Deep Drilling on Mars: Two Concepts and Prospects. Christopher Hoftun[1,2,3,4,5], Pascal Lee[1,2,5], Brage W. Johansen[1,4,], Brian J. Glass[5], Christopher P. McKay[5], John W. Schutt[1] and Kris Zacny[6]. [1]Mars Institute, NASA Ames Research Park, Bldg 19, Suite 2047, Moffett Field, CA 94035, USA, Email: christopher.hoftun@marsinstitute.net, [2]SETI Institute, Mountain View, CA 94043, USA, [3]University of Stavanger, 4036 Stavanger, Norway, [4]Space&Energy, 4021 Stavanger, Norway, [5]NASA Ames Research Center, Moffett Field, CA 94305, USA, [6]Honeybee Robotics, Pasadena, CA 91103, USA.

Summary: Deep drilling is anticipated to be an important activity in the future exploration of Mars, to search for any past or extant life in expected deep martian aquifers. Our review and analysis of deep drilling approaches that might be applicable to Mars identifies two promising concepts: 1) coiled tubing drilling, and 2) mole drilling.

Background and Motivation: The search for biosignatures and life on Mars is guided by NASA's *Follow the Water* strategy [1]. In this context, the deep subsurface of Mars is an attractive astrobiological target, because it is expected to offer on both global and regional scales (volcanic provinces) physical and chemical conditions that should allow liquid water to be abundantly present within the topmost 10 km of the martian crust. In spite of harsh if not forbidding conditions for terrestrial life at the surface of Mars today, the notion that there might be a thriving deep biosphere on Mars merits serious consideration, if only because an estimated 50% to 66% of the Earth's total biomass resides in a deep biosphere [2]. To first order, life on Earth is subsurface life.

In 2012, following an international planetary drilling workshop convened by Norway's Space & Energy network in Stavanger, Norway [3], the Mars Institute, in collaboration with NASA, several academic and industry partners in Norway (Space & Energy network, Statoil, University of Stavanger), and the company Honeybee Robotics in the USA, initiated a 1-year study of Deep Drilling on Mars [4]. Although Deep Drilling is a distant opportunity and goal in Mars exploration, planning for this long lead time activity should begin early and build on growing synergies between the space and energy industries on Earth in the exploration of extreme environments.

The objectives of our study were to review and analyze systematically past and current ideas about deep drilling on Mars, and to identify (if possible) a limited set of concepts that might offer reasonable promise of feasibility for Mars.

Challenges to Deep Drilling on Mars: Our preliminary assessment of the suitability of a drilling concept for Mars was established by examining how well it might perform given the specific set of challenges presented by operating on Mars, including conditions expected to be encountered both at the surface and in the subsurface.

Deep drilling on Mars faces first the obvious challenge of distance from the Earth and constraints on equipment mass. Mars is an extremely remote and isolated drilling site by terrestrial standards, requiring transportation across interplanetary space, EDL (entry, descent, and landing), and surface deployment solutions that are to say the least extreme by terrestrial drilling standards.

Aside from this surface access difficulty, the greatest technical challenges facing deep drilling on Mars compared to deep drilling on Earth stem from the low pressure and temperature conditions prevailing in the surface and near-surface environments on Mars. These physical challenges translate in turn into significant system development, operational, and logistical challenges [5,6].

Included in the challenges are the fact that the deep subsurface geology of Mars remains very poorly known, at least by terrestrial deep drilling standards. NASA's InSight mission scheduled to launch 2016 will the first geophysical lander to study Mars's deep interior [7], hence an important milestone to start developing concepts for deep drilling systems to operate at the extreme conditions encountered at the martian subsurface and identifying Strategic Knowledge Gaps (SKGs) to deep drilling.

Requirements of Deep Drilling on Mars: An important requirement we placed on candidate Mars deep drilling systems is that they be able to reach a depth of at least 2 km. Current models of the 3D distribution of H_2O on Mars suggest that, in general, aquifers would be accessible at depths of order 2 to 7 km from the local surface, although in some locations (e.g., the floor of Valles Marineris), they might be reached at depths of only 1 to 2 km [4].

To implement a successful deep drilling campaign on Mars with autonomous systems, several complex technologies must be developed, integrated and work together [8]. Conceptually the following systems will be needed: 1) An autonomous unit at ground level that can assemble, control and operate the drilling process; 2) A drilling method that can achieve 1-2 km down/up/diagonally to explore the subsurface geology and 3) Topside or in situ sensors that can identify and analyse biosignatures or life.

In this study we reviewed past, current and future extraterrestrial drilling concepts and integrated advanced, automated drilling technologies currently under development in the Norwegian oil & gas offshore industry to identify the best approaches to access deep aquifers on Mars. In addition to reviewing classical ideas about deep drilling on Mars, our study therefore included consideration of new technologies, developments and concepts for deep drilling on Earth. Our analysis of their potential suitability or adaptability for Mars benefitted in some cases from open discussions with the developers of the technologies in the energy sector.

Our study has identified two promising approaches or concepts for deep drilling on Mars. They are, in no particular order: 1) coiled tubing drilling, and 2) mole drilling.

Concept 1: Mars Coiled Tubing Drilling (MCTD): The MCTD concept is based on Reelwells award-winning Dual Drill String (DDS) technology [9], by imposing a dual coil tubed drill string with the key advantages of cuttings return through the inner drill string, compressed CO_2 gas pumped down throught the drill string annulus and downhole electric power and telemetry system for high speed data sent and received simultaneously. This method would give increased control of the flow to facilitate the studies and examination of the borehole topside. The borehole is continuously cleaned, and the lack of annulus turbulence provides less erosion of the tube. The MCTD system would have power from topside and advanced telemetry and sensoric systems downhole. The coil tube must be designed as dual drill string, but this is not complex or expensive. It is only the Bottom Hole Assembly (BHA) that rotates and drills, not the whole tube. The BHA could also be pushed ahead hydraulically, reaching 2 km controlled, with a suggested borehole diameter of 5” (15 cm), and could use almost any drilling head (rotary percussion, plasma jet et cetera). The MCTD would not require drilling mud (liquids) on Mars. Instead, compressed CO_2 would be used as a borehole cleaning gas. The main highligthted weaknesses to consider would be how to maintain the stability of the borehole, effect and friction induced by the formation on the drill tube downhole.

Concept 2: Mars Mole Drilling (MMD): The MMD mechanically drills and buries itself carrying logging sensors and instrumentation for subsurface *in situ* analysis to obtain data brougth to the surface by an electrical cable, which is spooled up inside the unit transmitting continuesly. The cable is connected to the topside, proveding electrical power to run the eletric motor in front of the mole. The MMD would crush, loosen and remove bedrock ahead of the tool by an mechanical drill and deposit the cuttings behind the mole as it advances deeper. The MMD concept is based on the Badger Explorer, which has many benefits such as almost no topside gear, low mass, autonomous by design, few components and leaves only a wire to communication and power source topside [9]. The MMD concept can be applied both horizontally and both directions vertically. The weakneses is how the mole operates in both consolidated and unconsolidated formations, depositions and erosion of the bit.

Recommendations: Following our 1-year study, we recommend investigating further the two main concepts identified as most promising in this study. Specific focus would include investigation of their applicability to Mars, proposed concepts of operations, and an estimation of system mass and power requirements.

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