VOLCANO COLLAPSE ON MARS: A POSSIBLE SOURCE FOR SEDIMENTS IN GALE CRATER?

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Introduction: On Earth, catastrophic sector collapse of volcanoes is relatively common, occurring once every ~25 years [1], including at Mount Saint Helens in 1980 and at Anak Krakatua in 2018. In the geologic record, volcano sector collapse is identified by an amphitheater-shaped reentrant into the edifice in association with a large debris avalanche deposit displaying hummocky topography with numerous small hills and closed depressions and longitudinal and transverse ridges [1]. Geomorphic features associated with volcano sector collapse, involving the heart of a volcano have not previously been identified on Mars.

We here consider a feature we call North Gale Landform (NGL) located near the Mars dichotomy boundary and ~60 km north of Gale crater (Fig. 1), the site of the Mars Science Laboratory (MSL) Curiosity rover. We propose NGL is a volcanic landform that experienced catastrophic sector collapse and discuss the origin of a hummocky terrain extending from NGL toward the Gale crater rim. Materials transported by mass movement from NGL may have remobilized and deposited as sediments in Gale.

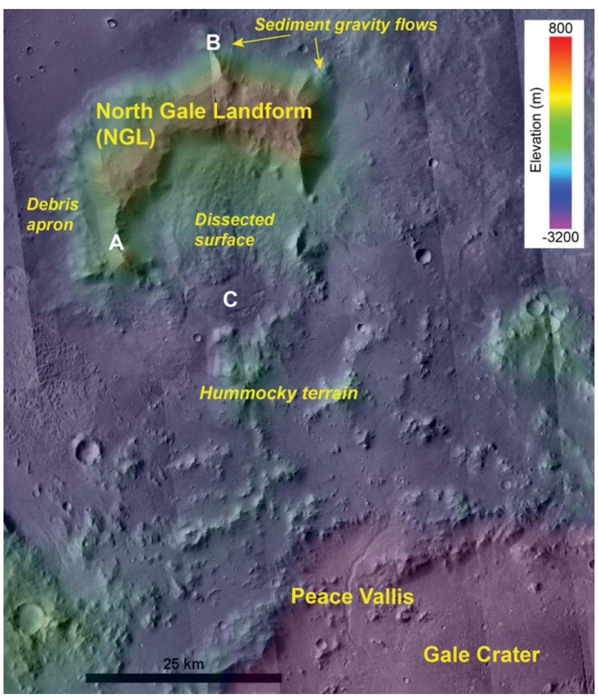

Fig. 1. Regional map surrounding NGL. CTX images [2] with MOLA elevation data [3]overlain.

Methods: Mars surface morphological information is provided by the Mars Orbital Laser Altimeter (MOLA) [3], the High Resolution Stereo Camera (HRSC) data [4], Context Camera (CTX) [2], and High Resolution Imaging Science Experiment (HiRISE) [5]. The region is too dusty for mineralogical interpretation from orbital datasets.

Physical Description of NGL: The arcuate-shaped, quasi-circular NGL (Fig. 1) is 44 km in diameter with a 3.2 km maximum relief above the surrounding terrain (581 m vs. approx. -2700 m). A capping geomorphic unit with a mottled surface, scarce craters, and rocky margins erodes as tightly spaced, branching spurs that project into steep talus slopes (up to 25˚) found on all sides of the NGL (Fig. 2A). A large amphitheater-shaped re-entrant (~25 x 20 km) opens to the south. The amphitheater interior has a dissected surface morphology and sits 700 to 155 m below the capping unit, sloping ~5˚ and dropping ~1500 m over ~17 km. The steep headwall of the amphitheater is consistent with formation by removal of a large volume of material that we estimate to be 470-530 km^3, assuming an original mesa-like morphology.

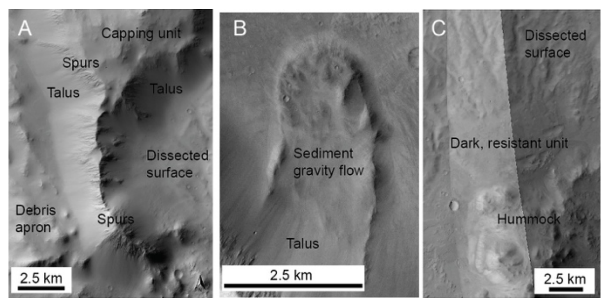

Fig. 2. CTX images of representative NGL surface morphologies. Image locations are in Fig. 1.

The slopes surrounding NGL are characterized by a variety of mass wasting features and deposits. Outer talus slopes have no craters, suggesting ongoing or relatively recent ground movement, while talus slopes around the interior of the amphitheater have a few small elliptical craters. A knobby unit interpreted to be an accumulated debris apron originating from the capping unit occurs below the talus slopes on the western exterior of NGL and northeastern interior of the amphitheater. Several relatively small landslides also occur around the margins of NGL, including a well-preserved, ~5 km-long, sediment gravity flow on its north flank (Fig. 2B). The mass wasting and few craters on all sides of NGL suggests the landform is comprised of poorly consolidated materials and is experiencing ongoing structural collapse.

Hummocky Terrain: An abundance of hills called hummocks of diverse morphology separated by depressions are hosted within a broad fan-shaped area, spanning the 58 km between NGL and Gale crater rim

(Fig. 1). Irregularly shaped hummocks have a higher boulder density and may retain a few small craters, while other, smooth to mottled hummocks are surrounded by talus and debris aprons. Transverse ridges appear comprised of multiple, irregular hummocks, rather than a continuous unit such as is observed in ejecta elsewhere around Gale crater. The ridges roughly parallel Gale rim, and their orientations may be an artefact of the Gale impact. Alternatively, the transverse ridges may have formed by southward-directed debris avalanche sourced from NGL.

Depressions between hummocks appear smoother with fewer craters than elsewhere around Gale rim and may contain sinuous to dendritic channel networks, which are evidence of late (Amazonian?) fluvial modification [6]. A dark, smooth (lacustrine?) unit containing dissected channels that appear sourced from dissected surface of the NGL amphitheater overlies and/or surrounds the northernmost hummocks (Fig. 2C).

An analysis of 766 hummocks discernable in CTX and HRSC images revealed hummocks range up to 1026 m in relief with 4 of the 5 largest found within 12 km of NGL. This size distribution suggests the hummocks may not entirely originate as Gale ejecta since ejecta ramparts do not typically exhibit such high relief [7]; at least the larger northernmost hummocks may derive from collapse of NGL.

Volcanic Origin of NGL: NGL (581 m) stands apart and above the surrounding terrain, and is unlike other dichotomy landforms. Platform mesas of Aeolis Mesae located east along the dichotomy boundary are internally stratified, lack erosional spurs, and sit at much lower elevations (-643 to -49 m). Other nearby features of comparable elevation include Aeolis Mons (787 m) and the southern rim of Gale crater (1345 m) and are clearly unrelated to NGL.

NGL is also probably not of impact origin. The 3.2 km relief of the amphitheater rim above surrounding terrain, as well as its south-sloping floor is unlike craters of comparable size. NGL lacks other features characteristic of impact structures of its size, including concentric ring fractures, shattered/damaged walls, central peak, or associated ejecta blanket.

As NGL cannot be explained by other hypotheses, we consider a volcanic origin using criteria by [8]. The size, slope (25˚), and height/width (0.07) of NGL are within range of terrestrial stratovolcanoes and similar to the Martian stratovolcano Zephyria Tholus [9]. The dissected surface of the amphitheater floor is consistent with being underlain by weak, pyroclastic materials.

Volcano Collapse: Stratovolcanoes are built relatively quickly of loose, fragmental materials; it takes ~1-5% of active lifetime for terrestrial stratovolcanoes to build a cone at a rate of 1-5 km^3/ky during its edifice-building phase [10]. The remaining lifespan and subsequent erosion is destructive, working to remove the edifice. The high relief and abundant evidence of mass wasting at NGL is consistent with rapid construction followed by prolonged collapse.

The NGL amphitheater in association with hummocky topography at NGL (Fig. 1) satisfies criteria for a sector collapse volcano. The topographic profile of NGL is like profiles of terrestrial stratovolcanoes that have experienced catastrophic sector collapse (Fig. 3).

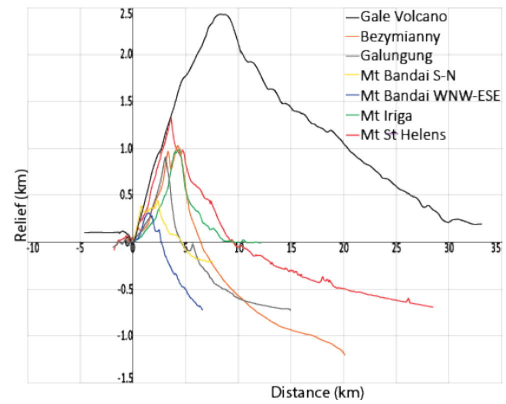

Fig 3. Profiles of NGL (HRSC) [4] and 6 terrestrial sector collapse stratovolcanoes [11]. Profiles are in direction of debris avalanche.

Did Debris Reach Gale Crater?: If the hummocky terrain in part contains materials derived from collapse of NGL, a runout efficiency (runout length / descent height) of 4-11 (13.7 to 4.3 km height, respectively) would allow the debris avalanche to reach Gale crater (58 km away); these values are within accepted runout efficiencies for landslides on Mars (2 – 23). At minimum, collapse of NGL plausibly contributed volcaniclastic materials to the Peace Vallis catchment that may have been carried into Gale crater. There is an intriguing possibility however, that NGL debris reached into Gale, contributing geochemically distinct, likely coarse-grained sediments with igneous compositions (such as the Jake M group [12]).

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References: [1] Siebert, L. (1984) *J. Volc. Geotherm. Res., 22,* 163-197. [2] Malin, M.C., et al. (2007) *JGR, 112,* E05S04. [3] Smith, D. et al. (1999) *NASA PDS,* MGSL_0001 - MGSL_0002. [4] Neukum, G. et al. (2004) *ESA Spec. Publ.,* 1240, 17-35. [5] McEwen, A.S. (2007) *JGR, 112,* E05S02. [6] Newsom, H.E. et al. (2019) 9th Intl. Conf. on Mars, Abstract #6119. [7] Komatsu, G. et al. (2007) *JGR 112* E06005 [8] Stewart, E.M. & Head, J.W. (2001) *JGR,* 106, 17,505-17,513. [9] Grosse, P. et al. (2014) *Bull. Volcanol.* 76, 784. [10] Thouret, J.-C. (1999) *Earth-Sci. Rev.*, 47, 95-131. [11] Google Earth. [12] Schmidt, M.E. et al. (2014) Lunar Planet. Sci. Con. 45, Abstract #1504.