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Evaluation of drilling-based water extraction methods for Martian ISRU from mid-latitude ice resources

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ABSTRACT

Mid-latitude shallow ice deposits are an abundant feature in Utopia Planitia confirmed by SHARAD georadar. Thick ice-rich subsurface makes establishing a temporal or permanent human presence on Mars more likely because water is within reach of existing sampling technologies and conceptual production mechanisms. Although such technologies have been studied, a comparison method is needed to quantify their projected results.

Herein the paper presents geological and thermal model of icy regolith created to measure water sampling and production efficiency. Various regolith and volatile sampling systems are standardized and compared using efficiency factor ε. For production purposes, heat transfer is studied for down-hole and beamed energy sources, seeking for an effective heating radius for ice sublimation. Paper concludes with the chosen system for Martian subsurface water acquisition.

1. Introduction

Martian water inventory, both past and present is a problem discussed broadly and thoroughly since the beginning of exploration of Mars [for instance (Lammer et al., 2003), (Lasue et al., 2013), (Carr and Head, 2015)] and outlined an interdisciplinary field of studies in geology, climatology and mineralogy with subject to extreme technological challenges. It is certain that the current Martian environment is different from ancient conditions, which allowed for (at least temporarily) liquid water to exist abundantly on the surface of the planet with most evidence shown by existence of extensive valley networks (Luo et al., 2017), outflow channels (Carr and Head, 2010), possible seas and oceans (Boyce et al., 2005), (Barker and Bhattacharya, 2017) and conditions for liquid water flow in general (Adeli, 2016).

The main problem for water on Mars concerns environmental conditions and their decay toward the current state implying that the planet during its early history might have been 'warm and wet' or 'cold and icy with temporary wet periods' (Wordsworth, 2016), where current research tries to answer those questions in detail with climate and water cycle studies [(Wordsworth et al., 2015), (Turbet et al., 2017), (Weiss and Head, 2017)].

Today however, with cold and icy conditions below the water triple point, Martian water resources are a domain of solid and gas phases as well as their interactions, which result in: (1) water vapour in the atmosphere and pore space, (2) surface ice deposits (including polar deposits and surface snow and ice), (3) shallow sequestrated ice, (4) ice-filled cryosphere (permafrost; including LDM, LDA, LVF and CCF formations), (5) potential groundwater below cryosphere and (6) hydrated minerals.

Under current conditions, water resources are strongly connected with so-called regolith breathing, i.e. diffusive interactions between regolith ice and Martian atmosphere (Hudson, 2008). This infers that Martian water ice may be (and at large is) stable in high latitudes above 55º (Schroghoffer and Forget, 2012) and at mid-latitude poleward facing slopes (Mellon and Phillips, 2001). These conditions are dynamic and strongly obliquity-driven and may change significantly over time (Head et al., 2009). Such distribution of stable ice however means that resources are less accessible for research and acquisition during early and critical phases of human exploration of Mars, as high-latitude and polar missions invoke higher mission risks that low-latitude ones.

Recently more attention is being focused on low and mid-latitude water locations, as new and updated research finds more evidence for that state [(Stuurman et al., 2016), (Wilson et al., 2017), (Dundas et al., 2018)]. Water ice presence in such conditions inherently implies its disequilibrium state with the atmosphere, however if shallow it makes a case for establishment of temporal or permanent human presence in such

Abbreviations: LDM, latitude dependent mantle; LDA, lobate debris aprons; LVF, lineated valley fill; CCF, concentric crater fill; WEH, water-equivalent hydrogen; WIP, water in place; EUR, Estimated ultimate recovery; RF, recovery factor.

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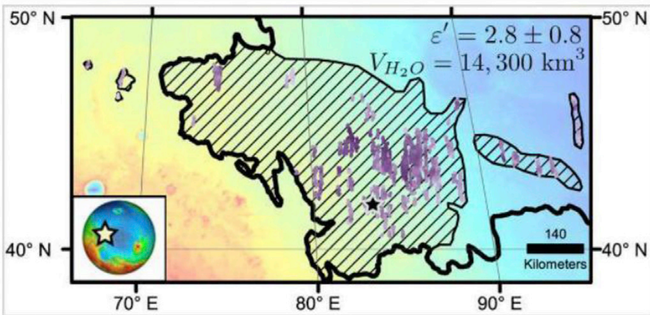

Fig. 1. Western Utopia Planitia. Extent of subsurface water ice evaluated by SHARAD mapping. Dark violet stands for ice-rich formation spanning up to 170 m below the surface, while brighter colours stand for extent to 10 m depth. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

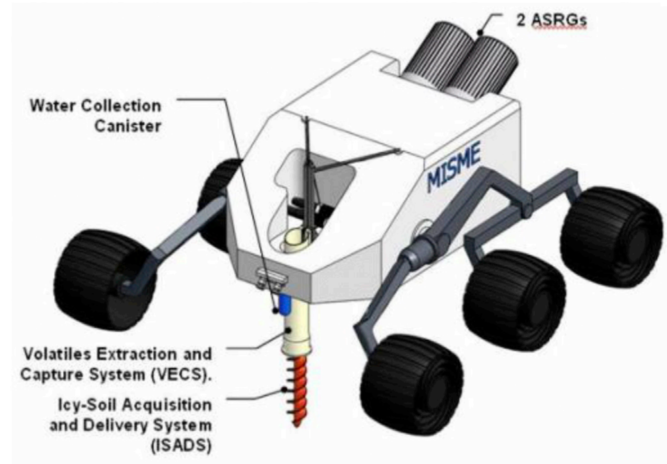

Fig. 3. Honeybee's MISWE concept (Zacny et al., 2012).

locations thanks to In-Situ Resource Utilization (ISRU), as local water utilization has been postulated as an enabling factor of manned space exploration plans (Moses and Bushnell, 2016). This paper outlines the problem of water resources and water acquisition in a specific location of potentially ice-rich Utopia Planitia, aiming at measuring recoverable volumes of water resources based on known technologies for sampling (i.e. extraction of small volumes of water, mainly research focused) and production (i.e. extraction of large volumes of water for a variety of commercial and mission-driven use). The analysis shown within this paper is part of the author's MSc thesis (Wasilewski, 2017).

2. Ice in western utopia

Utopia Planitia is the biggest plain and impact basin on Mars and is located between 13º-73º N and 72º-165º E (planetocentric). Its main characteristics to be considered are a plethora of periglacial features (Séjourné et al., 2012), primarily polygonal grounds and scalloped terrains that imply existence of ice-filled cryosphere. Utopia lies within Vastitas Borealis, which had been created from Hesperian outflow channels sediments and later on has been altered periglacially (Costard et al., 2016). Its geomorphological features have analog forms on Earth, which imply their fluvial, glacial, periglacial and aeolian alterations. Western part of the region is located around ice equilibrium zone, where ice may be stable in cryosphere at 1 m depth (Mellon and Jakosky, 1993), meaning that subsurface may be ice filled in forms of pore ice and excess ice or even pure ice (see Fig. 1).

Research done by Stuurman and others thanks to SHARAD data showed that ice deposits are indeed significant in Western Utopia and ice-rich regolith may extend from 10 to 170 m of depth. Those findings were a substantial foundation for an ISRU-wise analysis done in this paper. Here, a cryo-geological model of shallow subsurface have been created, which utilizes general physical-chemical characteristics of JSC Mars-1 analog regolith (Allen et al., 1998), porosity decrease function (Hanna and Phillips, 2005), regolith thermal parameters functions [(Piqueux and Christensen, 2011), (Siegler et al., 2012)] and ice concentration changes accordingly to boundary conditions set by observations. This allowed to create a theoretical subsurface water ice table, which may be further analysed with respect to recoverable water

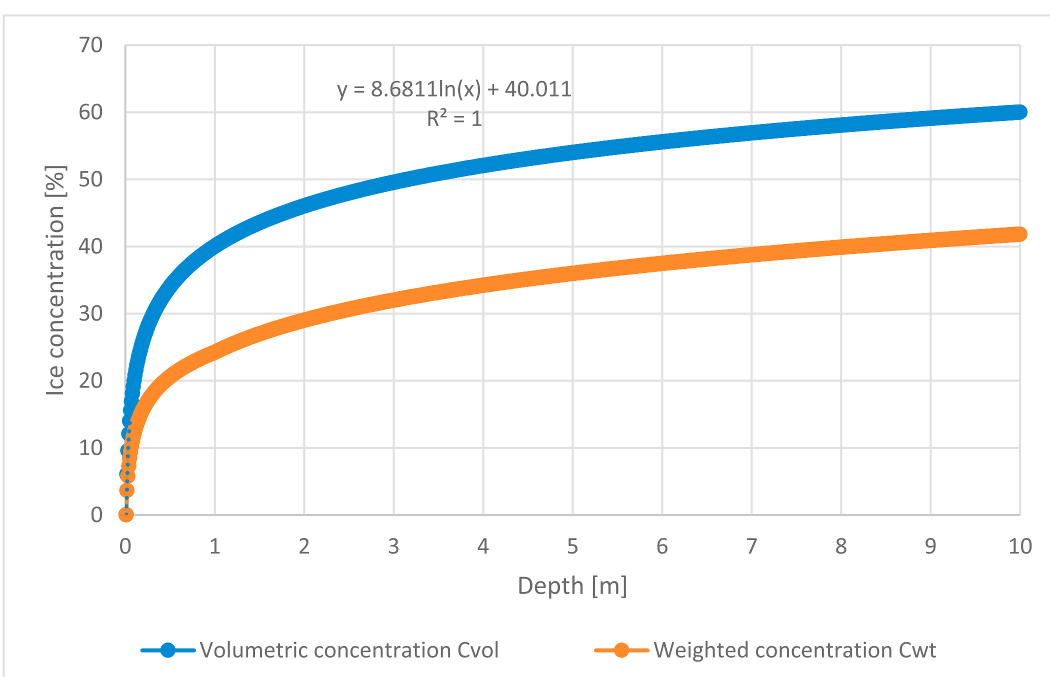

Fig. 2. Ice concentration modelling in regolith.