The Exploration of the Earth Subsurface as a Martian Analogue

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Abstract: This paper describes the conceptual effort and scientific practices though which space analogues – i.e. material settings in which one or more analogies between Earth and outer space are embedded – are built, sustained and experienced. Based on my ethnographic study of astrobiologists' and speleologists' analogue fieldwork activities in Sardinian subsurface environments, I claim that analogues are part of the process of making astrobiology as a discipline: they do not only constitute fundamental heuristics to understand Earthly – and perhaps one day extra-terrestrial – life, but they also reframe disciplinary boundaries and imagined futures on Earth and elsewhere in the Universe.

Keywords: extreme environment; space analogues; astrobiology; scientific fieldwork.

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1. Introduction

The breeze was warm and filled with the subtle aroma of the myrtle that in the late spring punctuates the gentle slopes of the southern Sardinian hills. The bushes and short trees did not offer much of a shelter from the sun shining high in the clear sky constantly swept by the Mediterranean air currents. Earlier in the morning, we had been warned to wear heavy clothes as the mine temperature is significantly lower than the temperature outside; in the rocky darkness of the mine, it barely varies between winter and summer. The water, copiously dripping from the rocky walls, keeps the humidity high and covers the muddy floor with stagnant water, creating the conditions for bacteria to recolonize what humans had ap-

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> propriated in 1880s and then abandoned a century later. The Su Zurfuru ("sulphur" in the Sardinian language) mine had been depleted of lead, iron, and fluorine for decades, before being deserted along with the adjacent small village where miners used to live and process the raw materials extracted from the nearby deposits[1].
> Our hiking boots were already sinking into the muddy soil just in front of the tunnel mouth, a regular opening excavated in the rock, almost completely covered in Mediterranean vegetation. Gabriele[2], an experienced member of the local speleological team, started the engine of his jeep, packed with scientists and their equipment, and slowly turned the car toward the entrance. The wheels sank into a deep puddle as the car moved into the tunnel, plunging into the reddish water. A small wave preceded us, rippling the silky surface of the water lit by the car's headlamps. Thus, we moved onwards, deeper and deeper into the abandoned mine.
> When the car stopped, we heard the voices of the group that entered the mine before us. "Don't walk alone" Gabriele said with an affable smile, "it takes nothing to get lost here". Then he turned the car and drove back to the entrance to carry the last group of scientists still waiting outside. Somebody approached us, lighting the space where we were standing with a cone of light shining from the top of her helmet. Laura, one of the organizers, joined our small group and showed us how to switch on the light on our hats and then led us to where the others were gathered, in a different tunnel, where the walls had been further excavated to almost form a chamber. John, a geologist from the University of Bologna, was casting his helmet light on a white and blue jelly substance formed around the groove excavated by the water gushing through a crack. He poked his finger into it; "this is biology", he claimed.

This paper is based on the second workshop organized by the GeoBiology for Space Exploration (GESE) ESA topical team and held in Sardinia[3] (Italy) in the Spring 2015. The workshop, titled "Extraterrestrial Subsurface Exploration and Geomicrobiology", aimed to encourage the development of a new interdisciplinary community focused on the study of possible uses and implication of mineral-microbe interactions in subsurface environments. These processes have a number of applications that can be linked to a broad range of space-related activities such as the search for evidence of life elsewhere in the universe; human and robotic space exploration of celestial bodies; and long-term settlement scenarios. This variety mirrors the multiplicity of scientific and technological endeavours funded by space agencies. By putting together experts in such different fields, ESA hopes, on the one hand, to optimise financial resources invested in emerging realms of inquiry and, on the other hand, to create or strengthen research collaborations. The participants to the workshop – biologists, biochemists, geologists, speleologists, astrobiologists, astronaut trainers, etc. – were charged with the compiling of a road map that would both set the direction of further studies and make the case for additional investments in this polyhedric field.

I participated to this workshop as part of my multi-sited ethnographic project on astrobiology. i.e a discipline committed with the study of life elsewhere in the universe. After eight months of participant observation of astrobiology laboratory activities, I had the opportunity to join two fieldwork training events attended by some of the laboratory members. Astrobiology fieldwork activities have often been framed in semiotic and representational terms (for example using the Peircean vocabulary of signs and indexes, see e.g. Helmreich 2006); in my project, I aimed at moving beyond such frameworks to pay attention to the situated and embodied dimension of practitioners' knowing (e.g., Goodwin, 2000; Gherardi, 2000). Fieldwork training activities opened a window on how participants practice experiencing their objects of interest through the sociomaterial infrastructures by which they are surrounded. I consider the analogies described in this article as a fundamental dimension of these infrastructures. Such narratives are produced and reproduced in astrobiological practice-based knowledge.

Astrobiologists often describe the quest for extra-terrestrial life as something that has only recently been included within the realm of scientific investigation. For centuries, philosophers and fiction writers indulged in bold speculations about exotic forms of life and civilizations that might populate distant celestial bodies (Blake 2006; Crossley 2011; Dick 1982). The situation changed during the 20th century, when extraterrestrial life increasingly came to be considered an object of scientific inquiry; toward the end of the century, astrobiology, the study of life in the universe, was born[4]. As often happens, this process was more complex than it may seem at first glance. For several decades the discipline, once called *exobiology*, the study of extra-terrestrial life (Lederberg 1963, 1126), was blamed for being a field of inquiry that "has yet to demonstrate that its subject matter exists!" (Simpson 1964, 769) and therefore, according to some, did not have the status of a science at all. When NASA funded the National Astrobiology Institute at the end of the 90s, the term exobiology was partially discarded and a new one, in which the prefix *exo-* (outside) had been replaced with *astro-*, was adopted (Dick and Strick 2005). What appeared to be just a mere rephrasing was in fact due to – and at the same time contributed to draw people into – a different way of studying and searching for life in the cosmos, defining the discipline in a way that would also include Earthly life as an object of interest. To pursue the study of life in the cosmic context, astrobiologists become equipped with "at least one data point of the life that we know: life on Earth" (Cockell 2015, 1).

Today, the study of extreme (i.e., unusual and unfriendly from a human perspective, requiring microorganisms to adapt and develop efficient physiological mechanisms to survive) environments[5], shapes the design of space missions and how the data collected during those missions are interpreted[6]. Despite being considered to be hostile for most of the forms of life we know, these environments revealed that they could host thriving ecologies sustained through a number of adaptations. Extreme environments have become an object of intense scrutiny to understand how life behaves in circumstances that, even if very unusual on Earth, might be comparable to average conditions on other planets.

Because many of the microorganisms living in extreme environments are still unknown or very hard to culture in the laboratory under standard conditions, the study of extremophiles (i.e., organisms able to live in extreme environments) has required astrobiologists to periodically vacate their lab benches to set foot (and hands, eyes and all the rest of their bodies and instruments) onto their chosen field sites.

In fact, not every astrobiologist engages in long and adventurous field trips: some of them focus on computer models and simulations, others are satisfied with doing experiments in the laboratory with samples that other scientists collected in the field. Nevertheless, a growing portion of those who would call themselves astrobiologists have started engaging in field work activities, and the resulting knowledge has been used to confirm the validity and legitimacy of what is done in other experimental spaces. "The field", Paxson and Helmreich note, relies "on the promise of microbes as revelatory entities that might reveal life's universals with reference to unexpected particulars." (2004, 181). The astrobiologists' engagement with extreme environments as analogue field sites thus informs the establishment of a new paradigm for what constitutes astrobiological research today. The present work investigates one of these analogue field sites and the experience of analogue making that scientists engage with.

By drawing on my ethnographic study of astrobiologists' and speleologists' fieldwork activities, I am looking into the use of *space analogues*, material settings in which one or more analogies between Earth and outer space are embedded. In particular, I will focus on how the analogies through which these scenarios are turned into epistemic tools to investigate life in the universe are built, sustained and experienced. I will argue that it is the multiplicity and redundancy[7] of the analogies that the field site is imbued with that keep its validity as a heuristic tool in place. Analogies between specific Earthly environments and their Martian counterparts are not a given a-priori; they are negotiated and made relevant through the scientists' experience of them which, at the same time, creates a dialogic space to envision, explore and negotiate tensions and alignments between alternative futures for space exploration.

During the time I spent with astrobiologists working, talking, and thinking through terrestrial analogues of Mars, I came to realize that astrobiology is a discipline deeply infused with a sense of place: researchers, research practices and the material settings mutually define each other. By taking the conceptual efforts and scientific practices that turn Earthly environments into space analogues as the focus of this paper, I investigate this process of mutual production.

By examining the embodied dimension of analogue making, I join scholars pursuing two contemporary projects. On the one hand, this article brings together experience, embodiment, and the communitarian dimension of science in the context of knowledge making practice. The Science and Technology Studies (STS) traditional focus on the laboratory has helped deconstructing the purported universality of science by casting a light on the social construction of the laboratory's rigid boundaries, oversimplifications and standardizations (Latour and Woolgar 1979; Knorr-Cetina 1981; 1995; Crabu 2014; Sormani 2014). On the contrary, with only few exceptions (for example Kohler 2002; Livingstone 2003), field sciences have enjoyed scarce attention. Fieldwork-oriented disciplines can tell a different (and complementary) story about science, a story in which the body of the scientist cannot be easily removed from the picture, and in which rhetoric and practice are stitched back together.

On the other hand, I join the debate about the sociological importance of space exploration and outer space technological activities. Olson and Messeri have recently problematized the spatial "inner/outer split" (Olson and Messeri 2015), the supposed division between what counts as the normative terrestrial sphere of human experience and what counts as outer space. They have argued for the inclusion of all those non-Earthly places (and maybe, one day, non-Earthly beings) whose conceptualization has been fundamental for the creation of contemporary perspectives on Earth but that, paradoxically, have been neglected because of the current "Earthbound turn", the inward orientation of what counts as the environment. To question the contemporary inner/outer dichotomy and its rhetorical topologies it is important to pay attention to how knowledge is made, to the contingency of what counts as Earthly or otherworldly, but also to what "does not quite fit" (Bertoni 2016) in the contemporary discourses about perceptions of the environment and the possibility of knowing Earthly and alien microbes. More generally Space analogues present an interesting case because of the twofold process through which scientists get to understand certain environments and through which their physical presence and lived experience of these very environments makes their identity as astrobiologists.

The embodied experience of analogues – and more in general, of knowledge making practices – is at the very core of this paper. Embodied experience, nevertheless, is not just an object of analytic interest, but also the dimension that substantiates this piece of research methodologically. The emphasis on embodied experience is thus echoed in how the ethnographic data were collected and how they are presented to the reader: this paper's argument is never detached from the embodied experience of the ethnographic fieldwork, which is granted a central role throughout the entire article. In drawing extensively from my fieldnotes, I hope to convey the sense of curiosity and affection toward *what we have not understood yet* that strikes the ethnographer from the field to the writing of her findings – what Jane Guyer (2013) called the "epistemology of surprise". In turn, this approach finds its parallel in the purposeful search for what we have not encountered yet, what is not-known (see also Marcheselli 2020) and unforeseen, that characterizes astrobiological fieldwork.

2. Analogies and Space Analogues

Analogies are ubiquitous in science[8]. We all – scientists included – think about gravitational waves in terms of *ripples in the fabric* of time, evolutionary phylogeny in terms of *branches of a tree* and light in term of *waves and particles,* to mention just a few examples. "Without models", Mary Hesse wrote in 1966, "theories cannot be genuinely predictive". Analogies, she claimed, provide the only effective way to search and test for new hypothesis to expand the explanatory power of a theory. Similarities and differences between the two terms of an analogy are not fixed, but they are object of testing and debate and in this very process lies the predictive power of analogical reasoning (1966, 51-100). Nancy Leys Stepan reminds us that scientific metaphors and analogies, unlike those used in literature, must not be considered arbitrary nor merely personal to come to count as valid epistemic tools. On the contrary, they require to be agreed upon by a community and their cultural sources have to be made unrecognizable. "Nevertheless," Stepan writes, "because a metaphor or analogy does not directly present a pre-existing nature, but instead helps *construct* that nature, the metaphor generates data that conform to it, and accommodates data that are in apparent contradiction to it, so that nature is seen via the metaphor and the metaphor becomes part of the logic of science itself" (1986, 274).

In their sociological analysis of scientific knowledge, Barnes and colleagues (1996) emphasize that, despite seeming obvious, the identification of modelling[9] in science as a contingent action is crucial. "When it is overlooked, the result is typically a purely formal account of modelling, which fails to grasp its purposive and goal-oriented character, and hence how it comes to be recognized as successful or unsuccessful. There is no perfect model […] A successful model is a pragmatic accomplishment, something which those who evaluate it take to serve their purposes" (1996, 108-109).

The literature on outer space analogies that emerged in the last decade is broad (for example Battaglia 2005; Helmreich 2009; Launius 2014; Praet and Salazar 2017; Salazar 2017), but caves and mines as analogue field sites for space exploration and settlement are fertile terrain to carry on with the work of unpacking the set of related questions on the inherently cultural sources of scientific analogies (Battaglia 2005), their role in making forms of life and life forms (Helmreich 2012), their normative consequences (Olson 2012), and the ongoing process by which they are agreed upon or changed. Because analogies are not *found,* but *made* – and, at the same time, *making* what counts as valid and legitimate – in astrobiological practice, the investigation of their conditions of possibility cannot be conclusively settled. On the contrary, the social scientists interested in how knowledge is made out of experience can extend the principle of finitism (Barnes et al. 1996, 53-59), which states that future applications of a term are open ended and no application is indefeasibly correct, to the making and use of analogue sites and the analogies embedded into them.[10] Space analogues raise continuous problems of correspondence and reconciliation between the meaningful relationships among the features of the surrounding environment and the ones that can be found within another – real or imagined – setting. Indeed, despite their being "extreme", no place on Earth is inherently Mars-like (or Moon-like or like any other body of the Solar System). Earth's atmosphere, soil composition, gravity, tectonic dynamics, just to mention a few features, are not the same[11]. Nevertheless, a number of these extreme environments are today used as analogues of other outer space environments[12], Mars in particular. These analogue sites are said to have characteristics that are *so* similar to the ones we would find on the red planet, that they can be considered valid Mars analogues. But how *similar* is *similar enough*? There is no one single answer to this question. Indeed, as it emerged during my field research, each analogue field site has its own history of why, how and when it was selected, and "its own stories about life to be told"[13].

3. Three Analogies between Outer Space and Subsurface Environments on Earth

There might seem to be an unbridgeable distance between the depth of a cave and the deep space where astrobiologists hope, one day, to find life. To understand how these *loci* have become thinkable within the same astrobiological discourse, we need to disentangle the narratives[14] – a rhetorical device that "unsettles landscapes as static images" and "structures both place and time as they manifest in landscape" (Messeri 2016, 31) – that are deployed by scientists when talking about and experiencing caves as Mars analogues.

Fieldwork is rarely a solitary experience: a small handful of scientists from a wide spectrum of disciplinary backgrounds join forces to understand multiple aspects of the environment and make them significant for reasoning about life beyond Earth. Very often, their collaborations are driven by logistics and by the necessity of optimizing resources as reaching remote and barely accessible sites requires laborious planning and preparation. Nevertheless, once in the field, their collaboration becomes part of how the science is done. The interaction among people with heterogeneous experience and expertise often leads to the mingling and intertwining of several analogies.

3.1 Caves as Microbial Habitats

The presence and activity of microorganisms underground became an object of interest in astrobiology when decades of data on the Martian soil and atmospheric composition made scientists agree that it is today very unlikely to find either presence of extant or traces of extinct forms of life *on the surface* of the red planet (Westall et al. 2021). The atmosphere on Mars is today about a hundred times thinner than the one shielding the Earth. Because of the low pressure, what was a landscape shaped in ancient times by rivers and lakes does not, at present, offer the conditions for liquid water anymore – except for flowing brines saturated in perchlorates, highly oxidizing salts that only very rarely form on Earth. What is more, the amount of UV radiation would constitute a severe threat for the stability of any organic compounds. Even if there was, once upon a time, life on Mars, astrobiologists think it would be very hard to find any trace of it left on the surface. Nevertheless, based on observations of how life behaves on Earth, they consider the possibility that there were residue colonies hidden underground for much longer after the surface had become uninhabitable, and their traces might be better preserved (for example Cockell 2003). Some astrobiologists have actually made the claim that some microorganisms might still be there, adapted to a niche where UV radiation is lower and where there seem to be reservoirs of liquid water (for example Mhlmann 2003; Bandfield 2007).

Astrobiologists are thus interested in the cave as an environment in which most of the solar radiation is filtered out and in which microorganisms have lived undisturbed and isolated for thousands or millions of years. On Earth, these conditions are *extreme*, while on Mars they are seen as the last bulwark to offer refuge from even more hostile surface conditions. Despite what every microorganism living on the Earth's surface would consider highly hostile conditions, caves are teeming with life forms capable of optimizing the resources available. If they do so on Earth, why they shouldn't act the same way on Mars, astrobiologists wonder. This unexpected multitude of microorganisms adapted to the deep darkness of Earth's caves reinforced the hopes of many astrobiologists. They conceive them as instances of life's great capacity for survival, despite the darkness, isolation, and lack of nutrients – conditions that might all be similar to those in the Martian subsurface. The differences, for example the copious presence of water which is indeed the primary force giving shape to caves on Earth, are considered negligible, and thus disappear into the background of what astrobiologists observe within the framework of the analogy.

3.2 Caves as Human Shelters

In the early 2000s, for the first time, satellites orbiting Mars sent pictures of possible cave entrances back to Earth (Cushing 2012). Speleologists suggested these might be used as shelters in the future human exploration of the red planet. The lava tubes, caves formed during volcanic eruptions, might offer a cost-effective solution to the danger of UV radiation exposure which is one of the main obstacles that will have to be faced when planning the establishment of long-term settlements on Mars (Boston et al. 2004). From 2002 to 2004, NASA funded the Caves of Mars Project, as part of the Institute for Advanced Concepts[15] to assess the best place to situate the research and habitation modules that a human mission to Mars would require. Microbiologists' and speleologists' interests have always been deeply rooted in understanding adaptive solutions that would allow microbes to thrive in caves. But to investigate them, they had to develop a parallel branch of expertise: during the long expeditions bringing these teams to still unexplored hollows, they live inside the cave for several days. In building up a network of people interested both in speleological themes and in the possibility of extending their technical and scientific expertise to space exploration, they had traced a second relationship between exploring caves and inhabiting other planets.

3.3 Caves as *Topoi* for Astronaut Training and Exploration

Sardinian caves have become periodically populated by groups of astronauts for training purposes[16]. In 2011 ESA established a training program called CAVES, acronym of "Cooperative Adventure for Valuing and Exercising human behaviour and performance Skills". Every year, the training happens in a different cave; avoiding contamination and keeping the environment pristine is one of the imperatives of the training. The depth of the caves had been chosen for their "dark and alien underground environment with *many analogies* to space" ("Why caves?"). The analogies here mentioned have nothing to do with microbes or UV radiation; they were relative to the astronauts' training needs.

> One of the terrestrial environments which best mimics a planetary world, such as the one on Mars, is without any doubt the cave: darkness, constant temperature, limited visibility, physical obstacles, strict safety rules, isolation, loss of temporal cognition, difficulty in supplying materials and food, the necessity of working in a team. If exploration and documentation tasks and scientific sampling and experiments are added to those factors, the similarity of a cave mission to an extraterrestrial one becomes even more striking. (Bessone 2013, 56-57)

Since the beginning of the space program, astronauts have been selected according to criteria that evaluate both technical skills and personal temperament[17]. Because of the stressful conditions they will be continuously exposed to during space missions, among all the applicants only those who demonstrate a high tolerance to demanding endeavours are considered for selection. Yet, for training purposes, they have to be exposed to conditions that exceed their tolerance, which are very hard to simulate in a controlled environment that does not present any real danger. As demonstrated by Olson (2010), during their career, astronauts are re-made into environmental subjects, or bodies whose performance require to be evaluated within the context of its functioning (namely, the hyper-technical space of the International Space Station). One of the strategies adopted is to bring small groups of them into unfamiliar contexts, where they feel uncomfortable, "where they have to *adapt*"[18]. Placing them in these alien conditions is, indeed, another form of "ecobiopolitics" (Olson 2010), that is the disciplining of the astronauts' bodies through the temporary remaking of their relation to a new and otherworldly environment.

During the six days of cave mission, the astronauts cannot be left idle, as this would be too inconsistent with the tight schedule of a space mission. For this purpose, ESA trainers asked speleologists to provide a number of scientific goals the trainees would have to achieve once into the cave. Each year the team is thus given a series of scientific projects they need to learn how to carry out to completion. The assignments usually take the form of collecting samples and specimens and making maps of the chambers that are still uncharted. What is at stake is not merely the survival in a cave by following standardized safety procedures, but being able to apply them while *exploring*. "Who's the real explorer?" asked Laura, one of the ESA trainers. Her goal is to turn the engineers into explorers, teaching them how to be attuned to what is new and surprising, to step inside the unfamiliar, inhabiting – sensing and dwelling in – an isolated space, with no weather or days, alien and alienating.

Through the experience in these particular field sites in Sardinia, the scientists were involved in the production of these three analogies at the same time: i) they were thinking about the field sites we visited as isolated subsurface microbial habitats; ii) as shelters protecting humans from the dangers of the Martian atmosphere, and; iii) as isolated enclosed spaces that reproduce some of the features specific of space journeys. The three analogies, in the lived experience, overlapped and became, at times, almost indistinguishable.

The workshop talks and presentations were carried in the auditorium of the local mining school, founded in 1871 in the attempt to improve the economy of a region still considered poor, but rich in raw materials. Mining represented, for several decades, the only industry of the region that employed and sustained the local people. The Art Deco building hosts, in the basement, the museum of mining. Established during the decline of the extractive sector, the museum is located in multiple smaller rooms and is arranged around different aspects of local mining life. It includes the 400m practice mine tunnel excavated by the students under the school and the nearby square. During the Second World War, the tunnel was used as an air raid shelter, infirmary and operating theatre, directly connected to the old hospital. More than only in strictly economical terms, mining and survival, in Iglesias, were deeply interrelated. During the 1990s almost all the mines of the district closed down and today the mining industry has mostly disappeared. The old buildings and tunnels remain there as ruins for industrial archaeologists, and attraction for the rampant tourist sector.

Lisa Messeri describes analogues as the successful super-imposition of planetary and local. In the Mars simulation facility based in the Utah desert that she gives an account of, this overlapping carves out "a unique place to inhabit and consequently forge a novel connection to or understanding of another world" (Messeri 2016, 26). The analogue is not just a simulation: the new way of thinking about outer space, both considered place-less and nevertheless deeply situated, is, according to Messeri, generative: "it creates a history even as it simulates the future" (ibid.). In creating a geo-microbiological history of the Earth within the broader Solar System, it makes it possible to think about the future inhabitation of other planets. Double exposure can be, in fact, multiple. By means of the first-hand experience and the group interaction, astrobiologists can quickly shift from one narrative to another and build up a shared vocabulary of *adaptation, isolation* and *exploration,* with which they can refer to all the three analogies, making the shift between one and the following even more immediate. The analogue was redundant in that even when one narrative failed to convince those involved in the analogue-making activity, others could support the legitimacy of the field site as a space of knowledge production about extra-terrestrial environments. In fact, the analogies drawn between a terrestrial cave and Mars might not have always been very strong or very obvious; but in the lived interaction the analogies were substantiated and tied together. Subsurface and survival – of microbes or humans – were superimposed in the analogue experience.

4. Co-presence, Colonization, Contamination

The GESE topical team's aim was to explore new research avenues and the ways in which mineral-microbe interactions might be put into use in future space exploration and settlement. Nevertheless, looking for life and establishing new settlements on Mars are based on different practices: biological (either astrobiological or speleological) approaches rely on keeping life forms apart to validate their findings (Metzer 2011), whereas human spaceflight practices focus on putting life forms – not only humans, but entire ecosystems designed to sustain micro- and macro-biological communities – elsewhere.

The high vulnerability of some of these Earthly environments requires scientists and astronaut trainees to pay attention to the consequences (both on the epistemic and the ethical level) of their physical presence and calls for reflections about both the future of the human exploration of space (see, for example, Cockell 2007) and the present use of these environments as spaces of knowledge production. As Stepan (1986, 268) suggested, a metaphor is not a one-way knowledge-making device; on the contrary "by their interactions and evoked associations both parts of a metaphor are changed".

Caves and mines are, in this respect, very different settings which encourage different considerations. Mines are human made spaces, whose astrobiological relevance is due to the resistance and resilience of the microorganisms inhabiting them, which have survived the depletion of their environments and then re-appropriated the newly created surfaces and the cracks as soon as they became available. Astrobiologists observe their resilience and are keen on not changing the conditions that make the microbial re-colonization possible. Caves are valued for their pristine and isolated conditions instead. Access to pristine caves is highly regulated; for scientific as well as logistic reasons, the scientists do not spend more than a few days inside caves, and no long-term settlement is established in their depths. During these exploration trips, it is imperative to bring back outside everything that has been introduced as part of the astrobiologists' and speleologists' gear. Nevertheless, there are a few things that cannot be removed: footprints and marks (for example those created by the hiking equipment), and microbes. The former can be considered within a framework of geological dynamism: footprints and small blemishes will be, given enough time, eroded by the same processes that have carved the cave out of the rock. The latter, microbial contamination, has a different status, which has to do with the ambiguities of "colonization" when considered at the microbiological level to describe the opportunistic and efficient entering and settling of new organisms within a certain ecosystem, which might not have been previously inhabited. The potential for colonization is in fact twofold: the scientists' bodies could be infected by bacteria from the cave, and the cave could be colonized by bacteria spread by the scientists' presence (their touching, breathing, sweating). The body and the cave are thus two habitats for microbial communities[19]. The tension between the value they attribute to these field sites' being pristine and the threat to this very condition posed by the scientists' physical presence in the analogue sites, mirrors the same ethical concerns that trouble the astrobiologists about outer space missions[20]. These tensions are materialized during the fieldwork experience: space analogues often raise both concerns and enthusiasm about the colonization of outer space, and they open up a discursive space within and outside the scientific community (McKay 2009; McKay and Zubrin 2002), a space where to negotiate alternatives and tame challenges to the science.

5. Back to Planet Earth

At the end of a walk in Is Zuddas, a show cave whose first kilometre has been equipped with steel stairs and neon light to become a tourist attraction, we were told that the key of the gate securing the entrance had been lost and the gate could not be re-opened to let us out until someone would come and fix it. A group of us stopped and waited on a terrace a few meters below the cave mouth. We started jokingly talking about how would we survive in the cave for a long time: would we need to hunt bats, collect bugs, drink the water dripping from the walls? Would our grandchildren evolve to see in the dark? Would we, like in Jules Verne's *Voyage to the Centre of the Earth*, discover prehistoric landscapes in the depth, moving in space and travelling in time? The expert guide looked at our faces and laughed: when the astronauts come for the training, she always plays the same trick to see their reactions. After many days of isolation, how do they cope with the impossibility of getting outside, metaphorically returning to Earth? For us, the gate had always been open anyway; we got out of the cave and started walking in the large path under the tree shade. Some veteran speleologists chat about how getting out of a cave makes the surface feel different and indeed very chaotic: the wind moves the leaves, birds tweet and insects fly and land on our clothes; the warm sun, high in the sky, suggests that it is time for lunch. I wonder whether we are back on Earth, or if we have travelled even further on a terraformed Mars, "This cannot be Mars," someone tells me, "too many mosquitoes. Who would want to put mosquitoes on Mars?!" The analogue experience overturned our idealistic conceptions of both Earth and other possible habitats. Earth is the only planet we know we can live on, but indeed what makes it feel unique are its many (perhaps imperfect) environmental relations.

This brings us back to the above-mentioned principles of finitism: if the first thesis says that the future applications of terms are open-ended, the last thesis says that the applications of different kind terms are *not* independent of each other. It follows that any act of use of a term "is liable to condition all subsequent acts of use of all those associated terms." (Barnes et al. 1996, 58-9) Even when stepping outside the analogue field site, the analogy keeps on its generative work: it has not only made Mars a little closer, but also the Earth surface and atmosphere unfamiliar and new, and a cave in southwestern Sardinia richer in interesting life forms.

Su Zurfuru mine does not seem *abandoned* anymore, but repopulated and given new life by different communities of microbial miners and dwellers.

Thinking about ecological futures in outer space unsettles visions of the Earth as well, in a way that is not dissimilar from the so-called "overview effect" (White 1987), the cognitive shift of awareness reported by some astronauts that, in the late sixties and seventies provided one of the conceptual bases for environmental movements[21]. Astrobiology and human space flight overlapped again in unexpected ways. "The [extraterrestrial] realm is not 'other' than earthly but acts back on and unsettles assumptions about commonplace brands of knowledge" (Battaglia 2005, 11), as a resource to articulate different ways of being humans on Earth, and also being humans on a planet shared with other micro- and macrobiological life forms. If ecological understandings of space are continuously being negotiated through analogues field sites (among other things), so is the other term of the analogy: Earth.

6. Conclusions

This essay focused on the ethnographic account of astrobiologists' and speleologists' analogue making activities. By moving beyond analogies as rhetorical tools and focusing on the lived, practical, situated and embodied experience of analogy making, this essay aims to cast a light on analogue making practices as fundamental tools to (re)define a discipline and to explore and negotiate tensions and alignments between different (and not always compatible) directions for future space exploration.

The first part of the essay focused on three scenarios that scientists embraced when exploring caves and mines in Sardinia during the GESE workshop, i.e., caves and mines as: 1) microbial habitats; 2) shelters and; 3) sites for astronaut training. I investigated their overlaps and consequences of the multiplicity and redundancy that keep the validity of the analogy as a heuristic tool in place. I then explored some of the issues and social dynamics involved in the shared experience of analogue fieldwork.

It is in the collective experience of otherworldly scenarios that analogues are negotiated and turned into collectively relevant epistemic tools. Once descended into the darkness of a cave, peripheral vision is completely inaccessible and what could be seen is always and only a sharp cone of light pointing straight. Seeing is a combination of the skilled art of pointing one's light in the right direction and involuntary movements, for example when stumbling on a rock and pointing the light downward, maybe to notice the presence of something unexpected, standing out against the surrounding darkness such as the unexpected view of a jelly substance, triggering the astonishment of the scientists who immediately claimed "this is biology". The possibility of unexpected findings is not unique to the field as opposed to the lab – even in the controlled and standardized space of the laboratory people are sometimes led to unexpected breakthroughs. What fieldwork provides is the possibility of *purposefully* searching for the unforeseen and unforeseeable. In fact, serendipity plays a significant role in laboratory or archival research as well, and nevertheless, in these contexts, the dominant narrative reconstructs findings (often in retrospect) as obtained through hypothesis testing. Astrobiological fieldwork (like many other field disciplines), on the contrary, rejects this narrative in favour of a more open-ended and less deterministic research trajectory. The non-trivial combination of skilled observations and serendipity is considered one of the features that make fieldwork experience a valuable analogue for the search for life in space.[22] The field, which represents the renewed encounter with a nature not allowed within the strictly filtering boundaries of the laboratory, "is believed to harbour a surplus of multiplicity, abundance, and potentiality humans have not yet discovered or characterized" (Paxson and Helmreich 2004). It is through the scouting for what is still *unknown* (Marcheselli 2020) that astrobiologists carve a space for their discipline within the broader academic landscape.

Accordingly, one of the issues that caves and mines uncover, is the question of how disciplinary boundaries are defined or blurred in analogy making. The boundaries between disciplines, as well as between science and other realms of action, are social phenomena; they are a "contextually contingent and interests-driven pragmatic accomplishment drawing selectively on inconsistent and ambiguous attributes" (Gieryn, 1995:393). In making different analogies coexist, merge or conflict, caves and mines as space analogues are trading zones (Galison 1997) in which different research directions and priorities are discussed, explored and opened up for future negotiation.

Training to prioritize microbe detection and protection techniques and stories of mining, survival and change provide resources to further articulate the analogies, aligning visions or taming challenges. Extreme environments turned into space analogues are crucial sites for "examining practices of future imagining in social terms, and for anthropological engagement with these practices" (Salazar 2017, 72). What in the collective experience becomes a common imaginary mixes intentions and different timescales. The ESA astronauts training in caves, for example, includes exercises on how to collect astrobiologically relevant samples in sterile conditions, even before the existence of an actual proposal for manned space missions on other planets. The trainers are "testing the training" for those who, in an indefinitely far future, will become the first (European) astronauts on other planetary surfaces but, at the same time, are also informing the astronauts' view of Earth, space and ecosystems.

But analogue-making work is never completed: agreement on what constitutes a good analogue setting is an ongoing negotiation between the epistemic practices that are implemented by those who identify themselves with the emerging discipline of astrobiology and what counts as a meaningful present and future for space exploration. This opens up a space for sociological inquiry about the particular social processes through which analogue practices require collaborations to be made, allow for new interactions and evoke previously unforeseen associations, and thus constantly unsettle and reframe all the terms of the analogy and the actors involved (Stepan 1986; Franklin 2014).

Exploration of space, exploitation of its resources and settlement establishment are not necessarily compatible goals or perhaps joinable by the thread of mineral-microbe interaction, but they are made so when seen through the lens of Sardinian caves and mines as analogue field site. Finding life on Mars and establishing a human presence on it (either as scientific outpost or long-term settlement) are often thought of as incompatible tasks, since the economic profitability and colonization of space as an exercise of political power is at odds with the ethical concerns about these environments. But strategically, astrobiologists align with geomicrobiologists and position themselves as to be relevant actors in any of these possible alternatives. At the same time, they do not exclude any alternative, but they order them chronologically: it is shown in practice how microbes can both be invaluably useful to humans, and at the same time understanding them depends on prioritizing a certain empirical approach which privileges "surprise" over scrupulous planning, and human sensibility over robotic functionality. Conflicting futures are not neglected, they are performed and tamed.

Notes

[1] A brief introduction to the history of the Su Zurfuru mine can be found at http://www.parcogeominerario.eu/images/files/pagina%20633(1).pdf (in Italian).

[2] All the people mentioned have pseudonyms.

[3] The location, Iglesias, was chosen in function of the three sites we visited during the field trips: two caves, Su Mannau and Is Zuddas and an old mine, Su Zurfuru. The vignette refers to the last one.

[4] For a comprehensive account of the history of exobiology and astrobiology, see Strick 2004; Dick and Strick 2005; see also Impey 2010.

[5] A popular definition of this concept can be found in Rothschild and Mancinelli 2001.

[6] Some good examples of this feedback process can be found in the *JGR-Biogeosciences* Special Issue "Field Investigations of Life in the Atacama Desert" available at https://agupubs.onlinelibrary.wiley.com/toc/21562202g/2007/112/G4.

[7] The word "redundancy" is intended here with a meaning similar to the one the Oxford English Dictionary attributes to the engineering use of the word: "the deliberate duplication of parts in a system so that its function is not impaired in the event of a malfunction or failure" http://www.oed.com/view/Entry/160537?redirectedFrom=redundancy - eid.

[8] Different perspectives on analogies in science can be found in Hofstadter and Sander 2013; Lakoff and Johnson 2013; Holyoak and Thagard 1995.

[9] Modelling is defined as the establishment of a link between two things – which might range from mathematical structures to verbalized systems – by means of resemblance or analogy (Barnes et al. 1966, 107-9).

[10] As above, I define *analogue sites* as material settings in which one or more analogies are embedded and *analogies* as the correspondences between Earth and outer space.

[11] "Especially important to the functioning of interactive metaphors" Stepan writes, "is their ability to neglect or even suppress information about human experience of the world that does not fit the similarity implied by the metaphor. In their 'similarity-creating' capacity, metaphors involve the scientist in a selection of those aspects of reality that are compatible with the metaphor" (Stepen 1986, 272).

[12] The same use of the word "environment" to designate other planetary surfaces has not to be taken for granted. Planets have not always been considered *places*, but what is considered the correct way of thinking about planets has changed over time. See for example Alexander et al. 2009; Messeri 2010.

[13] Interview with BW (astrobiologist) 21/10/2015.

[14] Messeri proposes *narrative* as a device that "unsettles landscapes as static images" and "structures both place and time as they manifest in landscape" 2016:31.

[15] The Institute encouraged creative and innovative thinking about space exploration related issued. See http://www.niac.usra.edu/.

[16] More details on ESA's astronaut activities in caves can be found at: http://www.esa.int/Our_Activities/Human_Spaceflight/Caves/.

[17] The astronaut selection processes and the "American hero" narrative it reproduces is deeply normative. Most astronauts are white males, often with a military training or a degree in engineering. Despite the effort to reverse this trend, its limits are enduring.

[18] 25/05/2015 private conversation with LB (astronaut trainer).

[19] An interesting parallel with reference to the ISS can be found at http://www.sciencemag.org/news/2015/10/international-space-station-home-potentially-dangerous-bacteria.

[20] For further historical insight on this, see Wolfe 2002, Anker 2005, Daly and Frodeman 2008.

[21] Despite looking at the planet Earth from orbit seemed objective because detached, this perspective has been shown to be inherently situated, like any other perspective. See Helmreich 2011 and Poole 2010.

[22] When astrobiologists imagine what it takes to find life in an alien environment, they acknowledge that they should probably not expect to find exactly what they look for – but they rely on the idea, often repeated in formal and informal settings alike, that they will recognize life, despite the different forms it might take, once they encounter it.

References

Anker, P. (2005) *The Ecological Colonisation of Space*, in "Environmental History", 10 (2), pp. 239-268.

Alexander, C., Carlson, R., Consolmagno, G. et al. (2009) *The Exploration History of Europa*, in R.T. Pappalardo, W.B. McKinnon and K. Khurana (eds.), *Europa*, Tucson, The University of Arizona Press.

Bandfield, J.L. (2007) *High-resolution subsurface water-ice distributions on Mars*, in "Nature", 447, pp. 64-67.

Barnes, B., Bloor, D. and Henry, J. (1996) *Scientific Knowledge: A Sociological Analysis*, London, The Athlone Press.

Battaglia, D. (ed.) (2005) *E.T. Culture: Anthropologies of Outer Space*, Durham, Duke University Press.

Bertoni, F. (2016) *Resources (Un)Ltd Of Planets, Mining, and Biogeochemical Togetherness*, in S. Oppermann and S. Iovino (eds.) *Environmental Humanities: Voices from the Anthropocene*, Rowman and Little Field Intl.

Bessone, L. et al. (2013) *Spatial Speleology – The CAVES Project of the European Space Agency: Caves as real and metaphoric Martian speleology*, in "Speleologia", 68, pp. 56-57.

Blake, M. (2006) *On the Plurality of inhabited Worlds: A brief History of Extraterrestrialism*, in "International Journal of Astrobiology", 5(2).

Boston, P.J., Frederick, G., Welch, S., Werker, J., Meyer, T., Sprungman, B. et al. (2004) *System Feasibility Demonstrations of Caves and Subsurface Constructed for Mars Habitation and Scientific Exploration*, in "Complex Systems Research, (CSR, Inc.) NIAC Phase", 2.

Cockell, C.S. (2003) *Impossible Extinction: Natural Catastrophes and the Supremacy of the Microbial World*, Cambridge, Cambridge University Press.

Cockell, C.S. (2007) *Space on Earth: Saving Our World by Seeking Others*, London, McMillan.

Cockell, C.S. (2015) *Astrobiology: Understanding Life in the Universe*, Oxford, Wiley Blackwell.

Crabu, S. (2014) *Give us a protocol and we will rise a lab: The shaping of the infra-structuring objects*, in A. Mongili and G. Pellegrino (eds.), *Information Infrastructure(s): Boundaries, Contexts, Ecologies,* Newcastle, Cambridge Scholars Publishing, pp. 120-165.

Crossley, R. (2011) *Imagining Mars: A Literary History*, Middletown, Wesleyan University Press.

Cushing, G. (2012) *Candidate Cave Entrances on Mars*, in "Journal of Cave and Karst Studies", 74 (1), pp. 33-47.

Daly, E.M. and Frodeman, R. (2008) *Separated at Birth, Signs of Rapprochement: Environmental Ethics and Space Exploration*, in "Ethics and the Environment", 13 (1), pp. 135-151.

Dick, S.J. (1982) *Plurality of Worlds: The Origins of the Extraterrestrial Life Debate from Democritus to Kant*, Cambridge, Cambridge University Press.

Dick, S.J. and Strick, J. (2005) *The Living Universe: NASA and the Development of Astrobiology,* New Brunswick, Rutgers University Press.

Franklin, S. (2014) *Analogic Return: The Reproductive Life of Conceptuality*, in "Theory, Culture and Society", 31 (2-3), pp. 243-261.

Galison, P. (1997) *Image & Logic: A Material Culture of Microphysics*, Chicago, The University of Chicago Press.

Gherardi, S. (2000) *Practice-based Theorizing on Learning and Knowing in Organizations*, in "Organization" 7 (2), pp. 211-223.

Gieryn, T.F. (1995) *Boundaries of Science*, in S. Jasanoff, G.E. Markle, J.C. Peterson and T. Pinch (eds.), *Handbook of Science and Technology Studies*, Thousand Oaks, CA: Sage Publications, pp. 393-407.

Goodwin, C. (2000) *Action and embodiment within situated human interaction*, in "Journal of Pragmatics", 32 (10), pp. 1489-1522.

Guyer, J. (2013) *"The Quickening of the Unknown": Epistemologies of Surprise in Anthropology*, in "HAU Journal of Ethnographic Theory", 3, pp. 283-307.

Helmreich, S. (2009) *Alien Oceans Anthropological Voyages in Microbial Seas*, Berkeley, University of California Press.

Helmreich, S. (2012) *Extraterrestrial Relativism*, in "Anthropological Quarterly", 85 (4), pp. 1125-1140.

Helmreich, S. (2006) *The signature of life: Designing the astrobiological imagination,* in "Grey Room", 23, pp. 66-95.

Helmreich, S. (2011) *From spaceship earth to Google ocean: Planetary icons, indexes, and infrastructures,* in "Social Research", 78(4), pp. 1211-1242.

Hesse, M.B. (1966) *Models and Analogies in Science*, Notre Dame, The University of Notre Dame Press.

Hofstadter, D. and Sander, E. (2013) *Surfaces and Essences: Analogy as the Fuel and Fire of Thinking*, New York, Basic Books.

Holyoak, K.J. and Thagard, P. (1995) *Mental Leaps: Analogy in Creative Thought,* Cambridge, The MIT Press.

Impey, C. (2010) *Talking about Life: Conversations on Astrobiology,* Cambridge, Cambridge University Press.

Knorr-Cetina, K. (1981) *The Manufacture of Knowledge: An Essay on the Constructivist and Contextual Nature of Science*, Oxford, Pergamon Press.

Knorr-Cetina, K. (1995) *Laboratory Studies: The Cultural Approach to the Study of Science*, in S. Jasanoff, G.E. Markle, J.C. Peterson and T. Pinch (eds.), *Handbook of Science and Technology Studies*, London, Sage, pp. 140-66.

Kohler, R.E. (2002) *Landscapes and Labscapes: Exploring the Lab-Field Border in Biology*, Chicago, University of Chicago Press.

Lakoff, G. and Johnson, M. (2013) *Metaphors We Live By,* Chicago, University of Chicago Press.

Latour, B. and Woolgar, S. (1979) *Laboratory Life: The Social Construction of Scientific Facts*, Princeton, Princeton University Press.

Lederberg, J. (1963) *Exobiology,* in "Science", 142 (3596), pp. 1126.

Livingstone, D.N. (2003) *Putting Science in Its Place: Geographies of Scientific Knowledge*, Chicago and London, The University of Chicago Press.

Launius, R. (2014) *The Power of Analogies for Advancing Space Scientific Knowledge*, in "Astropolitics", 12 (2-3), pp. 127-131.

Marcheselli, V. (2020) *The Shadow Biosphere Hypothesis: Non-knowledge in Emerging Disciplines*, in "Science, Technology, & Human Values", 45(4), pp. 636-658.

McKay, C.P. (2009) *Biologically Reversible Exploration*, in "Science", 323 (5915), pp. 718.

McKay, C.P. and Zubrin, R. (2002) *Do Indigenous Martian Bacteria have Precedence over Human Exploration?*, in "On to Mars: Colonizing a New World", Apogee Books Space Series, pp. 177-182.

Messeri, L. (2010) *The Problem with Pluto: Conflicting Cosmologies and the Classification of Planets*, in "Social Studies of Science", 4, pp. 187-214.

Messeri, L. (2016) *Placing Outer Space: An Earthly Ethnography of Other Worlds*, Durham and London, Duke University Press.

Metzer, M. (2011) *When Biosphere Collide: A History of NASA's Planetary Protection Programs,* NASA SP-2011-4234.

Mhlmann, D.T. (2003) *Unfrozen subsurface water on Mars: Presence and implications,* in "International Journal of Astrobiology", 2 (3), pp. 213-216.

Olson, V. (2010) *The ecobiopolitics of space biomedicine*, in "Medical Anthropology", 29(2), pp. 170-193.

Olson, V. (2012) *Political Ecology in the Extreme: Asteroid Activism and the Making of an Environmental Solar System*, in "Anthropological Quarterly", 85 (4), pp. 1027-1044.

Olson, V. and Messeri, L. (2015) *Beyond the Anthropocene: Un-Earthing an Epoch*, in "Environment and Society: Advances in Research", 6, pp. 28-47.

Paxson, H. and Helmreich, S. (2004) *The Perils and Promises of Microbial Abundance: Novel Natures and Model Ecosystems, from Artisanal Cheese to Alien Seas*, in "Social Studies of Science", 44 (2), pp. 165-193.

Poole, R.K. (2010) *Earthrise: How Man First Saw the Earth,* New Haven, Yale University Press.

Praet, I. and Salazar, J.F. (2017) *Introduction: Familiarizing the extraterrestrial/Making our planet alien*, in "Environmental Humanities", *9* (2), pp. 309-324.

Rothschild, L.J. and Mancinelli, R.L. (2001) *Life in Extreme Environments*, in "Nature", 409, pp. 1092-1095.

Salazar, J.F. (2017) *Microbial Geographies at the Extremes of Life*, in "Environmental Humanities", 9 (2), pp. 398-417.

Simpson, G.G. (1964) *The Nonprevalence of Humanoids*, in "Science", 143 (3608), pp. 769-75.

Sormani, P. (2014) *Respecifying Lab Ethnography: An Ethnomethodological Study of Experimental Physics*, Aldershot, Ashgate.

Stepan, N.L. (1986) *Race and Gender: The Role of Analogy in Science*, in "Isis", 77 (2), pp. 261-277.

Strick, J.E. (2004) *Creating a Cosmic Discipline: The Crystallization and Consolidation of Exobiology, 1957-1973*, in "Journal of the History of Biology", 37 (1), pp. 131-80.

Westall, F., Hickman-Lewis, K., Cavalazzi, B., Foucher, F., Clodoré, L. and Vago, J. (2021) *On biosignatures for Mars*, in "International Journal of Astrobiology", 20 (6), pp. 377-393.

White, F. (1987) *The Overview Effect: Space Exploration and Human Evolution*, Boston, Houghton Mifflin.

"Why Caves?" http://blogs.esa.int/caves/why-caves/

Wolfe, A. (2002) *Germs in Space: Joshua Lederberg, Exobiology, and the Public Imagination, 1958-1964,* in "Isis", 93 (2), pp. 183-205.