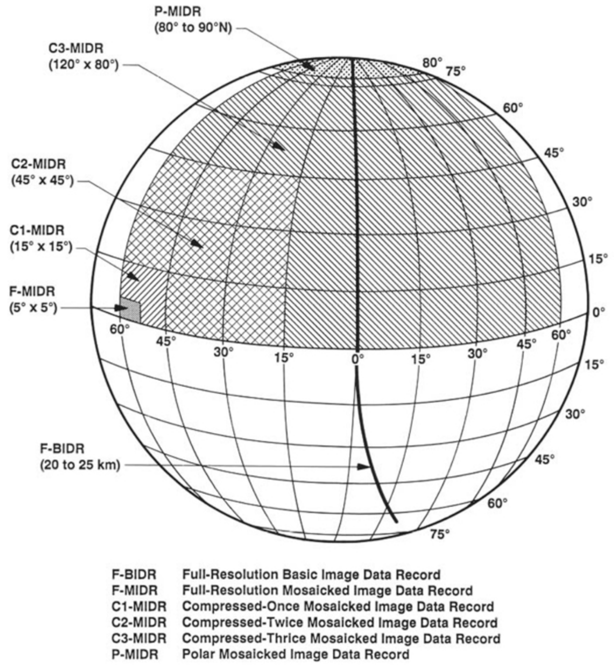

Figure 4. The different data-products of the Magellan SAR and their coverage on the Venus surface.

Although the SAR image dataset is by itself most important in structural analysis of the Venusian features, other measurements are also very important. Magellan also continuously measured the distance of the spacecraft and the surface below (region of 10-30 km in diameter). For every orbit, there were ~1000 footprints, producing eventually a topographic map with surface resolution of about 4-5 km/pixel. This data is available in two forms: 1) ARCDR altimetry with radiometric data and in 2) GxDR, Global Data Record –form. The data used for analysis of the volcano-tectonic structures is the Mercator projected GTDR, Global Topographic Data Record. Other important data bases are 1) global surface reflectivity, GREDR, 2) information on global slopes GSDR, and 3) global emissivity, GEDR.

3.3. 3D-modelling and style of mapping

In conjunction with FMAP and NIH Image/Photoshop image processing I have been using the Bryce 3D -program and ENVI 3.2 to create 3D-perspective views of the analysed structures by combining Magellan topographic data first with SAR-images, but also with created geological maps of the studied features and groups. Perspective views enable us to see more clearly the changes in topography in respect of geological units or structural formations (such as the arachnoid depressional fracturing, Fig. 5a, b).

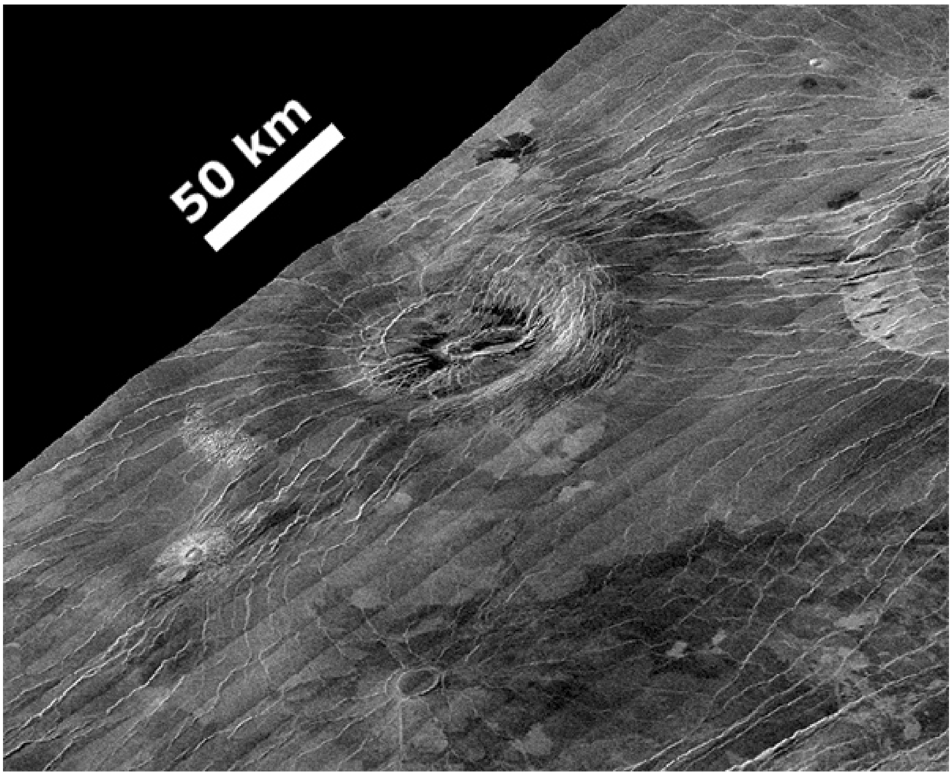

Figure 5a. 3D-perspective view of an arachnoid located in the Ganiki Planitiae group at .

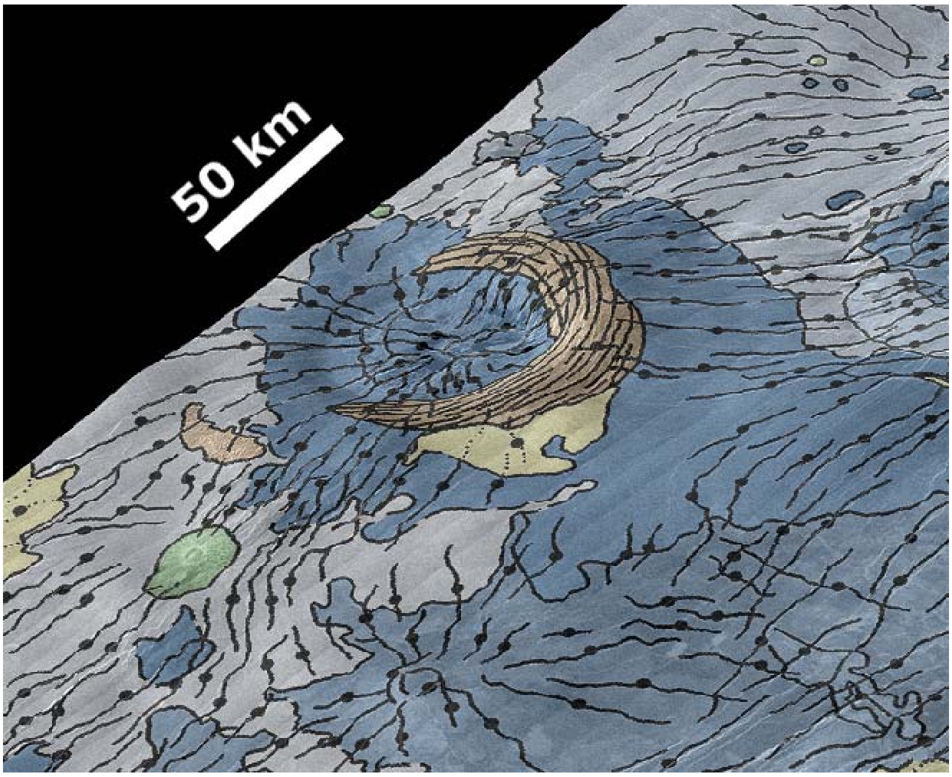

Figure 5b. Sketch map of the arachnoid and its surroundings.

For detailed analysis of features and groups of them, geological mapping was done using geological units drawn from the existent mapping of Venus, mostly from the works of Basilevsky and Head (1995a,b) and Basilevsky and others (1997). However, due to the controversy in regard to the wrinkle ridged plains unit (Pwr), this unit is replaced by use of one or more plains material units identified by numerals. Also the suites of tectonics are identified according to the form of deformation. It is also important to note that mapping of the singular structures does not address the question are these units global or not. Presented stratigraphy is for regional use only.

3.4. Identifying geological units

The surface of Venus is somewhat a puzzle. If we look at the craters marking the surface, we notice that the spatial distribution of impact craters is statistically random, or to be correct; it cannot be distinguished from a random population (Phillips et al. 1992; Schaber et al. 1992; Strom et al. 1994). In addition, the majority of craters seem to be largely unaffected by volcanic or tectonic activity (Strom et al. 1994). This has led to conclusions that Venus went possibly through large scale resurfacing event or events around 500-700 Myr ago (e.g. Schaber et al. 1992; Turcotte 1993). More recently it has been proposed that the impact crater population may not be regarded as completely spatially random (c.f. Bond and Warner 2006), and the resurfacing has been going on for much longer time (Ghail 2006). There are therefore two prevailing geological history models for Venus at the present time: 1) directional history and 2) the non-directional history model.

The directional history model assumes that Venus has had a history with a series of epochs, each represented by a different volcanic or tectonic process on a global scale (Basilevsky and Head 1995a,b; Basilevsky et al. 1997). In the global stratigraphy this means that similar geological units were formed simultaneously. In this model, the youngest units that postdate the emplacement of regional plains consist of impact craters (of almost all of them), of eolian material locating over the plains, and of dark parabola materials. Fig. 6 shows the general geological units used by Basilevsky and Head.

The non-directional history model (Guest and Stofan 1999; Stofan et al. 2005) explains that Venus has had a complex history in which most geologic processes have operated in a non-directional fashion to a greater or lesser extent throughout the planet's history. The plains have been built up by lavas erupted in a number of different styles, each occurring throughout the history represented by the exposed stratigraphy of the planet. Non-directional history is supported by the fact that the coronae have formed throughout the Venusian history; some rifting occurred before and after the emplacement of the regional plains; in places, wrinkle ridges are formed due to regional stresses and both pre- and postdate the emplacement of the plains (McGill 2004); and – even if we do not know the absolute ages of the main bodies of the volcanic edifices – the latest lava flows from volcanoes or similar structures are younger than the regional plains. Non-directional geology has operated on Venus at least locally and some regions are characterized by repeated episodes of volcanism and tectonics.

color scheme	unit description	unit groups
	cu - Impact crater materials, undivided	Impact craters, mostly pristine
	rt - Rift zone materials	Young volcanic plains; heavily deformed young rift zones
	pl - Lobate plains material	
	ps - Smooth plains material	
	pwr_2 - Plains with wrinkle ridges material (upper member)	Units of moderately deformed regional volcanic plains
	pwr_1 - Plains with wrinkle ridges material (lower member)	
	psh - Shield plains material	
	fb - Fracture belt materials	Old and tectonically deformed plains; heavily deformed belts of fractures
	pfr/rb - Fractured and ridged plains / Ridge belt materials	
	pdf - Densely fractured plains material	
	tt - Tessera terrain material	

Figure 6. The geological units used by Basilevsky and Head (1995a, b).

4. Venus geology and geological setting

4.1. Forms of volcanism and tectonism

On Venus, there is a wide range of both volcanic and tectonic features which are easily recognizable due to the fact that the surface is quite untouched by erosion. This is because of the absence of volatiles on the surface as well as the high pressure atmosphere which inhibits wind erosion. However, impacts on the surface may cause very forceful winds and thus they are very important in respect of material transport on the surface of Venus (e.g. Basilevsky et al. 2004).

When comparing the Venusian - Cytherean - surface to other terrestrial planets or large moons, the population of visible impact craters is surprisingly small. Only around 1000 craters (Phillips et al. 1992; Schaber et al. 1992; Strom et al. 1994; Herrick et al. 1994; McKinnon et al. 1997) can be recognized. Even more interesting is to note that there are very few highly modified craters (e.g. Schaber et al. 1992). Majority of craters is actually quite pristine in morphology and display rather fresh-looking details (Phillips et al. 1991; Strom et al. 1994). Lack of visible craters is understandable on the Earth where the erosion caused by wind and water related processes is the most effective process. Similar low population can be seen on the Jovian moons of Io and Europa, as well as the Saturnian giant, Titan. On Io, the reason for a low crater number is the apparent active volcanism. On Europa and Titan the reason is probably linked to some other form of endogenic activity which is renewing the surface of the moons in question.

The low crater amount is indicative of a young surface based on the ideas of crater retention models (e.g. Baldwin 1971; Bloch et al. 1971; Hartmann 1970, 1972; Neukum et al. 1972). In principle, the population of Venusian impact craters provides also a tool for age determination. The impact crater counting and surface age determination based on the crater density on the unit is currently the only available method to establish the ages and time durations of different geologic events and processes on planets for which we do not have any samples. There are several estimations of the mean age (*T*) of the Venus' surface: 200–500 x 10^6 years (Strom et al. 1994), 400-800 x 10^6 years (Phillips et al. 1992), 400–1600 x 10^6 years (Zahnle and McKinnon 1996) and 300–750 x 10^6 years (Schaber et al. 1992; Mckinnon et al. 1997). Due to the statistical nature of crater density dating, it would need a large sample of impact craters to come up with a reliable age. The very low number of craters on areas covered by coronae or other small features does not allow age estimations, which are statistically dependable and the obvious inaccuracy is too large (Campbell 1999). The impact crater densities can not be used for absolute or relative age determination for a single Venusian structure or small unit. For these we have to determine relative ages using geological relationships of units and structures.

Based on the data available at this time (pre-Venus Express) there is no active volcanism on Venus – no active renewal process of the Venusian surface. Still, the processes that worked the surface could have been active quite recently, as the mean age of Venusian surface could be as little as ~300 million years. The even distribution of the craters tells us another interesting fact: the surface is – in general – from the same period of time. This possible planet-wide resurfacing event and also the formation and evolution of different volcanic structures (e.g. Head et al. 1992; Janes et al. 1992; Squyres et al. 1992; Stofan et al. 1992) are usually related to the activity of the mantle and the subsurface convection-flows (Schaber et al. 1992; Namiki and Solomon, 1994; Price and Suppe, 1994). It seems obvious that the sub-crust activity is the governing regime that affects the surface processes, and the evolution of surface features and structures.

The most prominent features of this highly volcanic planet are the volcanic plains that cover 80% of the surface (Tanaka et al. 1997). The plains as well as the other features and structures of the surface are relatively young (Head et al. 1992), indicating quite recent if not contemporary volcanism. In general, the topographic deviation is small; the plains are located within 1-3 km of the planets mean planetary radius (MPR). Plains may be classified based on their location in relation to the MPR or appearance: planitiae, highland plains, mottled plains (i.e. Basilevsky et al. 1985; Campbell and Campbell, 1992; Guest et al. 1992; Arvidson et al. 1992). Plains may also be classified by using the geomorphic structures located within them or by noting the lack of these features (Saunders et al. 1991).

In general, the Venusian plains are by no means featureless. There are countless of geomorphic structures, ranging from smaller and scarce channels (Baker et al. 1992), domes of different sizes and shapes, volcanic shields and their fields to fractures, fissures and graben. The larger scale Planitiae are also broken by larger scale features such as the ridge and mountain belts, chasmata and larger volcanic centers. The majority of Venusian volcanism and associated edifices and centers are located within the plains regions of Venus higher than the MPR. For example, the BAT-anomaly, the topographically higher region formed by (Beta, Atla and

Themis Regio; Figs. 1, 7 and 8) has very large concentration of volcanic structures. This region actually includes ~40 - 50 % of the planets surface (Squyres et al. 1993).

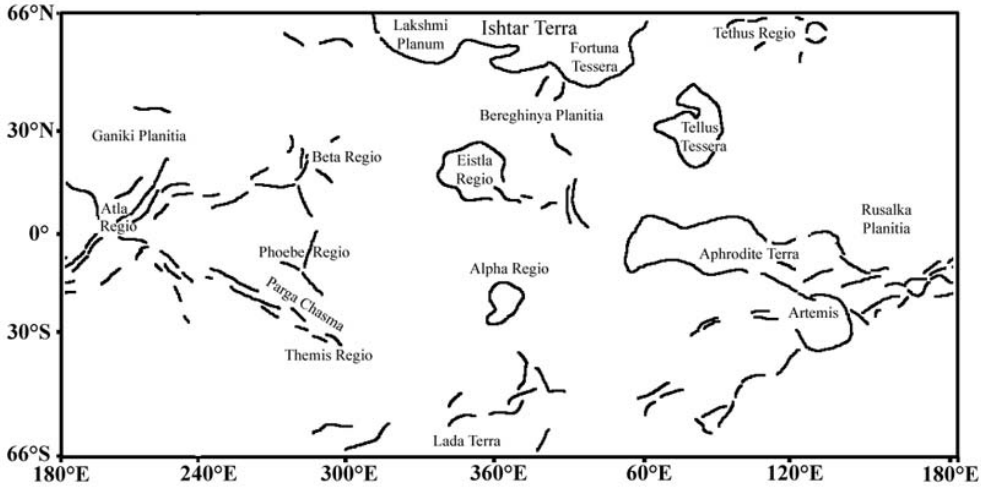

Figure 7. Schematic map of some of the major Venusian deformation zones (shown as lineations), tessera regions, and some distinct geological formations in Mercator projection. Major volcanic centre is the Beta-Atla-Themis, the BAT–region. Also shown are some of the main arachnoid locations, such as the Bereghinya and Ganiki Planitiae, and Phoebe Regio.

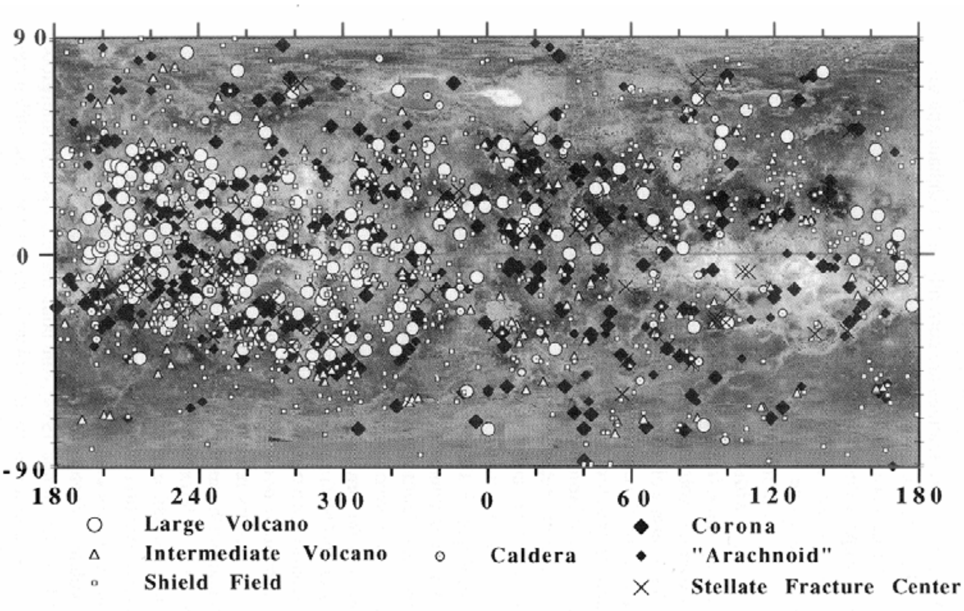

Figure 8. The surfacial distribution of the Venusian volcanic features (Crumpler et al. 1997). In this figure, the distribution for coronae, arachnoids and "SFC" (novae) is from the work of Crumpler and others (1996).

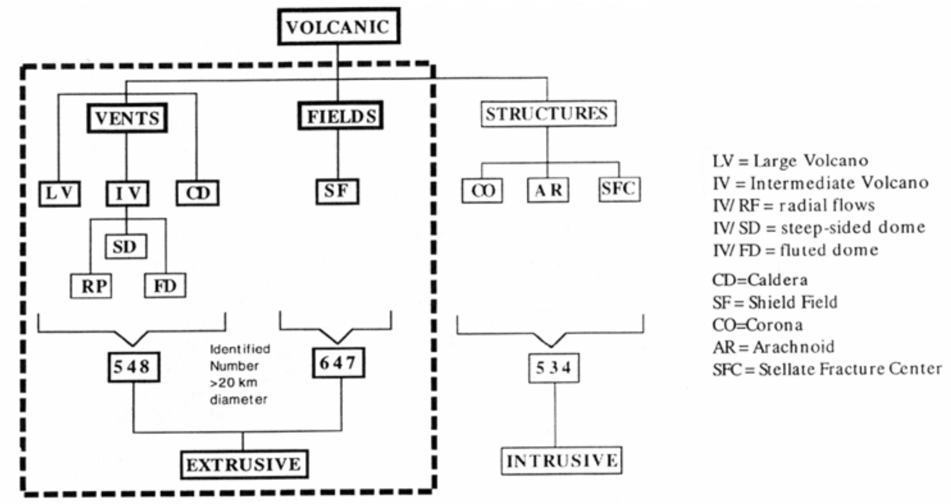

Figure 9. The major types of the Venusian volcanic structures. The vents and shield fields portray the extrusive type volcanism of Venus while the volcanic (-tectonic) structures (coronae, arachnoids, SFC/novae) are more intrusive in their characteristics (Crumpler et al. 1997).

The volcanic features may be distributed into three major categories (Fig. 9). The third group includes the radial-concentric coronae (Barsukov et al. 1986) and also the corona-like, but morphologically different structures (e.g. Crumpler et al. 1997; Kostama et al. 2000; Paper I) such as the arachnoids (Barsukov et al. 1986), novae (Schubert et al. 1991; Janes et al. 1992), and corona-novae joint structures (Paper IV). One can even identify a separate group of so called "multiples" (e.g. Stofan et al. 1992; Törmänen et al. 2005) of adjoined coronae and also adjoined arachnoid structures.

4.2. Volcano-tectonic interplay

Volcano-tectonics includes structures and features which show evidence or implications of both volcanism (e.g. lava flows, volcanic constructs, deposits) and tectonic movements (e.g. faults, graben, fractures, and ridges).

Endogenic surface structures can roughly be set on a changing scale that has on the other end a very simple volcanic construct, for example a single vent and on the other, simple tectonic structure, for example a fault. All the volcano-tectonic features and structures may be located on this scale with variable ranges from the scale ends, and variable degree of overlapping. Some features have more tectonic details than volcanic and vice versa. It is important to note that, this imaginary scale does not address the question "how much"; it simply describes the relation of volcanism and tectonics.

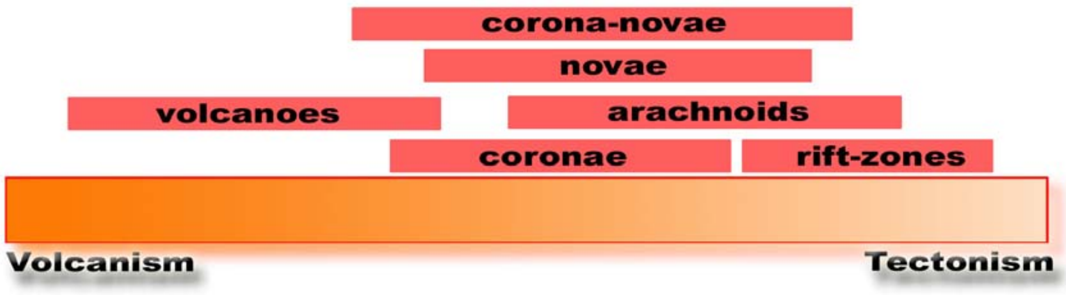

Figure 10. The volcano-tectonic scale. The volcano-tectonic structures may be distributed along this scale depending on the relation of apparent volcanism and tectonism.

The Figure 10 shows a rough view of distribution of volcano-tectonic features based on the observations on the structures. Majority of novae and coronae show high up in tectonics but also in volcanism placing them in the middle of the scale, novae preceding more to the tectonic side. Arachnoids are much less prominent in volcanism, so they locate in the more tectonic side. Corona-novae are a bit more complicated, their tectonic characteristics are increased by the fusion of nova as well as corona tectonic features, but still the extrusive volcanism is also a major process.

Krassilnikov (2006) presented another view of the volcano-tectonic features by placing them into a triangular view, where coronae are located in the middle, and arachnoids, calderas and novae in the tips of the triangle. Depending on the volcanic and tectonic characteristics, the singular features should be located in the different parts of the image, presenting various phases and types of the features. Coronae exhibit more distribution in their characteristics; they have varied topographical shapes and wide variety of tectonic features. Novae, calderas and arachnoids have transitional structures to coronae (Krassilnikov and Head 2003; Krassilnikov 2002; Krassilnikov and Head 2004). Because of that Krassilnikov (2006) suggested coronae to be transitional type of structures between novae, calderas and arachnoids. These structures were considered as end-members of his ternary relationship diagram (Krassilnikov 2006; Fig. 1 in that paper).

4.3. The parameters of Volcano-tectonics

Simplifying, we have three aspects that control and affect to the evolution of a volcano-tectonic feature:

1. **Time** – at which point in the planetary evolution the structure formed
2. **Formation process** – was the process long, or possibly a singular relatively short event; what is the role of volcanism and tectonism
3. **Location** – the geological environment of the structure

According to the contemporary studies, all the volcano-tectonics are roughly of same geologic age scale or at least set to the last 700 million years of Venus evolution. Age determination is also problematic on Venus. The formation processes of all the Venusian volcano-tectonic structures are not simple, detailed studies of singular structures (e.g. Aittola 2001; Basilevsky and Raitala 2002; Paper II and IV) show that they had complex and long lasting formation processes and – what is more important – a uniform evolution is very seldom seen. The structures do not necessarily evolve until some identical point; they may reach equilibrium in different phases.

My studies focus on the third presented aspect. In the accompanying works (Papers I-V) we have shown that geological environment has a definitive effect on the characteristics of the structure. Because of this, its morphology, topography, and also its evolution are defined by the local geology or in more simple terms – by the type of areal geology of the structures location.

5. Introduction to coronae and corona-like structures

Prior to any classification, typing or distribution analyses, it is imperative to set rules for the analysed structures. Controversial classifications, catalogues and more detailed analyses have resulted in an obscure view of the Venusian volcano-tectonics. To counter this, in our work, we recognize the structures based on their morphology identified from Magellan SAR-images. Every structure has been subject to discussion and either agreement or rejection by both researchers resulting in a list – catalogue – that we can confidently use in global analysis (Kostama and Aittola 2001, Paper I). We do recognize the fact, that some of the features are not included, but this catalogue presents a generalized but reliable view of the volcano-tectonic features.

5.1. Classification of morphological structures

Since Venera 15 and 16, and in more detail after Magellan, it has been recognized that Venus displays an intriguing collection of different volcano-tectonic features on its surface. The features share some similarities, but they all have unique characteristics that set them apart. Such characteristics as radial lineaments, annulus, central region, presence of volcanism, diameter, location, geologic contexts, topography, and complexity have been used when studying the structures. These characteristics or differences may be used in typing or recognizing separate structures, which has been done by numerous researchers (e.g. Head et al. 1992; Crumpler et al. 1996, 1997, 2000; Stofan et al. 1992; Kostama and Aittola 2001; Paper I, IV and V). There are also differences in regional as well as topographical settings. The detailed study of these two factors and comparison of structures and their types gives more detailed information on formation processes and evolution of these features (Aittola and Raitala 1999; Kostama and Aittola 2000; Paper I).

The feature groups presented are types of volcano-tectonic structures that should be recognized as separate groups. Not as only the already well acknowledged coronae but also as novae (*astra*), arachnoids and, corona-novae. The features of this last group are products of novae forming inside existing coronae. This group is somewhat controversial, but its acknowledgement is based on geomorphic evidence. We cannot be certain what the details of the controlling factors are, but we know that the association of structures is somehow very particularly controlled: the novae are always inside corona-ring and never outside; what is also important in respect of acknowledgement: similar association of nova structures and arachnoids does not exist.

5.1.1. Coronae

The coronae (Latin: *crown*) are a group of morphologic features. They have characteristically very complex volcanic, tectonic and topographic variations. These variations result in large deviations in corona classifications. In cases, coronae and features identified as arachnoids are somewhat mixed resulting in non-coincidental catalogues of the features (Stofan et al. 1992; Crumpler et al. 1996; Stofan et al. 2001). However, these two volcano-tectonic structures may and should be separated by several differences such as their size, relative age, and apparent morphology and distribution (Papers I, II and V). There has to be differences also in the formation processes, although this could apply for features within the same feature group also.

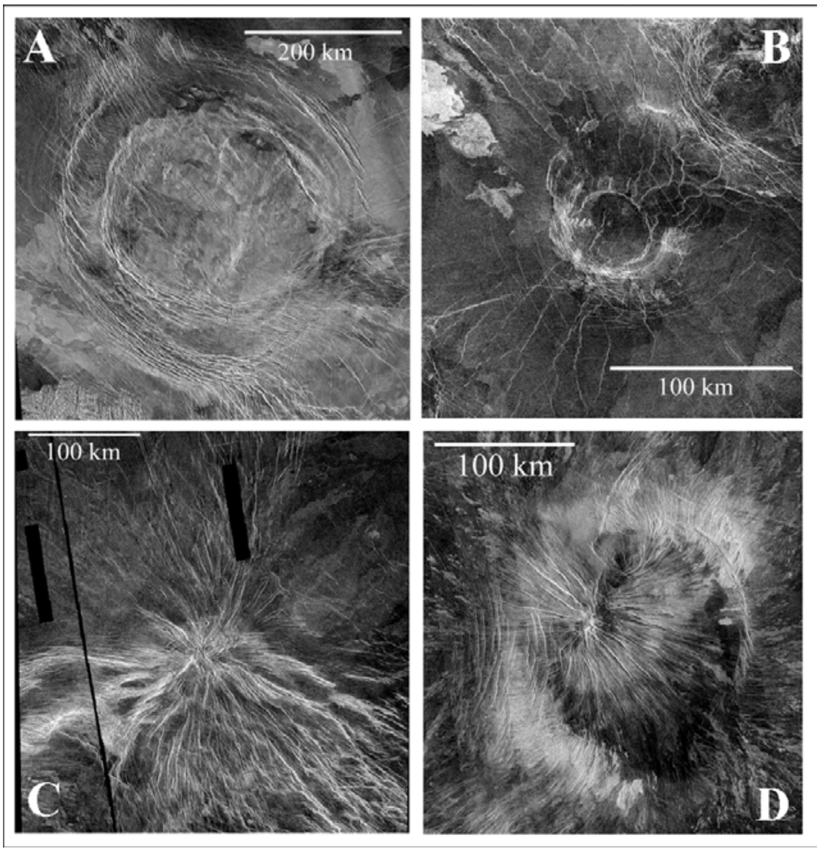

Figure 11. Examples of Venusian volcano-tectonic structure types. (A) Corona, (B) Arachnoid, (C) Nova, (D) Corona-nova (Paper IV, also mapped in detail by Koenig and Pollard, 1998).

Coronae are larger scale elongated features (average diameter >200km; Kostama and Aittola 2001). Characteristically the coronae are complex tectonic and volcanic features with variable topographic layouts (e.g. Stofan et al. 1992, 1997). The coronae are the governing surface feature group (Squyres et al. 1992) and they were already identified from radar images of Arecibo (Campbell et al. 1979; Campbell and Burns 1980), but their status as part of the volcano-tectonics of Venus was not affirmed until the Soviet Venera 15 and 16 (Barsukov et al. 1984, 1986). Coronae also form multiple coronae structures (coronae with at least 2 linked structures with a common annulus (Stofan et al. 1992; Stofan et al. 1997; Törmänen et al. 2005). This study of linked structures was initiated by the study of double-type coronae (Kauhanen and Törmänen 1994; Törmänen and Kauhanen 1995).

During the years of evolving Venus study, several origins have been proposed for the coronae. Barsukov et al. (1984, 1986) addressed the coronae as magmatic domes or rises that had been modified by the tectonics induced by larger scale impact processes. Basilevsky et al. (1986) first proposed the possibility of endogenic origin for these features and concluded that coronae were in fact representations of internal activity and later tectonism. Hot spot origin – similar to Earth – was also one of the presented scenarios even before Magellan (Schubert et al. 1989). Other, more exotic origins also existed (i.e. dike centers and lava plains that had not been as efficiently eroded as their surroundings (Masursky et al. 1987). Stofan and Head (1990) took the task to compare the different hypotheses and also presented another possibility: formation by a denser, descending diaper. Recent works propose that the coronae diapirism of Venus differs from the Earth plumes. Venusian plumes are proposed to be thermals, tailless diapirs of molten and solid hot material with less density than the surrounding mantle. This would also explain the fact that coronae do not evolve into shield volcano -like structures – no tail, no renewal of material. Lack of large amounts of magma would promote the survival of tectonic features which in case of a more plume-like "eruption" would be covered by lava-flows.

The number of coronae is highly debatable (as are the numbers for other features as well). The interpretational differences of separate workers and groups have led to the variable numbers of features. Some studies present every radial-concentric feature identified as being a corona (e.g. Stofan et al. 1992, 1997, 2001). The researchers following this trail have also presented features that are topographically identifiable to this growing population of coronae (Tapper 1997; Stofan et al. 2001; Smrekar and Stofan 2001). As another endpoint, some workers do recognize other groups or classes of volcano-tectonic, corona-like structures (e.g. Crumpler et al. 1996; Crumpler and Aubele 2000; Kostama and Aittola 2001a, b; Papers I and IV).

5.1.2. Arachnoids

Like coronae, the arachnoid (Greek: *Arachne* and *–oid*, spider-likes) central structures are also generally circular in shape. They are surrounded by a radial system of ridges (Head et al. 1992), fractures or a combination of both (Kostama 2001; Paper V). Our definition for the arachnoids is based on the morphological description proposed first by Barsukov et al. (1986) of a central circular structure adjoined with associated radial features. We recognize the fact that the list does not probably include all possible arachnoid-type features; our definition is guided by the fact that we approach all other volcano-tectonic features with the same criteria, using the SAR-based identification.

The following is the guideline to our arachnoid identification scheme:

a) Arachnoids are quasi-circular volcano-tectonic structures with a structural annulus and/or topographic rim, sometimes associated volcanism, with a system of radial ridges and/or fractures that originate at or are connected to the annulus or rim of the structure.

b) The features where fractures or ridges are not influenced by the annulus or rim are not arachnoids but coronae.

c) Also structures with a central dense radial swarm of fractures were not considered arachnoids (coronae w/ a nova-like fracture swarm).

The arachnoids have been thought to be a sub-type of coronae (Price and Suppe 1995) or a stage of corona development (Hamilton and Stofan 1996), and if considering only their rounded or elongated shape, this could well be the case in some arachnoid cases. The network of radial lineaments around the central depression, however, gives these features an identifiable morphology. This structural complexity gives arachnoids the appearance of their namesake (Barsukov et al. 1986). The lineaments of arachnoids do extend a significant distance, up to several radii of the arachnoid annulus, displaying commonly a single dominant orientation (Hamilton and Stofan 1996) caused possibly by regional tensional fields (Head et al. 1992; Grosfils and Head 1994a). Besides their distinguishable appearance, the arachnoids have a tendency to exist as close groups (example in Figure 12a and 12 b), where single features are adjoined structurally (Paper V). In this presented case, there are at least four, possibly five or even more arachnoid-structures (Ar 1-5) with adjoined linear features (Chapman 1999;Chapman and Kirk 1996; Kostama 2002; Paper V).

Despite the similarity of the central structures, the arachnoids do show differences to the coronae. They are generally much smaller in size than coronae, their mean diameter is 129 km while the coronae have a mean diameter of 207 km, placing the relation of the central structures to 1:1.58 (Paper I). There also seems to be differences in their formation process. The observations show that the concentric structures of arachnoids are formed probably due to depression rather than by uplift and formation of a plateau-like expression as in the proposed corona-case of Squyres and others (1992). The arachnoid lineaments are also in many cases different to the proposed radial fractures formed in the coronae formation, although with arachnoids there are probably several deviating processes that form the lineaments (Paper V). The arachnoids are also relatively young features compared to the surrounding environment; the volcanism of the surrounding plains is usually older than arachnoids and they generally post-date surrounding structures. One other important difference between coronae and arachnoids is also the fact that novae, which in many cases exist within coronae, are not associated similarly with arachnoids.

One additional difference is the fact that coronae are usually associated with large amounts of extrusive volcanic activity while this is not common to the arachnoids. The arachnoids have also relatively few volcanic features within them when compared to coronae (Head et al. 1992) or novae (Paper V). The extrusive volcanism appears to be a minor characteristic in general with arachnoids. This may reflect the fact that the magmatic process in arachnoid formation can be primarily intrusive rather than extrusive in some cases.

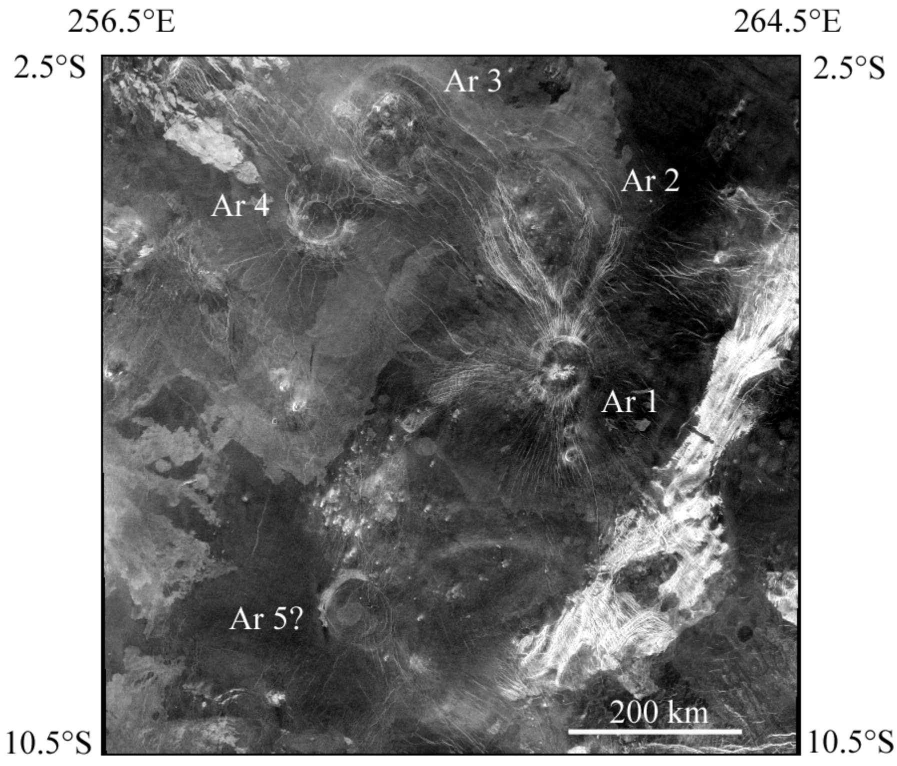

Figure 12a. The arachnoid chain in Phoebe Regio. this is an excellent example of joined arachnoid features. The geological map of this group is shown in Figure 12b. This group has been mapped and acknowledged also by Chapman (1999).

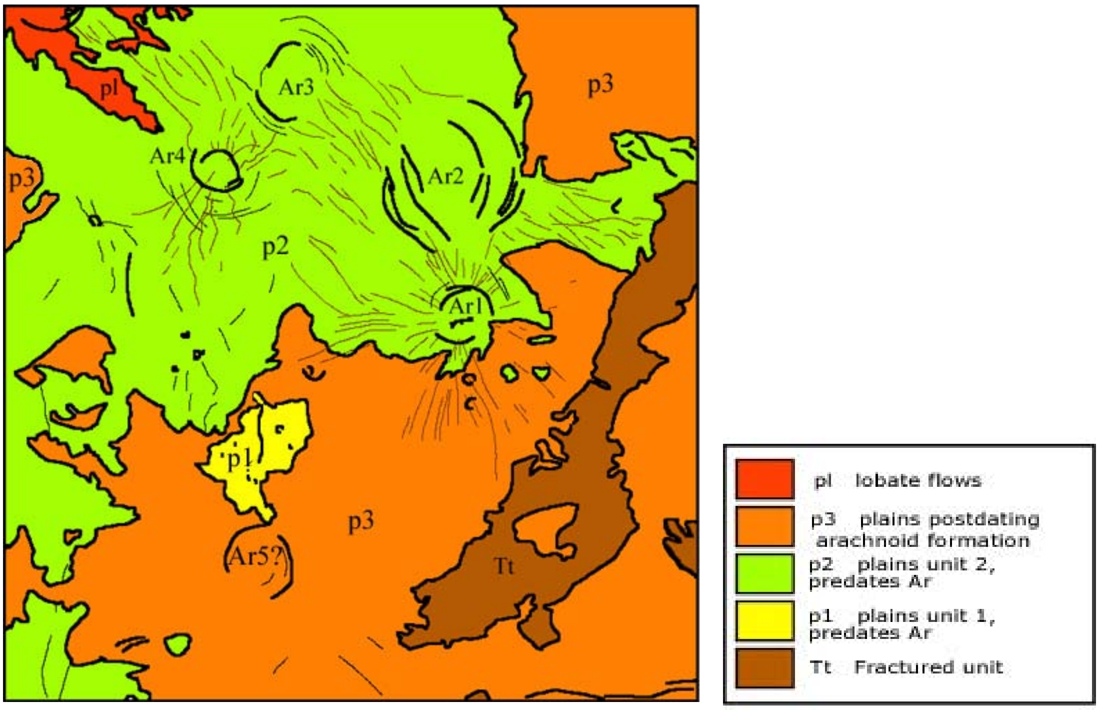

Figure 12b. A geological sketch map of arachnoid group within Hinemoa Planitia. The features of this chain form a continuous group – Ar 1 to Ar 4. It is possible that Ar 5 is also part of this chain (Paper V). Chapman (1999) also noted the age relationship of the separate arachnoids.

However, we cannot without doubt rule out the possibility that at least some of the arachnoids may also be an early phase of corona formation as proposed by Hamilton and Stofan (1996). Still, the two feature groups are different in many aspects, and the arachnoids also have a quite different global distribution than coronae as well as difference in altimetric properties (Paper I, see also Chapter 7; for global distribution, also Crumpler et al. 1997). The arachnoids can also be grouped in types by using their distribution in different geological environments (Kostama 2001; Paper V).

5.1.3. Novae and corona-novae

Novae are a special group of “star-like” structures with a stellate fracture or fissure pattern (Schubert et al. 1991; Janes et al. 1992) radiating around a central summit or an elongated fracture. Their morphology sets them apart from the elongated and circular coronae or arachnoid structures and they are easily recognizable to high certainty. Other names have been associated also with these structures: "radial corona-like feature"; Stofan et al. 1992), "radially fractured dome", "failed corona"; Janes and Turtle 1996) and "stellate fracture center" or simply "SFC" by Crumpler et al. 1996. In 2001, the use of the term "nova" was contradicted. It was not accepted by the Planetary Nomenclature Group of the IAU because it is already in use in astrophysics. As a substitute, it was suggested to use for these features the generic name "astra" ("astrum" for single) (Aksnes et al. 2001). However, the term "corona" is as well in use in astrophysics and the term "astra" also has a clear astronomical meaning ("*star*" in Latin).

Most of the studied novae are distinct elevations and they usually are associated with lava flows. These two observations allow us to assume, that novae are formed by volcanic uplifting, which is the most popular explanation for the formation of novae (Janes et al. 1992) and of radially fractured domes (Squyres et al. 1992), probably related to novae. Many novae are also identified as radiating dike swarms, which gives implications for the origin and formation process of the features (c.f. Grosfils and Head 1994b; Grindrod et al. 2005).

Novae can be classified by using the variations in morphological details or their geological environment (Aittola and Raitala 1999). The detailed studies have shown that the novae are not necessarily a part of corona formation process and they do not present coronae in certain phase of evolution in general (Aittola 2001; Paper IV). This means, that these structures are in some cases indifferent to the coronae evolution. The separation of arachnoids and novae is even clearer. They are never structurally associated and differ in distribution, geological characteristics (topography and volcanism) and are usually located in different geological environments (Paper I).

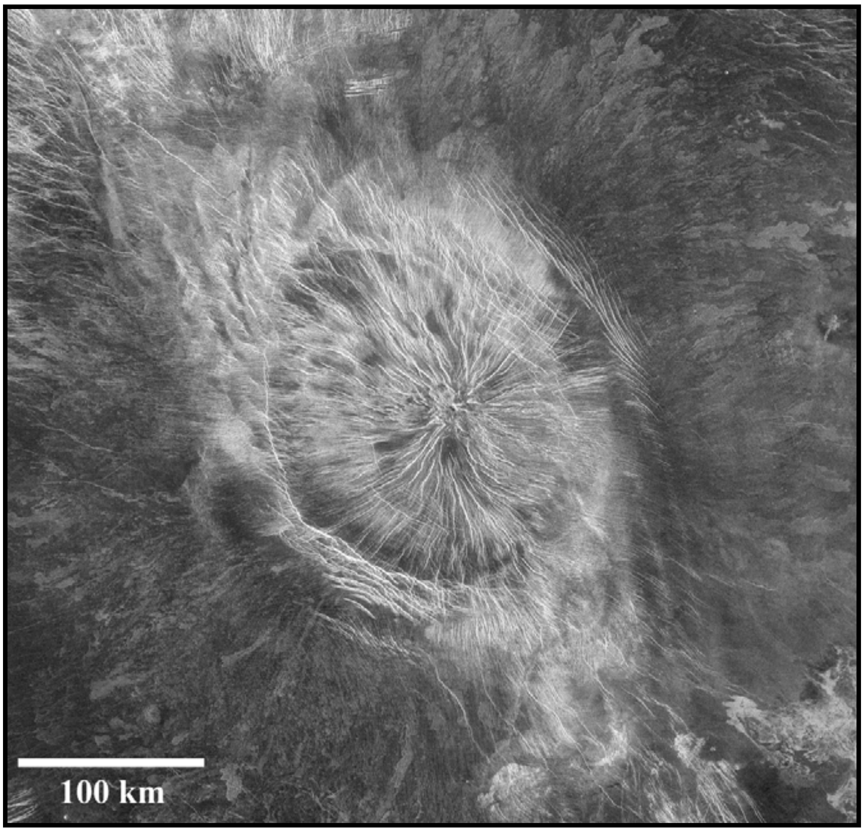

Figure 13. Type I corona-nova, *Dhorani Corona* located in 8°S 243°E. This feature was mapped by Grosfils and Head (1994) as an example of a radial fracture structure that cannot be clearly shown to be associated with dike emplacement. The radial fractures could be a product of uplift and dike injection (Grosfils and Head 1994b).

Two groups of the before-mentioned Venusian volcano-tectonic features display interesting association due to the fact that half of the novae are located within the interior part of the coronae (Aittola and Raitala 1999; Aittola 2001). In addition, they both are proposed to represent surface expressions of diapirs or mantle upwelling (Head et al. 1992; Janes et al. 1992; Stofan et al., 1992; Squyres et al. 1992; Stofan et al. 1991; Pronin and Stofan 1990; Stofan and Head 1990; Basilevsky et al. 1986). Furthermore, the novae have been interpreted to represent the initial stage of the corona evolution (Janes et al. 1992; Stofan et al. 1992; Squyres et al. 1992) and therefore are hypothesized to predate the corona rim structure (Krassilnikov 2001; Hansen et al. 1997). However, this presumption is in contrast to the studies, which show that the majority of the novae, which are located in the inner part of the coronae, seem to postdate the corona formation (Aittola 2001; Paper IV). It is displayed that a nova can form within different stages of corona development, which also reflects the nova characteristics, the overall topography, as well as the mutual age relationship of co-existing coronae and novae (Paper IV). These corona structures with nova inside them have been called as "*corona-novae*" (Fig. 1d; Paper). Novae, which in many cases exist within coronae, are never associated similarly with arachnoids. One explanation could relate to the possibility that novae, which are radial structures without the central structure are formed and underlain by dikes (e.g. Grosfils and Head 1994b) and lack central arcuate structures, whereas some of the arachnoids could be seen as composition of radial dikes with a central arcuate structure. In this case, the collapse of the dike-feeding mechanism that is forming the novae, causing down dropping or sagging, and forming arcuate structures, would shift the feature from a nova to an arachnoid. The survey of the arachnoid lineaments (Paper V) does certainly implicate this possibility.

The corona-novae can be classified into 3 main types based on the proposed formation sequence (Paper IV; See also Chapter 5.3.). The most interesting type of corona-novae is the type 3, where the age and shape of the corona and nova relationship is extremely clear. The areal distribution of this type is controlled by the youngest regions of Venus. Considering this and the youth of the structures of this type, we propose them to be the latest form or at least the last phase of activity in the regions.

5.2. Morphology and topography

The presented volcano-tectonic feature types differ in their characteristics. The apparent morphology (from SAR) is used in order to identify the volcano-tectonic group, but the topographic properties and altimetric characteristics are also different. The amount of associated volcanism and tectonism, as well as the appearance of them are other characteristics that promote difference and separation of the types. Between some of the sub-groups, the differences are somewhat clear (e.g. coronae/arachnoids vs. novae). However, in some cases the singular features may not be identified without doubt directly from their appearance and more careful analysis is in order. The corona-novae (Aittola and Kostama 2001; Paper IV) are a good example of this by being in principle a fusion of two separate feature types. Even within the other groups the identification is not casual, there are several of features that lie somewhere in between of the main types.

In general, the novae stand morphologically out from the other volcano-tectonic structures because of the missing tectonic annulus (still, some researchers do identify some features with annulus as novae, i.e. Krassilnikov 2002a). The topography of the novae is usually positive (dome-like) and they are located in higher locations than other types. Corona-novae structures apply some difficulties to the nova and corona identification, the fact that arachnoids and novae do not form similar joint-structures, facilitates their identification. However, in certain particular geologic environment, the arachnoids adopt more nova-like characteristics, for example raised topography and more associated volcanism (Paper V).

The relationship of arachnoids and coronae is more complicated. The previous works and studies have fused these two together, even promoting the view of non-existence at times (e.g. Price and Suppe 1995, Hamilton and Stofan 1996). In analysis of the two separate groups of structures, the differences and therefore the non-merging of the groups are solidly argued and defended (e.g. Paper I and V; Krassilnikov 2002b). Stofan and others (1992) did identify some lineaments with coronae but these are located within the central structure, annulus, or are not very prominent outside the annulus. One must remember however, that in the study in question, the workers did not identify arachnoids or corona-novae, and the specimens of these types of features are included in the addressed list of structures. We also do see coronae with "lineaments" in our studies, but these are usually connected to novae formation, which may indicate earlier or later activity (Paper IV). Recent studies have shown that in fact, radial elements are very common with Venusian volcanic features (c.f. Ernst et al. 2003).

Arachnoids and coronae do differ in appearance also within the annulus. Coronae annuli are more complex and prominent, and the coronae host more detail–rich internal regions. The arachnoid central region is usually quite featureless (Paper V). Another separating factor is the apparent volcanism that results in more volcanic features with coronae (lava shields, prominent lava flows etc.).

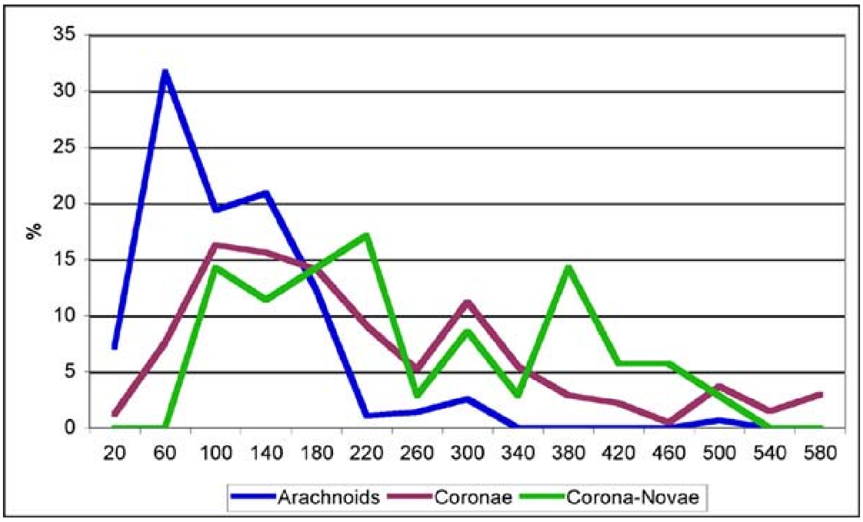

Figure 14. The diameters (in kilometres) of arachnoids (n=139), coronae (n=594) and corona-novae (n=35). The vertical axis presents the percentages of structures. The emphasis of arachnoids to the lower sizes is notable; more than half of the structures have diameters 20-100 km.

Besides the morphological differences, the arachnoids and coronae differ in general size (Fig 14). The mean diameter of arachnoids is ~130 km, which is considerably less than the mean diameter of coronae (Papers I and V). From our calculations, the mean coronae diameter is 207 km (Paper I), which is in agreement with Stofan et al. (1997) and their mean value of ~200 km. The calculations do not include the two largest coronae structures. The locations are also different in many respects: the coronae do favor the chasmata regions, where the arachnoids are totally missing. Finally, the last deviation between the two groups is the apparent topography: Coronae topography may be very complex, while the arachnoids do resemble more calderas by being usually more simple depressions (Paper V).

Corona-novae are identified from the other groups, as they are joint-structures of coronae and novae. We have proposed formation mechanism of re-activation of the volcanic location for these features (Paper IV). The reactivation has created a nova structure inside the previously existing corona during one of the coronae evolution phase (Paper IV). However, the members of this group are indeed very complex structures (variations in nova location, topography and apparent volcanism). The features seem to be – at least locally – young (the last phases of the corona-novae post-date generally the other local geology). Characteristically the latest deformation features are the arcuate graben that have modified the lava-flows of the corona-nova flanks (Kostama and Aittola 2003; Paper III).

5.3. Formation processes

As discussed before, the formation of the volcano-tectonic structures have all been basically linked to the processes of material rising, storing or descending beneath the Venusian crust or lithosphere. These processes deform the surface by effusive and intrusive volcanism, and associated tectonism.

5.3.1. Coronae

Magmatic diapirism was proposed as the origin for the coronae (e.g. Basilevsky et al. 1986). The "ideal" formation process may be represented in a simple chain of events. 1) The diapir encounters the surface, 2) pushes it upwards creating a topographic rise, and 3) finally collapses, creating a corona (Barsukov et al. 1986). Many other formation models were proposed for the coronae, but the diapiric origin is generally the accepted and most probable process. These ascending and descending diapirs form the circular structure of coronae (Stofan et al. 1987, 1988, 1991; Stofan and Head 1990). Squyres and others (1992) proposed a more detailed, but still a very simple three phase model for the formation process. This model (Fig. 15) is generally used as the basis for understanding how the coronae form.

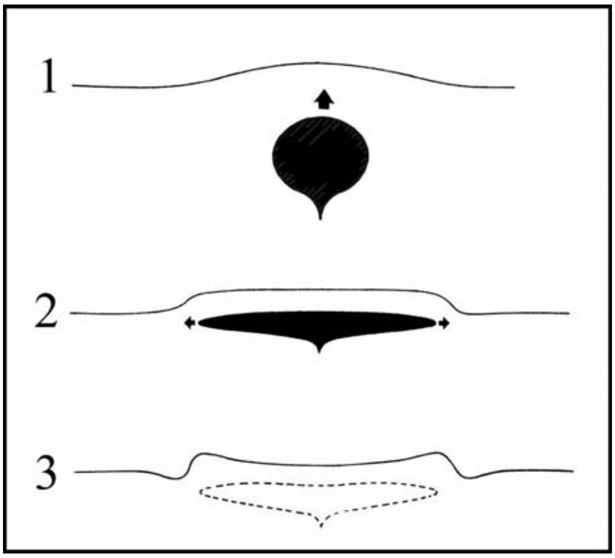

Figure 15. Coronae formation in the proposed three phases (Squyres et al. 1992); 1) uplift, 2) plateau formation, and 3) relaxation.

The corona begins its formation (1) when the hot material reaches the vicinity of the surface and presses against the base of the lithosphere. This process leads to the uprising of the surface (which depends probably also how deep the diapir is located and what is its extent - how much material is taking part in the process), thinning of the lithosphere and effusive volcanism. In the second phase (2), the magma chamber spreads against the lithosphere forming a hot layer of elastic material. This layer is thought to be responsible for the plateau-like topographic upraise of the apparent surface. Last phase (3) is reached when the magma of the diapir starts to cool and begins to descend. Cooling is due to the thin form of the magma chamber and associated conduction of heat to the crust. As the diapir descends, the elastic surface collapses and forms a depression (Squyres et al. 1992).

The different phases rework the surface in different ways. Phase 1 is thought to be predominantly governed by radial fracturing of the surface. In phase 2 the plate-like magma chamber forms the concentric form of the coronae shows up as circular rim is formed (Cyr and Melosh 1993). The plateau-like rise may also cause the depression within the central parts, and form complex topographic forms (topographic rim or moat may be formed). The concentric fracturing is also linked to this phase in coronae formation (in contrast to arachnoids, where the concentric fracturing may be more of the product of the cooling, the relaxation phase, the phase 3). In any case, volcanism may also be present during all these processes (Cattermole 1994). Coronae evolution continues with increased volcanic activity (which may cover largely or even totally the coronae radial fracturing (Cattermole 1994)). This model presents nova formation just in the first phase, and does not offer any options for later formation, for example during or after the rim formation or even the relaxation phase. This is in contrast to our observations which led to the model for corona-novae structures (Paper IV).

5.3.2. Arachnoids

The arachnoids are probably relatively young features, because the volcanism of the surrounding plains is usually clearly older (Papers II and V; Chapman and Zimbelman 1998). The arachnoids seldom display any evidence of a large volcanic center or of the fact that the radial lineaments have been produced by a large magma source. The general evidence of the volcanism of arachnoids´ central structures are the small shields nested within the central parts of the arachnoids. In addition to this, we see groups of these small shields, shield fields and chains of volcanic pits associated with the arachnoid lineaments, although they are not very common (Grosfils and Head 1994a). The arachnoids have therefore relatively few volcanic features when compared to coronae (Head et al. 1992) or novae (Paper II). This may very well reflect the fact that the magmatic process in arachnoid formation is primarily intrusive rather than extrusive or that the arachnoids are an early phase of coronae (Hamilton and Stofan 1996). The extrusive volcanism appears to be a minor characteristic in general. It has been proposed and shown, that the intrusive volcanism and dike emplacement may be a very important structure-forming process for those coronae and arachnoids which show minor amounts of extrusive volcanism (Grosfils and Head 1991; Head et al. 1992; Grosfils and Head 1994a,b). Although nearly all arachnoids display some evidence of volcanic flows, in the majority of cases the flows originate only from the arachnoid annulus and are not very extensive.

The most portrayed formation model for process for arachnoids is the presence of intrusive magmatism that forms the radial structures around the arachnoid. The lineaments of arachnoids have been thus formed by a deformation caused by intrusion of magma into the surrounding crust (Grosfils and Head 1994; McKenzie et al. 1992; Head et al. 1992). The arachnoids were thought to be products of similar mantle-related processes similar to the hot spots on Earth by Chapman and Kirk (1996). They assumed that the arachnoids were formed by small ascending plumes from the convecting mantle while the surface was not moving.

As the mantle material ascends as a diapir to relatively shallow depth the relief in pressure causes melting (Grosfils and Head 1994a). The magma released by the melting (White and McKenzie, 1989) then protrudes as dikes to the crustal structures of Venus. The theoretical models of the dike emplacement process prove that the length of the dike is primarily controlled by the renewal rate of the melt deposit in the magma chamber and by the thermal factors controlling the process (Parfitt and Head 1993a, 1993b; Bruce and Huppert 1989).

A ring-like, annulus bound depression is usually a characteristic found with the arachnoids. The presence of this structure is evidence of the endogenetic origin of the structure (Nikishin et al. 1992; Krassilnikov 2002b). When the shallow magma chamber beneath the arachnoid becomes exhausted, this is seen as a depression of the surface and formation of a caldera because of the downwelling or the fragility of the ring-like structure or possibly both (Walker 1984). Previous studies have shown that the width of the formed caldera is almost the same as the width of the underlying magma chamber (Marsh 1984; Ryan et al. 1983). It has been thought that the shallow magma chambers on Venus may develop up to a much larger size than the similar ones on Earth (Head and Wilson 1992). It is therefore possible to have a magma chamber the size of a few tens of kilometers under the central structure of an arachnoid which can produce, because of the over-pressuration process, dikes of several hundreds of kilometers long (e.g. Grosfils and Head 1994a). This lateral dike emplacement process, which is happening relatively close to the surface in to the surrounding crust of the arachnoid is seen as radial lineaments (Parfitt and Head 1993b). The possible dike emplacement process can be seen on the surface as the "legs" characteristic of the features in question.

The tectonic deformation of arachnoids is may be tied also to the proposed ascending of a diapir that forms the base of the structure. The diapir usually produces a dome-like rise which may be seen as extensional fracturing in the early evolutional phase. This extension can produce radial lineaments (Cyr and Melosh 1993; Janes et al. 1992; Squyres et al. 1992), but as in many cases, the lineaments of arachnoids do extend a significant distance, up to several radii of the arachnoid annulus. In these cases the lineaments cannot be formed only by the uplift. This has been shown by Grindrod and others (2005) in their study of the strain rates. Instead, in cases where the far reaching radial features are observed, their origin is probably due to dike emplacement (c.f. Grosfils and Head 1994b; Ernst et al. 1995, 2001).

The arachnoids are believed to form over a hot spot which has a relatively shallow magma chamber. The effusion of lava forms a rounded platform which is the base of the arachnoid. This may be accompanied by a dome-like uplift, which may, along with a regional stress field, form a system of radial dikes (Grosfils and Head 1994a,b; McKenzie et al. 1992). The concentric fracturing of arachnoids can be linked to the relaxation phase by analyzing the rim in conjunction to the radial structures. The rim features usually cut the radial fractures or ridges, and therefore postdate them (Paper V). In any case, the majority of arachnoids are, like coronae, probably volcano-tectonic in origin (Cattermole 1994; Head et al. 1992), although arachnoid central structures are usually smaller than coronae (Paper V).

However, besides the dike emplacement, there are also other options for the formation of the arachnoid radial or semi-radial structures. One must remember that the descriptive term for the structures is morphological and not genetic. Cyr and Melosh (1993) modeled tectonic patterns and regional stresses, and received quite good analogs comparable to some of the existing arachnoids (Fig. 16). McGill (1993) proposed that the Venusian wrinkle ridges may be affected by regional stresses for example around topographical changes (see Fig. 3 in McGill 1993). The relaxation of the surface and resulting shortening of the surface may also form radial ridges in some arachnoid cases. The survey of the arachnoid radial features (Appendix II, Paper V) gave implications for at least three possible, different formational processes of the arachnoid lineaments:

1) The lineaments are radiating from the central structure, resembling in cases the radial fracture centers (e.g. Grosfils and Head 1994b, 1995, 1996; Ernst et al. 1995, 2003). The two aspects of the structure (central structure and radial lineaments) are probably closely linked in these cases. The lineament formation could be due to a) topographical uprising (similarly as in proposed coronae evolution (Squyres et al. 1992), b) dike emplacement processes (e.g. Grosfils and Head 1994b,1995,1996), or more probably c) combination of both as was proposed by Grosfils and Head (1994b)

for their studied radiating centers. The length of the lineaments is more similar to the possible dike formation, since in the doming of the structure the lineaments would be more constrained within the topographically deformed area (Grosfils and Head 1994b).

2) The lineaments are with some arachnoids mostly just surface structures, which are identified in many cases as Pwr features. The ridges on the plains are affected by the arachnoid central structure (topography, magma chamber) resulting in identifiable arachnoid structure. This was proposed by McGill (1993) in his study of the Venusian wrinkle ridges.

3) The ridges of the arachnoid are "radiating" from the depressed central structure. In these cases, they may have been formed by the compressional effect of the formation of the topographical depression.

The survey showed that with 53.2% of arachnoids the lineaments are compressional (ridges), compared to the 29.5% of extensional cases (fractures or graben). As observed before, in 17.3% of arachnoids, both extensional and compressional features are present (Appendix II, Paper V). The discussed possible models of formation or origins for the lineaments as well as the observations of the structural composition enforce that similarly to the coronae, the arachnoid formational process has to be certainly very complex, and generalizations for the whole population cannot be made.

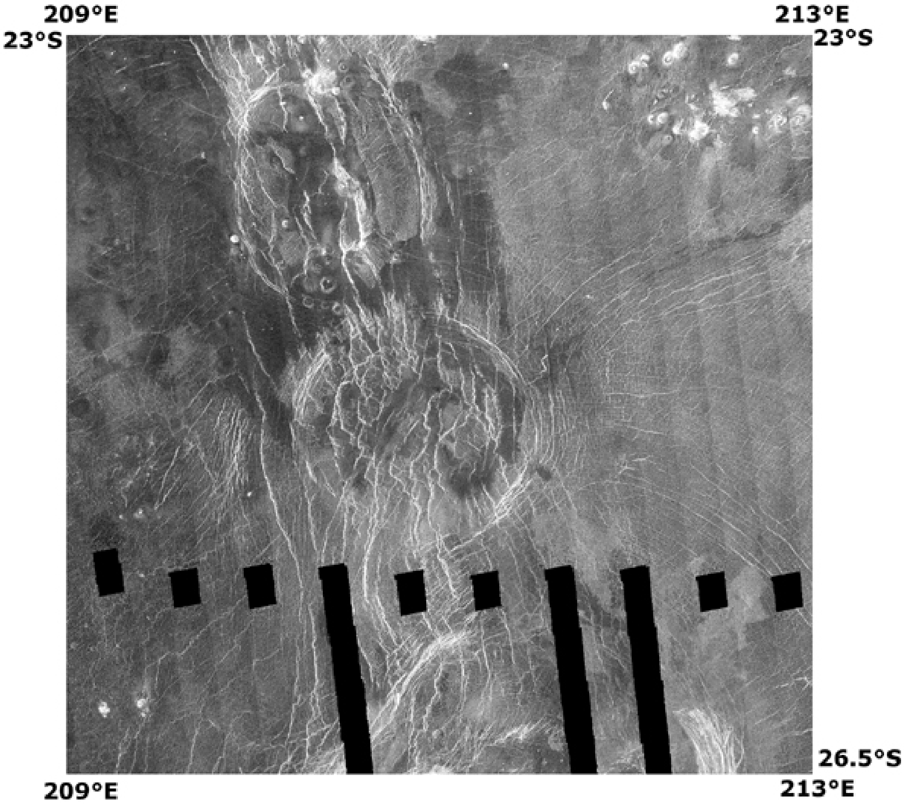

Figure 16. A good example of an arachnoid that corresponds well to the model presented by Cyr and Melosh (1993).

5.3.3. Novae

The prevailing coronae formation model of three phases (Squyres et al. 1992; Fig. 15) actively places the novae within the first phase of the coronae formation. In that, the rising diapir or plume presses against the lithosphere promoting the formation of dome-like upraise and radial fracturing (Squyres et al. 1992; Janes et al. 1992; Cyr and Melosh 1993). The problem with this model is, that as this uprising event is proposed as only the first phase within the coronae formation process, the novae are presumed to be older than the coronae in general (e.g. Squyres et al. 1992; Hansen et al. 1997). However, there are several novae outside the coronae, and this implies that not all the nova forming events are linked to corona formation (Aittola 2001; Aittola and Kostama 2001; Paper IV). The study of the radiating dike swarms (of which many are listed as novae) enforces this (c.f. Grosfils and Head 1994, 1995, 1996; Ernst et al. 1995, 2003). Analyzing the evolution and formation of singular novae, it has been noted that the formation process may actually be quite long and does not necessarily lead to coronae formation (Basilevsky and Raitala 1999; Aittola 2001; Paper IV). These observations do promote the independent analysis of novae, and inclusion of these structures to their own group of structures rather than including them to the already large and complex corona population (cf. Schubert et al. 1991; Janes et al. 1992; Crumpler et al. 1996; Crumpler and Aubele 2000; Aittola and Raitala 2001; Basilevsky and Raitala 2002; Paper I).

5.3.4. Corona-novae

Due to the observed age differences between the coronae and the novae located within them (cf. Aittola 2001; Paper IV), we analyzed the novae inside corona annulus. As a result of our study (Paper IV) we propose the novae to be representations of reactivation of the corona location. We believe that the morphology, topography and the age relations of corona annulus and nova radial features depend on the stage of corona evolution during the reactivation period or event when the nova is formed.

Squyres and others (1992) proposed a three-stage model of corona development (Fig. 15), characterized in the first stage by the updoming in the lithosphere with radial fracturing and volcanism. Transformation of the dome to a plateau-like structure due to a radial spreading occurs in the second stage and finally in the third stage is gravitational relaxation of the topography courtesy of the cooling of the diapir or the exhaustion of the magma supply. Naturally, formation of all the coronae cannot be fully explained by this simple three-stage model.

Our model (Fig. 17) is based on this corona evolution sequence which is further developed by adding modifying events responsible for the nova-formation. The circular image in the end of the sequence presents the final morphological form of the corona-nova joint structure. In the figure, only the nova-forming diapiric event is shown.

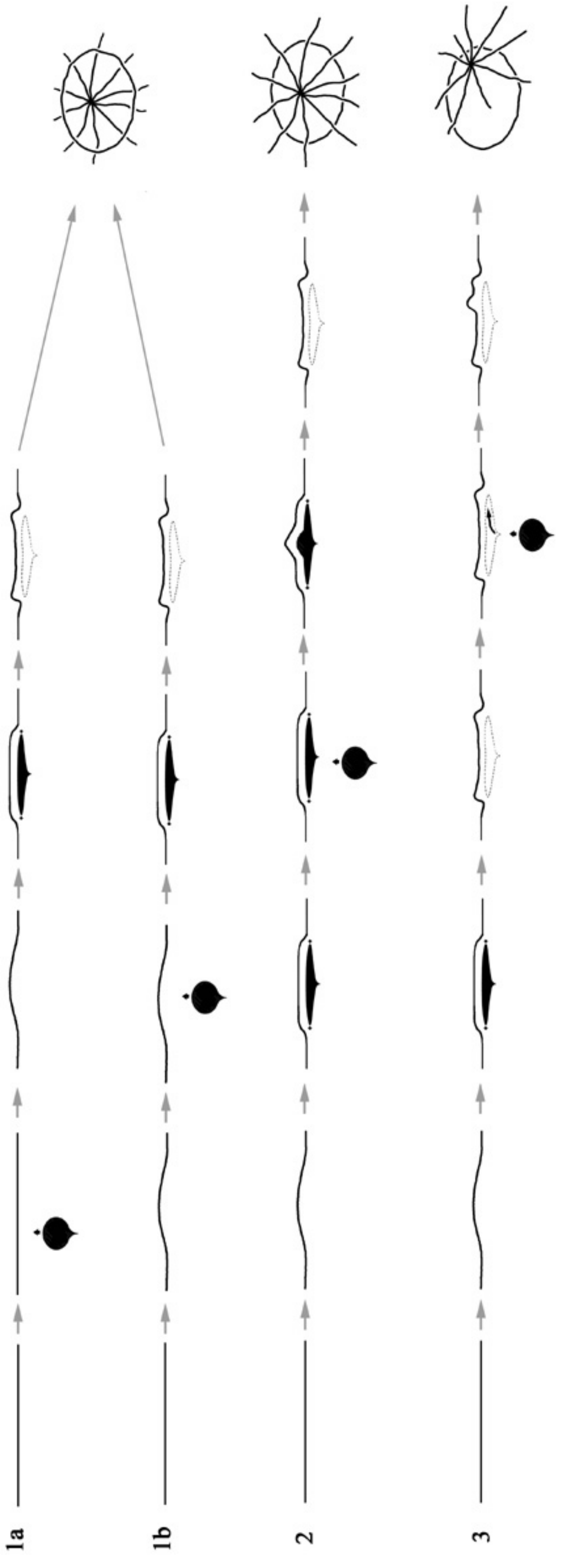

Figure 17. The proposed types for corona-nova chronology.

1a: the formation of nova begins prior to or in the first phase of corona formation.

1b: the nova is shown to form as a result of another pulse or increase in intensity in the doming phase of the corona.

2: the novae are formed by reactivation during plateau-phase and they will be modified by corona relaxation if the proposed corona evolution process continues to the third stage. In the final form, the nova is seen in the center of the corona ring-structure with the nova radial fractures post-dating the rim.

3: this type has their nova structures forming after the corona formation process, and therefore, they will not be affected by the corona evolution. In this case, the nova clearly post-dates the formation of the corona. In the final morphology, the nova is located near the corona annulus.

The formation of type 1 corona-novae follows the proposed three stage formation model. If the reactivation or the ascending of another diapir or a prolonged insertion of magma occurs within or right after the first stage, the corona-nova structure may go through the plateau-forming as well as through the relaxation phase (Fig. 17). Thus, the radial structures of nova are cut by the annulus of corona and the nova can be considered as a part of the corona formation process. For type 1a, we have a situation where the formation of nova begins prior to or in the first phase of corona formation by an intense or continuous magma plume which lifts the surface creating a dome-like rise and forming a series of radial fractures. After the formation of nova-structure, the corona evolution continues. The increase of magma creates a plateau with concentric fractures around the rim. These fractures in turn cut the radial features created by the nova formation. For type 1b, the nova is shown to form as a result of another pulse or increase in intensity in the doming phase of the corona. The corona evolution continues along the proposed cycle. In the final morphology, the concentric fractures cut the nova radial features. Although this model presents both possibilities (type 1a and 1b), it is impossible to identify them from the final structures. Although it is impossible to identify the types from the final structures, we feel that both possibilities should be shown in Figure 17.

For type 2 (Fig. 17) the evolution of corona has reached the point where the ascending material forms a plateau-like chamber along the neutral buoyancy level. At that point, a renewal of activity begins or a new pulse protrudes into the existing magma chamber. This increase lifts the corona center creating fractures which therefore were formed after the concentric structures of the corona. After this activity, the nova will be modified by relaxation if the corona evolution process continues to the proposed third stage, the cooling phase. In the final form the nova is seen in the center of the corona ring-structure, with the nova radial fractures post-dating the rim. It is also possible that the development of the corona continues for a long period of time which results in the deformation of the annulus as well as the nova radial features. In this case it is possible to have a result which morphologically resembles the structures in case 1a and 1b.

The novae in type 3 are formed after the corona formation process when the corona is mature and will not be affected by the corona evolution (Fig. 17 and 18). This indicates that the nova is clearly formed after the formation of corona. In these cases, the nova is usually located rather close to the rim of the corona and usually displays distinct elevation (Paper IV). Our model predicts that this specific location is a result of the zone of weakness formed by the earlier, already cooled diapir or by the exhaustion of the magma supply. Thus, if the uprising magma in the reactivation phase will use the same channel as the magma which formed the corona structure, it is logical to propose that the molten material will follow the easiest route possible which is not straight through the lithosphere, but along the zone of weakness which extends close to the corona annulus. The depressed center and the presence of these zones lead the diapir near the corona annulus which explains the specific location of the novae. Due to the sequence of events, the radial fractures of the formed nova structure cut the corona annulus. In general, the age relations of geological units and events within the corona-nova are easily identified. Furthermore, the topography of the nova will display a prominent elevation. Thus, the corona-nova joint structures of this third case are clearly distinct from the others.

Although this chronology does not exclude the fact that the novae formed near the corona annulus may develop further into coronae, we did not find any evidence supporting this suggestion in our research. The typing for every identified (n=35) corona-novae is presented in Table 2.

Figure 18. Terrain map of two corona-novae (Paper IV). The geological relationships of cutting and covering show, that the structure below - *Pavlova Corona* – is type III corona-nova. The upper corona-nova - *Didilia Corona* is presumably of type II.

6. Classification or characterization of the studied structures

6.1. Previous classifications

The volcano-tectonic structures have been a subject to many classification/typing studies like any other surface structure. The existing classifications as well as lists of recognized structures all form a good basis for contemporary and future Venus studies of structure populations. The first classification for the newly established coronae was based on the Venera 15/16 –mission SAR-images. This classification by Pronin and Stofan (1988), presented three morphological classes for the coronae:

- I Symmetric, classical coronae
- II Asymmetrical coronae
- III Subdued coronae.

In 1990, they also presented a new classification scheme from Venera 15/16 materiel, also based on morphology (Pronin and Stofan 1990):

1. Concentric coronae
2. Concentric, double ring (DR-coronae)
3. Radial-concentric coronae
4. Asymmetrical coronae
5. Multiple coronae.

After the Magellan mission, two additional classes were included (Stofan et al. 1992):

6. Radial concentric corona-like structures
7. Volcanic corona-like structures

Cyr and Melosh (1993) modeled the formation of the radial-concentric corona-like features, and proposed that these were relatively young features placing them within the early parts of coronae evolution model. These features were formed by radial fractures and their topography was usually dome-like. The features of this kind have been also referred as novae (Schubert et al. 1991) or astra (Aksnes 2001). At that time the arachnoid structures (Barsukov et al. 1986; Head et al. 1992; Crumpler et al. 1997) were seen as very similar to the novae.

Besides morphology and tectonic characteristics, the coronae have also been classified by their volcanism (Stofan et al. 1992), relative age, and also by their complex topography. The complexity is also a weakness in this type of classification, because it is very difficult to exactly identify the topography of the studied features with Magellan resolution. In this classification, the coronae were placed in separate groups by their larger scale surface features (Stofan 1995):

1. Depression
2. Rimmed depression
3. Rim and central high
4. Just rim
5. Outer rise, trough, rim and central high
6. Outer rise, trough, rim and central depression

7. Central plateau
8. Dome
9. No apparent topographic signature.

This classification was readjusted to some degree by Smrekar and Stofan (1997). The classes are shown in Figure 19.

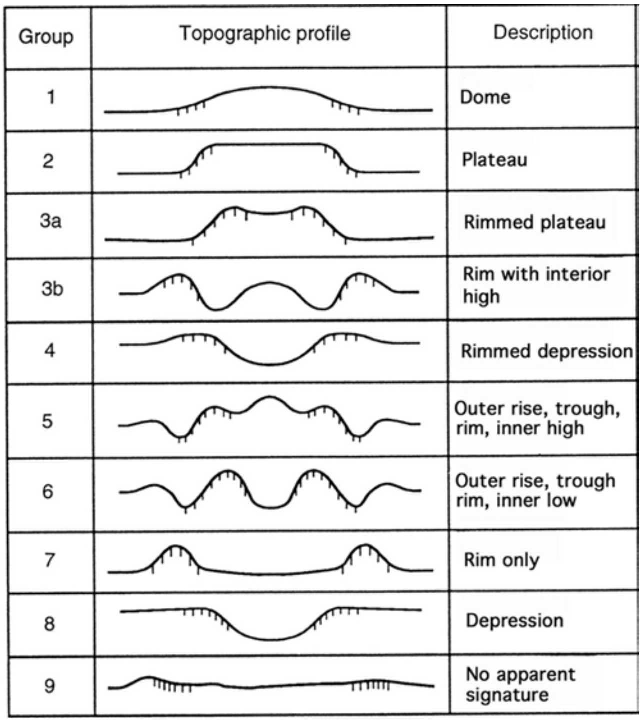

Figure 19. The topographic classification of Venusian Coronae (Smrekar and Stofan 1997).

The arachnoids were preliminary included to the Pronin and Stofan (1990) corona classification as one of the additional classes (Stofan et al. 1992), called class with radial concentric features. There were no classifications for arachnoid types, although the group itself was recognized and in cases populations were catalogued by several researchers (i.e. Hamilton and Stofan 1996; Crumpler et al. 1996; Crumpler and Aubele 2000). However, all the arachnoids are not exactly alike to each other, there are differences. The lack of classification for different types of arachnoids led us to search for a useful classification for the arachnoids, that would offer some reason to the occurring differences. The typing of the different structures was based on the surrounding environment of the arachnoids (Kostama and Aittola 2000; Aittola and Kostama 2000; Kostama 2001; Paper V). We also typed the arachnoids using observable topography and apparent volcanism (Paper V).

Later on, Krassilnikov (2002) (also Krassilnikov and Head 2002) presented a classification based on the deformational features of the structures. In this study, Krassilnikov (2002) used the already established catalogue of Crumpler and Aubele (2000) and studied 53 specimens at random from that list. In that list the arachnoid population identified is rather large, comprising from a total of 265 structures. Krassilnikov (2002) identified seven classes based on the exhibited tectonic features which for the arachnoid:

- I Concentric extensional structures
- II concentric extensional, radial compressional structures, and concentric compressional structures in central parts
- III concentric extensional structures and radial compressional structures, which usually extend beyond the arachnoid
- IV concentric and radial extensional structures.
- V concentric extensional structures and chaotic and/or concentric compressional structures located in the central parts of the arachnoids
- VI compressional structures that are both concentric and radial with respect to the arachnoid
- VII arachnoids that cannot be assigned in view of their specific tectonic structure.

Krassilnikov (2002) uses apparent morphology as basis for this classification, and also uses different catalogue, which set our works apart. We have used the population identified independently by us (Kostama and Aittola 2001; Paper I and IV), where the population of the feature group is much smaller than the previous one mapped by Crumpler and others (1996, 1997), and Crumpler & Aubele (2000). We presume that the different views, deviating definitions for the surveyed structures, and interpretations of the available data and the structures have resulted in these different catalogues. Stofan and others have also published lists of structures, but they do not recognize the arachnoids at all (Stofan et al 1992, 2001).

Similarly to arachnoids, the novae were also included in the "additional" class of volcano-tectonic "misfits" (radial corona-like structures; Stofan et al. 1992). Parfitt and Head (1993a) proposed a classification for the 188 radial fracture centers they had identified. However, this classification had many discrepancies with already existing nova lists, which would seem to imply that formational processes are similar for different structure groups or at least to some part of the structures. Besides novae, their classification included many volcanoes (cf. Crumpler et al. 1997; 2000), not just novae.

Besides the volcano-tectonic types presented here, Grosfils and Head (1994b) independently mapped and catalogued the global distribution of giant radiating dike swarms and found 163 radial lineament systems. They concluded that in 72% of the cases (n=118), the subsurface dike swarm emplacement was involved (Grosfils and Head 1994b). This population includes structures from all the four presented structure types.

Aittola and Raitala (1999), and also Aittola (2001) proposed several new schemes for the novae. They used the novae within the Crumpler and others (1996) list, and proposed four classes:

I	The radial fractures of the nova have a single place of origin
II	The origin is more like a fracture or other longer feature
III	The place of origin cannot be identified as the later lava flows cover the point/fracture
IV	It is impossible to determine any single place of origin for the fractures. The fractures are just partly radial concentric.

Aittola and Raitala (1999) also brought up an observation that some of the novae do have a tectonic rim and the nova is actually located within this rim. Later on, these features were identified as their own group of structures, the corona-novae (Aittola and Kostama 2001; Paper IV). In the end, we came to the conclusion that it was necessary to identify and make our own global list of structures (Kostama and Aittola 2001; Paper I), in order to feel confident in analyzing the gathered data of the studied features (Kostama and Aittola 2001a,b, 2002; Paper II-V).

6.2. Characterization based on geological settings

The previous chapter presented several classifications based on the appearance of the structures. The problem with this is that these classified structures are morphologic features – they are identified by their appearance. Classifications are therefore bound to have problems and interpretational disagreements between different studies. It is also known that the evolution processes for these structures are not very simple, but instead include a lot of variables. In order to fully understand the evolution of a singular feature, we must analyze each and every structure independently. Classifications based in morphological and topographic characteristics rely much on interpretation of the researcher and this reduces the universal applicability of the classifications in question.

When classifying or characterizing the Venusian lithospheric structures, their complexity and gamut of their divergences are the biggest challenges. I believe that one solution to the minimization of this problem lies within the general location of the structures rather than within the structures themselves. It has been thought – at least for part of the populations of the studied features – that their endogenetic origin is similar (e.g. Stofan and Head 1990; Head et al. 1992; Janes et al. 1992). Still, the features deviate in appearance and in other characteristics from minor to significant (e.g. Paper I and II). We did analyze the single features of the groups in different geological environments and noticed that this change did have effect on the overall characteristics (Paper II). It is probable that the environment – the general geology of the location has considerable impact how the structure evolves. As a result, we present a method to further characterize the studied structures, which is independent of the changes and formation processes of the structure types.

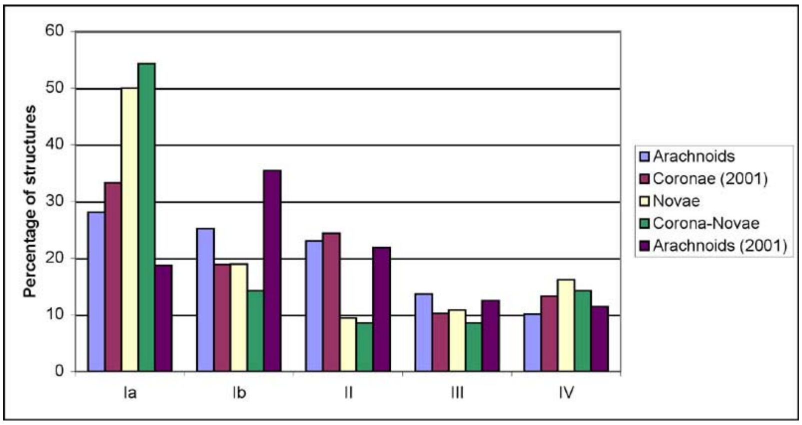

Figure 20. The percentage of volcano-tectonic structures within the types of the geological environment. Note that all the structures have a concentration to the type I (>50% of novae and corona-novae). Coronae and arachnoids are twice as frequent than others in type II. The figure shows also the older Kostama and Aittola (2001) population for arachnoids as reference, as the 2006 corona survey is still in progress.

We noticed that the general environments of the structures were different. For example the novae and coronae promoted the chasmata regions while arachnoids (regardless of being very corona-like in their appearance) favoured different regions. Based on the general environments, we created a four environmental type characterization method that can be used regardless of the structure type in question. The method uses four major geological surface types based on the globally prevalent Venusian environmental units.

Type I are the structures associated with the deformation zones

Ia – location within the deformation zone

Ib – located close to the deformation

Type II features are located on the major plains units

Type III are identified based on their close relationship with tessera

Type IV are identified based on their locations in highly volcanic areas (regions of large volcanoes, regions rich in volcanic edifices and structures)

The percentages of the environmental types in the separate four feature groups are shown in the Figure 20. All the structures seem to favour Type I (from 53% up to 69%), with arachnoids being more abundant in the Type Ib than Ia, while the others have an opposite trend. Coronae and arachnoids are both numerous in the Type II (21-25%) while Type II novae and corona-novae are scarce (less than 10%). For type III and IV, the distribution is similar for all structures (10-16%).

7. Planetary view of the studied structures

7.1. Areal distribution

The study begun as separate studies on arachnoids and novae, two groups of clearly identifiable features that had been both associated with coronae, either as a subtype, part of coronae formation process or belonging to the same class of corona-like features (Stofan et al. 1992; Janes and Turtle 1996; Price and Suppe 1995; Hamilton and Stofan 1996). The inconsistencies and different interpretations of structures in previous studies of these features and in coronae studies as well (i.e. Stofan et al. 1992; Crumpler et al. 1996), led to independent catalogue (Appendix I) of arachnoids, novae, coronae (Kostama and Aittola 2001; Paper I) and corona-novae as well (Paper IV).

Our list of volcano-tectonic structures aims to produce a consistent catalogue of the different volcano-tectonic structure types (Appendix I). The rationale for this work is a) to recognize all the different volcano-tectonic features and their distributions, b) We do recognize the usefulness and the value of the previous catalogues also, our work supplies to the common goal of mapping and understanding the surface structures better. The need for this newer catalogue derives, for example, from the fact that Stofan and others (1992, 1997, 2001) use only coronae as volcano-tectonic structures disregarding the obvious differences of novae and arachnoids to coronae. Also the major catalogues by Crumpler and others (1996) and Crumpler & Aubele (2000) included in our view misinterpretations in the feature identification These catalogues rightfully do recognize the different structure types besides coronae, and offer a good reference for example for comparison studies with our (by no means perfect) catalogue. Major interpretational difference was the identification and definition for arachnoid structures resulting in large difference in populations between the catalogues. We also introduced the corona-nova type into the volcano-tectonic "family" as a separate subtype of corona-nova interaction (Paper IV). In the future, the standing and status of the "multiple" coronae and Arachnoids (i.e. Törmänen et al. 2005), will be considered also.

During the first global study of the volcano-tectonics, we found 349 coronae, 96 arachnoids, 74 novae (including 35 corona-nova joint structures) (Table 2) on the Cytherean surface (Kostama and Aittola 2001a,b, 2002; Paper IV). Later on, the catalogue was revisited, mostly because of the possible "stealth" features and enhanced mapping possibilities. In these surveys the numbers were increased to 139 arachnoids (Kostama et al. 2006; Paper V) and 594 coronae (Törmänen et al. 2006; Paper I). Majority of the added structures were indeed the "stealth" - "Type 2" – features. The both arachnoid types are shown for reference in Fig. 22b; this distribution was presented in Berlin this fall (Törmänen et al. 2006).

The analysis of the features in global scale shows that they have very different distributions (Figs 20-25). Study of these distributions and correlating them to the differences in local geology is supplies to the understanding of formation and evolution processes of these features (e.g. Kostama and Aittola 2000; Paper IV; Aittola and Raitala 1999).

Latitude	Longitude	Diameter (km)	Nova-corona relation	Topography	Proposed type	Name
26.5	33	90	1:1.2	depressed	1	-
22	224	145	1:2	elevated	1	-
22	239.5	112	1:2.6	elevated	1?	-
19.5	227.5	145x125	1:1	plateau	1	-
18	34.5	260x310	1:1.3	elevated	2	Didilia Corona
17.5	252	400	1:5	elevated	3*	Taranga Corona
17	49	540x320		elevated	2	-
14.5	39	370x415	1:2.8	elevated	3	Pavlova Corona
12	225	125x215	1:2.9	elevated	3	-
12	49	520	1:1.3	elevated	2	Isong Corona
6	20	210	1:3.8	elevated	3	Belet-Ili Corona
2	223	225x440	1:6.3	missing data	3	-
-5	250.5	325x410	1:5	elevated	3	Javine Corona
-6.5	251	320x410	1:5.5	elevated	3	Javine Corona
-7.5	221	240	1:1.1	elevated	1	Maram Corona
-8	47	480	1:1	elevated	2	Nabuzana Corona
-8	243	160x215	1:1.1	depressed	1	Dhorani Corona
-8.5	106.5	220	1:1	depressed	2	-
-9	214	110x140	1:3.2	elevated	3 (2)	-
-10	211	110	1:1.7	depressed	1	Oduduwa Corona
-10.5	47	480	within annulus	elevated	3	Nabuzana Corona
-11	172.5	185	1:4	elevated	3	Khabuchi Corona
-12	251	170x280	1:6.8	elevated	3	Ludjatako Corona
-14	164	360	1:1.4	plateau	1?	Miralaidji Corona
-15	215	175	1:3	elevated	3	Mbokomu Mons
-22	271	130x185	1:3.8	elevated	3	Kapenopfu Corona
-27.5	280	140	1:1.1	elevated	2	Mielikki Mons
-32	276	185x165	1:1.5	elevated	2	Obiemi Corona
-34.5	287.5	100x110	1:1.7	depressed	2	Santa Corona
-36.5	298	240x124	1:2.7	elevated	3	Tamiyo Corona
-39	284	260	1:3.2	plateau	3	Shulamite Corona
-39.5	296.5	300	1:3	elevated	?	Ukemochi Corona
-42	278	360x420	1:4	plateau	3	Shiwanokia Corona
-42.5	6	320x420	1:1	elevated	2	Selu Corona
-45.5	303.5	400x440	within annulus	elevated	3	Bibi-Patma Corona

Table 2. The coordinates, diameters, the relation of nova location to the annulus, nova topography, the proposed type within our model, and the IAU name of the structure of the corona-novae covered by this study.

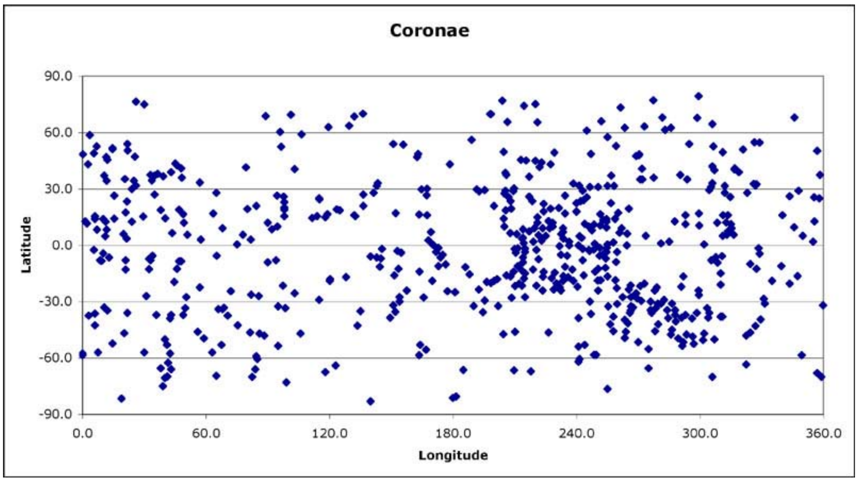

Figure 21. The global distribution of coronae. Their distribution is the most random of all types, but it still shows concentrations to the BAT-region.

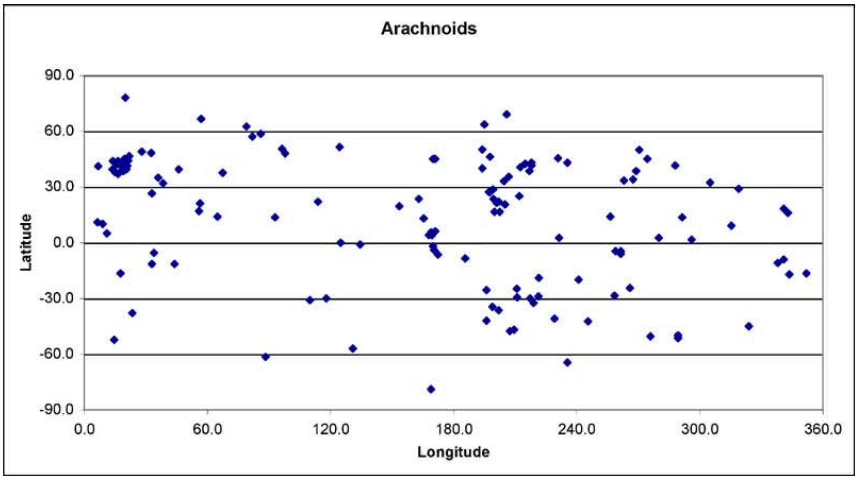

Figure 22a. The global distribution of arachnoids. Areal distribution is favouring the plains regions although majority of arachnoids is associated with ridge belts.

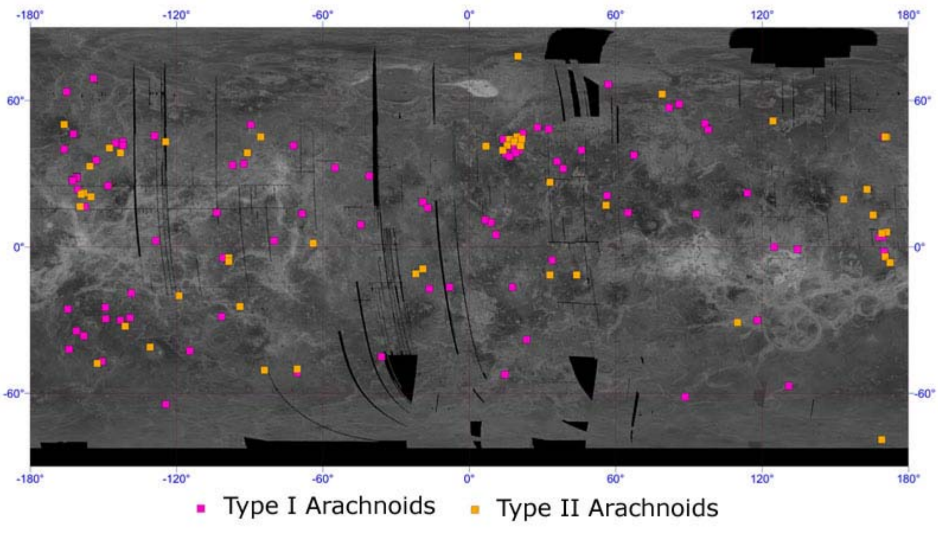

Figure 22b. The type I and type II arachnoids (Törmänen et al. 2006).

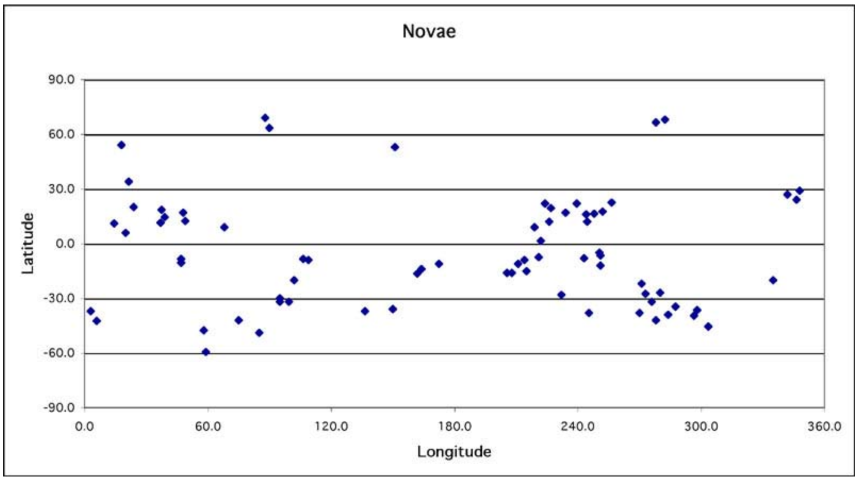

Figure 23. The distribution of novae. The features are almost entirely concentrated to the rift zones.

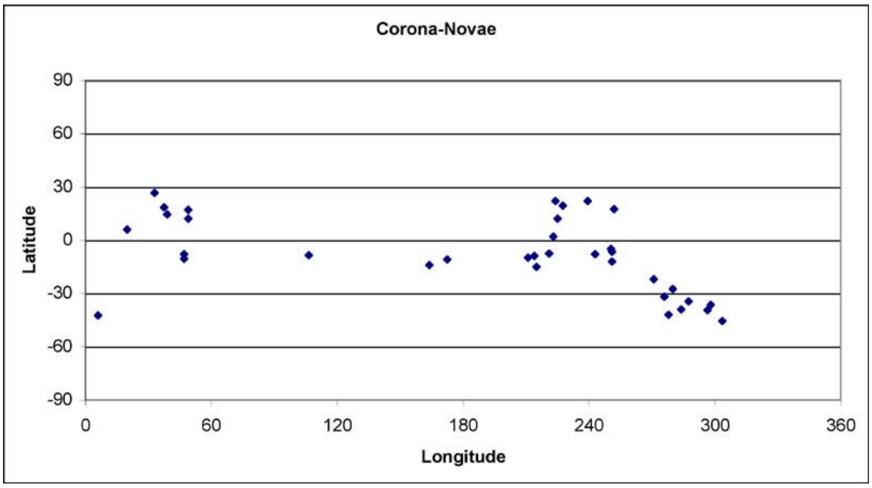

Figure 24. Global population of corona-novae joint-structures. The rift zone effect is even clearer. As we know that the rift zones are amongst the youngest regions on Venus, and considering the facts that the corona-novae are young structures in general, we may conclude that the corona-novae can be considered as presentations of the latest activity on Venus (Paper III).

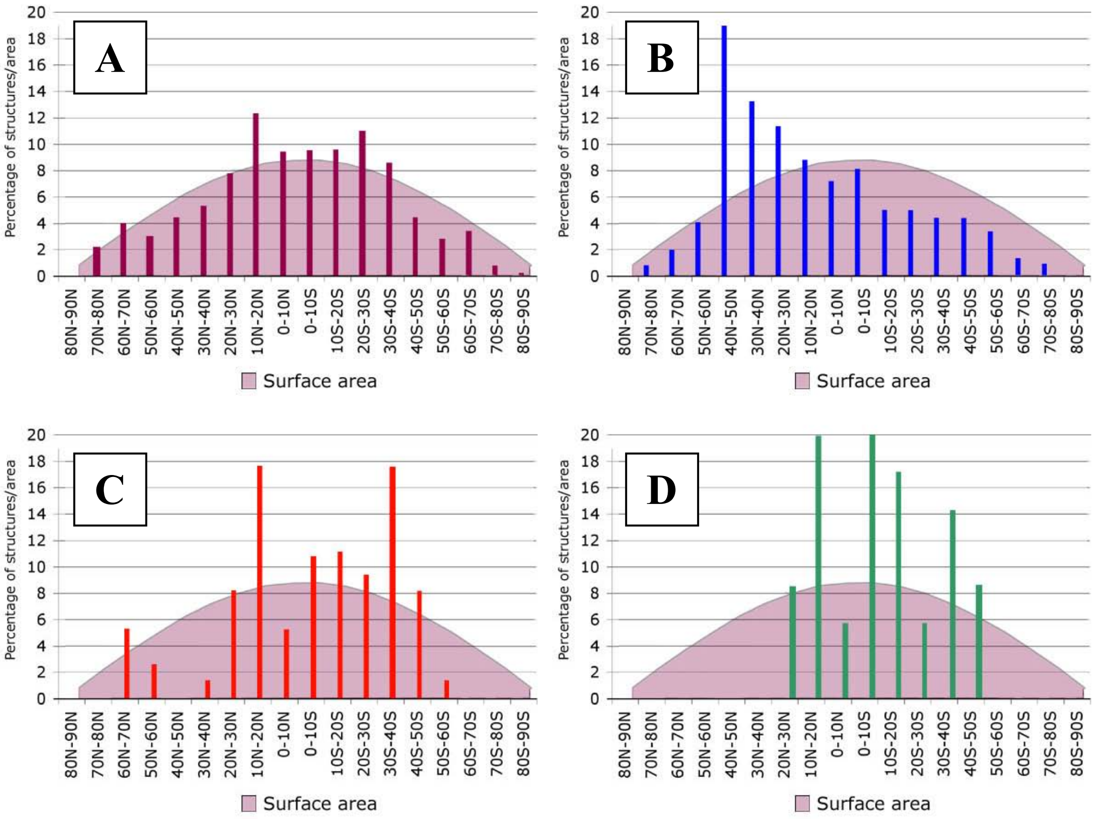

Figure 25. The latitudinal distribution of (A) coronae, (B) arachnoids, (C) novae and (D) corona-novae in percentages of total population in respect to the surface area. Notice the distinct peaks in arachnoid presence on the Northern hemisphere and lack of novae, as well as the opposite situation on the Southern Hemisphere. Coronae seem to be quite evenly distributed with minor concentrations near the Equator. The Corona-novae are concentrated to the equatorial region; the chasmata – the large deformational zones – are also concentrated to the equator.

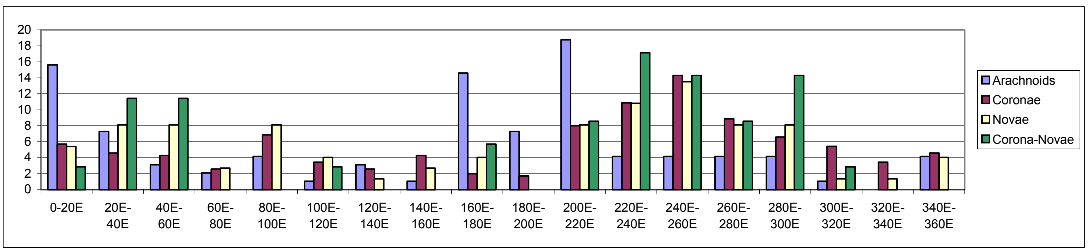

Figure 26. The longitudinal distribution of the volcano-tectonic structures (in percentages of total population). All four types seem to have high concentration to the area between the 180°E and 300°E longitudes (BAT -region). Between 100°E and 160°E the situation is mirrored by the lack of all four.

The latitudinal distribution (Fig. 25) of the features shows the expected lack of features in the very high latitudes and higher numbers in low latitudes near equator as the surface area increases. Coronae in particular seem to follow the expected curve. With the other structure types, the distribution is different: The arachnoids are clearly present in higher numbers in the northern hemisphere. Corona-novae have a strict region of distribution, which promotes the equatorial regions, where also the chasmata regions are located. Novae also show peaks and also concentration to the southern hemisphere. If we consider coronae, novae (and corona-novae) only - they are more numerous than arachnoids, the ratio is 1:4.8 - it seems that the volcano-tectonic processes responsible for their formation have been more effective in the southern latitudes. Longitudinal distribution (Fig. 26) of the features mirrors the areal extent of the BAT-region very well. Even the arachnoids seem to more frequent in the vicinity of it although are absent within the region itself.

When studying the structure types separately, we notice that the 596 coronae (Paper I) seem to be located almost everywhere on the surface of Venus (Fig. 21). However, the distribution is non-random with a definitive concentration of structures to the BAT-region (Fig. 26; Squyres et al. 1993). In a general sense, the coronae seem to favour the deformation zone areas. Examining the latitudinal and longitudinal distribution we notice the expected lack of structures in high latitudes (because of the lesser surface area) and the higher concentration between 30°N – 40°S and 200°E – 300°E which corresponds well to the BAT-region. The arachnoids have a higher distribution to the northern hemisphere as 67.6 percent (94 features) of the features are located north from the Venusian equator, while only 32.4 percent (45 features) is located in the southern hemisphere (Fig. 22). In addition to this concentration, 51.8 percent (72 features) of the arachnoids are located between the latitudes 45°N and 10°N (Fig. 22 and 25). This is majorily due to the large arachnoid groups in Bereghinya and Ganiki Planitiae. Notable in longitudinal and latitudinal distributions is the difference to the coronae distribution, which is following the distribution of the surface area. Also the distribution of multiple coronae (and arachnoids) (Fig. 27; from Törmänen et al. 2005) appears to be different from the overall distribution of coronae.

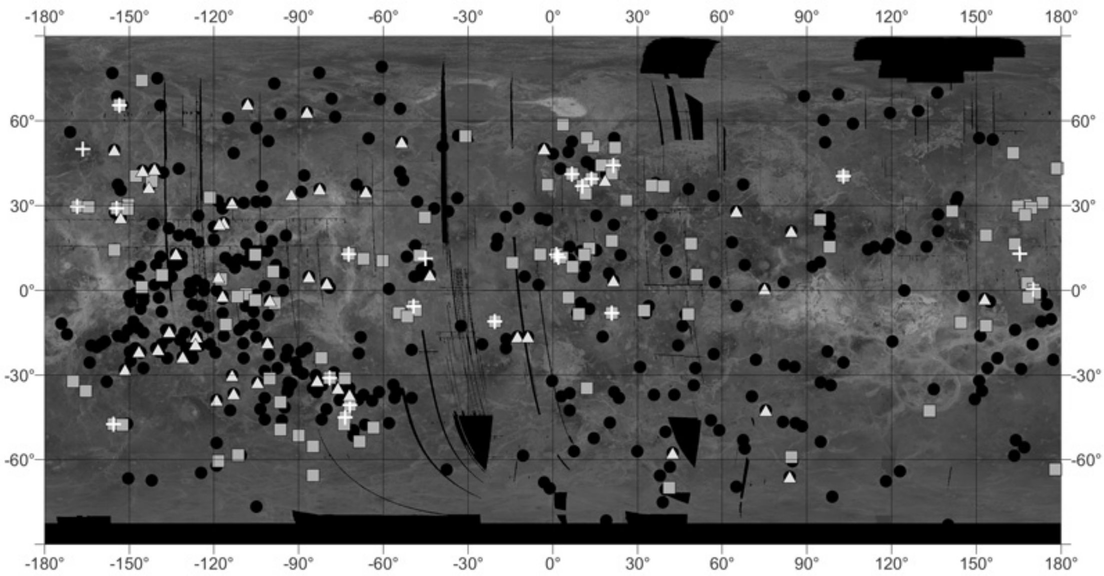

Figure 27. Distribution of multiple coronae: Grey triangles are Type 1 multiple coronae; white crosses are Type 2; Black circles are Type 1 coronae (Stofan et al. 2001); Grey squares Type 2. (Figure is modified from Törmänen et al. 2005)

The distribution of novae (Fig. 23) seems to promote the chasmata regions (rift zones) of Venus. We do have similar concentration to the BAT-region as coronae but when comparing to the arachnoids we see that the novae are scarce on the plains regions. The novae do not show the expected latitudinal distribution but instead are concentrated to the southern hemisphere. The by-product of coronae and novae, the corona-nova structures show even more prominently the close relationship of extrusive type volcano-tectonics with the large rifts of Venus. As seen in the global map of prominent Venusian formations, it is quite evident that the whole population of these joint-structures is found almost seldom on the young rift zones, chasmata regions of Venus (Fig. 24). This observation and the fact that they also represent (at least their last evolution phases) the youngest features locally, it is possible that these features are amongst the last active structures on Venus (Paper III). Corona-novae are concentrated to the equatorial regions and are totally extinct in the high latitudes. All features are found between 20°N and 40°S with some emphasis on the southern hemisphere. We see the impact of the volcanically important BAT-regio with the corona-novae as well.

In addition to the differences in morphology the four feature types deviate also in topographic and more importantly in altimetric aspects. The structures seem to favour regions with diverse general altitudes in relation to the mean planetary radius. The general topographic characteristics of the features are somewhat different but still the divergence in altimetric distributions is significant. The Figure 28 shows the altimetric distributions for the structure types. The arachnoids are most abundant in lower plains regions, usually less than, while the novae and corona-novae especially favour much higher regions. Even coronae have a high portion of their population in regions higher than MPR (Fig 28; Kostama and Aittola 2001a; Paper I). The altimetry for each structure was determined by the value of the structure center.

7.2. Distribution and geological settings

The distributions of coronae, novae and arachnoids differ from each other, indicating that their locations are in diverging geologic environments (Kostama and Aittola 2002). The deviations also occur even when the geological types are taken into account. This can be seen in Figures 29-33. The distributions for the structures are not of course comparable between the geological types, because the structures by definition follow certain geological areas. The information is within the single maps, and relative locations of the structures within the same type.

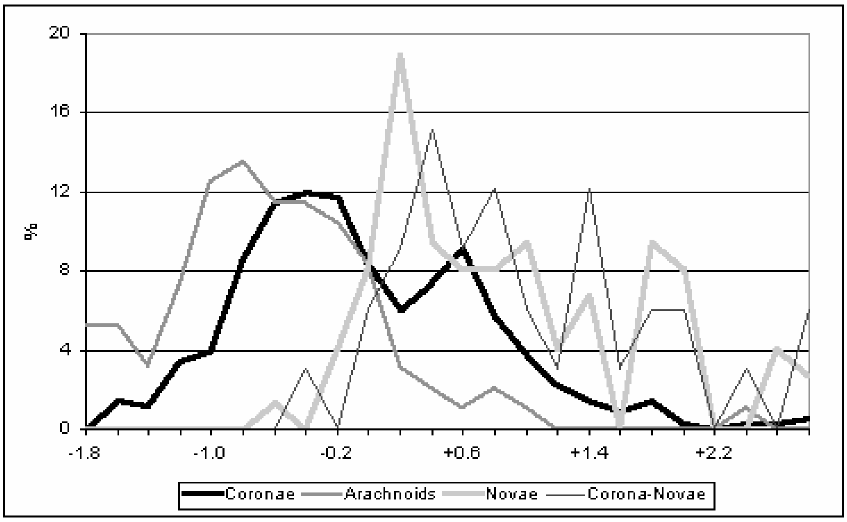

Figure 28. The altimetric distribution of the volcano-tectonic structures in relation to the mean planetary radius (MPR; 6051.84 km). Although the topographic properties of the features have some impact in this, the concentration of novae (n=74) as well as corona-novae (n=35) to the higher regions is clear. Notice also the difference between arachnoids (n=96) and coronae (n=349); the majority of arachnoid structures are located in regions lower than the MPR.

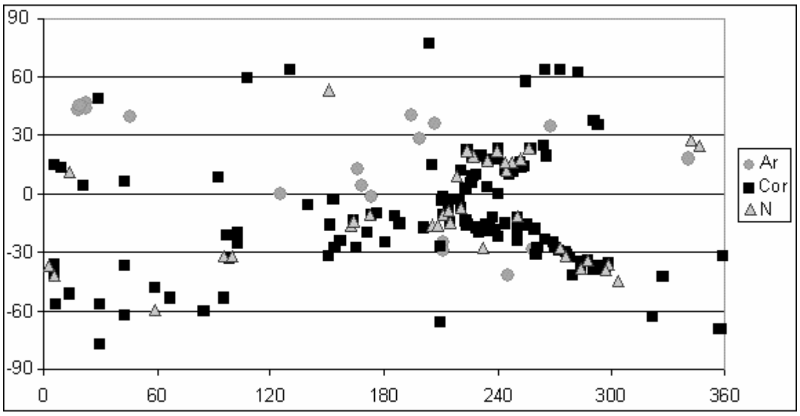

Figure 29. Distribution of type Ia volcano-tectonic structures on Venus´ surface. The arachnoids located within deformation zones are still different from the others, mainly because the form of deformation is different (compressional – ridge belts).

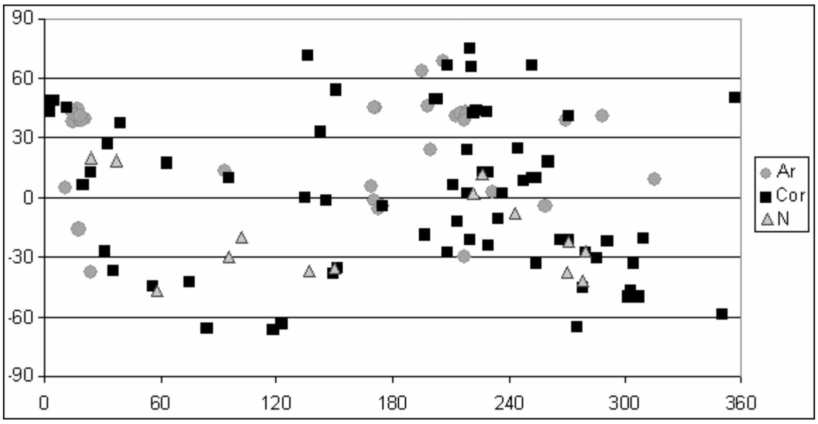

Figure 30. Distribution of type Ib volcano-tectonic structures.

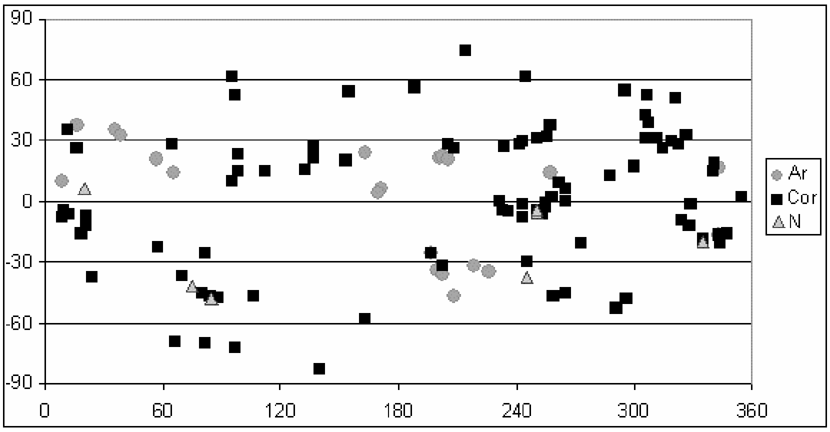

Figure 31. Distribution of type II volcano-tectonic structures.

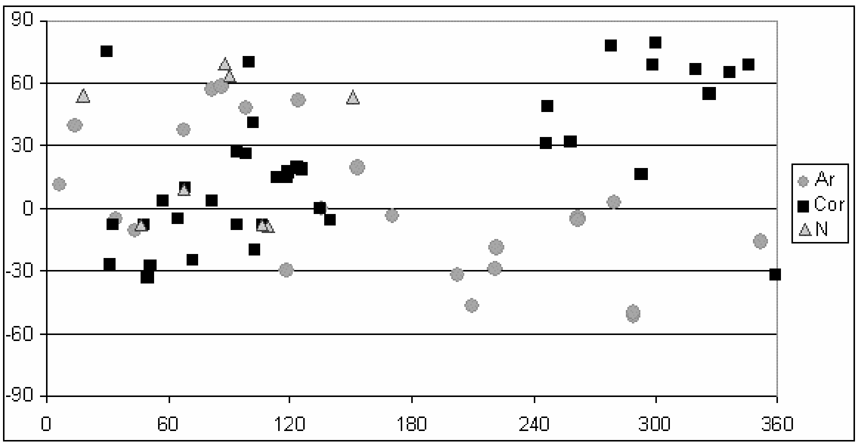

Figure 32. Distribution of type III volcano-tectonic structures. Although all located near tessera, the features are not in same locations.

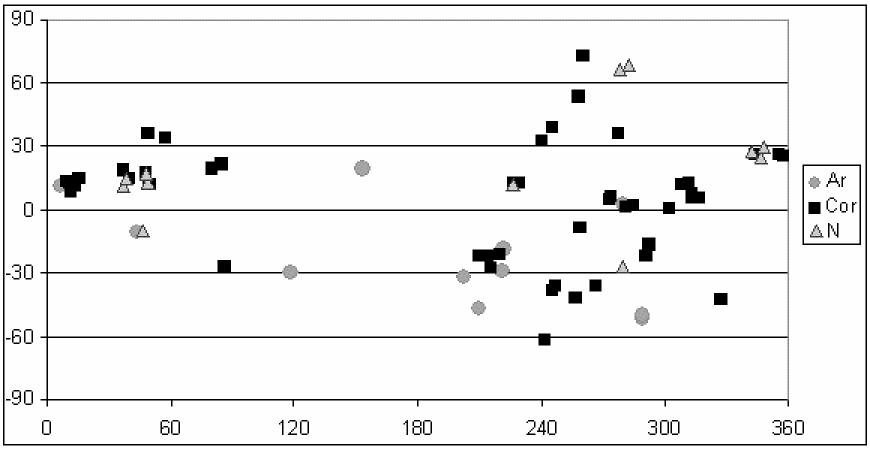

Figure 33. Distribution of type IV volcano-tectonic structures.

Particularly the structures on deformation zones (type Ia) display distinct divergences (Fig. 28) to each other. The novae have the most concentrated distribution, mainly within the BAT -region. Coronae are also situated to the rift zones close to the equator. Arachnoids, however, are located much more sporadically as they are not in association with the equatorial rift zones, but instead they are found on ridge belts and other compressional deformation.

Type Ib structures show the same kind of distributions, even though novae and coronae are not so distinctly connected to the BAT-region (Fig. 29). These divergences confirm the different nature of deformation zones associated with volcano-tectonic structures, with novae and coronae usually being in connection to rift zones and arachnoids to zones with compressional structures. Type II novae and coronae are rather evenly distributed, in contrast to the type I features, but arachnoids show distinguishable concentrations. These concentrations correspond well to area between Bereghinya Planitia and Bell Regio as well as to the regions to the north and south from the Atla Regio (Fig. 30).

The structures close to the tessera areas (type III) display very divergent concentration in different regions on the planet (Fig. 31). Coronae are situated close to the Ovda Regio and Lakshmi Planum and novae close to the Ovda Regio as well as around the region between Fortuna tessera and Tethus Regio. Arachnoids are distributed more evenly and totally different regions than type III coronae, displaying concentrations close to the Fortuna tessera and to region south from BAT-area. As in type III, the distribution of type IV structures reveals the diverse nature of coronae, novae and arachnoids (Fig. 32). Explicitly, coronae display concentrations within the region between Eistla and Bell Regii and on the volcanic plains of BAT Regio. On the contrary, most of the novae in type IV are situated to the surroundings of the Eistla and Bell Regii. This study confirms the interpretations of earlier studies, in which the arachnoids on the volcanic regions (type IV) were supposed to represent diverging properties compared to the other arachnoids (more nova- and corona-like), including also the distribution to the southern hemisphere (Kostama and Aittola 2000; Papers I and V).

7.3. Altimetric associations

The altitudes of coronae, novae and arachnoids have some variations with novae locating in highest and arachnoids in lowest altitudes, in general (Kostama and Aittola 2001; Kostama and Aittola 2002). By measuring altitudes of different types we can compare coronae, novae and arachnoids, but most of all, it enables us to observe altitudinal variation between structures placed in the same environmental settings, Type I-IV.

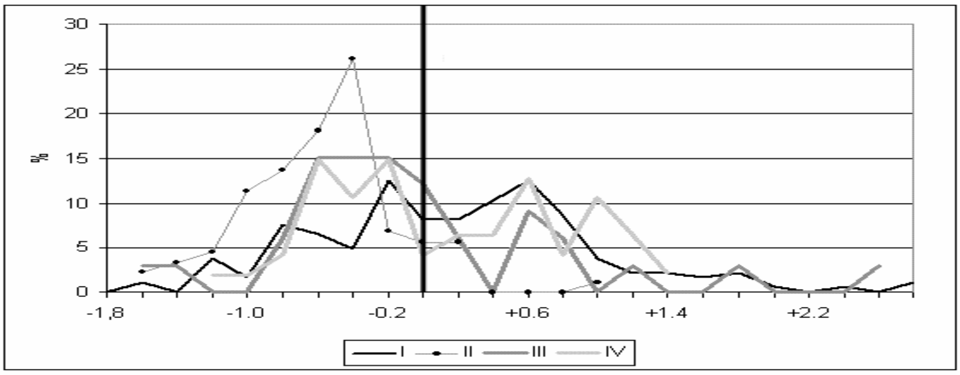

Figure 34. The altimetric distribution of corona types in percentages of total population. Dark vertical line represents the MPR, and the plot shows deviation from that in kilometers.

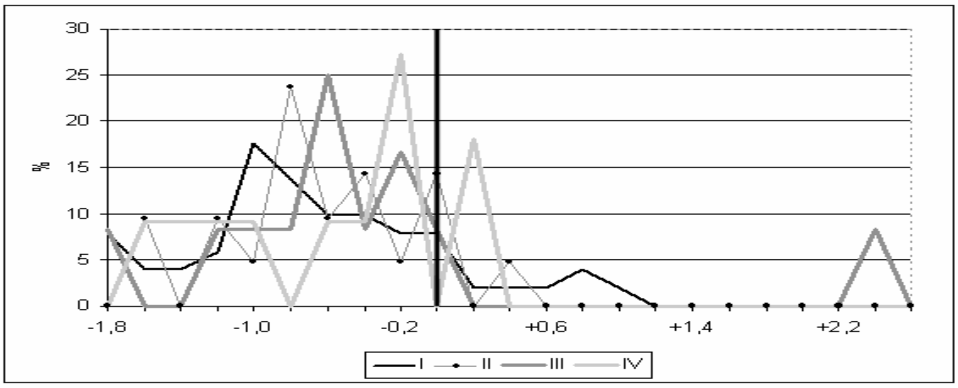

Figure 35. The altimetric data of arachnoid types in percentages of total population. Dark vertical line represents the MPR, and the plot shows deviation from that in kilometers.

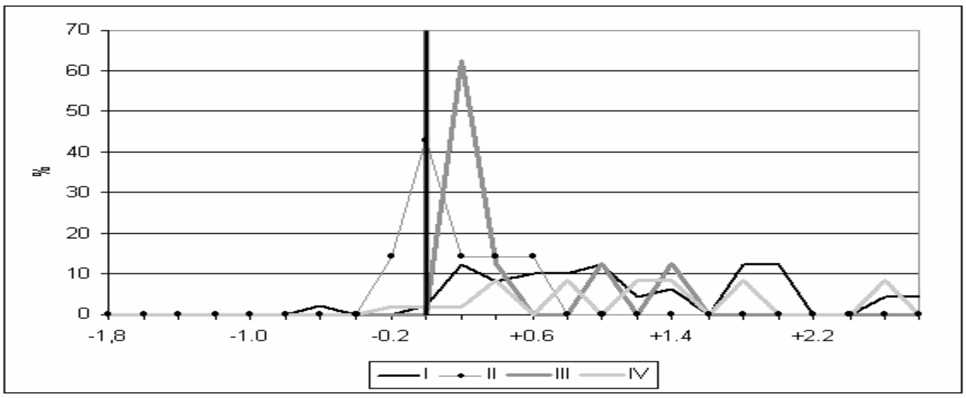

Figure 36. The altimetric data of nova types in percentages of total population. Dark vertical line represents the MPR, and the plot shows deviation from that in kilometers.

Coronae show some altitudinal variations with type II representing structures with distinctly lowest and types Ia and IV highest altitudes (Fig. 34) of the features. Majority of type II coronae locate below the MPR, and only few of them are found above the MPR. On the contrary, the type Ia coronae are situated above the MPR and also high number of the type IV coronae are located in high altitudes, i.e. volcanic highlands. Most of the type III coronae locate below the mean planetary radius, but there are few examples, which locate in very high regions (on the tessera terrain, which is high ground) and increase the mean altitude of type III coronae.

When comparing the arachnoids and coronae within the environmental types, we notice that they favor much lower regions than coronae, in general (Kostama and Aittola 2001; Fig. 35). In addition, there are not very distinguishable divergences between types than in the cases of coronae and novae (compare to Fig. 34 and 36). Types Ia and IV arachnoids include some amount of structures that are above MPR. In contrast to coronae and novae, the type III arachnoids tend to locate on higher altitudes than type I. In type III there are also structures with exceptionally elevated areas, thus representing the features on tessera terrain. Type I structures are located in lower regions compared to type I specimens of coronae and novae. That is probably due the nature of deformation belts, which arachnoids are associated with.

Generally, novae are located in higher grounds than the other volcano-tectonic structures (Kostama and Aittola 2002, 2001). The type II novae are exceptions with altitudes close to the MPR (which is expected due to the low lying areas (plains) of this environment type. Types Ia and IV novae have more or less same kind of altitudinal graphs and like in the case of coronae they are located in the highest areas (Fig. 36).

7.4. Size distribution and geology

As it was discussed in the previous chapters, the coronae tend to be larger in diameter than arachnoids (Kostama and Aittola 2002). However there are some engrossing variations, which depend on to which environmental type the feature belongs to. The mean diameter of type II arachnoids is smallest and type Ib arachnoids largest, while types Ia and IV represent approximately the average diameter of arachnoids (Fig. 37). In the case of coronae, the type Ib contains structures with smallest diameter and - in contrast to arachnoids - coronae in the type IV have diameter below the average value, in general (Fig. 12). The largest coronae tend to favor the deformation zones (Type Ia). Rather small ratios in diameter of coronae and arachnoids displays that arachnoids in type Ib and III have diameters closest to coronae (Table 3). On the contrary, coronae and arachnoids on the plains show larger ratio compared to other types, indicating that the arachnoids on plains (Type II) are exceptionally small.

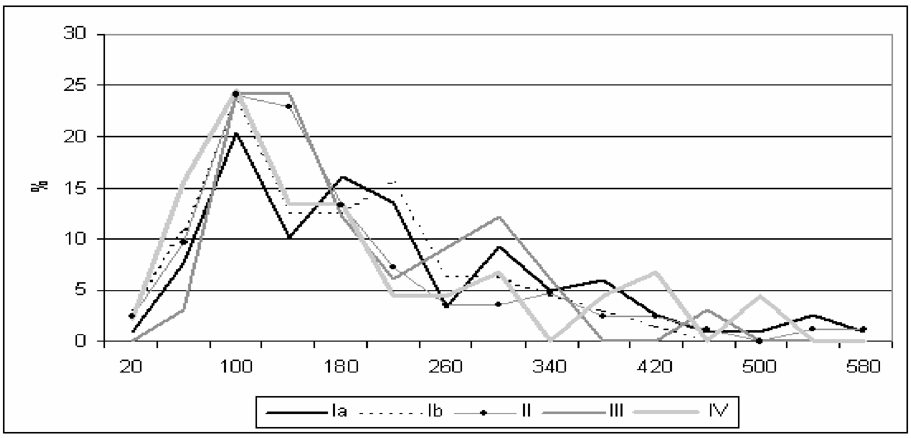

Figure 37. The proportions of different size coronae (diameters in km) in context with their types.

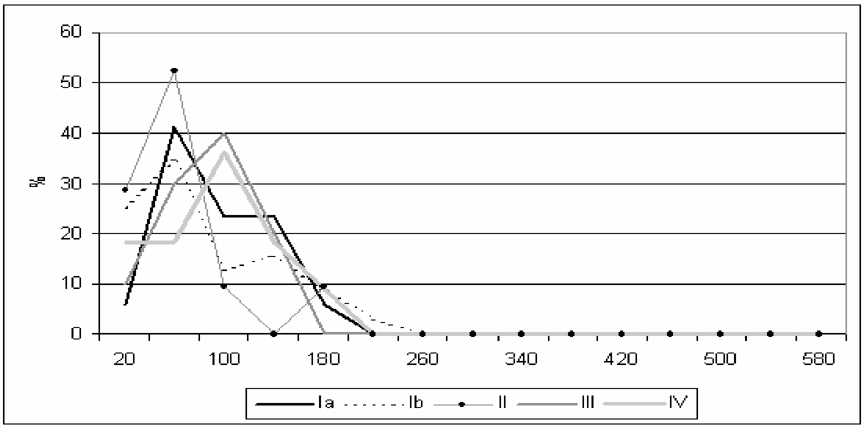

Figure 38. The proportions of different size arachnoids (diameters in km) in context with their types.

	Ia	Ib	II	III	IV	Avg.
Coronae	225.74	188.44	199.81	206.42	198.78	207.0
Arachnoids	119.31	139.10	114.88	133.11	130.36	128.9
ratio C/A	1.89	1.35	1.74	1.55	1.52	1.58

Table 3. The mean values (in kilometres) of the diameters of corona and arachnoid environmental types. Bottom row presents the ratio of corona and arachnoid diameters. The arachnoids are predominantly small in all types, while coronae (types Ia and II in particular) are much larger.

8. Conclusions and discussion

There are a few important points that were considered within this study :

Understanding Venus: Without plate tectonics, Venus must have an alternate heat transfer system. Considering the heat flow models (e.g. Solomon and Head 1982; Turcotte et al. 1995; Solomatov and Moresi 1996) the various endogenic structures and formations of Venus can substitute for an answer for at least part of this problem (e.g. Leitner and Firneis 2005; Stofan et al. 2001). The widely spread coronae and related structures have been a focus of much research (e.g. Stofan et al. 1992, 1997, 2001; Head et al. 1992; Crumpler and Aubele 2000; Papers I-V) since the first missions to Venus. However, understanding the whole picture of Venusian volcano-tectonics and endogenic activity requires a thorough research of the global suite of different feature types, and their relationships. Our still evolving catalogue (Appendix I & II; Table 2; Paper I) aims to enhance and clarify the previous work done by other researchers in order to **a.** more confidently recognize and characterize structure types **b.** add more information to the single structures within each group (Paper I, Paper IV, Paper V).

Acceptance of the variety of structure groups: During our research we have found that all the four volcano-tectonic surface forms (coronae, arachnoids, novae and corona-novae (Aittola and Kostama 2002; Paper IV)) deviate in their characteristics from each other in amount that they can and should be considered as separate structure types (Papers I-V). The proposed and already widely used terms are practical to use, but do not elaborate on the details of the formation process or their origin. This minimizes the interpretations of the separate researchers. It is important to note, that new, artificial terms for structures does not provide any new insight to the formations in question or to their characteristics, but neither does the other extreme: eradicating all but one governing group. It is certain, that the process leading to the formation of the volcano-tectonic structures is always very complex and understanding that process requires detailed study and mapping of the singular structure in question. Therefore, the terms that describe a formation or evolution process are not viable, because the morphology, volcanism, topography, geological environment and the phases of the formation process may differ in separate specimen. The simple and descriptive terms – corona, arachnoid, nova and corona-nova – of these widely studied structures, are convenient, readily characterize the specified features and can be successfully used for further classification and characterization studies. All things considered, the fact that these structures may be recognized apart from each other reinforces the use of separate terminology for these features.

Formation of the structures: The processes that result in different morphological features are complex. For arachnoids we can propose at least three different, but possible origins (Paper V). In one of those, the novae formed by possible dike injection (Grosfils and Head 1994b) may deform into some of the arachnoids (Paper V). Nova and Corona-novae formation (Paper IV) may include both radial fracturing and also the dike emplacement

Geological environment <u>does</u> have a great influence: It has been suggested that very likely coronae, novae, arachnoids and calderas were formed at least partly due to same basic processes controlled by few main geological factors that determine main characteristics of the structures. Still, based on our studies, all presented feature groups seem to have specified distributions of their own (Figs. 20-35) and also show deviations in morphology and other characteristics based on their locations. We do agree with - for example Krassilnikov (2006) - that the transition between types of structures is not sudden; the features do show characteristics typical to another group in certain geological locations (Paper II).

Areal geology can be used as basis for characterization: The location in different geological environment can be used in characterization of structures (Paper I). Four types of general Venusian surface were used: I - deformation zones, II - plains, III - tessera regions, IV - volcanic regions. The types are based on the plausible assumption that the geological environment must have a profound impact on the formation process (Paper II) of any structure and may well be the factor that determines which kind of feature is formed in the first place (Paper). Studying the structures in context with the different geological environment types, geological mapping and stratigraphy will, and already has revealed some new information useful in the ongoing effort of trying to clarify the complexity of the volcano-tectonics of Venus. The characterization is presented in this study for the studied four feature groups, but it is viable and usable for other endogenetic features as well.

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Appendix I

The Catalogue of Venusian Volcano-tectonic Features

Kostama and Aittola 2001

ARACHNOIDS

Lat.	Long.	Altit.	Env. Type	Name	Diameter
68.5	206	6050.37	Ib		88 x 48
63.5	195	6051.01	Ib		44
58.5	86	6051.41	III		48 x 84
57	82	6050.74	III	Malintzin Patera	66
51.5	124.5	6051.22	III		140
48	98	6050.94	III	Hiei Chu Patera	152
46.5	22	6051.23	Ia		100 x 64
46	198	6051.08	Ib	Razia Patera	188 x 128
45	19.5	6051.82	Ia		64
45	171	6050.31	Ib	Fedsova Patera	80
45	170.5	6050.63	Ib		56
45	170	6050.19	Ib		48
44.5	17	6050.98	Ib		148
44	14	6050.99	Ib		136
43.5	22	6051.34	Ia		28
43	18.5	6050.72	Ia		140 x 120
43	218	-	Ib		104 x 160
42	215	6050.87	Ib		136 x 200
41.5	15.5	6051.53	Ib		172
41.5	218	6051.16	Ib		80
41	18.5	6050.83	Ib	Trotula Patera	52
41	288.5	6051.59	Ib		208 x 180
40.5	212.5	6050.41	Ib		96 x 120
40	194	6051.66	Ia		80 x 60
39.5	20.5	6050.92	Ib		128 x 72
39.5	46	6051.8	III		110 x 92
39.5	14	6050.11	Ia		96 x 208
39	18.5	6050.68	Ib	Yaroslavna Patera	108 x 80
38.5	269	6051.1	Ib		328 x 60
38.5	217	6051.84	Ib		240
38.5	19	6050.99	Ib	Cavell Patera	48
38	15	6050.46	Ib		60
37.5	67.5	6050.07	III		120 x 100
37	16.5	6050.25	II		96
35.5	207	6050.03	Ia		132
35	36	6050.71	II	Hroswitha Patera	210
34	267.5	6051.53	Ia		48 x 88
32	38.5	6051.45	II		44 x 24
28	198.5	6051.89	Ia		140 x 120
23.5	199.5	6051.5	Ib		40 x 60
23.5	163	6051.11	II		32
22	202	6051.41	II		80 x 48
21.5	201	6051.12	II		40 x 48

20.5	205	6051.55	II		60
20.5	56.5	6050.22	II		88 x 80
19.5	153.5	6051.46	Ib	Ituana Corona	120 x 180
18	341	6050.27	IV	Chiun Corona	140 x 100
16	343	6050.59	IV		96
14	257	6050.98	Ia		80
14	65.5	6051.06	II		72 x 128
13.5	93	6050.88	II		68 x 80
13	165.5	6051.21	II		140 x 100
11	6.5	6050.06	Ib		120 x 160
10	9	6051.3	Ia		92 x 72
9	315.5	6050.66	IV	Madderakka Corona	220
6	171	6051.86	II		40 x 60
5.5	169	6051.16	Ib		88
5	11	6050.69	II		68
4	169.5	6051.26	Ib		60 x 80
4	168	6051.61	Ib		32
2.5	280	6051.1	II		80
2.5	231.5	6050.84	Ia		180
0	125	6052.69	Ia	Rosmerta Corona	
-0.5	135	6054.21	III	Blai Corona	
-1.5	173.5	6051.77	Ia	Saunau Corona	220 x 160
-2	170	6051.19	Ib		48 x 80
-4	170.5	6052.7	Ib		100
-4.5	261.5	6051.3	III	Krumine Corona	160 x 200
-4.5	259	6051.02	III		108
-5	175	6052.51	Ib	Eigin Corona	180
-5.5	34	6051.33	III		-
-6	261.5	6051.75	III		64
-6.5	172.5	6052.15	Ib		80 x 48
-11.5	44	6050.88	IV		140 x 200
-16.5	352	6051.63	Ib	Tumas Corona	360
-16.5	18	6051.81	III	Fatua Corona	48 x 60
-17	343	6051.02	II	Bhumidevi Corona	192
-19	221.5	6051.64	IV		140 x 180
-25	211	6050.89	Ia		120
-26	196	6051.6	II	Payne Gaposchkin Pat.	80
-28.5	258.5	6051.85	Ia		160
-29	221	6051.67	IV		24
-29.5	211	6051.01	Ia		80
-30	217	6051.4	IV		48 x 68
-30	118	6052.89	Ib		-
-32.5	219	6052.11	IV		140
-32.5	202	6051.67	II	Nott Corona	56
-34.5	199	6051.4	II	Libbu Patera	80
-35	226	6051.95	II		80
-36.5	202	6052.38	II		80 x 120
-38	23.5	6052.31	Ib	Ninhursag Corona	100
-42.5	245.5	6051.27	Ia		140 x 160
-47	209.5	6052.11	IV	Banba Corona	104
-47	208	6051.84	II	Banba Corona	120
-50	289.5	6051.7	IV		140
-51.5	289.5	6051.55	IV	Tureshmat Corona	88

Coronae

Lat.	Long.	Altit.	Env. Type	Name	Diameter
79.5	300	6052.08	III	Pomona Corona	280 x 240
77.5	278	6051.89	III	Anahit Corona	420 x 300
77	204	6052.34	Ia	Maslenitsa Corona	216 x 148
75	30	-	III		-
75	220	6051.75	Ib		120
74	214	6051.04	II		96 x 120
73	260	6052.85	IV	Bachue Corona	540 x 400
71	136	6052.54	Ib	Earhart Corona	280 x 260
70	100	6052.54	III	Tusholi Corona	380 x 140
68	298	6052.08	III	Otau Corona	160
68	346	6053.64	III		320 x 280
66.5	320	-	III		140 x 120
66	208	6050.7	Ib	Cassatt Corona	100 x 120
66	252	6051.67	Ib		350 x 250
65.5	221	6051.87	Ib	Ninkarraka Corona	80
64.5	336	6052.7	III	Sacajawea Patera	260 x 140
63.5	273	6052.03	Ia	Coatlicue Corona	200 x 240
63	130	6052.44	Ia	Nightingale Corona	400 x 480
63	265	6051.32	Ia	Rananeida Corona	480 x 420
61.5	283	6050.68	Ia		180
61	95	6051.84	II	Vacuna Corona	280 x 240
61	245	6050.73	II		80 x 120
59	108	6052.5	Ia	Fakahotu Corona	280 x 200
57.5	255	6052.76	Ia		252 x 160
56	188	6050.82	II	Aspasia Corona	232
54.5	295	6050.91	II	Demeter Corona	640 x 312
54.5	326.5	6051.23	III		172
54	151	6051.41	Ib	Mari Corona	160 x 120
53.5	155	6050.73	II	Holde Corona	140 x 180
53	258	6051.67	IV	Bau Corona	-
52.5	96.5	6051.37	II		84
52.5	306.5	6051.3	II	Beiwe Corona	-
51	321	6050.48	II	Xilonen Corona	-
50	357	6051.64	Ib	Ashnan Corona	220 x 320
49.5	201.5	6051.31	Ib	Cerridwen Corona	240 x 200
49.5	203	6051.1	Ib	Neyterkob Corona	180 x 220
49	3.5	6052.05	Ib		-
49	5	6051.99	Ib	Onatah Corona	320 x 300
49	29	6053.44	Ia		96 x 140
49	247	6050.39	III	Nalwanga Corona	280
48	360	6051.58	Ia	Ba'het Corona	160 x 272
45.5	12	6051.34	Ib	Audhumla Corona	132
44	223	6051.98	Ib		188 x 260
43	3	6051.52	Ib	Vasudhara Corona	140
43	228	6051.87	Ib	Ki Corona	420 x 360
42	222	6053.1	Ib		152 x 96
42	306	6050.7	II		100 x 148

Lat.	Long.	Altit.	Env. Type	Name	Diameter
41	271	6051.06	Ib	Rauni Corona	240 x 280
40.5	102	6051.39	III	Maa-Ema Corona	280 x 380
39	307	6051.03	II		140
38.5	245.5	-	IV		44
37.5	290.5	6051.12	Ia	Emegen Corona	100 x 140
37	39.5	6051.2	Ib	Kotlauer Corona	140 x 112
37	257	6051.23	II	Junkgowa Corona	232 x 144
36	49	6052.5	IV	Nefertiti Corona	372 x 220
36	277.5	6052.41	IV		64
35	12	6051.59	II		180 x 280
35	293	6051.76	Ia	Blathnat Corona	220
33.5	57	6051.41	IV	Kayanu-Hime Corona	120
33	143	6051.05	Ib	Ved-Ava Corona	184 x 252
32.5	326.5	6051.24	II	Renenti Corona	200 x 140
32	240	6051.27	IV	Mawu Corona	428
31.5	255.5	6050.94	II		180
31.5	258	6051.69	III	Zamin Corona	280 x 320
31	246.5	6051.1	III		140
31	250.5	6050.68	II		180
31	306	6051.42	II	Janzai Patera	240 x 180
31	312	6051	II	Zemire Corona	200
29	243	6050.47	II		160
29	319	-	II	Pasu-Ava Corona	300
28	65	6051.21	II	Hatshepsut Patera	96
28	141.5	6051.44	Ib	Cauteovan Corona	352
28	205	6051.84	II		196
28	241.5	6050.39	II		92 x 120
28	323	6050.9	II		-
27	136.5	6051.2	II	Boann Corona	260 x 220
26.5	94	6051.39	III	Eurynome Corona	212
26.5	233.5	6051.46	II	Pehilka Patera	92 x 108
26.5	33	-	Ib	Seshat Mons	120
26	16	6051.34	II	Beyla Corona	312 x 224
26	98	6051.54	III	Metro Corona	192
26	208	6052.27	II		160 x 120
26	314.5	651.11	II		224 x 260
26	343.5	6051.51	IV	Purandhi Corona	-
25.5	355.5	6052.67	IV	Nissaba Corona	180 x 160
25	358	6053.16	IV	Idem-Kuva Corona	220
24.5	244.5	6050.94	Ib		220 x 240
24.5	264	6056.49	Ia		88
23.5	218.5	6053.69	Ib		120 x 92
23	98	6051.21	II	Maya Corona	228
22.5	240	6052.62	Ia		112
22.5	257	6052.24	Ia		100
22	224	6054.79	Ia		152
21	84.5	6052.16	IV	Ereshkigal Corona	340 x 300
21	136.5	6051.2	II	Kamadhenu Corona	380 x 480
20	153.5	6051.46	II	Ituana Corona	192 x 128
19.5	80	6052.45	IV	Kunhild Corona	180 x 160
19.5	227	6054.79	Ia		140 x 180
19.5	231.5	6052.46	Ia	Pani Corona	292

Lat.	Long.	Altit.	Env. Type	Name	Diameter
19	123.5	6051.44	III	Nintu Corona	68
19	265.5	6052.32	Ia		160 x 128
18.5	37.5	6052.5	IV	Didilia Corona	340 x 260
18.5	125.5	6051.38	III	Abundia Corona	216
18.5	340.5	6050.27	II	Chiun Corona	132 x 112
18	240	6051.55	Ia		136
17.5	260.5	6052.36	Ib		248 x 192
17	48	6052.32	IV		540 x 320
17	63.5	6051.25	Ib		68
17	119	6051.52	III	Omeciuatl Corona	120 x 180
17	234.5	6053.07	Ia	Perchta Corona	360 x 280
17	299.5	6051.03	II	Grizodubova Patera	100
16.5	252	6052.2	Ia	Taranga Corona	400
16	293	6051.7	III		180 x 140
15.5	132.5	6051.52	II	Kubebe Corona	100 x 120
15	98	6051.79	II		168
15	114	6051.51	III	Allatu Corona	140 x 120
15	118	6051.28	III	Bhumiya Corona	136
14.5	6	6051.65	Ia		44
14.5	15.5	6052.81	IV		180
14.5	40	6052.88	IV	Pavlova Corona	360 x 400
14.5	112	6051.59	II	Dhisana Corona	96 x 72
14.5	205	6053.98	Ia	Nahas-tsun Mons	160 x 180
14.5	340	6051.11	II	Benten Corona	400 x 280
14	254.5	6050.36	Ia		68
13.5	10	6051.78	IV/Ia	Nehalennia Corona	272
13.5	253	6051.02	Ia		140
13	11	6051.38	IV		112
13	24	6051.59	Ib	Libera Corona	320 x 280
13	226.5	6053.26	IV/Ib		160
13	288	6051.42	II	Zhivana Corona	124
12.5	229	6052.74	Ib/IV		184
12.5	312	6051.58	IV		88
12	49.5	6053.2	IV	Isong Corona	520
12	221	-	Ia	Zisa Corona	360
12	244	6052.24	Ia		160 x 208
12	308	6052.44	IV	Hulda Corona	180 x 224
11	14	6053.1	IV		180 x 120
11	248.5	6051.4	Ia		220 x 260
10	95	6051.65	Ib/II		120 x 96
10	228.5	6051.31	Ia		160 x 128
10	246	6050.26	Ia		140
10	252	6050.64	Ib		128
9.5	68.5	6051.72	III	Huraru Corona	120
9.5	254.5	6051.19	Ib		124
9	226.5	6051.7	Ia		108
9	262	6052.32	II	Aruru Corona	360 x 280
8.5	92	6052.09	Ia	Atse Estsan Corona	100 x 120
8	12	6050.77	IV	Sunrta Corona	140 x 120
8	247.5	6050.73	Ib		148 x 108
7.5	313.5	6051.73	IV		96
6.5	43.5	6051.73	Ia	Calakomana Corona	300 x 360

Lat.	Long.	Altit.	Env. Type	Name	Diameter
6	20	6051.38	Ib	Belet-Ili Corona	200
6	211	6051.4	Ib		48
6	265	6051.1	II	Shulzhenko Patera	56
6	273.5	6050.89	IV		122
5.5	226	6051.98	Ia	Ayrton Patera	88
5.5	313	6051.82	IV		68
5.5	316.5	6052.16	IV		240 x 140
4.5	273	6051.78	IV		180 x 200
4	21	6051.69	Ia	Gaia Corona	360 x 240
3.5	234	6051.26	Ia		180 x 240
3	57.5	6051.66	III		100 x 140
3	82	6052.53	III	Habonde Corona	120
2.5	223	6052.6	Ia		-
2	219	6051.5	Ib		92 x 76
2	236.5	6052.41	Ib		216 x 240
2	285	6052.91	IV		220
2	355	6051.09	II	Heng-O Corona	920
1.5	258	6051.23	II		80 x 68
1	281	6051.06	IV		160 x 112
0.5	302	6051.92	IV	P–l–znitsa Corona	520
0	240	6051.1	Ia		84 x 100
0	264.5	6051.36	II		148 x 100
-0.5	134.5	6052.76	Ib/III	Blai Corona	60 x 80
-0.5	231.5	6051.32	II		140
-1	255	6050.92	II		100 x 120
-1.5	211	-	Ia		136 x 180
-1.5	328.5	6051.42	II	Yanbike Corona	140 x 184
-2	145.5	6052.5	Ib	Hepat Corona	112 x 80
-2	243	6051.51	II		168 x 120
-3	153	6052.41	Ia	Seia Corona	180
-3	215	6052.3	Ia		224
-3	220.5	6051.13	Ia		84 x 108
-3.5	255	6051.58	II		180 x 160
-4	210.5	6052.34	Ia		232
-4.5	10	6051.27	II	Kuan-Yin Corona	320 x 248
-5	175	6052.36	Ib	Eigin Corona	176 x 132
-5	232.5	6051.01	II		92
-5	251	6052.1	II	Javine Corona	320 x 420
-5.5	65	6051.68	III	Verdandi Corona	136
-5.5	235.5	6051.55	II		100 x 120
-6	140	6052.68	Ia/III		140 x 240
-6.5	214	6051.91	Ia	Jotuni Patera	80 x 104
-7	13	6050.84	II	Thouris Corona	160
-7	254	6050.85	II		68 x 48
-7.5	21	6051.41	II	Cybele Corona	440
-7.5	221	6053.71	Ia	Maram Corona	240
-8	9	6051.81	II	Atargatis Corona	-
-8	33	6051.2	III	Thermuthis Corona	160
-8	48	6051.84	III	Nabuzana Corona	480
-8	94	6054.42	III		160 x 180
-8	243	6052.23	II	Dhorani Corona	220 x 176
-8.5	106.5	6053.03	III		220

Lat.	Long.	Altit.	Env. Type	Name	Diameter
-9	214	6053.79	Ia		100 x 128
-9	259	6051.3	IV		84
-10	324	6051.11	II		164
-10.5	176.5	6052.9	Ia	Sith Corona	400 x 260
-11	173	6054.22	Ia		200
-11	211.5	6052.93	Ia	Oduduwa Corona	104
-11.5	234.5	6050.66	Ib	Erkir Corona	144 x 180
-12	186	6052.51	Ia	Zemina Corona	400
-12.5	250.5	6052.3	Ia	Ludjatako Mons	300 x 180
-12.5	328	6051.62	II		200
-13	21	6051.5	II		192
-13	213.5	6052.14	Ib		168
-13	237.5	6051.17	Ia		88 x 68
-14	164	6053.24	Ia	Miralaidji Corona	360
-14	223	6052.03	Ia		200
-15	215	6052.52	Ia	Mbokomu Mons	180
-15.5	188	6052.5	Ia		100
-15.5	244	6052.13	Ia	Atete Corona	500 x 300
-16	151.5	6051.68	Ia	Ceres Corona	340 x 620
-16	233.5	6052.73	Ia	Erkir Corona	200 x 232
-16	234.5	6051.71	Ia		160 x 240
-16.5	18.5	6051.81	II	Fatua Corona	392
-16.5	224	6051.64	Ia		128 x 96
-16.5	255.5	6052.93	Ia		136 x 112
-16.5	347.5	6051.56	II	Iyatik Corona	152
-17	236	6050.85	Ia		128
-17	292	6051.45	IV		188 x 160
-17	343	6050.98	II	Bhumidevi Corona	120
-18	201	6051.67	Ia		148 x 120
-18	228	6051.05	Ia		88 x 64
-18.5	250.5	6051.78	Ia		140 x 120
-18.5	259.5	6052.3	Ia	Nagavonyi Corona	100
-19	233.5	6051.05	Ia	Beruth Corona	120
-19	238.5	6052.3	Ia	Aeracura Corona	220 x 200
-19	335	6051.48	II	Pugos Corona	140
-19.5	196	6052.69	Ib		224 x 196
-20	102.5	6052.2	Ia/III		-
-20	171	6052.6	Ia	Atahensile Corona	560
-20	230	6052.11	Ia		120
-20.5	212	6051.64	IV		120
-20.5	273	6052.86	II		96
-20.5	309.5	6052.59	Ib	Iweridd Corona	340 x 400
-20.5	344	6051.27	II	Takus Mana Corona	120 x 80
-21	220	6051.71	IV/Ib		88
-21	266.5	6051.3	Ib		60
-21.5	97	6052.45	Ia		140 x 120
-21.5	220.5	6051.13	IV/Ib		124 x 80
-21.5	271	6053	Ib		128 x 184
-22	210	6051.21	IV	Villepreux-Power Pat.	88 x 108
-22	214	6051.36	IV		100
-22	240.5	6051.75	Ia		120
-22	291	6052.9	IV/Ib	Atai Mons	88

Lat.	Long.	Altit.	Env. Type	Name	Diameter
-22.5	57	6051.69	II	Ma Corona	400
-23.5	265	6052.75	Ia		300
-24	157	6052.85	Ia	Bona Corona	220
-24	229	6051.87	Ib		120
-24	251	6052.68	Ia		480 x 320
-25	72.5	6051.53	III	Nishtigri Corona	220
-25	181	6052.36	Ia		320
-25	269	6052.13	Ia	Hervor Corona	240
-25.5	103	6052.23	Ia		184
-25.5	196	6051.6	II	Payne-Gaposchkin Pat.	92
-26	82	6051.3	II	Aramaiti Corona	320
-27	31	6051.84	Ib/III	Mama-Allpa Corona	280
-27	86	6051.3	IV	Ohogetsu Corona	160 x 120
-27	210	6051.84	Ia		240 x 120
-27.5	51	6051.86	III	Umay-ene Corona	320 x 300
-27.5	154	6052.51	Ia	Mayauel Corona	160
-27.5	165	6052.65	Ia	Agraulos Corona	120 x 152
-27.5	208.5	6051.6	Ib	Epona Corona	240
-27.5	216	6051.67	IV		160 x 128
-27.5	261	6052.79	Ia		240
-28	270	6051.61	Ia	Xmukane Corona	160
-28	280	6053.27	Ib		140
-29.5	272	6052.06	Ia	Lilwani Corona	400 x 280
-30	245.5	6051.3	II		140 x 160
-30	276	6052.3	Ia	Gertjon Corona	140
-31	285.5	6051.8	Ib		220
-31.5	260	6051.89	Ia		300
-31.5	276.5	6052.37	Ia	Obiemi Corona	240 x 220
-32	151	6052.8	Ia	Colijnsplaat Corona	360 x 240
-32	202	6051.6	II	Nott Corona	120
-32	359	6052.57	III/Ia	Eve Corona	360
-33	278.5	6052.34	Ia	Rigatona Corona	180
-33.5	50	6050.48	III	Zernlika Corona	140
-33.5	98.5	6051.93	Ia	Gefjun Corona	300
-33.5	254.5	6050.85	Ib	Oanuava Corona	160
-33.5	304	6052.69	Ib		220
-34.5	287.5	-	Ia	Santa Corona	120 x 100
-35	284.5	6052.23	Ia	Erigone Corona	60 x 80
-35.5	152	6051.87	Ib	Annapurna Corona	360 x 240
-36	298.5	6052.56	Ia	Tamiyo Corona	240 x 124
-36.5	6	6052.17	Ia	Tamfana Corona	280
-36.5	247	6051.47	IV		180 x 220
-36.5	266.5	6052.03	IV	Nordenflycht Patera	240 x 160
-37	36	6052.23	Ib	Inanna Corona	180 x 220
-37	43	6050.76	Ia	Xcanil Corona	144
-37	70	6051.6	II	Indrani Corona	160
-37	293	6052.63	Ia	Semiramus Corona	340
-38	23.5	6052.31	II	Ninhursag Corona	112
-38.5	149.5	6050.66	Ib	Teteoinnan Corona	120
-38.5	245.5	-	IV	Chugindak Mons	
-38.5	284.5	6053.72	Ia	Shulamite Corona	260
-39	296.5	6053.52	Ia	Ukemochi Corona	300

Lat.	Long.	Altit.	Env. Type	Name	Diameter
-39.5	291	6052.31	Ia	Zywie Corona	200
-42	6	6052.16	Ia	Selu Corona	320 x 420
-42	256.5	6051.31	IV		100
-42	279.5	6053.57	Ia	Shiwanokia Corona	420 x 360
-43	75	6051.53	Ib	Copia Corona	340
-43	327	6052.43	Ia/IV		400
-45.5	55.5	6051.51	Ib	Codidon Corona	260 x 220
-46	80	6050.84	II	Khotun Corona	128
-46	264.5	6051.5	II	Enekeler Corona	320 x 240
-46	278	6052.06	Ib	Ama Corona	280 x 180
-47	84	6051.25	II	Iang-Mdiye Corona	240 x 260
-47	106	-	II		92 x 140
-47	258.5	6051.58	II	Tangba Corona	180 x 152
-47	302.5	6052.47	Ib	Bibi-Patma Corona	400 x 440
-48	88	6050.6	II	Cailleach Corona	88
-48.5	296	6051.7	II	Navolga Corona	104 x 164
-49	59	6051.82	Ia	Mou-nyama Corona	152 x 240
-50	307	6051.68	Ib		48
-50.5	301	6051.84	Ib		80
-52	14.5	6051.21	Ia	Sarpanitum Corona	124
-53	291	6051.55	II	Obasi-Nsi Corona	216
-54	67	6052.45	Ia	Marzyana Corona	-
-54	95	6051.84	Ia	Triglava Corona	200 x 300
-57	6.5	6052.56	Ia	Eithinoha Corona	480 x 380
-57	30	6052.79	Ia	Otygen Corona	368 x 460
-58.5	163	6051.01	II	Fotla Corona	180 x 120
-59	350	6052.48	Ib	Jord Corona	180
-60	85	6052.55	Ia	Dunne-Musun Cor.	480 x 520
-62	241.5	6052.4	IV	Seiusi Corona	108
-62.5	43	-	Ia	Toyo-uke Corona	160 x 280
-63.5	322	6053.22	Ia	Kamui-Huci Corona	280
-64	123	6051.66	Ib	Latmikaik Corona	440 x 330
-65.5	275	6051.24	Ib	Vesuna Corona	200
-66	84	-	Ib		152 x 112
-66.5	209.5	6051.18	Ia	Phra-Naret Corona	148 x 84
-67	118	6051.75	Ib	Deohako Corona	-
-69.5	66	6051.84	II	Ilyana Corona	360
-69.5	357	6053.12	Ia	Quetzalpetlatl Cor.	
-69.5	358.5	6053.15	Ia	Boala Corona	240
-70.5	82	6051.71	II	Ambar-ona Corona	540 x 640
-73	97	6051.6	II	Mykh-Imi Corona	160
-77.5	30	6051.75	Ia	Obilukka Corona	300 x 320
-83.5	140	6051.5	II		-

Novae

Lat.	Long.	Altit.	Env. Type	Name	Diameter
69	88	6052.32	III	Ops Corona	
68	282.5	6051.84	IV	Feronia Corona	
66.5	278	6052.67	IV	Bagbartu Mons	
63.5	90	6052.14	III		
54	18	6053.29	III		
53	151	6052.15	Ia/III	Ciuacoat Mons	
34	21.5	6052.04	Ia	BÈcuma Mons	
29	348	6051.65	IV	Tutelia Corona	
27	342	6052.02	Ia/IV	Mesca Corona	
24	346.5	6051.96	Ia/IV		
22.5	256.5	6052.07	Ia		
22	84	-	IV	Ereshkigal Corona	
22	239.5	6052.84	Ia		
22	224	6055.23	Ia		
20	24	6052.21	Ib		
19.5	227	6054.75	Ia		
18.5	37.5	6053.62	Ib	Didilia Corona	
17.5	252	6052.53	Ia	Taranga Corona	
17	48	6052.36	IV		
17	234	6052.24	Ia		
16.5	248	6053.04	Ia		
16	244	6054.53	Ia		
14.5	39	6053.06	IV	Pavlova Corona	
12.5	49	6054.5	IV	Isong Corona	
12	244.5	6052.32	Ia		
12	226	6053.62	Ib/IV		
11.5	37	6052.08	IV		
11	14.5	6053.85	Ia	Anala Mons	
9	219	6054.55	Ia		
9	68	6052.01	III		
6	20	6051.98	II	Belet-Ili Corona	
1.5	222	6052.58	Ib		
-5	250.5	6052.58	II	Javine Corona	
-6.5	251	6052.27	II		
-7.5	221	6053.75	Ia	Marami Corona	
-8	243	6051.34	Ib	Dhorani Corona	
-8.5	47	6052.14	III	Nabuzana Corona	
-8.5	106.5	6052.11	III		
-9	109	6052.98	III		
-9	214	6053.75	Ia		
-10.5	47	6051.64	IV		
-11	172.5	6053.92	Ia		
-11	211	6053.12	Ia	Oduduwa Corona	
-12	251	6052.34	Ia	Ludjatako Mons	
-14	164	6053.39	Ia	Miralaidji Corona	
-15	215	6052.89	Ia	Mbokomu Mons	
-16	205.5	6052.54	Ia		
-16	208	6053.93	Ia		
-16.5	162	6052.95	Ia		
-20	102	6052.71	Ib		
-20	335	6051.81	II	Pugos Corona	

Lat.	Long.	Altit.	Env. Type	Name	Diameter
-22	271	6053.34	Ib		
-27	280	6053.31	Ib/IV	Mielikki Mons	
-27.5	273	6052.82	Ia	Ts'an Nu Mons	
-28	232	6052.46	Ia		
-30	95	6052.71	Ib		
-32	95	6052.64	Ia		
-32	99.5	6053.83	Ia		
-32	276	6052.82	Ia	Obiemi Corona	
-34.5	287.5	6052.14	Ia	Santa Corona	
-36	150	6052.15	Ib	Annapurna Corona	
-36.5	298	6052.62	Ia	Tamiyo Corona	
-37	3	6052.53	Ia	Carpo Corona	
-37	136.5	6052.63	Ib		
-38	270	6053.93	Ib	Mertzeger Mons	
-38	245.5	6051.82	II	Chuginadak Mons	
-39	284	6053.76	Ia	Shulamite Corona	
-39.5	296.5	6053.73	Ia	Rhonina Tholus	
-42	75	6052.01	II	Copia Corona	
-42	278	6053.84	Ib	Shiwanokia Corona	
-42.5	6	6052.88	Ia	Selu Corona	
-45.5	303.5	-	Ia		
-47.5	58	6052.18	Ib		
-49	85	6051.7	II	Makli Corona	
-59.5	59	-	Ia		

LEGEND

Lat.	latitude
Long.	longitude
Altit.	Altitude in km (MPR = 6051.84 km)
Env. Type	Environmental type according to presented the characterisation scheme
Name	IAU name
Diameter	Diameter of the structure in km

Appendix II

The revised survey of arachnoids

Kostama and Törmänen 2006

LAT	LON	MAX_DIAM	GEOL_ENV_CHAR	TYPE_LINEAM
78.0	20.0	150.0	III	ridge
69.0	206.0	140.0	Ib	ridge
66.5	57.0	40.0	II	ridge
63.5	195.0	70.0	Ib	fract
62.5	79.0	100.0	II	fract
58.5	86.0	84.0	III	ridge/fract
57.0	82.0	80.0	III	ridge
51.5	124.5	140.0	III	fract
51.5	124.5	140.0	III	fract
50.5	96.5	50.0	II	fract
50.1	194.0	186.0	II	ridge
50.0	270.5	40.0	II	ridge
48.9	28.0	150.0	Ia	ridge
48.2	32.6	70.0	III	ridge
48.0	98.0	152.0	III	ridge
46.5	22.0	100.0	Ia	ridge
46.2	197.8	200.0	Ib	ridge/fract
45.5	231.0	75.0	II	ridge
45.0	19.5	70.0	Ia	ridge
45.0	170.0	80.0	Ib	ridge
45.0	170.5	80.0	Ib	ridge
45.0	274.5	75.0	II	fract
45.0	171.0	80.0	III	ridge
44.2	21.5	300.0	Ia	ridge
44.0	16.5	164.0	Ib	ridge
44.0	14.0	136	Ib	ridge/fract
43.0	18.5	140.0	Ia	ridge
43.0	235.5	100.0	Ib	ridge
43.0	218.0	270.0	Ib	ridge/fract
42.5	215.0	250.0	Ib	ridge/fract
41.5	218.0	170.0	Ib	ridge
41.5	15.5	175.0	Ib	ridge
41.5	288.0	208.0	Ib	ridge/fract
41.3	21.0	182.0	Ib	ridge
41.2	6.8	230.0	Ia	fract
41.0	18.5	175.0	Ib	ridge
40.5	212.5	150.0	II	ridge
40.0	194.0	80.0	Ia	ridge
39.5	13.7	265.0	Ia	fract
39.5	20.5	128.0	Ib	ridge
39.5	46.0	110.0	III	ridge
39.0	18.5	108.0	Ib	ridge
38.5	217.0	240.0	Ia	ridge/fract
38.5	269.0	328.0	Ib	fract

LAT	LON	MAX_DIAM	GEOL_ENV_CHAR	TYPE_LINEAM
38.5	19.0	75.0	Ib	ridge/fract
38.0	15.0	65.0	Ib	ridge
37.5	67.5	175.0	III	ridge/fract
37.0	16.5	100.0	II	ridge
35.5	207.0	150.0	Ia	ridge
35.0	36.0	210.0	II	ridge
34.0	267.5	88.0	Ia	fract
33.5	263.0	100.0	Ia/III	fract
33.0	204.5	90.0	Ib	ridge/fract
32.3	305.0	100.0	Ib/III	fract
32.0	38.5	60.0	II	ridge
29.0	319.0	250.0	II	ridge
28.6	199.3	60.0	Ia	ridge/fract
28.5	199.3	60.0	Ia	ridge/fract
28.3	199.0	60.0	Ia	ridge/fract
27.5	197.8	60.0	Ia	ridge
27.3	197.3	60.0	Ia	ridge
27.1	197.6	60.0	Ia	ridge
26.5	33.0	120.0	Ib	ridge
25.0	212.0	60.0	Ib	fract
23.5	199.5	70.0	Ib	ridge
23.5	163.0	32.0	II	ridge
22.0	114.0	70.0	II	fract
22.0	202.0	80.0	II	ridge
21.5	201.0	48.0	II	ridge
21.0	56.5	100.0	II	ridge
20.5	205.0	60.0	II	ridge
19.5	153.5	218.0	Ib	ridge
18.3	341.0	150.0	IV	ridge/fract
17.0	56.0	240.0	II	ridge
16.5	200.0	50.0	Ia	fract
16.5	202.5	100.0	Ib	ridge/fract
16.0	343.0	96.0	IV	ridge
14.0	256.5	180.0	Ia	fract
14.0	65.0	128.0	Ia	ridge
13.6	291.5	70.0	III	fract
13.5	93.0	80.0	II	ridge
13.0	165.5	250.0	II	ridge
11.0	6.5	200.0	Ia	ridge
10.0	9.0	92.0	Ia	ridge
9.0	315.5	95.0	IV	ridge
6.0	171.0	60.0	II	ridge
5.5	169.0	100.0	Ia	ridge
5.0	11.0	70.0	II	ridge/fract
4.0	169.5	80.0	Ia	ridge
4.0	168.0	50.0	Ia	ridge
2.5	231.5	180.0	Ia	ridge/fract
2.5	280.0	225.0	IV	ridge/fract
1.5	296.0	80.0	III	fract
0.0	125.0	300.0	III	fract
-1.0	134.5	125.0	III	fract
-2.0	170.0	80.0	Ib	ridge

LAT	LON	MAX_DIAM	GEOL_ENV_CHAR	TYPE_LINEAM
-4.0	170.5	100.0	Ib	ridge
-4.5	261.5	200.0	III	fract
-4.5	259.0	75.0	IV	ridge
-5.5	34.0	190.0	III	ridge
-6.0	261.5	80.0	III	fract
-6.5	172.5	190.0	Ib	ridge/fract
-8.5	185.7	150.0	Ia	ridge/fract
-9.0	341.0	50.0	II	ridge
-11.0	338.0	160.0	II	fract
-11.5	33.0	150.0	II	fract
-11.5	44.0	200.0	IV	ridge
-16.5	352.0	200.0	Ib	fract
-16.5	17.7	500.0	III	ridge/fract
-17.2	343.6	200.0	II	fract
-19.0	221.5	200.0	IV	fract
-20.0	241.0	70.0	Ia	fract
-24.5	266.0	80.0	Ia	fract
-24.8	210.8	120.0	Ia	ridge
-25.5	196.0	100.0	II	fract
-28.5	258.5	200.0	Ia	fract
-29.0	221.4	30.0	IV	ridge/fract
-29.5	211.0	80.0	Ia	ridge
-30.0	118.0	60.0	Ib	fract
-30.0	217.4	68.0	IV	fract
-31.0	110.0	100.0	Ia	fract
-32.5	219.0	140.0	IV	ridge/fract
-34.5	199.0	100.0	Ia	ridge
-36.5	202.0	120.0	Ia	ridge/fract
-38.0	23.5	125.0	Ib	fract
-41.0	229.2	150.0	II	ridge
-42.0	196.0	100.0	Ia	ridge
-42.5	245.5	160.0	Ia	ridge
-45.0	324.0	100.0	Ib	ridge
-47.0	209.5	110.0	IV	ridge
-47.7	207.5	136.0	IV	ridge
-50.0	289.5	150.0	IV	fract
-50.5	276.0	150.0	II	ridge
-51.5	289.5	150.0	IV	fract
-52.3	14.6	170.0	III	fract
-57.0	131.0	40.0	Ia	fract
-61.5	88.5	150.0	Ib	fract
-64.5	235.5	150.0	II	ridge
-79.0	169.0	140.0	II	fract

LEGEND

LAT	latitude
LON	longitude
MAX_DIAM	Maximum diameter of the structure in km
GEOL_ENV_CHAR	Environmental type according to presented scheme
TYPE_LINEAM	Type of the arachnoid radial lineaments

fract - fractures and graben; *ridge* - compressional features, including wr;

ridge/fract - both compressional and extensional features are present

Original publications