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One Mars Year: Viking Lander Imaging Observations

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On 7 June 1978, the Viking 1 lander (VL-1) had been observing the surface of Mars at Chryse Planitia for one complete Mars year; on 22 July, the Viking 2 lander (VL-2) completed one Mars year at Utopia Planitia. During the 669 sols, or Mars solar days, comprising this first Mars year, the landers' camera systems documented a variety of changes in the appearance of the two sites. These changes, which included the results of wind-induced entrainment of sediment and of a close interaction between the processes of soil redistribution and condensate formation, have provided the first indications that, on a yearly average, the landing sites are subject to continuous modification.

Summary. Throughout the complete Mars year during which they have been on the planet, the imaging systems aboard the two Viking landers have documented a variety of surface changes. Surface condensates, consisting of both solid H_2O and CO_2, formed at the Viking 2 lander site during the winter. Additional observations suggest that surface erosion rates due to dust redistribution may be substantially less than those predicted on the basis of pre-Viking observations. The Viking 1 lander will continue to acquire and transmit a predetermined sequence of imaging and meteorology data as long as it is operative.

All four cameras, two on each lander, continue to function at the time of this writing. Three types of imaging sequences have been acquired, and continue to be acquired, by the landers' cameras in the search for surface changes. The first type consists of monitoring selected areas on a time scale of tens of sols to detect any changes that might signal the onset of dust redistribution, formation of surface condensates, or other unanticipated phenomena. The second consists of reproducing images taken early in the mission, utilizing the same solar lighting geometry and thus minimizing shadowing and photometric differences. Such identically illuminated pairs of images, spaced over the greater part of a Mars year (*1*), permit computer image comparisons that are sensitive to subtle physical or albedo changes which might otherwise be undetectable. Although this procedure has sometimes been complicated by differing amounts of atmospheric dust, most "repro" images duplicate primary mission images—both being acquired at nearly identical low optical depths (*2*). The third type of sequence consists of inhibiting a camera's azimuthal stepping motor so that it repeatedly images the same vertical line. Since this "rescan" capability makes the camera a motion detector (*3*), it has been used to search for particle transport by the wind (*4*).

The VL-1 landed 16 sols and the VL-2 59 sols after northern summer solstice (*5*). As the spacecraft imaged the two sites during the ensuing northern summer, they were unable to detect any naturally occurring surface changes (*3*). The only dynamic changes, observed by both landers, were fluctuations in the atmospheric optical depth from about 0.2 to 0.6; these were attributed to varying amounts of suspended particulate material in the atmosphere above the landers and to morning ground fogs, which resulted from the condensation of H_2O on suspended dust particles (*6*). It was inferred (*7*) that the atmospheric dust visible during the summer either remained from previous dust storms or was transported from other locations, because during this period there was no observable wind-induced dust movement in the vicinity of either lander (*4*).

Pollack *et al.* (*8*) discuss in some detail the atmospheric phenomena observed during the following seasons. Both landers recorded two substantial peaks in the optical depth, which Pollack *et al.* correlate with the northerly extensions of two separate global dust storms. These storms were observed by the Viking orbiters as having originated in the middle southern latitudes (*9*). The initial increase in optical depth due to the first storm can be bracketed between VL-1 sols 209 and 210 (aerocentric longitude L_s = 207° to 208°) and VL-2 sols 160 and 173 (L_s = 204° to 212°). The first indications of the second storm occurred between VL-1 sols 311 and 314 (L_s = 273° to 275°) and VL-2 sols 257 and 269 (L_s = 266° to 274°). After rapidly reaching a maximum several sols after the initial increase, the optical depth during both storms slowly declined over a period of many tens of sols.

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Changes at the Viking 1 Lander Site

The first significant surface change occurred between VL-1 sols 74 and 183 (*10*). It consisted of an isolated slump of a fine-grained surface layer in the vicinity of a large rock (called "Big Joe") about 8 meters from VL-1 (Fig. 1). Slumping of a homogeneous plastic material on a slope occurs when shear stresses, resulting at depth from the weight of overlying material, approach the plastic yield strength of the material. Initial failure occurs along the surface of maximum shear stress and generally results in a rotational slump face with a lobate downslope deposition of material. However, the soil slump near Big Joe, rather than leaving a rounded depression, exposed a new surface approximately parallel to the original surface. This strongly implies that the slippage did not occur by simple plastic failure. Instead, the failure occurred along a boundary between materials with different physical properties—in this case an accumulation of sediment 0.5 to 1.0 centimeter thick overlying more cohesive material (*11*). The slump may be related to a number of isolated cracks in the soil, which can be seen extending to the distance of Big Joe in a number of locations. Much of the kinetic energy released during landing must have been partitioned into the shaking and fracturing of material in the vicinity of the lander. It seems probable that the slump is indirectly related to the touchdown of the lander, and that a subsequent disturbance triggered the actual slump.

A wide variety of processes can trigger slope failure in unstable material. In the Mars environment, wind gusts, thermal variations, frost formation, and seismic activity seem equally plausible. The VL-2, on the opposite side of the planet, observed a possible seismic event during the period when the slump occurred (*12*), but there is no way to correlate these events. Another possibility, that fines which had accumulated on the top or side of Big Joe fell to the surface and triggered the slide, has been rejected because images taken before and after the slump show no change in the material clinging to the rock's surface. No change in the slump has been detected since its initial formation, nor have any similar changes been observed.

However, the slump has shown that at

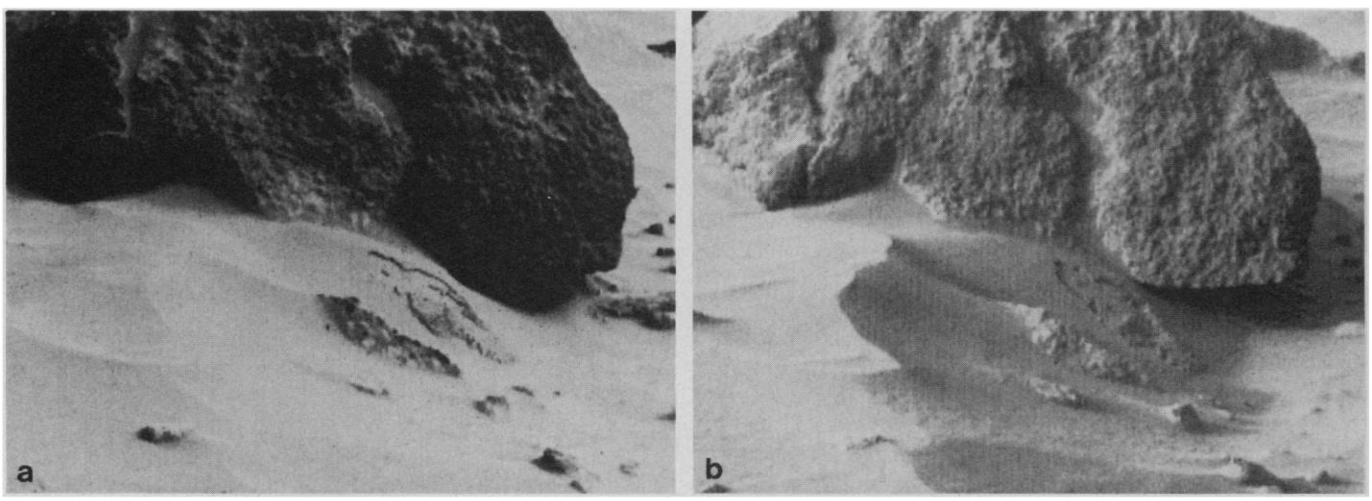

Fig. 1. Two views of a soil slump at the base of a large rock 8 m from VL-1. (a) Image acquired shortly after its initial discovery (image 11 C162, sol 239, local lander time 10:00), and (b) a more recent image acquired with more oblique lighting (11H083, sol 583, local lander time 17:52). In the earlier image, the downslope tonguelike accumulation of material shows numerous small extensions, giving the appearance of a freely flowing unconsolidated material. In the later image, the crustlike appearance of the top layer is clearly shown. For before and after comparison images, see (*10*).

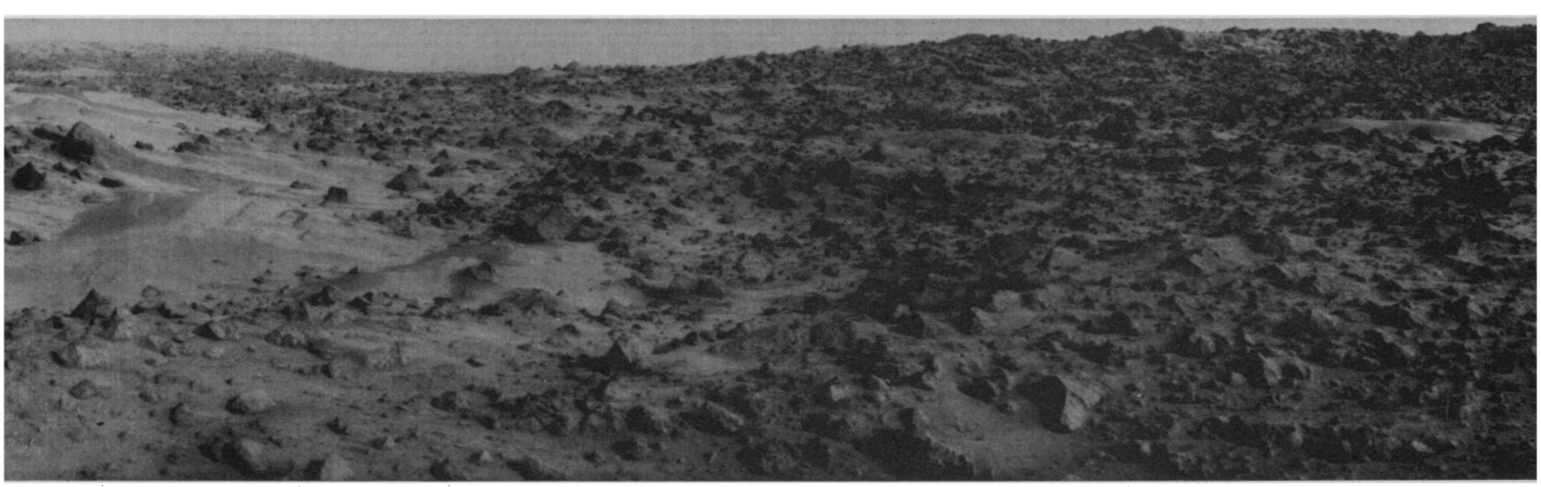

Fig. 2. Panorama (12F054, sol 400, local lander time 17:10) in front of VL-1 showing several of the important drift features at the site. On the surface of the isolated drift at the upper right there are two dark patches that were not present during the earlier part of the mission. They are interpreted as darker soil material exposed after wind removal of a thin (<< 1 cm) surface layer of bright dust. Additional areas of what appear to be equivalent darker soil beneath a bright dust cover are visible in the drifts in the left third of the images, although the appearance of these darker areas has remained unchanged throughout the mission. It is believed that similar dark material may underlie much of the drift deposits at the site.

least in terms of physical properties, the soil next to Big Joe is heterogeneous with depth. One possibility is that either the surface layer or the material immediately below the sediment layer developed a crust by some type of cementation of fines. This would not be completely unexpected since a duricrust layer has been described at both sites (*7, 13*).

Another surface change occurred between VL-1 sols 41 and 165. Two dark patches developed on the surface of a previously light drift located some 15 m from VL-1 (Fig. 2). The most plausible interpretation is that these patches are darker material exposed after wind removal of a thin (<< 1 cm) bright dust cover. Such removal could have occurred in only a few seconds once the threshold velocity was attained. Thus, we conclude that local wind gusts attained the magnitude needed to erode a light dust cover from the surface of this drift. This is the only clear-cut change at either site indicating that wind activity reached the threshold velocity required to initiate movement of surface fines that had been undisturbed by the lander.

Mutch *et al.* (*7, 14*) divided the dust drifts in the vicinity of VL-1 into two categories, light and dark, on the basis of a visual interpretation of the relative surface albedos of the drifts. The light drifts were most prevalent, blanketing about one-third of the landscape near VL-1. A single isolated dark drift was identified about 15 m from the lander. The change described above now suggests that a thin layer of bright dust may overlie much of the landing site, covering a deposit of darker material.

Figure 3 documents another wind-related change, within one of the three VL-1 footpads. During the final descent and touchdown, soil was entrained in the retrorocket exhaust. Some of the soil accumulated within the upwardly concave footpad and, as shown in Fig. 3, its position within the footpad has subsequently been significantly altered. Part of this material has been lifted up the interior wall of the footpad to form two delta-shaped patches spaced 180° apart. The appearance suggests that the redistribution of the dust was aerodynamically controlled and not due to lander vibrations. Only in the last image, Fig. 3d, where material in the left patch has slipped down the inner surface of the footpad, may the change have been caused by surface sampler activity and lander movement.

Changes at the Viking 2 Lander Site

The major surface change observed by VL-2 was the formation of a thin H_2O condensate layer, which lasted for more than one-third of a Mars year. The condensate has been related to the accumu-

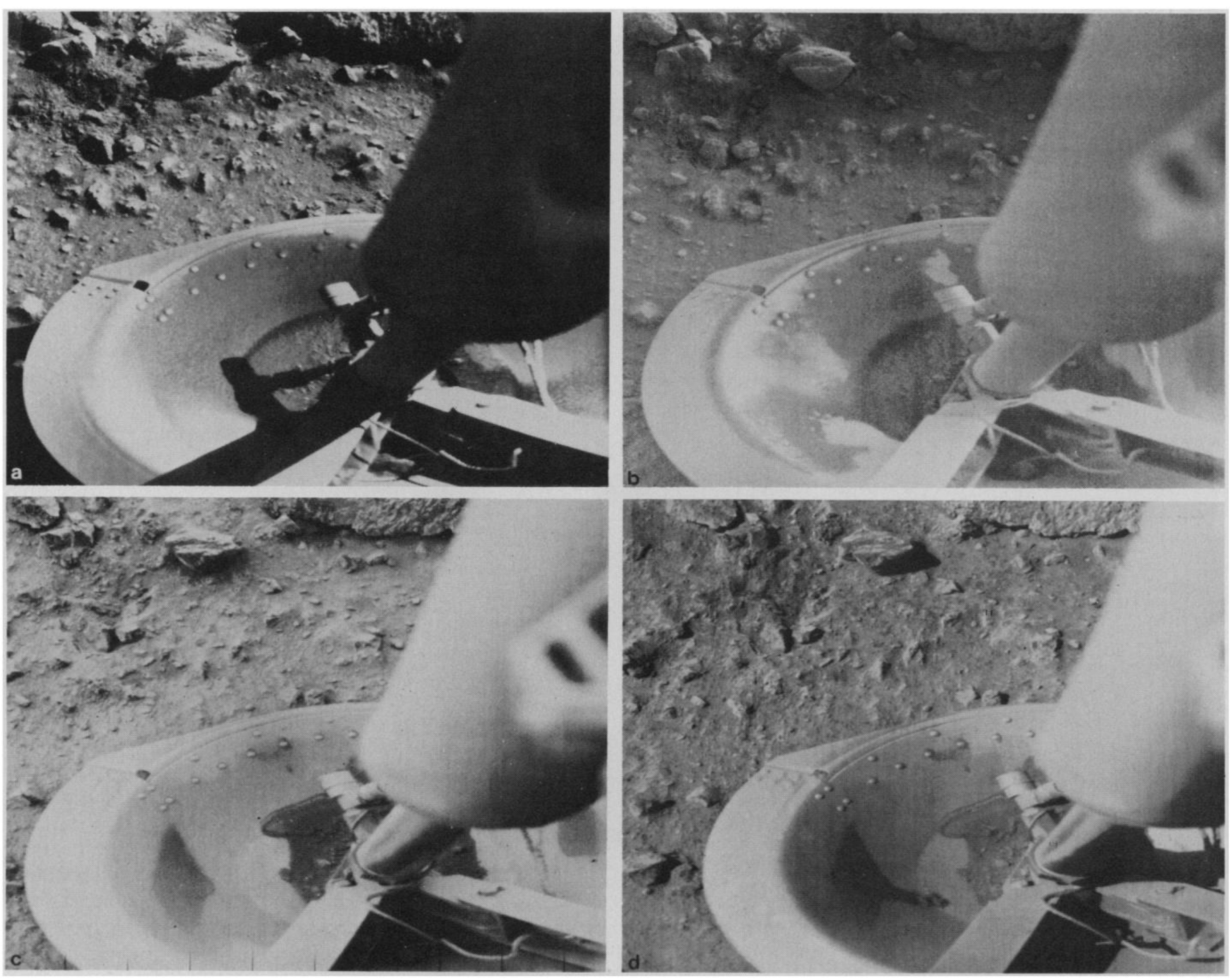

Fig. 3. Images (acquired throughout the mission) of one of the footpads of VL-1. These frames show a progressive redistribution by wind of soil material that accumulated in the footpad immediately after touchdown: (a) 12B017, sol 33, local lander time 15:03; (b) 12B244, sol 171, 17:30; (c) 12E062, sol 347, 10:00; and (d) 12H077, sol 580, 10:09.

lation of a thin bright dust cover at the site.

Using a thermal model based on early infrared thermal mapper results, Kieffer (15) predicted that, at the latitude of the VL-2 site, solid carbon dioxide—$CO_2(s)$—might form on the surface during the nights and rapidly disappear during the following mornings. Minimum winter temperatures (16) at the VL-2 site approached, and probably reached, the $CO_2(s)$ condensation point of about 151 K at 9 millibars. However, the observed behavior of the condensate that formed at the VL-2 site does not support a $CO_2(s)$ composition. Rather than the diurnal accumulation-disappearance cycle expected for $CO_2(s)$, the images indicate that the condensate thickness monotonically increased over at least 60 sols. Additional sequences (Fig. 4) spaced over many tens of sols clearly demonstrate extremely slow sublimation of the condensate as it returned to the gas phase. This behavior is inconsistent with either a $CO_2(s)$ (17) or a CO_2-clathrate (18) composition; the only plausible alternative composition is H_2O. However, as discussed below, $CO_2(s)$ may have played an additional role in precipitating H_2O-covered dust to the surface.

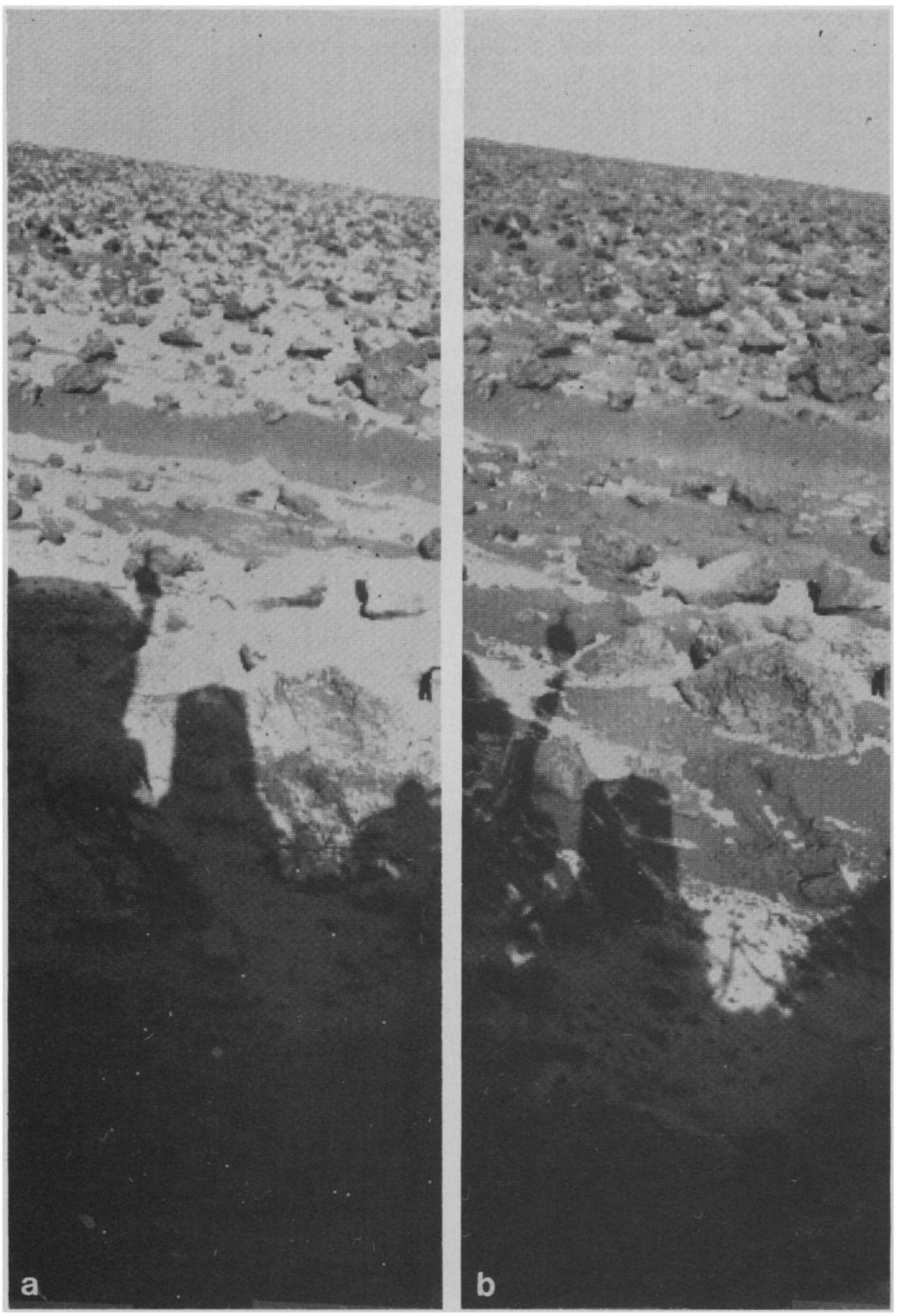

Fig. 4. Views of the surface directly north of VL-2 Utopia Planitia: (a) 21E113, sol 341, 12:59, and (b) 21E153, sol 365, 12:59. Both images were acquired with the blue-filtered diode, and show the disappearance of a thin but widespread layer of a bright condensate. The prominent darker feature traversing the earlier image is the south-facing wall of a small trough feature that had lost the condensate cover by the time the image was acquired. The foreground is shadowed by the spacecraft. Clearly visible are the silhouettes of the meteorology boom and the camera that acquired the image. Two trenches, created earlier in the mission by the surface sampler arm, are also visible in the foreground. A small amount of condensate is visible in the bottoms of the trenches. Rocks, as well as soil, are covered by the condensate.

The quantity of $H_2O(s)$ that accumulated on the surface is difficult to establish, but some of our colleagues doubt that there could have been even a few micrometers of precipitable water in the atmosphere and therefore have questioned the suggestion of an H_2O composition. Considering the atmospheric temperatures at the time, the slow disappearance of the condensate strongly implies that it consisted of $H_2O(s)$ rather than $CO_2(s)$, which has a much higher sublimation rate (17). The $H_2O(s)$ may have reached the surface at the VL-2 site as a solid or a vapor. One possibility is a slow but continuous transport of water vapor to the site from the equatorial regions, so that while observed condensate accumulated the partial pressure of H_2O never exceeded a fraction of a micrometer of precipitable water (19). A much more likely possibility is that H_2O was transported to the site as a solid condensed on the surface of dust grains (20). Condensation of H_2O as well as CO_2 on dust grains has been suggested by several authors (6, 8, 21). The added mass of both solids accelerates the precipitation of dust from the atmosphere (6, 8) and thus concentrates both H_2O (22) and dust closer to the surface than would be expected on the basis of atmospheric mixing alone.

Supporting a dust transport mechanism was the discovery of a thin covering of bright dust on the surface after the condensate disappeared. This dust cover does not appear on images acquired immediately before the formation of the condensate. Figure 5 shows a pair of repro images acquired by VL-2 on sols 36 and 503 under virtually identical conditions of lighting geometry, atmospheric opacity, and camera response. Although most of the dust-covered surface appears brighter in the later image, the dust deposit is best seen by observing the albedo change of the darker trench material relative to the surrounding surface. The trench at the left, which appears in both images, has become bright, while the trench in the center front, created after the dust storms, is dark. In addition to an overall increase in surface albedo, the deposited dust layer caused a significant reduction in contrast between adjacent surface features (*23*).

The cameras' resolution limit allows us to place an extreme upper limit of a few millimeters on the thickness of the dust accumulation. Even the smallest rocks and surface features that were visible before the dust accumulation are still visible. In images illuminated at a phase angle near 0°, where the backscatter is greatest, the light dust cover is immediately apparent, as shown in Fig. 5. However, in images that are backlit, where the cameras faced the sun, there is no indication of dust accumulation. This dependence on the lighting geometry suggests a low upper limit on the dust thickness, perhaps several tens of micrometers or less.

The first condensate began to form just before VL-2 sol 221 ($L_s = 243°$) 36 to 47 sols before the onset of the second dust storm. Initial accumulations preferentially formed on patches of fine-grained soil. Even some small vesicular rocks were completely coated by the bright condensate, suggesting at least some direct condensation of water vapor on these rocks (frost). In a separate study, in which Mars surface color was referenced to the dust-free high-gain antenna post on the spacecraft, we found that the condensate layer, manifested as a color shift versus time, accumulated largely between sols 233 and 281. Thus, although the formation of the condensate appears to be related to dust deposition and transport, the available data do not establish that the rate of condensate formation is directly related to the increase in optical opacity accompanying the passage of the second dust storm over the site.

As the optical depth decreased between sols 317 and 341, the surface condensate began to disintegrate into discrete patches, as shown in Fig. 4. Since the temperature increased only slightly during this time, the increase in solar radiation flux due to the reduction of atmospheric opacity was apparently sufficient to begin sublimating the condensate layer. This is supported by the fact that the disappearance of frost was clearly defined by local small-scale (~ 10 cm) topographic features—the first regions that lost condensates were south-facing slopes, the last were in constantly shadowed areas behind rocks. Thus the working hypothesis of many investigators—that in the low-pressure Mars environment solar radiative heating vastly dominates atmospheric conductive heating—is clearly supported. Although most of the condensate was gone by sol 415 ($L_s = 359$), at least one remnant was visible as late as sol 449 ($L_s = 16$). The temperatures during this period ranged from 175 to 220 K (*16*).

On the basis of these observations, the following hypothesis for the source and mechanism of formation of the surface condensate is proposed. During late autumn and early winter at the VL-2 site, the average temperature steadily decreased and the average pressure increased. The record of VL-2 minimum temperatures (*16*) is markedly uniform between about VL-2 sols 220 and 320; the minimum temperature descended on numerous occasions to 150 to 151 K, but never dropped below this (*24*). Although the absolute temperature, as measured by the meteorology instrument, may not be accurate within 1 K (*24, 25*), the consistency of the minimum temperatures may indicate a buffering effect of CO_2(s) formation on the atmospheric temperature.

Solid carbon dioxide may have condensed only on the surfaces of suspended dust particles and not directly on the surface of the planet; this remains to be determined. The growth of CO_2(s) on dust particles may have occurred primarily during the nighttime hours, because of the lower temperature and the absence of solar radiative heating. However, the effective settling rate of ice-laden dust particles may have been substantially slower—on a time scale of days (*26*).

We are fairly certain that although the residual condensate cover at the site was H_2O(s), condensation of water vapor alone on dust particles above the VL-2 site was not the mechanism for their precipitation. At these low temperatures

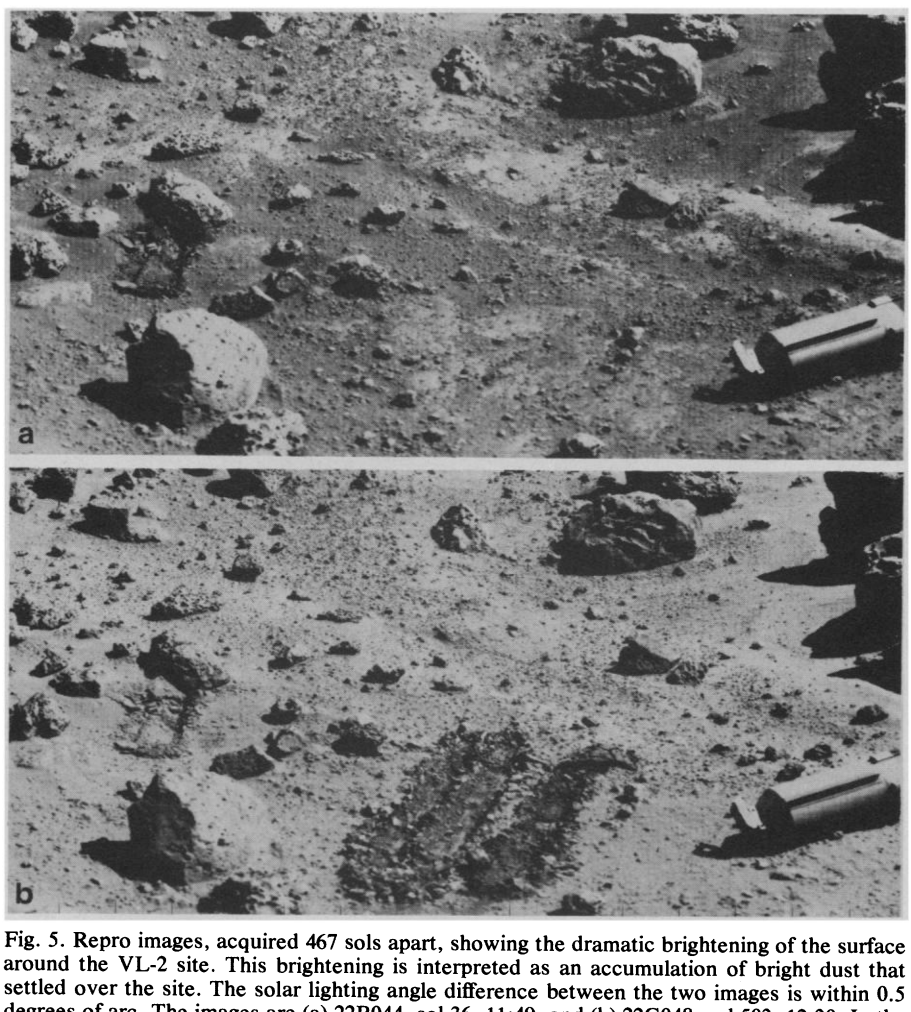

Fig. 5. Repro images, acquired 467 sols apart, showing the dramatic brightening of the surface around the VL-2 site. This brightening is interpreted as an accumulation of bright dust that settled over the site. The solar lighting angle difference between the two images is within 0.5 degrees of arc. The images are (a) 22B044, sol 36, 11:49, and (b) 22G048, sol 503, 12:30. In the earlier image, brighter duricrust features are visible against the darker material, but in the later images these contrast differences are masked by the bright dust layer. The trench at the left in the earlier image is covered by the bright dust in the later image. The newer trench in the later image was created after the dust deposition and appears dark. The metal canister at lower right is a shroud that protected the surface sampler arm during the journey to Mars and was jettisoned 2 days after landing. As of the time of this writing, the dust layer has remained unchanged.

there could be very little water vapor in the atmosphere—not enough to have added any significant mass to suspended dust particles if it froze out on them. Any condensation of $H_2O(s)$ on dust grains must have occurred before the dust reached the VL-2 site; the most likely source is the wetter equatorial regions. When the H_2O-covered dust particles reached the VL-2 site they were covered by $CO_2(s)$, so that a "snow" composed of $H_2O(s)$ and $CO_2(s)$ descended to the surface.

Some of the $H_2O(s)$ on the surface and on suspended dust grains may have been converted to a CO_2-clathrate. However, any $CO_2(s)$ would have quickly sublimed by early morning, and CO_2-clathrate would have reconverted to $H_2O(s)$ soon after. Most of the $H_2O(s)$, on the other hand, would remain long after the disappearance of the $CO_2(s)$, because even surface temperatures equal to the maximum atmospheric temperatures measured at the site during this period are well within the stability regime of $H_2O(s)$. In addition, some of the $H_2O(s)$, as well as any $H_2O(s)$ on dust grains that had not quite settled to the surface, may have sublimed during the early daylight hours, and the released water vapor recondensed directly on the Mars surface. This is one possible explanation of the ice-coated appearance of the early condensate accumulation.

The increase in the optical depth that signaled the arrival of the second dust storm at the VL-2 site protected the condensate from solar radiative heating, and, as would be expected, low atmospheric temperatures were measured during this period.

After around sol 317, the temperature began to increase while the optical depth declined. Condensation of $CO_2(s)$ on dust particles was no longer possible because of the warming. The H_2O condensates had reached their maximum thickness and began to sublime. The dust remained and, as of the time of this writing, the appearance of this residual dust layer remains unchanged.

Fig. 6. Localized dust storm passing directly over the VL-1 site as viewed from the Viking 1 orbiter. Shadows of the individual clouds may be seen to the right of each cloud; illumination is from the left. This orbiter image was one of a sequence acquired concurrently with lander images during the passage of the shadow of Phobos over the VL-1 site. Despite two global dust storms and at least one local dust storm over the site, the surface changes due to dust redistribution have been minimal (Viking orbiter image 467A31).

Implications for the Rates of Eolian Processes

Since the return of the first lander images, the single major question about the two sites has been whether they are ancient scenes, essentially unmodified for millions of years, or whether morphological surface changes routinely occur during a typical Mars year. In earlier publications (*7, 10*), it was hypothesized that the actual bedrock at the VL-1 site had been eroded, perhaps as much as several meters below an original surface, by atmosphere-related processes of weathering. The possible interpretation of rocks such as Big Joe as remnants from eroded intrusive dikes (*10*) suggested that meters of erosion of bedrock had occurred. The more likely explanation, that the blocks were ejecta from impact craters, was hampered by a paucity of clearly identifiable craters (*7*) in the vicinity of the lander. At the time of these earlier conclusions, a cratering process alone could not convincingly be invoked to explain the abundance of blocks at the VL-1 site.

Viking Orbiter images of the VL-1 site, acquired after the lowering of the periapsis to several hundred kilometers, have revealed numerous impact craters that were undetectable in earlier images. Small craters are visible down to the resolution limit of the new orbiter images (*27*). Many of the newly revealed craters are somewhat elliptical and have indistinct rims that resemble those of secondary craters. By correlating features that are visible in both lander and orbiter images, it is now possible to position the lander to within several tens of meters, an improvement of a factor of 10 over the accuracy possible with previous orbiter images (*28*). The impact craters that have been identified in the immediate vicinity of VL-1 explain the abundance and variety of loose blocks, and it now seems probable that since the initial flooding of the region by volcanic flows and the formation of the wrinkle ridges (*29*), cratering has been the single major process modifying the VL-1 site. Over the lifetime of the surface, the extent of subsequent eolian erosion and chemical destruction of the rock population seems minimal. Most of the blocks, although pitted and abraded on a scale of centimeters, do not appear significantly eroded.

At the VL-2 site, the numerous blocks were originally interpreted as part of the ejecta blanket from the large crater Mie (*13*), a conclusion that has not been altered. The larger blocks may have been preferentially concentrated on the top layer by the massive debris flow which emanated from the crater (*30*). As a consequence, the abundance of large rocks that are resting on top of the soil, as opposed to being partially buried, may not imply as much removal of fines as might at first be suspected. The importance of subsequent cratering at the VL-2 site remains unknown, since the high-resolution orbiter images for this site were obscured by haze and provide no improvement over earlier images. Nevertheless, there is no indication from the VL-2 images that the extent of eolian-type weathering has extended beyond ventification of rocks and removal of fine-grained debris.

The low erosion rates inferred from the surface appearance at the two sites do not agree with some of the predictions made before the landing. It was anticipated that eolian modification of the surface would be intense, especially during the perihelion dust storms (*31*). Despite the observations of two global dust storms by both landers and at least one local dust storm by VL-1, there has been little indication of suspended dust particles, other than the dust redistribution and changes in the atmospheric opacity discussed above. In many lander images acquired during the dust storms, the apparent surface brightness and shadow contrast are greatly reduced, but only the slightest obscuration of ridges on the horizon is observed. Since some of these horizon features are many kilometers distant (*28*), this indicates that there was no substantial concentration of dust in the boundary layer. Also, during the $\sim 10^2$ seconds required to obtain an image, at least some images should have shown lighting fluctuations if there had been dust turbulence in the boundary layer or differential concentrations of dust passing above the spacecraft. In an extreme case one might expect images similar to the first ones obtained by each lander (*7, 13*), which show lighting variations due to dust that was entrained in the retrorocket exhaust during touchdown and remained suspended long enough to be imaged. No equivalent lighting variations due to suspended dust have since been recorded. Analyses of rescan images acquired through both the primary and extended missions have so far failed to detect motion of particles either in suspension or saltation.

An additional set of images relevant to the question of dust storm intensities was obtained concurrently by the lander and orbiter cameras during three successive transits of the shadow of Phobos over the VL-1 site. During the third of these, on VL-1 sol 423 (L_s = 340°), the orbiter images show a locally intense dust storm directly above the VL-1 site (Fig. 6). The storm was $\sim$ 500 km in breadth and seemed to be moving from west to east over the site. However, the rescan image obtained by the lander indicates no dust or sand motion, only an expected lowering of the illumination level due to the Phobos shadow. The passage of the storm was detectable, however, through the VL-1 optical depth data, which show a 3-day spike during the passage of the storm. These data were obtained by imaging the sun and computing the optical depth from Beer's law.

It therefore seems possible that the large global dust storms, which appear from orbiter images to be maelstroms of destruction, may cause no more erosion, even at their source regions, than we have observed at the lander sites. The amounts of suspended dust seen from orbit may be deceptive. The albedo variations behind topographic obstructions, described by both Mariner 9 (*32*) and Viking Orbiter (*33*) investigators, may require the shifting of no more than a few micrometers of surface dust.

The remaining unknown is whether the Mars year that the landers have observed is typical. This applies not only to year-by-year variations, but also to long-term variations. We could speculate that by chance we saw the only frost formation in 1000 years at the VL-2 site, or that we missed the usual yearly sandblasting of the VL-1 site. However, the logical working hypothesis is that the landers have been present during a year that is not far from normal. On the basis of lander observations of bright dust movement, we can be fairly confident that, on a yearly average, both sites are subjected to the blanketing and windstripping of a thin layer of dust (*34*). The observed alternation of bright dust deposition and removal, if repeated over the lifetime of the surface, may alone be sufficient to explain the cumulative effects of weathering processes in shaping the appearances of the two sites.

Future of the Viking Lander Imaging Experiment

In mid-February 1979, the final commands were transmitted to the two Viking landers.

In mid-May, VL-2 will return both imaging and meteorology data acquired between February and May 1979. This covers an extremely important period corresponding to the time during the first Mars year when both condensate formation and dust storm activity were observed. Since a relay link via the orbiter is necessary to obtain data from VL-2 (the direct-to-earth capability having been lost early in the mission), that lander will then cease to be used. At that time, the small amount of attitude control gas in the remaining Viking orbiter will be almost exhausted, and additional relay links are not feasible.

However, in early March 1979, VL-1 began what has been formally named the Viking Survey mission. The direct-link capability for VL-1 is still operational. During the course of each Mars year, for as long as the lander's transmitter continues to work, imaging and meteorology data will be transmitted to earth five times during each 37-sol interval. We have developed an imaging sequence that will cover most of the visible scene during each Mars year and will repeat the same sequence during subsequent Mars years. Images will thus be obtained with nearly identical lighting geometries at one-Mars-year intervals. These images should dramatically extend the time base of the lander imaging experiment and allow future investigators to better understand the year-to-year variations in the appearance of the Chryse site.

References and Notes

1. Since twice each year (with the exception of the summer and winter solstices) the sun appears to pass through the same declination relative to the planet's equatorial plane, repro pairs for primary mission images were obtained just before northern summer solstice, at somewhat less than one Mars year. For all but a few of the more than 100 repro images so far acquired, the sun was within several tenths of a degree of its original position. The required accuracy was more restrictive for low sun elevations in order to minimize shadowing differences.
2. Comparison of repro images acquired during times of unequal optical depth has proved impractical. Any increase in the optical depth results in a decrease in the apparent total illumination of the scene. Initially, the apparent brightness of shadowed areas increases due to infilling by scattered light. However, at still higher optical depths, the apparent brightness of both shadowed and illuminated areas decreases. Although this type of behavior makes comparison of images difficult, it will later provide valuable data on the scattering properties of the atmosphere and the photometric properties of surface materials around the landing sites.
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5. Since the sol for each lander is measured from touchdown (equal to sol 0), there is an offset of 43 sols between the two lander times. In this article, images are identified by the sol corresponding to the lander that acquired them. The quantity L_s denotes the aerocentric longitude of Mars as it revolves around the sun and is a convenient method of measuring martian seasons: L_s = 0° corresponds to southern summer equinox; the other seasons commence every 90°, and the seasons are offset 180° between the northern and southern hemispheres. Perihelion, which is independent of the seasons, presently occurs at $L_s \cong 250°$.
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10. A. B. Binder *et al.*, *ibid.* **82**, 4439 (1977).
11. Since the slump occurred in a region that is not viewable by camera 2 (that is, there is no stereo-

scopic coverage), an accurate slope measurement cannot be obtained. A method using shadows may prove useful.
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14. T. A. Mutch *et al.*, *ibid.*, p. 87.
15. H. H. Kieffer, *ibid.*, p. 1344.
16. J. A. Ryan, personal communication; S. L. Hess *et al.*, *J. Geophys. Res.*, in press; J. A. Ryan and R. M. Henry, *ibid.*, in press.; J. E. Tillman *et al.*, *ibid.*, in press.
17. H. H. Kieffer writes (personal communication) that according to his calculations (*15*) "[on] a surface with the physical properties estimated for the VL-2 site, e.g., thermal inertia (units of 10^{-3} cal cm^{-2} $sec^{-1/2}$ K^{-1}) $I = 8$, and albedo $A = 0.225$, CO_2 frosts might form at night during the middle of winter but would not last through the day. Even for the soil alone (exclusive of rocks) with a thermal inertia of approximately 6.2, ground frost would not last through the day. Those calculations assumed a frost albedo of 0.65 whenever any frost at all was present. To have CO_2 last throughout the day, at least one of the following is required. [i] The effective frost albedo must be close to one. This is particularly a problem for thin frosts, where even a material with very high single scattering albedo will scatter a considerable fraction of the radiation into the underlying soil. [ii] The surface material must have a thermal inertia considerably less than expected. Preliminary calculations indicate that $I = 2$ or less is required for frost to last until mid-day. [iii] The insolation at VL-2 must be considerably lessened by the polar hood without a compensating increase in the infrared opacity of the atmosphere."
18. The minimum temperatures (151 to 157 K) and maximum pressures ($\sim$ 10 mbar) at the VL-2 site are thermodynamically consistent with the conversion of $H_2O(s)$ to a CO_2-clathrate. However, any CO_2-clathrate that formed would have reconverted to $H_2O(s)$ on about the same time scale as the expected disappearance of $CO_2(s)$, since the sublimation rate of CO_2-clathrate is similar to that of $CO_2(s)$ (S. L. Miller, personal communication).
19. The vapor pressure of $H_2O(s)$ is strongly dependent on temperature. However, over the temperature ranges measured at the VL-2 site, values vary from 2×10^{-7} mbar at 155 K to 2.2×10^{-6} mbar at 165 K. This converts into 5.5×10^{-3} and 5.9×10^{-2} precipitable micrometers of $H_2O(s)$—an undetectable thickness.
20. An additional source of H_2O that must be considered is water bound in soil materials beneath the surface at the site. The temperature gradient that results when the surface temperature drops below the subsurface temperature should favor an upward transport of water vapor. Water bound in soil materials or present as subsurface ice might tend to diffuse toward the surface. However, at the low temperatures measured at the site the diffusion rate would be extremely small. Whether it would be negligible is not easily determined. One must consider such complications as the presence of the duricrust at both sites, which may act as a barrier to the upward migration of water vapor. However, the dust transport mechanism seems clearly supported by the data and we believe that a subsurface source of H_2O is not required.
21. S. L. Hess, *J. Atmos. Sci.* **27**, 1117 (1970).
22. ——, *Icarus* **28**, 269 (1976).
23. Any equivalent dust accumulation on the body of either spacecraft is indistinguishable from material spilled during the numerous sampler deliveries to the lander's chemical and biological experiments.
24. J. A. Ryan, personal communication.
25. J. E. Tillman, personal communication.
26. H. H. Kieffer, personal communication.
27. At the altitude of 400 km the angular resolution of the orbiter cameras is $\sim$ 8 m per pixel. Two factors, however, significantly reduce the image quality. First, the sun angle was high when the images were acquired, and no shadow information was obtained. Second, the exposures were shortened to minimize blur due to spacecraft motion. Consequently, the images have very few discernible brightness levels, which are as important as angular resolution in identifying surface features. Nevertheless, they are a significant improvement over previous images.
28. E. C. Morris, K. L. Jones, J. P. Berger, *Icarus* **34**, 548 (1978).
29. M. H. Carr *et al.*, *Science* **193**, 766 (1976).
30. E. A. Guinness and R. E. Arvidson, *Eos* **59**, 313 (1978) (abstract).
31. C. Sagan, *J. Geophys. Res.* **78**, 4155 (1973).
32. C. Sagan *et al.*, *Icarus* **17**, 346 (1972); *J. Geophys. Res.* **78**, 4163 (1973).
33. J. Veverka, P. Thomas, R. Greeley, *J. Geophys. Res.* **82**, 4167 (1977).
34. The accumulation of a layer of bright dust where an equivalent accumulation did not already exist implies that the processes of deposition and removal alternate on a time scale measured in Mars years. Recently acquired repro images show a brightening of trenches, as well as what appears to be bright dust on the surface, at the VL-1 site. Although the quantity of bright dust is less than at the VL-2 site, it provides us with equivalent evidence that both sites experience this type of dust accumulation and removal on a regular basis. Having detected the dust at both sites, we anticipated documenting its removal (possibly as part of the "wave of darkening"), but this has not occurred.
35. We thank the Viking Orbiter Imaging Team for supplying the photograph for Fig. 6. We thank L. Cooley, D. Stuhr, and B. Vensel for typing the manuscript. This work was supported by NASA contracts NAS1-11500 to the Bionetics Corporation, NAS1-13889 to Washington University, and NAS1-9000 to Martin Marietta Aerospace and by NASA Langley Research Center.

Science and Industry, Challenges of Antagonistic Interdependence

Peter F. Drucker

Science and industry in the United States used to enjoy a relationship of mutual respect based on an unspoken conviction that they depended on one another. That relationship, while distant, was uniquely productive for both science and industry (*1*).

Summary. No one is responsible for the disenchantment of American science with its customers, government and industry, and of the customers with science. But the estrangement that has replaced the earlier relationship of mutual respect, while dangerous to both sides, is a mortal threat to American science.

The first change in the traditional American relationship occurred after World War II. Research became fashionable in industry and government alike. These were the years when the stock market valued a company according to the amount of money it spent on research, and in which a lavish campuslike research center was considered proof of a management's competence. Similarly in those years—culminating in the space program of the 1960's—science and research increasingly came to be seen as the mark of the effective well-planned and properly progressive government program.

During the years after the war, the ability of America to convert science into industrial application was considered the outstanding strength of both American science and American industry. Treatise after treatise pointed out that the British, for instance, were America's equals in science. But the British failed to convert their own scientific achievements—in electronics, in polymer chemistry, in the computer, in radar, or in aviation—into technology, products, and economic advancement, whereas America did.

Equally, especially during the Truman and the Kennedy years, the willingness, indeed eagerness, of the American politician and government executive to apply science—"hard" as well as "soft"—to both the study of social and political problems and to the design of social and political programs was seen both inside this country and outside as a distinct and great American achievement. The innovating ability of American society was

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