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Origin of circular collapsed landforms in the Chryse region of Mars

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ABSTRACT

The quasi-circular collapsed landforms occurring in the Chryse region of Mars share similar morphological characteristics, such as depth of collapse and polygonally fractured floors. Here, we present a statistical analysis of diameter, maximum and minimum depth, and amount of collapse of these features. Based on their morphometric characteristics, we find that these landforms have a common origin. In particular, the investigated landforms show diameter-depth correlations similar to those that impact craters of equivalent diameters exhibit. We also find that the observed amount of collapse of the collected features is strongly correlated to their diameter. Furthermore, the linear relation between minimum filling and pristine depth of craters, the constant ratio between collapse and the amount of filling and the fractured and chaotic aspect of the filling agree with melting and subsequent collapse of an ice layer below a sediment layer. This interpretation is consistent with a buried sub-ice lake scenario, which is a non-climatic mechanism for producing and storing abundant liquid water under martian conditions.

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1. Introduction

Numerous quasi-circular collapsed features are present in the Chryse region of Mars and they share similar morphological characteristics (Fig. 1): deeply collapsed quasi-circular areas with intensively fractured floor characterized by polygonal tilted blocks very different in size (Chapman and Tanaka, 2002; Glotch and Christensen, 2005; Rodriguez et al., 2005b; Meresse et al., 2008). It has been suggested that these circular landforms originated from the collapse of buried impact craters and can occasionally merge together forming larger chaotic terrains (Sato and Kurita, 2005; Rodriguez et al., 2005a). Despite that, different classifications of these objects occur in the literature. Some of them are classified as (Fig. 1a) chaotic terrains (Carr et al., 1973; Sharp, 1973; Carr, 1980; Rotto and Tanaka, 1995) and other as (Fig. 1b) floor-fractured craters (FFC, Schultz and Orphal, 1978; Korteniemi, 2003; Korteniemi et al., 2006). The third types includes circular collapsed features with fractured and broken floor within larger chaotic terrains (Fig. 1c and d). This is important, because different classifications are the basis for different explanations for their origin (see Bamberg et al. (2014) for an extensive review).

Based on their similarity with lunar FFC, Schultz and Orphal (1978) suggest uplift and fracturing of crater floor and filling sediment consequent to the rising of magma intrusion underneath the crater. The high amount of collapse can be explained by the withdrawal of magma sills or by the subsidence produced after the water discharge from the melted cryosphere (Sharp, 1973; Cabrol et al., 1997; Chapman and Tanaka, 2002; Ogawa et al., 2003; Leask et al., 2006; Meresse et al., 2008). More commonly proposed scenarios are based on the increase in pressure of global aquifer with consequent disruption of the cryosphere and fracturing, followed by intensive groundwater discharge and removal of sediment by water, that would explain the collapse (Carr, 1979; Clifford, 1993; Andrews-Hanna and Phillips, 2007; Marra et al., 2014a,b). Sato et al. (2010) propose a model of earth fissuring of sediments within the crater as result of differential compaction consequent to the increase of groundwater level. The groundwater piping active below the crater floor toward the rims would be responsible for the collapse. Some authors have highlighted the role of gas hydrated dissolution and release in the collapsing process (Milton, 1974; Lambert and Chamberlain, 1978; Hoffman, 2000; Komatsu et al., 2000; Tanaka et al., 2001; Max and Clifford, 2001; Montgomery and Gillespie, 2005; Kargel et al., 2007). Warner et al. (2011) suggest a mechanism of subsurface volume loss consequent to the effusion of groundwater to the surface along linear zones of preexisting regional fractures pattern where localized deep basins can develop. Collapse over subterranean groundwater bodies appears to have played a significant role in the generation of chaotic terrains within the study region. Rodriguez et al. (2003, 2005a,b) invoked the drainage of extensive water-filled caverns in southern circum-Chryse as a major causative

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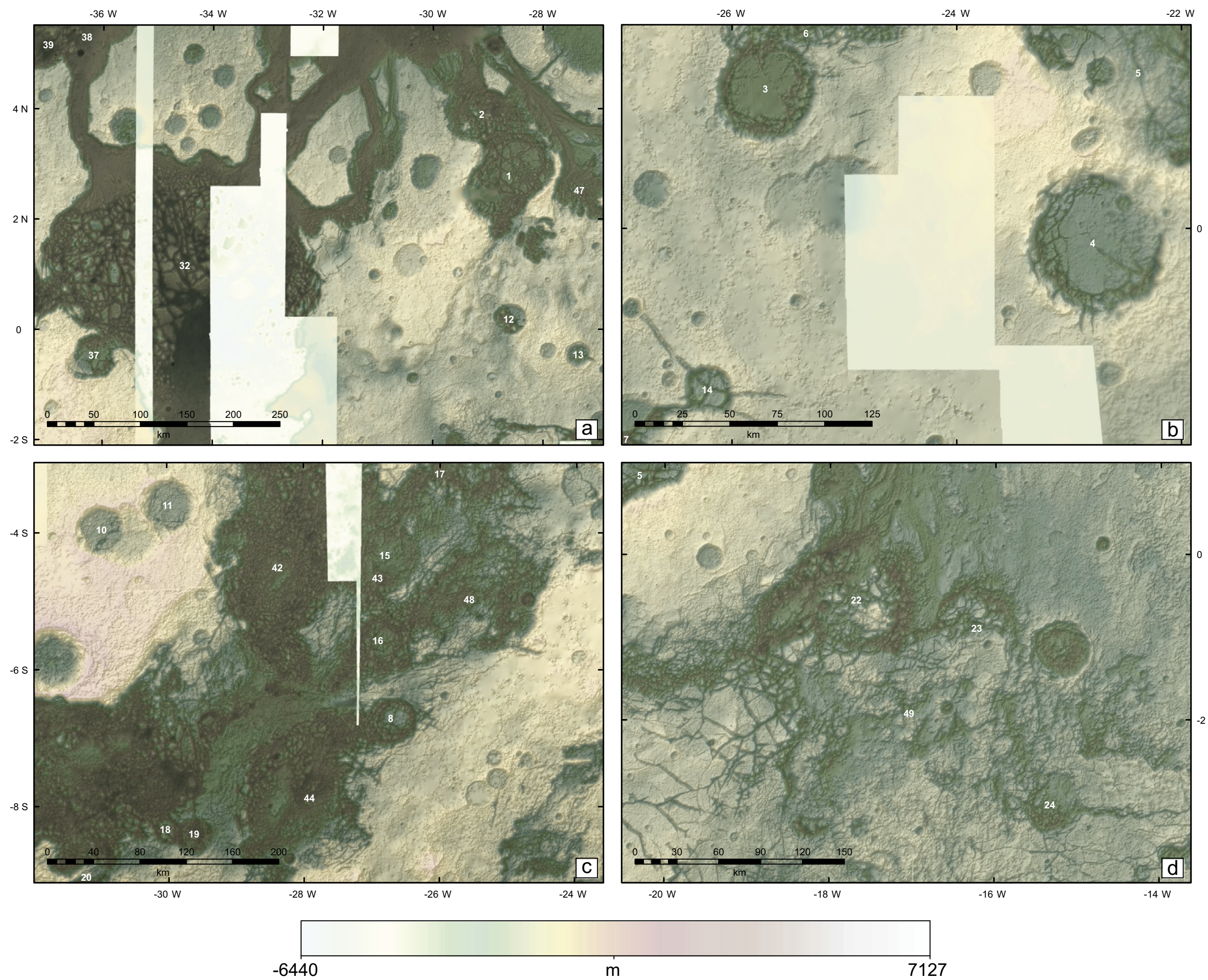

Fig. 1. Some examples of quasi-circular collapsed landforms in the Chryse region of Mars. They all represent deeply collapsed quasi-circular areas with intensively fractured floor characterized by polygonal tilted blocks very different in size. (a) Chaotic terrains (1,2-Hydaspis Chaos; 32-Hydraotes Chaos): they show a quite irregular shape but some circular features are clearly detectable from the distribution of fractures. (b) Floor-fractured craters. (c) Large chaotic terrains (43-Aureum Chaos; 44-Arsinoes Chaos) in which several small circular collapsed features can be detectable. (d) Low collapsed area (49-Iani Chaos) with some small circular collapsed features inside. DTM MOLA mosaic (Zuber et al., 1992) over shaded relief HRSC images (Jaumann et al., 2007).

condition leading to regional highland collapse. In subsequent investigations, Zegers et al. (2010) and Roda et al. (2014) identified geologic evidence indicative of chaos generation resulting from the collapse of sedimentary strata into underlying subsurface lakes.

Although all proposed scenarios predict fracturing and collapse, they are expected to result in very different morphometric characteristics. For example, the maximum subsidence resulting by an unrealistic complete discharge of a 20-km deep aquifer is limited to 1.2 km (using a depth-porosity relation suggested by Clifford et al. (2010)). Intrusions of magma may be followed by higher collapse during the withdrawal of magma (Meresse et al., 2008). The sub-ice lake scenario requires the existence of an original crater filled with ice which drives the resulting amount and morphology of the collapse (Zegers et al., 2010; Roda et al., 2014).

In order to discern the origin and the mechanism of the evolution of the quasi-circular collapsed features we investigate whether the chaotic terrains are really different from floor-fractured craters and then which mechanism can explain the peculiar morphology of these landforms. We will first focus on their origin. We analyze the diameter, maximum depth and observed collapse of the collapsed landforms and we study their statistical relationships to evaluate whether they show common distributions and therefore a possible common origin. Next we will focus on the morphological imprint of the evolution of the crater infill. On the basis of their morphometric characteristics, we will distinguish between the formation scenarios proposed to explain the evolution of these landforms.

2. Method

For about fifty quasi-circular collapsed landforms around Chryse region (Fig. 2) we measure the main morphometric characteristics such as the diameter and the maximum and minimum depth with respect to the surrounding, non-collapsed area (Fig. 3). We also measure the collapse as difference between the maximum and minimum depth and it is considered as the observed collapse depth. This represents the collapse achievable. In fact the amount of collapse can be higher if the measured minimum depth is generated by collapse with respect to the surrounding areas. In this case the collapse would coincide with the maximum depth. However, the minimum depth can be only the result of pre-existing difference in topography. Since it is not

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