STRUCTURAL AND MORPHOMETRIC CONTROLS ON THE ORIGINAL FORM OF THE GALE IMPACT STRUCTURE: TERRESTRIAL CONSTRAINTS FROM VREDEFORT, CHICXULUB, AND SUDBURY. John G. Spray, Planetary and Space Science Centre, University of New Brunswick, Fredericton, NB E3B 5A3, Canada. jgs@unb.ca

Introduction: The form of the Gale impact structure is poorly constrained due to the extensive sedimentary cover that buries it. With an apparent collapsed rim diameter (D_{ARIM}) of 155 km, the Gale impact structure is comparable in size to the three largest known impact structures on Earth: Vredefort, Chicxulub and Sudbury. Together, these terrestrial structures provide insight into Gale's morphometry.

Terrestrial Benchmarks: The three terrestrial structures afford complementary perspectives on internal structure and morphometry due to their different states of preservation. Vredefort, with a D_{ARIM} of ~160 km, is eroded to approximately 10 km below original surface to reveal its central core structure, which is reasonably well exposed [1]. Chicxlulub (with a rim diameter of 150 km), is buried and well-preserved, such that its morphometry is largely intact, though it remains inaccessible other than by drilling [2]. Sudbury (D_{ARIM} ~130 km) is highly deformed, having been both folded and thrusted, but retains a complete impactite section, which is exposed and accessible [3]. All three terrestrial craters possess two concentric ring systems beyond their rims at 200 and 300 km (Vredefort); 190 and 240 km (Chicxulub) and 180 and 240 km (Sudbury). These rings do not imply that they are multi-ring basins (although such rings remain a little considered feature of relatively small complex impact structures on Earth [4]). Rather, all were probably peak-ring structures. All three have basement uplifts of 80-90 km diameter (i.e., elevated basement underlying original morphometric features), which is exposed at Vredefort.

Implications for Gale: By combining field and geophysical evidence from these three terrestrial impact structures, it is possible to provide constraints on the original form, size and shape of Gale. This is important from a number of perspectives: (1) determining a likely morphometry for Gale following impact; (2) considering impact melt volumes and associated hydrothermal system size and longevity; (3) assessing the existence of rings beyond the rim.

These insights have to be considered in the light of different gravitational fields of Earth versus Mars with respect to the modification stage of the impact process (including ring diameters). In order to derive a 155 km rim diameter crater on Mars, approximate impactor requirements would be a 8-10 km diameter rocky projectile (or a 5.5 km iron projectile) impacting at 11 km/s [e.g., 5]. This results in a peak-ring structure. However, on Mars it is known that there is an overlap between protobasins (e.g., 90 – 300 km rim diameter) and peak-ring structures (e.g., 100 – 450 km rim diameter) [6], such that Gale may have possessed a protobasin (central peak with peak-ring) or peak-ring (no central peak) form. If a protobasin, then it would be comparable to Holden (Fig. 1a), if the latter then similar to Lowell (Fig. 1b), although neither is pristine.

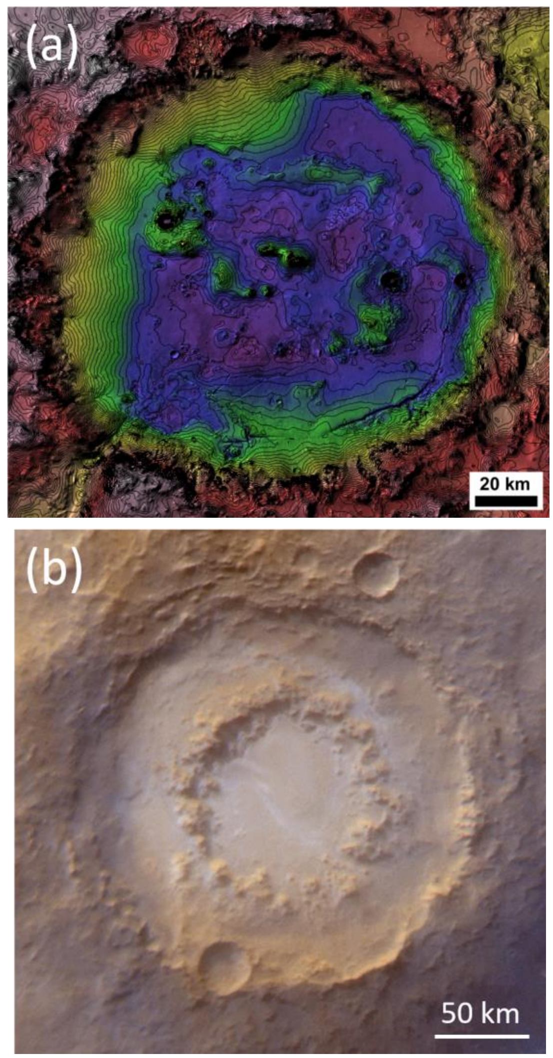

Figure 1. Gale impact structure shape comparisons: (a) Holden protobasin, Mars (~150 km rim diameter). Source: Planetary Science Institute, Tucson; (b) Lowell peak-ring, Mars (~200 km rim diameter). Source: USGS Astrogeology Research Program, Flagstaff.

The form of Gale may assist in providing controls on post-impact sedimentary processes (e.g., did a peak ring structure provide a supportive annulus wall for the development of the sedimentary central mound?); did the hydrothermal system drive fluid circulation, secondary mineralization and vein precipitation within the overlying sedimentary column? Did isostatic adjustments lead to faulting over 10s to 100s of millions of years following the impact, causing the reactivation of concentric failure zones and pre-impact fault systems?

Protobasin or Peak-ring: Peak-ring diameter is typically approximately half that of the rim diameter, which would result in a ring with ~77 km diameter at Gale. This is not presently apparent (i.e., south of the mound), so if such a ring was present then it has been either eroded, or is buried. There is a central mound present in the very centre of Gale (exposed as a 10 km-diameter peak), which defines one of the highest points in the structure, and this may indicate a central peak structure. If so, then this would favour Gale being a protobasin, assuming the peak-ring is buried or removed. Given its size, it is unlikely to have been a central peak structure, as these are typically <150 km diameter [7] (i.e., no peak-ring structure originally formed).

Thermal effects: By comparison with Sudbury, the impact melt sheet at Gale could have been 2-3 km thick and in excess of 120 km diameter. The melt body would have been initially superheated to well over 2000 ºC. Thermal calculations indicate cooling to complete crystallization taking ~100,000 years, and attaining ambient temperatures in ~1 million years [e.g., 8]. Gale's impact melt sheet would have been a driver for ice melting and water circulation via hydrothermal convection for up to ~1 Ma. During this time there would have been potential for bulk metasomatic alteration within, below and above the melt sheet, and precipitation of various mineral species from fluids into veins, fractures and faults. In order to influence overlying sedimentary sequences this would require sedimentation to have rapidly followed the impact event. Heat from the cooling impact melt sheet could have facilitated and accelerated lithification processes in the overlying sedimentary sequence (i.e., driving diagenesis), and sustained warm, briny lakes that precipitated evaporites. However, the temporal window for this thermal anomaly is considered limited (~1 Ma).

Rings beyond the rim: Given the age of Gale (~3.8 Ga) and the eroded and modified state of the surrounding terrain, evidence of concentric structures beyond the rim, which are indicated at Vredefort, Chicxulub and Sudbury, are seemingly absent. However, if ever present, they would likely occur ~195 and ~270 km diameters. These may have originally been manifest as scarps that influenced regional fluid flow and drainage patterns.

Summary: It is possible that Gale was a central peak structure, but its size would tend to favour it having originally formed as a peak-ring basin or protobasin [e.g., 6,7]. Remnants of a peak-ring are not apparent: it has either been eroded away or buried, but there may be indication of a surviving central peak. Comparisons with the Vredefort, Chicxulub and Sudbury impact structures will be discussed with respect to the probable original form of Gale, as well as its internal (subsurface) structure, impact melt sheet volume and cooling history, and associated potential hydrothermal influences on overlying sedimentary materials.

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References: [1] Gibson R. L. and Reimold W. U. (2008) *Council for Geoscience, South Africa, Memoir 97*, 181. [2] Kring et al. (2017) *GSA Today*, 27, doi: 10.1130/GSATG352A.1. [3] Spray et al. (2004) *Meteoritics & Planet. Sci., 39*, 287-301. [4] Thompson L. M. et al. (2010) *LPS XLI*, Abstract #2712. [5] https://www.open.edu/openlearn/science-maths-technology/science/physics-and-astronomy/astronomy/crater-calculator/ [6] Baker D. M. H. (2016) *LPS XLVII*, Abstract #3046. [7] Barlow N.G. [2008] *Camb. Uni. Press.* 264 p. [8] Prevec S. A. and Cawthorn R. G. (2002) *JGR Solid Earth*, *107*, https://doi.org/10.1029/2001JB000525