Reports

Recent Mafic Volcanism on Mars

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The evidence for volcanism on Mars is commonly accepted, but none has been documented in the Valles Marineris equatorial rift system. A recent survey of the troughs in this valley revealed dark patches that are interpreted to be volcanic vents. The configuration and association of these patches with tectonic structures suggest that they are of internal origin; their albedo and color ratios indicate a mafic composition; and their stratigraphic position, crispness of morphologic detail, and low albedo imply that they are young, perhaps even recent.

VOLCANISM ON MARS IS WIDESPREAD. It has formed enormous shields (*1*), large composite cones (*2*), lobate lava flows (*3*), and, perhaps, small cones and pseudocraters (*4*). Flood basalts similar to those filling lunar maria may have resurfaced ridged highland plateaus. Large deposits of pyroclastic material may also exist, although their presence is controversial (*5*).

Dark patches are common on Mars as they are on the moon, where they have been interpreted as pyroclastic materials (*6–9*). However, the association of dark patches with pyroclastic volcanism on Mars has been largely overlooked because most dark patches are inside craters and were obviously accumulated by wind (*10*); the possibility was neglected that some Martian dark patches, like lunar ones, may reflect pyroclastic vents. I describe dark patches in Valles Marineris that may be such vents and may reflect young mafic volcanism.

Dark patches in central Valles Marineris were revealed by high-resolution stereoscopic Viking Orbiter 1 images (*11*). The dark patches occur dominantly along tectonic structures, as judged by a general alignment of the patches and their association with faults (Fig. 1). Those in Ophir and eastern Candor chasmata occur mostly at the base of scarps formed on interior layered deposits; those along the north edges of Coprates and western Candor chasmata (Fig. 1, patches 1 and 2) occur along faults at the base of trough walls.

The patches that form a band in Coprates Chasma (1 in Fig. 1; also shown in Figs. 2 to 4) offer strong evidence for a volcanic origin. These patches, extending discontinuously for 200 km, occur mainly along a fault system that marks the north boundary of Coprates Chasma. The patches are unlikely to have been accumulated by the wind because of their preferential association with this large structural system (Fig. 4). Also, the dark patches were not derived from newly exposed necks, dikes, or sills reworked by the wind; the dark material occurs on top of a landslide deposit that would have buried outcrops of older materials on the trough floor (Fig. 2).

Individual patches give rise to wispy streaks (Fig. 4), which implies some explosive jetting of material. On the other hand, the patches that originate on the chasma wall (Fig. 3) shed debris downhill and into adjacent gullies. These materials apparently moved as debris flows or liquids. The chasma-wall patches also originate at probable faults, expressed as lineaments in the lower wall section (Figs. 2 and 3).

The patches have a conspicuous cross-canyon grain, which is unlikely to be caused by wind alone; in fact, wind directions along the long axes of the troughs are indicated by transverse dunes, the closest of which is only 60 km west of the patches shown. The cross grain may have other causes: (i) the north chasma-floor fault lies slightly uphill from the south one so that material originating at this fault flowed downhill, across the canyon (Figs. 2 to 4), and (ii) the crowding of eruptive material along the south chasma-floor fault forced the material to eject in directions perpendicular to the linear vents.

The apparent explosive jetting implies that patches had a pyroclastic component, though, as pointed out above, some liquid extrusions are indicated. Other dark patches in Valles Marineris also appear to be largely pyroclastic. Mafic pyroclastic deposits without extensive associated flows are uncommon on the earth but are probably present on the moon (*6*) and apparently exist in Valles Marineris on Mars.

The dark patches have low albedos in clear-filter images. Most measured albedos are about 0.08 to 0.09, but one is as low as 0.05. They are comparable with albedos of dark pyroclastic mantles on the moon (*12*) and are thus consistent with a pyroclastic origin. Color ratios show that the dark patches in Valles Marineris are very blue compared with other Martian materials. The patches' red-to-violet ratio of about 1.9 is similar to ratios of dark patches inside craters (*10*), but somewhat higher than that of the darkest areas of Juventae Chasma (*13*) and Kasei Vallis (*14*). Exposures in Valles Marineris, however, are small considering the resolution of the apoapsis color images—the only color images of the area acquired under clear atmospheric condi-

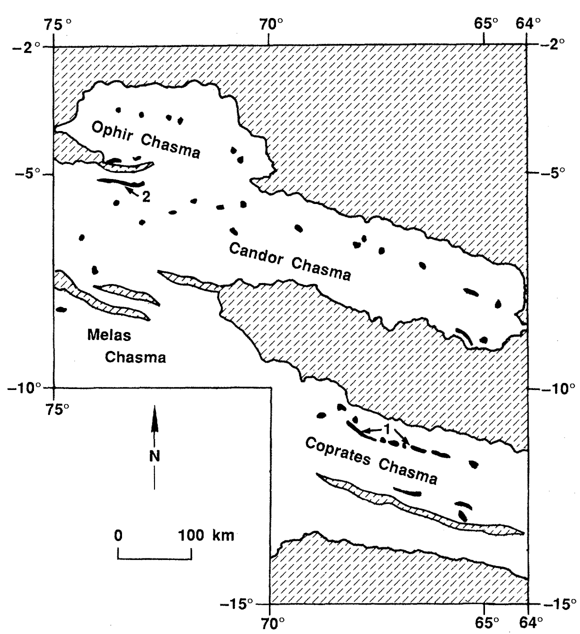

Fig. 1. Map showing dark patches of probable volcanic origin (black spots and bands, slightly enlarged for better visibility) in central Valles Marineris. Numbered localities are referred to in text. Plateaus surrounding valleys and ridge-forming plateau material within valleys are hachured.

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tions—and therefore the color measurements in Valles Marineris probably include values for the surrounding redder country rock.

The red-to-violet ratio of the dark patches in Valles Marineris falls within the range of those measured for slightly weathered basalt powder on the earth (*15*). Other dark deposits on Mars also have been interpreted as concentrations of slightly weathered mafic or ultramafic materials (*13, 14*) because of their spectral similarity to terrestrial volcanic materials (*15*). The similarity of the dark patches in Valles Marineris to these other dark deposits suggests that the patches are also of mafic or ultramafic composition.

Estimates of the grain size of the pyroclastic component of the dark patches come from various sources. Thermal-inertia measurements suggest that dark deposits inside craters elsewhere on Mars have grain sizes between 1 and 10 mm and that dune deposits have grain sizes less than 0.5 mm (*16–18*). The dark patches in Valles Marineris probably have grain sizes similar to those of dark deposits inside craters, because of their similar albedo and color ratio. Furthermore, the dark materials in Valles Marineris appear to have been blown about, as inferred from wind streaks emanating from patches in Ophir and Candor chasmata, from trapping of the dark materials in cracks and crevices (Figs. 2 and 4), and from reworking of the materials into dunes. The facility of wind transport indicates sand-sized grains near 0.1 mm (*19*). Perhaps, because of the rarefied atmosphere on Mars, the pyroclastic component of the patches consists of beads like those resulting from fire fountains on the moon (*6, 20*).

The dark patches in Valles Marineris are young. Because they occur on trough floors and walls in their present configuration, they have been emplaced after the major dissection of Valles Marineris. Furthermore, the patch material penetrated landslide deposits (Fig. 2) and is thus younger than these deposits. [Landslide emplacement is thought to coincide approximately with late activity of the Tharsis volcanoes (*21*).] A young age is also suggested by the morphologic crispness of the deposits: the preservation of the wisps suggests that these fine features have not yet been removed by the wind.

Their low albedo also suggests that the dark deposits are young; on Mars, where frequent dust storms deposit light-colored dust, materials tend to lighten with age. Albedos as low as 0.05 of the dark patches in Valles Marineris suggest the following possibilities: (i) fine, light-colored dust was never deposited inside Valles Marineris, (ii) fine dust was deposited but removed com-

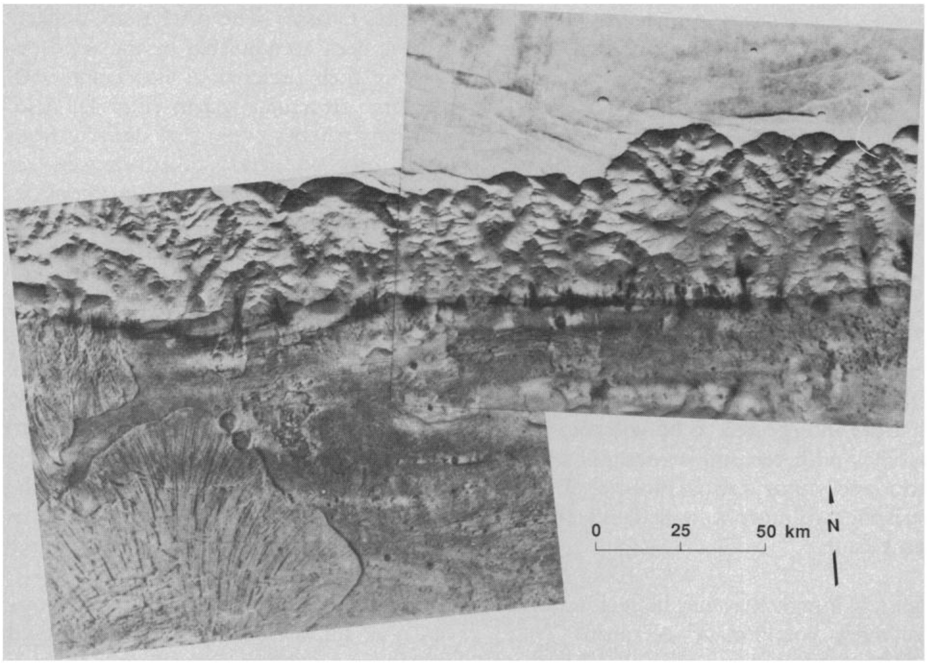

Fig. 2. Band of dark patches at base of north wall of Coprates Chasma. Most patches occur along a graben that is about 2 to 5 km wide. Smooth area in upper part of right image is plateau surface; gullied area in center is trough wall, having 7 km of relief. Trough floor is at bottom in lower half of images. Conspicuous fluted features on floor at left are landslides. Patch material penetrates upper edge of northern landslide. Patches are interpreted to be vents of pyroclastic material extruded along faults. Note dark material trapped in numerous small depressions on trough floor (right image); the material was apparently reworked from the vents by wind [Viking Orbiter 1 images 80A01 (left) and 81A04 (right)].

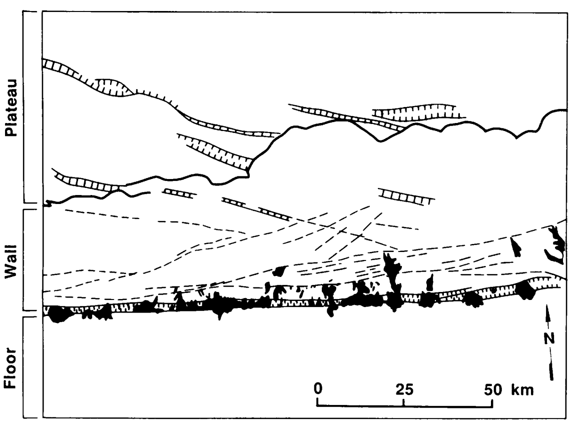

Fig. 3. Sketch map of right image in Fig. 2. The edge of the plateau is shown by the heavy line. The plateau surface is dissected by ancient faults and grabens (hachured lines), which extend into the walls. The boundary between the trough wall and the floor is marked by numerous subparallel lineaments (dashed lines), interpreted to be faults, and a conspicuous graben (hachured lines). Dark patches (solid black) apparently emanated from these faults.

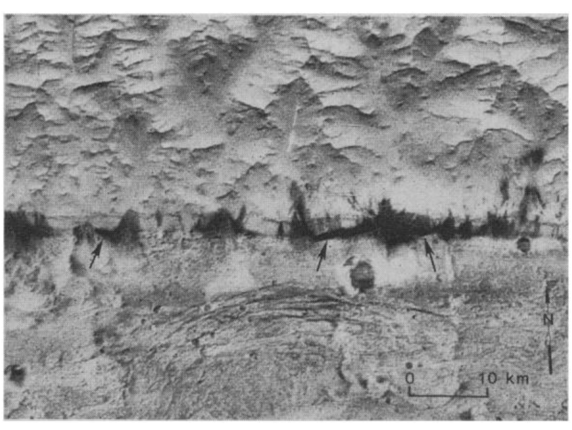

Fig. 4. Enlargement of central section of Fig. 2, showing elongate accumulations of dark material along faults (arrows) and wispy streaks emanating from accumulations. Cracks, craters, and small circular depressions on floor farther south apparently trapped some windblown dark material but did not produce wispy streaks.

pletely by subsequent storms, or (iii) the dark deposits are so young that they have so far escaped burial. The first possibility is unlikely because the darkest patch measured on an image taken early in the Viking mission became obscured by a light blanket during the subsequent dust storms of 1977.

The second possibility will be explored in more detail. How fast does light-colored dust obscure dark materials? Thomas *et al.* (*13*) calculated that a coating of light-colored dust covering as little as 30 to 50% of a region would result in maximum contrast between light and dark areas on Mars. Such a coating could come from only one-quarter of the annual dust fallout distributed evenly over the Martian surface (*17*). The time needed for dust to completely bury a dark-patch deposit (*22*) having an assumed grain size of 10 mm (an upper limit according to thermal-inertia measurements) would range from 30 years for densely packed dust to 1500 years for porous material; density of the latter corresponds to that of fine weathered glass (*23*). If dust fallout were erratic, the patches would be buried in 30,000 to 1,500,000 years (*22*). It appears that the dark patches would be buried rapidly and, if dust were never removed, they would be very young indeed.

However, removal of light-colored coatings is to be expected. How much would be removed during subsequent storms is difficult to assess. Some dust would certainly remain trapped in cracks and crevices and would eventually tend to lighten the dark patches. Thomas (*10*), considering the age of low-albedo splotches inside craters, suggested that the material had to be reworked continuously by saltation to prevent a rise in albedo due to a dust cover. For the thin dark streaks emanating from dark-crater splotches, Thomas (*10*) estimated a lifetime only of about 10 to 100 years because of the tenuous nature of the streaks and their susceptibility to wind action. The delicate structure of the feathery edges of the vent deposits in Valles Marineris would be blanketed or destroyed by mechanisms similar to those affecting the dark streaks from crater splotches. Thus, the third possibility is indicated: the dark patches are very young. In fact, they may be no older than a few million years at most.

It appears that the Valles Marineris tectonic troughs experienced a phase of mafic or ultramafic, pyroclastic volcanism. This observation is the first suggestion that Valles Marineris tectonism was accompanied by volcanism, as is common in most terrestrial rift systems. If this volcanism is indeed as young as it seems, Mars has been an active planet throughout most of its history.

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Superconductivity at 52.5 K in the Lanthanum-Barium-Copper-Oxide System

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A superconducting transition with an onset temperature of 52.5 K has been observed under hydrostatic pressure in compounds with nominal compositions given by $(La_{0.9}Ba_{0.1})_2CuO_{4-y}$. Possible causes for the high-temperature superconductivity are discussed.

The search for high-temperature superconductivity and novel non-phonon-mediated superconducting mechanisms is one of the most challenging tasks of condensed matter physics and material science. As a consequence, many compounds have been tested and numerous mechanisms proposed during the last three decades. However, only recently has a superconducting transition temperature (T_c) of 35 K been reported (*1*), and later of 40.2 K under hydrostatic pressure (*2*), almost twice the value of 23.2 K first reported (*3*) in Nb_3Ge sputtered thin films. Although the suggestions (*4*) of spin fluctuation–assisted electron-pairing and triplet superconducting states in heavy fermion superconductors are consistent with some experimental data, unambiguous evidence has yet to be established. No definitive guidelines exist, to date, for predicting those material systems that will exhibit high T_c or novel superconducting mechanisms. In this respect, an empirical search for new materials remains the most effective approach. It has been suggested (*5*) that it may be fruitful to investigate superconductivity under various conditions (high pressure, for example) in compounds generally not favorable for superconductivity. The superconducting oxide systems are examples of such systems.

Oxidation is known to degrade the metallic and, in particular, the superconducting characteristics of matter. However, superconductivity has been observed in some highly oxidized perovskites and related compounds (*6*) such as $SrTiO_{3-x}$, Na_xWO_3, $Li_{1+x}Ti_{2-x}O_4$, and $BaPb_{1-x}Bi_xO_3$, with a T_c reaching 13 K for the last two oxides. Such a high T_c is especially unusual for $BaPb_{1-x}Bi_xO_3$, which has no *d*-electrons near the Fermi level and exhibits an extremely low electron density of states. In spite of the great variation of their T_c values these oxides have several similarities (*7*). For instance, superconductivity occurs only over a narrow range of *x* values, with the highest T_c near the metal-insulator phase boundary. All these oxides possess oxygen octahedrons and mixed valence (that is, tungsten, titanium, bismuth, and copper) sites. Near the metal-insulator phase boundary, soft modes or interfaces (due to concentration fluctuations) may exist. Oxygen octahedrons in proper arrangements are known to be closely associated with soft ferroelectric modes. Mixed valence systems have been considered

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