

# Identifying the Most Practical and Planet-Protecting Method for Accessing the Deep Martian Subsurface in Search of Biosignature Evidence

Li-Norah Flynn

## Abstract

There is no current indication of past or present life on Mars. To successfully search Mars for biosignature evidence, access to the deep Martian subsurface is required, as here, potential biological molecules are protected from cosmic and UV radiation from space, wind and dust storms above the surface and subsurface isotopic radiation is also minimized. The cold and stable environment below the surface, and also deep within Martian polar ice, also contributes to ideal preservation conditions, effective for billions of years. Previous Mars missions have only drilled as deep as 7 cm, and virtual imaging of the subsurface has only reached up to 80 m, so a new mission and mechanism is needed to investigate and extract samples from depths in the order of 102 to 103 meters, where evidence of life is most likely to be preserved. Physical samples are needed for thorough analysis of the subsurface, whether this be in situ, at the surface, or in a laboratory on Earth. While logistical practicality is vital in planning a mission to Mars in search of biosignature evidence, protection of the planet from the physical effects of human activity is paramount too, and so is the protection of Earth and Mars from microbial contamination. In this paper, these factors are numerically evaluated for six different deep access methods, using a comprehensive rubric. The final scores indicate that the Inchworm Deep Drilling System is most likely to successfully search the deep Martian subsurface for biosignature evidence, although it has some limitations. This study nonetheless identifies several vital considerations that future missions must consider before exploring the deep Martian subsurface.

## Introduction

The lack of present indication that life exists on the surface of Mars is partly due to the lack of a

substantial, stable atmosphere (Atreya, Gu 1995) and of a thick, shielding magnetic field (Acuña et al. 1998). This leaves the planet's surface vulnerable to the direct effects of cosmic and UV radiation, which cause the decomposition of organic and biological material, if it were to exist on the surface Mars (Friedmann and Koriem, 1989). Nonetheless, gamma (cosmic) and UV radiation cannot penetrate far into the ground beyond a few meters (Dartnell et al. 2007), so it is possible that biosignatures may be preserved in the Martian subsurface or in Martian Ice (Kminek, Bada 2006). The subsurface is also protected from above ground conditions such as wind, that further contribute to the depletion of biosignatures (Moreau, Muller 2003). The cool, dry conditions of Mars (Bada, McDonald 1995) and its mineralogy (dos Santos et al. 2016) also aid the effective, longstanding potential preservation. It is also possible that the quantity and intensity of irradiation caused by radiogenic isotopes within the subsurface is insufficient to cause the depletion of biological molecules such as amino acids (Dartnell et al. 2007, Kminek, Bada 2006). The potential for the existence of water in the Martian subsurface (Westall et al. 2015) and the greater porosity of these depths (Michalski et al. 2018) also provide promising conditions for supporting life.

Therefore, accessing the Martian subsurface is a necessary step in identifying the existence of life on Mars (Kminek, Bada 2006). Yet no plan or method to carry this out has been established, although several theoretical ideas and mechanisms have been proposed. There are a number of vital considerations that must be made before implementing one of these projects, including practical feasibility. For the method to be possible in the foreseeable future, the equipment must have the appropriate technology to operate with minimal or remote human control, as we

are far from conducting a human Mars mission (Salotti, Heidmann 2014). Additionally, as the present knowledge of the composition of the Martian subsurface beyond 20 meters is scarce, partially due to the limitation of radar imaging (Li et al. 2022), it is very possible that instruments will come across unexpected physical and chemical obstacles that will obstruct their functionality. For example, there may be unknown environmental chemical and physical effects on the instrument's mechanisms (Blake et al. 2012). Furthermore, the physical extraction of samples is necessary to fully analyze the subsurface for biosignatures, so methods must take precautions to preserve and protect samples from alteration under external conditions, during excavation and analysis. It is also vital that methods consider the principle of Planetary Protection which states that the study of extraterrestrial environments must not interfere with extant or existing life that may have developed there. One major concern is forward and backward microbial contamination (Frick et al. 2014), but also the extent of the physical traces of human activity left on the planet.

Thus this literature based research identifies the most practical method to access the deep Martian subsurface to search for biosignature evidence, while adhering to the requirements of Planetary Protection. In particular, this study focuses on potential methods previously proposed by scientists that aim to reach significant depths of 100m to a few kilometers below the surface or more, due to the enhanced likelihood of finding biosignatures here (Westall et al. 2015). However, previous Mars missions have only drilled as deep as 7 centimeters (NASA/ JPL-Caltech) and high resolution imaging has only reached up to 80 meters deep (Li et al. 2022). Thus it has been proposed that there should be at least two future missions to Mars with the aim to reach penetrating depths of approximately 300m and 3 km respectively (Mancinelli 2000), and thus this study will focus on this range. This study aims to tangibly evaluate all of these proposed instruments and technologies using a quantitative assessment rubric as a standard.

## Methods

### *Data Compilation*

Literature articles that include depths between 100 m and 3 km are compiled, due to the pre-discussed increased likelihood of finding biosignatures at these depths. The search for biosignatures in the subsurface

is dependent on the ability to obtain samples that can be analyzed (Anderson et al. 2012) and as a result, I use studies that propose physical methods of reaching the subsurface, such as drilling, over remote sensing methods, for example. The proposals examined in this investigation are chosen to show a diversity of mechanisms and instrumentation, from thermal probe coring to deep borehole drilling (Mancinelli 2000), as this provides a more comprehensive picture of the all possibilities of accessing the Martian subsurface. Using a wide variety of authors, opinions and perspectives also enables a holistic perspective of all concerns associated with physically penetrating the surface of Mars, allowing a more critical evaluation of the included studies. More recent publications are used as they consider and improve upon errors or insufficiencies in previous studies, as well as they take into account the limits and possibilities of most recent technology (Sanders et al. 2015).

### *Analytical Framework*

First I examine the methods in the selected articles based on practical feasibility, to conclude if it is physically and logistically possible to carry out. This is based on factors including the time the project will take to plan and finalize (Zubrin 2011) and the ability for the mission to operate with remote human control (Choate, Jaffe 1973). As humans are not expected on Mars in the near future due to the extent of planning required (Portree 2001), a mission is presently more feasible if it does not require physical and direct human intervention. Other considerations are the sizes of instruments, the physical properties and composition of the Martian surface and subsurface (Spohn et al. 2022) and the ability of instrumentation to maintain function over a large range of temperatures, pressures and UV radiation exposure (Sobrado et al. 2014). Part of my evaluation of each method is based on how easily these proposed methods can overcome such obstacles based on past and possible future research.

I then assess the possible consequences of extracting samples in preserving the potential biosignatures contained in them. For example, exposing the subsurface to gasses, radiation and the conditions of the atmosphere and space via drilling can result in the destruction or loss of biosignatures in a sample (Allen et al. 1999). This can occur by reactions such as thermal decomposition when using thermal analysis or probes (Archer Jr et al. 2013), or by the physical loss of

shielding (Röstel et al. 2020) when the surface is excavated. I evaluate the method’s precautions taken and potential ability to prevent these risks.

Next I use a rigorous interpretation of Planetary Protection to evaluate if these methods will ‘interfere with extant or existing life that may have developed [on Mars]’. Part of this evaluation includes the consideration of preventing both forward and backward contamination (Rummel 2001, 2004), and also the possibility of the instruments leaving an irreversible and permanent impact on the physical Martian landscape, such as leaving deep excavation holes. The possible destruction of biosignatures mentioned above is also relevant to Planetary Protection. If the method poses unavoidable harm or threat to the planet and potential evidence of life, then it should strongly not be considered (McKay, Davis 1989). Humans do not have the right to interfere with the biotic environment of any planet (Zacney, Cooper 2006).

Weighting of each factor is dependent on their necessity in formulating a successful mission that searches the deep Martian subsurface for biosignature evidence. Planning and finalizing is of little weight as this can easily be changed by the amount of resources invested into research and space exploration. The physical access factors, including size of instruments, maintaining function over changes in physical conditions and autonomous operation are slightly more important as they determine if it is physically possible to carry out and operate on Mars. However, they are not weighted too high as they may be adapted in the near future given the pace of present scientific research. Preservation of samples before or during extraction and analysis is more important, as this factor is a key in determining if biosignatures do exist, the primary goal of this study and of the potential future mission. Sterilization is also of little weight as it is presently under intense examination and research by scientists, so the actual success of possible sterilization methods is still yet to be fully determined. Also, it is not always necessary for samples to be taken back to Earth if thorough analysis can be performed on Mars, so sterilization to prevent backward contamination may not be needed. Alteration to the Mars environment is weighted slightly more as physical pervasion of Mars should be minimized, otherwise humans may get too complacent or comfortable with exploiting foreign terrestrial bodies, which then leads to several, much larger issues.

**Evaluation**

Finally, I give a rating out of 5, using the rubric, for each of the categories described above, for each method. I then combine these ratings to determine how practical the method is while simultaneously meeting the requirements of Planetary Protection. I then establish the proposal with the highest rating and explain how it meets the necessary criteria, but also where it falls short and how it can be improved.

**Rating Rubric**

**Practical Feasibility**

Factor	Weight	5	4	3	2	1
Time to plan and finalize	10%	Already successfully and widely used on Earth and is easily applicable to Mars/ Mars conditions have been tested on this method	Already successfully and widely used on Earth but needs modifications to apply to Mars	Is a promising method that requires further refinement with presently possible technologies	Is reasonable but requires further refinement that no present technologies are able to complete	Is an unreasonable method that requires a significant amount of further work and research
Size/practicality of instruments required	15%	Small, lightweight, practical	Slightly impractical but can be easily adjusted to become more practical	Impractical in size and weight but can be adjusted with considerable modifications/ work	Impractically large OR heavy, cannot easily or foreseeably modified	Impractically large AND heavy, cannot easily or foreseeably modified
Maintaining function over changes in physical conditions	15%	Is able to withstand or accommodate for extreme radiation, pressure, temperature and physical changes with depth into the subsurface	Is able to withstand most extreme physical changes and is easily modified to do be fully effective for ALL extreme condition changes	Is likely to withstand some of these physical changes but may not be able to survive under extreme conditions	Is not able to withstand most of these physical changes	Will not be able to withstand any of these physical changes
Operate without direct human intervention	15%	Requires no human intervention to operate, remote or direct	Requires some remote human intervention to operate	Requires significant/constant remote human intervention to operate	Requires some direct human intervention (a few humans on Mars) to operate	Requires a large team of humans on Mars to operate
Preservation of sample/ biosignatures	20%	Samples will be protected from radiation, pressure, temperature and physical element exposure	Samples can easily be protected from these conditions using present mechanisms/ technology	It is likely that the method can be modified to successfully protect samples with future technologies	It will be extremely difficult to protect samples, even in the future	It is not presently nor foreseeably possible to protect samples with this method

**Planetary Protection**

Factor	Weight	5	4	3	2	1
Sterilization/ prevention of backward and forward contamination	10%	Is presently able to prevent forward and backward contamination easily by sterilization, for example	Can be easily adapted to be sterilized/ to prevent backward and forward contamination using present technologies/ methods	It is likely that the method can be modified to successfully prevent backward and forward contamination with future technologies/ methods	It will be extremely difficult to prevent backward and forward contamination, even in the future.	It is not presently nor foreseeably possible to protect samples with this method
Alteration to Mars environment	15%	Will create little to no alteration to landscape and little to no effect on wider environment	Alteration is small but has some effect on the wider environment, though not necessarily harmful	Moderate, permanent alteration that is likely to be harmful to environment	Alteration is significant, permanent and harmful to environment	Creates very large scale, harmful, permanent damage to landscape, severe harm to environment

## Results and Discussion

### *Vertical Drilling*

(Langhoff, S. R., 2008)

#### *Overview*

Vertical Drilling is a method that has been used readily on Earth since the late 20th century. The deep drilling tool has a drill bit which rotates to penetrate the ground. It has a hose in the drill pipes that keeps the drill cool and the borehole open under the intense pressure that the drill experiences as it reaches greater depths. One of the primary purposes of deep borehole drilling is for access to oil resources beneath the Earth's surface. On Earth, depths of several kilometers have been reached using various drilling techniques, so this method is useful in understanding how to access the deep Martian subsurface. Another purpose of drilling to such depths into Earth is for scientific research, in particular to study rock samples and to unearth fluids and microbial life preserved in them, so this method may be important in finding how to search the Martian subsurface for biosignatures and microbial life also.

#### *Practical Feasibility*

Time to plan and finalize - 4

While Vertical Drilling has been used for several decades on Earth, there are several untested challenges that drilling on Mars will encounter, such as low gravity, large temperature fluctuations, dust storms, and the presence of water-ice in the subsurface. Technological challenges include information transmission delays between remote human operators on Earth and the drilling machinery on Mars, of as large as 20 minutes one way, as well as the limited power and mass of a large scale drilling device on Mars. The colder, drier conditions on this planet also enhances the compactness of the surface and subsurface, meaning it is physically harder to drill into than on Earth. The main principles of vertical drilling on Mars do not need much planning, although some modifications are required for the drill to be able to withstand unforeseen environmental obstacles that are not present on Earth.

Size/practicality of instruments required - 1

To get to depths of several hundred meters as proposed by this study, extremely large machinery is required for vertical drilling into the surface of Mars. Human operation is presently necessary to perform deep borehole drilling. as autonomous drilling has not

yet comfortably been developed on Earth. Presently, getting instruments this large on Mars has not yet been achieved, but this may be possible with future research.

Maintaining function over changes in physical conditions - 4

Large scale drilling is able to maintain function with pressure and temperature changes deep into the Earth's surface, so it is possible that the same can be applied to Mars. As mentioned above, the main unprecedented potential challenges the drill will face are the compactness of the Martian surface, low gravity and dust storms. These conditions should be tested on Earth to ensure the machinery can operate on Mars. Large temperature changes, water ice and hard materials can be effectively overcome using the current durable Earth-drilling machinery.

Operate without direct human intervention - 1

Deep borehole vertical drilling on planetary surfaces is presently and foreseeably only practical with human involvement. Independent or remote operation is possible only on a small, shallow scale, as performed by Curiosity and other Martian rovers (Tang et al. 2022). NASA believes that autonomous drilling could reach depths of 40-50 m with appropriate modifications, but human intervention is necessary to reach the depths that this paper examines. Again, autonomous deep drilling has not been fully and comfortably established on Earth.

Preservation of sample/ biosignatures - 2

With such large and heavy machinery, it is extremely difficult to obtain precision and care when drilling into a planet's surface. Thus the act of drilling can destroy biosignatures physically. Deep borehole drilling also exposes the subsurface to exterior conditions such as radiation and temperature and pressure changes. This exposure will cause damage to biological molecules and can also cause harm to potential non-biological biosignatures. There has been little to no conversation about how vertical drilling can be adapted to protect samples in the surface from these exterior conditions but it is not something out of the reach of modern science.

#### *Planetary Protection*

Sterilization/ prevention of backward and forward contamination - 2

Due to the size of vertical drilling machinery

required for the purpose of accessing the deep Martian subsurface, sterilizing equipment is extremely difficult, both before arriving on Mars and before returning to Earth. Extreme care is needed to fully ensure that all exterior and interior surfaces are free of contaminants, which is time consuming and impractical over such a large instrument. It is likely that additional instrumentation would be required to ensure this. The current protocol for prevention of sample contamination from extra-terrestrial bodies includes double vacuum sealing and containment (Race, M.S. 1998), but this cannot be easily applied to a huge drill. Requiring a container for this instrument adds to the weight and size of equipment needed to deploy this method, thus enhancing the impracticality of it.

#### Alteration to Mars environment - 1

This method will leave a large, permanent physical mark on the planet's surface. Vertical drilling will cause deep and wide excavation scars such that the planet's surface cannot be returned to its original state. Furthermore, as it is likely that many drilling locations will be needed to search for evidence of life, there will be an extremely widespread footprint of human damage left.

Score: 2.05

#### ***Plasma Drilling***

(Tang, X. et al. 2022)

##### *Overview*

Plasma drilling uses a thermal melting probe to drill into the vast amounts of water ice present at the poles of Mars. Drilling into this ice will help scientists to understand the climate of Mars during the Amazonian period, and isotope identification can be used to determine the likelihood of past life existing. It is also possible that biosignatures can be preserved in ice. The heated probe is able to melt the ice to access depths of up to 2 km. The cracks in the Martian ice increase its surface area, meaning that the ice is much less thermally conductive, making it easier to penetrate.

##### *Practical Feasibility*

#### Time to plan and finalize - 5

This is a method that has been preliminarily tested under both Earth and Mars conditions, and has been so far successful, so there is not much more planning and finalizing required to make plasma drilling

practically possible on Mars. These test conditions include a vacuum vessel system, ice plate, controlled liquid nitrogen cooling, different ice porosities and a carbon dioxide feed-in. A large amount of power is required to operate thermal probes, so while it is feasible to carry out, the probes require modification to become more efficient before actual deployment.

#### Size/practicality of instruments required - 2

To obtain depths of several hundred meters or more, large equipment is required. As with vertical drilling, it would take significant effort to get such large equipment to Mars and back effectively and safely.

#### Maintaining function over changes in physical conditions - 4

Previous testing of plasma drilling equipment in a variety of conditions enhances the likelihood of the drills to maintain function over changes in physical conditions. Thermal conductivity of the probes have been tested or modeled under pressures of various possible porosities in the Martian ice, as well as temperatures as low as negative 100 degrees celsius. As the probe operates by melting through the ice, the main obstacle from the deep ice environment is the presence of sediment through which the probe cannot penetrate. Another major consideration is the probe being able to continually remain heated to a high temperature despite the freezing conditions surrounding it. A temperature control subsystem, as well as a pressure control subsystem, should be incorporated as part of the drill's design.

#### Operate without direct human intervention - 1

Again, the size of the machinery required means that direct human operation is needed for drilling at this scale. The probe also requires a large amount of energy to operate, and this deep into the ice, light and heat are not sustainable sources of energy. Thus it may require human intervention to ensure the instruments are properly powered over time.

#### Preservation of sample/ biosignatures - 1

The major issue is that the thermal probe is heated and therefore can permanently destroy any biosignatures or structures indicative of life. The high temperatures of the probe can cause the destruction or decomposition of isotopes or organic or biological molecules.

There is also no current method or precaution in place to prevent exposure of the subsurface to harmful radiation from space and other exterior conditions during drilling or extraction. Bringing a sample to the surface for analysis exposes it to radiation but also situates it in warmer temperatures which may affect its preservation.

#### *Planetary Protection*

Sterilization/ prevention of backward and forward contamination - 2

Again, due to the size of instrumentation required, it will be difficult to prevent forward or backward contamination by ensuring all equipment is sterilized or can be contained. As with samples, they are harder to sterilize given that compounds are preserved in solid ice and may need to remain in this state to be analyzed. Temperature control may be required for the sample to be extracted and transported, which can interfere with sterilization of the sample.

Alteration to Mars environment - 3

With ice drilling, there is no significant damage done to the physical geology or permanent landscape of Mars. However, solid ice has existed at the Martian poles for several billion years, so plasma drilling will destroy some portion of the ice landscape on Mars. On the other hand, plasma drilling does not need wide excavation holes to reach large depths.

SCORE: 2.40

#### ***Impact Excavation***

(Cockell, C. S., Barlow, N. G., 2002)

##### *Overview*

Also known as ‘nature’s drill’, impact excavation uses impact craters to access deep below the surface, without any need of human mechanisms. Simple craters can be used to examine depths as great as 270 m, but complex craters, which show more details than simple craters, are able to reach as deep as 6 km or more. These depths are dependent on the diameter of these craters, many of which originate from the heavy bombardment period, around  $3.8 \times 10^9$  years ago. Small, shallow samples can be taken from the surface of these craters, or loose material that has been excavated by the impact itself - the ejecta blanket - can be collected for examination for biosignatures.

#### *Practical Feasibility*

Time to plan and finalize - 5

No complex, new technologies or methods are required to reach these significant depths, as no deep human penetration of the surface is used. Present surface exploration and shallow sample extraction methods can be applied to these craters. Complex craters can be targeted as landing sites for rovers and small samples can be taken out of the crater surface, from drilling as shallow as the 7 cm previously achieved by Martian rovers. These samples will be representative of depths of several hundred or thousand meters below the surface. Similarly, the ejecta blanket can be analyzed, in which no penetration into the surface is required at all. It may be possible that a rover presently on the surface of Mars can relocate to these craters and perform this sample extraction or analysis, without the need for another mission.

Size/practicality of instruments required - 4

The size of past rovers on Mars, including NASA’s Sojourner, Curiosity and Perseverance, are suitable for this method, so using a rover to complete this exploration, shallow penetration and analysis is certainly practical. Rovers are small enough to easily traverse the terrain of Mars. The main concern is the ability for the rover to travel up and down steep slopes to access the base of the craters, considering some are deeper than 6 km. The Opportunity rover launched in 2003 failed to overcome a slope of 32 degrees on the Martian surface (Webster, G., Brown, D., Cantillo, L., 2016)

Maintaining function over changes in physical conditions - 5

Considerations when collecting material from the ejecta blanket include the mass and weight of individual pieces of sediment. The mechanism required to collect the loose material does not need to overcome severe changes in environment such as pressure and temperature. For drilling a few centimeters into the crater surface, there is no significant change in pressure or temperature. Rovers on Mars also have the ability to traverse over difficult and uneven terrains and withstand environmental changes such as wind and dust storms. One obstacle is the unknown physical properties of subsurface materials in these craters; they may be too compact or hard for a small drill to penetrate.

Operate without direct human intervention - 5

Again, the success of previous rovers on Mars in operating, exploring and taking small samples without direct human intervention enhances the likely success of using impact craters to access the subsurface. Enhanced technology can be implemented if rovers cannot access the base of the crater due to slope or terrain, or cannot penetrate the ground due to surface hardness or size of loose material, for example. Direct human intervention is of little necessity in making this method successful.

Preservation of sample/ biosignatures - 1

A major concern of this method is the preservation of potential biosignatures on the surface of these craters and in the ejecta blanket. As this layer of the Martian subsurface has been exposed to exterior environmental conditions for billions of years, including weather and temperature changes and UV and cosmic radiation, it is highly likely that biosignatures excavated from impact and existing a few meters deep into these craters, would have been destroyed.

Planetary Protection

Sterilization/ prevention of backward and forward contamination - 3

By using rovers already on the surface of Mars to collect and analyze samples, or by using new, future rovers and present sterilization techniques, forward contamination can most certainly be prevented. If samples are to be returned to Earth, success of sterilization to prevent backward contamination is more complex; it is uncertain what kind of biosignatures or molecules will be contained in the samples. Thus designing a sterilization process that successfully protects the sample from contamination, but also does not damage the biosignatures it may contain, is extremely difficult. It is not certain that present sterilization protocols will successfully eliminate contamination risk.

Alteration to Mars environment - 5

This method greatly limits any physical alteration to the Martian landscape and environment, as nature has completed the excavation and no further significant human physical alterations are required, other than the potential removal of small samples. Man-made high velocity impact craters have also been proposed (Baker, 1995) to make craters at desired sites to access the deep Martian subsurface. However, due to

the large width of craters required for large depths to be achieved, these man made craters cannot reach as deep as great as natural impact craters, without inconveniently large machinery. Man-made impact craters, however, remove the issue of long term exposure to radiation that natural impact craters possess, but will also cause extremely large human damage to the Martian landscape and potential life.

SCORE: 3.85

### *Subsurface Cavities/Caves/Lava Tubes*

(Léveillé, R. J., Datta, S., 2010)



Figure 1. Portion of MO/THEMIS visual image of lava tube collapsed pits, possibly related to flows from Hadriacia Patera.

### *Overview*

On Earth, the natural conduits through which lava travels beneath the surface, or lava tubes, can reach as deep as 2 km. On Mars, lava tubes have been observed, and similar depths could also be reached. Importantly, microbial life has been discovered in these lava tubes or caves on Earth, which also suggests that it is possible for life to be preserved in Martian lava tubes, as they offer a stable, temperature controlled environment, may also contain water, as seen on Earth, and provide protection from radiation and surface weather conditions.

### *Practical Feasibility*

Time to plan and finalize - 3

Underground cave exploration using rovers is limited, although ReachBot, designed in 2018 by Marco Pavone of the Autonomous Systems Lab at Stanford University, was invented to explore Martian caves.

ReachBot still has significant further developments to be made before it can be deployed. As the interior of Martian caves are unfamiliar to scientists, more research into the caves themselves and their physical conditions is required.

#### Size/practicality of instruments required - 3

The ReachBot is small so robots like it can maneuver through tight spaces, and is light enough to be easily transported to Mars. However, for a robot like this to collect physical samples, it needs additional technologies and mechanisms, potentially making it larger and heavier. Robots can be tested in lava tubes on Earth to develop effective cave exploration and sample collection, although it is not certain that Martian caves will mirror Earth caves.

#### Maintaining function over changes in physical conditions - 3

Rovers are able to withstand high radiation doses from space. In subsurface caves, there likely exists radiation from radiolytic compounds, but the rover's composition of metals such as titanium protect it from this. Temperatures in the tubes are expected to be constant, and the depths of these caves will protect the robot from harsh winds and dust storms. The major physical changes that pose a challenge are the pressure changes at extreme depths and the uneven surfaces or tight spaces within the cave in which the rover may get stuck.

#### Operate without direct human intervention - 3

Operating a rover in lava tubes, especially remotely, is very challenging due to the obscured and obstructed path that the radio waves must take to communicate between the rover and surface or orbiters. As a result, it is of high importance that an underground cave-exploring rover must be made autonomous and independent of aid or communication from surface Mars rovers. While this is possible, it will take some time to develop. Having humans on Mars would not necessarily support the functionality of such a rover exploring lava tubes however, as a human may be unable to access the tubes and explore small spaces, for example.

#### Preservation of sample/ biosignatures - 5

Potential biosignatures in these lava tubes are protected from the exterior conditions of weather, temperature, pressure and radiation from above the surface that are likely to cause harm to biological

molecules or signatures. By traveling to the subsurface rather than attempting to unearth it, no new exposure to surface conditions will occur. Samples are also extracted in this protected, stable environment, maintaining their protection. Autonomous analysis or sterilization within the subsurface also enhances the success of finding preserved biosignatures, as bringing samples to the surface exposes it to the harmful conditions stated above.

#### *Planetary Protection*

Sterilization/ prevention of backward and forward contamination - 4

It is likely that present sterilization methods can be applied to lava tube exploration with subsurface rovers due to their small size - it is easier to ensure that the robot is fully sterile, in comparison to larger machinery. Its size also limits the mass and volume of samples it can collect, and thus similarly sterilization is more effective. However due to the unfamiliarity of cave conditions to scientists, there may be obstacles, such as the temperature difference between the subsurface and surface, that make the sterilization of samples in transit difficult.

#### Alteration to Mars environment - 5

As with impact craters, the natural formation of this landform means that no drilling or physical change of the landscape is required. The small size of a rover needed for this subsurface exploration means that it will not cause much physical or erosional harm to the environment by exploring the caves or taking small, shallow samples.

SCORE: 3.80

#### *Inchworm Deep Drilling System*

(Rafeek, S. et al. 2001)



Figure 2. CAD Rendering of the Inchworm Deep Drilling System concept. Uses a two part inchworm motion to thrust into ice.

*Overview*

The Inchworm Deep Drilling System (IDDS) is a subsurface transport system initially designed for Jupiter's moon, Europa, although it has been suggested that this system is applicable to ice on Mars. (Rafeek et al. 2001). It uses an inchworm burrowing method to achieve depths in the order of kilometers. The IDDS drill thrusts into the ground in two parts under its own power, and is able to do so autonomously. Samples can be taken and analysis can be performed at depths, as the system operates independently of gravity.

*Practical Feasibility*

Time to plan and finalize - 3

The IDDS has been in conversation from as early as the 2000s, so much consideration has been taken into how the IDDS can effectively burrow, as well as the possible in-situ analysis and sample extraction that it can complete. The IDDS was designed initially for ice penetration and so is not certainly effective into the Martian regolith. In ice, however, the IDDS is promising.

Size/practicality of instruments required - 5

The IDDS robot stands at between only 10 and 15 centimeters in diameter and 1 meter in length. It is small, compact and can easily be transported to Mars and carried by a rover.

Maintaining function over changes in physical conditions - 4

The burrowing method is independent of gravity, so the IDDS is able to operate with changes in pressure as it descends. Its metallic composition allows it to withstand radiation, and its narrow, small shape and operation within the subsurface means that weather conditions such as wind are unlikely to affect it. Additional considerations are temperature control and the ability to withstand rocks and minerals that the device may encounter deep below the surface.

Operate without direct human intervention - 5

This robot is autonomous so does not require direct human intervention to operate. The drilling technology, namely an Athena Mini-Corer, requires little power so the IDDS has a high reliability, power density and output duration. Thus humans are not needed to ensure the device is continually powered,

and it is likely to be able to operate over depths of several kilometers and over prolonged periods of time.

Preservation of sample/ biosignatures - 5

A great advantage of the IDDS is that it is able to take samples and analyze them from within the subsurface. There is no need for the sample to be removed from the subsurface to determine if biotic signatures exist, and therefore the sample is not exposed to radiation or changes in temperature or pressure that may damage biosignatures. Preservation of samples is more difficult if they must be taken to a rover on the surface of Mars, or back to earth, as the sample is then exposed to harmful exterior conditions.

*Planetary Protection*

Sterilization/ prevention of backward and forward contamination - 4

As with plasma drilling, the fact that samples are taken from frozen conditions means that sterilizing the samples will be difficult, particularly if higher temperatures are required to complete sterilization. This may be possible with future research, but in situ analysis means that removing the sample from the subsurface and therefore sterilization may not be required.

Alteration to Mars environment - 4

Again, as with plasma drilling, penetrating ice is arguably less harmful than penetrating Martian soil or ground. The IDDS is not very wide so will not create large scars in the landscape. The fact that analysis can be completed within the subsurface means that samples can be left in their initial environment.

SCORE: 4.4

*Site Characterization and Analysis Penetrometer System (SCAPS)*

(Wesnousky, J. et al. 1996.)

*Overview*

The Site Characterization and Analysis Penetrometer System (SCAPS) is a real time in-field subsurface screening method, presently used on Earth in the context of petroleum, oil and lubricants. SCAPS was developed with efforts from the Army, Navy and Air Force and has the ability to analyze soil depths as great as 100 feet or more. The cone penetrometer is responsible for physically penetrating

the ground. Remote sensors attached to it enable analysis of the subsurface composition. Laser Induced Fluorescence (LIF) and X-Ray Fluorescence analyze petroleum, and thermal desorption and Hydrosparge sensors detect volatile organic compounds. In comparison to the IDDS, SCAPS can be used in the Martian regolith.

#### *Practical Feasibility*

Time to plan and finalize - 4

This method is already successful on Earth, used by the Army, Navy and Air Force. Primarily it is used for petroleum, oil and lubricant analysis and detection, so modifications are required for it to detect biological molecules and biosignatures. There also needs to be further consideration around the difference in the Earth's subsurface composition versus that of Mars.

Size/practicality of instruments required - 3

The SCAPS cone penetrometer device used on Earth weighs around 20 tons, 5 times the mass of Curiosity. While it is not impossible to get machinery this large onto Mars, it is more difficult.

Maintaining function over changes in physical conditions - 4

SCAPS is successful in the Earth subsurface conditions, although it has mostly only operated in soil and groundwater environments. Mars is drier than Earth and so the subsurface is likely harder, denser and more difficult to penetrate. SCAPS is able to withstand temperature changes in the subsurface of Earth, but the Martian subsurface is much colder so a temperature control system is important in ensuring the analysis and drilling devices can operate effectively at low temperatures. The heaviness and solidity of this large instrument means that it is likely to be able to withstand pressure changes associated with increasing depth into the subsurface.

Operate without direct human intervention - 2

Again, size is a major inhibiting factor of this device being able to operate autonomously. Presently on Earth, human operation of the penetrometer is required, in terms of choosing a boring location and situating the penetrometer into the ground effectively, although it is not as large and impractical as vertical drilling, for example.

Preservation of sample/ biosignatures - 4

As with the Inchworm Deep Drilling System, SCAPS is able to perform in situ analysis so samples do not need to be taken above the surface to determine if there are biosignatures or organic compounds present at the given site. Thus samples need not be exposed to radiation and exterior surface conditions that harm the preservation of the sample and potential biosignatures it contains. The main concern is using thermal desorption or excitation to identify organic molecules, as presently practiced on Earth using SCAPS. Thermal methods can chemically or physically change and harm biosignatures before or during analysis.

#### *Planetary Protection*

Sterilization/ prevention of backward and forward contamination - 4

Again, due to the in situ analysis, samples are not required to be taken out of the ground, thus removing the concern of backward contamination from the samples. The large and heavy nature of the cone penetrometer and the instrument as a whole makes it difficult to completely implement sterilization methods.

Alteration to Mars environment - 3

This method physically creates a permanent excavation scar into the Martian surface. The size of the penetrometer means that a large, wide hole is created per borehole location, and it is likely that scientists will intend to look at multiple sites, increasing the physical damage.

SCORE: 3.4

#### **Conclusion**

The scores show that of the six methods assessed, the Inchworm Drilling Device System best meets the needs of physical practicality and planetary protection. It is highly successful as it can reach depths of up to several kilometers, is small, lightweight and practical, can operate autonomously and can complete in situ analysis. It creates a direct path from the subsurface to the surface so that communication to rovers and satellites via radio waves is effective and efficient. However, there are further considerations required for the IDDS to be fully successful, including developing the ability to penetrate the Martian soil or regolith rather than merely ice. This will be challenging given that the Martian surface is rough and composed of rocks and

minerals, whereas ice is smoother and more uniform and so suits the inchworm mechanism well. More research is required into this and it is not certain that the IDDS will be successful in penetrating the Martian regolith.

Initially, it seemed that natural access methods, such as impact excavation and lava tubes or caves would be most feasible, as they require no physical deep penetration of the surface. The results show that deep mechanical excavation is majorly impractical to depths of several kilometers due the size and weight of equipment required and the need of direct human intervention. These deep drilling methods also severely damage the Martian landscape and are harder to implement sterilization methods on. The natural methods work best in terms of keeping the planet unaltered by human activity. However, impact excavation and cavity exploration also encounter challenges beyond human control, such as the long-term exposure of craters to radiation from space, limited subsurface exploration in caves due to their narrow and undulating structure and communication difficulties with the surface.

While the IDDS is the most promising out of all of the methods examined here, there may be future designs, robots or techniques that are better suited to accessing the deep Martian subsurface in search of evidence of past or present life, while considering physical practicality and planetary protection. However this study also highlights important factors that any proposed mission should include; equipment should be small and lightweight for transport, sterilization and automation purposes. Smaller instruments also create less drastic damage to the planet's surface and landscape. Sites on Mars where large depths naturally occur should be prioritized, as deep drilling, which requires human operation and creates greater physical damage, can be avoided. Operations should be tested in the subsurface of Earth and in replicated Martian conditions on Earth thoroughly. Equipment should be durable for penetrating hard, compact material and maneuvering uneven terrain and potentially tight, uneven spaces. Machinery should be made autonomous and designed to complete extensive in-field analysis so that samples do not need to be brought to the surface or back to Earth, eliminating the risk of backward contamination and the exposure of biosignatures to harmful radiation and surface conditions. Methods should also minimize harm to the physical Martian landscape, so natural access methods should still be considered alongside

less harmful penetration methods, such as the IDDS, to maximize the likelihood of successfully searching the deep Martian subsurface for biosignature evidence.

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