GEOLOGIC ANALYSIS OF THE SURFACE THERMAL EMISSION IMAGES TAKEN BY THE VMC CAMERA, VENUS EXPRESS. A.T.Basilevsky[1,2], E.V.Shalygin[2], D.V.Titov[2], W.J.Markiewicz[2], F.Scholten[3], Th.Roatsch[3], B.Fiethe[4], B.Osterloh[4], H.Michalik[4], M.A.Kreslavsky[5], L.V.Moroz[6,3]; [1]Vernadsky Institute, Moscow, Russia (atbas@geokhi.ru); [2]Max-Planck-Institut für Sonnensystemforschung, Katlenburg-Lindau, Germany; [3]Institut für Planetenforschung, DLR, Berlin, Germany; [4]Institut für Datentechnik und Kommunikationsnetze (IDA), TU Braunschweig, Germany; [5]University of California, Santa Cruz, CA, USA; [6]Institut für Planetologie, Universität Münster, Münster, Germany.

Introduction. The Venus Monitoring Camera (VMC) onboard Venus Express takes images in 4 channels, one of which is centered at 1.01 µm. When the camera looks at the night side of Venus, this channel registers thermal emission from the planet surface from mid-southern to mid-northern latitudes [1]. Due to scattering of the emitted radiation in the atmosphere and the cloud layer, the effective spatial resolution in the surface images is ~50 km. Thus, modeling the atmospheric blurring is essential for this work. Here we report results of preliminary analysis of some VMC 1-µm images.

Intensity of the surface thermal emission at 1 µm depends strongly on its temperature and thus on surface elevation as well as on surface emissivity and cloud opacity. But emissivity of the surface material depends also on surface texture and mineralogy so the image analysis can provide an information on these parameters. Also, if there is an ongoing volcanic eruption in the camera field of view, it might be noticed on the images.

Modeling surface blackbody emission at the top of the atmosphere. The 1 µm spectral "window" is free from atmospheric absorption bands [2]. The dense atmosphere affects the surface images in two ways: it strongly attenuates the emission and leads to degradation of spatial resolution, or blurring. Thus, intensity distribution registered at the top of the atmosphere can be expressed by the following formula:

$$I(x,y)=\iint \frac{t\,\varepsilon}{1-(r\,(1-\varepsilon(x,y)))} B[T_s(x',y')]F(x-x',y-y')\,dx'\,dy',$$

where t is the atmospheric transmittance, r is the atmospheric reflectance of surface radiation in back direction, $\varepsilon(x,y)$ is the spatial surface emissivity distribution, $B(T_s)$ is the Planck function given the surface temperature T_s, and F is the blurring function. We applied here the two-stream approximation to a single layer atmosphere to account for attenuation and convolved it with the blurring function. We use a Monte-Carlo code to model light scattering in flat multi-layer atmosphere and get F, t and r. The vertical structure of clouds as well as their optical properties have been taken from [3] and Rayleigh scattering coefficient of the lower gaseous atmosphere from [4]. Such thick atmosphere (together with not very oblong phase function) give orthotropic radiation field on the atmosphere top. Due to this we can obtain point spread function of atmosphere and use it to blur images of surface brightness in azimuthal (orthographic) projection. Such modeling gave us point spread functions with half-width ~50 km, which is in agreement with the acquired VMC data.

We used the GTDR topography data set [5]. These data were converted into maps of the blackbody emission $B(T_s)$ assuming thermal equilibrium with the atmosphere and constant lapse rate of 8.1 K/km [6]. To get rid of uncertainties in the VMC absolute calibration, we normalized the measured images by the observed brightness at a reference location with assumed emissivity ε_0 individually selected in each image. One can derive the following expression for the unknown surface emissivity distribution:

$$\varepsilon(x,y)=\frac{R(x,y)\varepsilon_0 t}{1-r(1-\varepsilon_0)-R(x,y)\varepsilon_0 r},$$

where R is a ratio of VMC and model images. It can be applied only to the areas where the spatial scale of emissivity variations exceeds the width of the blurring function (~100 km), which typically corresponds to ~10 VMC pixels. The distance between reference site and the place where we determine emissivity should not exceed the typical size of the deep cloud inhomogeneity (~1000 km).

Geologic analysis. The goals of our analysis are: 1) to look for areas whose emissivity at 1 µm differs from surroundings due to differences in surface mineralogy or texture and 2) to search for ongoing volcanic activity.

Strategy for ***the 1st direction*** of the analysis is to focus on terrains whose mineralogy could differ from that of basalts dominating Venus surface. The best candidate for that is tessera terrain. Several pieces of evidence [7] indicate that tessera might be composed of the material geochemically more evolved than basalts, e.g. more silicic rocks or analogs of lunar highland materials, whose mineralogy and thus 1 µm emissivity differs from that of basalts. The analysis of [8] indirectly supports [7].

For our analysis it is important to know the 1-µm emissivity of candidates of rocks and minerals. We acquired 1-µm reflectivity R from ASTER Spectral Library (http://speclib. jpl.nasa.gov) and RELAB Spectral Catalog (http://lf314-rlds.geo.brown.edu) and transformed it into emissivity $\varepsilon = 1–R$ (**Tab. 1**, $T = 20^{o}$C). These are values for fine-grained powders because the *in-situ* observations on Venus surface [9] and some analyses of Magellan data [10] suggest that surface materials on significant part of the planet are fine-grained.

Table 1. *1-µm emissivity of powder samples, %*

T^{o}C	Basalt	Andesite	Rhyolite	Anorthite	Magnetite	Pyrite
20	80	70	50	30	95	88
500	85	80	50	30	96	92

The 1-µm reflectivity of geological materials may be significantly affected by the temperature-depended changes in the Fe^{2+}absorption band. Experimental studiesof this effect are very scarce, but some very preliminary estimates can be done. We did it based on measurements of [11] for the -193^{o}C to 127^{o}C temperature range and extrapolated the change to 500^{o}C. From this extrapolation we suggest a very rough estimate that for basaltic and other materials containing Fe^{2+}, the temperature increase from laboratory to the Venus surface could lead to decrease in *R* by 25-30%. For materials having small / negligible amounts of iron, this effect might be much smaller or even absent. Results of such estimates (in %) are also given in **Tab. 1** (T = 500°C).

As it is seen from Table 1 if terrain is composed of materials like rhyolite, andesite, anorthosite, their 1-µm emissivity should differ significantly from that of basalts. However, reflectivity/emissivity pf powdered materials depends also on the grain size [12] (**Tab. 2**).

Table 2. *1-µm reflectivity of different size (µm) fractions*

Mineral	<25	25-63	63-125	125-250
Anorthite	0.70	0.60	0.53	0.43
Oligoclase	0.78	0.76	0.70	0.62
Orthoclase	0.72	0.64	0.57	0.47
Olivine Fo_{90}	0.48	0.28	0.18	0.1

It is seen from Table 2 that the reflectivity/emissivity dependence on grain size is more prominent than the effect of difference in mineralogy and could mask the latter.

Calculations of surface emissivities. Based on the described procedure we calculated surface emissivities for the area SW of Beta Regio topographic rise (**Fig. 1**). This area includes plains of Hinemoa and Gunda Planitiae with Tuulikki Mons volcano and small Chimon-mana Tessera branching from the Phoebe Regio rise. Summit parts of Chimon-mana tessera and Tuulikki Mons stand over the adjacent plains by 1-2 km. Based on current knowledge of Venus geology we suggest that plains and Tuulikki Mons volcano are made of basaltic lavas, while the composition of material of Chimon-mana tessera is enigmatic.

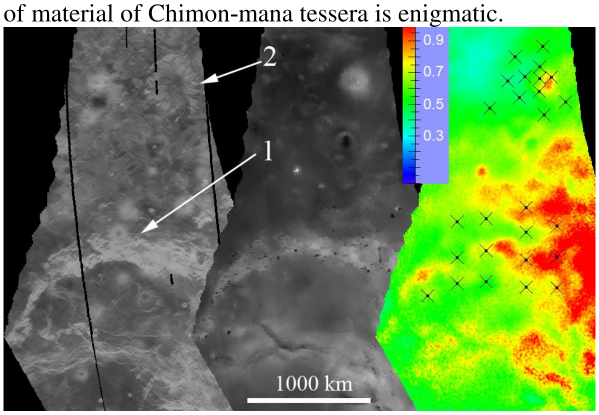

Fig. 1. *Study area SW of Beta rise, a) SAR, b) Topo, c) Surface emissivity. 1 - Chimon-mana Tessera; 2 – Tuulikki Mons. Crosses are points of measurements.*

As it can be seen from Fig. 1, surface emissivity of Chimon-mana tessera is noticeably higher than that of the surrounding plains. If tessera was composed of geochemically evolved material its emissivity should be lower than that of plains (Tab. 1) and if tessera is basaltic, its emissivity should be the same as for plains. The emissivity of basaltic Tuulikki Mons volcano in our calculations also is higher than for the adjacent plains. Surface emissivity of the summit areas of the tessera and volcano could be higher due to the coarser grain size of the surface material at higher altitudes which could be due to stronger winds at higher altitudes. Another possibility is that this may be an artifact of our still imperfect model.

Strategy for ***the 2nd direction*** is to search for anomalous brightening at areas of geologically young rifts and volcanoes. Simple estimations based on lava black body emission and atmospheric blur show that lava surfaces with temperature of 1500, 1100, and 900 K could be detected by VMC if they occupy 0.5-1, 20-30, and 500 km^2 respectively. Similar assessment has been made by [13]. Analyzing rift zone we have found that they show surface emissivity higher than the adjacent plains. This could be either because rift valleys are systematically deeper than if follows from the Magellan altimetry, or surface emissivity of rifts is higher due to the surface material of coarser grain size.

Because of this effect, rifts are not favorable for search of ongoing volcanic activity. Only very extensive eruptions have chances to be detected. So we concentrated on observation of Maat Mons volcano (Fig. 2). For this volcano there is some geological and geochemical evidence suggesting that the latest eruptions here are among the youngest on the planet [13-16] and thus it might be active even now.

Figure 2 shows SAR image of the Maat volcano, topography, and two VMC images of this area taken on 20.02.2008, and 07.02.2009. The latter don't show any brightening in the vicinity of Maat Mons suggesting no significant ongoing volcanic activity of this volcanic structure.

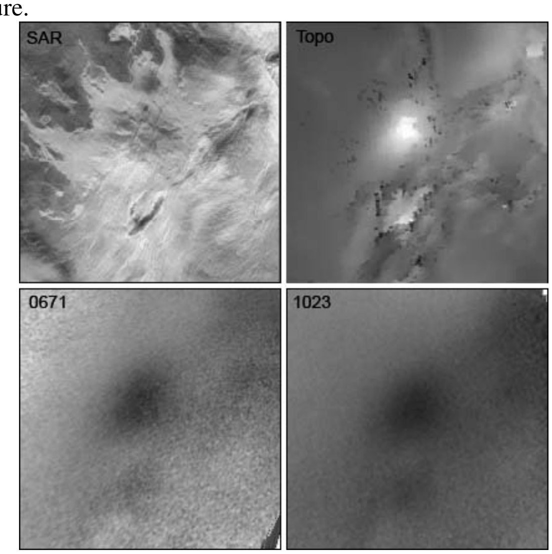

Fig. 2. *Maat Mons: SAR, Topo and VMC images taken at orbits 0671 and 102. Shown area is 1055 x 1055 km.*

References: [1] Markiewizc W. et al. (2006) *Bull. Am. Astron. Soc. 38*, 511. [2] Meadows, V. & Crisp, D. (1996) *JGR 101*, 4595. [3] Tomasko M. et al. (1985) *Adv. Spece Res.*, 5, 71. [4] Moroz V. (2002), *PSS* 50, 287. [5] Ford P. & Pettengill G. (1992) *JGR*, *97*, 13091. [6] Sief et al. (1985) *Adv. Space Res. 5* (11), 3. [7] Nikolaeva O. et al. (1992) in *Venus Geology, Geochemistry and Geophysics,* 129. [8] Kuchinskas A. et al., (1996) *JGR 101*, 4725. [9] Florensky C.P. et al. (1977) *Geol. Soc. Am. Bull. 88*, 1537. [10] Basilevsky A.T. et al. (2004) *JGR 109*, E002307. [11] Hinrichs J.L. & Lucey P.G. (2002) *Icarus 155*, 169. [12] Moroz L.V. et al. (2007) *LPS 38*, 1741. [13] Hasimoto G. & Imamura T. (2001) *Icarus 154*, 239. [14] Basilevsky A.T. (1993) *GRL 20*, 883. [15] Klose K. et al. (1992) *JGR 97*, 16353. [16] Robinson C.& Wood J.(1993) *Icarus 102*, 26.