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Abstracts of the Annual Planetary Geologic Mappers Meeting

June 22–24, 2000
Flagstaff, Arizona

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with a section on

Field Trip Notes:

Geologic Controls on Select Springs Near Flagstaff, Arizona

June 24, 2000

By Donald J. Bills[3]

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U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

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INTRODUCTION

This year's Planetary Geologic Mappers meeting was held at the U.S. Geological Survey Flagstaff Field Center on June 22-23, 2000, with an optional field trip on Saturday the 24th. Though the meeting started at 9 a.m. on Thursday morning, meeting attendees were notified the night before of a NASA Press Conference announcing the discovery by the Mars Orbiter Camera (MOC) on Mars Global Surveyor of possibly very young fluid-carved gullies on pole-facing slopes at middle latitudes on Mars.

Investigators who are currently funded by the Planetary Geology & Geophysics (PG&G) Planetary Geologic Mapping Program are required to present their progress at this meeting. Preliminary reviews of these presentations are forwarded to the PG&G panel meeting at the end of July. At the same time, this science meeting affords the investigators a unique opportunity to present new science to an audience of people similarly focused on geologic mapping issues. It is an excellent place to get feedback on specific concerns regarding mapping conventions, styles, or formats, such as involving digital mapping software packages. In addition, individuals who wished to present plans for future mapping, such as describing plans in a new mapping proposal, were encouraged to do so.

The meeting began with presentations from Mars mappers on Thursday morning through early afternoon. Then, focus switched to Venus mappers on Thursday afternoon through Friday morning. After the map presentations, Ken Tanaka spoke about age-dating issues for geologic mapping. Ken's talk was followed by two proposals for future regional Mappers' meetings. The first presentation, by Tim Parker, described preliminary plans for hosting a meeting in Delta, Utah, with a ~3-day field trip to study volcanic and sedimentary stratigraphy and geomorphology in the southern Bonneville Basin. The second presentation, by Larry Crumpler, described plans to hold a Mappers' meeting and field trip to investigate volcanological and structural features in New Mexico.

On Saturday, the remaining mappers were treated to a field trip to several ground water springs in and around Flagstaff. Also present was a reporter and camera crew from Space.com, who were interested in hearing what the scientists had to say regarding the press conference announcement. Thanks to all who took part in the interviews throughout the day!

Beginning this year, Ken Tanaka solicited one-page (including figures) abstracts pertaining to planetary geologic maps and mapping procedures. This volume is the compilation of abstracts submitted by the meeting attendees.

GEOLOGIC MAP OF THE MTM 85080 QUADRANGLE, PLANUM BOREUM REGION OF MARS

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Introduction: The polar deposits on Mars probably record martian climate history over the last 10^7 to 10^9 years [1]. The area shown on this 1:500,000-scale map includes polar layered deposits and polar ice, as well as some exposures of older terrain. This quadrangle was mapped in order to study the relations among erosional and depositional processes on the north polar layered deposits and to compare them with the results of previous 1:500,000-scale mapping of the south polar layered deposits [2,3].

The polar ice cap, areas of partial frost cover, the layered deposits, and two nonvolatile surface units—the dust mantle and the dark material—were mapped in the south polar region [4] at 1:2,000,000 scale using a color mosaic of Viking Orbiter images. We constructed Viking Orbiter rev 726, 768, and 771 color mosaics (taken during the northern summer of 1978) and used them to identify similar color/albedo units in the north polar region, including the dark, saltating material that appears to have sources within the layered deposits [5]. However, no dark material has been recognized in this map area. There is no significant difference in color between the layered deposits and the mantle material mapped by Dial and Dohm [6], indicating that they are either composed of the same materials or are both covered by aeolian debris [3,4]. Therefore, in this map area the color mosaics are most useful for identifying areas of partial frost cover. Because the resolution of the color mosaics is not sufficient to map the color/albedo units in detail at 1:500,000 scale, contacts between them were recognized and mapped using higher resolution black-and-white Viking Orbiter images.

No craters have been found in the north polar layered deposits or polar ice cap [7,8]. The observed lack of craters larger than 300 m implies that the surfaces of these units are no more than 100,000 years old or that they have been resurfaced at a rate of at least 2.3 mm/yr [8]. The recent cratering flux on Mars is poorly constrained, so inferred resurfacing rates and ages of surface units are uncertain by at least a factor of 2.

Stratigraphy and structure: The oldest mapped unit, Amazonian mantle material (unit Am), is distinguished by its rough, sometimes knobby surface texture. The knobs and mesas of mantle material that crop out within areas of smooth layered deposits suggest that the mantle material was partly eroded before the layered deposits were laid down over them. The layered deposits appear to cover the mantle material except on steep scarps that expose the mantle material. The layered deposits may be more resistant to erosion than the mantle material, so that the steep scarps formed by more rapid erosion of mantle material beneath layered deposits. Therefore, the mantle material in this area does not appear to have been derived from erosion of the polar layered deposits.

The layered deposits (unit Al) are recognized by their distinct bedded appearance, red color and lower albedo relative to the polar ice cap and frost deposits; they appear to be the youngest bedrock unit in this area. In both polar regions, layers are apparent at least partly because of their terraced topography, especially where accented by differential frost retention [13,14]. Early Mars Orbiter Camera (MOC) images show that layered deposit exposures are rough, with evidence for deformed beds and unconformities [16]. No definite angular unconformities have been found within the south polar layered deposits [2,3], unlike the north polar layered deposits, where truncated layers have been recognized in higher resolution images [7,13]. Angular unconformities have been found in various locations within this map area, including lat 85.7° N., long 61° W., lat 82.6° N., long 82° W., and lat 83.6° N., long 90° W. The unconformities are mapped using hachures on the side of the contact where layers are truncated. The final line color and symbol to be used to map such unconformities will be decided during the production of this map.

The partial frost cover (unit Af) is interpreted as a mixture of seasonal frost and defrosted ground on the basis of its albedo, color, and temporal variability. Bass and others [17] found that frost albedo reaches a minimum early in the northern summer, then increases during the rest of the summer season. This behavior is not observed in the south polar region [2]. The increase in albedo is interpreted as resulting from condensation of H_2O from the atmosphere onto cold traps in the north polar region [17]. Because the images used for the base and for mapping were taken in mid-summer, the extent of the high-albedo units shown on this map is greater than during early summer.

The albedo of the residual polar ice cap (unit Ac) is higher than all other units on this map. The contact with the partial frost cover (unit Af) is gradational in many areas, most likely because unit Af represents incomplete cover of the same material (H_2O frost) that comprises unit Ac. The summer extent of the north polar cap was the same during the Mariner 9 and Viking Missions [17], which suggests that it is controlled by underlying topography. Albedo patterns in these summertime images are correlated with topographic features seen in springtime images. Areas of the highest albedos must be covered by nearly pure coarse-grained ice or dusty fine-grained frost [18,19]. The presence of perennial frost is thought to aid in the long-term retention of dust deposits [20], so areas covered by frost all year are the most likely sites of layered-deposit formation.

References: [1] Thomas P. et al. (1992) Polar deposits on Mars, in Mars, University of Arizona Press, 767-795. [2] Herkenhoff K.E. and Murray B.C. (1992) USGS Misc. Inv. Series Map I-2304; Herkenhoff K.E. and Murray B.C. (1994) USGS Misc. Inv. Series Map I-2391; Herkenhoff K.E. (2001) USGS Misc. Inv. Series Map I-2686 (in press). [3] Herkenhoff K.E. (1998) USGS Misc. Inv. Series Map I-2595. [4] Herkenhoff K.E., and Murray B.C. (1990) JGR, 95, 1343-1358. [5] Thomas P.C. and Weitz C. (1989) Icarus, 81, 185-215. [6] Dial A.L. Jr. and Dohm J.M. (1994) USGS Misc. Inv. Series Map I-2357. [7] Cutts J.A. et al. (1976) Science, 194, 1329-1337. [8] Herkenhoff K.E. and Plaut J.J. (2000) Icarus (in press). [9] Zuber M.T. et al. (1998) Science, 282, 2053-2060. [10] Smith D.E. et al. (1999) Science, 284, 1495-1503. [11] Murray B.C. et al. (1972) Icarus, 17, 328-345. [12] Cutts J.A. (1973) JGR, 78, 4231-4249. [13] Howard A.D. et al. (1982) Icarus, 50, 161-215. [14] Herkenhoff K.E. and Murray B. C. (1990) JGR, 95, 14,511-14,529. [15] Blasius K.R. et al. (1982) Icarus, 50, 140-160. [16] Edgett K.S. and Malin M.C. (1999) LPS XXX, Abstract #1029. [17] Bass D.S. et al. (2000) Icarus (in press). [18] Clark R.N. and Lucey P.G. (1984) JGR, 89, 6341-6348. [19] Kieffer H.H. (1990) JGR, 95, 1481-1493. [20] James P.B. et al. (1979) Icarus, 68, 422-461.

GEOLOGIC AND TOPOGRAPHIC MAPPING OF THE SOUTH POLAR REGION OF MARS: LOCAL STRATIGRAPHIC RELATIONS AND TROUGHS OF PLANUM AUSTRALE. E.J. Kolb and K.L. Tanaka, U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001; EKolb@gecaz.com.

Introduction: Initial efforts to compile a 1:3,000,000-scale map of the South Polar Region of Mars (>70°S) have been enhanced by the use and interpretation of MOLA datasets. MOLA derived results have included determining stratigraphic relations and morphology of deposits in Promethei Rupes, general characterization of trough features within the south polar layered deposits (SPLD), and topographic analysis of the SPLD and surrounding deposits.

Deposit stratigaphy within Promethei Rupes: An extensive depositional layer within Promethei Rupes (mapped previously by [1] as part of the upper member of the Dorsa Argentea Formation (unit Hdu)) was studied to determine stratigraphic relations of features within the crater basin. Morphological features of the deposit include a lobate front along its periphery, closely spaced east-west-trending linear depressions, and many windows into underlying stratigraphy. MOLA elevation models and Viking images reveal that the deposit mantles much of the basin floor, covering approximately 80,000 km^2. Observed thicknesses range from 60 to ~150 meters, whereas the total volume of material is ~4,800 to 12,000 km^3.

Regional deposits and landforms include both intact and degraded knobby SPLD material, layered deposit mantle material, Chasma Australe, and several sinuous ridge features. The northern extent of the flow deposit embays Promethei Rupes crater rim material, and the eastern front, near 252°W, overlies Promethei Rupes crater floor material. The western and southern deposit extent appears locally overlain by the SPLD or mantled by material presumably derived from the SPLD. Part of the southern deposit front is observed at the mouth of Chasma Australe, north of the blocky, east-west trending elongated massifs (Fig. 1). The deposit is not observed south of the massifs, and elevation models identify a trough parallel to and between the massif and deposit. In Figure 1, a topographic profile of these features illustrates an abrupt unit Hdu termination followed by a smooth upward-sloping massif profile. At 253°W, 78°S where the eastern extent of the deposit is clearly visible, no observed features show the deposit originated from this area. The east-west linear features within the deposit and lack of features identifying an eastern source suggest a likely western source region.

One and possibly two ridges roughly 3 km wide and 40 km long are observed south of the area shown in Figure 1. These ridges cross half the distance of the chasma mouth, whereas another ridge is observed within the deposit directly north of the chasma mouth (Fig. 1). The spatial associations suggest that the aforementioned trough marks the extent of a pre-chasm SPLD where the adjacent unit Hdu flowed alongside, whereas the ridges represent moraines or esker features.

The esker-like ridges, including those at the western edge of Promethei Rupes, have been attributed to discharge [e.g., 2], and the stratigraphic relations between the ridges and flow deposit could represent a genetic linkage.

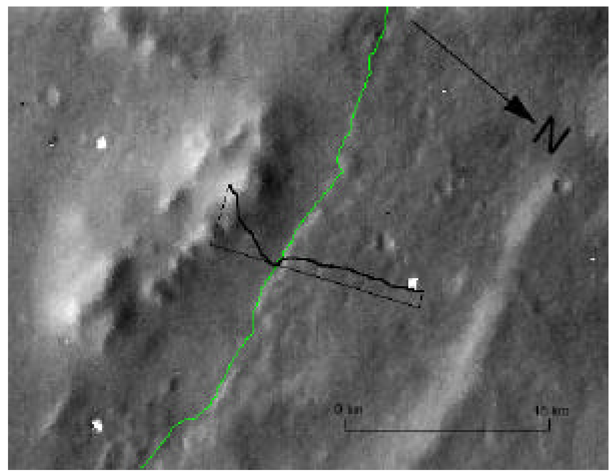

Figure 1. Section of Viking image F383b52 illustrating contact (thin line) of unit Hdu and massif at the mouth of Chasma Australe. The deposit thickness is ~60 meters. Vertical exaggeration of the topographic profile is 20X. A ridge is observed within the deposit crossing the lower right section of the figure.

SPLD trough characterizations: A profile across several troughs of the SPLD is shown in Figure 2. The profile is representative of trough topography observed within all generated profiles and can be described as a rhythmically repeating series of steps that descend from the center of the cap. Across each profile, equator-facing slopes of the trough walls are uniform, as is the thickness of the SPLD from trough floor to plateau top, or each "stair–step". Heights of the equator-facing walls range 400 to 600 m. Trough floors and plateau levels are consistently higher poleward, and trough floors are always higher than plateau levels two steps below.

Cross sections also were generated along the length of several of the largest SPLD troughs. The troughs spiral down and away from the center of the cap, and a rapid decrease in trough floor elevation is noted whenever trough direction changes. The seemingly rhythmic placement of the troughs observed in each profile, the uniformity of step thickness from profile to profile and the inward increase in trough-floor elevation suggest that topographically controlled processes such as insolation and basal melting govern the formation and placement of the troughs seen on the present day cap.

References: [1] Tanaka K. L. and Scott D. H. (1986) *U.S. Geol. Surv. Misc. Inv. Series Map I-1802C*. [2] Head J. W. (2000) LPSC XXXI, #1121.

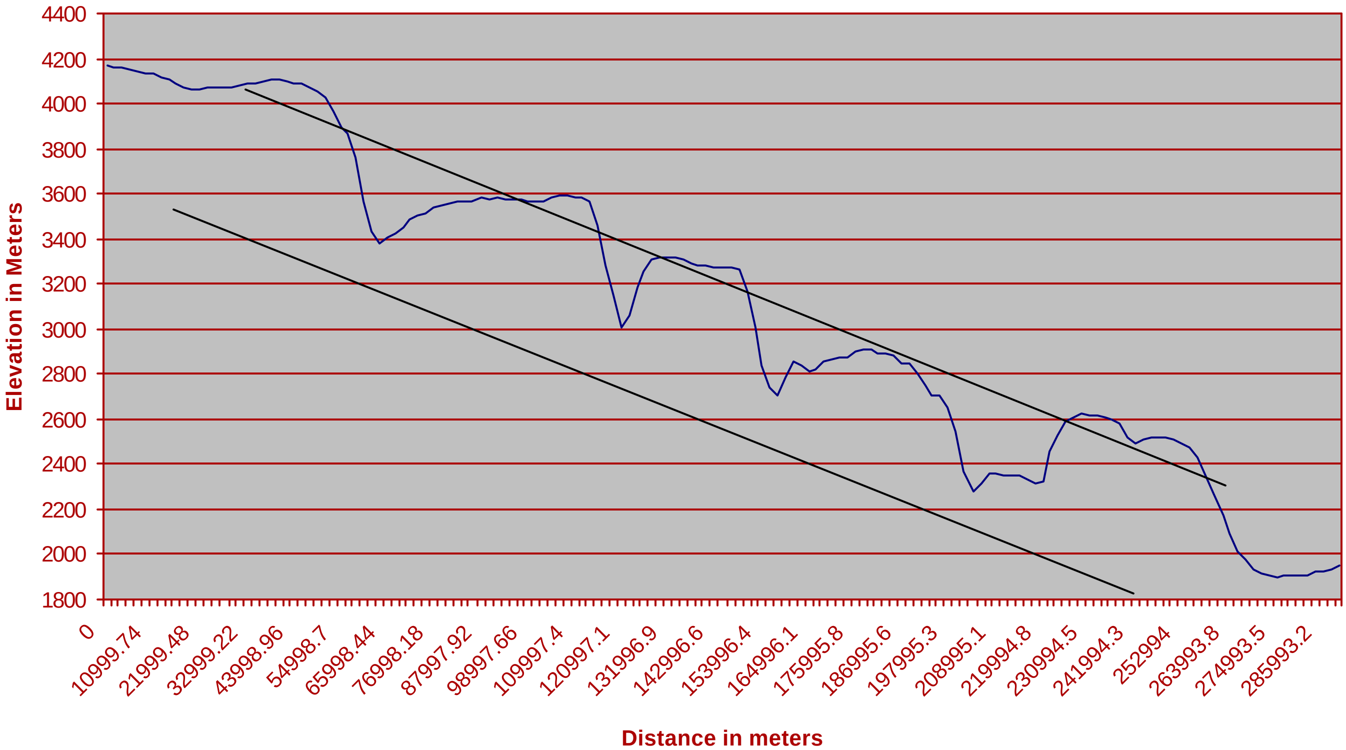

Figure 2. Topographic profile and trend lines across several major trough features of the SPLD and residual CO_2 polar cap. Symmetries observed in the profile include (1) the uniform thickness of material from plateau to trough floor, (2) the horizontal spacing of the trough "steps", (3) uniform slopes of the equator-facing trough walls, and (4) as compared to the graph trend lines, parallel slopes between the trough floors and plateaus. The symmetries suggest that topographically controlled processes govern the formation and placement of the troughs seen on the present-day cap.

GEOLOGIC MAPPING OF THE REULL VALLIS REGION OF MARS

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Introduction: Geologic mapping studies coupled with geomorphic analyses are being used to characterize the Reull Vallis outflow channel system and to determine the stratigraphy of the eastern Hellas region of the martian cratered highlands. Geologic studies of the Reull Vallis region examine the roles and timing of volatile-driven erosional and depositional processes and provide constraints on potential associated climatic changes. Current MTM mapping complements earlier investigations of the eastern Hellas region of Mars, including regional analyses [1-3], volcanic studies of Hadriaca and Tyrrhena Paterae [4-6], and mapping studies of highland outflow channels [7]. Key scientific objectives include assessment of mechanisms of highland degradation, the origin and evolution of Reull Vallis, and the role of Reull Vallis in the formation and subsequent dissection of the widespread plains units identified in the region.

Project Status: Analysis of the Reull Vallis region includes preparation of three formal mapping products: (1) Geologic map of MTM -40252 and -40257 quadrangles [8], (2) Geologic map of MTM -45252 and -45257 quadrangles [9], and (3) Geologic map of MTM -30247, -35247, and -40247 quadrangles (compiled on single 1:1M scale base) [10]. Crater-size frequency distributions compiled in the regional study of Mest [6, 11] are being utilized along with photogeologic observations in MTM mapping for martian time-stratigraphic designations. Maps of MTM -40252, -40257, -45252, and -45257 quadrangles have been prepared and submitted in digital format (for current versions of these maps, see http://viking.eps.pitt.edu/~dcrown).

Mapping Results: MTM -40252, -40257, -45252, and -45257 quadrangles contain an extensively modified portion of the highlands of Promethei Terra. Remnants of Noachian highland terrain occur as expanses of cratered terrain and as isolated or clustered massifs. Highland terrains in the region record the effects of diverse, multistage degradational sequences, which in some places may have extended into recent geologic time. Low-lying parts of the Noachian basin-rim unit appear to have been filled with a younger sedimentary deposit that in some cases has been dissected by well-developed, dendritic to rectilinear valley networks. Numerous highland massifs, as well as some crater rims and walls of Reull Vallis, exhibit prominent debris aprons/flows that extend for tens of kilometers. These debris deposits are locally the youngest features throughout the region and their surface morphologies (i.e., lineations, ridges, and pits) are suggestive of incorporation of volatiles, perhaps as interstitial ice, that enhance their mobility. Adjacent to high-standing remnants of the highlands are widespread smooth and channeled plains through which part of Reull Vallis extends. The role of collapse in the evolution of Reull Vallis is clearly indicated by its irregular planform morphology, the occurrence of large slump blocks along its walls, and debris extending from tributary canyons and merging with materials that fill Reull Vallis to different degrees in different locations. Mapping studies have suggested that smooth and channeled plains represent the product of a series of depositional and erosional events tied to large-scale flooding from Reull Vallis and/or deposition of material eroded from the surrounding highlands. Smooth plains, which may have originally been much more extensive, are thought to have been removed to the southwest of Reull Vallis, with local erosion and redistribution of materials forming the channeled plains. Deposits filling crater interiors and a series of dark ejecta pedestal craters may be evidence for burial and exhumation in areas now covered by channeled plains. Current studies of the Reull Vallis region are incorporating MOLA data and MOC images to assess unit origins and stratigraphic relations derived from MTM mapping.

References: [1] Crown, D.A. et al., Icarus, 100, 1-25, 1992. [2] Tanaka, K.L. and G.J. Leonard, JGR, 100, 5407-5432, 1995. [3] Mest, S.C., Geologic history of the Reull Vallis region, Mars, M.S. Thesis, University of Pittsburgh, 217 pp., 1998. [4] Greeley, R. and D.A. Crown, 1990, JGR, 95, 7133-7149. [5] Crown, D.A. and R. Greeley, 1993, JGR, 98, 3431-3451. [6] Gregg, T.K.P. et al., U.S. Geol. Surv. Misc. Inv. Ser. Map I-2556, 1998. [7] Price, K.H., USGS map I-2557, 1998. [8] Mest, S.C. and D.A. Crown, Geologic map of MTM -40252 and -40257 quadrangles, USGS map I-2730 [in press] 2001. [9] Mest, S.C. and D.A. Crown, Geologic map of MTM -45252 and -45257 quadrangles, USGS map, in review, 2000. [10] Crown, D.A. and S.C. Mest, Geologic map of MTM -30247, -35247, and -40247 quadrangles, USGS map, in preparation, 2000. [11] Mest, S.C. and D.A. Crown, Geologic history of the Reull Vallis region of Mars, to be submitted to Icarus, 2000.

PROGRESS IN GEOLOGIC MAPPING OF THE NORTHERN PLAINS OF MARS

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Introduction: We have initiated a new geologic map of the northern plains of Mars at 1:15,000,000 scale which will incorporate the new data from Mars Orbiter Laser Altimeter (MOLA), the Mars Orbiter Camera (MOC), and the Thermal Emission Spectrometer (TES) on board the Mars Global Surveyor (MGS) spacecraft. This project is funded by the Mars Data Analysis Program and will result in a published map in the U.S. Geological Survey's Geologic Investigations Series.

Methods: A preliminary version of the geologic map based on Viking images has been compiled on the Mars Digital Image Mosaic (MDIM), version 1.0. Because this mosaic is being revised to display improved radiometric and geometric controls, we need to remap preliminary contacts. Map data are being assembled in a Geographic Information Systems database to produce a digital map that can be used for studies of the map units and features. Also, solid versus dashed contacts are distinguished.

Results and future work: Thus far, we have mapped 42 units. These units include interior and local plains materials, volcanic flows, polar materials, highland units, crater materials, and other local units. Many of the units are provisional, because (1) we have not been able to map the extents of some units completely, (2) we may later choose to combine some units, and (3) we have not investigated their topographic, morphologic, and mineralogic characteristics fully with MGS data. Moreover, stratigraphic relations and crater-density data need to be compiled to establish relative ages of units as well as their individual outcrops. We also would like to unravel the geologic history of the region, including erosional, sedimentary, volcanic, tectonic, and impact events and processes and their interrelations. For example, we are exploring the erosion of the Chryse outflow channels, their relation to deposition in the northern plains, and tectonic sagging related to thick sedimentation within the northern plains; rapid sedimentation, sedimentary volcanism, and tectonism of the deposits in Isidis Planitia; and volcano-ice interactions that produced troughs in northwestern Elysium Mons and extensive channels and lahars in Utopia Planitia.

SOUTH ISIDIS RIM: TESTING GEOLOGIC CONTACT MAPPING USING MOC DATA

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Introduction: The geologic map prepared in this work is representative of the type of complex, multi-layer data that will be importable by users into a GIS web site to be developed in support of Mars landing site investigations. Such a site will enable timely additions of newly released and derivative data sets (such as geologic maps) critical to mission science objectives and engineering constraints.

The results of detailed geologic mapping in support of landing sites within the intermontane plains of possibly fluvial origin (unit Hi) have been reported at several LPSC meetings and Surveyor Landing Site workshops [1-5]. The Isidis rim was selected as the top priority landing sites in the originally scheduled series of landings in the Mars Surveyor Program.

Problem: In this discussion, details of the geologic map are compared with high resolution MOC image data. The objective is twofold: (1) determine whether the mapped units have any obvious surface characteristics at lander (1 to 2 m) scales and (2) to determine if contacts in the geologic map relate to any features that may be detected in the MOC data.

Results: Comparison of the two data sets imply that geologic mapping in lower resolution image data are reasonable and accurate. Although details of the surface texture, shallow deposits, and recent modifications may be undetected in low-resolution mapping, the fundamental interpretations are not rejected.

References: **[1]**Crumpler, L. S., abstract, Second Mars Surveyor Landing Site Workshop, 22-24, LPI, Buffalo, June 22-23, 1999; **[2]** Crumpler , L. S., in *Lunar Planet Sci.* XXVIII, 1999; **[3]** Crumpler, L. S., in *Lunar Planet. Sci.* XXIX, Abstract #1946, LPI, Houston, (CD-ROM), 1998; **[4]** Crumpler, L. S., in *"Mars Surveyor 2001 Landing Site Workshop"*, NASA-Ames, Moffett Field, CA, January 26-27, 1998; **[5]** Crumpler, L. S., in *Lunar Planet. Sci.*, XXVII, 273-274, 1997.

Figure 1. Central segment of the geologic map of the Isidis Rim, Libya Montes region overlain on the regional DIM. Ellipses represent 10 x 26 km ellipses originally proposed for MS Landers '01 or '03. For discussion of geologic units see [3, 4, 5]. Also shown are footprints for MOC data and corresponding image numbers. This work focuses on a comparison of interpretations based on MOC data and the interpretations based on the geologic map.

GEOLOGY OF BEREGHINYA PLANITIA QUADRANGLE (V-8), VENUS

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The Bereghinya Planitia quadrangle (V-8) lies between 25° and 50° N., 0° and 30° E. Bereghinya Planitia lies north of Eistla Regio, and the Bereghinya Planitia quadrangle is immediately north of the Sappho Patera quadrangle (V-20), which has already been mapped (McGill, 2000, USGS map I-2637). Work is in progress on a first draft map of V-8, which is being prepared digitally using Adobe Illustrator.

As is expected, many of the plains and volcanic units present in V-20 continue northward into V-8. At least two of the three members of regional plains materials that were mapped in V-20 also can be delineated in V-8. In addition, scattered exposures of a reticulated plains unit in V-8 were not present in V-20. Some of these occurrences of reticulated plains are associated with clusters of small volcanic constructs ("shield fields"), and thus it is possible that at least some of the reticulated plains material consists of flows derived from these small constructs. Although not yet certain, the final map may have two reticulated plains units, one associated with small constructs, one not. Also, numerous shield fields are not associated with reticulated plains. Bereghinya Planitia includes an interesting suite of coronae and corona-like features, including the "trilobite-shaped" Beyla Corona. Most of these coronae appear to be associated with belts of closely spaced ridges and fractures, and thus this quadrangle is an excellent place to attempt an understanding of the genetic relation between deformation belts and coronae. Scattered within the plains are numerous inliers of tessera material, most of which are deeply embayed by regional plains materials. Also present are small patches of a "bright plains" material that generally is characterized by a single set of closely spaced lineations (as opposed to tessera material, which generally exhibits at least two sets of lineations). The term "bright plains" is being used rather than "lineated plains" because the lineations are most likely superposed younger structural features and, furthermore, there are places within these bright plains where the lineations are bsent. One of the major mapping problems is to consistently separate (1) ordinary (member "b") regional plains that have been cut by abundant younger structures from (2) slightly older and brighter member "a" regional plains from (3) bright plains. The criteria being used involve the necessity of a brightness or texture contact in addition to any change in the density of superposed structures. Problems arise when a brightness contact fades away along trend!

The quadrangle also has an unusually large number of dark-centered bright patches apparently caused by bolides that disintegrated in the atmosphere before reaching the surface. At least three impact craters possess parabolic haloes that are characterized by alternating dark and light streaks, suggesting significant modification by wind.

GEOLOGIC MAPPING AND HISTORY OF THE OVDA REGIO QUADRANGLE (V-35), VENUS

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The Ovda Regio quadrangle (V-35), Venus, is a geologically complex region that has been exposed to many episodes of volcanism and deformation interspersed through time. It is host to a variety of geomorphic features including portions of two crustal plateaus (eastern Ovda and western Thetis), Inari and other coronae, numerous small volcanic edifices, impact craters, large flows, and Kuanja Chasma (fracture zone). With the exception of plains material (non-existent), V-35 contains examples of nearly every geologic featured observed on Venus. Utilizing the mapping methodology outlined in Hansen [1], a geologic history of the V-35 quadrangle is proposed.

Mapping indicates that tesserae, whether as part of a crustal plateau or as an isolated inlier, locally represents the oldest deformed crust. Within the tesserae of eastern Ovda, a radial pattern of shear fracture ribbons represents early extension, and a set of semi-concentric marginal folds are cut by late forming grabens [2,3]. The kinematic history (early extension, followed by contraction and further extension) represented by the structures within Ovda supports an upwelling model for crustal plateau formation. Similar structural relations and patterns are observed in the tesserae of Thetis. The two, distinct, coherent sets of structures strongly suggest that the tesserae of Ovda and Thetis did not form in the same deformational event, but rather were the result of a similar process operating independently at each location.

After formation of the tessera structures, volcanism is seen in the form of Intra-Tessera-Basin (ITB) lava fill [4]. ITB lava indiscriminately fills both small- and large-scale structural depressions in Ovda and Thetis. Banks et al. and Hansen et al. have studied other ITB's and have shown that volcanism is an important process throughout crustal plateau construction [4,5]. More detailed study of Ovda and Thetis ITB's is required to make a robust comparison to the ITB's of other authors. In addition to ITB's within the crustal plateau, volcanism is present on the flanks and surrounding the crustal plateaus. These materials are found primarily on the slopes and at the bases of crustal plateaus. Lavas, originating from sources within the crustal plateau, converge and follow localized paths until they spill over the slope of a crustal plateau coalescing into regional topographic depressions.

The remainder of the geologic history is dominated by localized volcanic flows, either originating from corona, shield fields, or fissures. Very large flows emanate from Inari Corona in the southeast and flow to the west, whereas Ovda Fluctus and corona cluster volcanism dominate in the west. The relative timing of these events is difficult to determine since there are no direct embayment relations.

Pervasive east-west fracturing, associated with the Kuanja Chasma, cuts most material units and dominates the recent history of V-35. In addition to a major episode of deformation, the Kuanja Chasma is a minor source of surface volcanism in the form of fissure-fed flows.

References: [1] Hansen, V.L., 2000, Earth and Planetary Science Letters, v. 176, p. 527-542. [2] Ghent, R.R. and Hansen, V.L., 1999, Icarus, v. 139, p. 116-136. [3] Bleamaster, L.F. and Hansen, V.L., 2000, LPSC XXXI, #1788. [4] Banks, B.K. and Hansen, V.L., 2000, J. Geophys. Res. (in press). [5] Hansen, V.L., Banks, B.K., and Ghent, R.R., 1999, Geology, 27, p. 1071-1074.

RUSALKA PLANITIA QUADRANGLE (V-25), VENUS: EARLY RESULTS

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Introduction: The V-25 quadrangle (15 to 18 E., 0 to N.) shows volcanism at all scales, from extensive corona-sourced flows through moderately sized shield volcanoes to small volcanic cones, all of which interact with tectonic elements of the planitia, such as wrinkle ridges, lineaments (presumed fractures), deformation belts and broad scale topography.

Methodology: Initial mapping is compiled digitally on a 225-meter/pixel image base derived from the FMAP dataset, to which synthetic stereo and Magellan geophysical data have be geographically referenced and linked for easy access. Additional image processing and analysis of the high-resolution FMAP images is carried out with IMAGE SXM freeware.

The mapping philosophy is similar to that employed in the Diana Chasma quadrangle (V-37) immediately to the south [1, 2]. Mapping follows USGS guidelines, with the caveats outlined [3].

Preliminary results: The earliest regional structural suite comprises NE- to NNE-trending subtle lineaments that fan out from the southwest corner of the quadrangle.

A network of wrinkle ridges deforms most definable material units (including large coronal outflows) that lie below mean planetary radius. Some wrinkle ridge sets that occur on younger units trend parallel to the aforementioned lineaments, indicating contractional reactivation of the earlier, shallowly buried structures [2].

Two corona associated flows dominate the quadrangle: the Llorono Planitia flows filling the northwest corner of V-25 (associated with Ituana Corona), and the Rusalka Planitia flows in the south-central area of the map (associated with the "stealth" coronae of Zaryanitsa Dorsa). Both units are clearly confined by observed regional topography. However, retreating lava "shorelines" in the Llorono Planitia group, and topographic arch development within the Rusalka Planitia group flows indicate enhancement of the region's topography occurred during and after emplacement of these units.

Crater scarcity makes them useless for dating units within the context of this map [3]. Figure 1 shows a very simplified composite of geomorphic units in the Rusulka Planitia region—NO temporal correlation of units is implied.

Conclusions: Reconnaissance mapping in V-25 indicates that coronae resurfaced the planitia. Tectonically, a radiating pattern of lineaments predates a topographically (but not stratigraphically) confined wrinkle ridge network, consistent with patterns mapped to the south. Topography has been enhanced over the time period recorded by the mapped units.

Currently we are developing an integrated geological history for both V-37 and V-25.

Note: IMAGE SXM macros used for processing the map base data are available at http://www.geology.smu.edu/~tectonics/young.html

References: [1] DeShon H.R. and Hansen V.L. (1998) LPS XXVIII, #1438, DeShon H.R. and Hansen V.L., Diana Chasma (V-37), USGS map, in review, [2] DeShon H.R. et al. (2000) JGR 105, 6983-6995, [3] Hansen V.L. (2000) Earth Planet. Sci. Lett., 176, 527-542, [4] Campbell B.A. (1999) JGR 104, 21951-21957.

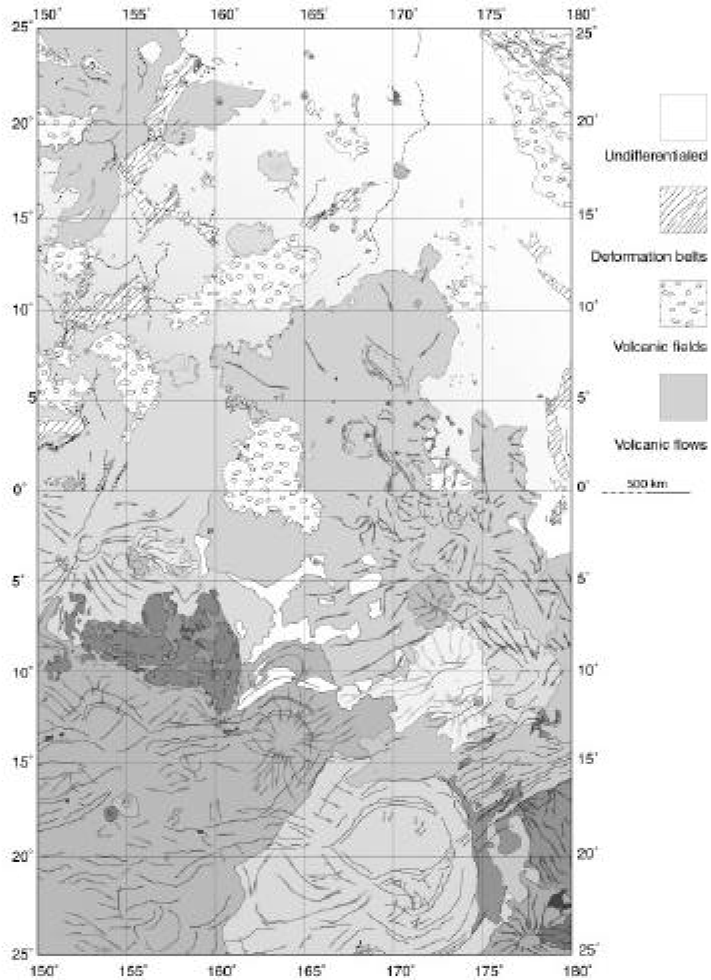

Figure 1. Simplified composite map of Rusulka Planitia region to date. From V-37 [DeShon and Hansen, in review] and V-25 [Young and Hansen, in progress]. V-25 comprises northern half.

HESTIA RUPES (V-22) AND IX CHEL CHASMA (V-34) QUADRANGLES

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V-22 (0°-25° N., 60°-90° E.) and V-34 (0°-25° S., 60°-90° E.) quadrangles comprise the west-central portion of Aphrodite Terra (including Ovda Regio) and the plains to the north and south. The overall purpose of this mapping is to investigate the structures of Aphrodite Terra (tessera and chasma) and document their spatial and temporal relation with adjoining plains.

V-22: Tessera formation is the earliest event. The tessera in this part of Ovda contains several tectonic domains, where central Ovda comprises a disorganized network of primarily extensional features (identified by 1, 2). Toward the plateau margins, this fabric yields to one dominated by margin-parallel folds and margin-normal extensional structures, recording maximum compressional strains perpendicular to the margin. Relatively minor intratessera plains are concentrated in topographic lows and may record extensional deformation.

Two major plains units cover most of the quadrangle: one with low backscatter and wrinkle ridges of variable trend, and a second of low to moderate backscatter that contains numerous structural and small (<tens of kilometers) volcanic features. Several units predate these regional plains. The oldest plains units include areally concentrated episodes of ridge and fracture formation. Ridge belts have a rather consistent northwest trend throughout the quadrangle. Two coronae also predate the regional plains, one (Kaltash) erupted within tessera terrain and has an extensive associated fracture system. Subsequent to the regional plains, two coronae (Kunhild and Ereshkigal) that have extensive radial flows and one large volcano (Uti Hiata) and associated flows were emplaced. Much of the radar contrast in the western part of the quadrangle is subdued by deposits from Mead crater and the crater Adivaar. This area includes topographic lows in the plains marked by radial and concentric compressional structures that may represent lithospheric downwelling or delamination.

V-34: Tessera formation is also the earliest event in this quadrangle. There is more variability of tectonic domains in this region than to the north, and the easternmost part of Ovda contains very high and low reflectivity materials typical of Venus mountaintops. Large (hundreds of kilometers) kipukas of tessera terrain lie within the plains south of Aphrodite proper. The tessera terrain is embayed by a regional plains unit that contains prominent wrinkle ridges trending generally north-northwest. Within these plains is an unusual ~30 km shield volcano with caldera [3]. Both the tessera, intratessera plains, and regional plains units are deformed by the structures of Ix Chel Chasma, which contain numerous fractures, arachnoids, and possibly the Verdandi Corona, which has erupted within tessera terrain. Substantial (hundreds of kilometers long) sinuous rilles emanate from Ix Chel and are associated with braided delta deposits and significant lava flows flowing downhill from the chasma south to the plains. Many of these rilles have large depressions at their heads (Lo Shen Valles). The relation between two coronae (Nishtigri and Aramaiti) and the regional plains remains uncertain at the time of this writing. Areas around craters seem to have an unusually large (relative to the average on the planet) amount of local aeolian deposits. This may be a result of winds associated with the high topography in this region.

Plains-Tessera Margins: The relation between plains and tessera is primarily one of embayment, where the plains postdate tessera structures. However, much of the plains along both the north and south boundaries of Ovda are tilted and uplifted, where the plains-tessera boundary may lie up to one kilometer above the average regional plains. In the V-22 quadrangle, ridges in the plains adjoining tessera trend subparallel to tessera ridges, suggesting a common stress regime. This relative displacement is attributed to tectonic modification of the plains by several mechanisms we hypothesize here. Post-plains uplift of the tessera plateau may indicate the final stages of plateau formation. Gravitational relaxation of the plateau may concentrate stress outward producing margin-parallel compressional structures. Finally, subsidence of the plains due to cooling of the lithosphere or other mechanism subsequent to plains formation may account for the observed topographic variation.

References: [1] Ivanov and Head, JGR 101, 14861, 1996. [2] Hansen and Willis, Icarus 123, 296, 1996. [3] Guest and Stofan, Icarus 139, 55, 1999.

NEPTHYS MONS QUADRANGLE (V-54): PROGRESS REPORT FOR YEAR 1

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Work has begun on Nepthys Mons quadrangle (V-54), Venus. This quadrangle exhibits a complex assemblage of tectonic and volcanic features whose stratigraphic relations can only be deduced from detailed geologic mapping. Because this work is being filed in the midst of the first year of funding, only initial results can be reported, which are subject to revision as mapping progresses. Some important observations follow.

General Stratigraphy: Overall quadrangle stratigraphy is similar to that found for many other regions on Venus. Tessera, distributed as scattered inliers, appears to be the oldest unit and is truncated by tectonized plains, which are, in turn, truncated by untextured plains. Stratigraphically above these regional plains units are scattered fields of shields and associated flows (the position of these shield plains is in contrast to interpretations of other mappers who find them generally confined to the basal strata of plains). Flows associated with coronae and shield volcanoes cap the sequence. In all cases, craters appear to be younger than adjacent units, consistent with other areas on Venus. No craters occur on large shields.

Tessera and tectonized plains: As in other quadrangles, tessera is the oldest unit where stratigraphic relations are seen. Four units make up tessera and units associated with tessera: (1) Tessera blocks (t) are large areas of radar-bright, tectonized terrain that are not heavily embayed by lava flows. (2) Tessera-adjacent textured plains material (ptt) consists of plains that ramp up to tessera blocks and preserve some tessera fabric beneath a cover of dark plains material. It is interpreted as plains that have covered tessera prior to uplift centered on the adjacent tessera block. (3) Densely fractured plains (pdf) are somewhat tectonized and embay nearby tessera. (4) Intermixed tessera and plains (tp) is a new type of unit that I am proposing. In many areas of V-54 tessera ridges are separated by valleys filled with embayed plains material. The scale is such that mapping two units is difficult. Therefore, a combined unit, tp, is proposed to represent a region of tessera that is infilled on a small scale by plains.

Volcanic Features: All of the large volcanoes in the quadrangle share broad similarities in stratigraphy. The oldest material is generally made up of radar-dark flows. In most cases, it cannot be determined from initial mapping whether the flows represent pre-existing uplifted plains or lavas erupted from the volcano. Radial flows, which are generally radar bright, post-date these flows. Late stage volcanism, represented by small domes, cones, and pits, and possible pyroclastic deposits in the form of radar-bright regions, appear to occur after the radial flows, although in some cases the stratigraphy is difficult to interpret. The relations at Tefnut Mons indicate that regional extension, represented by fractures associated with Parga Chasma, occurred prior to the radial flows, at least in this one case.

The plains are rich in other types of volcanic features, reflecting a complex geologic history. At least fourteen fields of small shields can be identified. The shields are distinct from large shields elsewhere in the quadrangle, probably reflecting differences in magma supply and plumbing in non-extensional regimes. The shield fields and associated flows appear to be stratigraphically young, commonly truncating structural fabrics superposed on the regional plains. This is in contrast to many other areas on Venus, where shield fields are old and generally define the base volcanic unit. Four large and many small steep-sided domes occur within the plains and are indicative of either silicic volcanism or basaltic volcanism at low extrusion rates. Radar-bright lava flows are common. Digitate flows adjacent to coronae are generally oriented radially, recording extensive volcanism occurring after the formation of the coronae topography.

A preliminary geologic map and images to support the map and the observations reported here will be presented.

GEOLOGIC MAPPING IN GANIKI PLANITIA (V-13), VENUS

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We have undertaken mapping of the territory of Ganiki Planitia quadrangle (V-13). The map area covers a significant portion of a large basin. This is a feature from the family of regional equidimensional basins on Venus, two of which--Lavinia and Atalanta Planitiae--we have already mapped. Our goals at this step of the mapping were to (1) develop a sense of the general geologic themes of the area under study, (2) see if the stratigraphic scheme we developed and used during the mapping of two remote quadrangles, V-55 (Lavinia Planitia) and V-4 (Atalanta Planitia) is applicable to an additional area of large basins on Venus, and (3) establish the main relations of units and structures in the area of V-13 quadrangle.

Main geologic features of the area: The V-13 quadrangle covers the area from 25° to 50° N. and from 150° to 180° E. and spreads from the southern margins of Atalanta Planitia to Niobe Planitia (southwest part of the area) and Nokomis Montes (southeast part of the area). The majority of the quadrangle is characterized by vast regional plains the surface of which is deformed by numerous wrinkle ridges. In places, wrinkle ridges are collected into broad zones that are preferentially oriented east-west in the south of the quadrangle and in a northeast direction in its northern portion. Fragments of ridge belts are seen through the whole area of V-13. The belts make up local ridges that separate the surface of the regional basin into relatively small (a few hundreds of kilometers across) second-order basins. The belts are oriented preferentially in a north-northeast direction in the western part of the area and in a north-northwest direction in the eastern part of the quadrangle. There are no coronae within the quadrangle. Several small coronae (within the territory of V-4 quadrangle) are at the southern edge of Atalanta Planitia, in the transition zone between Atalanta and Ganiki Planitiae. There is one large volcanic structure in the northern part of V-13 quadrangle. The structure is also in the transition zone between the Atalanta and Ganiki basins. The most unusual feature of the V-13 quadrangle is the narrow curvilinear channel, Baltis Vallis, which runs through the whole area from north to south. At the regional scale, the channel is broadly curved around high-standing Nokomis Montes, and the channel is apparently deflected by the local heights such as fragments of ridge belts.

Stratigraphic units in the V-13 area: The surface in the V-13 area is composed of several units that appear similar to those mapped elsewhere [1-9]. The units are as follow (from oldest to youngest).

Tessera terrain (unit t) is represented by tectonically deformed materials and occurs as slightly elongated massifs from a few tens up to a few hundreds of kilometers. The surface of the unit bears several sets of intersecting tectonic features of contractional and extensional origin. The main occurrence of tessera within V-13 is in the Nokomis Montes area where elongated tessera patches are sub-parallel and oriented roughly in a west-northwest direction.

Densely fractured plains (unit pdf) surfaces are heavily dissected by numerous densely packed narrow sub-parallel lineaments a few tens of kilometers long and a few hundred meters (and down to the resolution limit) wide. The plains usually form small (tens of kilometers across) equidimensional, elongated, and arc-like occurrences slightly elevated relative to their surroundings. Within the quadrangle, unit pdf is in close spatial association with tessera and occurs predominantly in the Nokomis Montes area. Where units t and pdf are in contact there is evidence for the embayment of tessera by unit pdf.

Fractured and ridged plains (unit pfr) and *ridge belts* (br) are materials having the morphology of lava plains occasionally deformed by broad ridges. The ridges are up to 10-15 km wide and up to several tens of kilometers long. Where not ridged, unit pfr has a gently rolling and morphologically smooth surface. Ridges of the belts gradually merge with the less deformed unit pfr, suggesting that the belts are tectonic facies of the same material unit. The radar backscatter cross-section of unit pfr is higher than that of regional plains and typically lower than that of tessera and unit pdf. Where units pfr and pdf are in contact, there is evidence that the material of unit pfr embays outcrops of unit pdf. Ridge belts are more widely distributed and make up local ridges throughout the quadrangle.

Shield plains (unit psh) are characterized by the presence of numerous small (from a few up to 10 km across) shield-like features, interpreted as volcanic edifices. Shield plains typically occur as small equidimensional areas several tens of kilometers across. Material of the plains embays older units and there is evidence for the embayment of unit psh by material of the regional plains.

Plains with wrinkle ridges, lower member (unit pwr_1) are characterized by morphologically smooth surfaces moderately deformed by numerous wrinkle ridges. The surface of the plains usually has uniform and relatively low radar backscatter cross section. The homogeneous albedo pattern of unit pwr_1 without visible flow-like features precludes identification of the sources of the unit material. The unit makes up the majority of the surface within the quadrangle (about 70-75%).

Plains with wrinkle ridges, upper member (unit pwr_2) are characterized by morphologically smooth surfaces moderately deformed by wrinkle ridges with a distinctly higher albedo than unit pwr_1.

The above stratigraphic column, which is applicable to the area of V-13 quadrangle, is generally similar to those for the Lavinia and Atalanta basins. However, the set of units that composes the surface of Ganiki Planitia appears incomplete. For instance, there is no evidence for the presence of fracture belts (FB), which are widespread throughout the territory of Lavinia and concentrated along the margins of Atalanta. Also, within V-13 quadrangle there are apparently no occurrences of the youngest units, smooth plains (unit ps) and lobate plains (unit pl), which are typical of the edges of the Lavinia and Atalanta basins. Tentatively, we may conclude that the above three basins are characterized by a broadly similar geologic history which, however, is different in details. More detailed mapping of V-13 will further document the differences in the evolution of the basins.

References: [1] Head J.W. and Ivanov M.A. *LPSC XXVII (Abstr.)*, 515, 1996; [2] Aubele J.C. *LPSC XXV (Abstr.)*, 45, 1994; [3] Basilevsky A.T. and Head J.W. *EMP*, 66, 285, 1995; [4] Rosenberg L. *LPSC XXVI (Abstr.)*, 1185, 1995; [5] Tanaka K.L. et al., in: *Venus II*, S.W.Bougher et al., eds., Univ. Arizona Press Tucson, p. 667, 1997; [6] Basilevsky A.T. and Head J.W. *JGR*, 103, 8531, 1998; [7] DeShon H.R. and Hansen V.L. *LPSC XXIX* #1438, 1998; [8] Dohm J.M. and Tanaka K.L. *LPSC XXIX* #1920, 1998; [9] Ivanov M.A. and Head J.W. *LPSC XXIX* #1261, 1998.

STRATIGRAPHY AND EVOLUTION OF QUETZALPETLATL CORONA (V-61), VENUS

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Introduction: We are mapping the V-61 1:5M-scale quadrangle (50°-75° S.; 300°-0° E.) on Venus as part of our ongoing analysis of the geology, stratigraphy [1], history, and origin of major rises and depressions on Venus [1-3]. The most spectacular feature in the area is Quetzalpetlatl Corona, which is about 800 km in diameter and characterized by massive volcanic eruptions [4,5]. We have focused on Quetzalpetlatl in order to (1) establish a detailed stratigraphy of the corona and adjacent regions, (2) distinguish and trace visible episodes of corona evolution, and (3) compare the stratigraphic and temporal position of the very large Quetzalpetlatl corona with the time intervals of evolution of far smaller coronae and corona-like features in the global geotraverse that we mapped at 30° N. latitude [6].

Stratigraphic units and structures at Quetzalpetlatl: There is no evidence for tessera fragments either in the corona core or rim. The oldest visible unit inside Quetzalpetlatl is densely fractured plains (unit pdf) which make up isolated equidimensional and elongated fragments heavily embayed by younger lava plains. Kipukas of unit pdf are arranged in a radial zone which is oriented in a N-S direction and runs radially to the north from the corona center. Outcrops of unit pdf are heavily dissected by numerous short and parallel lineaments, many of which are resolved as fractures. The northern and western portions of the corona rim are made up by a ridge belt that is about 500-600 km long and several tens of kilometers wide. The belt consists of densely packed ridges with morphologically smooth surfaces. Individual ridges of the belt are about 10 km wide and can extend several tens of kilometers in length. Morphologically, the features of the ridge belt appear to be similar to the common ridge belts elsewhere on Venus [2,3]. Locally, material of unit pdf is deformed by the features of the belt and this is evidence that the belt is younger. Quetzalpetlatl is broadly surrounded to the south, west, and north by material of regional plains with wrinkle ridges (unit pwr_1). At the south edge of the western portion of the rim there is evidence for the embayment of the ridge belt by unit pwr_1 plains. This means that the ridge belt formed after unit pdf and before unit pwr_1. In the southern portion of the corona core there is a cluster of small shields. The shields resemble the typical features of shield plains (unit psh), which are abundant outside of Quetzalpetlatl, and could represent kipukas of the unit. However, such a characteristic of the shields is questionable because of the lack of direct contact between the shields and other units older than the youngest plains, and the likelihood that small shields could be present in the central portion of such a large volcanic source region regardless of age. All previous units are deformed by numerous fractures and grabens that make up a broad system of features radiating away from the corona center. The most abundant unit at the corona is lobate plains (unit pl) consisting of a great number of morphologically smooth radar bright and dark flows. Lobate plains almost completely cover up the core area of Quetzalpetlatl, appear to fill a moat attached to the northern and western portions of the rim, and make up a distal skirt of volcanic materials outside the corona.

Discussion: Although there is a significant block of tessera eastward from the corona, there are no tessera fragments inside Quetzalpetlatl. This could be due to complete flooding of tessera pieces by later volcanic materials in the corona interior. However, both densely fractured plains and tessera appear to have comparable topography and sometimes the tessera appears to have higher relief. This suggests that the separation of tessera from unit pdf simply by flooding appears implausible. Thus, evidence for unit pdf inside the corona and the absence of tessera there suggests that Quetzalpetlatl formed in an area lacking significant amounts of tessera. This makes unit pdf the oldest unit in the corona area.

The first unit which is a significant corona element is the ridge belt. Wrinkle ridges of unit pwr_1 are circumferentially arranged around Quetzalpetlatl. This suggests that the formation of the ridges could be governed by the stress field introduced by the presence of the corona. Regional plains with wrinkle ridges, surrounding the corona, are deformed by the radial system of fractures and grabens, which means that the most prominent extensional features at Quetzalpetlatl were formed after the emplacement of unit pwr_1. The formation of the radial fractures and grabens was followed by massive eruption of the youngest lobate plains. Superposition of individual flows indicates that the formation of unit pl took place during several (or many) eruptive episodes. The vast majority of the radial grabens are flooded by the unit pl material. However, some of the grabens appear to cut through the surface of unit pl.

The above relations of the units and structures permit us to outline a generalized scheme of events in the evolution of Quetzalpetlatl. As Quetzalpetlatl evolved, it experienced at least two main tectonic episodes separated by the emplacement of regional plains with wrinkle ridges. The first, a dominantly compressional regime, was responsible for the formation of the ridge belt in the northwest part of the corona rim. The second episode, an extensional regime, led to the formation of the radial system of fractures and grabens. The last visible activity at the corona was the emplacement of vast deposits of lobate plains. Thus, as is the case with the majority of coronae in the geotraverse, Quetzalpetlatl apparently started to form before the emplacement of regional plains and, in a manner similar to a few coronae in the geotraverse, the evolution of Quetzalpetlatl continued through the long period of time until the formation of lobate plains.

Reference: [1] Ivanov, M.A., and Head, J.W., 1998, Global stratigraphic units on Venus: Results of a geotraverse around the Venus globe at 30 N latitude, LPSC 29; [2] Head, J.W., and Ivanov, M.A., 1996, LPSC 27, 515-516; [3] Basilevsky, A.T., and Head, J.W., 1995, EMP, 66, 285-336; Basilevsky, A.T., and Head, J.W., 1995, PSS, 43, 1523-1553; [4] Stofan, E.R. et al., 1992, JGR, 97, 13347-13378; [5] Roberts, K.M. et al., 1992, JGR, 97, 15991-16016; [6] Ivanov, M.A., and Head, J.W., 1998, Stratigraphy of coronae: Results from the mapping of global 30 N geotraverse, LPSC 29.

MAPPING OF THE HECATE CHASMA QUADRANGLE (V-28), VENUS

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We are mapping the Hecate Chasma quadrangle (V-28) at 1:5,000,000 scale as part of the NASA Planetary Geologic Mapping Program. V-28 covers the region from 0°-25° N. and 240°-270° E. Magellan synthetic aperture radar (SAR) data are used for the map base. Standard planetary geologic mapping techniques [e.g. 1, 2] are being used to construct a geologic map for the Hecate Chasma quadrangle. Mappable geologic features within the quadrangle include thirteen impact craters, several large volcanoes, over eleven coronae of varying morphology, three chasmata, and the northern portion of Hinemoa Planitia.

Full-resolution Magellan image mosaics (FMAP's) and synthetic parallax stereo images, produced by the U.S. Geological Survey, are being used to aid in determining the stratigraphic relations between map units. Unit characters and boundary locations not resolvable at C1-MIDR scale (250 m/pixel) were clearly seen at FMAP scale (75 m/pixel). The large format of the FMAP prints, the synthetic stereo data, and the digital data are key to determining stratigraphic relations. Apparently contradictory stratigraphic relations between major map units are commonly caused by the presence of additional subtle units only noticeable through digital manipulation of FMAP data. Magellan altimetry, roughness, reflectivity, and emissivity datasets [3, 4] provide additional information on map units.

There are difficulties in utilizing radar data to construct a geologic map [e.g. 5]. Geologic units will only be visible in radar images if they have backscatter characteristics distinctly different from surrounding units. In volcanic or plains regions, younger and older units are likely to be mistakenly incorporated into a single unit if they have similar backscatter characteristics. If the surface of a unit changes laterally, and thus potentially its radar signature changes also, it may be mapped incorrectly as two or more units. In addition, structures tend to be more visible if they are oriented perpendicular to the radar look-direction [e.g. 6]. Thus, in Magellan data, north-south-trending lineaments will tend to be well defined, but east-west structures are likely to be underrepresented or only weakly represented in the data unless associated with a rough talus slope.

The V-28 quadrangle contains a wide range of volcanic features with mappable deposits, from shields at the limits of resolution of the data to a large volcano (Polikmana Mons, 24.8° N., 264° E.). Polik-mana Mons, diameter >600 km, is superposed on Hecate Chasma. A smaller construct, Shulzenko Patera (6.1° N., 264.5° E.), lies in Hinemoa Planitia to the south of Hecate Chasma, with surrounding flow deposits which postdate both the local plains as well as flows from Aruru Corona. Most of the coronae in the quadrangle have associated volcanic activity, including interior constructs and flows as well as surrounding volcanic deposits. Aruru Corona, at 9° N., 262° E., has the largest volume of associated volcanic deposits of any of the coronae in the quadrangle. It is morphologically similar to Benten Corona [7] and also appears to have undergone multiple phases of annulus formation. Taranga Corona, at 16° N., 252° E., has much less associated volcanism, with some interior flows and surrounding deposits.

The V-28 quadrangle contains three chasmata: Hecate, Zverine, and an unnamed chasma (chasma A) parallel to Hecate, which lies south of Taranga Corona. Hecate Chasma and chasma A have numerous coronae along them. In this quadrangle, Zverine has no coronae, but has rifted apart a large volcano at 19° N., 267° E. Hecate Chasma extends for over 8000 km, from Atla Regio through Asteria Regio [8]. It is a discontinuous trough and fracture system, with en echelon offset along strike. Regions where the trough is more distinct tend to be characterized by more dense fracture spacing [8]. Coronae along this chasma range from 85 to over 500 km in diameter. Some coronae are topographic highs (domes, plateaus, rimmed plateaus) whereas others are depressions or rimmed depressions. Coronae along chasma A are most commonly depressions.

We have mapped over ten plains units on the Hinemoa Planitia region, indicating that multiple episodes of plains volcanism have occurred over the last approximately 700 m.y. These plains were cut by rifting, which occurred concurrent with corona and volcano formation.

References: [1] Wilhelms, D.E. 1972, Geologic mapping of the second planet, USGS Interagency report, Astrogeology 55; [2] Wilhelms, D.E. 1990, Geologic mapping, *in* Planetary mapping, Greeley, R. and Batson, R.M., eds. Cambridge University Press, 296 p.; [3] Pettengill et al. 1992, Venus surface radiothermal emission as observed by Magellan, JGR, 97, 13,091-13,102; [4] Campbell, B. 1998, Surface formation rates and impact crater densities on Venus, JGR; [5] Ford, J.P. et al. 1993, Guide to Magellan Image Interpretation, JPL Publ. 93-24, 148 p.; [6] Stofan, E.R. et al. 1989, Geology of a Venus rift zone: Beta Regio and Devana Chasma, GSA Bull., 101, 143-156; [7] Copp et al. 1998, New insights into coronae evolution: Mapping on Venus, JGR, 103, 19,401-19,417; [8] Hamilton, V.E. and E.R. Stofan 1996, The geomorphology and evolution of Hecate Chasma, Venus, Icarus 121, 171-194.

PLANETARY GEOLOGIC MAP UNITS: LIMITATIONS AND IMPLEMENTATION

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Introduction: The goal of geologic mapping is to reconstruct the geologic history of a study area with the objective of understanding the evolutionary processes and controls involved. Maps attempt to characterize and organize spatial and temporal geologic data, which includes stratigraphy and tectonic, volcanic, erosional, and depositional entities. We must appreciate that the geology is more complex than can be fully realized and represented on a geologic map. Another problem is that relative-age correlations of map units and structures in some instances are poorly constrained. Therefore, geologic mappers need to discuss methodologies and acknowledge critical uncertainties and avoid over-interpretation and bias. A fundamental issue is how map units are defined, mapped, and relative-age dated.

Limitations: In planetary mapping, we have inherent limitations in available data, which dictates what can reasonably be achieved. Importantly, we do not have field data to work with, but terrestrial field experience is essential to properly apply spacecraft data to photogeologic mapping. The image base provides the primary data used for mapping. Data quality and resolution commonly vary from place to place. Also, environmental aspects can be variable, such as atmospheric and illumination conditions. Other available types of data (e.g., spectra, altimetry, radar, and geophysical) may enhance the observations that can be made. In many instances, planetary map units cannot be made to represent rock-stratigraphic units in a strict sense. Instead, they may define modified *terrains* that may correspond to *rock* units.

Implementation: Rock-stratigraphic units are the preferred unit type, but secondary characteristics many times have to be used as a basis for deciphering the geologic and resurfacing history. Units based solely on secondary features represent modified rock materials of uncertain makeup and relative age. Thus in some cases, a map unit may comprise rocks of multiple ages and origins; in other cases, multiple map units represent different modificational states of a single rock material. All of these issues should be adequately described in the map text and properly portrayed on the geologic map (e.g., solid vs. dashed contacts and contact triple junctions) and correlation chart (e.g., saw-tooth boundaries), such that the results are reproducible.

In order to reflect temporal relations accurately, map-unit correlation charts must show relative ages of the features used to define the unit. For units based on secondary characteristics, the relative ages of the modificational features constrain the upper age of the material(s) they modify. But the actual upper age of the material may be much older than the secondary features. In some cases, adjacent, less-modified units may include similar characteristics that provide a basis for inference of contemporaneity with the modified unit. These and other situations illustrate that material and relative-age information of map units may vary greatly and be sorely lacking in many cases. Cross sections can show relations among stratigraphy and structure. Additional columns on the correlation chart may be used to show the time of formation of modificational landforms, which will assist with understanding what the map-unit boxes in the chart represent. The mapping of both rock and modified units, though disconcerting to the purist, cannot be avoided in planetary mapping and, when thoughtfully performed, can result in a greater understanding of the geologic history of the region of interest.

A VIRTUAL COLLABORATIVE WEB ENVIRONMENT FOR MARS SURFACE SCIENCE STUDIES

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INTRODUCTION: A virtual collaborative web environment is now available for the planetary community to better utilize, visualize, and analyze Mars Global Surveyor data. These tools have grown out of a 2 year effort by the Center for Mars Exploration (CMEX) at NASA Ames Research Center (ARC), the Ames data visualization group, and the Mars Surveyor Program to promote interactions among the planetary community to coordinate landing site activities.

In collaboration with information technologists at Ames, CMEX is developing this state-of-the-art web site environment to foster interaction of interested members of the planetary communities with the Mars Surveyor Program. This web site will continue to evolve over the next several years as new tools and features are added to support the ongoing Mars missions and the analyses of the returned data.

WEB SITE FEATURES: A variety of tools have been developed and are accessible at the Ames Mars Surveyor Landing Site Studies web page http://marsoweb.nas.nasa.gov/landingsites/. Recently added tools include: (1) online JAVA-based image processing of MOC images for users of the Internet Explorer browser, (2) on-the-fly creation of zoomable, rotatable 3D perspective image views (VRML's) of any location on Mars, incorporating all available MOC and MOLA data, and (3) an information window that gives the latitude, longitude, and elevation at a given point as the user moves the cursor along MOLA profile superimposed on MOC images.

Additional tools include: (1) a clickable, zoomable Map Interface from which web pages for all candidate Mars Surveyor landing sites can be accessed, (2) the entire collection of released high-resolution MOC images with annotated Viking context images, (3) low- and high-resolution zoomable, rotatable 3D image views of all proposed Mars Surveyor landing sites--these VRML's include geologic map overlays and embedded MOC and MOLA data where available, (4) a downloadable macro that allows both Windows and Macintosh users to import MOC images in PDS format directly into the popular NIH Image and Scion Image shareware programs, and (5) a Postdoctoral Mars Surveyor Landing Site Studies group. Postdoc users can propose a landing site, submit both science and engineering evaluations, post supporting image, graphics or word documents of their proposed landing site(s), or create their own email subgroup list for their respective landing sites.

PLANNED ENHANCEMENTS: Future enhancements to the web site include integration of geologic (from USGS maps or user supplied) and mineralogic (from TES released data) maps composited with surface images and as overlays on 3D VRML terrains. We also plan to integrate rock abundance, and thermal inertia data. Other enhancements include the use of Concept Maps as a user interface for links to relevant site data (e.g. abstracts, science evaluations, images, maps, and online reference materials). The goal is to allow users and peer reviewers to create and edit Concept Maps in a collaborative fashion.

New Java-based application tools for analyzing and visualizing MGS data are also planned. For the first time this will allow Macintosh users the ability to read and work with MGS TES data, since a Macintosh application program is currently unavailable. Other web-based applications will allow users to easily locate and work with available MOLA data of their sites. For example, from within the 3-D image models, users will also be able to move their cursor over the MOLA profile to find out the latitude, longitude, and elevation of any given point along the profile.

Collaborative tools will be enhanced to include collaborative whiteboards, collaborative image viewing and annotation, and support for possible Usenet news groups, chat rooms, and/or list-serve mailing lists. Some of these capabilities are already provided on Postdoc, which allows user-uploadable and retrievable materials and threaded mail archives.

CONCLUSION: This website is intended to be an integrated repository for the latest Mars mission images, data, and data products that pertain to landing site selection and Mars surface science studies. This site provides user-friendly visualization and data analysis tools including on-the-fly image retrieval, auto-mosaicking, and VRML creation, with options to include surface context images, topographic profiles, geologic and surface composition maps, and other relevant data. We encourage the planetary community to make use of this resource not only for landing site studies but also for general Mars surface science studies. We welcome suggestions for enhancing and improving this site.

Field Trip Notes, June 24, 2000
Geologic Controls on Select Springs near Flagstaff, Arizona
Planetary Geologic Mappers Meeting, Flagstaff, Arizona
June 22-24, 2000

INTRODUCTION

Volcanic rocks, unconsolidated rocks, sandstone, siltstone, and limestone that are Recent to Permian in age underlie the greater Flagstaff area and contain several perched aquifers and a regional aquifer. Geologic structure increases the complexity of the aquifer characteristics and ground-water flow systems in the Flagstaff area and is the main control on the occurrence and location of most springs in the area.

Recent evidence of young landforms on Mars, seen in high-resolution images acquired since March 1999, suggest the presence of sources of water at shallow depths beneath the martian surface. All of these landforms display geomorphic features that can be explained by processes associated with ground-water discharge and surface runoff. Geomorphic features associated with spring areas of the southern Colorado Plateau in Arizona are similar to some of the geomorphic features seen on Mars. This field trip was organized to observe select springs in the Flagstaff area that show a variety of landforms, geomorphic processes, and structural controls, in a terrestrial setting, that may be analogous to similar features seen in the martian images. Photographs of select springs at the west end of the Grand Canyon also are included. In figure 1 a series of sketches show the general geologic and structural relations of principal spring types.

REGIONAL SETTING

The Flagstaff area is on the south edge of the Colorado Plateau at an elevation of about 7,000 ft (2,134 m) and receives annual precipitation of about 22 inches (559 mm); thus the region is classified as semi-arid. At higher elevations on the nearby mountains annual precipitation is as high as 35 inches (890 mm). Highly permeable, cindery soil and fractured rocks generally allow precipitation to percolate to great depths. For this reason, perennial streams are absent in the immediate area.

Flagstaff and the surrounding area overlie a complex series of volcanic and sedimentary rocks (fig. 2). These rock formations are deformed locally and regionally by a series of folds and fractures that collectively define the geologic structure of the area (fig. 3). This structure partly controls the occurrence and movement of ground water. Ground water in some areas is perched close to land surface by dense and unfractured volcanic rocks or by fine-grained sediments and sedimentary rocks. Ground water also occurs throughout the area in sedimentary rocks deep in the subsurface in a regional aquifer. This regional aquifer is the source of water for many springs along the south rim of the Grand Canyon and the source of springs and perennial flow in tributaries to the Verde River to the south.

Perched Aquifers

In some areas near Flagstaff, ground water is ten's to less than 300 ft (2 to 91 m) below land surface in fine- to coarse-grained volcanic rocks, sediments, or sedimentary rocks. These water-bearing zones supply many of the seeps and springs in the Flagstaff area. They occur in a variety of environments that are represented by one or more types of geomorphic and structural controls.

Regional Aquifer

Ground water also occurs in the sedimentary rocks that underlie the entire area. These water-bearing zones are recharged by precipitation and runoff that percolates deep into the subsurface. Fracturing associated with structural deformation increases recharge locally. Ground water in this regional aquifer moves laterally and vertically until it discharges as springs in deeply incised canyons to the north and south. These canyons are developed along regional structural trends that have been exploited by ground-water flow and surface runoff.

FIELD TRIP STOPS

The locations of field trip stops are shown on figure 4.

Stop 1: Coyote Spring (fig. 5).

One of several springs in this area, Coyote Spring has about 5 gal/min (0.31 L/s) perennial flow and is an unconfined, perched, fracture and contact spring. The developed spring issues from fractured basalt (Pliocene to Miocene in age) overlying Moenkopi Formation (mid-lower Triassic in age) on the west side of Switzer Mesa next to U.S. Hwy 89A and the Museum of Northern Arizona. The fracturing in this basalt flow is from differential stress as the flow cooled. Also, a northwest-trending fault runs parallel to the west side of Switzer Mesa. The upthrown block to the east and south probably contributes to Coyote Spring and other springs in this area by restricting ground-water flow across the fault plane. A debris apron of fine silt deposited by the spring is visible downstream and is overgrown with vegetation.

Stop 2: (optional) Tunnel Spring.

Tunnel Spring is an ephemeral, unconfined, perched fracture and contact spring. The spring is north of the railroad tracks behind the new Railroad Springs development. Undeveloped, the spring flows downstream into a stock tank constructed to catch flow. The spring issues from the upstream end of an enlarged and incised channel in fractured basalt (Pleistocene in age) on top of an older basalt flow (Pliocene to Miocene in age) at the south end of Observatory Mesa. The spring is currently dry owing to the dry conditions this year. Mounds of raised silt on both sides of the channel are densely vegetated and may represent old secondary seeps. Tunnel Spring is typical of several springs that issue from fractured basalt at the base of Observatory Mesa. Water from these springs only flows for short distances at land surface before it is evapotranspired back to the atmosphere or infiltrates into underlying rock units

Stop 3: Turnout, Lake Mary Pumping Station (fig. 6).

The turnout at the Lake Mary Pumping Station offers views of Lake Mary graben, Anderson Mesa, and Lake Mary faults. These regional geologic structures have a major influence on the occurrence and movement of ground water in the regional aquifer in this area. Lake Mary graben is the downdropped block between the Anderson Mesa fault to the north and Lake Mary fault to the south. Upper Lake Mary and Lower Lake Mary, within the Lake

Mary graben, are man-made lakes and store runoff from the drainage upstream. No springs feed the lakes owing to the offsets of the faults and fracturing associated with the faults, which enhances the infiltration of water deep into the subsurface. The depth to water in the regional aquifer in this area is about 350 ft (107 m) below land surface as indicated by the static water level in well LM-4 about 300 ft (91 m) to the south of the pumping station. Local drawdown when the city of Flagstaff wells are pumping can be an additional several hundred feet (150 to 200 m). Recovery when the wells are off, however, is rapid. The Anderson Mesa fault is uplifted several hundred feet to the north (about 150 m). The Lake Mary fault is uplifted 50 to 100 ft (15 to 30 m) to the south. Just to the east and south of the turnout (center and right of photograph) in Lower Lake Mary and behind the coffer dam are several small depressions and openings. These features have developed directly over fractures in the Kaibab Formation that have been widened over time by dissolution and erosion of the rock.

Stop 4: Clark Spring.

Clark Spring issues from fractured Kaibab Formation (lower Permian in age) at the base of slopes and where the drainage intersects the water table in the regional aquifer. The spring is a perennial, unconfined, regional aquifer spring controlled by fractures in the Kaibab Formation and by subregional northeast- and northwest-trending faults. The channel below the spring is incised into alluvium and bedrock, and the drainage is significantly wider just downstream of the spring. Overall the drainage is constrained by northeast-trending geologic structure. Although Clark Spring is dry this visit, the site typically has a flow of 20-40 gal/min (1.26 to 2.54 L/s). Clark Well, hand dug into alluvium and Kaibab Formation about 1,000 ft (305 m) downstream, currently has a water level about 5 ft below land surface. During more normal years Clark Well also flows at land surface. The current dry conditions are likely due to a combination of drought and City of Flagstaff water use.

Stop 5: Hoxworth Springs.

Hoxworth Springs issue from the contact with old basalts (Pliocene to Miocene in age) at the upstream end of the reach and from fractured Kaibab Formation at the downstream end of the reach where these rocks are exposed at land surface. The springs are perennial, confined regional aquifer springs controlled by formation contacts and fractures. Some flow in the upper reach is from water perched in fractures in the basalt rocks. The basalt flows, however, mostly confine water in the Kaibab Formation in this area. During this visit, the lower reach where water typically flows from the Kaibab Formation was dry, except for a few areas of ponded water. First flow is at the middle pool where water issues from the basalt/Kaibab Formation contact. Flow here is about 1-2 gal/min (0.12 L/s) and increases upstream to about 10 gal/min (0.63 L/s). Note that the drainage upstream of the springs is very narrow. At the springs the drainage expands to a large flat valley of alluvial material overlying bedrock with the main channel downstream of the springs being incised into the alluvium and bedrock.

Stop 6: Un-named spring adjacent to I-17 just north of Kachina Village (fig. 7).

With 2 outlets, the un-named spring issues from large fractures in the base of a dense basalt flow (Pleistocene in age). The spring is perennial (20-40 gal/min; 1.26-2.52 L/s), unconfined, perched, and controlled by fracture in basalt. Two small alcoves with incised channels and weak sapping of the overlying basalt have developed at the head of the spring area. This un-named spring is at the north end of the Munds Park graben on the upthrown side of one of the bounding faults. Directly opposite this spring on the east side of I-17 the Kaibab Formation is exposed at land surface. The depth to water in the regional aquifer in this area is about 1,200 ft (366 m) below land surface.

Stop 7: O'Neil Spring.

O'Neil Spring issued from a contact between fractured basalt and dense basalt in a well-developed ravine. There is no direct access to this site but it is visible from the frontage road between the freeway and Kachina Village to the south. The spring is perennial, unconfined, perched, and controlled by contact between basalt flows and fractures in the basalt. The perennial flow of this spring contributes most of the water to the wetland at Kachina Village just downstream. O'Neal Spring has a developed headwall with sapping of overlying basalt. The channel below the spring flows out of the ravine incised into a small distributary flow apron of material eroded from the ravine. There is no significant drainage upstream of the spring.

Stop 8: Griffiths Spring.

Griffiths Spring has two outlets that issue from fractured basalt (Pleistocene in age). Both of these outlets have well developed debris fans and incised channels. The spring is ephemeral, unconfined, perched, and controlled by fractures in basalt. Griffiths Spring is on State highway 89A just south of Fort Tuthill. Lindergh Spring, about 0.75 mi. south on 89A, is similar to Griffiths Spring except it has perennial flow. The spring area use to be a rest stop on 89A and is currently fenced off to facilitate redevelopment of the original vegetation and wetland.

Stop 9: Oak Creek Canyon Overlook (fig. 8).

The Oak Creek Canyon overlook provides views of Oak Creek and the Oak Creek fault. The fault is upthrown to the west about 500 ft (152 m) at this point and records both Laramide compression and more recent Basin and Range extension. This has implications for the occurrence and movement of water in the regional aquifer, because compressional faults are typically closed and impede the flow of water across the fault plane and extensional faults are more open allowing water to flow more freely across the fault plane and down the fault. All of the springs in Oak Creek Canyon occur on the west or upthrown side of Oak Creek fault. The perennial flow of Oak Creek is spring fed beginning at Sterling Spring at the base of the switchbacks on 89A. Sterling Spring issues from the very fractured Coconino Sandstone (lower Permian in age) where the fault plane intersects the water table in a short, very steep tributary canyon. The spring is perennial, flowing at about 300 to 400 gal/min (18.9 to 25.2 L/s), unconfined, and controlled by Oak Creek fault. Pumphouse Wash, the much larger and more developed drainage to the east on the downthrown side of the fault, is dry except for seasonal runoff.

Stop 10: Call of the Canyon and West Fork Springs (fig. 9).

Just upstream on the West Fork of Oak Creek are several un-named springs that issue from the Coconino Sandstone by seepage through pore spaces in the rock and from fractures associated with the Oak Creek fault. The flow in West Fork at this point is about 500 to 600 gal/min (31.5 to 37.9 L/s). The West Fork of Oak Creek has incised a channel below the regional water table in this area. Springs in this area are characterized by two different geologic processes. Some springs are broad seeps and seepage faces that cover several hundred square feet (a hundred or more square meters) and are characterized by flat to overhung seepage faces with hanging gardens and where rock spalls from the seepage face in small to large sheets. These types of springs and seeps are identical to the sapping springs and features described by Howard and others (1988) and are the result of the main channel having rapidly incised bedrock to well below the regional water table. In some areas spring flow is concentrated to a point by fracturing in the rock caused by the Oak Creek fault. Horizontal and vertical to near vertical feeder fractures can be seen in the rock face concentrating flow to a single fracture that has been further widened by dissolution and erosion of the rock by the concentrated flow.

Select Regional Aquifer Springs at the West End of the Grand Canyon

Clay Spring (fig. 10).

Clay Spring is controlled by a near vertical fault in the Muav Limestone (Cambrian age) that parallels the north side of an east-west canyon in the Grand Wash Cliffs at the west end of the Grand Canyon. The spring is perennial and unconfined. The scarp is clearly visible as a line running nearly horizontal across the middle of the photograph. The spring is at the left center of the photograph marked by the increase in surrounding vegetation. The drainage upstream of the spring and the fault are poorly defined. At the fault and spring the drainage becomes a series of three well-defined channels that combine into one larger channel at the bottom of the photograph. This spring correlates well to features seen in recent Mars Orbiter Camera images.

New Water Spring (fig. 11).

New Water Spring is controlled by solution-widened fractures in the Muav Limestone (Cambrian age) associated with the north-northwest-trending Rampart Cave fault. A north-northwest-trending drainage has developed along the fault on the Grand Wash Cliffs at the west end of the Grand Canyon. The spring is perennial and unconfined. The spring is marked by a semi-circular area of collapse on the west side of the canyon with small trees and brush defining the perimeter. The main channel below the spring is about twice as large as above with two distinct branches.

Quartermaster Spring (fig. 12).

Quartermaster Spring is controlled by solution-widened fractures in the Muav Limestone and contact with the underlying Bright Angle Shale (Cambrian age). The spring is perennial and unconfined. Spring flow varies seasonally from about 450 to more than 15,000 gal/min (28.4 to 946 L/s). The current outlet for Quartermaster Spring is from a depression on top of a travertine mound on the northwest edge of a much larger, older travertine mound. In both cases these spring outlets and travertine mounds have developed near the contact with the Bright Angle Shale. The Bright Angle Shale is very fine grained siltstone and shale and is the lower confining layer for ground-water flow in the limestone aquifers in this part of the Grand Canyon. Quartermaster Spring is still actively depositing travertine, and the deposits have dammed the drainage resulting in over 600 ft of alluvial fill in the drainage upstream of the spring and a waterfall to the Colorado River downstream of the spring.

Boundary Spring (fig. 13).

Boundary Spring is controlled by the contact between the Muav Limestone and the underlying Bright Angle Shale. The spring issues from the base of Muav Limestone cliffs through solution-widened fractures in the limestone. The active part of the spring is visible in the upper right of the photograph and is marked by dense vegetation. Older, currently dry, outlets are visible in the middle of the photograph and are marked by well-defined, deeply incised channels in the talus and colluvium that have little or no relation to poorly defined drainage above the limestone cliffs. Another discharge point is noted in the left center of the photograph where still active seeps support moderate to thick vegetation at and downstream of the cliff face. In addition this area has the beginnings of an alcove type structure that appears to be eroding back to the headwall seeps. Although this feature could be due more to erosion from surface runoff in the main channel the constant presence of moisture provided by the seep probably is an agent in weakening the rock and thus facilitating its erosion. The geomorphic features of Boundary Spring are very similar to features seen in the recent Mars Orbiter Camera images.

Figure 1. Sketches showing the different types of springs.

Figure 2. Generalized stratigraphic section of rock units, Flagstaff, Arizona.

Figure 3. Landsat Thematic Mapper image, June 22, 1991, Flagstaff, Arizona (from Chavez and others, 1997).

Figure 4. Map of the Flagstaff area showing field trip stops.

Figure 5. Photograph showing Coyote Spring.

Figure 6. Photograph showing turnout, Lake Mary Pumping Station.

Figure 7. Photograph showing un-named spring adjacent to I-17 near Kachina Village.

Figure 8. Photograph showing Oak Creek Canyon overlook.

Figure 9. Photograph showing Call-of-the-Canyon and West Fork Springs.

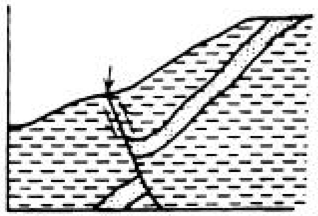
Figure 10. Photograph showing Clay Spring.

Figure 11. Photograph showing New Water Spring.

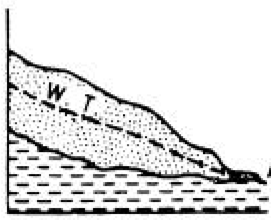
Figure 12. Photograph showing Quartermaster Spring.

Figure 13. Photograph showing Boundary Spring.

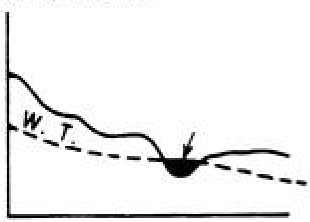
A. Artesian



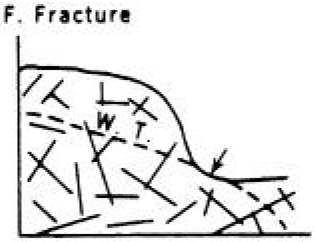
C. Contact



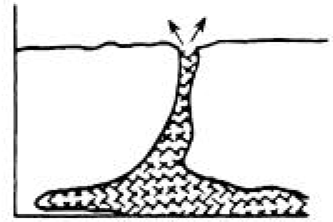
D. Depression



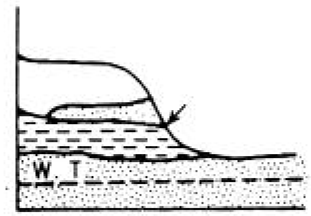
F. Fracture



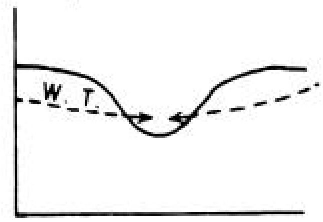
G. Geyser



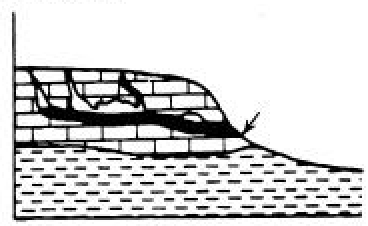
P. Perched

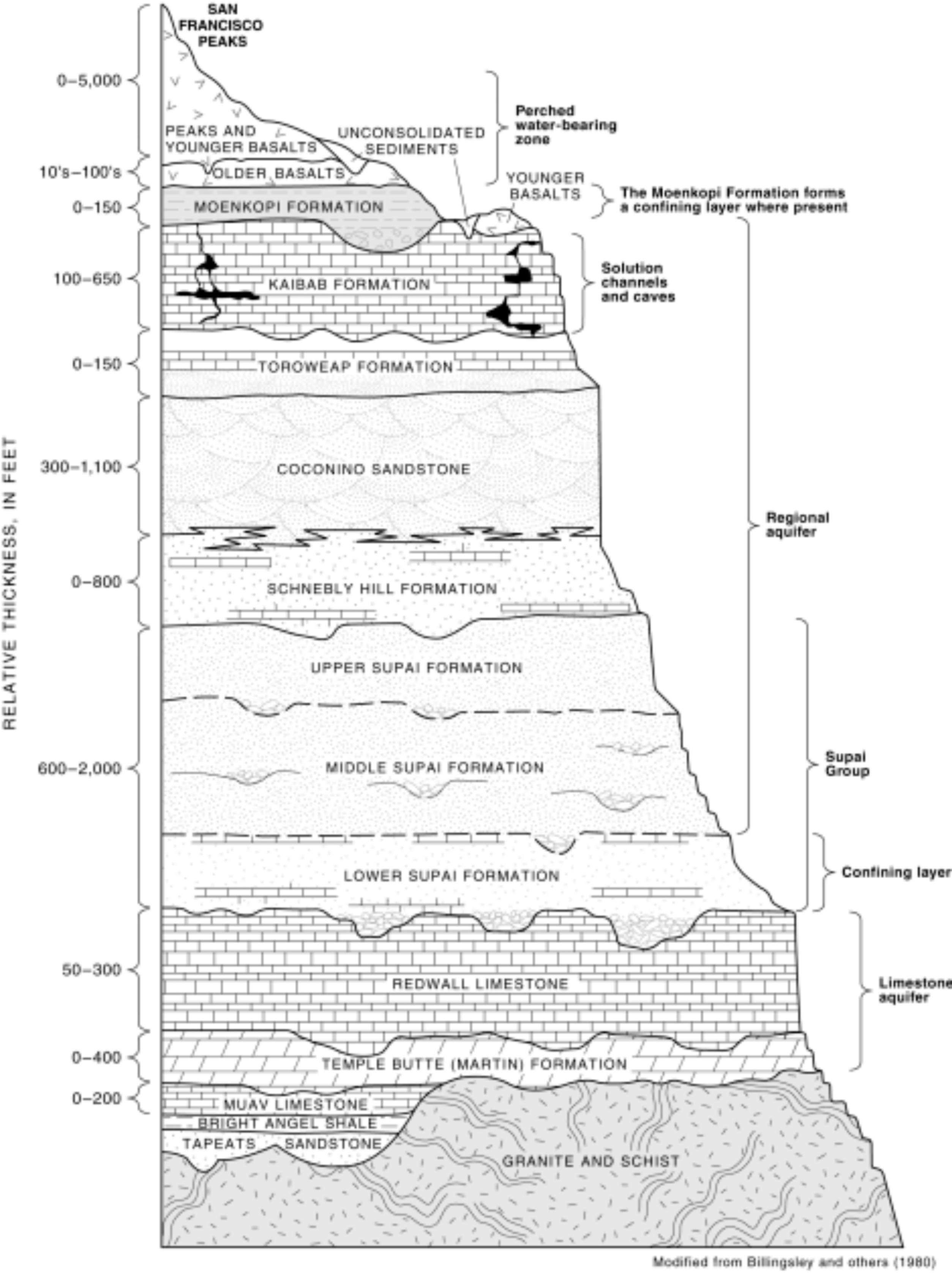


S. Seep or filtration



T. Tubular





Modified from Billingsley and others (1980)

Landsat TM 245 --- June 22, 1991
Flagstaff Area


Stop 1
Stop 2
Stop 3
Stop 4
Stop 5
Stop 6
Stop 7
Stop 8
Stop 9
Stop 10
Flagstaff
East Flagstaff
Flagstaff City Reservoirs
Observatory Mesa
Switzer Mesa
Lowell Observatory
Mars Hill
Hospital
Northern Arizona University
US NAVAL RESERVATION
Observatory
Radio Facility
A-1 Mtn
Belle Spring
Tunnel Spring
Elden Spring
Big Fill Lake
Substation
Dry Lake
Cinder Pit
Sinclair
Flagstaff City Wells
Woody Spring
Woody Mtn
Racetrack
Pulliam Airport
Skunk Canyon
Black Spring
Garden Spring
Landon Spring
Griffiths Spring
Lindergh Spring
Woody Ridge
Black Pass
Kellam Tank
Fay
Pumping Station
Lower Lake Mary
Schoolhouse Draw
Mountainaire
Priest Draw
Howard Draw
Kelly Canyon
Kelly Seep
Fry Canyon
Pumphouse Wash
James Canyon
Clark Well
Hoxworth Springs
Thomas Spring
Howard Mtn
Mortgage Spring
Wilson Seep
Campground
Scott Spring
Sterling Spring
Cookstove Draw
Smith Butte
Pine Flat Campground
Ritter Butte
Ritter Mtn
Ritter Spring
Coulter Mtn
Coulter Hill
Oak Creek Canyon
Sterling Canyon
R 6 E
R 7 E
0 1 2 3 4 5 6 7 8 9 10 KILOMETERS
0 1 2 3 4 5 6 MILES

Planetary Mappers Meeting Agenda
Thursday, June 22

9:00	Tim Parker & John Grant	Opening Remarks
9:20	Ken Tanaka	Mapping program status
	Mars Geologic Mapping	
9:30	Ken Herkenhoff	Polar Regions
9:50	Eric Kolb/Ken Tanaka	South Polar Region
10:10	Jim Zimbelman	Medusae Fossae Formation
10:30	*Break and Map Poster Session*	
11:20	David Crown/Scott Mest	Reull Valles
11:40	*Lunch*	
1:20	Tim Parker/Brenda Franklin	Central Acidalia Planitia
1:40	Ken Tanaka	Northern Plains
2:00	Larry Crumpler	Isidis Rim Landing Sites
	Venus Geologic Mapping	
2:20	George McGill	V-8
2:40	Jim Zimbelman	V-15 & V-16
3:00	*Break and Map Poster Session*	
4:00	Les Bleamaster/Vicki Hansen	V-35
4:20	Duncan Young/Vicki Hansen	V-25
4:40	Virginia Gulick	A Virtual Collaborative Web Environment for Mars Surface Science Studies
	Friday, June 23	
9:00	Marty Gilmore	V-22 & V-34
9:20	Nathan Bridges	V-54
9:40	Jim Head	V-61 & V-13 (+preliminary work on V-56 & V-14)
10:00	*Break and Map Poster Session*	
10:40	Ken Tanaka	Age-dating planetary surfaces for geologic mapping
11:00	Tim Parker	FY 2001 regional Mapper's meeting: "Quaternary Stratigraphy and Volcanology of the Sevier and Black Rock Deserts, Utah"
11:20	Larry Crumpler	FY 2001 Mappers Meeting and Field Excursion: Rio Grande Rift Structure, Volcanism, Spring Deposits, Valles Caldera (and Colonial Span ish Culture), New Mexico
11:40	*Discussion and Closing Remarks*	
1:50	Trent Hare & Ken Tanaka	Planetary GIS on Web and Mapping with ArcView Demo
4:00	Don Bills, Sara Kelley, & Pat Chavez	Pre-Field Trip Orientation (field trip guides will be available)

Posters to be displayed

Mars	
George McGill	Arabia Terra (in revision)
John Grant	Margaritifer Sinus
Venus	
Dave Senske	V-41
Jeff Plaut/Dave Senske	V-10
H. DeShon & V. Hansen	V-37 Diana Chasma (in review)
Ellen Stofan/Antony Brian	V-39

Planetary Mappers Meeting Agenda

Thursday, June 22

9:00	Tim Parker & John Grant	Opening Remarks
9:20	Ken Tanaka	Mapping program status
	Mars Geologic Mapping	
9:30	Ken Herkenhoff	Polar Regions
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4:00	Don Bills, Sara Kelley, & Pat Chavez	Pre-Field Trip Orientation (field trip guides will be available)

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H. DeShon & V. Hansen	V-37 Diana Chasma (in review)
Ellen Stofan/Antony Brian	V-39

Planetary Geologic Mappers Meeting
Attendance List
June 2000

Jayne Aubele	New Mexico Museum of Natural History and Science 1801 Mountain Road, NW Albuquerque, New Mexico 87104	jaubele@nmmnh.state.nm.us (505) 841-2840
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