Journal of Scientific Exploration, Vol. 13, No. 3, pp. 401–412, 1999 0892-3310/99

Geomorphology of Selected *Massifs* On the Plains of Cydonia, Mars

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Abstract — Mars exhibits a remarkable hemispherical dichotomy that divides the planet into smooth, relatively sparsely-cratered, lowland plains and rough, heavily-cratered upland terrains. At some places along the boundary between the two, there exist fields of isolated *massifs* that appear to be erosional remnant outliers of the dichotomy boundary scarp. In recent high-resolution images (4–5m/pixel) acquired by the Mars Orbiter Camera (MOC), these isolated *massifs* appear to have been subjected to at least several erosional and depositional process regimes, and appear to exhibit grossly layered structures. The geomorphically muted appearance of these *massifs,* the apparent presence of superjacent sediment "drapes" and their scattered planimetric distribution are evocative of terrestrial submarine and sub-lacustrine isolated *massifs* (of a variety of origins) seen in bathymetric imaging. Recently acquired MOC images of the famous "Face on Mars" *massif,* first identified in Viking Orbiter images, reinforce its interpretation as an unremarkable individual within a field of isolated *massifs* in Cydonia.

Keywords: Mars — Cydonia — planetary geomorphology — Mars hemispherical dichotomy — submarine processes — "Face on Mars"

Author's Comment

On July 31, 1976 the Public Information Office (PIO) at the Jet Propulsion Laboratory (JPL) issued the following statement as part of a press release describing a rather bland and unremarkable Viking One Orbiter image of a part of the martian northern plains called Cydonia. The caption read, "...the picture shows eroded mesa-like landforms. The huge rock formation in the center, which resembles a human head (my emphasis), is formed by shadows giving the illusion of eyes, nose and mouth." (National Aeronautics and Space Administration, 1976). Scientists and press assembled in the Viking Press area that morning noticed the peculiar feature with some humor. The fortuitous position of a "bit hit" (*i.e.,* data drop in which the pixel values are set to zero or black) was in the position of the left nostril, strongly enhancing the illusion (Figure 1). Not to be outdone, those of us on the Viking Lander Imaging Flight Team asserted that we could discern the initials of every Team Member embossed on the large "Big Joe" boulder perched on the surface of Mars, just a meter or two away from the Viking One Lander.

Both Viking teams, and the public at large, were absolutely entitled to see faces, letters, or whatever else came to mind, as we looked at these pioneering images. There is an ancient and time-honored tradition of man anthropomorphizing nature, probably beginning with the Man in the Moon. It was good fun, and that was the spirit that moved us at the time. Little did we imagine the ruckus that would follow, and the "...cottage industry..." that would develop (Malin, 1995), as some observers astonishingly elevated the humble crumbling mesas and buttes of Cydonia to the status of putative intelligently sculpted artifacts. Those of us who had first looked at the images could see no logical basis for these hypotheses, even though many of us (including me) were then, and are now, strongly predisposed toward the Search for Extraterrestrial Intelligence (SETI) investigations. Finally, the ludicrous allegations of conspiracy and data suppression that followed over the years were particularly galling and scurrilous. Those of us on the Viking Orbiter and Lander Science Teams would have liked nothing more than to trumpet to the world the discovery within our data of the evidence of an extraterrestrial civilization, but we just didn't see it. I firmly believe that someday — in this solar system or in some other — man will inevitably encounter such evidence, but for me, the "Face on Mars" is not it.

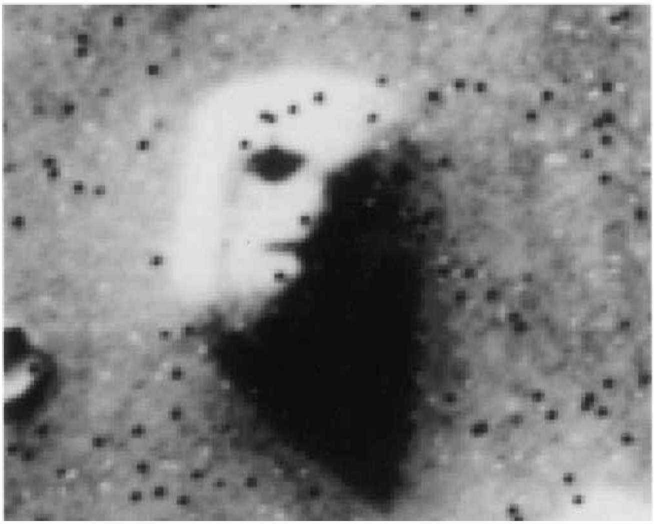

Fig. 1. The famous "Face on Mars" picture, cropped from the original JPL Press release photograph (Viking 1-61, P-17384 (35A72), July 31, 1976). Note the fortuitous black pixel "bit-hit" that suggests the presence of a left "nostril." The black and white pixels seen in this picture are examples of so-called "salt and pepper" noise that was later removed using adjacent pixel average techniques. Feature is 1.5 – 2 km across. Courtesy NASA/JPL.

Introduction — Scope of the Problem

"The devil is in the details..." –anonymous

One of the most remarkable aspects of the geology and geography of Mars is its hemispherical dichotomy — a southern hemisphere mainly filled with ancient (3–4 billion years old) heavily cratered, rough terrain, and a northern hemisphere mainly filled with relatively smooth terrain and relatively uncratered plains and volcanic constructs. These two global landform regimes have very likely resulted from vastly different processes, geologic histories, and contrasting martian surface environments. Furthermore, the interface between the two kinds of terrain may yield important clues as to the constitution of both (Sharp, 1973).

The resolution of the origins of the northern plains and the genesis of the "transitional" region between the two zones is an outstanding question of martian geology. Since the return of digital imagery data from the Mariner and Viking spacecraft in the 1970's, planetary geologists have predominately speculated that the martian plains were probably formed by the eruption of relatively low-viscosity mafic lava. It is speculated that they are the result of inundation of low areas by many thin lava flows, in a fashion similar to the process that is thought to have created the lunar maria (Wilson & Head, 1983). More recent theories have proposed that the northern martian plains are the abyssal plains of an ancient ocean bottom, or possibly even the ocean itself, now frozen solid (Parker & Banerdt, 1998). Both of the latter theories are consistent with very recent Mars Orbiter Laser Altimeter (MOLA) measurements that show the northern plains have relaxed to follow the shape of the Mars equipotential geoid (Head *et al.*, 1998). That is, the plains' average surface is approximately perpendicular to the local gravity vector — in other words, dead flat. This flat topography is consistent with that of oceanic abyssal plains (Heezen & Tharp, 1977).

The so-called "transitional boundary," the zone in which the Cydonia "Face" lies, and which is the focus of this short note, consists of a variety of landforms. They range from isolated *massif*s, mountains, or mesas with large flat inter-mesa (lightly cratered) plains to the "fretted terrains" (Sharp, 1973) which are basically a series of mesas separated by *graben* (*i.e.,* down-faulted troughs). It is also throughout this zone that Tim Parker and colleagues (Parker *et al.*, 1993) have claimed to have identified "shoreline" features. These narrow linear features are similar to the ancient strand lines visible along the edges of what was once Pleistocene Lake Bonneville (14,000–32,000 years ago). Strand lines occur at different levels, representing at least four stable lake levels over that time. The giant lake formerly covered a large area of Utah and parts of Idaho and Nevada, leaving behind the Great Salt Lake, Utah Lake, and Sevier Lake as remnants. Other geomorphic features associated with Lake Bonneville are a class of mesas that exhibit "wave-cut benches" (Parker *et al.*, 1993). The "bench" or circumferential flat apron surrounding a central hill represents the progressive wave erosion of an inundated hill or *massif*, at the level of the lake. Such erosion occurs also in the open ocean, eventually planing off the sub-aerial summits of submarine volcanoes. This results in a near-surface shoal, or *guyot*, just below sea level, upon which coral reefs can grow. The search for comparable features on Mars by proponents of the "Mars ocean" theory has really just now begun in earnest with the advent of new high spatial resolution Mars Global Surveyor Camera imaging data (Malin *et al.*, 1998) (Figure 2). Nevertheless, the possibility of an ancient ocean on Mars may well be part of the unfolding story of the "transitional boundary" and the Cydonia *massif*s.

The purpose of this short note is to describe the geomorphological appearance of isolated *massif*s in Cydonia, to comment on their geological context, and to provide some informed speculation on their origin(s).

Geomorphology of Isolated *Massifs*—What Do We Know About Examples on the Earth?

The word *massif* originates from the French term with a rough translation of "mountainous mass." In geological use, the term can refer to multiple peaks, groupings of isolated mountains or to single isolated mountains, which are generally less common (American Geological Institute, 1976).

On the earth, such mountains or *massifs* can take a variety of forms and can have a variety of origins. In areas with humid climates (*e.g.* Africa, South America, Europe) isolated hills are often rounded blocks or solid rock that can

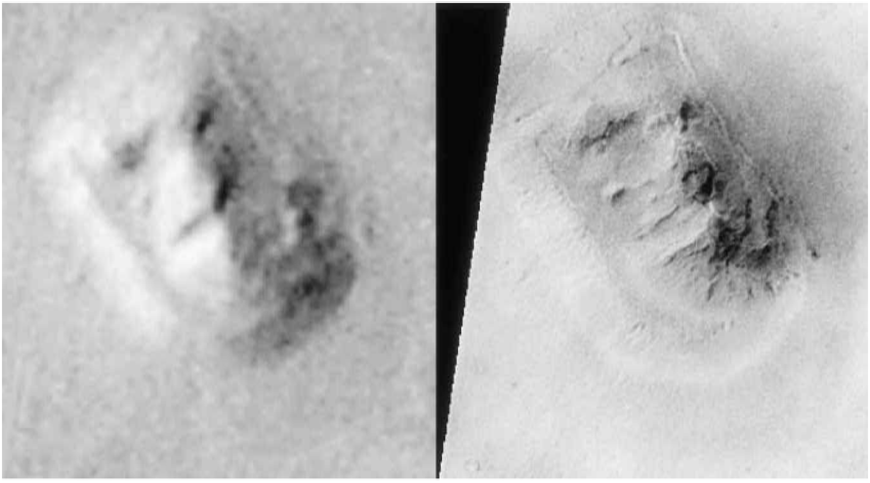

Fig. 2. Shown here is a comparison between Viking Orbiter 1 frame 070A13 of the "Face on Mars" that has had noise-removal and contrast enhancement, and MOC frame 22003 of the same feature. The MGS image has been contrast reversed for correct shadow orientation, and contrast enhanced and geometrically corrected. Courtesy of MSSS/NASA.

protrude from surrounding plains. Such features are often called *inselbergs* or "island mountains." Generally, they result from long-term weathering (chemical and mechanical decomposition) of very durable rocks, mostly granites or other types of igneous rocks. In these kinds of terrains, the more vulnerable parts are weathered down into soils to some considerable depth, but the more resistant (less weathered) individual areas stand up as *inselbergs*.

Another kind of sub-aerial erosional *massif* that is often seen in the American Southwest deserts is the *mesa*. Generally, these features are flat-topped islands that stand hundreds of feet above the flat surrounding desert. Monument Valley is a classic type-example of a group of such mesas (Figure 3). Cut into the red Cutler Formation in the Four Corners area of Arizona, Utah, Nevada, and Colorado, the mesas are the remnant of a high surface of the Colorado Plateau. In ancient times, the plateau experienced a broad or "epeirogenic" uplift, which increased erosion of the flat lying (originally shallow marine and eolian) sandstones. More resistant layers in some areas have protected softer underlying sandstones, resulting in a sturdy cap-rock overlying friable, rubbly sandstone that weathers out into sloping scree deposits. Sometimes the layer-cake-like affair is weathered to the point where the overlying protective

Fig. 3. Subaerial erosional remnants ("buttes") in Monument Valley, Arizona in the Southwest United States. The Permian de Chelly Sandstone is the cliff-forming layer, capped by the Moenkoepi shale which is protected by remnants of the Shinarump Conglomerate. All of this overlies the more friable Organ Rock Shale (Cutler red beds) expressed as a basal slope-forming layer. The more coherent cliff-former provides a shield, or caprock, that allows the softer sloped layer to persist. Elsewhere throughout the adjacent landscape, the erosion has completely removed the entire stratigraphic section. Note that the morphology of these buttes is controlled by the lithologic contrasts between the stratigraphic layers, which is also likely to be the case in similar features on Mars, such as in Cydonia. Such lithologic contrast implies the potential for strong environmental contrasts as a function of time, and complex sedimentological facies.

cap-rock is only a pinnacle. In Monument Valley, this is a common occurrence, producing spectacular rock formations of high interest to tourists and artists.

Isolated hills also are often found in lacustrine and marine geologic environments. In the ocean, deposits from adjacent sub-aerial continental and near-shore areas (*e.g.,* debris flows, landslides) can be seen in bathymetric imaging data. On abyssal plains, there are many scattered hill-like features of indeterminate origin. In zones of volcanic activity, conical flat topped guyots can be seen reaching almost up to sea level, and are generally extinct or dormant undersea volcanoes. In deep lakes, such as Lake Tahoe on the Nevada-California border, similar features can be discerned, probably tied to sub-aerial mass-wasting processes (*e.g.,* landslides, slumping) that have deposited material out onto the lake bottom away from shore (Figure 4).

Geomorphology of Martian *Massifs* — What Can we Observe from Examples on Mars?

Isolated *massif*s, ranging in size from very small (<100meters across) to moderate-sized ($1 - 10$km across) are visible in a zone (delineated by Mutch *et al.* (1976) as a great circle inclined at about $30^{\circ} - 35^{\circ}$ to the equator) that surrounds much of the northern plains of Mars. It appears that this zone of *massif*s has been generated, in part, by the fracturing and equator-ward recession of a 2–3km thick (probably heavily brecciated) layer of martian crust comprising of mostly ancient, heavily-cratered terrain. The manifestation of this dual lowland-upland terrain suite has been termed the "martian crustal dichotomy"

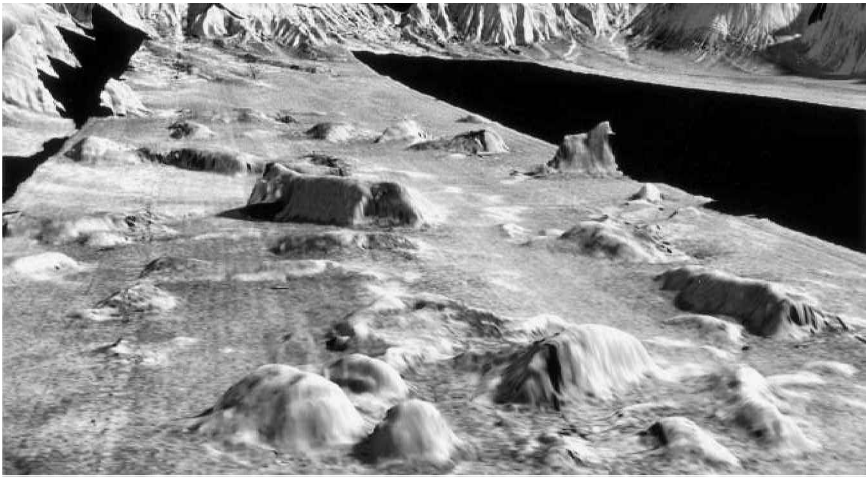

Fig. 4. Bathymetric imaging from the floor of Lake Tahoe, California. The image shows a field of isolated blocks of the order of 100m in characteristic dimension. The sub-aqueous depositional environment tends to soften the observed morphologies, qualitatively resembling many of the morphologies seen in the Cydonia region. From Gardner *et al.* (1998).

(Hartmann, 1973) and is perhaps the most important basic geological and geomorphological feature on Mars.

A variety of morphology is displayed along this boundary. Part of the boundary is somewhat subtle, with little apparent topographic discontinuity, where presumably younger lava or sedimentary deposits on-lap the boundary into more heavily cratered terrains. At other places, like the Cydonia region, the boundary is formed by a series of scarps that represent the fractured edge of the highland cratered terrains. It is this part of the boundary that frequently has isolated *massif*s associated with it.

Guest *et al.* (1977) suggested that the formation of the "knobby terrain" in Cydonia was accomplished by an areally extensive erosional process that removed overlying cratered plateau material. The remnant, lower plains then consisted of exhumed parts of older cratered terrains, along with more erosion-resistant igneous intrusive bodies and/or remnants of cratered plateau units. Their discussion tends to suggest an areally contemporaneous formation process. In some zones, however, *massif*s tend to occur most frequently right at the edge of the fractured or "fretted" terrain, and tend to decrease in frequency of occurrence as one moves away from the boundary into the plains. The *massif*s themselves tend to become smaller and more widely spaced, lower, and exhibit morphological "softening" as one transits away from the highland-plains boundary out into the low-lying plains. Such progressive changes toward a more diminutive and softer *massif* presence suggests at least either (a) progressive southward recession of the main scarps, (b) the action of a process that changes in erosional or depositional intensity as a function of distance from the scarp, or (c) a combination of both. Whatever the processes or sequence of processes were involved, it is clear that near the highland-lowland dichotomy boundary in Cydonia, these processes operated more-or-less in concert on materials that were of more-or-less similar composition and stratigraphic structure, producing a correspondent and consistent suite of landforms over an area of millions of km^2.

This overall uniformity and consistency is an important observation in the "Face on Mars" discussion. By singling out the "face" *massif*, there is an implicit implication that the "face" in Viking Orbiter imaging appears special, and thus deserves to be scrutinized separately from other nearby features. In fact, the "face" *massif* in Viking Orbiter images is an undistinguished feature, very similar in overall appearance to many other isolated *massifs* in the region. Thus, as an individual geomorphic feature, the "face" *massif* is rather unremarkable.

Viking Orbiter images of the Cydonia area, taken at relatively low spatial resolution ($40-500$m/pixel) reveal a variety of smooth-surfaced hills, widely separated by relatively flat and bland-appearing inter-hill plains material (Figure 5). The overall impression is that of a "blanketing" by a layer or layers of some sort of fine-grained deposit or sediment. The MOC images acquired recently, at much higher spatial resolution ($4-5$m/pixel) show these hills to be somewhat more rugged, and though a blanketing layer appears to be somewhat more discontinuous, it is definitely seen in these images, as well. Detail in the MOC images hints that these hills have undergone a variety of erosional and depositional processes (Figure 6).

Geomorphically, the famous “face” *massif* clearly appears to have undergone mass wasting or “landsliding.” It also appears to have been buried by previous deposition, and this deposition appears to have occurred in at least three discrete layers. Geologically speaking, the *massif,* itself appears to be composed of two major structural parts. They are: (a) an upper zone that appears friable and which has undergone substantial erosional alcove formation, probably mainly by landsliding, and (b) a stratigraphically lower and more substantial (probably mechanically more coherent) shelf-forming unit that is embayed circumferentially by either scree deposits or the remnants of a superposed sediment “drape.” An additional thin (< 50m thick) “drape” deposit appears superposed over the lower drape and the original *massif*, and subsequently to at least some of the erosional degradation. The layering and contrasting mechanical competence/incompetence is very common in a variety of mesas and buttes within sub-aerial landscapes of the American Southwest, as mentioned before. Typically these features are composed of fine-grained eolian and marine sandstones with greater or lesser degrees of calcareous or siliceous inter-

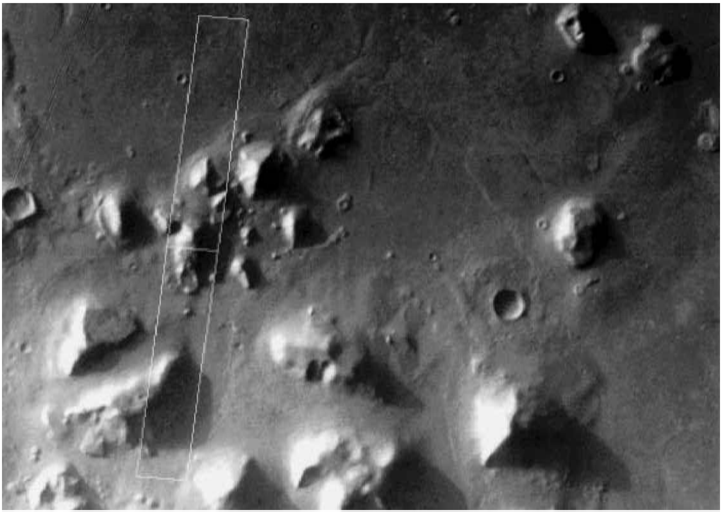

Fig. 5. This MGS targeting image shows the area in Cydonia southwest of the "face" feature (upper right corner). Compare with the overall appearance of Figure 4. The terrain overall appears to be softened or blanketed, and to have been subject to a variety of erosional and depositional process. Some of those processes may have been subaerial (*e. g.,* eolian erosion) however, the depositional blanketing, along with MOLA topographic data, and the presence of putative shorelines, may all be consistent with a submarine phase. White graphics box is a MOC high-resolution targeting footprint. Courtesy of JPL/NASA and MSSS/NASA.

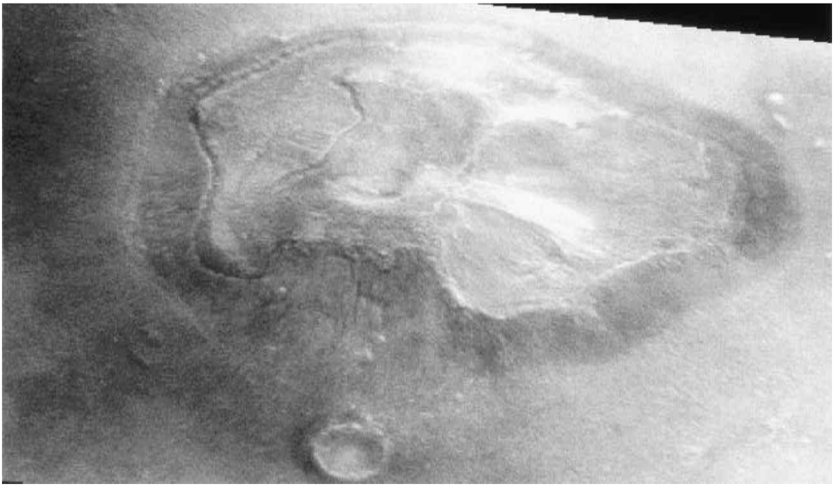

Fig. 6. Closeup of another nearby massif in Cydonia. This feature is approximately 2km across and 100-200m high. Note, as in the "face" massif, the multiple layering and the appearance of a draped layer. This feature also suggests a relatively complex erosional and depositional environment, possibly as the result of surface environmental changes over time. Courtesy MSSS/NASA.

grain cementation, susceptible to a variety of mechanical and chemical (usually aqueous) sub-aerial erosional processes. Drape deposits are often seen in submarine and lacustrine deposits on the earth, in areas where sedimentation rates are high, such as in the Mississippi pro-delta (*e.g.,* Nummedal & Prior, 1981).

Interpretation and Conclusions — What is Going On?

The *massifs* of Cydonia are exciting features. The geological excitement stems not so much from any anthropomorphic allusions, but rather from the details of sedimentation and erosion visible in the newly available MGS high resolution frames provided by the Malin Space Science Systems MOC camera. Such image data suggest a complex formation history, and a complex post-formation depositional and erosional history.

Most significantly, taken as a group, these features appear to have at least a qualitative morphological affinity with terrestrial submarine or lacustrine features. The (a) softened, relatively non-angular appearance, (b) the evidence of substantial mass wasting, (c) the lack of any apparent rilling even in high spatial resolution images, (d) draped morphology of superjacent thin sedimentary layers, and (e) the shelf-like morphology of the basal geologic layer are all qualities consistent with these *massifs* having been at least modified in a sub-aqueous (as opposed to sub-aerial) environment, that could have been marine, lacustrine, or possibly littoral (*i.e.,* near shore) (Figures 7a,b). While individual *massifs* may exhibit some or all of these qualities, a more compelling case is made when the isolated *massifs* are assessed as a group, in which the described morphologies are repetitive and reinforcing.

Clearly, such an interpretation based on a qualitative assessment of photogeologic and topographic evidence is necessary but not sufficient to establish the argument of a marine period in martian history. It is, however, possibly another piece to the puzzle. An extensive quantitative morphometric comparison

Fig. 7a. Topographic model of "face" *massif* constructed by Malin Space Science Systems using "shape from shading" photoclinometric techniques applied to Viking Orbiter data. When three-dimensional height models such as are available, they may provide important information on feature geomorphology. Courtesy MSSS/NASA

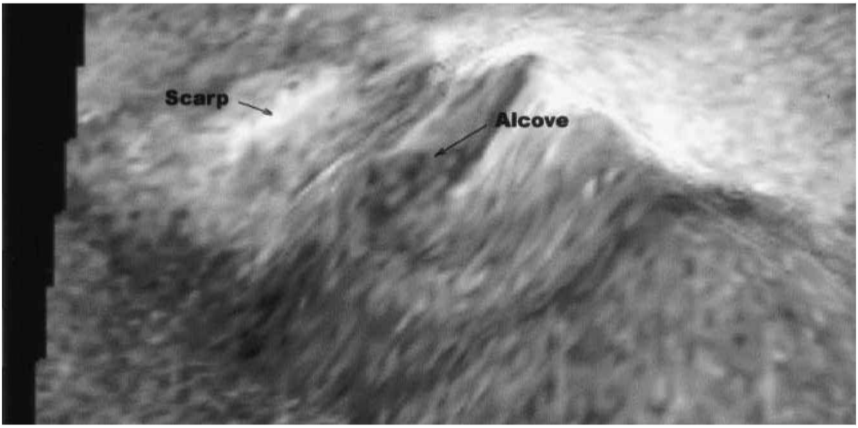

Fig. 7b. MOC MGS image of "Face" *massif* draped over height model from Figure 6 with approximately the same perspective. Image processed by author. The main utility of such "image drapes" is to try to correlate planimetric morphologies with topographic scene elements. Here both a scarp (mid left) and a landslide alcove (center) can be positively associated with topographic features. More detailed MGS-provided topography will allow better, more precise image drapes as the mission progresses.

with terrestrial marine features, taking into account gravity scaling and distribution of spatial frequencies within individual features and within the group would provide a more definitive comparison, but is beyond the scope of this short paper. Such further work, however, is suggested by the initial observations made here.

Taken in a larger context, the marine analogy for the Cydonia *massifs* tends to be consistent with other recent findings from the Mars Global Surveyor. For instance, recent Mars Orbiter Laser Altimeter results show that the degree of correspondence of the northern martian plains to the geoid is consistent with the plains having been abyssal. Likewise, Head *et al.* (1998) have revisited putative shorelines mapped by Parker *et al.* (1993). They've concluded that at least the lowest mapped shoreline, when topographically compared to the martian plains datum, is consistent with having been formed by a standing body of water (*i.e.,* shallow ocean). In that context, the isolated *massifs* in Cydonia, along with other such features along the great martian dichotomy boundary, could provide important clues to an ancient martian marine environment, now only dimly perceived or appreciated. The implications for related issues regarding the possibility of martian biogenesis are manifest.

Acknowledgement

This work was carried out by the author, in part, at the Jet Propulsion Laboratory under a Comparative Planetology contract with NASA. Additional support was provided by the NASA Advanced Concepts Program. The author thanks Michael Abrams for his review and comments.

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