AGE RELATIONSHIPS AND CHRONOLOGY FOR THE ORCUS PATERA REGION OF MARS

JESSE YOBURN
Geosciences, Franklin & Marshall College
Faculty Sponsor: Don Wise, Franklin & Marshall College

RODERICK YAZZIE
Crownpoint Institute Of Technology
Faculty Sponsor: Steven Chischilly, Crownpoint Institute Of Technology

INTRODUCTION

Discoveries of recent water and lava flows on the surface of Mars have renewed interest in radiometrically dating rock samples from specific locations on the planet. In order to choose these locations strategically, we need to constrain relative ages on Mars via superposition and cross-cutting relationships. We can then begin to relate Martian ages to absolute lunar ages through crater dating. In this study we examine the area from 176-190°W, and 2-21°N in the Elysium Planitia region on Mars (Figure 1). This area is interesting due to its varying terrain and apparent range of relative ages—older looking rough terrain combined with relatively young looking lava flows and fluvial channels (Marte Vallis). In addition, there are eolian features, tectonic wrinkle ridges, and the Orcus Patera depression. Here we first identify and map the units using characteristics such as albedo variation and observed texture. Next we determine the relative ages of these units where possible using cross-cutting and superposition relationships. Third, we test our stratigraphy by using crater counts to assign absolute ages to the units. Finally, we integrate all our age information in order to develop a better understanding of the regional geologic history.

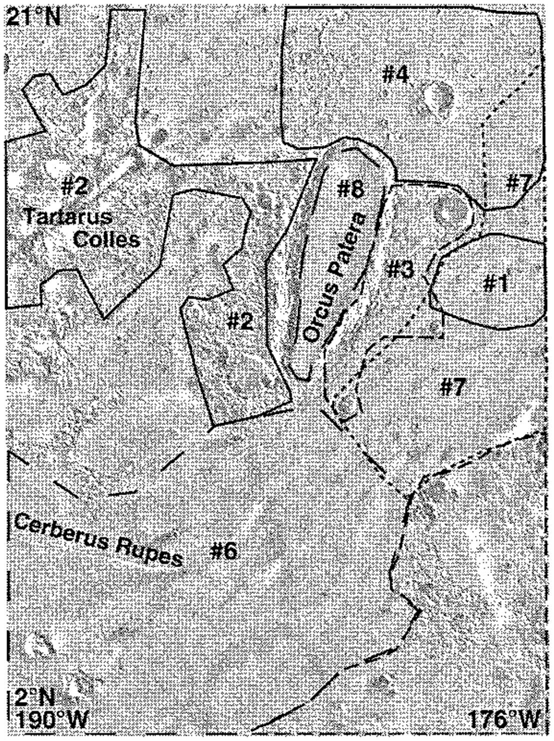

Figure 1. The 14° by 19° study area divided into the eight study areas, which are outlined using different dashes.

WHY USE CRATER COUNTING?

The only way to estimate ages on Mars is to compare it to other planetary bodies where absolute ages are known — namely, the Earth and Moon. The Earth is a rather poor comparative subject: there are only a few craters, and all of them are constantly being subjected to high erosion and burial rates which obliterate traces of the crater in a geologically short period of time. These processes are very weak on Mars and the Moon, and thus the Moon's high number of fresh craters makes it a better analogue for Mars than the Earth. We know absolute ages of some of the areas on the Moon because lunar missions of the late 1960s and early 1970s brought back rock samples for radiometric dating. These were used to derive a calibrated time scale curve for the Moon.

METHODS

Unfortunately, a direct correlation is difficult to draw between Mars and the Moon in terms of the number of craters hitting each body over the past few billion years (Hartmann, 1999). The two bodies differ significantly in mass (and therefore gravity), diameter, atmosphere, and proximity to the asteroid belt and sun. These factors directly affect how many bolides are drawn into the planet's gravity field and eventually end in a surface impact. A ratio can be set up, however, that attempts to take these factors into consideration. This ratio allows us to compare cratered areas on Mars that are statistically similar to cratered areas on the Moon, in terms of size and saturation per unit area. This ratio:

$$\boxed{R = \frac{\text{crater production at diameter D on Mars}}{\text{crater production at diameter D on the Moon}} \quad \text{(Hartmann, 1999)}}$$

has been under debate since the mid 1970s when the Viking orbiters transmitted the first clear pictures of Mars. Hartmann (1999) has taken all previous estimates into consideration and has concluded that $R \approx 1.6$ plus a factor of 2, or minus a factor of 3. This value is built into the equations used to create the age isochrons on Hartmann's graphs, which allow us to estimate absolute ages for our study area. Changing R due to new research or because of uncertainty changes the estimated ages.

In this study we performed crater counts in our study region by mapping and size-binning every visible crater in eight study areas on the 256 pixel/degree Viking digital image mosaic; we used this image base to ensure consistent resolution. Each of the eight areas exhibits relatively homogeneous cratering—i.e. a fairly uniform distribution of a particular size crater—and each was chosen within a different stratigraphic unit. Because of the crater homogeneity, we make the assumption that each individual area was last resurfaced quite rapidly.

RELATIVE AGE DETERMINATION

Moderate to low bombardment of small bolides and the smoothness of the area indicate a region that is relatively young. The knobby units (K) (Table 1) are remnants of a terrain that may have looked similar to the heavily cratered southern highland area of Mars and are one of the oldest features in the region. Using that information combined with the principles of superposition, we conclude that the knobby terrain units are older than the plains units. These knobs are part of a broader cluster that appear between the Elysium volcanoes and the Tharsis volcanoes. In determining the ages of the knobs in relation to each other, we could not successfully differentiate nor relate them.

Units	Definition	Explanation
B	Blocky material	Mesas, cuestas, and sharp ridges rising above plains units
C1	Irregular shaped Crater terrain	Rim and wall of Orcus Patera
C2	Crater Material	Materials of craters that are well defined and are >~20 km. Including ejecta, rims, and basin.
C3	Flank Material	Possible flanks of Orcus Patera
CH	Channel Terrain	Grooves resembling a channel formed by some sort of flow
K	Knobby/Hummocky	Rounded to sub angular hills forming rugged upland terrain. Mostly composed of knobs.
P	Plains	Smooth plains, but with more features (small knobs, craters, etc.)
Ps1	Smooth plains	Flat, light, feature-less surface at either high or low resolution.
Ps2	Basin of Orcus Patera	Resurfacing that may have formed from a different source

Table 1. *Geologic Units for the Orcus Patera region, sorted alphabetically. Units modified after Scott and Allingham (1976).*

Among the youngest features of the site are the plains units (Ps1, Ps2, P), which cover the low-lying areas of the knobby terrain units (K). The plains units may have originated through a common global resurfacing event that occurred in the northern lowland region of Mars (Frey et al., 1988), or perhaps the nearby Tharsis and Elysium volcanic region caused the resurfacing (Cattermole, 1996). A more plausible suggestion is both events caused the resurfacing in the region, but at different times in the planet's history. The first event may have occurred on a mass scale and the second event occurring regionally by either the volcanoes in the Elysium Mons region or by Appollinaris Patera. Our interpretation is that the (P) unit is a remnant of the first resurfacing event and therefore is the oldest plains unit. The unit's high crater density and increased surface imperfections in relation to the other plains units indicate that the surface was exposed for a significant period of time.

Orcus Patera is divided into three geologic units: Ps2, C1, C3. The first unit, Ps2, represents the basin inside Orcus Patera. The second unit, C1, represents the rim and interior walls of Orcus Patera, and the third, C3, represents the outer flanks. The channel terrain, CH, is interpreted to have formed from fluvial or volcanic flows that cut across the region. The sectional linear features, faintly appearing to the west of Orcus Patera, were not given a geologic unit because of their weak presence in the region.

RESULTS AND DISCUSSION

The geologic time units of Mars are based on periods and epochs. The periods, termed Noachian, Hesperian, and Amazonian, are grounded on rock sequences and represent major periods in geologic activity. They are divided into epochs: the Noachian and the Amazonian have three epochs (late, middle, and early), while the Hesperian has two (late and early). The geologic units in Table 2 go from youngest units on the left to oldest units on the right. Our interpretations are the geologic units and the placing of them in their correct context. As shown, our units go from Middle Late Noachian to Middle Amazonian.

Period	Epoch	Age range (GY)	Geologic Units
Amazonian	Late Amazonian	0.25-0.0	
	Middle Amazonian	0.70-0.25	Ps1 CH
	Early Amazonian	1.80-0.70	Ps2 C2
Hesperian	Late Hesperian	3.10-1.80	P C3 C1
	Early Hesperian	3.50-3.10	
Noachian	Late Noachian	3.85-3.50	B K
	Middle Noachian	3.92-3.85	
	Early Noachian	4.60-3.92	

Table 2. *Stratigraphic column. Periods, epochs, and age ranges derived after Hartmann and Tanaka in Tanaka, 1992.*

Crater counts in our eight areas (Figure 1, Table 1) are summarized in Table 3. Approximately 3 GY separate the calculated absolute ages of the oldest and youngest units.

Site	Primary Unit	Diameter Range (km)	Neukum & Wise (GY)	Hartmann (GY)
6	Ps1	1.2 - 21.3	0.6	0.8
1	P, CH	0.9 - 8.7	3.6	2.3
8	Ps2	0.9 - 9.9	3.4	2.5
7	P, CH	0.9 - 27.8	3.6	3.2
5	P, K	2.3 - 34.6	3.4	3.5
4	P	0.9 - 53.8	3.8	3.5
3	C1, C3	1.5 - 60.4	3.8	3.7
2	K	2.1 - 69.7	3.7	3.9

Table 3. *Calculated absolute age of each crater-count site (Hartmann 1999; Neukum and Wise, 1976) Neukum & Wise's age results have a ±10% error value. Table sorted by age based on the Hartmann-style results (Hartmann, 1999; Hartmann and Berman, 2000)*

Low crater counts normally translate directly to young relative ages. The youngest units are the plains (Ps1, Ps2) which correspond to areas 6 and 8, and unit (P), found in small amounts in nearly every study area. These younger units also cover the low-lying locations within the knobby terrain (K). The (Ps1) unit is a very smooth plain with little to no crater formations and a surface texture that is uniform and only very lightly cratered, suggesting an extremely young feature. It is presumed to be composed of volcanic material, which may have originated through a resurfacing event in the northern lowland region of Mars and/or from eruptions linked more directly to the nearby Tharsis and Elysium volcanic provinces. The knobby units (K), which correspond to area 2, are remnants of a terrain that may have looked similar to the nearby heavily cratered southern highlands of Mars; this unit is one of the oldest in the region. These knobs are part of a broader cluster that appear between the Elysium volcanoes and the Tharsis volcanoes, but the relative ages of individual knobs and known clusters could not be established.

The (Ps2) unit inside Orcus Patera is suggested by us to be a resurfacing event disassociated from the other events mentioned above, principally because the (Ps2) materials are spatially isolated by the high rim of Orcus Patera. The (Ps2) unit within Orcus Patera is thus inferred to have originated within and then slowly filled the basin (Tribbett and van der Kolk, 2001). The flanks of Orcus Patera (C3) and rim (C1) both coincide in location with area 3, whereas the channel terrain unit (CH) can be found in areas 1 and 7 (which themselves overlap).

Similarly, we expected areas 1, 7, and 8 to be very young because they closely resemble the southern section of the Marte Vallis channel (area 6). All are relatively smooth, and observed crater diameters are close to those seen in area 6. We were surprised by the absolute age results: most units look similar to area 6 in appearance, so we expected more units to be similar in age to that of 6. The resulting ages therefore tell us one of three things: (1) the areas are deceptively old, (2) there is a crater selection effect inducing error in our crater-counting technique, or (3) crater-counting techniques are not very accurate in areas with only a few small craters, as they deal ineffectively with the statistics of small numbers.

The final four areas are significantly closer to our expected ages. Areas 2, 3 and 5 are rough, hummocky terrain that we infer has not been recently resurfaced, as varying crater sizes are preserved—many of which would have been obliterated during a recent resurfacing event. Area 4 is not as hummocky as the others, but still yields an old age due to its high number of small craters. Some of these could perhaps be attributed to secondary impacts from larger nearby craters, a process that can yield an abnormally old age (Hartmann, 1999).

Overall, our crater count results agree with our relative age predictions. The CH, Ps1, and Ps2 units had young ages of 2.5 GY or under, and the C, P, and K units all resulted in ages between 2.5 GY and 3.9 GY. In Table 3, one can see a correlation between the diameter range of our crater-count regions and the ages calculated — smaller diameter ranges yielded younger ages. This is explained by simple statistics — larger impacts happen less frequently, so any area with one or more large craters is an older surface than one with only small craters.

CONCLUSIONS

Our absolute age calculations yield older ages than expected overall, although they agree in terms of sequence with our relative age evaluation. The majority of our units fall within the middle Noachian to late Amazonian periods. We feel that Hartmann's technique for crater counting yielded more reliable ages than Neukum and Wise's method, especially when the area being studied had a small range of crater diameters. Hartmann's technique uses a lunar production curve that encompasses all previous research on the subject, whereas Neukum and Wise used only their own lunar production curve. Our data show that areas with a wide range of craters are older than areas with all craters nearly the same size, which is statistically logical. Overall, our study region appears to have a mixture of very young and very old surfaces; we find that the rough and knobby area on the west side is < 3.5 billion years old, and the smooth units to the south and east of Orcus Patera are likely to be between 500 million and one billion years old.

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