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.

METHODS

After using characteristics such as texture and albedo in Viking images to define and map the different units, we used cross-cutting and superposition relationships to establish a relative age sequence. Then, to constrain absolute ages, we collected impact crater size-frequency data to compare with published isochrons [1-3].

Crater-Counting Procedure: It is difficult to correlate the number of craters that should have formed on Mars and the Moon over the past few billion years [1]. The two bodies differ significantly in mass (gravity), diameter, atmosphere, and proximity to the asteroid belt and sun. These factors affect how many bolides are drawn into each planet’s gravity field, eventually producing a surface impact. 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), we use the ratio $R = \frac{\text{CP}(D)_{\text{Mars}}}{\text{CP}(D)_{\text{Moon}}}$, where $\text{CP}(D)_{\text{Mars}}$ is the crater production rate for craters of diameter $D$ on Mars and $\text{CP}(D)_{\text{Moon}}$ is the equivalent production rate for craters of diameter $D$ on the Moon. Recently, a study taking all previous estimates into consideration concluded that $R \approx 1.6$ plus a factor of 2, or minus a factor of 3 [1].

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: 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.

The (Ps2) unit is inside Orcus Patera and 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 (Ps2) is thus inferred to have originated within and then slowly filled the basin [4]. 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).

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

<table>
<thead>
<tr>
<th>Site</th>
<th>Geological Unit</th>
<th>Neukum &amp; Wise (GY)</th>
<th>Hartmann (GY)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Ps1</td>
<td>0.6</td>
<td>0.8</td>
</tr>
<tr>
<td>1</td>
<td>P, CH</td>
<td>3.6</td>
<td>2.3</td>
</tr>
<tr>
<td>8</td>
<td>Ps2</td>
<td>3.4</td>
<td>2.5</td>
</tr>
<tr>
<td>7</td>
<td>P, CH</td>
<td>3.6</td>
<td>3.2</td>
</tr>
<tr>
<td>5</td>
<td>P, K</td>
<td>3.4</td>
<td>3.5</td>
</tr>
<tr>
<td>4</td>
<td>P</td>
<td>3.8</td>
<td>3.5</td>
</tr>
<tr>
<td>3</td>
<td>C1, C3</td>
<td>3.8</td>
<td>3.7</td>
</tr>
<tr>
<td>2</td>
<td>K</td>
<td>3.7</td>
<td>3.9</td>
</tr>
</tbody>
</table>

Table 1. Calculated absolute age of each crater-count site, following the methods in [1,2]. Neukum & Wise’s age results have a ±10% error value. Table sorted by age based on the Hartmann-style results [1,3].

In terms of relative ages, the absolute age information, in agreement with relative dating results, suggests that the knobby terrain units (K) are older than the plains units (P, Ps1, Ps2). 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.

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 are 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 craters sizes are preserved—many of which would have been obliterated during a recent resurfacing event. Area 4 isn’t 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 [1].

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 a billion years old.