4

Other Environmental Parameters

16

Earth Analogues

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Terrestrial analogue environments are places on Earth with geological or environmental conditions that are similar to those that exist on an extraterrestrial body [1]. The purpose of using these terrestrial analogue sites for planetary missions can be divided into four basic categories: (i) to learn about planetary processes on Earth and elsewhere; (ii) to test methodologies, protocols, strategies, and technologies; (iii) to train highly qualified personnel, as well as science and operation teams; and (iv) to engage the public, space agencies, media, and educators [1, 2]. A recent ESA study, CAFE—Concepts for Activities in the Field for Exploration [3], resulted in a catalogue of all planetary analogue sites used and currently in use [4]. This catalogue contains in-depth descriptions of each of these field sites, including location, geological context, environmental information, and infrastructure, and is currently the most extensive and up-to-date catalogue. A very comprehensive overview of analogue sites grouped per planetary surface feature can be found in [5]. Current analogue activities focus on five planetary bodies: the Moon, Mars, Europa and Enceladus, and Titan. Below we highlight a few planetary analogue sites for these five bodies summarized from [5], as well as field-testing campaigns and semipermanent field-testing bases.

16.1 Planetary Analogues

16.1.1 The Moon

The lunar surface features that can be studied in terrestrial analogues are craters, lava fields, and the lunar dust. The Vredefort dome in South Africa was studied as an analogue for the fine-grained granulite facies rocks that were returned from the Moon by the Apollo astronauts [6]. Most lunar analogue sites, however, are chosen to study mission concepts and test instruments. This already started with the Apollo astronaut training in the Lava Mountains, California [7], and the volcanic fields around Flagstaff, Arizona. Specific prerequisites here are aridity, low temperature, and the presence of abrasive dust. Another example of a lunar analogue is the Haughton Impact Structure in Canada [8].

16.1.2 Mars

Most analogue sites are devoted to Mars. These analogue sites can be divided into three categories: early Mars, middle Mars, and present Mars. *Early Mars* is here defined as roughly the first billion years of its lifetime, when liquid water was still presumed to be present on the surface. Example analogue sites are the Pilbara region in Australia as an analogue for flood basalts, water-related minerals, and preservation of early life [9], Rio Tinto in Spain as an analogue for past rivers, iron oxides, and sulfates [10], and Yellowstone as an analogue for silica-rich soils, hydrothermal activity, and extremophiles [11]. *Middle Mars* is defined as the second billion years where a large drop in temperature and loss of water led to a global cryosphere and subsurface ice. The Antarctic Dry Valleys [12] and Antarctic permafrost [13] serve as analogues for the Polar Layered Deposits and the Northern Highlands as well as for potential life preserved in ice deposits. Iceland [14] and the Bockfjord Volcanic Complex on Svalbard, Norway [15], serve as analogues for subglacial volcanism. *Present Mars* starts about 2.5 billion years ago and is characterized by a hyperarid climate. The Antarctic Dry Valleys are a good analogue for present-day Mars and is the closest terrestrial analogue to Mars. Additionally, the Atacama Desert [16], the Egyptian Desert [17], and the Hawaiian volcanoes, for example, Mauna Kea [18], are well-studied Mars analogue sites.

16.1.3 Europa and Enceladus

Both Europa and Enceladus are characterized by a planet-wide ocean covered with a thick ice-crust. Hydrothermal activity at the ocean floor is hypothesized as an energy source to keep the oceans liquid. Analogue sites for all three parts of planets can be found on Earth. Ocean floor analogues can be found in the hydrothermal vents of Lost City on the Mid-Atlantic Ridge [19] and the high-pressure low-temperature environments of the Mariana Trench in the Pacific Ocean [20]. Mono Lake in California, USA, and the Dead Sea in Israel are analogues for the alkaline and saline brine oceans expected on these icy moons. Lake Vostok on Antarctica is one example of a surface ice analogue [21].

16.1.4 Titan

Like the Earth, Titan has a thick atmosphere and diverse geology with land and lakes. These lakes, however, are composed of hydrocarbons, making terrestrial tar fields good analogues for the Titan surface, for example, Pitch Lake in Trinidad and Tobago [22].

16.2 Semipermanent Field-Testing Bases

Long-term field-testing campaigns with some more permanent infrastructure are established to provide a base for multidisciplinary field research as well as for the development of new technologies for planetary missions. Most of these sites are very much technology and mission development focused; however, they do offer the opportunity to carry out scientific campaigns as part of the technology-driven frameworks. These sites include the Aquarius Undersea Research Station at the Florida Keys established in 1993 and host to 114 underwater missions up to 2012, primarily studying coral reefs [23]; the Haughton-Mars Project Research Station at Devon Island, Canada, focusing on “developing new technologies, strategies, and operational protocols geared to support the future exploration of the Moon, Mars, and other planets” [8, 24]; the Pavilion Lake Research Project, a “science and exploration effort to explain the origin of freshwater microbialites in Pavilion Lake, British Columbia, Canada” [25]; the Pacific International Space Center for Exploration Systems (PISCES) at Hawai’i [26, 27]; the Ibn Battuta Centre for exploration and field activities in Morocco, established in 2006 to support the exploration of Mars and others planets, and to provide opportunities for scientists and the public for experiencing the exploration on Earth and in the Solar System [28]; and the recently (2013) established Boulby International Subsurface Astrobiology Laboratory, BISAL, in the UK, the world’s first permanent subsurface astrobiology lab, focusing on deep subsurface geochemistry and biology, as well as instrument testing for robotic and human planetary missions [29].

16.3 Field-Testing Campaigns

Long-term field-testing campaigns have been established to provide a framework for planetary instrument and mission testing. The Desert Research and Technology Studies (Desert RATS) field-testing campaigns started in 1997 in support of future manned mission scenarios. The Desert RATS campaigns have taken place in various locations, including Mauna Kea, HI, and Black

Point Lava Flow, AZ. These locations were selected based on their physical resemblance of lunar and martian surface. The scope of these campaigns has varied widely over the years from testing single space suit configurations to multi-day integrated mission scenarios [30]. Even though the focus is mainly on technology-related testing, integrating science into these technology-driven scenarios and getting scientists and engineers to communicate is an important aspect. The NASA Extreme Environments Mission Operations campaigns [31] started in 2001 and 16 missions have been undertaken since then. NEEMO uses the Aquarius Station, since the station habitat and its surroundings provide a convincing analogue for space exploration. Like Desert RATS, NEEMO is rather technology and mission oriented. The Arctic Mars Analog Svalbard Expedition (AMASE) at Svalbard, Norway [32], is an astrobiology- and Mars-focused science and technology campaign taking place on Svalbard, Norway. This campaign is specifically focused on the understanding of Svalbard in an astrobiological context. Technology that is taken along is tested in support of the science and not the other way around, as is merely the case in, for example, Desert RATS and NEEMO.

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