CERBERUS PLAINS VOLCANISM: CONSTRAINTS ON TEMPORAL EMPLACEMENT OF THE YOUNGEST FLOOD LAVAS ON MARS. P. D. Lanagan and A. S. McEwen; Lunar and Planetary Laboratory, University of Arizona, Tucson AZ 85721 (planagan@lpl.arizona.edu).

Introduction: The Cerberus Plains (CP) (Fig. 1) are located on the southeastern margin of the Elysium Rise and extend for over 3000-km from east to west and ~600-km from north-to-south. The plains are bounded to the northwest by the Athabasca Valles outflow channel and ridged Elysium lavas, to the north by cratered, knobby terrains, and to the south by the Medusae Fossae Formation and ridged plains. The Marte Valles outflow channel joins the eastern Cerberus Plains with the lower-elevation western Amazonis Planitia. A system of WNW-ESE trending fissures of the Cerberus Fossae cut across the Cerberus Plains, the northern knobby terrains, and portions of the ridged Elysium lavas.

Since the Cerberus Plains exhibit smooth surfaces at Viking image resolutions and few impact craters, [1] and [2] interpreted this region as being the youngest on Mars and defined this region as the referent for Upper Amazonian units. The presence of teardrop islands in Marte Valles and the smooth character of the plains led them to interpret the surfaces in this region as fluvial deposits from floods emanating from Cerberus Fossae. On the basis of USGS Viking-based topographic maps which indicate that the plains lay in a closed basin, Scott and Chapman [3] interpreted surfaces in the region as pluvial sediments deposited on top of volcanic surfaces by a paleolake which subsequently debouched through Marte Valles and westward in the southwestern plains. However, Plescia [4, 5] noted the presence of sparsely cratered, lobate, convex-ridged surfaces with morphologies consistent with unmodified lava flows and interpreted the surfaces to be lava flows filling pre-existing fluvial channel systems. MOC images confirmed that these plains are covered by lava flows, and that they are very similar to flows in Iceland [6]. Sakimoto [7] identified several shields, edifices, and lava flows and argued for a period of plains-style volcanism in this region.

We examine the spatial and stratigraphic relationships between Cerberus Plains volcanic units and surrounding units and derive constraints for volumes of volcanic materials extruded and the duration of volcanic activity within the Cerberus Plains.

Major Features of the Cerberus Plains: Both Mars Orbiter Laser Altimeter data and high-resolution Mars Orbiter Camera (MOC) images were used in this study. A digital elevation model (DEM) and shaded relief map of the Cerberus Plains and Amazonis Planitia were produced from MOLA data using the natural-neighbor interpolation technique [8]. Mars Orbiter Camera (MOC) narrow angle images of the Cerberus Plains and Amazonis Planitia with resolutions up to ~1.5 m/pixel [9] were also examined. MOC images, while covering a very small fraction of the entire Cerberus Plains, are useful for examining meter-scale morphologies of surfaces.

Lava Plains: The MOLA DEM shows the Cerberus Plains exhibits extremely low gradients with regional slopes on the order 0.025 degrees. In some isolated locales, knobby terrains with relief on the order of 200-300 m, rims of large (> 20-km diameter) craters, and 100-m amplitude wrinkle ridges are visible. A low amplitude topographic divide trending roughly NE-SW southeast of Athabasca Valles splits the CP into the western Cerberus Plains (WCP) and eastern Cerberus Plains (ECP). In the ECP, surfaces generally slope downward to the east towards Marte Valles (MV).

Several shields measure up to ~100-km in basal diameter and rise up to ~100-m elevation above the surrounding plains. Linear edifices lie on portions of the trace of the Cerberus Fossae and measure up to several 100-km in length and have elevations of several 10's of meters above the surrounding terrains. Extending from many of these shields and linear edifices are large lava flows which extend downslope in length from 10's of kilometers to over 1000-km and in width from several kilometers to over 100-km. Several of these lobes extend into Marte Valles, truncate kilometer-wide, 20-m deep dendritic depressions near the proximal end of MV, and terminate in southwestern Amazonis Planitia (AP). The surfaces of some of the flow lobes exhibit a central depression down the long axis of the deposit. Many of these units overlap, suggesting they were emplaced at different times. The flow fronts within the ECP and southwestern AP are as high as 40-m. In the WCP, flow fronts, which often bound wrinkle ridges, are nearly undetectable in the shaded relief map; however, there are local variations of ~5-10-m in topography in places.

Narrow angle MOC images show that many of the surfaces within the Cerberus Plains are covered by platy-ridged surfaces, patterned surfaces, and surfaces exhibiting topography indicative of inflated lava flows (Fig. 2). Platy-ridged surfaces are comprised of plates 100-1000-m long which appear to have been rafted apart. These plates often appear to fit together like a jig-saw puzzle, exhibit shear structures around positive relief features, and have ridges ~10-m in height (as derived from shadow measurements).

Between plates are smooth areas (at MOC scales) covered by small-scale polygons approximately a few 10's of meters in diameter. Shading relationships indicate that the edges of the polygons appear to be depressions and do not show signs of warping upwards at their edges, as is typical from cooling and contraction of ponded lava.

The margins of some of the platy-ridged surfaces are bounded by surfaces which are composed of small, positive relief elongated bumps often a few 10's of meters across which exhibit a mottled appearance at MOC resolutions. In many places, the surface appears to have risen around positive topographic features such as small knobs, ridges, or crater rims, like inflated lavas.

Martian platy-ridged surfaces have been interpreted as insulated sheet lava flows based on comparisons with Icelandic flows with similar platy-ridged morphologies [6]. According to Keszthelyi et al. [6], insulated sheet flows initially form as inflated pahoehoe fields. A surge in the eruption rate forces more lava to be injected into the flow than the lava tubes can conduct; as a result, the surface of the pahoehoe flow is disrupted into large (100-m to km long plates) and rafted downslope. Such lava flows on Earth often show shear structures where lava flows around and over obstacles, compressional ridges, and lobate margins [6]. The martian surfaces in this region display each of these characteristics.

Patterned surfaces are consistent with chilled ponded lavas. As ponded lavas cool, tensional cracks form at the surface, thus resulting in a patterned appearance to these lavas. Terrestrial examples of such lavas occur in former lava lakes such as Kilauea Iki [10]. As noted previously, patterned morphologies are noted on the margins of insulated sheet flows. That suggests that lavas at the margins of the platy-ridged flows were ponded and stagnant as they cooled. Patterned lavas are also noted in intra-plate regions within insulated sheet flows. This suggests that, in these regions, an initially ponded lava was allowed to cool to the point where cooling cracks formed on the surface until a surge in the eruption rate caused the ponded surface to break into plates which were subsequently rafted.

The hummocky and mottled appearance of some surfaces is consistent with those expected of tube-fed inflated pahoehoe fields. During early emplacement of such lavas, small topographic barriers dam or divert initially thin lava flows. As the eruption continues, lava injected under the cooler, hardened surface via tubes lifts the surface of the flow above the initial barrier. In the Laki flow, inflated lavas are found near the margins of platy-ridge flows. A similar relationship is found within the Cerberus Plains.

Medusae Fossae Formation: The Medusae Fossae Formation (MFF) bounds the southern portions of the Cerberus Plains and Amazonis Planitia. The maximum elevation of these units is approximately 1-km over the CP. Large valleys are noted within the MFF with elevation excursions of several 100-m. MOC images of the MFF reveal massive friable deposits exhibit weak, large scale layering and yardangs. In several locations, most notably in southern Amazonis Planitia and south of Athabasca Valles, these friable materials clearly overlie nearly pristine platy-ridged surfaces [9]. However, lava flows appear to embay the lower members of the MFF in the extreme southwestern and southeastern portions of the CP. These observations suggest that periods of lava emplacement and MFF deposition are interweaved.

The lava surfaces eroding out from under the MFF are well-preserved and not noticeably eroded, thus suggesting that the MFF may be made of low density materials. Additionally, the MFF has been associated with regions of low radar backscatter, also consistent with low density materials. Radar-stealthy portions of the MFF may be reticulite, deposits of high porosity pyroclastic materials [6].

Fluvial Channels: Streamlined knobs, anastomosing channels, and longitudinal grooves are noted in both Athabasca Valles and Marte Valles [11]. The edges of several pristine flow lobes are visible on the banks of Athabasca Valles. In Marte Valles, while the channel appears to cut through older lavas, the channel floor is embayed by platy-ridged lavas.

Discussion: *Volume estimates for volcanics:* The areas covered by lava flows which postdate the last fluvial event in Marte Valles in the western Cerberus Plains is approximately 1.7×10^5-km^2. Areas covered by post Marte Valles lavas originating in the ECP is approximately 9.3×10^5-km^2. The total area of the Cerberus Plains lavas emplaced after the last Marte Valles fluvial episode is 1.1×10^6-km^2. Identifiable individual flows vary widely in area, from several small flow lobes in the vicinity of the Cerberus Fossae with areas of ~1000-km^2 to a flow which terminates in the proximal end of Marte Valles with an area of ~72000-km^2.

Estimates on the thicknesses of individual lava flows may be obtained through flow front height measurements, and estimates on the thicknesses of a package of overlapping lava flows may be obtained from an examination of craters embayed and partially filled by lavas. In the WCP, the few recognizable flow fronts are no larger than 10-m in height. However, wrinkle ridges with amplitudes of ~90-m disappear under the embaying lavas, so the total thickness of WCP lavas may be >100-m thick in some places.

In the ECP, individual flow fronts identified in the shaded relief map range in heights between 20-40 m. Based on partially filled craters, Plescia [4, 5] estimated that the average thickness of the eastern Cerberus Plains volcanics was approximately 200-m. However, as the post-MV flows may have been emplaced over pre-MV flows, this is likely an upper bound for total thicknesses of the ECP flow fields.

The 72000-km^2 flow identified above has a flow front thickness of ~25-m, which indicates that the flow would have a volume of 1800-km^3. Assuming thicknesses of WCP lavas range between 10-100 m, likely volumes for WCP lavas range between 1.7×10^3-1.7×10^4 km^3. Assuming the total average thicknesses of post-Marte Valles flows in the ECP range from 25-200-m, the likely volumes for ECP lavas range between 2.3×10^4-1.8×10^5 km^3. The total volumes of post MV lavas in the CP would range between 2.5×10^4-2.0×10^5 km^3.

Age of Most Recent Volcanism: Statistics of small craters have indicated that these lava surfaces have model ages as young as 10 Ma [11, 12, 13]. However, most of the craters counted in all three of these studies may be secondary craters from a single 10-km primary crater [14]. Craters larger than 1-km diameter are much more reliable for age estimates. Plescia [4, 5] counted 89 craters larger than 1-km diameter over the plains, suggesting an age of 200-500 Ma. However, we concur with [12] that many of these large craters are embayed by the youngest lavas. In fact, we have not found a single large crater directly superimposed over the youngest lavas. There is one 0.5 km crater superimposed over the lava, seen from MOC images covering a total of 6600 km^2. This single crater, if it is a primary crater, suggests an age for the lava of less than 100 Ma according to the chronology of either Hartmann or Neukum [15].

Time to Emplace CP Volcanic Fields: Modeling of insulated sheet flows suggest that the average eruption rates for CP lavas were likely on the order of 10^4-m^3/s [6]. At such a rate, a flow with a volume of 1800-km^3 would be emplaced in roughly 6 years. As this volume applies to one of the larger lava flows, this suggests that individual lava flows were emplaced in time periods of less than a decade. Smaller lavas emplaced at this volumetric rate would correspondingly be emplaced in less time. For the volumes of all post-MV lava flows calculated in the previous section, all post-MV flows would be emplaced within roughly 30-300 years. Crater counts have been interpreted to indicate that there is an age difference of at least several 10's of millions of years between lavas in Marte Valles and Athabasca Valles [11]. If this is correct, then it is likely that there were significant periods of quiescence between volcanic events.

Vent Migration: Vent activity appears to migrate westward with time. Lava flows originating from western portions of the CF tend to overlie flows originating from more eastern portions of the CF. This trend echoes the conclusion of Burr et al. [11] that channels in the region tend to be younger the further west they are located. The migration of loci for volcanic eruptions, source regions for outflow channels, and the continued extension of the Cerberus Fossae suggest that the regional stress field is not static.

References: [1] Scott D.H. and Tanaka K.L. (1986) *USGS Misc. Invest. Ser. Map I-1802-A*. [2] Tanaka K.L. (1986) *JGR*, *91*, E139-E158. [3] Scott D.H. and Chapman M.G. (1995) *USGS Misc. Invest. Ser. Map I-2397*. [4] Plescia J.B. (1990) *Icarus*, *88*, 465-490. [5] Plescia J.B. (1993) *Icarus*, *104*, 20-32. [6] Keszthelyi, L.P. et al. (2000) *JGR*, *105*, 15027-15050. [7] Sakimoto, S.E.H. et al. (2001) *AGU FM 2001*, Abstract #P31B-09. [8] Abramov, O. and McEwen A.S. (2001) *AGU FM 2001*, Abstract # P42A-0567. [9] Malin, M.C. and Edgett, K.S. (2001) *JGR*, *106*, 23429-23570. [10] Green, J. and Short N.M. (1971) *Volcanic Landforms and Surface Features*. [11] Burr D.B. et al. (2002) *Icarus*, *159*, 53-73. [12] Hartmann, W.K., and Berman, D.C. (2000) *JGR*, *105*, 15011-15026. [13] Berman, D.C. and Hartmann, W.K. (2002) *Icarus*, *159*, 1-17. [14] McEwen, A.S. (this conference). [15] Neukum, G. et al. (2001) *SS.Rv.*, *96*, 55-86.

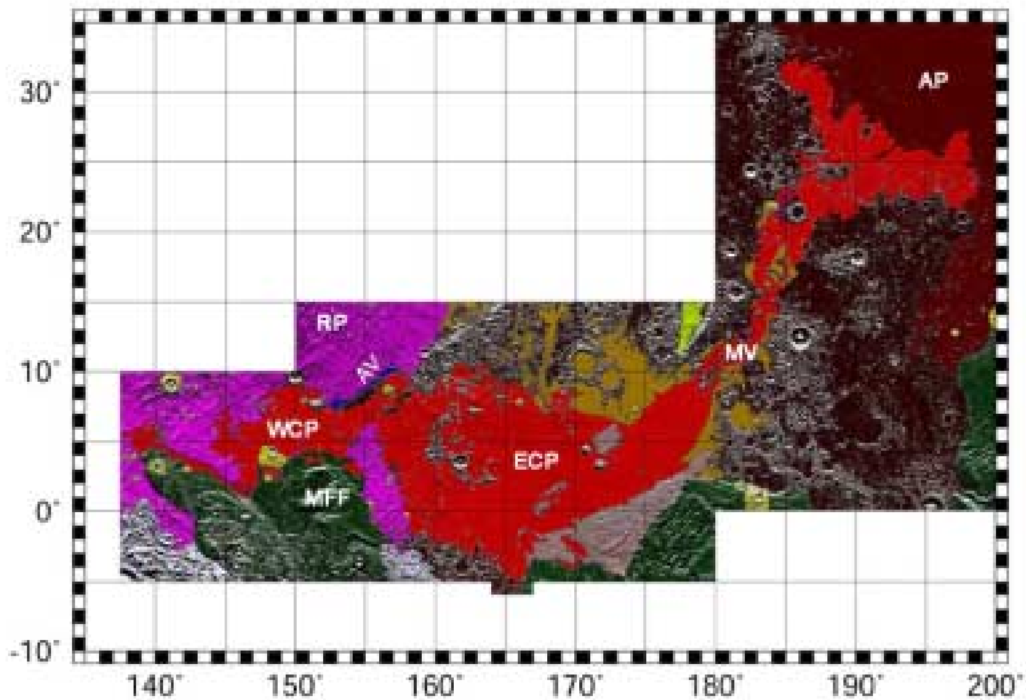

Figure 1: Shaded relief map of the Cerberus Plains and vicinity. Colors indicate geomorphic provinces. Units described in this paper are as follows: red - lavas emplaced after last Marte Valles fluvial episode; blue - fluvial surfaces; green - Medusa Fossae Formation; purple - ridged plains; brown - highland remnants. Abbreviations for regions are as follows: WCP - Western Cerberus Plains; ECP - Eastern Cerberus Plains; AV - Athabasca Valles; MV-Marte Valles; AP - Amazonis Planitia; MFF - Medusa Fossae Formation; RP - ridged Elysium Plains.

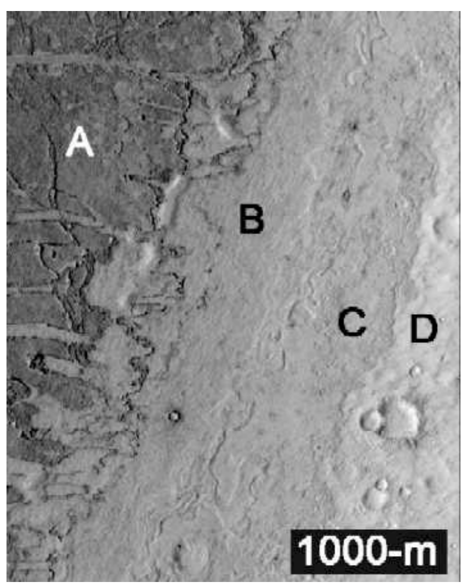

Figure 2: MOC image M07/02340 showing different morphologies of lava surfaces. A - platy-ridged lavas; B - patterened lavas; C - inflated lavas; D - cratered terrain.