

"White Rock": An eroded Martian lacustrine deposit(?)

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ABSTRACT

The existence and location of ancient lake sites and sediments have important implications for Martian paleoclimate and exobiology. White Rock, an enigmatic crater interior deposit, may be the eroded remnant of such a lacustrine deposit. Stereogrammetric analysis of newly processed Viking images allows better determination of the dimensions of White Rock (12.5×15 km, thickness 180 to 540 m, volume ~ 40 km³), reveals differences in erosion patterns that may reflect differences in depositional environment, and allows the identification in or on the crater wall of a possible source region of the high-albedo White Rock material. If White Rock is the remnant of a once-larger deposit, then open-system circulation may have been required to deliver the required quantity of evaporites.

INTRODUCTION

The existence and persistence of lakes and oceans in the Martian past is one of the most intriguing and controversial topics in modern planetology (see Baker, 1991; Carr, 1991; Baker et al., 1991). The creation of large standing bodies of water reflects the prevailing nature and change of the paleoclimate and may also have implications for exobiology (Clark, 1978; Clark and Van Hart, 1981).

Lacustrine deposits can be difficult to identify remotely. One approach is chemical, based on evaporites having distinctive reflection spectra. Previous Earth-based and spacecraft remote sensing (summarized in Soderblom, 1992) and Viking lander observations (summarized by Banin et al., 1992) have set limits on the globally averaged abundance of some sulfates, chlorides, and carbonates. Another approach uses the traditional elements of photo interpretation: location, shape, and association. Lakes formed in (what were then) topographic lows, and are commonly found associated with scour erosion or other evidence of water impoundment and identifiable inlet and/or outlet channels. Other morphologic features diagnostic of standing water include beach ridges, wave-cut notches, tombolos and other sand spits and bars, and hanging deltas. Lacustrine sediments are fine grained and typically are poorly indurated, and so they erode into distinctive shapes and produce distinctive deposits (Mabbutt, 1977). The biggest obstacle to the use of morphology to identify lacustrine deposits is that most features indicative of standing water have a very low preservation potential. Nevertheless, several possible shoreline and

other lacustrine features have been identified (Parker et al., 1989, 1993).

BACKGROUND

Several possible small ocean basins and other probable lacustrine sites have been identified on Mars (Parker et al., 1989; Forsythe, 1990; Baker et al., 1991; De Hon and Pani, 1992; Scott et al., 1992; Farmer et al., 1993; and others). We propose as a strong candidate the unusual feature called "White Rock," an eroded crater interior deposit (Fig. 1). Its unusual shape and albedo contrast drew early attention (McCauley, 1974), although care has been urged in relying on the albedo contrast to be important in interpreting White Rock (Evans, 1979). Regardless of albedo contrast, the morphology of White Rock is that of a weakly indurated, fine-grained deposit that has not undergone any apparent postdepositional erosion by large-scale mass wasting, fluvial, and/or glacial action, but has been subjected to extensive wind erosion (Ward, 1979). Ward (1979) also discussed the paleoclimatic ramifications of White Rock being a lacustrine deposit and critiqued alternative formation and evolution mechanisms for White Rock, summarized as follows. White Rock is not ice, because the surface temperatures do not allow it and because no changes have been observed in White Rock over several years of observation. There are no volcanic features in the vicinity of White Rock, so it is unlikely that it is an eroded remnant of an ignimbrite deposit that was once more extensive. Nor is White Rock likely to be a wall landslide deposit, because that would fail to account for the albedo contrast between White Rock and its surroundings.

An eroded crater deposit somewhat resembling that at White Rock is found in the crater Becquerel; it may also have a lacustrine origin. Lee (1993) acknowledged the possible lacustrine origin of White Rock and identified other possible lacustrine deposits. Additional evidence of evaporites in the Martian surface environment comes from Viking lander X-ray fluorescence measurements of considerable quantities of sulfates and chlorides in the Martian soil (Banin et al., 1992; and others). Thermodynamic considerations and other Viking lander observations suggest that magnesium sulfate and sodium chloride would be the dominant evaporites on Mars and that carbonates would be very rare, with the possible exception of siderite (Clark and Van Hart, 1981). Local conditions may let other chlorides and sulfates (including gypsum) precipitate in large quantities.

WHITE ROCK

A detailed examination of a newly processed stereogram of the best Viking images of White Rock (Fig. 2) and Viking images of the surrounding terrain were the basis of this study. White Rock has a teardrop shape, in general; its 15-km-long axis of symmetry is oriented northwest-southeast. The width at the broad, northwest end is 12.5 km, and it is characterized by several deep reentrants in the tapered end that run parallel to the axis. A secondary set of grooves, perpendicular to the deep reentrants, is best exposed at the broad, thick end of the deposit. The orientation of reentrants and grooves suggests that some sort of rectangular joint system exists in the White Rock deposit along which preferential eolian erosion oc-



Figure 1. White Rock (arrow) is located in unnamed 90-km-diameter crater southeast of Schiaparelli impact basin in Sinus Sabaeus region of Mars (lat -8° , long 335°). Other craters in vicinity appear also to have interior eolian deposits, but morphology of White Rock and albedo contrast between it and its surroundings are unique. Shown is mosaic of Viking orbiter photographs of northwest corner of MC-20 NE quadrangle; north is up.

curs. Several fragments of the White Rock deposit have fallen from its thick upwind edge into locations where they have been protected from subsequent destruction by eolian erosion. No fragments are present along the flanks of the tapered margin; presumably, saltation enhanced by the deflection of local air flow results in relatively rapid destruction by eolian erosion. Transverse grooves found on the broad part of White Rock occur only in its upper ~ 360 m.

The new high-resolution stereogram (Fig. 2) allows estimation by stereogramme-

try of the thickness of the White Rock deposit. The stereogram was calibrated as follows. The 1.3-km-diameter crater located due south of the tapered tip of White Rock was observed to have a parallax of -3 pixels between the rim of the small crater and its floor. If that crater is assumed to be typical of Martian bowl-shaped craters, then it would have a depth of ~ 270 m (Pike, 1980). Therefore, each pixel of parallax represents ~ 90 m in relative elevation. By that scale, the thickest part of White Rock lies ~ 540 m above the plains to the north and east, and

the escarpment at that edge of White Rock is ~ 180 m high. These estimates are necessarily limited in precision, but they are sufficient for simple volumetric calculations, which show the total aggregate volume of the high-albedo material at White Rock to be ~ 40 km³.

DISCUSSION

Two indirect lines of evidence indicate that the White Rock deposit is either being eroded by the wind now or has been in the geologically recent past. First, there appears to be a local abundance of mobile sand-sized material capable of abrading surface materials. The shape and color of unresolved dark patches in the vicinity of White Rock resemble closely those of active sand-dune deposits described at other locations on Mars (Edgett and Christensen, 1991). The dark material on the floors of the deep reentrants may be sand that is contributing to their present-day eolian erosion and enlargement. Second, high-albedo material is apparently being deflated from the White Rock area, appearing as narrow streaks in some places and collecting in others more protected from the wind (R. Greeley and S. H. Williams, unpublished). The streak orientation is approximately parallel to the potential sediment transport direction determined for present-day conditions from atmospheric circulation models (Greeley et al., 1993); a close match is not expected due to topographically induced wind deflections caused by the rim of the impact basin containing White Rock.

Determination of the volume of the White Rock deposit and the geometry of the impact basin in which it resides can be used to determine the size of the body of water evaporated to produce White Rock. If the water originally filling the basin had the initial salinity of terrestrial sea water (~ 3.5 ‰), then 2600 km³ of water would be required to yield 40 km³ of evaporites, equivalent to filling the impact basin to a depth of ~ 700 m. This depth should be considered a lower bound because the present-day White Rock appears to be the erosional remnant of a previously more extensive deposit. The upper bound for evaporites required would have filled the entire basin to a depth of ~ 500 m, comparable to the maximum height of White Rock. The evaporite volume in that case is 1900 km³, requiring 130 000 km³ of terrestrial seawater equivalent, corresponding to a depth in the basin of an impossible 34 km. Waters of significantly higher salinity than terrestrial seawater would reduce the water requirements somewhat, but not sufficiently to allow for an extensive White Rock de-

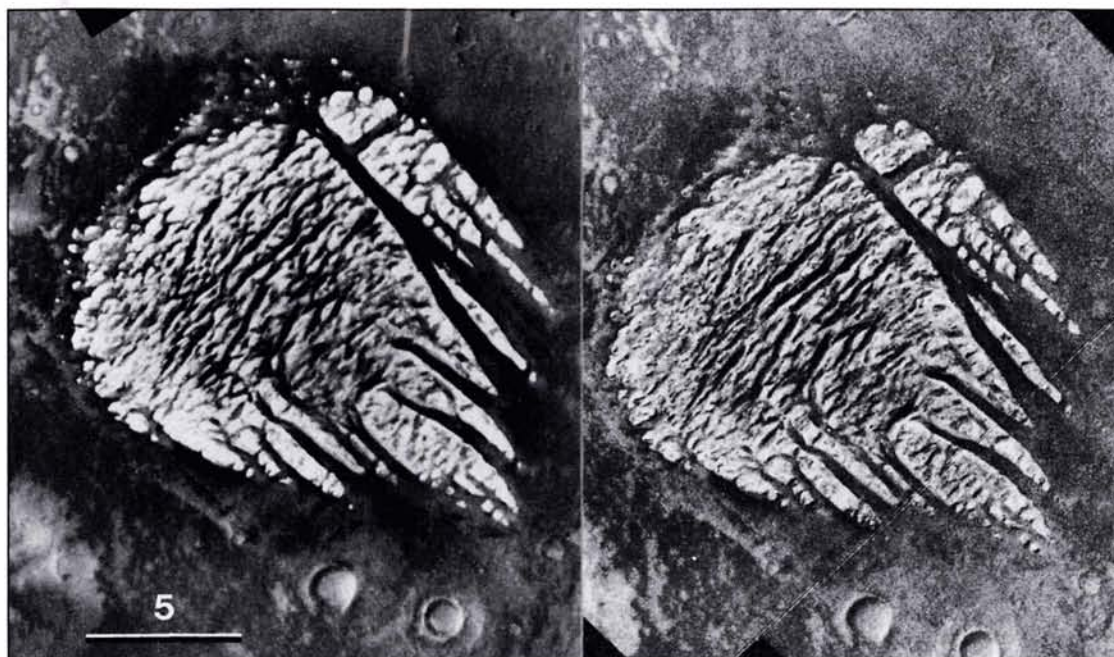


Figure 2. New stereogram of White Rock produced by processing and mosaicking Viking orbiter images 826A34-36 (red filter) for left image and frames 826A66 and 68 (blue filter) for right image. Spatial resolutions are 29 and 24 m/pixel, respectively. Images are printed with north up; scale bar = 5 km.

posit to have formed from the evaporation of a single filling of the basin with saline water.

Terrestrial analogy raises the intriguing possibility that the large volume of water required for White Rock indicates that the impact basin was, at least temporarily, an open hydrologic system. Saline waters were added continually to the basin at a rate that matched approximately the evaporation loss. Dense brines that formed at the surface by evaporation would sink and precipitate salts and gypsum. When the input of new saline waters ceased, the body of water dried up, leaving behind one last deposit of evaporites. The crude zonation thus produced may be responsible for the difference in the style of erosion observed on the transverse ridges on White Rock.

Wind-eroded deposits in the interior of craters are common on Mars, yet the morphology and albedo contrast of White Rock are unique. It is therefore unlikely that any widespread geologic process was responsible for its formation, unless some sort of special local conditions were involved to make the White Rock environment different from that in other impact basins. Such a condition would be met if there were a local deposit of older White Rock-type material that was available for incorporation into the forming White Rock deposit. Close examination of the wall of the crater containing White Rock reveals a thin, discontinuous layer of high-albedo material that may have been the source of, or at least contributed to, the White Rock material (Fig. 3). If that is the case, then White Rock may be grossly similar to White Sands, New Mexico, and the surrounding area. There, gypsum in beds



Figure 3. Thin, discontinuous line (arrows) of high-albedo material is visible in wall of impact basin containing White Rock, which lies just out of image area, to north. Line may represent at least part of original source of White Rock material. This Viking orbiter frame, 826A38, has spatial resolution of 29 m/pixel; scale bar = 5 km.

high in the San Andres Mountains undergoes erosion by rainfall and running water and is carried in solution to Lake Lucero, a playa where it recrystallizes. The wind then remobilizes the gypsum, creating the barchanoid ridges for which the White Sands

National Monument is famous. The significance of White Sands being an analog to White Rock arises from the potential of the original source of the White Rock material predating the crater that contains White Rock. If the analogy is apt, then conditions

that allowed at least the local formation of evaporite-type deposits prevailed in the early part of Martian geologic history, a fact that can be used to constrain models of Martian geology and climate history. If the high-albedo layer is part of a regional veneer, postdating the basin, then it and White Rock can be much younger. White Rock is too small for accurate dating by impact crater population, but should have collected a few craters if it had been exposed in its present form for an appreciable part of Martian history.

Many lacustrine sediments have distinctive infrared signatures and display numerous diagnostic small-scale features. The loss of Mars Observer is sorely felt; the optical camera and the thermal emission spectrometer would readily have been able to detect Martian lacustrine sites and materials, the gamma-ray spectrometer could have detected near-surface ice, and the laser altimeter would have provided much better regional topographic control than is currently available. The need for improved Martian data remains unchanged, as does the rationale for site targeting. We hope that future missions to Mars can soon help identify any Martian lacustrine materials and resolve the mystery that is White Rock.

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