

knowledge, then they will be more difficult elsewhere where the questions are unknown.

Conclusions and Site Recommendations: It is tempting to set the sights for future prospects on many of the additional interesting areas defined on Mars since the Viking mission and expand the database for ground truth to new and different terrains. This desire should be balanced with the critical need for success in planetary exploration in general and avoidance of an inconclusive mission result in particular. An important goal should be learning how to operate on Mars and addressing answerable questions. A firm start on the latter can be attained by a new mission to Chryse Planitia in the region specified, in which the existing ground truth of the Viking Lander 1 is used to constrain the engineering choices and to design appropriate instrument goals to fully utilize the lander limitations and capabilities. Three proposed sites are indicated on Fig. 1 along with the currently defined landing ellipses. Site E1 is most likely to be similar to VL-1; site E2 is less well constrained and is likely to differ from VL-1 in some respects; and site E3 is likely to be similar to VL-1, but incorporates slightly less hazardous, but slightly different terrain.

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A HIGHLAND SAMPLE STRATEGY FOR PATHFINDER.
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Mission Constraints: Potential landing sites are confined to latitudes between 0° and 30°N and surfaces below 0 km elevation. The landing ellipse is 100 × 200 km oriented N74°E. The constraints essentially eliminate the slopes of Elysium Mons, Olympus Mons, Tharsis Ridge, Lunae Plauum, all the southern highlands, and almost all the Noachian material of Arabia Terra. Those areas that remain as potential landing sites are chiefly lowland plains of Amazonis Chryse, Isidis, and Elysium Planitia.

Siting Strategy: With only two previous Viking landing sites in widely separate locations, almost any landing will provide new data. Viking 1 landed on Chryse Planitia on a surface that is presumed to be Hesperian ridged plains material, which is interpreted to consist of volcanic flows [1]. Viking 2 landed on knobby material in Utopia Planitia, which is interpreted as eolian and volcanic materials [2]. The large landing ellipse precludes a finely targeted sampling strategy. Several site selection strategies are equally valid. Presumably, Noachian materials are more representative of the geochemical character of the planet than the volumetrically less important surficial flows and sedimentary materials.

Any attempt to sample highland material further constrains the possible landing sites by eliminating areas of Hesperian or Amazonian lavas and sediments. Materials of possible Noachian age are primarily located above 0 km elevation and at southern latitudes, except for minor occurrences in Arabia Terra and a narrow zone along the southern edge of Elysium Planitia.

One possible sampling strategy is to sample materials within those few "highland" terrains that extend to low elevations. Minor occurrences of Noachian materials are exposed at low elevations as

outliers flanked by younger material within Nepenthes Mensas and Aeolis Mensas, but such areas are rugged and unsuitable for a safe landing. However, parts of western Arabia Terra extend to acceptable elevations and are reasonably smooth.

A second strategy is to sample materials at the mouth of an outflow channel that drains from the highlands. Channels may terminate in deltas, alluvial fans, or sheet deposits. For simplicity these deposits will be referred to as "fans." Fans provide materials from a large sampling area, and dissected fans offer the advantage of providing a vertical section of exposed stratification that records the history of the outflow.

On first appraisal, any fan at the mouth of a channel draining from highlands offers a potential target, but not all fans offer equal opportunities. Many outflow channels have ponded along their length; hence, any sediment carried by the discharge at the mouth is derived only from the last site of ponding [3]. Further, although catastrophic outflows are characterized by high sediment load and large caliber, the last sediments deposited during waning discharge are generally fine grained.

Potential Landing Sites: Potential landing sites include outflow channel material at the edge of Chryse Planitia and highland materials bordering southern Amazonis Planitia. The circum-Chryse channels include Kasei Valles into northwest Chryse Planitia; Bahram Vallis, Vedra Valles, Maumee Valles, and Maja Valles into western Chryse; Shalbatana Vallis into southwest Chryse; channels draining from Capri and Eos Chasmata into southern Chryse (Simud, Tiu, and Ares Valles); and Mawrth Vallis into northeast Chryse Planitia. With so many large outflow systems terminating within Chryse Basin, it is probable that any landing site within the basin (including Viking 1 landing site) will be blanketed by sediments from catastrophic outflows or outflow sediments reworked by eolian activity. Channels in southern Chryse Planitia, originating within Vallis Marineris or chaotic terrain south of Chryse Planitia, traverse Noachian material before entering the basin, but they do not provide readily identifiable fans.

Best Bets: Mawrth Vallis of the Oxia Palus region cuts Noachian cratered plateau material, which is interpreted to be largely impact breccia of ancient crust [4]. The plateau surface bordering the lower reaches of the channel, below 0 and -1 km elevation, is one of the few places on Mars where typical highland material can be found below 0 km elevation. Three landing sites are feasible. One potential site is at the mouth of the channel (29°N, 21°W); an alternate site is on the plateau surface adjacent to the valley (28°N, 18°W); and a third site is south of Mawrth Vallis and east of Ares Vallis (2°N, 2°W). The highland site adjacent to Mawrth Vallis is more likely to contain less surficial cover than the site east of Ares Vallis. If not covered by surficial material, highland sites are likely to consist of highly commuted materials; they would provide an estimate of the geochemical character of the homogenized early crust.

The mouth of Maja Canyon (18°N, 50°W), with remnant fan material cut by late-stage discharges [5,6], offers the best channel mouth target. The chief constituents here are likely to be detritus from Noachian material of the Xanthe Terra region carried by outflow that spilled onto Chryse Planitia following ponding behind a barrier massif of Noachian basement material.

Pitfalls and Predictions: The large landing ellipse and low resolution of Viking images do not allow assurance that the landing site will contain any particular anticipated material. Extremely

localized deposits of young materials are possible in the highlands, and mature, winnowed sediments are possible in the plains. Interpretation of chemical analyses of fan materials without corresponding petrologic comparison will be challenging.

In all probability, the final choice of a landing site will be a level lowland within the planatiae. A sedimentary surface of an essentially monomineralic, eolian (sand or loesslike) material or a lacustrine deposit should not be a surprise.

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OPPORTUNITY TO SAMPLE SOMETHING DIFFERENT: THE DARK, UNWEATHERED, MAFIC SANDS OF CERBERUS AND THE PATHFINDER 1997 MARS LANDING.

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Dark Material Critical to Understanding Mars Surface: A very important surface component, typically described as “dark gray material” [1], was not seen at the Viking lander sites, but is common to all low-albedo regions on Mars. Dark material probably includes unaltered mafic volcanic and/or crustal rock and soil not coated by dust, weathering rinds, or varnish [2].

A Pathfinder landing in Cerberus (9°N–16°N, 194°W–215°W) will guarantee examination of materials that are distinctly different from the two Viking lander sites. *In situ* study of dark material will provide vital ground truth for orbiter-based observations like those anticipated from Mars '94/'96 and Mars Global Surveyor.

Surface Properties and Regional Context: The Cerberus region is (1) not as rocky as the Viking sites, (2) not blanketed by dust, and (3) offers sampling of a range of rock and soil types including lava flows of different ages, ancient crustal rock, dark sand, bright dust, and possible fluviolacustrine materials. Cerberus lies between 0 and –1 km elevation (± 1 km; USGS 1991 topography), and is large enough to meet our main objective within the landing ellipse constraints. Cerberus is an active eolian environment, but major dune fields are absent and activity is not as vigorous as in Syrtis Major [3]. The landing will occur in northern summer, a period when predicted winds are not at their strongest in the region [4].

The dark surfaces have low albedos (<0.15) and intermediate thermal inertias [5] ($300\text{--}400\text{ J m}^{-2}\text{ s}^{-0.5}\text{ K}^{-1}$), which indicate that much of this material is sand ($100\text{--}1000\text{ }\mu\text{m}$). Rock abundance [6] varies from ~12% in the east, where the surface has many knobs and mesas, to ~1% in the west, with average over most of Cerberus ~7%. (Viking 1 rock abundance was ~10% and Viking 2 was ~20% [5]).

The dark soil of Cerberus is superposed on several different geomorphic features. Central and western Cerberus is underlain by Early Amazonian volcanic flows originating on the Elysium Rise [7]. Cerberus is bounded in the south and east by interpreted paleolake deposits [7,8] and very recent (0 to 700 Ma) lava flows [9]. Eastern

Cerberus includes a smooth surface of Late Amazonian fluvial, lacustrine, and/or volcanic deposits [7–9] and Noachian(?) mesas and knobs of the Tartarus Colles [7].

Dark Material and Source: Dark sand has been transported through and deposited within Cerberus [3,10,11]. Lateral variation in sand deposit thickness is probable, with sand filling low areas on and between lava flows. Dark material has blown from east to west over the lava flows of southern Elysium, perhaps making Cerberus similar to the Amboy volcanic field of Southern California. Amboy has lava flows overlain by windblown sand stripped from an upwind dry lake [12].

Dark material might be eroded from sediments of the proposed lacustrine basin [8] east of Cerberus. Alternatively, the sand may have a volcanic source, perhaps pyroclastic material from the Elysium volcanos or from eruptions along the Cerberus Rupes fractures. Dark material appears to emanate from some Cerberus Rupes fractures ([11], Viking image 883A09). Do the fractures expose a layer of dark material that is now eroding [10,11]? Did dark material from the east fill the fractures, and now is being deflated? Or were the fractures the sites of pyroclastic eruptions? One fracture seen in the upper left corner of Viking frame 385S23 has a dark, semi-elliptical mantle deposit similar to pyroclastic deposits on the Moon and Io.

Pathfinder Science: Cerberus is large enough that several landing sites could be chosen. Although any landing in Cerberus will satisfy our main objective, we suggest a site near 13°N, 200.5°W (see Viking frame 883A06), because it has both dark material and proximity to the three major geomorphic units in the region (lava flows, possible lake sediments, and knobs of ancient crust). In addition, at this site there is a dark lobe that appears to emanate from a Cerberus Rupes fracture (Viking frames #883A04–06) that might be one of the youngest, unaltered lava flows on Mars. Although not reporting on this specific flow, Plescia [9] proposed that the Cerberus Rupes were the source of some very young lava flows (<700 Ma).

The main objective for a Cerberus landing will be to determine the composition and physical properties of dark soils thought to be derived from unaltered primary igneous crustal material. Characterization of the size, shape, and mineralogy of dark grains 0.1 mm to 10 cm will allow assessment of sediment maturity. Is martian sand formed of ancient, resistant mineral grains or fresher, easily altered material? The answer to this question will place constraints on chemical weathering and eolian abrasion rates. Bright wind streaks in the lee of craters in Cerberus suggest that dust might also be available for sampling, particularly in the lee of meter-scale obstacles. Finally, the presence of sand or granule wind ripples would provide insight into the nature of surface-atmosphere interactions on Mars.

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