Topographic evidence for lakes in Gale Crater. W. E. Dietrich[1], T. Parker[4], D.Y. Sumner[5], A Hayes[1,2], M. C. Palucis[1], R.M.E. Williams[3], F. Calef[4], and the MSL team, [1]Department of Earth and Planetary Science, University of California, Berkeley, CA, bill@eps.berkeley.edu and mpalucis@berkeley.edu, [2]Department of Astronomy, Cornell University, Ithaca, NY, hayes@astro.cornell.edu, [3]Planetary Science Institute, Tucson, AZ, Williams@psi.edu, [4]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, Fred.Calef@jpl.nasa.gov and timothy.j.parker@jpl.nasa.gov, [5]Department of Geology, University of California, Davis, Davis, CA, dysumner@ucdavis.edu,.

Introduction: Many have suggested that Gale Crater may have contained one or more lakes (see review in [1], presentations in [2,3] and recent paper [4]). Here we exploit imagery and topographic data compiled for the Curiosity mission and build upon these previous suggestions to identify three probable lake levels that occupied large portions of the crater. We also suggest the possibility of former shallow lakes near the landing area

Methodology: We used two orbital datasets for topographic analysis. For areas within the landing ellipse [5] and on Peace Vallis fan, we used 1-m/pixel georeferenced Mars Reconnaissance Orbiter (MRO) HiRISE images and DEMs and orthophotos that were generated by the USGS Astrogeology Center in Flagstaff, Az. Context Camera (CTX) imagery was used to locate topographic features.

Evidence for former lake levels consists of deltas, morphologic changes from canyons to local fan deposits, and topographic benches. We describe the possible lake levels from highest to lowest, and hypothesize that this also records a time progression in lake levels because of preservation patterns.

Highest level (~-2100 m) lake: Mt. Sharp is flanked by broad, gently sloping terrace-like features that are approximately the same height as the northern rim of the crater. The terrace-like features have previously been interpreted as generated by wind scour [6] or cut by shoreline processes [7]. Distinguishing between these models is difficult, and we did not indentify any evidence of scour or depositional features suggesting spillage from or into Gale Crater along the northern rim that would occur at this high water level. However, other observations hint at a former lake, including bedform-shaped features on the terraces in HiRISE images that are consistent with subaqueous deposition. In addition, a 9 km long, roughly 1 km thick exposure of inclined layers just below the terraces, visible in CTX and Mastcam images, may record an ancient delta. A deltaic interpretation is problematic, however, in that there is not an obvious sediment source other than reworked Mt. Sharp deposits. If these beds were deposited subaqueously from reworked Mt. Sharp sediments, the lake level would have been well above the northern rim. This high lake level is very roughly coincident with the Di Achille and Hynek [8] proposed mean ocean level of -1848 m. Although such a lake or ocean is highly speculative, it is consistent with geomorphic observations within Gale Crater.

Second level (~-3300 m) lake: As noted by Irwin et al. [9], a prominent delta developed into the southwestern corner of Gale crater. The delta is a dark-toned, ~18 km accurate feature that is ~100 m high. The delta level roughly corresponds to the lower ends of inverted channels on the south side of Mt. Sharp and to a distinct bench on the northeastern side of the crater. To the west of the delta, a canyon drains roughly 270,000 km^2 to the south, which may have contributed to delta sedimentation. A lake occupying current topography to this height would have been about 5830 km^2 in area with a mean depth of 650 m.

Third level (~-3780 m) lake: This is morphologically the best defined lake. At the southern end of Gale, where the large canyon enters the crater, there is a distinct bench downslope of a fan or delta at -3780 m. Tracing this elevation along the wall of the crater and Mt. Sharp reveals other corresponding benches, another fan delta, and several places that correspond to a benched downslope transition from canyon to fan-like deposition. This level also roughly corresponds to mapped boxwork features in Mt. Sharp deposits. This lake would have a circumference of 400 km and would have been confined to the northern and eastern sides of Mt. Sharp The mean lake depth would have been about 170 m.

Possible shallow lakes, Glenelg area: Peace Vallis cuts a canyon 500 m below the third proposed lake level before reaching the current fan head. The Peace Vallis fan enters into a closed basin downslope toward Glenelg [10], which is 670 m below the third lake level. Ridges exposed in the fan are likely inverted channels, averaging 27 m in width (for some 43 channels). The fan continues to the second lowest area of the crater near Glenelg, and given that it drains to a terminal basin, it seems highly probable that shallow lakes may have episodically formed there. Very low gradient, heavily cratered topography in this area may be underlain by relatively coherent lake sediments.

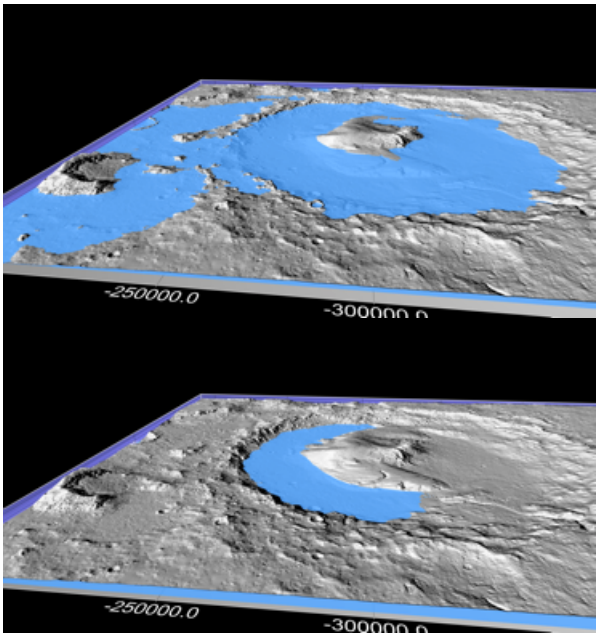
Discussion: The simplest interpretation of this succession of lake levels is that the crater filled with water and then the lake level progressively fell, perhaps stalling at two levels long enough to create a topographic record of the shoreline. The two lower deep lakes are marked by deltas at the mouth of the large canyon entering from the south, hence the southern

uplands likely served as a source of water as well as sediment. These deltas are modest in size compared to the possible drainage area. The three high lake levels would have caused saturation of the deposits in Mt. Sharp and in the crater walls. As lake levels in Gale decreased, the low area immediately adjacent to the Curiosity landing site would have been one of the last areas to dry out. The fan postdates the three high lake levels [10].

Summary: HiRISE, CTX and MRO data provide imagery and topographic data for Gale Crater that suggest at least three distinct lake levels. Extensive shallow gullying and formation of the Peace Vallis fan followed these high lake levels and may have contributed to shallow localized transient lake formation along the floor of the crater.

References: [1] Anderson and Bell (2010) *Mars Informatics, 5*, 76-128 [2] Sumner D (2010) 5th MSL Landing Site Workshop, May 17, 2010 [3] Parker T. (2007) *marsoweb.nas.nasa.gov/landingsites/msl* [4] Schwenzer S.P. Planetary and Space Science 70 (2012) [5] Grotzinger J. et al. (2012) *Space Science Reviews, 140*, 5-56 [6] Pelkey S.M. et al. (2004) *Icarus, 167*, 244-270 [7] Cabrol et al. (1999) *Icaruc, 139*, 235-245 [8] Achille G. and Hynek B.M. (2010) *Nature Geoscience*, 3, 459-463 [9] Irwin R.P. et al. (2005), *JGR, 110*, E12S15 [10] Palucis M.C. et al. (2013) *LPSC XXXIV*, Abstract XXXX

Figures:



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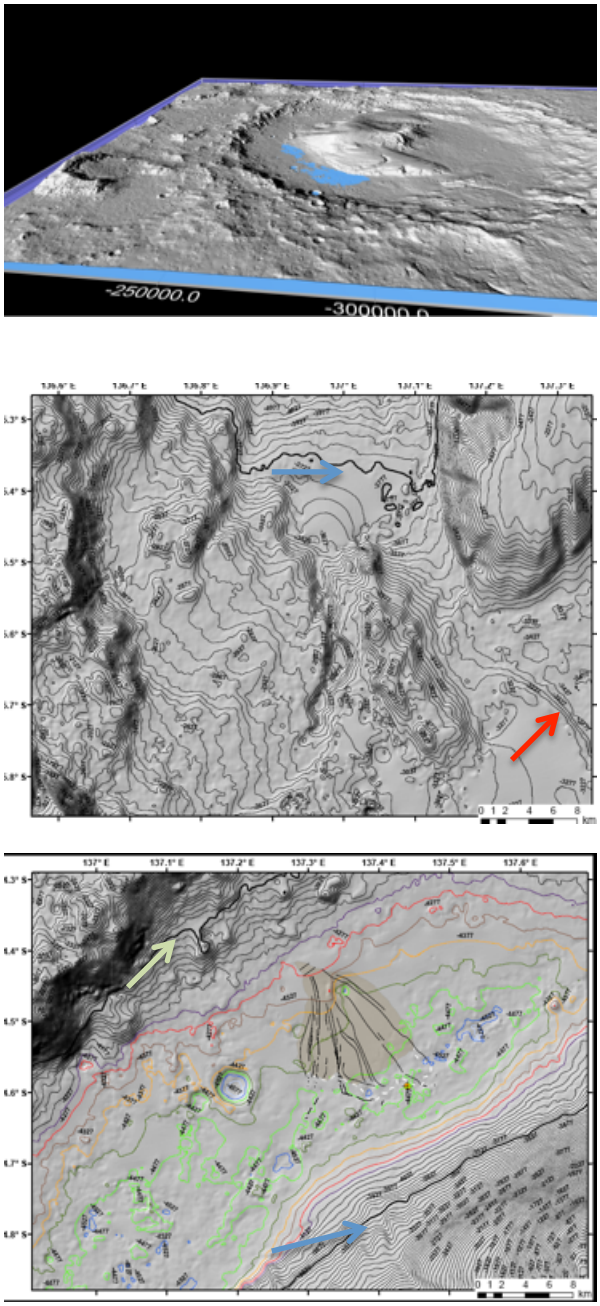

Figure 1: Three lake levels at Gale: at -2277 m spilling over the northern rim, at -3380 m where most consistent morphologic features are found, and at -4477 m infilling local closed depressions.

Figure 2. Topographic maps with heavy line showing the -3777 m contour. In the upper panel the two arrows point to the two prominent delta at different levels associated with the large canyon entering from the south. The lower panel shows a typical bench (upper arrow) and canyon to fan morphology at the inferred shoreline transition. Also shown is the coase outline of Peace Vallis fan (shaded) black lines depicting flow paths and 50 m contour interval colored to show local topography and closed depression at toe of fan.