GEOLOGICAL TESTING OF CLIMATE CHANGE MODELS ON VENUS R.E. Ernst[1,2], C. Samson[1,3], Y.D. Kuiper[4], S. Khawja[1], [1] Department of Earth Sciences, Carleton University, Ottawa, Canada, [2] Faculty of Geology and Geography, Tomsk State University, Tomsk, Russia, [3] Department of Construction Engineering, École de Technologie Supérieure, Montréal, Canada. [4] Department of Geology and Geological Engineering, Colorado School of Mines, Golden, Colorado, USA

Introduction: There is growing recognition that large-scale intraplate magmatism (Large Igneous Provinces (LIPs) and Silicic LIPs (SLIPs)) is a major driver of rapid climate change on Earth, with global consequences such as mass extinctions [1-2]. Given that Venus is dominated by intraplate-style magmatism (due to the absence of plate tectonics), lessons from the relationship between Earth's intraplate magmatic history and climate change are relevant to Venus.

On Venus, a major phase of intraplate (LIP-style) mafic magmatism occurred at ~700 Ma [3-5]. There has been considerable debate whether this was a catastrophic global magmatic resurfacing event (occurring over tens or several hundreds of million years) or whether Venus has undergone steady state resurfacing. The recognition of volcanic resurfacing of impact crater floors seems to favour the latter [6-9]. In either scenario, in the absence of significant environmental sinks (e.g. subduction zones), CO_2 released by mafic volcanism accumulated in the atmosphere and progressively increased the global temperature via the greenhouse warming mechanism. This phenomenon led to the current extreme hothouse conditions (450ºC), a CO_2 dominated atmosphere that is 90 times as dense as Earth's, and a loss of water (evidenced by a D/H ratio 150 times that of terrestrial water) [10-11]. It has been recently suggested that for much of its history, prior to the global warming event, Venus may have had a habitable climate with oceans and water erosion at low latitudes [11-12].

Consequences of the Global Warming Event on Venus: The hypothesis that mafic magmatism was responsible for the massive CO_2 flux that caused Venus' global warming has the following implications that could potentially be tested via detailed remote geological mapping using synthetic aperture radar (SAR) images from the Magellan spacecraft at the highest resolution available (75 m/pixel):

1) Tesserae (complexly deformed pre-mafic plains terrains) would have formed during habitable conditions prior to the global volcanism that caused extreme hothouse conditions (Fig.1). However, it is unclear whether tesserae developed at the paleosurface or were formed and deformed at depth and later exhumed (tectonically and/or by erosion).

2) The earliest mafic lava flows would have been emplaced during more habitable climate conditions, while later flows would have been emplaced at progressively higher temperature and atmospheric CO_2 content (Fig. 1).

Any alternatives to this simple unidirectional model of temperature and CO_2 increase would require modified initial conditions and identifying non-subduction sinks. This more complex approach would affect the volatile budget independently of the gas release from the volcanism (see discussion in [11, 13-14]).

Observations from Geological Mapping: Specific aspects being addressed through mapping and associated modelling would be:

1) Depth of formation of tesserae (at paleosurface or at depth); characteristics and causes of ductile and brittle deformation; nature of unroofing (tectonic and/or erosional); evidence for erosion; and the ambient climate during tessera formation.

2) Identifying differences between early and late basaltic flows, which could be potentially correlated with progressive warming and increasing CO_2 in the atmosphere.

Tesserae: Lineaments are widespread in tesserae and can represent primary rock layering or deformation structures, including faults (strike slip, reverse, normal) and/or fold axial traces. Understanding the nature and relative age of each type of lineament provides constraints on the protolith and deformation histories. Integration of lineament mapping with topographic profiles can be used to estimate the dip of layers/structures associated with the lineaments (rule of V's) [15]. Those with sub-vertical orientation are most likely graben-fissure systems (in some cases underlain by dykes) and/or strike-slip faults; those with sub-horizontal orientation may be linked with thrust faults or primary rock layering; and broad lineaments may be linked to fold axial traces [8, 15-16].

Recognition of erosional features (e.g. streams downcutting through landforms, gravelly/braided stream deposits, mudslides, alluvial fans, or deltas) would be confirmation of much cooler temperatures than at present time [11]. Figure 2 shows a NNE-SSE reentrant area of the southern portion of Salus Tessera which has been flooded by younger plains lavas. This trough may have formed by structures such as a synform or by faults. An alternative interpretation is that this trough represents an area of erosion due to an ancient

river flowing southward off the central part of the tessera.

Plains Volcanism, Flow Fields and Volcanic Edifices: Mafic volcanism associated with flow fields and volcanic edifices is typically younger than plains volcanism (planitia) [17], and the textures and patterns of the Venusian lava flows can be interpreted in the context of terrestrial basaltic volcanism [18-19]. In particular, mapping of the distribution of pahoehoe (low radar reflectivity) and a'a (high reflectivity) flows can provide information on local flow thicknesses based on evidence for flow inflation/deflation, and can reveal flow pathways and sources (central vents versus fissures). This type of mapping is easier done for the flow fields (fluctüs) [19] than for older plains volcanic rocks whose variations in radar reflectivity are more subtle. However, detailed mapping reveals that the plains do exhibit patchy variation in radar reflectivity which represent different generations of flows [17].

Comparison of older and younger generations of flows may reveal differences (e.g. the lengths of fluctüs, canali and sinuous rilles, the width of flows, and the proportions of pahoehoe to a'a style lavas) that may be inversely correlated with increasing atmospheric temperature. Furthermore, the scale of pyroclastic eruptions can potentially be linked to increasing ambient atmospheric pressure. From such observations, the record of mafic volcanism can potentially be used to provide clues on the progressive warming of Venus from ambient to hyper-thermal conditions.

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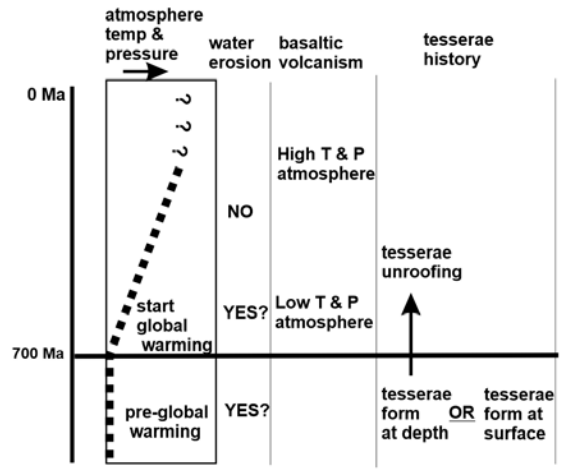

Figure 1. Climate change model assuming increasing atmospheric temperature (T) and pressure (P) starting at ~700 Ma. Linear increase in atmospheric T and P shown for simplicity.

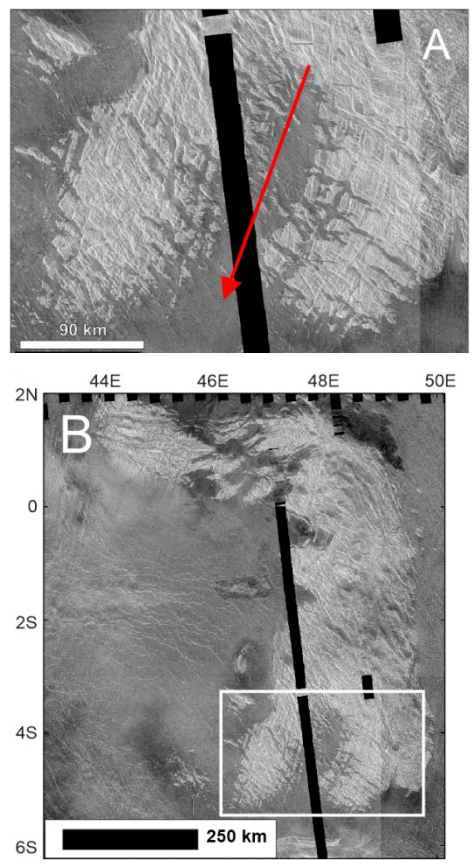

Figure 2: A) Magellan SAR image from the southern part of Salus Tessera, showing a reentrant (red arrow) into the tessera that has been flooded by younger plains lavas. Such flooding is filling a topographic low that could have been caused by deformation (e.g. along a synformal hinge) and/or erosion. B) Inset map. Box locates part A.