ROVER EXPLORATION OF ACIDALIA MENSA AND ACIDALIA PLANITIA: PROBING MUD VOLCANOES TO SAMPLE BURIED SEDIMENTS AND SEARCH FOR ANCIENT AND EXTANT LIFE

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Here we develop a plan to explore mud volcanoes near Acidalia Mensa with an MSL-class rover and propose a traverse based on geologic observations.

Introduction:

Bright pitted cones are common in the northern plains of Mars and have been documented to occur in numerous locations including Acidalia Planitia [1,2,3]. Various interpretations of these features have been proposed but growing consensus in recent literature has favored mud volcanism as the most likely formation mechanism [3,4,5,6,7]. Mud volcanoes are provocative targets for exploration because they bring to the surface sedimentary materials otherwise inaccessible by normal surface exploration [3,8] and can aid in reconstructing the sedimentary history of the northern plains. Also, by sampling fluids and sediments from deep in the Martian crust, mud volcanoes may be among the best places to search for ancient and extant life.

Geologic Setting

The geologic history of Acidalia Planitia can be summarized in five stages (i) basin formed by a mega-impact into early Noachian crust, (ii) volcanic resurfacing by Hesperian ridged plains, (iii) deposition of sediments likely derived from outflow channels, (iv) formation of Vastitas Borealis (ABv), possibly by ocean sedimentation or as a sublimation lag from a frozen water body, (v) Amazonian resurfacing by obliquity-related periglacial processes [9,10,11]. The current surface of the planitia is dissected by kilometer scale polygon-forming troughs, bright pitted mounds and cones, and high concentrations of pedestal and rampart craters, all evidence of a volatile-rich subsurface history [7,12].

Acidalia Mensa is an isolated massif and is one of the highest topographic landforms in the northern plains, exposing the oldest bedrock north of the dichotomy boundary [9]. The mensa is modified by troughs and fractures and is adjacent to a knobby colles indicating a volatile-rich history (Fig.1).

Geologic Observations in Exploration Area

The oldest unit in the exploration area is interpreted to be Nepenthes Mensa (Nn), as mapped by [9, and is comprised of knobs and mesas that erode to aprons of high-albedo material. The unit is dissected by linear troughs that extend tens of kilometers and are several kilometers in width (Fig.1A, white arrows) [13].

The next oldest unit is interpreted to be volcanic that appears to embay Nn, flowing into and filling troughs and craters and will not be accessed by the rover.

Dome and cone shaped high-albedo mounds occur south of the mesa and are interpreted to be mud volcanoes. The mounds often express one to several muted central depressions or vents and occasionally are associated with flow-like protrusions (Fig. 1B,C). The features have a CRISM [14] visible spectral response best matching ferric oxide coatings, consistent with previous observations of similar mounds [3].

The mounds are located within a low-albedo unit having concentric flow features with lobate margins and is interpreted to be younger than the mounds, although evidence for the stratigraphic relationship remains unclear. This unit contains circular to quasi-circular features of that appear to be collapsed domes, possibly of relict mud volcanoes. The domes are up to 6 km in diameter and are often associated with topographic highs and occasionally have mud-like flows protruding from their rims (Fig. 1D).

The youngest feature is a ray of ejecta and secondary craters emanating from Bonestell Crater ~160 kilometers to the southeast that superposes all other units.

Table 1. Summary of exploration parameters.

Name	Acidalia Mensa
Ellipse Center Lat/Long	44.58°N, 331.48°E
Ellipse Elevation	-4650 meters
Launch Window	Summer 2024
EDL/Traverse	Assume MSL capability
Primary Science Targets (minimum distance from ellipse)	Mud volcanoes (6km), Noachian Acidalia Mensa Scarp (3km)
Landing Hazards	Few sub-km craters (5% total area)
Dust Cover Index	~0.9674 (low-med)
Ellipse Slopes (10m)	<1° to the South
Rock Abundance	Approx. ~1%

Outstanding Questions to be Addressed in Exploration

(1) What is the nature of the supposed mud volcanoes? Do they contain organics? What can they tell us about the sedimentary history of the northern plains? (2) How did Acidalia Mensa form? What was the role of volatiles? (3) What is the composition of the younger flow unit (mud or volcanic)? How does it relate to the mounds? What are the composition and origins of the collapsed domes? (4) How have tectonics shaped the Nepenthes Mensa unit and the formation of troughs on the mensa? (5) What is the nature of the

interaction of ejecta rays and secondary craters with preexisting terrains?

Exploration Plan:

A traverse has been formulated that would address the main science questions within two Martian years allowing time for winter 'hibernation' (Fig. 1). Upon arrival at each scientific target detailed measurements of bulk chemistry, mineralogy, grain size, and sedimentary structures if applicable will provide geologic context and allow for correlation of materials among different locations along the traverse. A possible payload of instruments would include a similar suite to MSL including color and hyperspectral imaging cameras, a microscopic imaging camera (preferably with the ability to detect microfossils), mass and laser spectrometers, gas chromatograph, XRD/XRF, and rock abrasion tools.

Upon landing on the mensa the rover will assess its surroundings and perform chemical analyses to determine the composition and origin of the landing materials. After ~75 days and 6 kilometers of traverse the rover will encounter the first science target – a string of secondaries from Bonestell superimposed on the landing materials. After a brief investigation of secondary impact processes the rover will begin to descend off the mensa during which it can sample the scarp of the Nepenthes Mensa unit, looking for any sedimentary structures and evidence of water.

At the base of the mensa the rover will and arrive at its first mud volcano (Fig. 1A) after a traverse of around 15 kilometers and 300 days of surface operations. Here the rover will perform detailed analyses of mound materials, possibly accessing the interior. If it is a mud volcano, the rover should administer the full-suite of analyses on the matrix material as well as a collection of 5-10 different clasts. These analyses would include a search for organics in samples with the best preservation potential and analysis of aqueous indicators (hydrated minerals, structures). Next the rover would travel towards the largest flow feature after 22-km of traverse (Fig. 1B), taking time along the way to investigate the proposed collapsed domes. Similar analyses will be made at subsequent mud volcanoes, with attention to sedimentary structures and possible flow events. The rover will continue to traverse over flow materials towards the mound that best represents similar features elsewhere on Mars (Fig. 1C), at 27-km. Here the rover will attempt to drive to the central edifice of the mound to explore a potential vent. The final exploration target is a lobate structure emanating from collapsed dome feature (Fig. 1D).

Possible long-term targets include more mud volcanoes, isolated mesas and knobs in the plains (potentially a 'layered' mesa to the west), more of the scarp of Acidalia Mensa, and a nearby gullied mesa.

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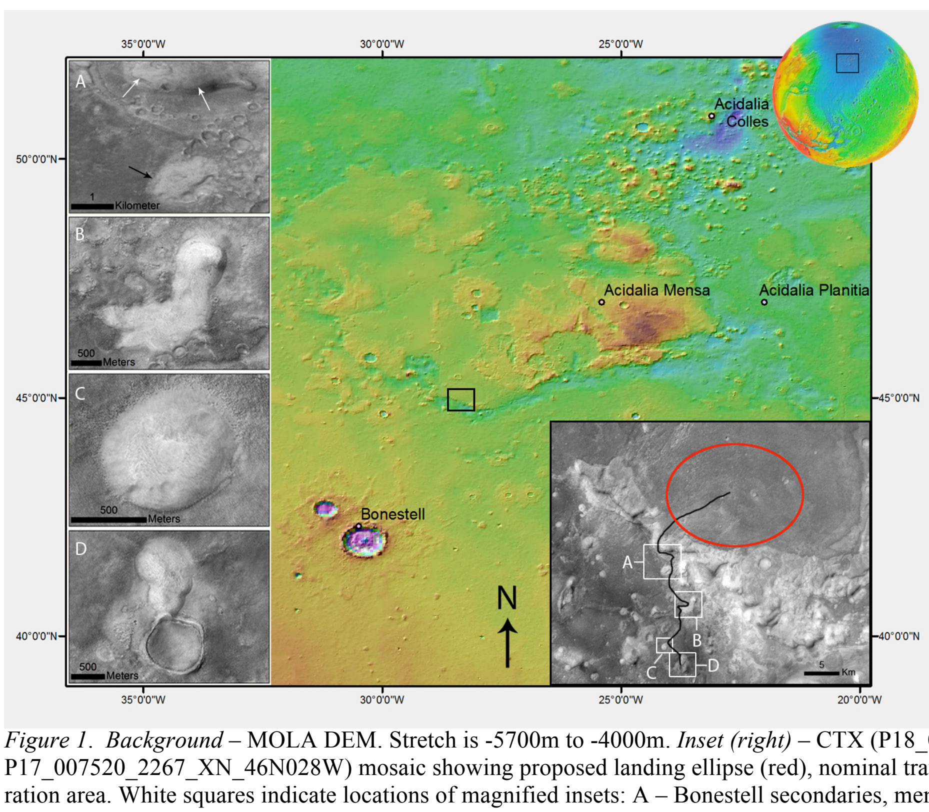

Figure 1. *Background* – MOLA DEM. Stretch is -5700m to -4000m. *Inset (right)* – CTX (P18_007889_2288_XI_48N023W, P17_007520_2267_XN_46N028W) mosaic showing proposed landing ellipse (red), nominal traverse (black), and context of exploration area. White squares indicate locations of magnified insets: A – Bonestell secondaries, mensa scarp (white arrows), and first mud volcano (black arrow), B – Mound with extensive flow feature, C – well-formed mound with central edifice and vents, D – flow-like feature protruding from enigmatic annular raised-rim feature (B, C, D – HiRISE image ID ESP_018649_2250).