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NASA Mars Geologic Mapping Program Grant NAGW-2171: "Erosional and Depositional History of Central Chryse Planitia"

Summary and Final Technical Report

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We accomplished several tasks under the 1:500,000-scale Mars geologic mapping program concerning the geologic history and origin of the central Chryse Planitia region through geologic mapping and geologic analysis of the results (Crumpler et al., 1993; Craddock et al., 1992a,b, 1993):

(1) The principal objective was to determine the detailed depositional and erosional history of Central Chryse Planitia through geologic mapping, interpretation of surface geologic units, and determination of the relative stratigraphic relations between the units; (2) a second objective was to determine the regional geologic context of the Viking Lander 1 site which is situated within the mapped area; and (3) a third objective was to determine on the basis of the geologic mapping, how representative the Viking Lander 1 site is of the characteristics of plains surfaces elsewhere on Mars.

On the basis of geologic mapping, we determined that the erosional and depositional history of this part of Chryse Planitia is a result of a combination of early volcanic, fluvial and impact cratering processes followed in more recent times by continued minor aeolian erosional and depositional transport. The initial surface was determined to be have formed during emplacement of a thick cover of unspecified material, possibly lavas, most likely over cratered surface units similar to the Noachian materials of the cratered highlands to the south, or by filling of a topographic basin centered at Chryse Planitia possibly derived from an early impact basin. Subsequent impact cratering occurred together with regional mare ridge-type regional compressional deformation resulting in the formation of the approximately north-south striking Xanthe Dorsa and adjacent ridges that characterize the region.

Based on the stratigraphic relations of the geologic units and the results of determination of crater abundances for these units, following the initiation of mare ridge-type deformation, catastrophic outflows of water from Maja Valles to the west and Kasei Valles to the northwest scoured and incised the plains and ridges of central Chryse Planitia. Based on our crater counts for each of the geologic units within the mapped area, the geologic unit on which the Viking Lander is situated appears to have buried an early mare-type ridged plains surface and superposed impact craters to a depth of several hundred meters. The origin of this resurfacing event cannot be uniquely determined from lander scale surface observations, but the coincidence with the age of channeling suggest that the regional surface was resurfaced at least in part by the deposition of sediments carried by Maja Valles and Kasei Valles.The Viking Lander 1 is determined to be situated near a mare-type ridge, and we attribute the local presence of bedrock to a cover of sediment draped over this ridge that is relatively thin compared with that immediately to the east and west.

In summary we determined that the local surface is the results of variable degrees of weathering of an impact ejecta field developed in fluvial outwash sediments veneering a fundamentally basaltic substrate. The surface in central Chryse Planitia is unlikely to be similar in detail to plains surfaces elsewhere on Mars due to the unusual erosional and depositional history associated with catastrophic water outflow channels of Maja and Kasei Valles. The combination of unique geologic characteristics and detailed ground truth will make it a strong candidate for any future successful lander missions.

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NASA Mars Geologic Mapping Program Grant NAGW-2171:
"Erosional and Depositional History of Central Chryse Planitia"

Manuscript #1 in Preparation:

Text Accompanying the Geologic Map of the MTM 1:500,000 Photomosaic Sheets 20047 and 25047

by

L. S. Crumpler, J. C. Aubele, and R. A. Craddock

Geologic Map of Part of Chryse Planitia: Viking Lander 1 Region [MTM 1:500,000 Photomosaic 20047 and 25047]

by

L.S.Crumpler. J.C.Aubele, and R.A.Craddock

Introduction

This map uses high resolution image data to assess the detailed depositional and erosional history of part of Chryse Planitia. This area is significant for the global geology of Mars because it represents one of only two areas on the martian surface where planetary geologic mapping is assisted with "ground truth"; in this case, Viking Lander 1. Additional questions addressed in this study include the geologic context of the regional plains surface and the local surface of the Viking Lander 1 site, and the relative influence of volcanic, sedimentary, impact, aeolian, and tectonic processes at the regional and local scales.

Setting and Background

The MTM 20047 and 25047 sheets are located near the center of the Chryse Planitia basin and include part of a widespread plains-forming unit of Hesperian age (Scott and Tanaka, 1986) occurring near the boundary between the cratered highlands and northern lowlands of Mars. Chryse Planitia is a part of the northern hemisphere lowlands. Based on previous mapping at scales of 1:1,000,000 and 1:15, 000,000 (Scott and Carr, 1978; Milton, 1974; Greeley *et al.*, 1977; Theilig and Greeley, 1979), these plains are thought to consist largely of basaltic flood lavas overlain locally, and possibly extensively, by aeolian and fluvial sediments. On a regional scale it is modified primarily by impact craters and by wrinkle ridges similar in morphology to features in the lunar maria and is regionally among the smoothest surfaces on Mars. However, geologic maps at these scales were unable to show local scale geologic units within the larger plains unit.

Chryse Planitia is part of a large region extending east from Lunae Planum that is interpreted to have been disturbed by catastrophic outflow. Out-liers of the Maja Valles and Kasei Valles outflow channels to the west and Shalbatana Vallis to the south converge toward the site of the Viking Lander 1, which is relatively well-located on the surface with respect to regional features (Morris, et al. 1978; Craddock and Zimbelman, 1988) near the boundary between the MTM 20047 and 25047 1:500,000 sheets. Despite the apparent convergence of outwash channels toward the site, the evidence in surface images for fluvial deposits or erosion is equivocal. Specific models outlined by Mutch *et al.* (l976) to explain the apparent absence of the effects of outwash channels at the landing site include: (a) Chryse Planitia is mostly volcanic, but the fluvial units that were deposited are relatively smooth and consist of only slightly re-worked indigenous rock; (b) volcanic flows are locally younger than the channeling; and (c) channel deposits are younger but did not reach the landing site. Additional possibilities are (1) that the fluvial deposits overlie the volcanic rocks at the site, but that the sediments are largely fined-grained easily transported materials that ponded and were subsequently deflated by aeolian erosion, or (2) that fluvial deposits and volcanic rocks were both overlain by subsequent aeolian materials which were stripped partially from the landing site to produce a complex multi-lithology surface.

Detailed analysis of local surface distribution and shape characteristics of boulders at the Viking Lander sites by Garvin *et al.* (l981) demonstrated that fluvial erosion and modification of the near-field surface boulders at the Viking Lander site could not be unequivocally demonstrated or refuted. They present evidence for multiple local lithologies or an influx by outwash channels of deposits of multiple provenance. Spectral modelling of Viking Lander 1 images by Adams *et al.* (l986) supports relatively simple local lithology consisting of one unweathered rock-type, coarse soil derived from this rock type, and palagonite-like dust.

Stratigraphic Units

The oldest materials exposed are Hesperian age equivalent ridged plains. Ridged plains and incised channels units occurring within ridged plains together are the most extensive units portrayed in the MTM 20047 and 25047 quadrangles. Ridged plains are characterized by numerous linear to sinuous mare-type wrinkle ridges, occur throughout the topographically low Chryse Planitia basin, and are stratigraphically equivalent to Hesperian age units throughout the northern hemisphere of Mars (Scott and Tanaka, 1986). Channeled plains are characterized by numerous arcuate to linear and approximately parallel ridges, valleys, and scours associated with the floors and down slope termini of Maja and Kasei Valles where they debouch onto Chryse Planitia.

Scattered throughout Chryse Planitia are local discontinuous aeolian streaks, many associated with small impact craters. The orientation of streaks uniformly indicate regional southwesterly winds and movement of material across surface toward the northeast. This is in accordance with lander meteorology experiment measurements which indicated recurring strong down-slope winds in the vicinity of the Viking Lander 1.

Hesperian System

The basal unit within the map area is a ridged plains unit (*Hr1*) located in the southern and southeastern one-half of the 20047 photomosaic quadrangle. *Hr1* is distinguished from ridged plains elsewhere within the mapped area by (1) topographically more prominent and more continuous ridges, (2) depositional surface characteristics with little evidence of subsequent channeling, erosion or scouring seen in other local plains units, and (3) greater cumulative number of impact craters than other plains units and absence of significant degradation or filling of impact craters.

The basal ridged plains unit (*Hr1*) is interpreted by analogy with the ridged mare surfaces of the moon to be generally flat-lying sheeted basaltic (flood) lava plains deformed by regional compression, the long ridge-style of deformation resulting from crustal shortening of only a few percent over broad areas. It is estimated that the thickness of ridged plains material throughout Chryse Planitia is a minimum of several hundred meters (De Hon, 1982).

The north-south strike of ridges throughout *Hr1* implies an east-west sense of shortening. Hr1 appears to lie on a regional topographic gradient sloping from the highlands down to the center of the Chryse basin in the north and east of the mapped areas. The topographically lower northern part of *Hr1* is conformably overlain by ridged plains materials of *Hr3.*

The similarity of crater abundances between ridged plains units *Hr3* and *Hr2* implies that they both post-date the original plains surface represented by *Hr1*. *Hr3* and *Hr2* consist of relatively flat plains and mare-type ridges similar to *Hr1*, but are distinguished by (1) relatively fewer and more discontinuous or modified ridges, (2) overall lower crater abundances compared with that of *Hr1*, and (3) local evidence for both the effects of deposition and erosion subsequent to development of many mare-type ridges.

Hr2 is characterized by widely distributed local topographic knobs, and isolated flat-topped ridges (*Hrki*). The flat topped ridges occur frequently in association with the crests of mare-type ridges. The occurrences of *Hrki* within *Hr2* are interpreted to be scattered topographic remnants of the pre-outflow surface resulting from erosional stripping associated with regional outflow. Based on the similarity in orientation of some of the associated elongate ridges within *Hr2* with the striations associated with Kasei Valles, stripping of *Hr2* may have accompanied outflow from Kasei Valles.

Hr3 is characterized by the presence of partially filled craters, discontinuous mare-type ridges with more subdued relief than those within Hr1 or Hr2, and an absence of residual knobs characteristic of Hr2. Whereas *Hr2* is interpreted to represent deposition and erosion, Hr3 appears to represent deposition and little, if any, significant regional erosion. The absence of erosional or channel features within *Hr3* implies that it was emplaced largely through depositional processes and is probably not extensively incised or eroded. Ghost crater rings and residual rims of craters along the southern contact of *Hr3* and *Hr1* likewise imply that here the surface of *Hr1* and its impact craters have been inundated by the materials forming unit *Hr3.* Using rim-height to diameter ratios previously established for martian impact craters [Pike and Davis, 1984], the depth of burial is estimated at ~300m. The relative dearth of craters smaller than 10 km diameter within *Hr3* as compared with *Hr1* indicate that craters smaller than 10 km were regionally obliterated and is in agreement with the evidence for burial of craters within *Hr3*.

The nature of the deposition process and source of the the regionally deposited materials remains undetermined. Although the basal plains materials may have been emplaced through lava flooding as asserted for *Hr1*, catastrophic water outflow events from Kasei and Maja Valles are likely to have resulted in transport and deposition of sedimentary material within Chryse Planitia. An alternative interpretation is that *Hr3* represents a lava flooded plains surface emplaced subsequent to the outflow events and overlies and masks sediments emplaced from those outflows. This interpretation cannot be completely rejected based on Lander image data, but its likelihood is decreased by the absence of evidence for lava flow fronts analogous to Lunar mare plains flows within *Hr3*, as well as the general lack of evidence for volcanism this young throughout the region.

The contact between *Hr3* and *Hr2* is gradational at 1:500,000 scale. Although the surfaces of these units appear distinctly different at widely separated points in the map, *Hr3* and *Hr2* might nonetheless be the same age and surface material regionally distinguished by differences in surface erosion and deposition characteristics. If so, the differing surface characteristics could reflect local and regional differences in emplacement or erosion of otherwise geologically similar materials. For this reason *Hr2* and *Hr3* are interpreted to be located at similar levels within the regional stratigraphic column. Local overlapping relationships between outflow striations in an area approximately 3 to 5 km east of Bremerhaven Crater within MTM 25047 imply a small probability that Maja Valles outflow at least locally post-dates Kasei outflow. If so, *Hr3* could represent Maja Valles sediments (or late lava plains) deposited unconformably on the eroded and stripped surface forming *Hr2*. Based on the contingency of this interpretation of the map relations, *Hr3* is tentatively assigned a higher stratigraphic level.

The Viking Lander 1 is located on *Hr3* along an en echelon offset between mare-type ridge segments; the surface of this unit has been well characterized (Mutch *et al.*, 1976; Sharp and Malin, 1984; Arvidson *et al.*, 1989; Craddock and Zimbelman, 1989) at scales down to centimeters and up to meters. At these scales the surface characteristics appear to be influenced mostly by the presence of abundant moderately angular, equi-dimensional, and locally pitted blocks surrounded by silt-like fine-grained surficial materials undergoing local aeolian transport. The composition of the source for the local surface material is consistent with a fundamentally mafic to ultramafic mineralogy (Clark *et al.*, 1982). The surface appears disturbed in relation to the primary morphology of basaltic lavas (Aubele and Crumpler, l987), a result of either the subsequent deposition of sedimentary materials or impact cratering debris mantles. The local geological evidence at lander scale is not adequate to uniquely determine the emplacement mechanism for *Hr3* .

The incised channel unit (*Hchi*) consists of parallel, linear striations, elongate ridges, troughs, pedestal craters, such as Dromore Crater, and mare-type ridges with locally streamline shaped segments. Incised channels occur principally at two localities on the north and south along the western margin of the MTM 20047 and 25047 sheets. The striations and scours within *Hchi* situated on the north strike southeast and those on the south strike northeast. Streamline shapes indicate an apparent direction of catastrophic fluid flow from west to east.
Channeling is most prominent at Xanthe Dorsa along the western border of MTM 20047. Here deep, curved valleys are etched around Dromore Crater and locally have incised gaps though

Xanthe Dorsa. The characteristic striations of Hchi are interpreted to be due to erosional channeling scars resulting from catastrophic water outflow toward the topographic low of Chryse Planitia across pre-existing ridged plains. Flow appears to have been directed down the regional slope toward the center of Chryse Planitia from Maja Valles on the south and from Kasei Valles on the north.

The downstream contact of the incised channels with the ridged plains is gradational, and there is no apparent evidence for incised channel effects on the surface at the Viking Lander 1 site, nor are there rounded cobbles or boulders apparent in the lander images. The lander is situated 50 km along strike from the last downstream evidence of the effects of erosion from Maja Valles outwash and 40 km along strike from that of the Kasei Valles outflow. This is a small fraction of the total length of both Kasei and Maja Valles, yet there is no evidence to indicate the past presence or fate of the water that must have flowed through this region located at their termini.

Within unit *Hchi* water flow appears to have been locally confined and locally modified by the presence of mare type plains ridges. The contact of the incised channel unit with the surrounding ridged plains and variations in the magnitude of incision of channels are locally strongly influenced by the presence of mare-type ridges. Incision appears abruptly at points immediately downstream from the larger mare-type ridges. This is interpreted to imply that the depth of flow shallowed over the local relief accompanying the mare-type ridges and velocity of flow increased. Corresponding increased erosion occurred over elevated ridges, and local pooling, slowing the flow, and deposition of suspended materials occurred in lows. Deposition by this means could have been common in dynamically dammed areas upstream of ridges. This may account for the local variations in incised channeling within *Hchi*. The absence of incised channels in the central region, downslope from the basin-ward edges of the incised channel unit, may represent decreased erosion due to (1) a shallower topographic gradient, (2) regional ponding (standing body of water), or (3) subsequent burial by materials carried in the Maja and Kasei outflow channels.

isolated ridges and knobs (*Hri*) occur scattered throughout the area of *Hr2*., but are frequently situated along the crests of mare-type ridges in the eastern third of MTM 25047 and an area near the contact of *Hr2* and *Hchi*. The knobs are generally less than 1 to 2 kilometers in diameter and approximately equant in plan shape. The ridge segments are flat-topped, generally elongate, and locally oriented along the crest, and parallel to, a prominent mare-type ridge. Isolated ridges also strike parallel to the outflow channel scour lines adjacent to unit *Hchi* farther west.

Isolated knobs and ridges (*Hri*) are interpreted to be erosional residuals, possibly originating during outflow from Kasei and, to a lesser extent, Maja Valles outwash events. The presence of residual knobs and ridges typically downstream from the crests of mare type ridges implies that they represent erosion of ridged plains materials where catastrophic flow was forced up and over the relief associated with pre-existing mare-type ridges as described above. Alternately the presence of *Hchi* typically in association with mare-type ridges, implies that they could represent isolated highs associated with buried structures such as large crater rims.

Smooth plains within the incised channel units (*Hcp1*) and sinuously channeled plains (*Hcp2*) occur at two sites along the western margin of the map area. Occurrences of *Hcp1* are characterized by little evidence for regional erosion or scouring in contrast to the surrounding surface of incised channels with which they appear associated. The featureless characteristics of *Hcp1* occur on the upstream side of features with topographic relief, such as the occurrence west-southwest of Xanthe Dorsa near Dromore Crater and is interpreted to represent areas of little to no incision where the flow was dynamically dammed, the flow deep, and surface scouring was correspondingly inhibited. In fact, some deposition may have occurred upstream of topographic obstacles as indicated by the presence of partially buried small craters within this unit south and west of Dromore Crater.

The upper unit of interchannel plains (*Hcp2*) consists of anastomosing and sinuous channels. *Hcp2* occurs only in the extreme southwestern edge of the map and consists of channels oriented east-northeast, generally more northerly than the local orientations of Maja Valles striations. It is interpreted to be late-stage depositional materials that were subsequently incised by smaller scale, late-stage fluvial events, or by residual draining of internal fluids during the waning stages of material emplacement. These channels bear some similarity, including orientation, to small channels occurring throughout Chryse Planitia to the west. Based on this observation, there is a small probability that the current isolated unit of *Hcp2* represents a previously more widespread regional pattern of earlier outflow.

Impact Craters.

Three classes of craters have been identified and are interpreted to represent variable degrees of erosion of initially similar impact crater morphology. Class *C1* craters are characterized by circular map shape, flat, probably filled, interior floors, and discontinuous rim. Class *C2* impact craters are distinguished by raised rims, rough and hummocky ejecta aprons, and rough interior floors. Class *C3* craters are distinguished by narrow and sharply-crested rims, bright, radial striae in ejecta aprons and associated discontinuous ejecta patterns, and complex hummocky interior floors.

Because *C3* craters post-date channel formation in this region they are interpreted to be equivalent to Amazonian in age, on the basis of probable Amazonian time of catastrophic outwash events associated with Maja and Kasei Valles [Carr, 1979].

Summary

On the basis of stratigraphic relations and interpreted origin of units occurring within MTM 20047 and 25047, the erosional and depositional history of this part of Chryse Planitia is interpreted to be a result of volcanic, fluvial, and impact processes. The initial surface in this area was emplaced most likely on underlying Noachian materials, filling what has been previously identified as an early Chryse Planitia impact basin (Schutz *et al.*, 1982), in a manner similar to mare flood basaltic lavas. The resulting surface represents a thick, relatively smooth, and geologically uniform layer. Subsequent impact cratering occurred together with regional mare ridge-type deformation forming Xanthe Dorsa and adjacent ridges. Ridges throughout this area are oriented north-south across the western to central part of the proposed proto-Chryse Planitia impact basin. If the basin center is correctly identified, then the local orientations of ridges do not appear to correspond simply to inner and outer basin rings as is typical of ridges in lunar mare basins. Alternately, the mare-type ridges in Chryse may not represent simple deformation induced by long-term basin subsidence. Instead the regional ridge patterns could reflect pervasive deformation in this hemisphere of Mars (Plescia and Saunders, 1982) resulting from the stresses associated with the topographic and gravity anomaly of the Tharsis province further south and west (Banerdt *et al.*, 1982).

Subsequent to the initiation of mare ridge-type deformation, catastrophic outflows of water from Maja Valles to the west and Kasei Valles to the northwest scoured and incised the plains and ridges of central Chryse Planitia. Both valleys are associated with a system of scours and striations that almost converge at the site of the Viking Lander 1. At about the same time, based on crater abundances, the unit on which the Viking Lander is situated appears to have flooded the central map area and buried early ridged plains, including ridges and craters to a depth of several hundred meters locally. Long-term, accumulated deformation may be typical of mare-type ridges (Aubele,1988), and the greatly subdued characteristics of mare-type ridges within this unit may reflect continued deformation at the site of earlier ridges. The Viking Lander 1 is located along one of these mare type-ridges at an offset between two short ridge segments. The origin of this resurfacing event cannot be determined, from lander scale surface observations, but the coincidence with the age of channeling suggest that the regional surface was resurfaced at least in part by the deposition of sediments carried by Maja Valles and Kasei Valles. The local Lander surface shows little evidence of eroded and rounded debris associated with the outwash event and bears no evidence of fluvial emplacement of material.

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GEOLOGIC MAPS OF A PART OF CHRYSE PLANITIA:

THE VIKING LANDER 1 REGION

MTM 20047 AND 25047

DESCRIPTION OF UNITS

PLAINS FORMING MATERIAL

Hr3 *Ridged Plains Material.* Smooth plains characterized by partially filled craters, subdued and discontinuous mare-type ridges. Impact crater abundance is lower than Hr1. Interpreted to be dominantly depositional surface conformably overlying unit Hr1.

Hr2 *Ridged Plains Material.* Smooth plains characterized by knobs and flat-topped relief features on mare-type ridges. Impact crater abundance is similar to Hr3. Interpreted to be both depositional and erosional surface overlying unit Hr1.

Hr1 *Ridged Plains Material.* Smooth plains with prominent and continuous mare-type ridges striking north-south. Absence of channeling, erosion or significant filling or degradation of impact craters. Crater abundance is greater than Hr2 or Hr3. Basal unit within mapped area. Interpreted to be lava plains deformed by regional compression.

CHANNEL AND VALLEY RELATED MATERIALS

1 **Hcp2** *Interchannel Plains Material, Upper unit.* Anastomosing and sinuous small channels occurring with Hchi. Interpreted to consist of late-stage depositional materials subsequently incised by small scale fluvial events.

Hcp1 *Interchannel Plains Material, Lower unit.* Featureless plains occurring within Hchi. No evidence for erosion or scouring. Interpreted to be areas within Hchi shielded from erosion by locally dammed pools.

Hchi *Incised Channel Material.* Characterized by parallel, linear striations, ridges, troughs, mare-type ridges with streamlined shapes and the occurrence of pedestal craters. Interpreted to be erosional surface formed by catastrophic fluid flow moving from west to east.

Hri *Isolated Ridge and Knob Material.* Equant knobs less than 2 km in diameter and flat-topped ridges occurring within unit Hr2. Interpreted to be erosional remnants of degraded mare-type ridges or isolated topographic highs representing buried structures.

1 may be similar to Npl2 or Hpl3 (subdued cratered plateau material)

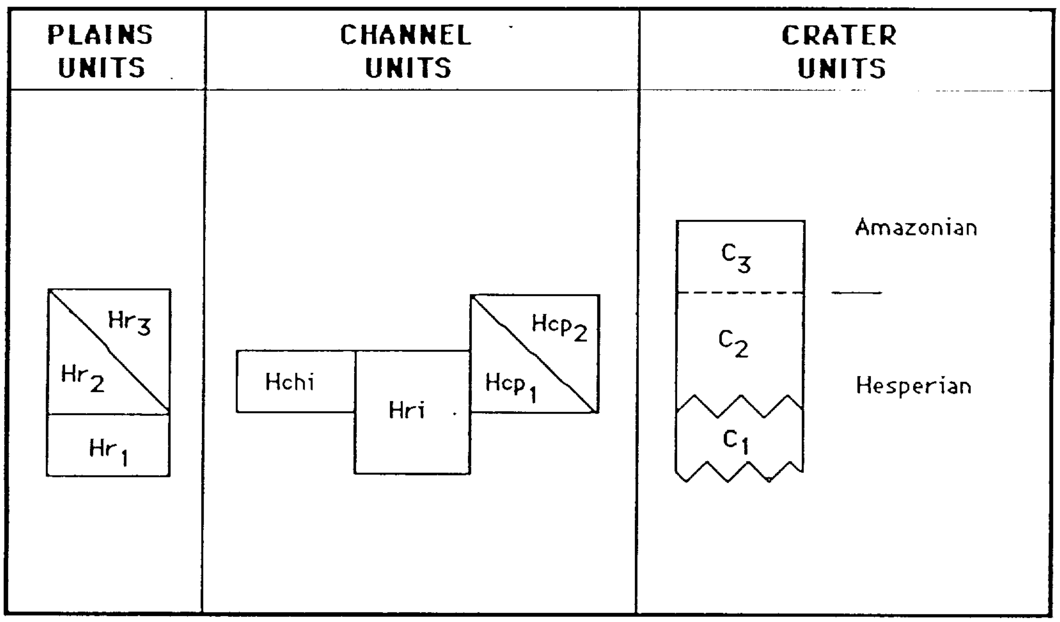
CRATER MATERIAL

C3 *Impact Crater Material.* Impact craters characterized by distinct rims, bright radial striae in ejecta aprons and hummocky interior floors. Little evidence of erosion or degradation. Interpreted to be Amazonian in age.

C2 *Impact Crater Material.* Impact craters characterized by raised rims, unmodified interior floors, unmodified to partially modified ejecta aprons. Interpreted to be Hesperian in age.

C1 *Impact Crater Material.* Impact craters characterized by discontinuous rims, (no ejecta aprons?), and filled interiors. Interpreted to be Hesperian in age and highly modified by subsequent deposition of plains forming material.

CORRELATION OF MAP UNITS FOR GEOLOGIC MAP OF PHOTOMOSAIC QUADRANGLES MTM 20047 and 25047



Crater Rim

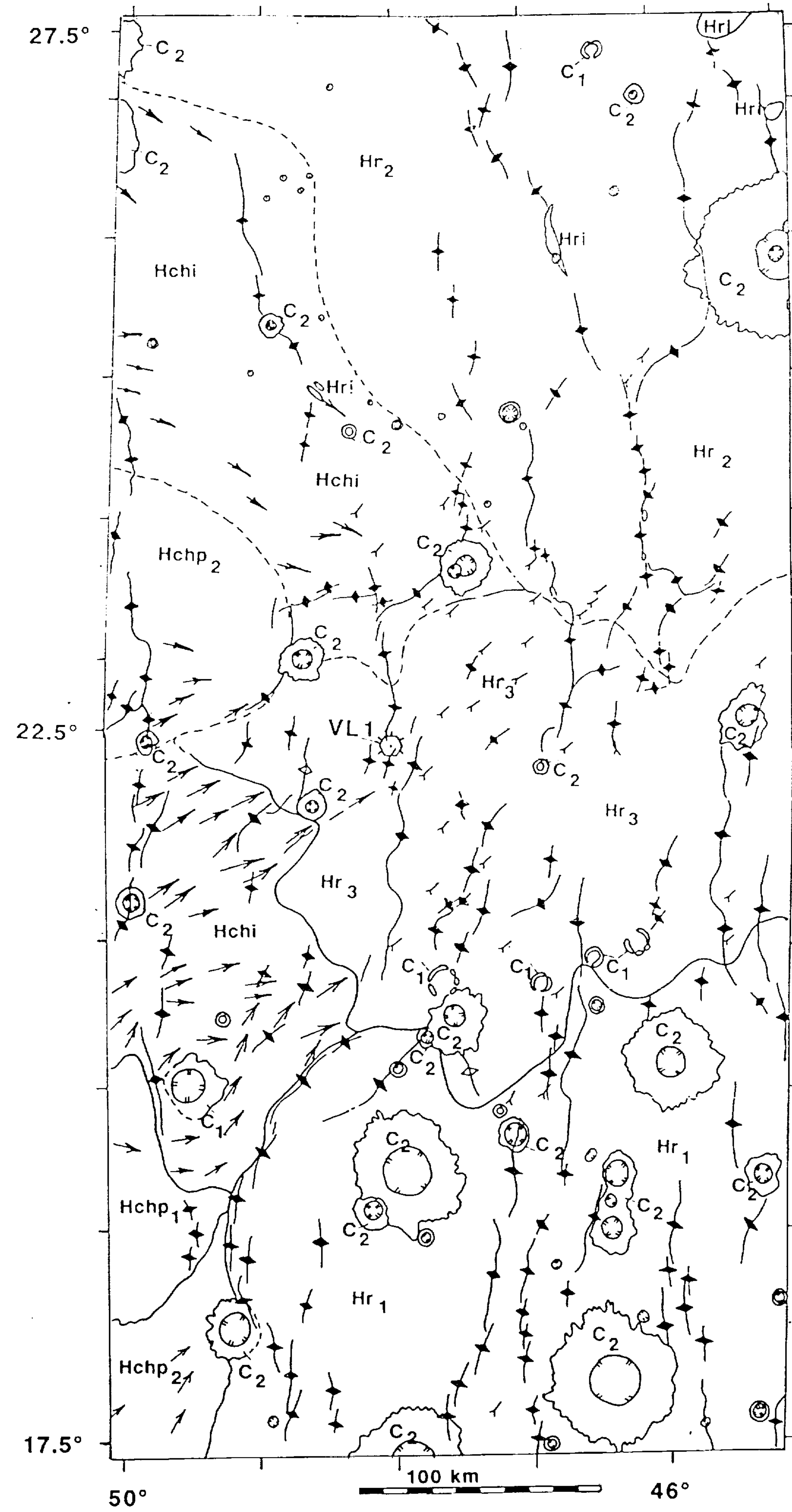
Viking Lander 1 Site

Axis of mare-type ridge

Wind streak

Outflow channel or scar (arrow indicates interpreted direction of flow)

LSC/JCA
MTM 20047/25047
8/92



27.5°
22.5°
17.5°
50°
46°
100 km
C2
C1
Hr1
Hr2
Hr3
Hri
Hchi
Hchp1
Hchp2
VL1

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Geologic History of Central Chryse Planitia and the Viking 1 Landing Site, Mars

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Geologic History of Central Chryse Planitia and the Viking 1 Landing Site, Mars

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INTRODUCTION

On the morning of July 20, 1976 the Viking 1 spacecraft successfully landed on the surface of Mars. Based on Mariner data Chryse Planitia had been selected as the primary site for this first landing several years earlier; however, the actual targeted site was not certified until the Viking spacecraft had been in orbit for several weeks. The preselected Chryse Planitia landing site at 19.5°N, 34.0°W was rejected when Viking orbiter data indicated that this area had been heavily eroded by fluvial processes, wind stripping, and also contained volcanic terrain all hazardous to a safe landing [Masursky and Crabill, 1981]. The landing site was retargeted for the central portion of the Chryse basin (22.4°N, 47.5°W) 3 km below Mars datum where it was assumed that the regional gradient caused deposition rather than erosion from the large circum-Chryse outflow channel complex [Masursky and Crabill, 1981]. Earth-based radar data, an important consideration in the Viking site certification, also showed reflectivity of 5-10%, which is close to the martian average [Tyler et al., 1976].

Masursky and Crabill [1981] discuss that in preparation of the first Mars landing, geologic maps of Chryse Planitia were prepared by an ad hoc group of investigators using available Mariner 9 images of the region. Mariner 9-based geologic maps of Chryse Planitia have been presented by Milton [1974] and Wilhelms [1976]. During the Viking mission, orbiter-based geologic maps of Chryse Planitia were produced literally within hours after receiving the data. A synthesis of these geologic maps has been presented by Greeley et al. [1977]. Several other investigators have also mentioned brief descriptions of the regional geology of Chryse Planitia when discussing the observed geology of the landing site [e.g., Binder et al., 1977]. However, an exact correlation between the orbiter and lander data has not yet been made. A major part of the problem was in determining the precise position of the Viking 1 Lander (VL-1) on the surface of Chryse Planitia. But following the Viking primary mission, the location of VL-1 was determined confidently to within 50 m [Morris and Jones, 1980]. Also, additional high-resolution photographic coverage of central Chryse Planitia was obtained following the successful landing of VL-1 (i.e., Viking orbiter frames 452B1-16).

1:500,000-scale mapping of central Chryse Planitia and the Viking 1 landing site (MTM's 20047 and 25047; Fig. 1) was undertaken with the following objectives: (1) correlate Viking orbiter data of central Chryse Planitia with Viking lander "ground-truth" observations, (2) determine the depositional and erosional history of the Chryse basin, (3) determine how representative the surface materials observed by the Viking lander are of the region and of plains units in general, and (4) determine the extent of channel materials versus ridged plains materials in the region. Determining the geologic history of Chryse Planitia is important for understanding the observations and results from the Viking lander, understanding the volatile history of Mars and the mechanism of outflow channel formation, and potentially in deciphering the relation between volcanism and fluvial processes on Mars.

BACKGROUND

Chryse Planitia is an extensive, semi-circular basin centered at approximately 25°N, 40°W (Fig. 2). At a maximum depth of more than 3 km below the mean Martian datum it is one of the lowest regions on Mars (topography from the U.S. Geological Survey, 1976), suggesting that it may be an ancient impact basin [Schultz et al., 1982]. The boundary separating the southern cratered highlands from the northern smooth plains borders most of Chryse Planitia, but unlike other areas on Mars the transition across the "dichotomy" boundary in this region is not marked by a sharp change in topography. The boundary has, however, been incised by most of the large outflow channels, including Kasei and Maja Valles to the west and Shalbatana, Simud, Tiu, and Ares Valles to the south.

Mariner 9-based analysis of Chryse Planitia showed that materials within the basin are relatively smooth and sparsely cratered. These interior deposits were interpreted as being volcanic in origin [Milton, 1974] or possibly containing some fluvial sediments, especially in southern Chryse Planitia [Wilhelms, 1976]. This interpretation apparently changed little during evaluation of Viking orbiter data for certification of the VL-1 landing site: Greeley et al. [1977] also report the smooth plains of Chryse Planitia as being composed of a thin discontinuous veneer of sediments superposing volcanically derived materials. Subsequently, other investigators have described the general region surrounding the Viking 1 landing site as resembling the lunar mare with, presumably, the same type of volcanic origin [Binder et al., 1977; Arvidson et al., 1989].

Interpretations of the geology of the Viking 1 landing site differ widely. It has been suggested that the blocks observed in VL-1 images (Fig. 3) are the result of in situ weathering of basaltic materials [Mutch et al., 1976; Binder et al., 1977; Garvin et al., 1981], ejecta emplaced by local impact craters [Garvin et al., 1981; Sharp and Malin, 1984; Arvidson et al., 1989], or possibly fluvial deposits from the circum-Chryse basin outflow channels [Mutch et al., 1976]. Despite the fact that the VL-1 site was chosen as an area where fluvial deposition, as opposed to erosion, most-likely occurred [Masursky and Crabill, 1976], this later interpretation is not strongly advocated. Because erosional scour from channel emplacement do not reach the vicinity of the VL-1 landing site, volcanic materials post-dating channel formation are thought to exist in central Chryse

Planitia [Carr et al., 1976; Carr, 1981, pg. 20]. Alternatively the area around VL-1 may be higher than the surrounding plains, and thus isolating the landing site from channeling processes [Greeley et al., 1977]. As discussed below neither of these scenarios is likely.

REGIONAL GEOLOGY

Plate 1 shows the principal geologic units mapped at 1:500,000-scale. Formal stratigraphic systems for Mars have previously been defined by Scott and Carr [1978]. They are, from oldest to youngest, Noachian, Hesperian, and Amazonian. Tanaka [1986] subdivided these systems into series based upon impact crater frequencies. According to this scheme, relative ages to geologic units can be presented as the number of craters greater than 2 or 5 kilometers in diameter, N(2) or N(5), expressed as the cumulative number of craters greater than or equal to the specified diameter [N(x)] per 10^6 km^2. Although the absolute ages for martian geologic units are controversial (see discussion by Tanaka, 1986), assigning relative ages to the units allows investigators to place geologic events occurring in one area into a regional or global context.

Numerous geologic units were defined during the mapping; however, only those units essential to discussing the broad geologic history of Chryse Planitia are presented here. The oldest principal materials in the area are Hesperian in age. Noachian materials are not exposed, although degraded and buried impact craters may have formed in underlying Noachian materials. Chryse Planitia is thought to be the result of a giant impact [Schultz et al., 1982], as well as Acidalia Planitia immediately to the north [Schultz and Frey, 1990]. Presumably the Chryse and Acidalia basins formed during the early to middle Noachian, or the peak period of heavy bombardment on Mars [~3.5 G.Y.; Tanaka, 1986]. This suggests that all the units within the map area overlie highly fractured crustal rock.

The oldest unit in the map area is the Hesperian ridged plains materials, unit 1 (Hr_1). Hesperian ridged plains materials, unit 2 (Hr_2) is the most extensive unit portrayed in the map area. Both units are characterized by numerous linear to sinuous wrinkle ridges, or Xanthe Dorsa. Ridged plains materials in Hesperia Planum having similar crater abundances (i.e., relative ages) and morphological characteristics are the referent for the Hesperian period on Mars [Scott and Carr, 1978; Tanaka, 1986]. Unit Hr_1 is distinguished from unit Hr_2 on the basis of relative crater abundances (Fig. 4; Table 1), frequency of ridges, and degree of modification to the ridges. The ridges on both units are morphologically similar to lunar mare-ridges and are interpreted to be the result of regional compressional strains in a competent, layered surface unit. The Xanthe Dorsa ridges trend predominately north-south as opposed to being circumferential to the Chryse basin, which is unlike lunar mare-ridges. This suggests that basin subsidence was not the mechanism for Xanthe Dorsa formation as has been suggested for lunar ridges [Maxwell et al., 1975].

Amazonian/Hesperian channel materials (AHch) occur east of Kasei and Maja Valles and are separated from Ridged plains materials, unit 2 (Hr_2) by a very gradational contact. These materials are distinguished by small parallel channels which seem to have initiated at topographic highs and which anastomose around preexisting topography such as wrinkle ridges and impact crater rims. These materials probably represent the late-stage erosional incision associated with the large-scale fluvial outwash toward the topographic low of the Chryse basin. Hesperian channel materials (Hch), characterized by arcuate, streamlined mounds located behind topographic features, may represent large channel deposits or channel modification of high-standing ridges. A Hesperian age is inferred for these materials based on superposition relationships; they represent too small of a counting area for accurate crater statistics.

Crater size-frequency distribution curves (Fig. 4; Table 1) for the Amazonian/Hesperian channel materials north and south in the map area suggest that the formation of Maja Valles (south material) pre-dates the formation of Kasei Valles (north material). Crater counts of channel materials from Maja Valles indicate an age of N[2] = 690±218 (Upper

Hesperian) versus 276±92 (Lower Amazonian) for Kasei Valles materials. Ridged plains materials, unit 2 (Hr_2) have an age of N[2] = 466±79 (Upper Hesperian), which suggests that this unit was emplaced after the formation of Maja Valles, but before the formation of Kasei Valles. However, it is important to keep in mind the limitations of crater statistics. The crater curve for the Kasei Valles materials also includes eroded or modified impact craters. This suggests that the difference in age between the two groups of channel materials may actually be a reflection of the intensity of the channeling process (i.e., the formation of Maja Valles removed more impact craters in the map area through burial or erosion than the formation of Kasei Valles).

Evidence for Standing Water?

Carr et al. [1987] calculated that as much as 6.3 x 106 km3 of water may have been released into the Chryse basin during formation of the circum-Chryse outflow channel complex.

The large crater Guaymas (20 km in diameter; 26.2°N, 44.8°W) also appears to have been effected by fluvial processes. The southern edge of its ejecta blanket has been heavily eroded (Fig. 5). Providing the local slope increases towards the north in the vicinity of the crater, then a standing body of water ~200 m deep would be sufficient to partially erode this crater's ejecta. Because this crater superposes Ridged plains materials, unit 2 and is eroded only partially, it suggests that there were multiple episodes of channel deposition and flooding within the Chryse basin.

A Case for Sedimentary Deposits

Because martian wrinkle ridges are so similar to lunar mare ridges, numerous investigators have suggested that the ridged plains material in central Chryse Planitia (Hr_1 and Hr_2) are volcanic in origin [Mutch et al., 1976; Binder et al., 1977; Carr et al., 1976; Greeley et al., 1977; Mutch and Jones, 1978; Theilig and Greeley, 1979; Arvidson et al., 1989]. However, despite the high resolution of available images (<10 m/pixel), primary volcanic features such as flow fronts or vents have not been observed. Binder et al. [1977] suggested a very low viscosity lava incapable of forming a flow front observable from orbit or, alternatively, degradation of the original relief. However, the interpretation of ridged plains as volcanic in origin cannot be supported without additional geologic evidence. As pointed out by Watters [1988] wrinkle ridges can also form in sedimentary materials, so the presence of lunar mare-like ridges does not preclude the possibility of extensive fluvial deposits within central Chryse Planitia.

Materials in Chryse Planitia are at one of the lowest elevations on the planet (approximately -2.5 km below Mars datum; topography from the U.S.G.S., 1977) and are surrounded by a large outflow channel complex. Chryse Planitia was certified as the Viking 1 landing site based on the reasoning that some channel materials, presumably smooth, were in the Chryse basin [Masursky and Crabill, 1981]. Carr et al. [1987] calculated that 5.89×10^6 km^3 of material was eroded from the circum-Chryse highlands during channel formation, which suggests that a fluvial deposit ~4 km thick may be present throughout Chryse Planitia (assuming a radius of Chryse Planitia of ~700 km). Over 36.9×10^4 km^3 of material is estimated to have been removed by the formation of Kasei Valles alone. Available digital topographic data [U.S. Geological Survey, 1992] shows a topographically high lobe of material extending from the mouth of Kasei Valles into Chryse Planitia (Fig. 6). In addition, other investigators have suggested that large volumes of standing water were contained in Chryse Planitia during the Hesperian [Carr, 1986; Carr et al., 1987; Scott and Tanaka, 1986; Scott et al., 1992]. Although channel deposits are not obvious (both fluvial depositional and erosional units contain many of the same features), logic dictates that materials of fluvial origin must be located within the Chryse basin.

It is especially likely that Ridged plains materials, unit 2 (Hr_2) consist of fluvial deposits. The wrinkle ridges in this unit have a very noticeable subdued appearance suggesting burial and subsequent tectonic deformation by a long-lived compressional stress regime in the region. The contact between Ridged plains materials, unit 2 and channel materials is very gradational. As suggested by Masursky et al., [1980] and Scott et al. [1992, Fig. 1] Ridged plains materials, unit 2 also appear to follow a topographic "trough" into Acidalia Planitia to the north (Fig. 6), which would be the likely path of volatiles released into the Chryse basin. Finally, several partially buried craters are present along the southern contact of this unit which also suggests a depositional origin (Fig. 7, Plate 1; dotted circles).

Analysis of these buried and modified craters in Ridged plains materials, unit 2 yield possible information about this unit's spatial distribution. Using Pike and Davis' [1984] equations for fresh martian craters, the rim heights for the buried craters (2.3-11.3 km in diameter) were calculated. These values were then compared to the actual rim heights measured through shadow lengths. In a technique similar to DeHon's [1985] where the thickness of volcanic material in Lunae Planum was measured, we calculated that Ridged plains materials, unit 2 are ~50 m thick along its southern contact and possibly become thicker towards the basin interior. Thickening is probably the case because the sharp bend-over in the crater production curve at 5-km-diameter (Fig. 4) suggest that most craters smaller than this diameter were eradicated during the emplacement of the unit. This would require a substantially thicker deposit with a mean value of ~170 m.

Earth-based radar measurements made for each Mars opposition between 1971 and 1980 [Downs et al., 1982] provide an extra piece of evidence for possible channel deposits within the eastern portion of the Chryse basin (Fig. 8). Radar data collected in tracks along ~10°N latitude reflect the bowl shape of the southern Chryse basin and are punctuated with topographic lows which identify the location of Simud and Tiu Valles. Radar data collected north of this area at ~22°N show a much lower and broader bowl-shape because these data were collected along a track reflecting the maximum depth and diameter of the Chryse basin. However, between 31°W and 40°W longitude the topography is 100's of meters higher along this track than it is to the south. Material in this location shows extensive modification by channel forming processes from the south. Because the floors of Simud and Tiu Valles are much lower, it is possible that this material was deposited during the initial formation of these channels. As erosion continued but intensity decreased, the volatiles and materials released during channel formation moved westwards toward the center of the basin. The initial deposit, which is visible topographically in the radar data, became isolated with time and continued channeling. It is impossible, however, to state definitively that these or any other channel material is depositional in origin. Alternatively, and just as likely, the material in eastern Chryse Planitia may have been resistant to erosion or not subjected to channel processes as intense as those to the south.

Extensive deposits of materials from the formation of the circum-Chryse outflow channel process should not be ruled out. Wrinkle ridges alone do not provide the definitive morphologic criteria of a geologic unit's volcanic origin. The low topography, the number of channels surrounding the Chryse basin, and the subdued appearance of many of the geologic units and morphologic features suggest the probability that channel deposits do exist in Chryse Planitia. As originally suggested by Mutch et al. [1976] and described below, some materials observed by the Viking 1 lander may also be fluvial in origin.

GEOLOGY OF THE VIKING 1 LANDING SITE AND THE VIEW FROM ORBIT

Geology of the Landing Site

The Viking 1 Lander is located within Ridged plains material, unit 2 (Hr_2; Plate 1). Based on triangulation of topographic features visible in lander images with those seen in high resolution (~8 m/pixel) Viking orbiter images, the precise location of the lander was believed to be latitude 22.483°, longitude 47.968° or line 293, sample 1099 in Viking orbiter frame 452B11 (NGF Rectilinear) [Fig. 9; Morris and Jones, 1980]. The precise geographic coordinates changed in 1983 to 22.480°N, 47.962°W with an updated control network of Mars [Davies and Katayama, 1983]; however, the exact location of the lander within Viking orbiter frame 452B11 did not change. This location is estimated to be accurate to within 50 m [Morris and Jones, 1980] and is important for correlating the surface units seen in lander images to the regional geology described previously.

Several impact craters which are 100's of meters in diameter surround the Viking 1 Lander and are plainly visible in the lander images [Morris and Jones, 1980]. The most prominent feature besides impact craters is a wrinkle ridge of the Xanthe Dorsa system ~500 m to the east and wrapping around to the north. A portion of this ridge is visible from the lander between 72° to 90° from Mars' north [Morris and Jones, 1980]. A less obvious feature visible from the lander is a depression seen between 182° to 244° from Mars' north. The edge of this depression can be seen from orbit in Viking orbiter frame 452B11 (Fig. 9).

Analysis of stereo images suggests that the southern depression is not unique. In both the due north and due south directions a series of undulations a few 10's of centimeters high can be seen (Fig. 10). These undulations are not apparent in the east or west directions and suggest a series of low amplitude "ridges" running east-west. Such fine-scale features would not be visible in the high resolution (~8 m/pixel) Viking orbiter frames. However, in instances moderately bright (DN ≈ 156) pixels do line up in the east-west direction which may correspond to related, larger amplitude undulations (Fig. 11). If real, these features may represent volcanic flow fronts, sand ripples from aeolian processes, or ripples or large-scale sediment waves from fluvial processes. The resolution of available Viking orbiter images is at the threshold of allowing detailed mapping and correlation with lander images to be made. Presently, however, positive identification of fine-scale features seen by the Viking lander will have to wait for Mars Observer Camera data.

There are several surface units seen by the Viking 1 Lander of sufficient scale to be mapped on Viking orbiter images. These units can be separated based on the amount of loose, wind-blown drift material contained between the rocks on the surface (Fig. 3). Specifically these units include Rocky (*r*), Moderately rocky (*mr*), and Drift material (*d*). The most extensive is the Rocky unit, covering a majority of the surface visible by the lander. This unit is older than the other two and, we assume, represents unblanketed Ridged plains material, unit 2 (Hr_2). The Moderately rocky unit covers only ~80,000 m^2 in plan view and represents Rocky material partially blanketed by wind-blown Drift material. The Drift material itself, however, is not a pure end member of loose, aeolian debris: this unit does contain concentrations of rocks. It is, however, an area where large drifts and dunes are closely spaced and where rocks are completely buried in places. The surface area of this unit is only ~8,000 m^2, but it is of sufficient areal extent to be mapped on Viking orbiter images (Fig. 9).

Other authors interpretation of windblown material

Suggestions as to what our map units mean

- -extent of drift material and relationships between units
- -implications for hr2 materials...modification, emplacement of aeolian material

Emplacement of Ridged Plain Materials, Unit 2

Yorktown and Lexington

Many other geomorphic features seen at the Viking landing sites have identified from orbit through Viking orbiter images [Mutch et al., 1976; Binder et al., 1977; Morris et al., 1978; Morris and Jones, 1980]. However, these reports describe only a portion of distant objects that may be visible from the landers. Curvature of the planet, atmospheric refraction, topography, and feature height all influence the distance from which an object can be seen. Perhaps the most spectacular example of a distant object clearly visible by either of the two Viking Landers is the crater Mie [Carr, 1981, p. 23]. This 90-km-diameter crater is 170 km east of the Viking 2 lander in Utopia Planitia, yet it occupies about 10% of the visible horizon (or about 36° along the horizon; U.S. Geological Survey, 1984). Less obvious features are visible at both landing sites, most notably the craters Yorktown and Lexington seen by the Viking 1 Lander [Craddock and Zimbelman, 1989]. Identification of these impact craters supports the regional physiography presented in Fig. 6 and illustrates the full amount of information that may be gained from future surface missions to Chryse Planitia.

Yorktown is a 7.9-km-diameter rampart (i.e., fluidized ejecta) crater located at 23.12°N, 48.68°W, or approximately 50.5 km northwest of the Viking 1 landing site. Based on the position of the Viking 1 Lander [Morris and Jones, 1980], this crater is at an azimuth of 318° from Mars' north and would occupy 9.0° of angular width across the horizon. Lexington is a 5.0-km-diameter lunar-like crater located approximately 41.7 km southwest of the landing site at 22.05°N, 48.65°W with an azimuth of 233.5° from Mars' north and having an angular width of 6.9° across the horizon. The immediate problem with viewing objects at this distance from the lander is the curvature of Mars. Assuming that Mars is a perfect sphere with an equatorial radius of 3389.32 km [Davies and Katayama, 1983] and has neglible atmospheric refraction, at the nominal height of the Viking Lander cameras [1.3 m; Leibes and Schwartz, 1977] the distance an object on Mars can be seen by the Viking Landers before disappearing below the horizon is 2.97 km. However, this does not take the height of the object to be viewed or the local topography into account. Accounting for these parameters, the distance at which an object can be seen before disappearing below the horizon (d) is:

$$d = (R + r) \sin \theta_1) + 2.97 \text{ km} \qquad (1)$$

where R is the radius of the planet, r is the height of the object, and θ_1 is the angle between the apparent horizon for the observer and the object measured from the center of the planet. This significantly increases the distance over which objects can be viewed.

Rim height estimates for Yorktown and Lexington were calculated from Pike and Davis' [1984] equations and elevation differences between the base of the crater rims and the landing site were determined from U.S. Geological Survey [1976, 1977] data. Based on this information, the rim of Yorktown is ~480 m above the elevation of the Viking 1 Lander and should be visible up to 60.17 km away. Likewise, the rim of Lexington is ~380 m above the elevation of the Viking 1 Lander and should be visible up to 53.82 km away. Examination of Viking 1 lander photographs shows that distinct features are visible at the predicted locations of both craters.

Symmetrical mounds centered in the direction anticipated for Yorktown crater subtend 8.9° of arc (to the nearest 0.1°), the left part of the which may be obscured by a small crater closer to the lander (Fig. 12). These measurements retain the precision of the Viking Lander cameras [Patterson et al., 1977] and compare well to the predicted arc of 9.0° for the visible crater rim. Of particular importance is the height of these mounds. The visible (or apparent) height of the crater rim above the horizon can be calculated from the equations:

$$\theta_2 = \tan^{-1} (d_m - 2.97/R) \qquad (2)$$

$$\begin{aligned} r_o &= (R/\cos \theta_2) - R \qquad (3) \\ &= R((1/\cos \theta_2) - 1) \end{aligned}$$

where θ_2 is the angle between the observer's horizon and the object, d_m is the measured distance from the observer to the object, and r_o is the amount of object obscured by the curvature of the planet. From these equations 200 m, or approximately 75% of the total rim height of Yorktown, should be visible from the Viking 1 Lander. This translates into an angular height of 0.42°; however, only a maximum value of 0.15° can be measured for the mounds form lander photographs. Partial obstruction of the crater rim by another topographic feature in the field of view seems likely.

Equations 2 and 3 suggest that all of the crater rim (~190 m) and perhaps some of the surrounding terrain should be visible at the location of the Viking 1 Lander. A very distinctive feature is visible in the predicted location of Lexington (Fig. 12). Binder et al. [1977] suggested that this object was a ridge; however, it occupies almost the entire amount of predicted angular width before being obscured by local topography (5.0° versus 6.9°) and is centered at the predicted location of Lexington. This feature possesses a distinct albedo difference with the foreground and is truncated sharply to the left, suggesting that it is not related to a ridge of the Xanthe Dorsa complex. It has a measured angular height of 0.21° versus a predicted 0.28°, suggesting that like Yorktown a portion of the crater rim is being obscured by intervening topographic obstacles. In either case, such topographic obstacles would only need to <100 m high and be somewhere between these craters and the lander. Ridges of the Xanthe Dorsa system are at the right amplitude, occur between each crater, and thus make logical candidates for partial crater obstruction.

SUMMARY

The geologic history of central Chryse Planitia and the Viking 1 landing site (Fig. 13) can be summarized as follows:

During the Noachian the formation of the Chryse Planitia depression occurred, probably as the result of a giant impact [Schultz et al., 1982]. The northern rim of this basin was excavated when the Acidalia Planitia was formed, probably also as a result of a giant impact [Schultz and Frey, 1990]. The intersection of these two basins, or the resulting overlap in topography, produced a large trough connecting Chryse Planitia to the plains to the north.

Emplacement of the Ridged plains materials, unit 1 (Hr1) occurred during the early Hesperian. These materials are seen primarily in southern Chryse Planitia and also as windows (i.e., fensters) in the central portion of the basin. Because they pre-date most of the other material in the region, their exact extent is uncertain. Morphologically they are very similar to ridged plains materials seen else where on Mars. Crater size-frequency distribution curves indicate that they are also identical in age to the ridged plains materials in Lunae Planum bordering Chryse Planitia immediately to the west. They probably represent flood lavas extruded through deep-seated faults associated with the formation of the Chryse Planitia impact basin or, alternatively, they may represent fluvial sediments from early channel forming events. The sharply defined wrinkle ridges suggest that regardless of lithology, these materials have been subjected to a compressional stress regime which was stable for a long period of time (early Hesperian through at least the middle Amazonian).

During the late Hesperian, Maja Valles formed. These channels cut volcanic material from Lunae Planum and carried the sediments into Chryse Planitia, debouching them into the lowest portions of the basin. Perhaps as much as 62,500 km3 of volatiles were released during the formation of these channels [DeHon, personal communication, 1992]. These volatiles may have formed a standing body of water several hundred meters deep. Formation of the circum-Chryse outflow channels to the south probably occurred soon after. The volume of water within Chryse probably exceeded the -1 km topographic contour line and flowed northward into Acidalia Planitia.

Kasei Valles appears to be the last outflow channel to have debouched into Chryse Planitia. This occurred during the late Hesperian through the early Amazonian. Sediments reaching the pre-existing standing body of water

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Published Abstracts (3)

CENTRAL CHRYSE PLANITIA, MARS: GEOLOGIC UNIT INTERPRETATION FROM 1:500,000-SCALE MAPPING; *Robert A. Craddock*[1], *L.S. Crumpler*[2], *and Jayne C. Aubele*[2]; [1]*Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, Washington, D.C. 20560;* [2]*Department of Geological Sciences, Brown University, Providence, R.I. 02912*

Central Chryse Planitia represents one of two areas on the martian surface where planetary geologic mapping is added by Viking lander "ground-truth" observations. The broad-scale geology of Chryse Planitia [1] and the geology of the Viking 1 landing site [2] have been previously examined by other investigators. 1:500,000 scale mapping of central Chryse Planitia and the Viking 1 landing site (MTM's 20047 and 25047) was undertaken to synthesize these results and to address the following questions: (1) What is the depositional and erosional history of the Chryse Planitia basin? (2) How representative are the Viking 1 surface materials of the region and of plains units in general? (3) What is the extent of channel materials versus ridged plains materials? (4) As a result of the Viking lander investigations, what are the initial, primary objectives future missions to the surface should address?

Figure 1 shows a generalized 1:500,000-scale geologic map. The oldest materials are Hesperian in age, although degraded and/or buried craters may have formed on underlying Noachian materials. Ridged plains materials (Hr_1, Hr_2, and Hr_3) are the most extensive units protrayed and are characterized by numerous linear to sinuous wrinkle ridges (Xanthe Dorsa). These materials are defined on the basis of relative crater abundances, frequency of ridges, and degree of fluvial modification of the ridges. The ridges are morphologically similar to lunar mare-ridges and are interpreted to be the result of regional compressional strains in a competent, layered surface unit. Unlike lunar mare-ridges, the Xanthe Dorsa ridges trend north-south as opposed to being circumferential to the Chryse basin. This suggests basin subsidence was not the mechanism for Xanthe Dorsa formation as has been suggested for lunar ridges [3]. Despite the high resolution of the available images (<10 m/pixel), primary volcanic features such as flow fronts or vents have not been observed. The depositional nature of ridged plains, unit 3 (Hr_3) is suggested by the occurrence of several partially buried craters (c_1) along its southern contact. Using rim height to diameter ratios for martian craters [4], the thickness of this unit is ~300 m. Despite these observations, at the surface no unequivocal depositional features have been identified [2].

Distinct flat-topped and isolated ridges (Hri) occur along the crest of several of the more prominent mare-type ridges in the north-eastern half of the map area. These are interpreted to represent erosional remnants (i.e., inselbergs) of earlier ridges degraded and subsequently re-developed during continued regional deformation, or isolated highs representing buried structures (i.e, kipukas) such as large crater rims. The former suggests that ridge development is geologically long-lived [5] and span intervals of time great enough that several fluvial episodes occurred during the development of a single ridge. The latter interpretation suggests that ridge formation occurs where the ridged plains are thinnest, similar to mare wrinkle ridge development [3]. The incised channel unit (Hchi) and channeled plains materials, units 1 & 2 ($Hchp_1$ and $Hchp_2$) occur east of Kasei and Maja Valles and are superposed on the ridged plains. These materials represent complex episodes of fluvial deposition and erosion.

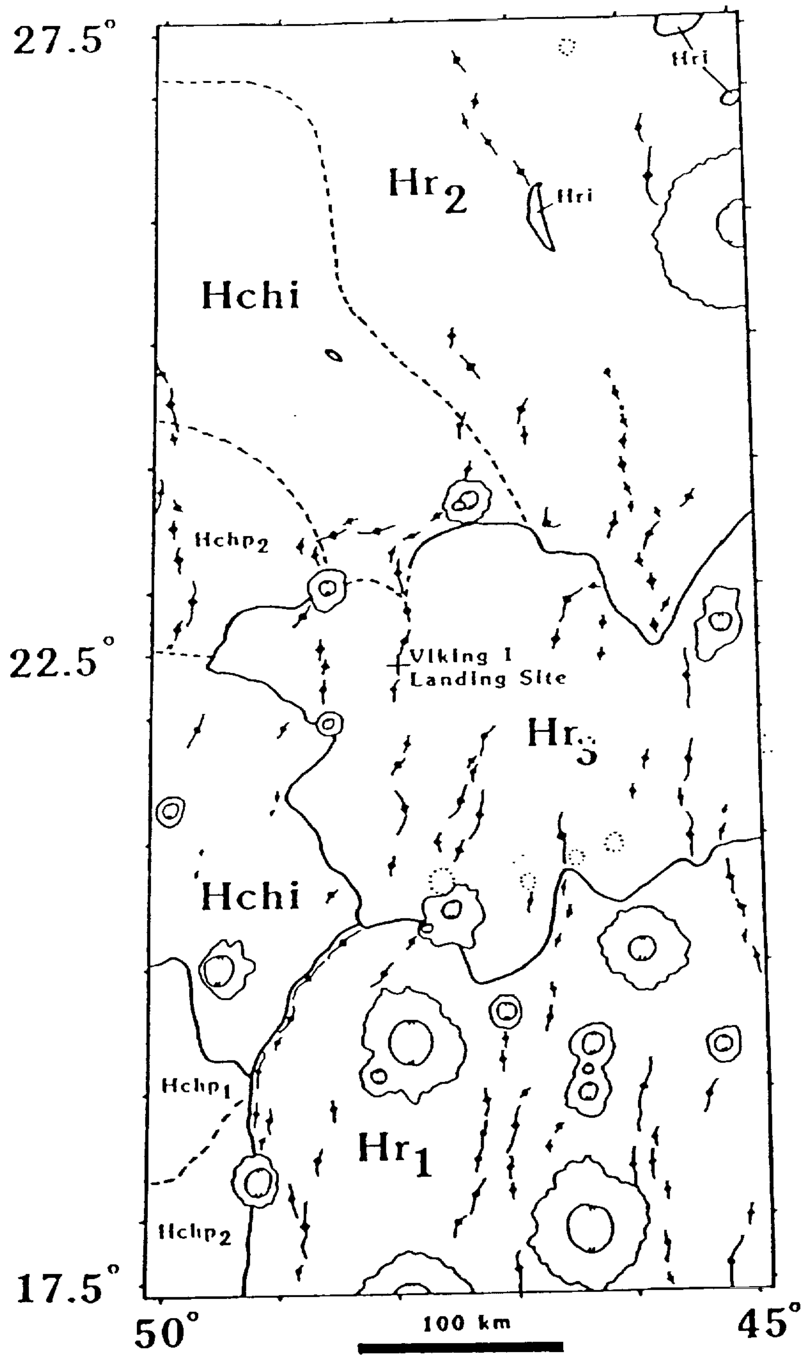

Figure 1. Generalized geologic map of the central Chryse Planitia region and the Viking 1 landing site. See text for explanation of units.

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GEOLOGIC HISTORY OF CENTRAL CHRYSE PLANITIA AND THE VIKING 1 LANDING SITE, MARS; *Robert A. Craddock[1], L.S. Crumpler[2], and Jayne C. Aubele[2]*; [1]Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, Washington, D.C. 20560; [2]Department of Geological Sciences, Brown University, Providence, R.I. 02912

1:500,000 scale geologic mapping was undertaken to synthesize the broad-scale geology of Chryse Planitia [1] with the local geology of the Viking 1 landing site [2]. The geology of MTM's 20047 and 25047 has been presented previously [3]. As part of the goals for the Mars Geologic Mapping program, the rational and scientific objectives for a return mission to Chryse Planitia and the Viking 1 Lander have also been presented [4]. However, in mapping central Chryse Planitia our principle objective was to determine the depositional and erosional history of the Chryse Planitia basin. These results are outlined and illustrated (Figure 1) below.

The Chryse Planitia topographic depression was formed during the Noachian (~4.2 Ga), probably as the result of a giant impact [5]. The northern rim of this basin was destroyed when Acidalia Planitia was formed, which may have also been the result of a giant impact [6]. The intersection of these two basins, or the resulting overlap in topography, produced a large trough connecting Chryse Planitia to the northern plains (topography from [7]).

Emplacement of the Ridged plains materials, unit 1 (Hr_1) occurred during the early Hesperian (~3.5 Ga). These materials are seen primarily in southern Chryse Planitia and also as windows (i.e., fensters) in the central portion of the basin. Because they pre-date most of the other material in the region, their exact extent is uncertain. Morphologically they are very similar to ridged plains materials seen elsewhere on Mars. Crater size-frequency distribution curves indicate that they are also identical in age to the ridged plains materials in Lunae Planum bordering Chryse Planitia immediately to the west. They probably represent flood lavas extruded through deep-seated faults associated with the formation of the Chryse Planitia impact basin or, alternatively, they may represent fluvial sediments from early channel forming events. The sharply defined wrinkle ridges suggest that regardless of lithology, these materials have been subjected to a compressional stress regime which was stable for a long period of time (early Hesperian through at least the middle Amazonian; ~3.5-1.5 Ga).

During the late Hesperian (~2.8 Ga), Maja Valles formed. These channels cut volcanic material from Lunae Planum and carried the sediments into Chryse Planitia, debouching them into the lowest portions of the basin. Perhaps as much as 62,500 km³ of volatiles were released during the formation of these channels [DeHon, personal communication, 1992], forming a standing body of water several hundred meters deep in the central portion of the basin. Formation of the circum-Chryse outflow channels to the south occurred soon after, releasing as much as 6.3×10^6 km³ of water into the Chryse basin [8]. Such a large volume of water would have exceeded the volume of the basin contained within the -1 km topographic contour line and flowed northward into Acidalia Planitia.

Kasei Valles appears to have been the last outflow channel to have debouched into Chryse Planitia, forming during the late Hesperian through the early Amazonian. Sediments from the formation of these channels would have debouched into a pre-existing standing body of water emplaced by the younger circum-Chryse outflow channels. Kasei Valles sediments may have discharge across Chryse Planitia by hypopycnal flow so that suspended clays and silts were carried into Acidalia Planitia (as suggested by [9]). Because of the subdued nature of the wrinkle ridges in Ridged plains materials, unit 2 (Hr_2), it is especially likely that these materials consist of fluvial deposits from the late-stage, Kasei Valles episodes of channel formation. Additional observation suggesting that these materials are fluvial in origin is the fact that they are at one of the lowest elevations on the planet (approximately -2.5 km below Mars datum; topography from [7]), have a very gradational contact with Maja and Kasei Valles channel materials, contain several partially buried craters, and are surrounded by a large outflow channel complex.

Analysis of the buried and modified craters (i.e., *eroded* craters, Figure 2) in Ridged plains materials, unit 2 yield possible information about the spatial distribution of this material. Using equations for fresh martian craters [10], the rim heights for the buried craters (2.3-11.3 km in diameter) were calculated. These values were then compared to the actual rim heights calculated through shadow measurements. By subtracting the difference between predicted and measured rim height values, we calculated that Ridged plains materials, unit 2 are ~50 m thick along the southern contact and possibly become thicker towards the basin interior. This is probably the case because the sharp bend-over in the crater production curve at 5-km-diameter (Figure 2) suggests that most craters smaller than this diameter were eradicated during the emplacement of the unit. This requires a substantially thicker deposit with a mean value of ~170 m. Throughout the Amazonian to the present, this unt has been reworked by aeolian activity.

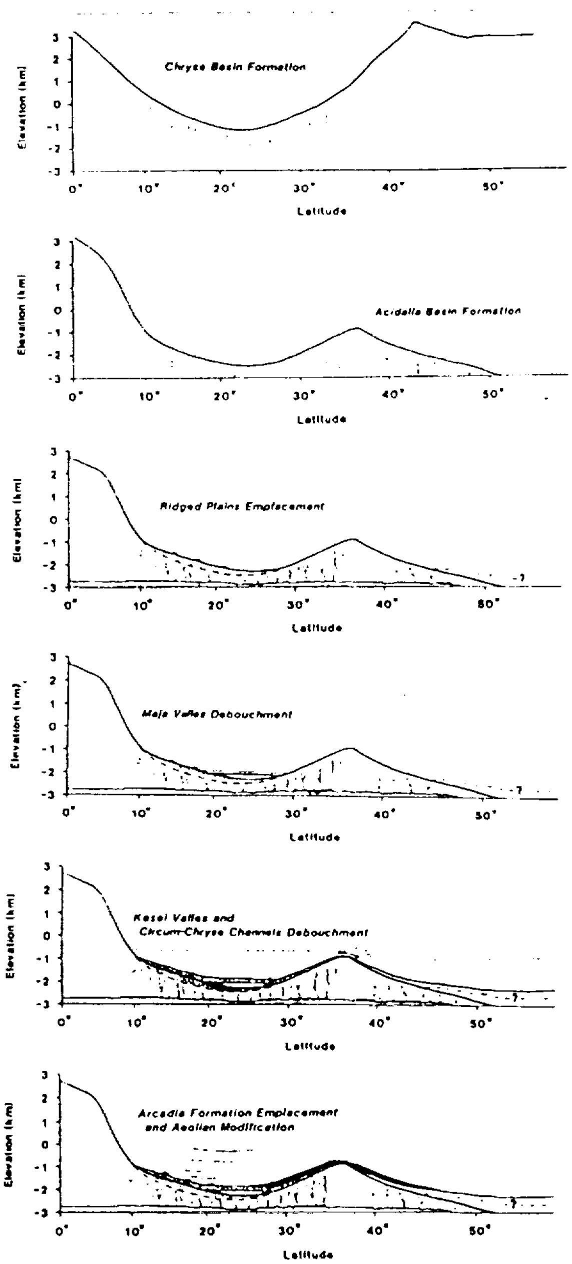

Figure 1 (left). Geologic history of Chryse Planitia. Oldest is at the top. Noachian: 1. Formation of the Chryse Planitia depression from an impact. 2. Formation of Acidalia Planitia depression from an impact and possible subsidence of Chryse Planitia. Hesperian: 3 . Emplacement of Ridged plains material, unit 1 in central and southern Chryse Planitia. Deposition of these materials in Acidalia Planitia is questionable. 4. Maja Valles debouches material from Lunae Planum into Chryse Planitia, perhaps filling the the lowest portion of the basin with sediments and volatiles. 5. Kasei Valles debouches material from northern Lunae Planum into Chryse Planitia. The total volume of water discharged by the circum-Chryse outflow channel complex is approximately 6x the volume of the Chryse Planitia below -1 km in elevation. Volatiles would have overflowed into Acidalia Planitia, carrying finer-grained sediments into the northern plains. Were the boulders and rocks seen by the Viking 1 lander deposited by Kasei Valles as they emptied into a standing body of water? Amazonian: 6. Arcadia formation emplaced in northern Chryse Planitia and southern Acidalia Planitia (not seen in area investigated). If volcanic, the emplacement of these materials may have induced by further Chryse basin subsidence. Note also continued formation of wrinkle ridges, suggesting that the compressional stress regime remained since the beginning of the Hesperian. Aeolian processes continued to winnow away finer-grained materials from Chryse Planitia.

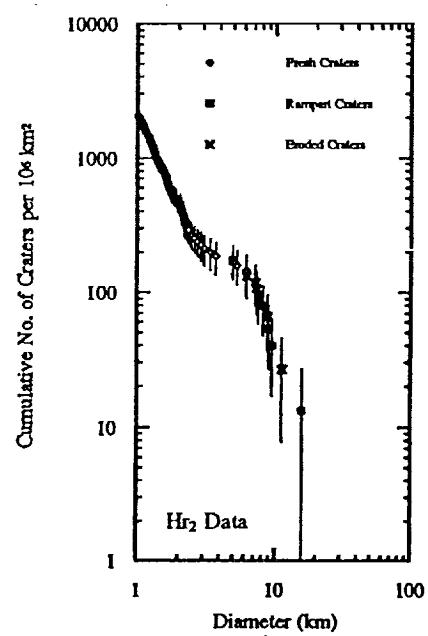

Figure 2 (right). Crater counts for Ridged plains material, unit 2 (Hr_2). Craters are classified as either fresh, rampart, or eroded (i.e., modified or buried). Note the bend over in the production curve at ~5 km suggesting that Hr_2 is ~170m thick.

References:

[1] Greeley, R. *et al., J. Geophys. Res., 82*, 4093-4109, 1977. [2] Binder, A.B. *et al., J. Geophys. Res., 82*, 4439-4451, 1977. [3] Craddock, R.A. *et al., Lunar Planet. Sci., XXIII*, 257-258, 1992. [4] Craddock, R.A., *Proc. Space '92 Conf., 3rd*, 1488-1499, 1992. [5] Schultz P.H. *et al., J. Geophys. Res., 87*, 9803-9820, 1982. [6] Schultz, R.A. and H.V. Frey, *J. Geophys. Res., 95*, 14,203-14,214, 1990. [7] U.S.G.S., *Misc. Invest. Ser. Map I-2030*,1989. [8] Carr, M.H. *et al., Lunar Planet. Sci., XVIII*, 155-156 1987. [9] Scott D.H. *et al., Proc. Lunar Planet. Sci. Conf., 22*, 53-52, 1992. [10] Pike, R.J. and P.A. Davis, *Lunar Planet. Sci., XV*, 645-646, 1984.

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Geologic History of Chryse Planitia, Mars

R.A. Craddock (CEPS/NASM/Smithsonian Institution), L.S. Crumpler, J. C. Aubele (DGS/Brown University)

Chryse Planitia represents one of two areas on the martian surface where planetary geologic mapping is aided by Viking lander "ground-truth" observations. 1:500,000 scale mapping of central Chryse Planitia and the Viking 1 landing site (MTM's 20047 and 25047) has been undertaken to determine the depositional and erosional history of the Chryse basin, synthesizing both Viking lander and orbiter observations. Because of its low elevation and circular shape, the Chryse basin is thought to have formed by a large impact in the early Noachian (Schultz et al., 1982). Quite possibly the Acidalia Planitia depression, which overlaps Chryse to the north, was also formed by a large impact following the formation of the Chryse basin (Schultz and Frey, 1990). Crater age-dates indicate that ridged plains material was emplaced concurrently in central and southern Chryse Planitia and Lunae Planum at the beginning of the Hesperian. Because of their morphologic similarities, numerous investigators have interpreted these materials as flood basalts (e.g., Craddock and Maxwell, 1991). Also during the Hesperian, flooding within Maja Valles eroded eastern Lunae Planum and debouched sedimentary materials into the lowest portions of the Chryse basin. Immediately following the emplacement of these materials the larger circum-Chryse outflow channels formed, possibly discharging ~6.3×10^6 km^3 of water into the Chryse basin (Carr et al., 1987), or 6x the volume of Chryse Planitia below -1 km in elevation. The evidence is that the volatiles overflowed into Acidalia Planitia, probably carrying the finer-grained sediments into the northern plains. We suggest that volatiles released during Kasei Valles formation debouched into this standing body of water, causing the boulders and rocks seen by the Viking 1 lander to be deposited and allowing finer-grained materials to be carried northward. During the Amazonian, the Arcadia formation was emplaced in northern Chryse Planitia and southern Acidalia Planitia. If these materials are volcanic, then their emplacement may have been induced by further subsidence of the Chryse basin. Some wrinkle ridges appear to have formed during this time as well, suggesting that a compressional stress regime was present throughout the Hesperian. Presently, aeolian processes continue to winnow away finer-grained materials from Chryse Planitia.

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