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Abstract

The first man to step on Martian soil must be prepared and trained for everything he will face on the Red Planet, knowing what difficulties he will encounter, knowing where to explore, and what actions to take. All these aspects have to be learned here on Earth. That is why it is critical to have analog bases simulating Mars here on Earth. The primary objective of this work is to propose the 'Salar de Uyuni', located in Bolivia, as an analog base to simulate exploration missions on Mars. Uyuni's environmental characteristics make it a good alternative when one need to simulate exploration of other planets. In the present work, we can observe a comparison of the main features of the different simulation stations of Mars and the environmental characteristics of Uyuni.

Keywords: Analog Mars, Mars, Uyuni, Planet Exploration, Human Exploration, Simulation

1. Introduction

The growing interest to explore the Universe, discover new planets, has led us to develop scientific and technical projects, to discover the unknown.

The exploration of Mars has been a project that has emerged since the beginning of the cold war, the reasons for exploring the red planet are several, for example, ancient astronomers have evidenced the presence of furrows on the surface of the red planet that would be an indication of the existence of water. On the other hand, Mars would have a strategic position respect to the Sun, contemplating the red planet for human expansion in the future. Finally, the existing technology of space exploration can take us to that planet.

In the last years, different projects have come up to make the exploration of Mars come true, first by sending rover explorations like Spirit, Opportunity, Curiosity and others. On the other hand, there have also been projects to develop human exploration, with initiatives such as Mars500, MarsOne, and others.

To crystallize the human explorations on Mars, it has been understood that the first thing to do is to understand the necessary considerations for a manned space mission, for this, the Mars Society launched the Mars Analog Research Station (MARS) project. A global program of Mars operations research that includes four simulated Mars base habitats located in Australia, Iceland, the Canadian Arctic, Australian and the American Southwest. This mission is designed to understand on earth aspects such as the conditions of life that would have to be faced on Mars for exploration, also carried out geological, biological, electronic and even psychological investigations.

In this paper, we want to make a comparison of environmental conditions, geologic features, and biological attributes that we can see in the four simulated Mars base habitats, and we want to propose a location for the existence of a fifth simulated Mars base habitats located in the 'Salar de Uyuni' in Bolivia. The 'Salar de Uyuni' is a place that has the climatic, and geological conditions that are required and also has a quality of radiation. The salt and lithium that exist in the territory affect the correct functioning of electronic components, a quality that we would find interesting to simulate in search of a future human exploration mission to Mars.

This paper is structured as follow. Section 2 presents some characteristics of the Mars environment. In Section 3 one describe different analog Mars station around the world. Section 4 shows the advantages of Uyuni to be considered an analog Mars station. In Section 5 one shows the results. In Section 6 one interprets the results although the discussion. Section 7 present the arrived conclusion of this study.

2. Environmental conditions on Mars

2.1 General environmental conditions on Mars

Mars is the fourth inner planet in the solar system, the most distant planet belonging to this group, is mainly composed of rock and metal and have two natural satellites Deimos and Phobos.

The red planet is the second smallest planet in the solar system, and it is smaller than the Earth, the Martian year lasts 687 days.

The Martian atmosphere was destroyed by the solar wind; therefore it is now composed mostly of carbon dioxide, and the red color of this planet comes from iron oxide in its soil. [1]

Its surface is peppered with volcanoes, such as Olympus Mons, which reaches a height of 21,129 meters, on the other hand, is also composed of valleys such as Valles Marineris.

Also on the planet are the famous dust storms, which have a duration of weeks or even months that come to darken the sky completely and have winds that can reach a speed of more than 150 km / h.

Comparing the most relevant environmental conditions between our planet Earth and the red planet, we have the following table:

Table 1. Environmental conditions on Mars and Earth

Parameters	Mars	Earth
Mass (10^{24} Kg)	0.639	5.97
Gravity (m/s)	3.7278	9.81
Solar UV radiation (nm)	λ≥200	λ≥290
Solar particle events (Sv/h)	~ 0.1	-
Cosmic ionizing radiation (mSv/a)	100 to 200	1 to 2
Pressure (mbar)	4 - 7	1013
Temperature range (°C)	-140 to 20	-90 to 60
Atmosphere Composition		
CO2 (%)	95.3	0.33
N2 (%)	2.7	78.1
02 (%)	0.1	20.9
Ar (%)	1.6	0.9

The environmental conditions of Mars are extreme because as mentioned earlier this planet is farther from the sun than the Earth, it has an average temperature of -63 °C, also because of its tenuous atmosphere and the absence of magnetic field the radiation in the red planet is very high. [2]

Experts indicate that the environmental condition that would most affect the human being in a future mission on Mars would be the high radiation.

2.2 Radiation on Mars

To talk about radiation on the red planet, we must first consider that there are two types of radiation:

Ionizing radiation: this radiation carries enough energy to remove an electron from its orbit. Within this kind of radiation, we can see the following:

- Wave radiations: X-rays and gamma rays.
- Corpuscular radiations: Alpha radiation, beta radiation, neutron radiation.

Non-ionizing radiation: this radiation does not emit photons with enough energy to cause that an electron is removed from its orbit. Within this kind of radiation, we can see the following:

- Microwave radiation
- Infrared radiation
- Ultraviolet radiation
- Visible light
- Laser
- Radio Frequency Fields

In the following figure, we can observe more clearly the division of the mentioned two types of radiation, the first constituted by particles and the second with an electromagnetic nature. [3]

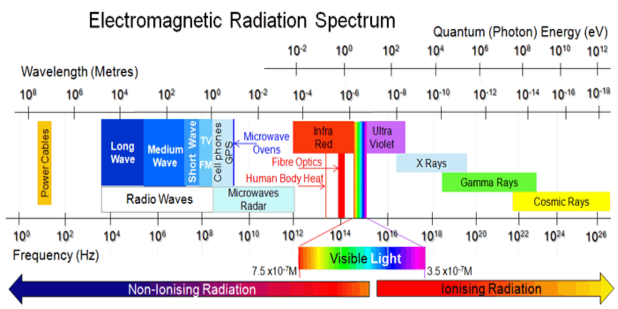

Fig. 1. Radiation spectrum

In this research, we will focus on the ultraviolet (UV) radiation about non-ionizing radiation.[4] Inside the ultraviolet radiation we can find the following three bands:

- UVA: It is the closest to the visible spectrum and is not absorbed by the ozone. Its range goes from 320 to 400 nm. This type of radiation damages the skin in the long term.
- UVB: It is a more dangerous type of radiation, although it is absorbed almost completely by the ozone, its spectrum goes from the 280 to the 320 nm. It affects DNA and also causes melanoma and other types of skin cancer.
- UVC: They have more energy than other types of UV rays, which is why this kind of radiation is extremely dangerous but is completely absorbed by the ozone and oxygen of our planet. Its spectrum is less than 280 nm.

Because the atmosphere of Mars is composed primarily of carbon dioxide (CO2), the UV radiation can reach the Martian surface.

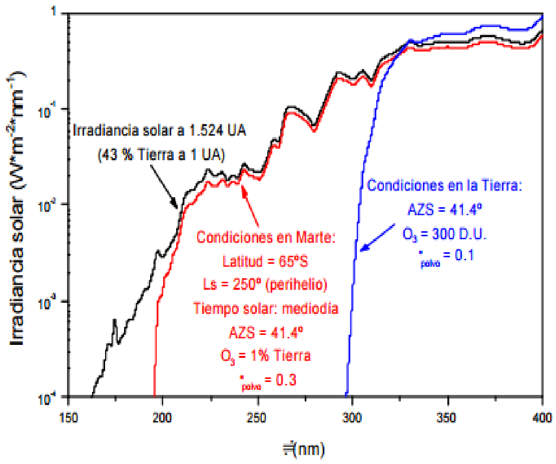

Fig. 2. UV radiation in Mars and in Earth

As can be seen in Figure 2, the cut-off point for UV radiation on Mars is given at 200 nm; the primary cause is provided by the existence of the majority of carbon dioxide in the atmosphere of the red planet.

On the contrary, in the case of the Earth, oxygen and ozone cause the cut-off point of UV radiation in the Earth's atmosphere at 290 nm. [5]

The spectral difference indicates that the surface of Mars is exposed to UVC and UVB radiation, which is very harmful to any organism.

In Figure 3, we will observe the spectrum of biological action, which quantifies the sensitivity of organisms to UV radiation. We also can see several examples of the action spectra of the most important biological targets:

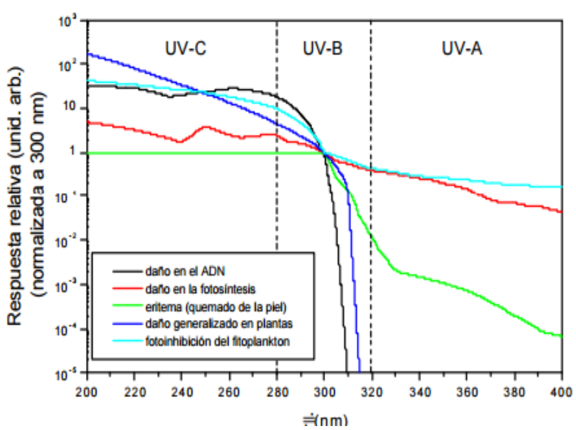

Fig. 3. UV radiation

One can see that for any action range if the wavelength of the radiation received is low, the damage will be greater. Therefore UVC radiation is the most harmful in all processes.

3. Mars analog research stations in the world

For many years, an important mission for space exploration has been the arrival of humans to Mars, for many reasons, but the most important are: the search for water and possible life on Mars, another important strategic reason is the possibility of contemplating the red planet for human expansion in the future, due to its position in the habitable zone of our solar system.

For these reasons Mars analog research stations have been created over time for ground research, in order to be able to develop the knowledge necessary to prepare a future mission to Mars, performing key activities like a “living on Mars” simulation wearing a space suit simulator, developing Extra Vehicular Activities (EVA), testing the All Terrain Vehicle (ATV). [6]

The most important analog missions and their main objective are described below.

3.1 The Mars Society’s Mars Analog Research Station

The Mars Society is an american association that was established in 1998 by Dr. Robert Zubrin, it is an organization truly dedicated to promote and research the human exploration in Mars. [7]

THE MARS SOCIETY

Fig.4. Mars Society

This international non-profit organisation developed the Mars Analog Research Station (MARS) project and built and operates four Mars surface exploration habitats, the location and specific details of each of these stations will be explained in more detail below.

3.1.1 Flashline Mars Arctic Research Station (FMARS)

FMARS is the first simulated Mars habitat established for the Mars Society, it was builded in the year 2000 with the help of different major companies that sponsorship the final cost of this project which was US$1.3 million. [8]

The station was designed by architect Kurt Micheels and design engineer Wayne Cassalls, the infrastructure of the station is composed of a unique type of fiberglass honeycomb construction technology.

At this station different missions are conducted and operated with different main objectives, such as habitat design tests, design of field exploration protocols, geological and biological researches under conditions similar to those found on the red planet. [9]

The location of this analogue station is in Canada on Devon Island at 75° 25' 52.75"N 89° 49' 24.19" W, its location is strategic, as it is located on a polar desert, a few kilometers from the Magnetic North Pole and in the vicinity of the Haughton impact crater, a crater of 23 km diameter.

Fig. 5.Location of Devon Island, Canada

The environmental conditions of this island are used to conduct research for different environmental characteristics that are similar to those found on the red planet, for example the average annual temperature is -16 ° C, because the soil remains frozen for most of the year.

This base location has an altitude of 1479 masl, an atmospheric pressure of 985.10 hPa, a UV radiation index of 4 and its mean temperature is -16 °C.

Another factor used to simulate the conditions of Mars in the Earth is the desert and barren environment that is exposed in summer season when the snow disappears for around 50 days. [10]

Also in the base they can perform geological studies of erosion in the Haughton crater.

Fig. 6. *Flashline Mars Arctic Research Station (FMARS)*

Finally another factor taken advantage of by the researchers is the psychological factor that affects to the crew by the isolation of the base, the difference of the cycle of the day and Arctic night and the impossibility of communication, since they are factors that will appear in a space flight of long duration. [11]

3.1.2 Mars Desert Research Station (MDRS)

MDRS is the second simulated Mars habitat established for the Mars Society, it was builded in the early 2000s. This station is located on the San Rafael Swell in southern Utah, United States of America, its coordinates are 38°48′47″N 110°51′18″W.

This location has the following environmental conditions: an altitude of 2022 masl, an atmospheric pressure of 896.14 hPa, a UV radiation index of 10 and its mean temperature is 11.5 °C.

Fig. 7. San Rafael Swell, Utah

This desert area was chosen for its type of terrain and appearance similar to those found on Mars, because you can see valleys, gorges and canyons of sandstone, shale, and limestone, where you can see rocks eroded by floods.

Its infrastructure has a center of activities or habitat of 10 meters of diameter and two floor, where we can find the laboratories and housing of the analogous astronauts, the station also has a greenhouse used to process the water of the habitat and also to raise and monitor the growth of plants and finally owns an observatory that have the Schmidt-Cassegrain telescope. [12,14]

Fig. 8. MDRS infraestructure

In MDRS are directed different research studies are established by each crew and take advantage of its environmental characteristics like biological studies of the extremophile organisms that live in the desert [13]. On the other hand, geological studies are also made when studying the rocks and the composition of the terrain to find microorganisms that live inside the rocks. Finally, there have also been studies of skill tests with the space suit and test of manipulation of different tools in the field.

Fig. 9. EVA at MDRS - Crew 138

The scientific investigations conducted at this station are carried out during the winter months of the northern hemisphere by small voluntary crews selected by the Mars Society who are installed in the station for short periods of time and are composed by a multidisciplinary specialists like geologists, engineers, doctors, psychologists, astrobiologists, mechanics, journalists and others.. [14]

3.1.3 European Mars Analog Research Station (EuroMARS)

This analogue station is the third run by the Mars Society, initially funded by the UK-based Euro-MARS scientific program, but operated by the chapters of the European Mars Society which also comprises France, the Netherlands, Italy, Belgium and Spain. [15]

The geographic location selected for the installation of this simulation station is classified as an area with geographic and topographical characteristics similar to those found on the red planet, because it is possible to observe furrows produced by water and characteristics produced volcanically similar to those found on Mars.

Euro-MARS will be located in the volcanic rift called the Krafla in northern Iceland in the region of Mývatn, its coordinates are located in a volcanic crack with the following coordinates 65 ° 46 '7.18 "N 16 ° 45' 30.50" W.

This location has the following environmental conditions: an altitude of 625 masl, an atmospheric pressure of 1006.10 hPa, a UV radiation index of 3 and its mean temperature is 1.5 °C.

Fig. 10. Krafla Iceland

Taking advantage of the characteristics of the terrain that are similar to Mars, the main purpose of this station is to conduct geological and biological explorations in search of anaerobic microbes that are located in volcanic fissures and fumaroles. [16]

In addition, unlike the first two analogous bases of Mars simulation, this base has a different habitat design, as it has three floors instead of two, with more extensive research and housing facilities and a better designed separation between them. [17]

Fig. 11. Design of Euro-MARS

Unfortunately after the construction of the habitat, it was stored until it is expected to acquire the funding to mobilize it from the United Kingdom to Iceland, during this period of time and during the mobilization the structure was irreparably damaged, so for the moment the project continued at the planning and implementation stage. [16]

3.1.4 Australia Mars Analog Research Station (MARS Oz)

It is the fourth station of the Mars Society designed by the chapter of Mars Society Australia, under the direction of David Wilson, who is the project manager. [18]

The selected location for this analogous station is located in the Arkaroola sanctuary region of South Australia its coordinates are: 30° 18' 13.91"S 139° 26' 39.55"E.

This location has the following environmental conditions: an altitude of 347 masl, an atmospheric pressure of 1035.56 hPa, a UV radiation index of 0 and its mean temperature is 18.65 °C.

This region contains a variety of geological and astrobiological features that are interesting for research, such as dune fields, gravel desertic areas and weathering surfaces. [19] On the other hand as far as the biology and paleontology they have fossil bacteria, extremophile populations in mineralization of uranium and sulphurs associated with radioactive hydrothermal springs.

Fig. 12. Arkaroola Australia

The habitat of MARS Oz has a very different and innovative design, as it contemplates the use of a cabin, a propulsion module, thermal shield, landing engines, this design is due to the habitat would travel to the Martian surface directly from Earth. [20]

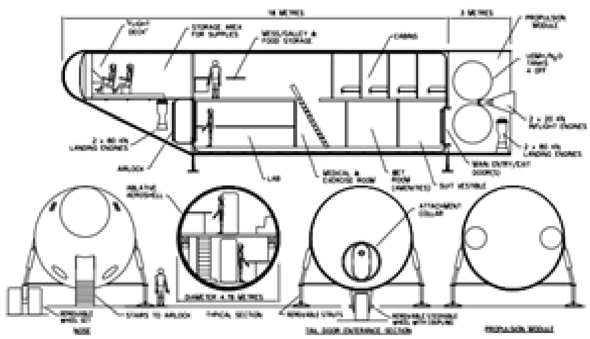

Fig.13. Design of MARS Oz habitat

In this analogous Mars station, different projects will be carried out, such as: habitat design test, evaluation of psychological factors in the crew, design of selection strategies for crews, study of the effect of EVAs on heart rates and blood pressures of members of the crew, geological and astrobiological studies and others. [18]

3.2 Hawaii Space Exploration Analog and Simulation (HI-SEAS)

This base station is located in Mauna Loa, Hawaii [21] at an approximate height of 2438 masl. The HI-SEAS was designed mainly for the geological aspect simulations since HI-SEAS has a geology very similar to those observed on Mars. Likewise, the communication system installed in HI-SEAS has implemented a communication with high latency, to simulate the fact that a message between Mars and Earth would be approximately 20 minutes.

3.3 Concordia Research Station

It is a permanent Franco-Italian station located about 3233 masl on the high Antarctic plateau at Dome Charlie (Antarctic french side). The main research activities at this location are astronomy and astrophysics, glaciology, atmospheric sciences, geophysics, and human biology and medicine. The average temperature is -51 Celsius degrees [22][23].

3.4 Mexo-Hab

The Mexo-Hab is a station in a project. The idea is that it is located at 5000 msnm on the Mexican volcano Pico de Orizaba (PO) [24][25].

4. 'Salar de Uyuni' as a simulated Mars station

4.1 The 'Salar de Uyuni'

The 'Salar de Uyuni', located in Bolivia in the department of Potosi, located at 20°08′02″S 67°29′21″O has an altitude of 3692 masl, is the largest salt flat in the world, with an area of 10582 km2, is the only natural attraction that can be seen from space. [26]

Fig. 14. Location of the 'Salar de Uyuni' Bolivia

It is a tourist destination very famous in the highland country, because the 'Salar de Uyuni', also called "the Andean jewel", is the place where the sky merges with the earth, when the salt becomes impermeable and the water accumulates in the surface, creating a natural mirror reflecting the sky.[27]

Fig. 15. Reflection effect, ‘Salar de Uyuni’ Bolivia

Its land is composed of lithium, potassium, boron, magnesium, carbonates and sodium sulfate. In addition it owns approximately 11 layers of salt with thicknesses that vary between the two meters and ten meters. Its depth is of 120 meters composed by lacustrine mud and dead salt.[28,29]

Stores 10000 million tons of salt and 140 million tons of lithium, 70% of the world's lithium reserves.

Its formation goes back until 40000 years, when Lake Michin along with other smaller lakes began to evaporate. [30]

Fig. 16. ‘Salar de Uyuni’ Bolivia

According to the Uyuni weather station in the salar the atmospheric pressure is 628.51 hPa, and it is possible to have an annual average temperature of 8.46 ° C, with a minimum annual temperature of up to -11.7 ° C and a maximum annual temperature of up to 21.4 ° C.

The ‘Salar de Uyuni’ region is cragged, volcanic, desert with the presence of geothermal waters and geysers. This adverse climatic conditions is reflected in a permanent water deficit due to the notorious imbalance between precipitation and evaporation in the zone. [31]

Fig. 17. Tunupa volcano, ‘Salar de Uyuni’ Bolivia

We can see important elevations such as the Tunupa volcano and 32 islands within the salt marsh that are actually mountain tops on which has given rise to an impressive ecosystem with varied vegetation and petrified algae. [32]

Most of the time the skies are clear, so you can see the milky way without difficulty, Also the salar is used for the calibration of radiometric sensors, for example was used to evaluate the accuracy and precision of ICESat instruments. [33]

On the other hand in the region the winds are intense almost all the year because they can reach speeds of more than 90 km / h.

4.2 Characteristics analogous to Mars

4.2.1 Geological

Near to the ‘Salar de Uyuni’ area you can find different geological formations that can be considered as analogous to those found in the red planet.

The terrain is made up of Paleozoic, Mesozoic and Cenozoic formations. There is an area close to the Andean mountain range, which consists mainly of volcanic rocks, volcanic sedimentary sequences and lava formations, such as lava flows, pyroclastic deposits, stratovolcanoes, volcano-sedimentary successions, and domes. [33]

Fig. 18. Desert of Salvador Dalí, Uyuni Bolivia

On the other hand can also be found saline deposits, alluvial deposits, fluvial, lacustrine, fluvial glaciers and dunes. [34]

You can also observe a fossilized coral barrier and the elevation of giant rock formations resulting from the erosion of thousands of years of wind and rain.

4.2.2 Biological

The biological characteristics found in the 'Salar de Uyuni' are interesting because they can be found as an important subject of study in the field of astrobiology.

Because according to the analog field work [35] in the simulation stations they must include and direct the investigations towards the field of astrobiology.

The 'Salar de Uyuni' has interesting characteristics for research in this field, such as the study of the dissolution and formation of salt crystals, the study of extremophile organisms and cyanobacteria tolerant to high concentrations of salt, the process of formation of crust of salt and lacustrine mud , study of formation of the erosion patterns observed in the salar, study of the great levels of evaporation and the freezing point in the salar. [34]

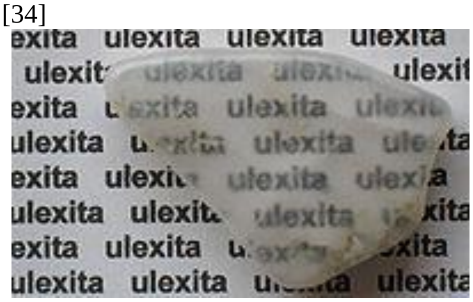

Fig. 19. Ulexite Mineral

Finally an interesting investigation is found in the analysis of a very curious mineral found in the 'Salar de Uyuni', called ulexite or TV stone that is transparent and has the property of refracting to its surface the image of what is underneath it.

4.2.3 Radiation

As explained in previous sections, the sun emits different types of radiation, but the component to be studied in this case is the spectrum of UV radiation.

According to a research carried out in [36] the Uyuni area has typical factors that make it more vulnerable to UV radiation, this because it has reflective surfaces, no clouds and a sandy soil.

On the other hand, it was also observed that radiation increases in the presence of reflective surfaces such as the 'Salar de Uyuni' and that the intensity of UV radiation reaching the earth's surface increases by 25% per 1000 meters of altitude. [37,38]. In fact in Andean populations like Uyuni the levels of UV radiation leave the international scale that goes from 0 to 16 and has reached values of 18 or up to 20 on totally clear days. [39]

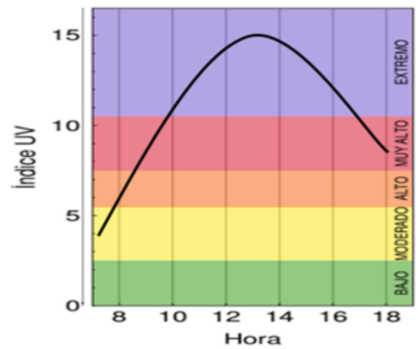

Fig. 20. Radiation level in Uyuni

The Atmospheric Physics Laboratory of the Universidad Mayor de San Andrés (UMSA) was able to perform measurements of albedo performed by a UV radiometer for erythremically effective radiation showing a value of 0.69 ± 0.02. [40], Which means that the percentage of reflected radiation, relative to the incident radiation is 69-71%. While the average albedo of the Earth is 37-39%.

The levels of radiation in Uyuni are a constant concern so that they have installed "solmáforos" that have five colors that alert to the population the levels of ultraviolet radiation present in the day. [39]

Fig. 21. Solmáforo in Uyuni

Finally, it is possible to indicate that, due to the action of the ozone layer, it is not possible to simulate the type of radiation UV-C, which is the type of radiation found mostly on Mars. We can find levels of UV-A radiation and especially of the radiation component also found on Mars: UV-B higher than the common ones due to the large reflective surface that means the salar and the level of its altitude.

This means the contribution of a number of new life sciences research on Mars, as well as for the design and testing of space suits in analog simulation, design of fieldwork protocols and Extra Vehicular Activities (EVA) for testing the All-Terrain Vehicle (ATV) under these conditions.

5. Results

As results of this study, it is presented a comparison of the environmental conditions of the Mars analog research stations installed in different parts of the world and the environmental conditions of the 'Salar de Uyuni', which in this work has been proposed as a good option to be an analog research station in the near future:

Table 2. Environmental conditions on Mars analog research stations and the 'Salar de Uyuni'

Parameters	FMARS	MDRS	Euro-MARS	MARS Oz	Salar de Uyuni
Country	Canada	USA	Iceland	Australia	Bolivia
Location (Lat, Lon)	75° 25' 52.75"N 89° 49' 24.19" W	38°48'47"N 110°51'18"W	65 ° 46 '7.18 "N 16 ° 45' 30.50" W	30° 18' 13.91"S 139° 26' 39.55"E	20°08'02"S 67°29'21"O
Average Temperature (°C)	-16	11,5	1,5	18.65	8,46
Altitude (masl)	1479	2022	625	347	3692
Presure (hPa)	985.10	896,14	1006.10	1035.56	628,51
UV Index	4	10	3	0	15

A comparison of different parameters such as altitude, mean annual temperature, pressure and radiation index can be observed.

6. Discussion

Different criteria make the location of the 'Salar de Uyuni' an appropriate environment to implement an Mars analog research station, which are described below:

The geology of the place that contains different volcanic formations and eroded rock formations.

Another important criterion is the biology of the place that contains extremophile organisms that live inside the stones or in volcanic fissures and cyanobacteria tolerant to high concentrations of salt.

On the other hand an interesting criterion is the radiation index registered in the 'Salar de Uyuni', that has a high index of UV radiation, due to the altitude of the place, the reflective surface of the salar and the desert composition of the terrain.

In addition, the 'Salar de Uyuni' is also a propitious place to be an astronomical observatory, due to its characteristic clear sky during the majority of the year.

Finally the landscape is a remote place to perform psychological tests on the crew and there are open spaces for perform Extra Vehicular Activities (EVA), testing the All Terrain Vehicle (ATV), testing the rovers and different tools used in the field tests.

7. Conclusions

On our planet there are areas that are analogous to Mars, either because of its weather conditions or its geological characteristics.

This study has indicated that the 'Salar de Uyuni' is one of these areas analogous to Mars because of its temperature, height, dryness, its geological characteristics and, above all, the high UV radiation.

All these characteristics, together with the fact that the field activity and the Mars analog research will be more frequent in the near future, make it possible to propose to the 'Salar de Uyuni' in Bolivia as a future Mars simulation station, since this geographic location would provide an unusual and exotic scene, with extreme conditions where different types of research and testing of classic tools of the geological and biological field could be carried out.

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