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Chapter 1 : Exploring Earth Investigations

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Messenger Metallic shrapnel flying faster than bullets; the Space Shuttle smashed to pieces; astronauts killed or ejected into space. Space debris â€” remnants of a Russian satellite blown up by a Russian missile. The one survivor, Ryan Stone, has to find her way back to Earth with oxygen supplies failing and the nearest viable spacecraft hundreds of miles away. Over on Mars, 20 years in the future, an exploration mission from Earth is going wrong. An epic dust storm forces the crew to abandon the planet, leaving behind an astronaut, Mark Watney, who is presumed dead. He has to figure out how to grow food while awaiting rescue. Hollywood knows how to terrify and inspire us about outer space. Matt Damon is â€¦ Pe3k This is only part of the story, however â€” the bit with people centre stage. Sure, no one wants to see astronauts killed or stranded in space. Valuing space But should we care about the universe beyond how it affects us as humans? That is the big question â€” call it question 1 of extraterrestrial environmental ethics, a field too many people have ignored for too long. How we ought to value the universe depends on two other intriguing philosophical questions: Most people would accept that all humans have intrinsic value, and matter not only in relation to their usefulness to someone else. Accept this and it follows that ethics places limits on how we may treat them and their living spaces. People are starting to accept that the same is true of mammals, birds and other animals. So what about microbial beings? Some philosophers like Albert Schweitzer and Paul Taylor have previously argued that all living things have a value in themselves, which would obviously include microbes. Philosophy as a whole has not reached a consensus, however, on whether it agrees with this so-called biocentrism. Arguably we care about our environment on Earth primarily because it supports the species that live here. If so, we might extend the same thinking to other planets and moons that can support life. Some have proposed an idea called aesthetic value, that certain things should be treasured not because they are useful but because they are aesthetically wonderful. Could that apply to other planets? Alien environments Supposing we could answer these theoretical questions, we could proceed to four important practical questions about space exploration: But is scientific clarity all that matters, or do we need to start thinking about galactic environmental protection? Drilling for core samples, perhaps, or leaving instruments behind, or putting tyre tracks in the dirt? The race is well underway to develop technology to harvest the untold trillions of pounds of mineral wealth presumed to exist on asteroids, as already reported in The Conversation. It helps that no one seems to think of asteroids as environments we need to protect. Gold in them craters. Jan Kaliciak The same goes for empty space. The movie Gravity gave us some human-centred reasons to be worried about the buildup of debris in space , but might there be other reasons to object? The seven most extreme planets ever discovered Question 7: We also need to factor in the inevitable risks and uncertainties here. Terra-ism Discussions about outer space have the advantage that we have very little attachment to anything out there. These ethical questions might therefore be some of the only ones humans can address with a large measure of emotional distance. For this reason, answering them might help us to make progress with Earth-bound issues like global warming, mass extinction and nuclear waste disposal. Space exploration also directly raises questions about our relationship to Earth â€” once we overcome the technological puzzles preventing the terraforming of a planet like Mars, or find ways of reaching habitable exoplanets.

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Exploring Environments can be used to enhance and extend the study of landforms. After students have had experiences with Earth studies and can identify major landforms on our Earth, a natural extension to the learning is to study the environments that are found on and near those landforms.

Page 87 Share Cite Suggested Citation: Exploring Organic Environments in the Solar System. The National Academies Press. The lunar surface as a witness plate. That is, it is a location that provides for long-term integration of collected material and thus might have sampled other carbonaceous asteroids that are not present in recent meteorite collections; and The lunar surface as the abode of special microenvironments. The second possibility is of considerable potential interest, and the remainder of this section is devoted to its discussion. Permanently shadowed regions exist at both lunar poles. As long ago as , Watson, Murray, and Brown suggested that the extremely low temperatures experienced in these locations, less than some 50 K, would act as cold traps for volatile material impacting the lunar surface. The possibility of water ice deposits at the lunar poles raises the issue of the presence of other volatiles, including organic volatiles, since the likely sources of the water, particularly from comets, may also be abundant sources of organic materials. Given a source of raw materials and the availability of likely energy sources e. The irradiation of carbon-, hydrogen- and oxygen-bearing ices by ultraviolet radiation or cosmic rays can lead to the synthesis of organic compounds. Similarly, organics may be formed at the lunar poles by the action of the solar wind on the ice there in the same way that they are formed in ice on interstellar dust particles. These instruments include the following: The Lunar Exploration Neutron Detector LEND , which will map the flux of neutrons from the lunar surface to create 5-km-resolution maps of the hydrogen distribution and characterize the surface distribution and column density of near-surface water ice deposits; The Diviner Lunar Radiometer Experiment, which will map the temperature of the entire lunar surface at m horizontal scales to identify cold traps and potential near-surface and exposed ice deposits; and The Lyman-Alpha Mapping Project LAMP , which will observe the entire lunar surface in the far ultraviolet to search for exposed surface ices and frosts in the polar regions and will provide subkilometer-resolution images of permanently shadowed regions at the lunar poles. Indeed, it is not clear that the definitive detection and study of lunar organics are possible within the current generation of remote-sensing instruments. Page 88 Share Cite Suggested Citation: This mission is, however, designed to address questions relating to the absolute chronology of the lunar surface, the timing of the late heavy bombardment and the impact frustration of the origin s of life on Earth, and the history of lunar differentiation. The study of volatiles and organics is, nevertheless, a major scientific theme identified in the solar system exploration decadal survey. Possibly early in its history when the luminosity of the young Sun was approximately 30 percent less than its present value, there may have been a period when exogenous organic carbon delivered during the late heavy bombardment phase of planetary accretion might have accumulated on the surface. However, as the surface temperature rose to the current high values, this carbon would have been pyrolyzed, yielding various volatile molecules e. It appears likely that volatile products of such pyrolytic reactions would be lost to the minimal mercurian atmosphere. Pristine exogenous organic carbon might, however, survive in one environment, the bottoms of deep craters at the poles. Given that Mercury has essentially no atmosphere, any surface environment that is not directly illuminated e. Therefore, it is likely, that complex organic carbon could persist and accumulate in the regolith at such locations. Note that a similar argument can be made for the Moon. Venus By virtue of its distance from the Sun, Venus had a larger inventory of organic carbon than Mercury. In fact, it was proposed that extensive radial mixing of protoplanetary material across a wide region of the accretionary disk may have resulted in an initial volatile content and composition of Venus similar to that of Mars and Earth. Currently, the atmospheric pressure is approximately 90 bar. The atmosphere is dominated by CO_2, where extensive green-house warming leads to temperatures on the order of K near the surface. Given this extreme thermal boundary condition, the accumulation and preservation of significant organic carbon is unlikely. It is also unlikely that any exogenous organic carbon would be preserved on the surface due to these extreme conditions. In order for any endogenous organic matter to be detectable today it should be sequestered in the subsurface. Unfortunately, the extremely high surface temperatures create a thermal boundary condition that precludes the existence of cooler subsurface regions in which thermally labile organic carbon might be found. Earth The current inventory of organic matter on Earth is dominated by biological sources, in particular the structural biopolymers of vascular plants, i. Page 89 Share Cite Suggested Citation: First, uplift of organic carbon-rich sedimentary rocks by tectonic processes may lead to surface exposure and erosion. The previously sequestered organic carbon is thus susceptible to oxidative, photochemical, or microbial degradation. Alternatively, the entire sedimentary section may be buried deeper, resulting in progressive thermal metamorphism, whereby the organic carbon entrained in the sediments is thermally converted initially to petroleum and ultimately to methane and various forms of inorganic carbon e. Subduction and volcanism associated with melting of igneous and sedimentary rocks provides a conduit through which organic carbon is recycled back into the atmosphere. Abiotic sources of organic carbon currently include the persistent rain of exogeneous organic carbon derived from carbonaceous chondritic meteorites, interplanetary dust particles, and the occasional comet. Note that impacts would also destroy or modify organic matter. As has been observed in carbonaceous chondrites, the concentration of simple organic molecules under aqueous conditions would ultimately result in the formation of some of the more complex organic compounds e. Endogenous abiotic production of simple organic compounds currently occurs in volcanic fumaroles e. One estimate proposes that, based on purely thermodynamic grounds, hydrothermal vent systems could provide up to to kg of organic carbon per year. By virtue of its distance from the Sun, Mars is expected to have formed from volatile-rich materials and also received volatile-rich exogenous complex organic matter after planetary accretion. Moreover, the current conditions of low temperature, no liquid surface water, low partial pressures of oxygen, and an apparently dormant tectonic state would be expected to provide a good environment for the preservation and accumulation of complex organic carbon absent the ubiquitous oxidizing materials found in the upper-most layers of the martian regolith. Mars has a lower atmospheric entry velocity for infalling debris because of its surface gravity is lower than that of Earth. The mass of meteoritic debris that survives martian atmospheric entry without melting has been estimated to be 8. Although a small amount of organic matter is found in martian meteorites, the Viking lander experiments found no organic matter in the martian regolith. It has been proposed that oxidants in the martian regolith oxidize any exogenous or endogenous carbon contained within the near surface. In the absence of an active biosphere, the most important endogenous source of organic matter on Mars is probably the abiotic production of organic compounds e. Organosynthesis could have occurred both during volcanic exhalations and by hydrothermal alteration of basaltic crust early in martian history. Actual levels probably depended on details of planetary accretion, interactions between the crust and mantle with out-gassed volatiles, the ultraviolet flux from the Sun which could rapidly destroy CH_4 and NH_3 , and rates of outgassing of chemical compounds into the atmosphere. If any of the terrestrial planets had such a reduced atmosphere, it appears likely that synthesis of organic compounds might have been a significant factor in generating a surface inventory of organic compounds. An intriguing mechanism involves the synthesis of HCN via photochemical reactions between CH_4 of volcanic origin and N_2. Rainout of substantial quantities of HCN would make the subsequent synthesis of purines, pyrimidines, and amino acids possible in the aqueous phase. This layer absorbs ultraviolet photons in a region of the solar spectrum where there are no other absorbers and where substantial damage to organic molecules can occur upon absorption. However, despite the oxidizing capacity of the atmosphere, significant amounts of CH_4 present at 1. This input is predominantly from the biosphere e. Lightning produces significant amounts of nitrogen oxides, but no species with carbon-carbon bonds. Both are composed of approximately 95 percent CO_2, with most of the remainder N_2. As a result, more complex carbon-bearing species are not produced in the atmospheres of either Mars or Venus. Thus, the only carbon-bearing species observed in the martian atmosphere are CO_2 and CO. In contrast, COS is produced predominantly biotically on Earth by marine organisms, although COS is also detected in volcanic gaseous emissions. Irrespective of such speculations, the evolution and present states of the atmospheres of Venus and Mars still bear on the history and evolution of both biotic and abiotic organic compounds in the solar system. For example, given the similar location in the solar nebula of Mars, Earth, and

Venus, they should all have had similar bulk chemical compositions 4. Mars and Venus may also provide clues to the composition of past atmospheres on Earth that ultimately would have influenced the Page 92 Share Cite Suggested Citation: The present atmospheric compositions of Venus and Mars also provide guidance as to the likelihood of finding organics produced abiotically or by ancient biota: Mars, for example, has no effective ultraviolet shield, whereas Earth and Venus do, the former via its significant ozone layer and the latter due to absorbance by sulfur compounds in the upper atmosphere. Therefore, ultraviolet-labile organics deposited on the surface of Mars as a result of either biotic or abiotic processes in the past will have been destroyed by ultraviolet light. Moreover, the photolysis of H_2O by ultraviolet light reaching the martian surface would generate OH and HO_2 radicals that would oxidize any organic compounds at the surface. Abiotic Organic Synthesis in the Interior of Earth There is a broad range of physical environments across the surfaces and in the interiors of the terrestrial planets; some of these may support conditions suitable for the abiotic synthesis of organic material. Notably, understanding of abiotic synthesis within the interior of Earth has grown considerably. For example, abiotic methane has been detected in fluids emitted in deep-sea hydrothermal vents, 54 as fluid inclusions within recently formed ocean-crustal rocks mid-oceanic ridge basalts , 55 and in remarkably preserved ancient seafloor rocks some 3. These two possibilities are discussed in detail in the next two sections. At very high temperatures e. This crust is basaltic and is created by the partial melting of mantle rocks deep within Earth, leading to melt migration through the mantle and its emergence along various mid-oceanic spreading centers deep under the oceans. While considerable heat is lost immediately at the spreading center, sufficient remains in the new seafloor to initiate Page 93 Share Cite Suggested Citation: If recirculating hydrothermal fluids contain dissolved CO_2, then methane can be formed. This has been shown to occur experimentally. The CH_4 formation mechanism is as follows. The hydrothermal alteration serpentinization of basalt and exposed peridotite in particular, transformation of the major mineral constituent, olivine yields a more magnesium-rich hydrated silicate, serpentine. The excess ferrous iron reacts with water to produce magnetite mixed ferrous and ferric iron and hydrogen gas. It is likely that this newly formed magnetite provides a suitable catalyst for methane formation. A proposed physical scenario for such chemistry in natural systems is as follows. Fluids containing CO_2 and H_2 originate at depth within the new oceanic crust via the previously described processes. The fluids migrate upward to the surface via a fracture-pore network. The fluids pass through rock containing catalytic mineral phases. These catalysts promote the dissociation of CO_2 and drive catalytic hydrogenation of carbon, leading to the synthesis of CH_4. However, in addition to methane, sequential insertion of CO followed by reduction leads to chain growth and the formation of ethane, propane, and higher homologs. Given this reasonable scenario, it is not surprising that FT chemistry may occur naturally in hydrothermal vent systems as well as in volcanogenic massive sulfide deposits. As for the significance of such systems as global sources of abiotic organic carbon, it has been estimated that between and kg of organic material per year could be synthesized via hydrothermal systems. However, this simple picture assumes that the protoplanetary dust particles and the progressively larger bodies that accreted from them all derived from the immediate neighborhood of the growing planets. Recent work has shown that considerable radial migration of source material due to collision and scattering of protoplanetary nuclei was likely, perhaps enhanced by the perturbative effects of an early-formed Jupiter. As a result, more-volatile-rich, cooler material might have contributed to the terrestrial planets. As stated earlier, Mars and Venus are likely to have formed from material that was compositionally similar to that of Earth. This similarity would suggest that all three planets started out with comparable inventories of water and carbon. Both Mars and Venus exhibit evidence of extensive volcanism. The estimated composition of their mantles suggest that, at least early in their respective histories, both planets had the potential for generation of at least methane and hydrocarbons, either via the thermal equilibra- Page 94 Share Cite Suggested Citation:

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Cabrol I realize how immodest the title of this first blog may sound and it is certainly not my intention to convince anybody that I will answer this question in the limited space allowed here or even in a lifetime. My hope is, instead, to stir thoughts and invite an exchange of diverse perspectives to make this a thread that we can all pull from time to time. It is an immense subject debated in an abundant literature, but discussing it is certainly not the exclusive privilege of those called explorers. All beings, from the greatest minds to the simplest forms of life on this planet and possibly others, are explorers. All are, thus, without exception, competent to contribute to this discussion in one form or another. Exploring may mean a number of different things for each of us but I argue that we all do it for the same reasons, whether those are reasoned or subconscious, and that the fundamentals of why we do explore have been the same since the dawn of life on our planet. My perspective stems from a passion for exploration, for living, breathing and imagining it every day of my life and dreaming about it at night. The sky is not even the limit. It is our starting point. There is a very large universe out there and according to the String Theory, it could be only one out of an infinity of universes. These explorations take us beyond the limits of where, directly or indirectly, our hands can touch, our eyes can see, and our bodies can travel, to look at all the angles our imaginations can reveal. There, we embrace an addictive freedom, while still clinging to the laws of physics with which we have come to evolve. One day these laws might fall but for now, they are still what make our universe go round. We explore at microscopic to macroscopic scale but this is not a human privilege. All species that made the journey thus far with us are still here because they were greater explorers than those that did not. This takes me to what I feel strongly is the most fundamental, primeval essence of exploration: While we are seeking brethren in the universe, our own beginnings remain unclear. Life on Earth may have developed and gone extinct many times before finally taking roots on a planet heavily bombarded by asteroids and comets for hundreds of millions of years, a planet ravaged by volcanic eruptions the likes of which we do not know anymore, and by many more countless deadly threats. In such an environment, immobility and scarcity were not the name of the game. Survival resided in the diversification of environments that life could make available to itself by multiplying when it could, and by colonizing the next crack in the rock, the next rock in the field, and finally all the fields in the continent, the next continent and the next ocean in the planet, and soon at geological scale , the next planet. This is our journey so far. Each species goes as far and as fast as its evolutionary path can take it. We as in life in general are all trying to constantly expand our horizon, for there is gain in doing so. At the most primary level the gain is physical survival through a greater range of environments, which provide additional resources to supply a greater number of individuals of the same group. The curiosity and awe that we humans associate with exploration is a late comer. Understanding when this driving force developed is by itself a fascinating subject. I do not believe the first bacteria were curious about their environment; they simply tried to adapt to it. Curiosity requires first questioning, which is the attribute of a number of superior species who do not simply react but rather interact with their environment. Those species also show creativity and imagination, which are both signs that they are exploring their mental and cerebral abilities. I am now going much too far outside my area of expertise and will hope that others will comment farther on this. But as far as humans go, beyond survival, exploration is certainly associated with physical, mental, and spiritual questioning that fuel each other by changing our perception of all the dimensions we know of, and give to the universe. Iterative questioning and exploring expands our imagination, thus our ability to further question and explore. The curiosity we apply to exploration is also one way for us to stimulate our imagination and gauge its validity in understanding our universe and its endless diversity. To some extent, it is the way each generation has to create its own universe. Today, we still strive to survive but now life has also reached the point where its exploration path has come to question its own origin. Indeed, we do explore to understand where we came from and define the meaning, if any, of this wonderful universal journey of ours. It is fascinating to realize how, as we walk the Earth, the surface of other planets, soon the Milky Way and beyond, that this journey gives greater depth to our consciousness, for exploration is also very much an inward voyage. We are made of all the bricks of this universe. There is, therefore, a chance that part of this answer that we have set out to seek so far away in the unknown confines of the universe, might be within us, waiting for the time when exploration will take us back home.

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