

[E] 口頭発表 | セッション記号 P (宇宙惑星科学) : P-PS 惑星科学

■ 2019年5月26日(日) 10:45 ~ 12:15 | 会場 A02 東京ベイ幕張ホール

**[P-PS04] 火星と火星圏の科学**

コンビーナ:宮本 英昭(東京大学)、臼井 寛裕(東京工業大学地球生命研究所)、松岡 彩子(宇宙航空研究開発機構 宇宙科学研究所 太陽系科学研究系)、Sushil K Atreya(University of Michigan Ann Arbor)、座長:宮本 英昭、臼井 寛裕

In view of unprecedented advances in our understanding of Mars, primarily due to new and ongoing observations of the planet with a number of spacecraft missions of the US, Europe and Asia, we propose a session on Mars. Mars is an object of intense scrutiny. Currently, eight spacecraft are operating at Mars, with six in orbit (Odyssey, MRO, MAVEN, Mars Express, Mangalyaan and TGO) and two on the surface (MSL-Curiosity and MER-Opportunity), the largest number ever at any given time. In addition, InSight is on track to land on Mars in November 2018, and several spacecraft are in various stages of implementation with launches scheduled for 2020 (Mars 2020, ExoMars 2020, Emirates Mars Mission Hope, Chinese Mars Mission and the Japanese Mars Terahertz Microsatellite), 2022 (ISRO's Mangalyaan 2), and 2024 (JAXA's MMX mission to explore Phobos, Deimos, and Mars). All this is a clear demonstration of public's strong fascination with and commitment to Mars exploration and the resulting scientific bonanza. Synergistic investigations with ongoing and already completed missions along with modeling studies and earth-based observations are gradually revealing the nature of Earth's most closely resembling planet that took on a different evolutionary track than our home planet. Morphology and variable phenomena seen on the surface (RSLs, e.g.) and in the atmosphere (methane) indicate that Mars is possibly currently active. Available data are providing a better understanding of Mars' present geologic and atmospheric state, climate evolution, and habitability. Thus, the scope of this session will be the recent results from a broad spectrum of Mars studies encompassing the interior, surface, atmosphere, plasma environment, and the Mars system including its two satellites. Abstracts on modelling, instrumentation and future mission plans are also encouraged.

10:45 ~ 11:00

**[PPS04-07] MODELING MORE COMPLEX EARLY MARTIAN ATMOSPHERES AND DETERMINING THE RESULTING PRECIPITATION AND EROSION RATES**

\*Ramses M Ramirez<sup>1,2</sup> (1.Earth-life Science Institute、2.Tokyo Institute of Technology)

11:00 ~ 11:15

**[PPS04-08] GCM simulations of the present and past water environment on Mars**

\*黒田 剛史<sup>1,2</sup>、鎌田 有紘<sup>1</sup>、鳥海 克成<sup>1</sup>、笠羽 康正<sup>1</sup>、寺田 直樹<sup>1</sup>、中川 広務<sup>1</sup> (1.東北大学 大学院理学研究科、2.情報通信研究機構)

11:15 ~ 11:30

**[PPS04-09] Cold-based glaciation at Pavonis Mons, Mars: Evidence for moraine deposition during glacial advance**

★Invited Papers

\*Reid Parsons<sup>1,2</sup>、Tomohiro Kanzaki<sup>3</sup>、Ryodo Hemmi<sup>1</sup>、Hideaki Miyamoto<sup>3</sup> (1.University Museum, University of Tokyo、2.Earth and Geographic Science Dept., Fitchburg State University、3.Dept. of Systems Innovation, University of Tokyo)

11:30 ~ 11:45

**[PPS04-10] Possible Earth-like tectonic scenario on Mars; a mineralogical and geochemical perspective**

\*Trishit Ruj<sup>1</sup>、Gene W Schimdt<sup>2</sup>、Goro Komatsu<sup>2</sup>、Kenji Kawai<sup>1</sup> (1.Department of Earth and Planetary Science, School of Science, UTokyo, Japan、2.International Research School of Planetary Sciences, Università d'Annunzio, Italy)

11:45 ~ 12:00

[PPS04-11] Hydration state of the Martian lithosphere constrained from gravity and topography

\*James Daniel Paul Moore<sup>1</sup>、Jon Wade<sup>2</sup>、Anthony B Watts<sup>2</sup>、Richard M Palin<sup>3</sup>、Lars M Hansen<sup>2</sup>、Brendan Dyck<sup>4</sup>、Jun Muto<sup>6</sup>、Andrew J Smye<sup>5</sup>、Adam D Switzer<sup>1</sup> (1.Earth Observatory of Singapore、2.University of Oxford、3.Colorado School of Mines、4.Simon Fraser University、5.Penn State、6.Tohoku University)

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12:00 ~ 12:15

[PPS04-12] SUBGLACIAL ANTARCTIC LAKE VOSTOK VS. SUBGLACIAL SOUTH POLE MARTIAN LAKE AND HYPERSALINE CANADIAN ARCTIC LAKES – PROSPECTS FOR LIFE

\*Sergey Bulat<sup>1</sup> (1.NRC KI - Petersburg Nuclear Physics Institute, Saint-Petersburg-Gatchina, Russia)

# MODELING MORE COMPLEX EARLY MARTIAN ATMOSPHERES AND DETERMINING THE RESULTING PRECIPITATION AND EROSION RATES

\*Ramses M Ramirez<sup>1,2</sup>

1. Earth-life Science Institute, 2. Tokyo Institute of Technology

The early Mars climate problem remains one of the most interesting ones in planetary science. In particular, the high degree of fluvial surface erosion, as exemplified by modified craters and large winding ancient valley networks, suggests that early Mars may have exhibited a more Earth-like climate in the past. However, climate models have always struggled to simulate the warmer and wetter conditions that were apparently required to explain these observations, given that early Mars (~3.8 Ga) received less than 1/3 the solar insolation that reaches our planet today. One possibility is that warm climate conditions on early Mars were maintained by a multi-bar CO<sub>2</sub>-rich atmosphere (with H<sub>2</sub>O vapor), mirroring conditions that may have been true during the early days of Earth and Venus. However, climate models have repeatedly shown that a dense CO<sub>2</sub> atmosphere alone is insufficient to generate warm conditions.

This inability of climate models to warm planets using the conventional greenhouse gases (i.e. CO<sub>2</sub> and H<sub>2</sub>O) had prompted us and other groups to consider additional warming from secondary absorbers, such as H<sub>2</sub> and CH<sub>4</sub>. Both CO<sub>2</sub>-H<sub>2</sub> and CO<sub>2</sub>-CH<sub>4</sub> atmospheres have been shown to generate above-freezing mean surface temperatures, which are high enough to explain the existence of geological features that were most likely carved by running water.

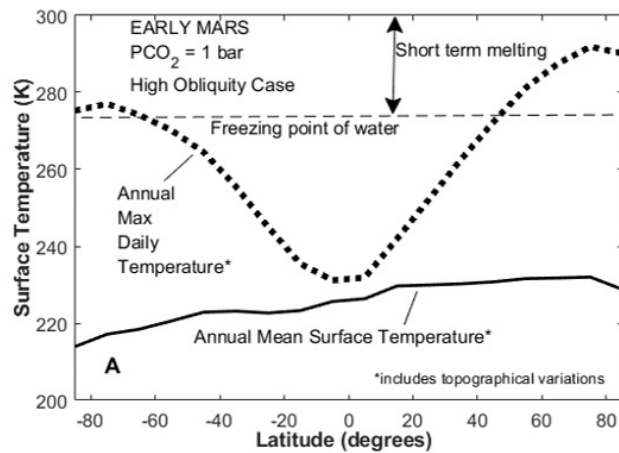
However, these previous calculations were performed by single-column radiative convective climate models that can only compute mean-averaged planetwide properties and are unable to spatially resolve atmospheric and surface parameters. Such models are also unable to evaluate the effects of oceans on climate, or compute precipitation and the resulting erosion rates to compare with those inferred from observations. On the other end, 3-D models, although quite complex, are very expensive computationally and are unable to explore parameter space as fully and completely as can simpler models. For best results, 3-D models also require a level of knowledge about the planet that, although available for present Earth, is simply unavailable for early Mars, which necessarily results in making many assumptions that cannot be tested or verified as with any other model.

Here, I present my advanced 2-D non-grey energy balance model, which provides a nice compromise between complexity and speed for this problem. It contains 36 latitude bands, clouds, topography, the ice-albedo feedback, and accurate radiative transfer directly computed from detailed single-column climate modeling calculations. Ocean sizes can be varied and planetary parameters, including eccentricity and obliquity can be computed. A typical simulation takes less than a minute. I present some preliminary results (Figure 1).

We will present simulation results for CO<sub>2</sub>-H<sub>2</sub> and CO<sub>2</sub>-CH<sub>4</sub> atmospheres of various H<sub>2</sub> (0 -20%) and CH<sub>4</sub> (0- 10%) concentrations, pressures (0 -3 bar), while varying ocean size given various literature estimates. From these simulations, we will compute atmospheric and surface temperatures as a function of latitude, yielding precipitation rates, and the resultant erosion rates as a function of latitude. These latitudinal erosion rates will be compared against those inferred for observations. Should such erosion rates be too

high, we can conclude that the resultant climates are too wet/warm. Likewise, should they be too low, the climates are not wet enough. Thus, for the first time we will be able to constrain realistic atmospheric compositions using a relatively complex model that may satisfy the available atmospheric and geologic constraints, providing a glimpse into what the ancient atmosphere could have actually been like. We will also discuss the implications of our results and give hypotheses that can be tested by upcoming and future missions searching for ancient geology and even life.

Keywords: early Mars, life, climate, atmospheres, erosion



**Figure 1:** Computed surface temperatures per latitude band, which agrees well with the similar 1-bar case from the 3-D model of Wordsworth et al. 2015 Fig.1.

## GCM simulations of the present and past water environment on Mars

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Though the current Mars is a dry planet, the ancient Mars is thought to have been a water-rich planet like the present Earth. There are many topographic evidences of past liquid water flow, which should be hints for the past climate on Mars. Most of the liquid water is thought to have escaped into space, but even on the present Mars, some water environments have been found as the permanent north polar cap, underground ice, and possibly salty liquid water.

On the present Mars, water vapor exists in the atmosphere with the mixing ratio of up to hundreds of ppmv from surface up to ~100 km altitude, and water ice clouds also exist in low-latitudes around aphelion (northern summer) with the infrared opacity of up to ~0.2 and winter polar regions. The north polar ice sheet is thought to be the main source of atmospheric water, as well as possibly the underground water. Also the detection and mapping of HDO/H<sub>2</sub>O ratio in the atmospheric water could be hints for the history and movement of water. Our Mars global climate model (MGCM), DRAMATIC, has simulated such water environment consistently with the available observations, and the detailed investigations are ongoing with high-resolution (horizontal resolution of ~67 km) simulations.

Moreover, we have simulated the paleoclimate on Mars using a MGCM for paleoclimate (PMGCM), with a dense CO<sub>2</sub> atmosphere with the surface pressure of up to a few bars. Radiative effects of water vapor may contribute the warming, and the existence of liquid ocean and lakes contributes the supply of water in the atmosphere. Our PMGCM simulation with ocean/lakes estimated the distributions of fluvial and sediment discharges from the precipitation and snow accumulations, and showed the agreements with the observed valley networks with several exceptions.

キーワード：火星、水循環、水環境、古気候、全球気候モデル

Keywords: Mars, water cycle, water environment, paleoclimate, global climate model

## Cold-based glaciation at Pavonis Mons, Mars: Evidence for moraine deposition during glacial advance

\*Reid Parsons<sup>1,2</sup>, Tomohiro Kanzaki<sup>3</sup>, Ryodo Hemmi<sup>1</sup>, Hideaki Miyamoto<sup>3</sup>

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The three large volcanoes in the Tharsis region of Mars: Arsia, Pavonis, and Ascraeus Montes all have fan-shaped deposits (FSDs) on their northern or western flanks consisting of a combination of parallel ridges, knobby/hummocky terrain, and a smooth, viscous flow-like unit. The FSDs are hypothesized to have formed in the Amazonian during a period of high spin-axis obliquity which redistributed polar ice to the equatorial Tharsis region resulting in thick (>2 km), flowing ice deposits.

The ridged units in the FSDs are hypothesized to be deposited during glacial recession based on their similarity to terrestrial analogs in the Dry Valleys of Antarctica [1] and Iceland [2,3]. Crater age dates [4] suggest glacial recession took place slowly over hundreds of millions of years, but that recession episodically halted for a period of about a million years [4] in order to deposit an individual ridge. However, the 120 kyr periodicity in obliquity [5-7] is the most likely climate signal to influence the redistribution of ice and glacial dynamics. Therefore, there is an inconsistency between the million-year timescale attributed to ridge formation and the climate variation timescale. To investigate the process of ridge formation, we conducted numerical simulations of ice accumulation and flow using temperature and mass balance assumptions associated with Amazonian global circulation models [8] and laboratory experiments of ice sublimation under martian conditions [9].

We find that ice flow ceases during glacial retreat due to the reduction in ice thickness associated with the slow sublimation (0.5 mm/yr) of buried ice. Laboratory experiments of sublimation of buried ice supports this model assumption [9] as does the presence of remnant ice deposits within the Pavonis FSD. Because ice flow has ceased during glacial retreat, there is no mechanism to advect surface debris to form a ridge.

The model results, when combined with topography observations of a long sequence of ridges located interior of the Pavonis FSD, show that the ridged units were more likely deposited during one or more periods of glacial advance (instead of retreat) when surface temperature variations caused by 120 kyr periodicity obliquity oscillations propagated through the ice deposit resulting in a fluctuating ice flow rate. A model-derived ice flow rate of 3 cm/yr during glacial advance can deposit an average interior ridge in less than 100 kyrs if the supraglacial debris layer is two or more meters thick.

The pattern in ridge spacing observed at Pavonis Mons is more consistent with ridge deposition occurring during glacial advance. These ridges were overrun by the advancing ice, but remained preserved due to the cold temperatures at the glacier bed. Evidence supporting the preservation of ridges underneath an ice sheet comes from intersecting ridge sequences at Arsia and Pavonis [10], as well as the superposition of remnant ice (the smooth unit) on top of ridges.

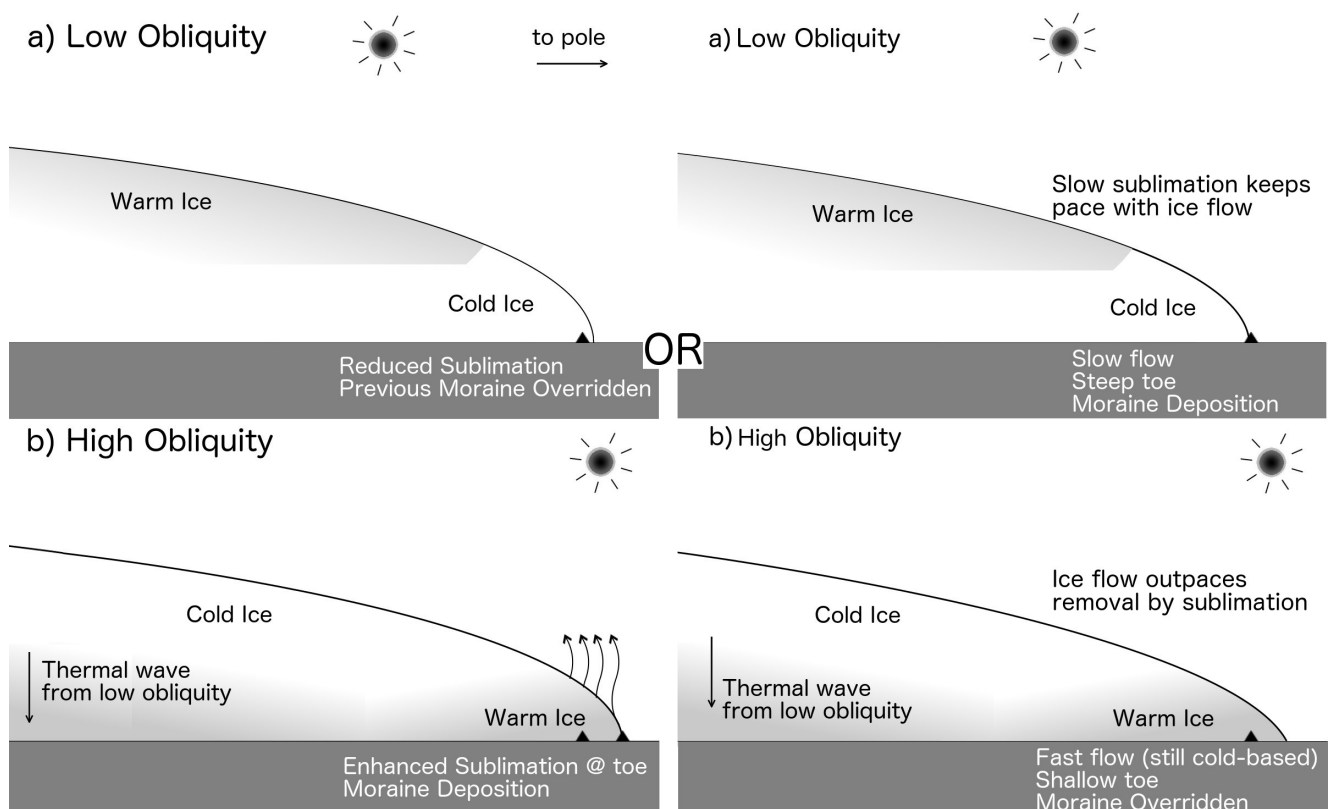
Our hypothesis links the dominant, 120 kyr periodicity in obliquity to the time interval between adjacent ridges. By measuring the spacing between these ridges and dividing by the obliquity periodicity, we constrain the velocity of glacial margin to be between 0.2 and 4 cm/Earth yr - in close agreement with the

numerical simulation. Furthermore, a comparison with a simulation conducted under terrestrial gravity confirms the prediction of steeper ice margins on Mars during glacial advance which may contribute to ridge deposition via mass wasting, although invoking mass wasting is not required by our hypothesis so long as the supraglacial debris layer is >2 m thick. This re-interpretation of the FSD ridged unit suggests that the timescale of FSD formation (and perhaps the duration of the Amazonian high obliquity period) was shorter than previously reported.

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Keywords: Mars, Glaciation, Climate



## Possible Earth-like tectonic scenario on Mars; a mineralogical and geochemical perspective

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The southern highlands of Mars preserve a series of Noachian aged (Eoarchean equivalent to Earth) grabens with multiple orientations and morphologies (Ruj et al., 2018). We have found traces of a 3000 km long succession of grabens (with individual grabens ranging from 30 to 1200 km) in the Noachis Terra and Terra Sabaea region around the western boundary of the massive Hellas basin. However, the origin of these grabens is neither confirmed to be a result of Earth-like plate tectonics or related to giant impacts such as Hellas, Argyre and Isidis. Here, after preparing the geological map, we present our preliminary observation (using remotely sensed datasets) on the mineralogy of the rocks and the geochemistry of the crust associated with the grabens. The hyperspectral analysis of several CRISM (Compact Reconnaissance Imaging Spectrometer, onboard the Mars Reconnaissance Orbiter) observations indicates the presence of olivine, pyroxene (clino), plagioclase, phyllosilicates and hydrated sulfates. GRS (Gamma Ray Spectrometer onboard on Mars Odyssey) observation of the area shows a higher abundance of Potassium (K) and Thorium (Th) than their average global distribution. Plagioclase, olivine and pyroxene are the main constituents of basalts and the GRS derived geochemistry confirms the existence of this alkali basalt type with a higher abundance of Potassium (K). Meanwhile, Thorium (Th) content is higher than the surroundings, indicating the presence of granitic composition rocks which are typically found within continental rift zones on Earth associated with bimodal volcanism.

Keywords: Mars, Tectonics, Martian mineralogy

## Hydration state of the Martian lithosphere constrained from gravity and topography

\*James Daniel Paul Moore<sup>1</sup>, Jon Wade<sup>2</sup>, Anthony B Watts<sup>2</sup>, Richard M Palin<sup>3</sup>, Lars M Hansen<sup>2</sup>, Brendan Dyck<sup>4</sup>, Jun Muto<sup>6</sup>, Andrew J Smye<sup>5</sup>, Adam D Switzer<sup>1</sup>

1. Earth Observatory of Singapore, 2. University of Oxford, 3. Colorado School of Mines, 4. Simon Fraser University, 5. Penn State, 6. Tohoku University

Widespread aqueous alteration of the Martian crust suggests that metamorphic hydration reactions may have played a critical role in the sequestration of water early during the planet's history. The presence of hydrous phases in the Martian crust reduce its bending strength, and we show that observations of the Martian gravity anomaly may be used to constrain the fate of Martian surface water.

Using the gravity anomalies associated with notable topographic features, such Olympus Mons, as well as the global gravity and topography, we construct yield strength envelopes for hydrous and anhydrous end-member crustal sections, and derive the predicted elastic thicknesses,  $T_e$ , a proxy for the long-term lithospheric strength of Mars. We also use spherical harmonic coefficients that describe the Martian gravity anomaly and topography fields to quantify the role of isostasy in contributing to crustal and upper mantle structure. Power spectra of these fields reveal that the gravity effect of topography and its flexural compensation contributes significantly to the observed free-air gravity anomaly spectra for spherical harmonic degree  $8 < n < 50$ , corresponding to wavelength  $300 < \lambda < 3000$  km. The best-fit global average is for an elastic plate (flexure) model with  $T_e$  of  $\sim 126$  km. All isostatic models under-predict the spectra at  $2 < n < 5$ , and we interpret the low-order Martian gravity field, at least in part, to be the result of processes that formed the Northern Basin. By comparing the observed Martian  $T_e$  to that predicted for our metamorphic mineral assemblages, we iterate on the water content until convergence. In short, we show the bending strength of Mars places constraints on the amount of hydration of the Martian crust, which in turn we use to calculate the planetary water budget. Notably, the stiffer flexural response of Olympus Mons is consistent with its younger age and eruption predominantly into a dry environment.

Keywords: Mars, Flexure, Gravity

# SUBGLACIAL ANTARCTIC LAKE VOSTOK VS. SUBGLACIAL SOUTH POLE MARTIAN LAKE AND HYPERSALINE CANADIAN ARCTIC LAKES –PROSPECTS FOR LIFE

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The objective was to search for microbial life in the subglacial freshwater Antarctic Lake Vostok by analyzing the uppermost water layer entered the borehole following successful lake unsealing at the depth 3769m from the surface. The samples included the drillbit frozen and re-cored borehole-frozen water ice. The study aimed to explore the Earth's subglacial Antarctic lake and use the results to prospect the life potential in recently discovered subglacial very likely hypersaline South Pole ice cap Martian lake (liquid water reservoir) [1] as well as similar subglacial hypersaline lakes (reservoirs) in Canadian Arctic [2].

The Lake Vostok is a giant (270 x 70 km, 15800 km<sup>2</sup> area), deep (up to 1.3km) freshwater liquid body buried in a graben beneath 4-km thick East Antarctic Ice Sheet with the temperature near ice melting point (around -2.5°C) under 400 bar pressure. It is extremely oligotrophic and poor in major chemical ions contents (comparable with surface snow), under the high dissolved oxygen tension (in the range of 320 -1300 mg/L), with no light and sealed from the surface biota about 15 Ma ago [3].

The water frozen samples studied showed very dilute cell concentrations - from 167 to 38 cells per ml. The 16S rRNA gene sequencing came up with total of 53 bacterial phylotypes. Of them, only three phylotypes passed all contamination criteria. Two phylotypes were reported before [4] - hitherto-unknown and phylogenetically unclassified phylotype w123-10 likely belonging to *Parcubacteria* Candidatus *Adlerbacteria* and 3429v3-4 showing below-genus level (93.5%) similarity with *Herminiimonas glaciei* of *Oxalobacteraceae* (*Beta-Proteobacteria*) -water-inhabited ultramicrobacterium isolated from a deep Greenland ice core. The new third finding (the phylotype 3698v46-27) proved to be conspecific with several species of *Marinilactobacillus* of *Carnobacteriaceae* (*Firmicutes*). All three bacterial phylotypes may represent ingenious microbial communities in the subglacial Lake Vostok.

Two newly discovered (RES) subglacial hypersaline lakes (5 and 8.3km<sup>2</sup> areas) in the Canadian Arctic are settled in bedrock throughs beneath 560 and 740m ice cap with modeled temperature below -10.5°C [2] and isolated by a glacier for at least 120 Ky ago. The biology is not yet studied (lakes are not unsealed), but the life potential is rather high (while dissimilar to the Lake Vostok). Their estimated salinity (140-160 psu) is in a range of that observed for brine-rich water body beneath Taylor Glacier (-7.8°C, 125 psu) and the ice-covered Lake Vida (-13°C, 200 psu) in Antarctica, both inhabited by active unique microbial communities.

The just discovered (RES) 20km-wide subglacial lake beneath the South Pole ice cap on Mars [1] should be ultra-hypersaline because it is buried beneath a 1.5km water ice cap with modeled temperature -68°C. It is well below known low-temperature limits supporting terrestrial microbial cell propagation and metabolism as well (-18°C and -33°C, respectively [5]). Such conditions may indicate zero-level life potential for this lake from the Earth-bound point of view, but its exploration may give us surprises.

In general, all three subglacial lakes (complexes) –two Earth-bound and one Martian, may host unique life forms never met before but their exploration (unsealing) is challenging as it happened with the Lake Vostok.

The reported study was partly funded by RFBR according to the research project No.18-55-16004.

**References:**

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Keywords: Antarctica, Subglacial Lake Vostok, Subglacial Mars South Pole ice cap lake, Subglacial hypersaline Canadian lakes, Bacterial 16S rRNA genes, Astrobiology

## SUBGLACIAL ANTARCTIC LAKE VOSTOK VS. SUBGLACIAL SOUTH POLE MARTIAN LAKE AND HYPERSALINE CANADIAN ARCTIC LAKES – PROSPECTS FOR LIFE

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### Keywords:

Antarctica, subglacial Lake Vostok, Mars, subglacial South Pole ice cap lake, subglacial hypersaline Canadian lakes, Lake Vostok unsealing, frozen water, life, extremophiles, bacteria, 16S rRNA genes, astrobiology

### Introduction:

The objective was to search for microbial life in the subglacial freshwater Antarctic Lake Vostok by analyzing the uppermost water layer entered the borehole following successful lake unsealing at the depth 3769m from the surface. The samples included the drillbit frozen and re-cored borehole-frozen water ice. The study aimed to explore the Earth's subglacial Antarctic lake and use the results to prospect the life potential in recently discovered subglacial very likely hypersaline South Pole ice cap Martian lake (liquid water reservoir) [1] as well as similar subglacial hypersaline lakes (reservoirs) in Canadian Arctic [2].

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