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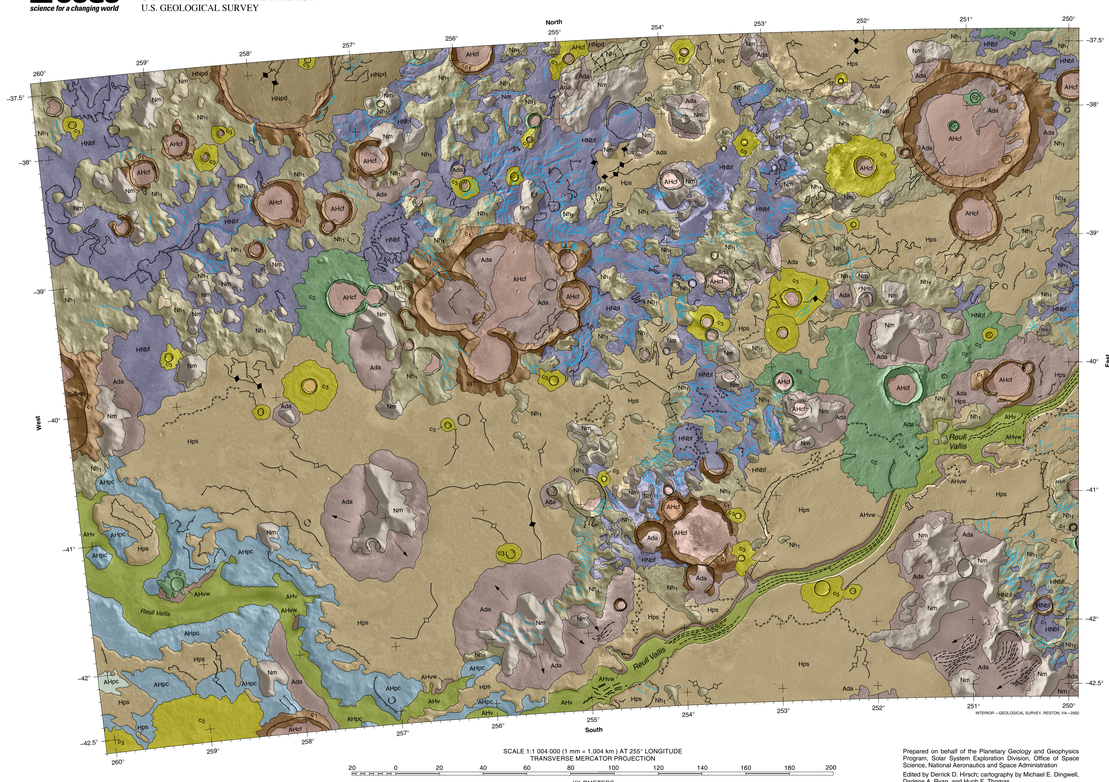

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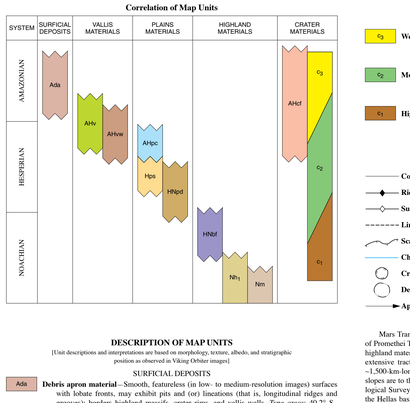
Correlation of Map Units



DESCRIPTION OF MAP UNITS

[Unit descriptions and interpretations are based on morphology, texture, albedo, and stratigraphic position as observed in Viking Orbiter images]

SURFICIAL DEPOSITS

Ada **Debris apron material**—Smooth, featureless (in low- to medium-resolution images) surfaces with lobate fronts, may exhibit pits and (or) lineations (that is, longitudinal ridges and grooves); borders highland massifs, crater rims, and valls walls. *Type areas:* 40.2° S., 251° W. (pits) and 42.3° S., 251.3° W. (lineations). *Interpretation*: Deposits of unconsolidated material resulting from mass wasting of rugged highland massifs, crater rims, and valls walls; mobility possibly due to incorporation of water or ice [for example, Squyres and Carr, 1986; Crown and others, 1992]; pits may be from collapse of volatile-rich debris; longitudinal ridges and grooves may indicate sorting of material within the flow or shearing of debris as it moved [Squyres, 1978, 1979]

VALLIS MATERIALS

AHv **Vallis floor material**—Deposits that form floor of Reull Vallis; lineated parallel to valls walls; smooth or pitted. *Type areas:* 40.2° S., 250° W. (lineated), 42.4° S., 254.8° W. (smooth), and 40.7° S., 251° W. (pitted). *Interpretation*: Sedimentary material of surrounding units [Crown and others, 1992; Tanaka and Leonard, 1995] emplaced by a combination of collapse and fluid flow; modified by small-scale deflation and fluvial redistribution; pits may result from partial collapse of volatile-rich material; lineations may be related to flow of water through the canyon and/or from coalescing debris aprons [Squyres, 1978]

AHvw **Vallis wall material**—Smooth deposits occurring at base of walls of Reull Vallis; typically overlain by valls floor material. *Type area:* 40.5° S., 250.4° W. *Interpretation*: Materials eroded from highland and plains units deposited at the base of the walls of Reull Vallis, similar to talus

PLAINS MATERIALS

AHpc **Channeled plains material**—Occurs in the southwest corner of MTM –40257 and along segment 3 of Reull Vallis. Smooth to irregular surface characterized by ridges having subdued morphologies and degraded craters; dissected by channels and scarps south and west of map area; fluted where gouged along Reull Vallis and in a large side canyon near the south end of main canyon of Reull Vallis (south of map area). *Type area:* 41.7° S., 258.5° W. *Interpretation*: Material deposited following erosion of surrounding highland and plains materials. Sinuous channels and scarps and degraded ridges and craters due to subsequent fluvial erosion of unit, possibly related to flooding from Reull Vallis. Mapped as smooth plains material (unit Hps) by Price [1998] and previously mapped as channeled plains rim unit (unit AHhg) by Greeley and Guest [1987], Mest [1998], and Mest and Crown 2001

Hps **Smooth plains material**—Occurs adjacent to Reull Vallis and in northern part of MTM –40252. Consists of smooth, relatively featureless materials embaying highland units; some occurrences have lobate margins; appears pitted adjacent to Reull Vallis (MTM –40252). Wrinkle ridges within unit have subdued morphologies. Also occurs as flat-topped, scarp-bounded mesas south of Reull Vallis (MTM –40257) within channeled plains material. Lightly cratered. *Type area:* 41° S., 256° W. *Interpretation*: Sedimentary deposits resulting from overflow of rich flows and (or) from transient body of water; also may contain materials eroded from highland terrains [Mest and Crown, 2001]; subdued morphology of wrinkle ridges due to erosion and burial by plains material. Mapped as mesa material (unit AHm) by Price [1998] and previously included within smooth plateau unit (unit Hpl&) by Greeley and Guest [1987]

HNbf **Dissected plains material**—Occurs in the northern part of map area. Consists of smooth material that fills low-lying areas between knobs and massifs of highland units. Majority of plains, especially in southwestern extent of unit (north of map area), dissected by sinuous scarps and small channels. Wrinkle ridges and craters within unit have subdued morphologies. *Type area:* 37.5° S., 254.1° W. *Interpretation*: Volcanic and (or) sedimentary materials modified by surface runoff. Previously mapped as ridged plains material (unit Hr) by Greeley and Guest [1987]

HIGHLAND MATERIALS

HNbf **Intermontane basin fill**—Smooth to slightly hummocky deposits filling low-lying regions within highlands. In map area, unit contains numerous valley networks, dendritic to rectilinear in nature; less dissected in the western part of MTM –40257. Some occurrences, especially where adjacent to smooth plains, have scarp-bounded edges. *Type area:* 38.7° S., 253° W. *Interpretation*: Sedimentary deposits derived from highland materials; may also contain eolian deposits with non-local sources; most deposits eroded by fluvial processes forming channels

NHs **Basin-rim unit**—Material of Hellas basin rim; consists of rugged, mountainous terrains with small sections of smooth deposits; dissected by channels which may extend onto younger materials; typically embayed by younger plains; heavily cratered. *Type area:* 39° S., 253.3° W. *Interpretation*: Impact-generated unit of ancient martian crust modified by fluvial and eolian processes [Greeley and Guest, 1987]; channel formation due to combination of ground water sapping and runoff.

Nm **Mountainous material**—Occurs throughout map area. Forms small to large, rugged, isolated massifs within basin-rim unit and younger units; typically embayed by younger plains; some surrounded by debris aprons. *Type area:* 41.4° S., 253.4° W. *Interpretation*: Ancient crustal material uplifted during formation of impact basins [Greeley and Guest, 1987]

CRATER MATERIALS

[Impact craters <4 km in diameter not mapped]

AHcf **Crater fill material**—Forms smooth or pitted surfaces on crater floors; displays lobate margins against crater wall units. *Type areas:* 38.3° S., 251° W. (smooth) and 40.1° S., 250.6° W. (pitted). *Interpretation*: Fluvial and (or) eolian sedimentary deposits and (or) coalesced debris aprons from crater rim materials that accumulate on crater floors; pitting may be due to partial collapsed volatile-rich materials. Mapped as smooth floor material by Greeley and Guest [1987]

c_3 **Well-preserved crater material**—Characterized by pronounced, continuous crater rim ejecta blanket and (or) well-defined, continuous ejecta blanket. *Interpretation:* Pristine crater material exhibiting little degradation; some crater floors may contain deposits emplaced by mass wasting, eolian activity, and (or) fluvial processes

c_2 **Moderately degraded crater material**—Characterized by a crater rim that may exhibit only minor relief above surrounding materials and by discontinuous, poorly exposed ejecta. *Interpretation:* Impact craters with moderate degree of degradation; most crater floors contain deposits emplaced by mass wasting, eolian activity, and (or) fluvial processes

c_1 **Highly degraded crater material**—Characterized by a degraded crater rim that may be discontinuous and exhibits little relief relative to the surrounding materials; ejecta and smooth, featureless crater floors. *Interpretation:* Highly degraded impact crater material. Ejecta has been completely eroded or mantled by younger materials; rim has been modified by erosion. Most crater floors contain deposits emplaced by mass wasting, eolian activity, and (or) fluvial processes

Contact—Dashed where approximately located or gradational

Ridge

Subdued ridge

Lineament

Scarp—Hachures at top of scarp point downslope; dashed where inferred

Channel

Crater rim crest

Degraded crater rim crest

Apparent flow direction

INTRODUCTION

Mars Transverse Mercator (MTM) quadrangles –40252 and –40257 cover a portion of the highlands of Promethei Terra northeast of the Hellas basin (fig. 1). The map area consists of heavily cratered ancient highland materials of moderate to high relief, isolated knobs and massifs of rugged mountainous materials, extensive valley networks and channeled plains, and other surficial deposits. Reull Vallis (fig. 2), an ~1,500-km-long outflow channel system, cuts through the southeast corner of the map area. Regional slopes are to the southwest, toward the Hellas basin, as indicated by martian topographic maps [U.S. Geological Survey, 1989; Smith and others, 1999] and the orientations of channels along the northeast rim of the Hellas basin. The martian highlands cover more than 60% of the planet's surface and are primarily in the southern hemisphere [Tanaka and others, 1992]. Most of the highlands consist of rugged, densely cratered terrains believed to represent the final phase of heavy bombardment that ended over 3.9 billion years ago [Murray and others, 1971; Schubert and others, 1992; Tanaka and others, 1992]. Parts of the martian highlands show evidence of extensive degradation and modification. The map area exhibits landforms created by numerous geologic processes, including impact, volcanism, fluvial activity, and mass wasting. The occurrence of fluvial features, such as outflow channels and valley networks, has significant implications for past martian conditions. Determining the geology of the highlands northeast of the Hellas basin provides a better understanding of the role and timing of fluvial activity in the geologic evolution of the highlands. Photogeologic mapping at 1:500,000 scale from analysis of Viking Orbiter images complements geomorphic studies of Reull Vallis and other highland outflow systems, of drainage networks, and of highland debris aprons and lineated valley fill and also supports studies of the highlands at the 1:2,000,000 scale [Mest, 1998; Mest and Crown, 2001] and 1:1,000,000 scale [Mest and Crown, 2002]. Crater size-frequency distributions have been compiled to constrain the relative ages of geologic units and determine the timing and extents of the observed geologic processes.

REGIONAL GEOLOGY

Noachian materials are the principal components of the rugged highlands surrounding the Hellas basin and represent the oldest rocks on Mars [Murray and others, 1971; Tanaka, 1986; Tanaka and others, 1988, 1992; Schubert and others, 1992]. According to Greeley and Guest [1987], erosion of highland materials began during the Late Noachian Epoch and continued throughout the Hesperian Period, resulting in deposition of extensive plains materials in and around the Hellas basin. The units of the Hellas basin and its surrounding rim are grouped into the Hellas assemblage [Greeley and Guest, 1987]; these units range from the basin rim, consisting of rugged highland plateaus and massifs, to dissected plains materials and valley networks, to younger plains units, some of which contain channels, ridges, scarps, and mesas.

Highland units, both Noachian and northern and southern plains units of the Hellas Early Hesperian Epochs with the formation of Hadriaca and Tyrrhena Paterae [Crown and others, 1992; Tanaka and Leonard, 1995; Crown and Greeley, 1993; Gregg and others, 1998], and northeast of the map area with emplacement of ridged plains material of Hesperia Planum [Tanaka, 1986; Greeley and Guest, 1987]. The highland paterae are interpreted to be composed of pyroclastic deposits possibly resulting from phreatomagmatic eruptions [Greeley and Spudis, 1981; Greeley and Crown, 1990; Crown and Greeley, 1993]. However, the presence of ~1000-km-long flank units extending from Tyrrhena Patera that contains lava flows and a smooth deposit infilling the caldera of Hadriaca Patera suggests some effusive activity occurred late in the volcanoes' histories (presumably mid- to Late Hesperian/Early Amazonian) [Crown and others, 1992]. The highland plains of Hesperia Planum is one of many areally extensive volcanic plains-forming units found on the surface of Mars [Scott and Tanaka, 1986; Greeley and Guest, 1987]. Ridged plains material exhibits wrinkle ridges, may contain lobate scarps (possibly flow fronts), and is interpreted to be composed of flood lavas which fill low-lying areas [Potter, 1976; King, 1978; Greeley and Spudis, 1981; Scott and Tanaka, 1986; Greeley and Guest, 1987].

Water is believed to have played a major role in modifying the martian highlands, and MTM quadrangles –40252 and –40257 exhibit extensive evidence of fluvial activity (see "Fluvial Features"). Numerous well-developed valley networks appear to be the oldest fluvial features in the study area; they are found in rugged ancient highland terrains and are most likely Noachian to Hesperian in age [Crown and Mest, 1997]. The presence of several widespread plains units northeast of the Hellas basin provides evidence that extensive degradation and resurfacing occurred in the highlands. Subsequent erosion of these plains units is believed to have occurred in the Late Hesperian/Early Amazonian Epochs [Greeley and Guest, 1987]. Also during the Hesperian the highland outflow channels (Reull, Dao, Niger, and Harmakhis Vallis) formed, depositing significant amounts of eroded material on their floors and along their banks, as well as on the floor of the Hellas basin. Recent studies of the four mid-Hesperian/Early Amazonian-aged outflow channels in the eastern Hellas region suggest an origin by subsurface flow and collapse of pitted chain materials combined with fluvial processes, followed by modification by wall retreat [Crown and others, 1992; Tanaka and Leonard, 1995; Crown and Mest, 1997]. Each outflow channel heads within or adjacent to a major local volcanic feature: Dao Valls cuts into the flank materials of Hadriaca Patera, Niger and Harmakhis Valles are located adjacent to the Tyrrhena Patera flank flow, and Reull Vallis begins in the ridged plains of Hesperia Planum. The fact that the outflow channels are in close proximity to these volcanic features suggests valles formation may be in part due to mobilization and release of subsurface volatiles by volcanic heat [Squyres and others, 1987; Crown and others, 1992]. Lastly, evidence of mass wasting has been observed in the form of debris aprons that extend from highland massifs, interior crater walls, and valles walls, and appear to be the youngest features observed [Crown and others, 1992; Crown and Stewart, 1995; Tanaka and Leonard, 1995; Crown and Mest, 1997; Crown and others, 1997].

STRATIGRAPHY

Relative ages of the geologic units mapped in MTM quadrangles –40252 and –40257 were determined using observed stratigraphic relations in combination with crater size-frequency distributions compiled for the regional study of the Reull Vallis region (table 1) [Mest, 1998; Mest and Crown, 2001]. Craters were counted on a Mars Digital Image Mosaic at 231 m/pixel (latitude –27.5° to –47.5°, longitude 245° to 270°). With a few exceptions, crater size-frequency distributions show relative ages that tend to be consistent with previous studies [for example, Greeley and Guest, 1987; Crown and others, 1992; Tanaka and Leonard, 1995].

Heavily cratered highlands contain the oldest materials exposed in the area. The oldest rock units visible are mountainous material (unit Nm) and the basin-rim unit of the Hellas assemblage (unit NH_3) (fig. 3), previously mapped by Greeley and Guest [1987]. Mountainous material (unit Nm) forms large rugged, isolated or clustered massifs throughout the study area. Most massifs are found within exposures of the basin-rim unit or are surrounded by younger volcanic or sedimentary plains material. Numerous massifs of mountainous material in the area, especially near Reull Vallis, are surrounded by debris aprons derived from highland terrains [Crown and others, 1992; Crown and Stewart, 1995; Stewart and Crown, 1997]. The basin-rim unit forms the rugged, mountainous terrain of Promethei Terra. Most of the unit in the map area is north of Reull Vallis, but some is exposed to the southeast. Massifs within the basin-rim unit tend to be incised with small valleys and are more eroded than other highland materials in the area. In places, the basin-rim unit may also contain some sedimentary deposits derived from local materials. Mountainous materials and the basin-rim unit are interpreted to consist of ancient crustal materials (impact breccias and volcanics) uplifted during impact basin formation [Scott and Tanaka, 1986; Greeley and Guest, 1987].

Crown and others [1992] noted that intermontane regions within the basin-rim unit appeared to have smooth surfaces. The current study shows that these areas are filled with smooth material, called intermontane basin fill (unit HNbf), that was subsequently eroded by channels and well-developed valley networks (fig. 3). Exposures of intermontane basin fill in MTM –40252 and the eastern part of MTM –40257 are heavily dissected by valley networks and channels, whereas the remaining exposures in the region appear relatively smooth with only a few small channels and scarps. The difference in the amount of dissection may be due to the lower resolution images of western MTM –40257. The presence of highly eroded intermontane basin fill among highland massifs provides evidence of deposition and erosion by fluvial processes in the oldest parts of the map area. See the section entitled 'Fluvial Features' for a description and discussion of valley network morphology.

The basin-rim unit of the Hellas assemblage (unit NH_3) and mountainous material (unit Nm) are some of the oldest materials exposed in the map area, but crater size-frequency distributions show ages slightly younger than other studies (Middle Noachian to Early Hesperian). These younger ages are most likely due to the degradational history of these units and their small areal extents in the Reull Vallis region. Also, intermontane basin fill (unit HNbf—not mapped in the regional studies of Mest [1998] and Mest and Crown [2002]) within the basin-rim unit would have buried small- and medium-size craters, giving the basin-rim unit a younger age than expected. Thus, the basin-rim unit proper is most likely Middle Noachian in age, and mountainous material Middle to Early Noachian. Although crater statistics were not compiled for intermontane basin fill, superposition relations place it between the basin-rim unit and smooth plains material (unit Hps), suggesting a Late Noachian to Early Hesperian age.

Dissected plains material (unit HNpd) is an extensive unit north of the map area nestled between the basin-rim unit and the ridged plains material (unit Hr) of Hesperia Planum and was previously mapped as the southwesternmost extension of Hesperia Planum [Greeley and Guest, 1987]. A small exposure of dissected plains material occurs in MTM –40252 along the north edge of the quadrangle, and a larger exposure occurs north of the basin-rim unit in MTM –40257. Dissected plains material is characterized by narrow sinuous channels, irregular scarps, and dissected and eroded ridges and is interpreted to consist of volcanic and (or) sedimentary materials modified by fluvial processes (fig. 4). Dissected plains material appears to have filled low-lying areas of the highlands, as numerous isolated knobs and hills of mountainous material (unit Nm) are embayed by the plains. The contact between the ridged plains and dissected plains materials is not well-defined and may be gradational; however, the mottled texture and the lack of high concentrations of cross-cutting pristine wrinkle ridges in dissected plains material allow it to be distinguished from ridged plains material.

Crater size-frequency distributions for dissected plains material (unit HNpd) show the unit to be Late Noachian to Early Hesperian in age and slightly older than the ridged plains material (unit Hr) of Hesperia Planum. Two possibilities exist for the ages of dissected plains material: (1) dissected plains material is an older part of Hesperia Planum (as mapped by Greeley and Guest [1987]) that underwent a period of fluvial erosion, or (2) dissected plains material is a discrete unit (volcanic or sedimentary) that predates the ridged plains and was subject to extensive deformation and fluvial erosion.

Most exposures of smooth plains material (unit Hps) are immediately adjacent to Reull Vallis (Figs. 3, 5–8); smaller exposures are north of the basin-rim unit in MTM –40252. Smooth plains material appears to embay Noachian highland units (unit Nm, and NHs) and exhibits lobate terminations in places where the plains meet the highlands (fig. 3). At moderate resolutions, smooth plains material displays relatively featureless surfaces and is found in the regional lows between highland massifs, irregular scarps, and valley networks. Higher resolutions reveal numerous wrinkle ridges, interpreted to be tectonic in origin, and small channels in the plains.

Few craters are observed within valls floor material (unit AHv), and previous studies have shown these deposits to be Late Hesperian [Greeley and Guest, 1987] to Early Amazonian [Crown and others, 1992] in age. Crater statistics determined for valls floor material for Reull, Dao, Niger, and Harmakhis Valles in the regional studies of Mest [1998] and Mest and Crown [2001] show the unit to be Early Hesperian to Early Amazonian in age. However, relations between valls floor and smooth plains materials constrain the range to Late Hesperian to Early Amazonian. Older ages for these deposits are most likely due to the inclusion of the entire canyon of Reull Vallis; the study by Crown and others [1992] only measured a portion of segment 3 of Reull Vallis near its terminus. If individual segments of Reull Vallis are considered separately, differences in age are evident. Valls floor material in the upper part of segment 2 contains more craters than the lower part of segment 2 and segment 3 of Reull Vallis and floor material in Dao, Niger, and Harmakhis Valles. This relation suggests that the upper part of segment 2 of Reull Vallis could have a floor that is older than the other segments (Lower Hesperian versus Upper Hesperian to Lower Amazonian) or that it has not been affected by wall collapse and infilling to the same degree as the lower part of segment 2 and segment 3. On the basis of crater statistics, the formation of Reull Vallis would have begun in the Lower Hesperian and is an older system than Dao, Niger, and Harmakhis Valles. Crater counts for valls wall material (unit AHvw) in Reull Vallis were not determined in the regional study [Mest, 1998; Mest and Crown, 2001] due to their limited exposure but are believed to be Upper Hesperian to Lower Amazonian based on superposition relations with vallis floor material.

Many craters in the region have smooth floors and have been infilled with crater fill material (unit AHcf) (fig. 9). This material varies morphologically among craters in the map area, which indicates multiple origins of crater fill material. Crater fill material observed in some craters presumably consists of materials eroded from the crater walls by fluvial processes and deposited on the crater floor. Crater fill material observed in other craters has pitted surfaces and lobate edges, similar to local debris aprons, and may be composed of coalescing volatile-rich debris mass–wasted from crater rims. Other occurrences of crater fill may consist of material deposited from external sources. Some craters in the map area, especially within the basin-rim unit, have discontinuous rims and may have been infilled with material eroded from the highlands, similar to intermontane basin fill. Craters found in channeled plains material with continuous, well-defined rims (outside of map area) appear to be filled with smooth deposits similar to nearby flat-topped mesas and smooth plains material. These craters may provide evidence that floodwaters were deep enough to flow over and deposit material inside craters. Also, some crater fill material could be composed of eolian deposits.

Mass wasting appears to have formed the youngest deposits in the map area. Debris apron material (unit Ada) occurs throughout the region, extending from massifs of Noachian mountainous material (unit Nm) (figs. 6–8), crater walls (fig. 9), and valls walls (fig. 7) [Crown and others, 1992; Crown and Stewart, 1995; Stewart and Crown, 1997]. They are interpreted to consist of unconsolidated material. Most of the debris aprons in the area are associated with mountainous material (unit Nm). Debris aprons associated with isolated highland massifs frequently completely surround their parent massifs, spreading laterally and extending for distances up to ~40 km, whereas debris aprons in craters and within Reull Vallis tend to be confined and therefore relatively small [Crown and Stewart, 1995; Stewart and Crown, 1997]. Debris aprons around highland massifs have uniform or mottled albedoes and may exhibit lineations on their surfaces parallel and (or) perpendicular to the direction of motion; those in craters and within Reull Vallis have mottled albedoes, relatively featureless surfaces, and arcuate to lobate fronts. Some massif-related aprons, especially the largest deposits, have lobate frontal morphologies and appear to be composed of multiple coalescing lobes [Crown and Stewart, 1995; Stewart and Crown, 1997]. Pitting is seen on the surfaces of massif-, crater-, and canyon-related debris aprons, especially close to Reull Vallis.

Lineations parallel to the direction of flow occur on the surfaces of large debris aprons and suggest shearing of materials facilitated by interstitial water and (or) ice [Squyres and Carr, 1986; Zimbelman and others, 1989; Crown and others, 1992], similar to lineated valley fill [Squyres, 1978, 1979]. This type of ice creep appears to be a dominant process in middle to high latitudes on Mars, causing landforms to undergo "terrain softening" and forming concentric crater fill and debris aprons [Squyres and Carr, 1986]. The fretted terrain in the northern hemisphere (30°–50° north) displays landforms produced by creep-related processes, in which ice-rich materials flowed downslope [Squyres, 1978, 1979; Squyres and Carr, 1986]. Here, valley floors contain lineated valley fill, characterized by lineations parallel to the valley walls, and debris aprons with lineations parallel to the apparent direction of flow, both indicating slow movement of volatile-rich debris [Squyres, 1978, 1979].

Debris apron (unit Ada) and crater fill (unit AHcf) materials contain few craters on their surfaces and are not areally extensive, and therefore show low crater densities. Crater size-frequency distributions of these materials suggest they are some of the youngest deposits in the study area, ranging from Late Hesperian to Middle Amazonian for debris apron material, and Late Hesperian to Early Amazonian for crater fill material. Crater fill material is found in craters within units of various ages and is interpreted to have several different origins (for example, eroded from crater walls and rims, coalescing debris aprons, and external sources such as fluvial and eolian deposits). Mest [1998] and Mest and Crown [2001] observed in the regional study that crater fill material resulting from erosion of crater walls and rims contained more craters on their surfaces than crater fill material formed by coalescing debris aprons or eolian deposits; thus a range of ages for crater fill material is expected.

Crater materials within the map area display various states of preservation, indicating degradation of these materials has been a continuing process throughout the evolution of this region. Well-preserved crater material (unit c_3) shows the least amount of degradation and is characterized by pronounced, continuous crater rims that are elevated relative to the surrounding materials, and also by well-defined, continuous ejecta blankets. Many of these crater types, especially in the smooth plains near Reull Vallis, display rampart morphologies that suggest impact in volatile-rich materials [Squyres and others, 1992]. Moderately degraded crater material (unit c_2) shows moderate amounts of degradation and is characterized by crater rims (in places discontinuous) exhibiting minor relief above the surrounding materials, and by discontinuous and (or) poorly exposed ejecta blankets. Highly degraded crater material (unit c_1) shows the most degradation, with discontinuous crater rims exhibiting little to no relief above the surrounding materials and ejecta blankets that have either been completely eroded or mantled by younger materials. Many craters of all types (units c_3, c_2, and c_1) appear to have smooth, featureless, crater fill material (unit AHcf) though still retaining their other characteristic morphologies. The fact that crater fill material may have various origins, and therefore ages, makes the presence (or lack) of this deposit an inappropriate method of characterizing craters within the map area.

FLUVIAL FEATURES

Fluvial processes appear to have played a major role in the geologic evolution of the map area. Numerous valley networks and channels are observed within many of the geologic units in the map area, including the basin-rim unit, intermontane basin fill, and dissected and eroded ridges and craters of volcanic and (or) sedimentary materials modified by fluvial processes (fig. 4). Dissected plains material appears to have filled low-lying areas of the highlands, as numerous isolated knobs and hills of mountainous material (unit Nm) are embayed by the plains. The contact between the ridged plains and dissected plains materials is not well-defined and may be gradational; however, the mottled texture and the lack of high concentrations of cross-cutting pristine wrinkle ridges in dissected plains material allow it to be distinguished from ridged plains material.

Valley networks in intermontane basin fill consist of narrow channels (<1 km wide) several tens to hundreds of kilometers long. They exhibit well-developed dendritic to rectilinear patterns (terminology from Mars Channel Working Group [1983]) (fig. 3), similar to other networks observed in the cratered highlands of Mars [Carr, 1995, 1996]. The drainage basins that contain the networks are 80 to 240 km wide and 80 to 640 km long; the longest basins exist for the specially confined channels. (1) dissected plains material is an older part of Hesperia Planum (as mapped by Greeley and Guest [1987]) that underwent a period of fluvial erosion, or (2) dissected plains material is a discrete unit (volcanic or sedimentary) that predates the ridged plains and was subject to extensive deformation and fluvial erosion.

Most exposures of smooth plains material (unit Hps) are immediately adjacent to Reull Vallis (Figs. 3, 5–8); smaller exposures are north of the basin-rim unit in MTM –40252. Smooth plains material appears to embay Noachian highland units (unit Nm, and NHs) and exhibits lobate terminations in places where the plains meet the highlands (fig. 3). At moderate resolutions, smooth plains material displays relatively featureless surfaces and is found in the regional lows between highland massifs, irregular scarps, and valley networks. Higher resolutions reveal numerous wrinkle ridges, interpreted to be tectonic in origin, and small channels in the plains.

Few craters are observed within valls floor material (unit AHv), and previous studies have shown these deposits to be Late Hesperian [Greeley and Guest, 1987] to Early Amazonian [Crown and others, 1992] in age. Crater statistics determined for valls floor material for Reull, Dao, Niger, and Harmakhis Valles in the regional studies of Mest [1998] and Mest and Crown [2001] show the unit to be Early Hesperian to Early Amazonian in age. However, relations between valls floor and smooth plains materials constrain the range to Late Hesperian to Early Amazonian. Older ages for these deposits are most likely due to the inclusion of the entire canyon of Reull Vallis; the study by Crown and others [1992] only measured a portion of segment 3 of Reull Vallis near its terminus. If individual segments of Reull Vallis are considered separately, differences in age are evident. Valls floor material in the upper part of segment 2 contains more craters than the lower part of segment 2 and segment 3 of Reull Vallis and floor material in Dao, Niger, and Harmakhis Valles. This relation suggests that the upper part of segment 2 of Reull Vallis could have a floor that is older than the other segments (Lower Hesperian versus Upper Hesperian to Lower Amazonian) or that it has not been affected by wall collapse and infilling to the same degree as the lower part of segment 2 and segment 3. On the basis of crater statistics, the formation of Reull Vallis would have begun in the Lower Hesperian and is an older system than Dao, Niger, and Harmakhis Valles. Crater counts for valls wall material (unit AHvw) in Reull Vallis were not determined in the regional study [Mest, 1998; Mest and Crown, 2001] due to their limited exposure but are believed to be Upper Hesperian to Lower Amazonian based on superposition relations with vallis floor material.

Many craters in the region have smooth floors and have been infilled with crater fill material (unit AHcf) (fig. 9). This material varies morphologically among craters in the map area, which indicates multiple origins of crater fill material. Crater fill material observed in some craters presumably consists of materials eroded from the crater walls by fluvial processes and deposited on the crater floor. Crater fill material observed in other craters has pitted surfaces and lobate edges, similar to local debris aprons, and may be composed of coalescing volatile-rich debris mass–wasted from crater rims. Other occurrences of crater fill may consist of material deposited from external sources. Some craters in the map area, especially within the basin-rim unit, have discontinuous rims and may have been infilled with material eroded from the highlands, similar to intermontane basin fill. Craters found in channeled plains material with continuous, well-defined rims (outside of map area) appear to be filled with smooth deposits similar to nearby flat-topped mesas and smooth plains material. These craters may provide evidence that floodwaters were deep enough to flow over and deposit material inside craters. Also, some crater fill material could be composed of eolian deposits.

Mass wasting appears to have formed the youngest deposits in the map area. Debris apron material (unit Ada) occurs throughout the region, extending from massifs of Noachian mountainous material (unit Nm) (figs. 6–8), crater walls (fig. 9), and valls walls (fig. 7) [Crown and others, 1992; Crown and Stewart, 1995; Stewart and Crown, 1997]. They are interpreted to consist of unconsolidated material. Most of the debris aprons in the area are associated with mountainous material (unit Nm). Debris aprons associated with isolated highland massifs frequently completely surround their parent massifs, spreading laterally and extending for distances up to ~40 km, whereas debris aprons in craters and within Reull Vallis tend to be confined and therefore relatively small [Crown and Stewart, 1995; Stewart and Crown, 1997]. Debris aprons around highland massifs have uniform or mottled albedoes and may exhibit lineations on their surfaces parallel and (or) perpendicular to the direction of motion; those in craters and within Reull Vallis have mottled albedoes, relatively featureless surfaces, and arcuate to lobate fronts. Some massif-related aprons, especially the largest deposits, have lobate frontal morphologies and appear to be composed of multiple coalescing lobes [Crown and Stewart, 1995; Stewart and Crown, 1997]. Pitting is seen on the surfaces of massif-, crater-, and canyon-related debris aprons, especially close to Reull Vallis.

Lineations parallel to the direction of flow occur on the surfaces of large debris aprons and suggest shearing of materials facilitated by interstitial water and (or) ice [Squyres and Carr, 1986; Zimbelman and others, 1989; Crown and others, 1992], similar to lineated valley fill [Squyres, 1978, 1979]. This type of ice creep appears to be a dominant process in middle to high latitudes on Mars, causing landforms to undergo "terrain softening" and forming concentric crater fill and debris aprons [Squyres and Carr, 1986]. The fretted terrain in the northern hemisphere (30°–50° north) displays landforms produced by creep-related processes, in which ice-rich materials flowed downslope [Squyres, 1978, 1979; Squyres and Carr, 1986]. Here, valley floors contain lineated valley fill, characterized by lineations parallel to the valley walls, and debris aprons with lineations parallel to the apparent direction of flow, both indicating slow movement of volatile-rich debris [Squyres, 1978, 1979].

Debris apron (unit Ada) and crater fill (unit AHcf) materials contain few craters on their surfaces and are not areally extensive, and therefore show low crater densities. Crater size-frequency distributions of these materials suggest they are some of the youngest deposits in the study area, ranging from Late Hesperian to Middle Amazonian for debris apron material, and Late Hesperian to Early Amazonian for crater fill material. Crater fill material is found in craters within units of various ages and is interpreted to have several different origins (for example, eroded from crater walls and rims, coalescing debris aprons, and external sources such as fluvial and eolian deposits). Mest [1998] and Mest and Crown [2001] observed in the regional study that crater fill material resulting from erosion of crater walls and rims contained more craters on their surfaces than crater fill material formed by coalescing debris aprons or eolian deposits; thus a range of ages for crater fill material is expected.

Crater materials within the map area display various states of preservation, indicating degradation of these materials has been a continuing process throughout the evolution of this region. Well-preserved crater material (unit c_3) shows the least amount of degradation and is characterized by pronounced, continuous crater rims that are elevated relative to the surrounding materials, and also by well-defined, continuous ejecta blankets. Many of these crater types, especially in the smooth plains near Reull Vallis, display rampart morphologies that suggest impact in volatile-rich materials [Squyres and others, 1992]. Moderately degraded crater material (unit c_2) shows moderate amounts of degradation and is characterized by crater rims (in places discontinuous) exhibiting minor relief above the surrounding materials, and by discontinuous and (or) poorly exposed ejecta blankets. Highly degraded crater material (unit c_1) shows the most degradation, with discontinuous crater rims exhibiting little to no relief above the surrounding materials and ejecta blankets that have either been completely eroded or mantled by younger materials. Many craters of all types (units c_3, c_2, and c_1) appear to have smooth, featureless, crater fill material (unit AHcf) though still retaining their other characteristic morphologies. The fact that crater fill material may have various origins, and therefore ages, makes the presence (or lack) of this deposit an inappropriate method of characterizing craters within the map area.

FLUVIAL FEATURES

Fluvial processes appear to have played a major role in the geologic evolution of the map area. Numerous valley networks and channels are observed within many of the geologic units in the map area, including the basin-rim unit, intermontane basin fill, and dissected and eroded ridges and craters of volcanic and (or) sedimentary materials modified by fluvial processes (fig. 4). Dissected plains material appears to have filled low-lying areas of the highlands, as numerous isolated knobs and hills of mountainous material (unit Nm) are embayed by the plains. The contact between the ridged plains and dissected plains materials is not well-defined and may be gradational; however, the mottled texture and the lack of high concentrations of cross-cutting pristine wrinkle ridges in dissected plains material allow it to be distinguished from ridged plains material.

Crater size-frequency distributions for dissected plains material (unit HNpd) show the unit to be Late Noachian to Early Hesperian in age and slightly older than the ridged plains material (unit Hr) of Hesperia Planum. Two possibilities exist for the ages of dissected plains material: (1) dissected plains material is an older part of Hesperia Planum (as mapped by Greeley and Guest [1987]) that underwent a period of fluvial erosion, or (2) dissected plains material is a discrete unit (volcanic or sedimentary) that predates the ridged plains and was subject to extensive deformation and fluvial erosion.

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