Evidence for rapid and widespread emplacement of volcanic plains on Venus: Stratigraphic studies in the Baltis Vallis region

Alexander T. Basilevsky1,2 and James W. Head2

Abstract. Geological mapping of the area around Baltis Vallis, the longest (6,800 km) canali-type channel on Venus, has led to the determination of stratigraphic relations which appear to be consistent over this entire region comprising ~20 x 10^6 km^2 or ~5% of the total surface of Venus. The most abundant unit in the study area, plains with wrinkle ridges (Pwr), consists of two subunits separated by the formation of Baltis Vallis, a feature which is interpreted by most workers to have formed essentially geologically instantaneously. The wrinkle ridges deform both subunits of Pwr, while ridge belts are emplaced on the Pwr plains. Consistent age relationships between the Pwr subunits, wrinkle ridges, Baltis Vallis and ridge belts along the entire 6,800 km channel length is evidence that unit Pwr is a real stratigraphic marker unit and not a mosaic of plains emplaced at significantly different times, at least in the ~5% of the surface of Venus comprising the study area. The Baltis stratigraphic sequence was compared with stratigraphic relations found in earlier studies of thirty-six 1,000 x 1,000 km sites randomly distributed over the surface of Venus [Basilevsky and Head, 1995] and was found to be comparable. This supports the interpretation that these stratigraphic units represent generally globally quasi-synchronous geologic events rather than the products of geologic activity in different areas of the planet at different times.

Introduction

There is an ongoing discussion concerning the character of the recent geologic history of Venus and the mechanisms of emplacement of the volcanic plains which make up the majority of the surface of the planet. The extreme opinions in this discussion are represented by two end-members. In the "global resurfacing" model, it is suggested that ~300-500 m.y. ago the surface of Venus was flooded by extensive volcanic eruptions which covered almost all preexisting formations, followed by waning volcanism since that time [Schaber et al., 1992; Strom et al., 1994]. In the "equilibrium resurfacing" model, it is proposed that the observed surface geology is the result of continued endogenic activity which occurred as local deposits of limited size (typically less than ~400 km across) emplaced in different places around the planet at different times [Phillips et al., 1992]. In recent photogeologic analyses of thirty-six ~1000 x 1000 km areas randomly distributed around the planet, we outlined a model of the global stratigraphy of Venus [Basilevsky and Head, 1995]. The model describes the geology of the planet as a combination of six major material stratigraphic complexes and a number of structures typically formed at several different periods during the observed geologic history. This model may correspond to either of two different options for the geologic history of Venus: 1) The proposed stratigraphic units and equivalent geologic events were generally synchronous over the whole planet, or 2) the proposed stratigraphic sequence represents typical sequences of local events which occurred in different places at different times. The first option is consistent with the "global resurfacing" model and the second is consistent with the "equilibrium resurfacing" model. In our previous observations we never saw a case of superposition of one local stratigraphic sequence on another one (with repetition of all or part of the sequence of units), which would seem to be inevitable at the boundaries of neighboring local activity zones if the second scenario is correct. On the basis of this, we concluded that the first option (consistent with the "global resurfacing" model) agrees better with the observations than the second one. However, the validity of this conclusion remains tentative for other areas and requires additional testing. Stratigraphic studies in the area of Baltis Vallis is a further step in this direction because of the potential for the use of canali-type channels as stratigraphic time markers.

Mode of Emplacement

The area under study (Fig. 1) has the longest canali-type channel on Venus, Baltis Vallis (previously named Hildr Fossa). It has been proposed that the venusian channels originated through erosion of volcanic plains by some highly fluid liquid [Baker et al., 1992; Gregg and Greeley, 1993; Komatsu et al., 1993; Kargel et al., 1994] by thermal or mechanical means, or perhaps both. The duration of these events is likely to be relatively short geologically. Kargel et al. [1994] estimated a duration of formation of the 6,800 km long channel as 1 to 100 years. Its inferred rapid formation provides a unique opportunity to correlate the traces of geologic activity along the channel in time [Baker et al., 1992; Parker et al., 1992], thus permitting us to test for the existence of the zones proposed in the equilibrium resurfacing model.

Regional Geology

Photogeologic mapping of a large area (4,500 x 4,500 km) around Baltis Vallis was undertaken based on analysis of the Magellan C1- and F-MIDRP images, altimetry, and related data.
sets. Six major material stratigraphic complexes consistent with units described by Basilevsky and Head [1995] were distinguished (Fig. 1). From older to younger they are:

1) Tessera terrain (Tt), as in other areas of Venus, consists of at least two sets of intersecting ridges and grooves which cut the precursor material of unknown origin. All varieties of plains embay tessera.

2) Densely fractured regions of plains (Pdf) and coronae (COdf) are the plains-forming units cut by swarms of subparallel and sometimes (COdf) intersecting fractures with typical spacing of about 1 km or less.

3) Fractured and ridged plains (Pfr) are present in the form of remnants among the younger plains with wrinkle ridges (Pwr). Among the typical characteristics of these plains is the presence of broad linear ridges and fractured inliers, some of which may be identified as embayed areas of Pdf. In some places the previously mentioned broad linear ridges are concentrated in clusters, thus forming Ridge Belts (RB).

4) Plains with wrinkle ridges (Pwr) occupy the predominant part (~80%) of the study area. These plains consist of two subunits: 1) the stratigraphically lower one (Pwr1) is represented by moderately radar-dark plains and is predominant (~90% of Pwr) in its areal distribution; 2) the upper one (Pwr2) is composed of brighter plains which typically form spots of 200-300 km across, sometimes coalescing into areas of 1000-1500 km long. Both Pwr1 and Pwr2 are deformed by wrinkle ridges and typically the wrinkle ridges cross the Pwr1/Pwr2 boundary without changing in orientation and abundance.

5) Lobate plains (Pl) consist of a series of superposed usually radar-bright lava flows not deformed by wrinkle ridges or deformations typical for Pdf/COdf and Pfr/RB units. They cover or embay all other plains.

6) Craters with associated dark parabolas (Cdp). They are one of the youngest features on the venusian surface [Campbell et al., 1992]. Basilevsky [1993] and Strom [1993] showed that Cdp were evidently emplaced not earlier than 30-50 m.y. ago. There are four Cdp craters with associated parabolas in the study area. Besides, there are 35 more craters without parabolic features. Most of the 39 impact craters in the area studied (37 of them) are superposed on Pwr.

**Baltis Vallis and its Surroundings: A Description of Relationships**

Baltis Vallis channel (Fig. 1) originates north of a circular volcanic construct (a possible source of the channel; 1.6 km in relief and 150 km in diameter) located at 44.5°N, 185°E (Fig. 2a) and terminates at 11.5°N, 167°E [Baker et al., 1992]. Its total length is about 6,800 km. The channel width is 2-3 km and is almost constant over its entire length. Baltis Vallis is incised into Pwr1 plains and is covered locally by Pwr2.
Discussion and Conclusions

The photogeologic relationships of the area around Baltis Vallis described above show that except for the channel itself the geology of this area is typical for Venus. Stratigraphic material units and structures deforming them are practically the same as those identified previously in thirty-six 1,000 x 1,000 km sites randomly distributed around the planet that were studied earlier [Basilevsky and Head, 1995]. The predominant type of terrain in this study area, as in the majority of other areas of Venus, is plains with wrinkle ridges (Pwr). This unit is evidently formed by extensive basaltic volcanism and deformed by widely distributed compressional deformation. If the observed geology in the study area is the result of equilibrium resurfacing, forming local activity zones of limited size (less than ~400 km across; [Phillips et al., 1992]), the vast areas of plains with wrinkle ridges should be a mosaic of such zones formed in different places at different times.

If we ignore for a moment the existence of Baltis Vallis, the observed relative age sequence (Pwr1-Pwr2-WR...) in 14 geologic observation stations (Fig. 1) does not contradict the idea of equilibrium resurfacing in separate local activity zones. But if this idea is correct, the relative age sequence has to be formed in different areas at different times, and the relations between the local stratigraphic columns of the geologic ob-

![Figure 3](image-url)
In the area under study, plains with wrinkle ridges are not a relatively small local activity zones and proves that, at least in the region and proves that the Pwr 1 subunit has consistent stratigraphic meaning all around this region. This situation is shown as case B in Fig. 3.

However, the stratigraphic observations in this area put constraints on Pwr 1 emplacement too. All around this area this subunit embays a complex of fractured and ridged plains (Pfr) and ridge belts (RB). The observations clearly show that the Pwr 1 subunit was emplaced after the deformation of Pfr plains and predates unit Pwr 2. Because the channel was formed essentially geologicallyinstantaneously along all its length, at least parts of the local stratigraphic columns of all these stations are very strictly correlated along the time axis. Moreover, Schaber et al. [1992] and Strom et al. [1994] showed that among several hundred impact craters of the entire planetary population superposed on regional plains, only several craters are deformed by wrinkle ridges; yet wrinkle ridges disturb the surface of the majority of these plains. This means that the interval between the time of emplacement of the plains material and its deformation by wrinkle ridges was very short. The situation in the Baltis area appears to be practically the same as that over the whole planet. The wrinkle ridge network here typically has a ridge-to-ridge spacing of 5 to 15 km. Among 37 craters superposed on Pwr plains, the relations of 14 craters with the wrinkle ridges are unclear. They are mostly small craters whose diameter is less than the typical wrinkle ridge spacing. But among the remaining 23 craters, 22 craters are evidently superposed on the wrinkle ridges and only one (crater Nadira, 44.13°N, 201.53°E, 31 km) looks as if it is deformed by wrinkle ridges. All of those 22 craters are larger than 7.6 km in diameter. Fifteen of them are larger than 15 km. So if those 22 craters were formed before wrinkle ridges, the chance of a ridge-crater intersection would be quite high. This strongly compresses in time all the Ch-Pwr-WR assemblage of the area under study and correlates in time the Pwr 1 subunit at different observation stations, but leaves open the possibility that the Pwr 1 subunit may be a mosaic of plains formed in different places of this region at significantly different times. This situation is shown as case B in Fig. 3.

However, the stratigraphic observations in this area put constraints on Pwr 1 emplacement too. All around this area this subunit embays a complex of fractured and ridged plains (Pfr) and ridge belts (RB). The observations clearly show that the Pwr 1 subunit was emplaced after the deformation of Pfr plains into ridge belts of this region. The ridge belts form a structurally consistent, generally NS-trending system. The ridges of this system sometimes form rhomboid junctions but they never criss-cross each other. So one may think that they evidently formed in a single tectonic episode. It is difficult to estimate how long in time this episode might have lasted. Only one crater (Blackburne, 11.09°N, 180.3°E, 31 km) is superposed on this unit so the ridge-crater relations consideration is not helpful in this case. But independently of how long that episode might be, within the area of study, it evidently terminated quasi-synchronously. Thus, the system of ridge belts in this region may be considered an additional stratigraphic marker. So the emplacement of the Pwr 1 subunit occurred within a definite period of time between the tectonic episode that formed the ridge belts of this region and the moment of formation of the Baltis Vallis channel. This correlates in time Pwr 1 subunits at different localities in this region and proves that the Pwr 1 subunit has consistent stratigraphic meaning all around this region. This situation is shown as case C in Fig. 3.

All of this contradicts the idea of equilibrium resurfacing in relatively small local activity zones and proves that, at least in the area under study, plains with wrinkle ridges are not a mosaic of such zones formed in different places at different times. Instead, they are the result of large-scale volcanic activity where each of two resolvable phases of this volcanism was quite synchronous within this very large region. This favors the first of the two scenarios of volcanic history of Venus considered by Basilevsky and Head [1995], implying that the suggested stratigraphic units and equivalent geologic events were generally broadly synchronous over the whole planet. In turn, this is inconsistent with the "equilibrium resurfacing" end-member model [Phillips et al., 1992] and consistent with the "global resurfacing" end-member model [Schaber et al., 1992; Strom et al., 1994] or with any other model which involves the described synchronicity of the discussed stratigraphic units and equivalent geologic events.

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