Icarus 217 (2012) 184–193

Contents lists available at SciVerse ScienceDirect

Icarus

journal homepage: www.elsevier.com/locate/icarus

Uninhabited habitats on Mars

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ARTICLE INFO

Article history:
Received 30 May 2011
Revised 15 October 2011
Accepted 31 October 2011
Available online 9 November 2011

Keywords:
Mars
Astrobiology
Cratering
Exobiology
Extrasolar planets

ABSTRACT

Investigations of Mars as a potential location for life often make the assumption that where there are habitats, they will contain organisms. However, the observation of the ubiquitous distribution of life in habitable environments on the Earth does not imply the presence of life in martian habitats. Although uninhabited habitats are extremely rare on the Earth, a lack of a productive photosynthetic biosphere on Mars to generate organic carbon and oxygen, thus providing a rapidly available redox couple for energy acquisition by life and/or a lack of connectivity between habitats potentially increases the scope and abundance of uninhabited habitats for much of the geological history of the planet. Uninhabited habitats could have existed on Mars from the Noachian to the present-day in impact hydrothermal systems, megaflood systems, lacustrine environments, transient melted permafrost, gullies and local regions of volcanic activity; and there may be evidence for them in martian meteorites. Uninhabited habitats would provide control habitats to investigate the role of biology in planetary-scale geochemical processes on the Earth and they would provide new constraints on the habitability of Mars. Future robotic craft and samples returned from Mars will be able to directly show if uninhabited habitats exist or existed on Mars.

1. Introduction

All environments in the Universe can be placed into one of three categories, which can be represented as a habitability 'triad' (Fig. 1). An environment can be uninhabitable, either because of a physical (e.g. extreme temperature) or chemical (e.g. high concentrations of heavy metals) limitation, or the lack of a vital element required for life (e.g. nitrogen). Uninhabitable environments are often easy to identify and include obvious candidates such as the core of the Earth, the interior of the Sun and other similarly extreme locations. An environment can be habitable and inhabited. Many inhabited habitats can be located and observed on the surface and in the subsurface of the present-day Earth. Evidence for past inhabited habitats can be found in the rock record. The exact physical and chemical extremes that separate habitable from uninhabitable conditions are often undefined and subject to revision based on new discoveries in biology.

A third type of environment is one that is habitable, but uninhabited (Fig. 1). Some clarification on nomenclature is required to describe these places. They are distinct from vacant 'niches' (Lawton, 1982; Chase and Leibold, 2003; Rohde, 2005; Lekevičius, 2009). A niche is a functional definition of a specific set of energy and nutrient availabilities that could be used by life. In a vacant niche they are unused. If a habitat has no life in it, it contains, by definition, vacant niche(s).

An uninhabited habitat could be described as a 'vacant habitat'. Previously in the literature this term has been used to mean a habitat vacant of one particular species, but inhabited by other types of life (Thomas et al., 1992; Osbourne et al., 2001). The habitats discussed in this paper and previously (Cockell, 2011) are vacant habitats, but they are a specific type of vacant habitat – a habitat devoid of any life at all.

The term 'uninhabited habitat' more convincingly conveys a habitat that is not inhabited (i.e. being actively used as a habitat) by any life. There are instances in the literature in which it has been used synonymously with 'vacant habitat' to mean a habitat uninhabited by a specific species (Ohba et al., 1990; Bosakowski and Smith, 1997), but we would like to propose here that it is adopted to mean a habitat without any life.

The term, 'lifeless habitat', has been used to describe habitats in environments such as newly created lava flows (e.g. Gudmundsson, 1970). However, this term is problematic because uninhabited habitats on an inhabited planet could contain inactive life for which conditions are inappropriate for growth, for example the spores of an organism entrained from an inhabited region. Thus, an uninhabited habitat need not be lifeless. Similar problems are encountered with the term 'sterile habitat'.

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0019-1035/$ - see front matter © 2011 Published by Elsevier Inc.
doi:10.1016/j.icarus.2011.10.025

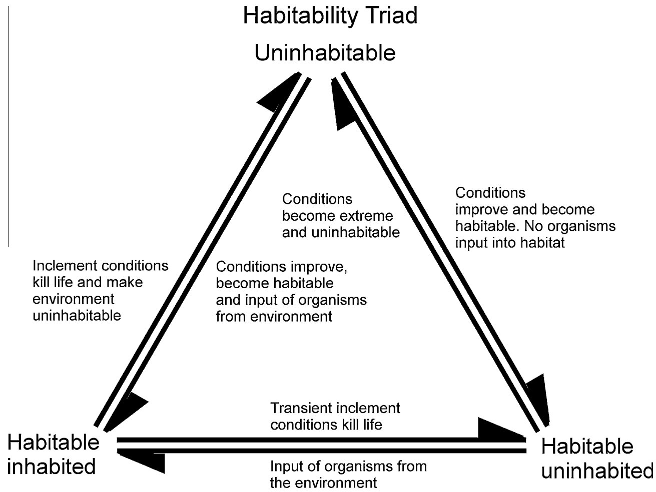

Fig. 1. A habitability 'triad'. Any planetary environment can be binned into one of three categories: (1) uninhabitable, (2) habitable and inhabited and (3) habitable, but uninhabited. The three types of environment are potentially interchangeable as environmental conditions at a particular location change.

The assessment of the extent of uninhabited habitats is conservative and bounded by what we know about life. Environments classified as uninhabitable, for instance, might be suitable for life with biochemistries that are yet to evolve; therefore these environments only appear uninhabitable. Thus, the set of uninhabited habitats that are catalogued is a maximum set. A potential example of a habitat that was empty of life on account of biochemical limitations might have been areas of the Earth's early land masses before microorganisms developed an ability to tolerate the extremes to be found there, such as desiccation (Battistuzzi and Hedges, 2009). However, in some cases, environments can be confidently said to be uninhabitable, regardless of potential biochemical adaptations. An example would be the centre of the Earth.

Any of the three types of planetary environment – uninhabitable, habitable and inhabited, and habitable but uninhabited – can be transient and they are can be interchangeable if environmental conditions alter in a particular location (certain uninhabitable environments such as the hot interior of some planets remain uninhabitable for the lifetime of a planet). For example, uninhabited habitats can become uninhabitable through deterioration in conditions that drive the habitat outside of habitable conditions. Uninhabited habitats can become inhabited by the influx of microorganisms through the atmosphere or in water, capable of growing in the habitat (Fig. 1).

Discussions on uninhabited habitats are absent from the ecological or planetary science literature probably because these environments are rare on the Earth, and where they do occur, they are usually transitory (Cockell, 2011). Two factors account for this. Firstly, in almost all habitats on the Earth that are connected to the photosynthetic biosphere on the surface, and where physical and chemical conditions are conducive to microbial growth, there are microorganisms. Carbon produced by photosynthesis, of which approximately 1×10^{16} moles is synthesised per year (Field et al., 1998; Raven, 2009), leaches into available habitat space and provides energy for microorganisms that use organics as an electron donor for growth, or they ferment. Aerobic organisms use oxygen as an electron acceptor, which is also produced as a waste product of photosynthesis. Thus, the pervasive availability of energy on the Earth leads to the observation that most habitable spaces are colonized (Whitman et al., 1998). Secondly, habitats on the Earth generally display connectivity, both through the widespread presence of liquid water, and thus a hydrological cycle which distributes carbon and microorganisms to newly formed habitats, and the distribution of carbon and microorganisms though the atmosphere.

In this paper, we discuss the significance of uninhabited habitats on Mars, and their implications for the search for life.

2. The significance of uninhabited habitats

If uninhabited habitats are discovered or suggested by robotic craft, what would be their significance to science? Terrestrial biological sciences would learn a substantial amount. For example, geochemical processes on the Earth have been linked to life since the early Archean when sulphur, carbon and iron cycles on the Earth, and other elements, were influenced by microorganisms (Canfield et al., 2006; Sleep and Bird, 2007; Lyons and Gill, 2010). However, we lack a set of abiotic controls with which to develop an insight into the influence and magnitude of these biological contributions. Abiotic and biological influences can sometimes be separated, for example, by investigating fractionation patterns of certain elements (Horita, 2005; Thomazo et al., 2009; Craddock and Dauphas, 2011), but, in the case of iron, for example (Balci et al., 2006), these are not always effective at resolving the biological contribution.

Uninhabited habitats in which geochemical processes occur without biota, but in which the conditions approximate to environments in past or present terrestrial habitats, would offer a new set of controlled comparisons. An example might be the weathering interactions of water with rocks. Weathering rates on Mars have been investigated (e.g. Hausrath et al., 2008). The application of these methods to the study of weathering in uninhabited habitats could provide a better understanding of the rate of chemical reactions at rock–water interfaces without the confounding effects of biology. These insights are vital for improving understanding of the role of abiotic and biotic weathering in the carbonate–silicate cycle on the Earth and more generally in global elemental cycles. Yet another example would be ancient habitable hydrothermal systems on Mars where the study of mineral sequences and deposition could be compared to identical systems in volcanic or impact environments on present-day Earth that contain life, to unravel more completely the effects of biology on hydrothermal mineral deposition and chemistry, thus improving our understanding of the role of biota in extreme environment biogeochemistry.

From an astrobiological perspective, the search for uninhabited habitats on Mars is an essential task in understanding what controls the distribution of life in the Universe and what conditions limit its distribution. For example, based on the empirical observation that all life on Earth is linked to the presence of liquid water, it is widely assumed that where there is liquid water, there is life. Although water is a necessary requirement for life, the presence of water in habitable conditions does not imply the presence of life. The assumption that it does is embedded within the wider assumption that where there are habitats there will be life, an inductive inference based on empirical observation that this is the case for most environments on the Earth.

Both of these generalizations are driving the search for life beyond Earth, especially in the case of Mars (Irion, 2002; Hubbard et al., 2002; Mottl et al., 2007; Jones and Lineweaver, 2010). However, there are several plausible scenarios by which uninhabited habitats might exist on Mars, and they need to be considered as likely outcomes of our exploration of the planet. These scenarios are derived from the categorisation in Cockell (2011), ignoring the one that is not relevant to Mars (a planet that is too young for an origin of life, but where habitable environments exist), and