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Abiotic methane in continental serpentinization sites: an overview

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Abstract

Until 2008 methane in land-based serpentinized peridotites (MSP) was considered to be an unusual and rare occurrence of abiotic gas. Today, reports of MSP are increasing for numerous localities worldwide in low temperature settings in ophiolites, orogenic massifs or intrusions. CH_4 emanates from focused seeps, hyperalkaline water springs or through diffuse seepage from the ground, typically along faults. MSP has a combination of stable C and H isotope composition that is different from that of biotic methane; it is likely produced by Fischer-Tropsch Type reactions between CO_2 (or other C compounds) and H_2 (from serpentinization) at low temperatures (typically <100°C) and its carbon is fossil, ^{14}C free, which does not derive from the more recent C dissolved in the hyperalkaline waters. MPS is more common than previously assumed; it may have played a key role in the origin of life, may fuel microbial life in igneous rocks on Earth and other planets, and can be an additional source of gas in atypical petroleum systems hosting ultramafic rocks.

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1. Introduction

Serpentinization, i.e. the hydration of olivine and pyroxene in mafic and ultramafic rocks (mainly peridotite), is today recognized as a fundamental water-rock interaction responsible for the production of secondary minerals, hyperalkaline water and gases, with implications in geophysics (changes in mantle rock rheology and seismic velocities), geochemistry (geochemical fluxes and carbon cycle), biology and astrobiology (energy ad raw materials for organic compounds and chemosynthetic microbial life)[1,2]. Serpentinization can produce hydrogen gas (H_2) that, with successive C reduction via Fischer-Tropsch Type (e.g. Sabatier) reactions, may lead to the generation of

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abiotic methane (CH_4) and other hydrocarbons[3,4]. H_2 and CH_4 are energy source (electron donors) in prebiotic chemistry and may have played a key role in the origin of life. Serpentinization, through H_2, can be a source of CH_4 in atypical petroleum systems where reservoir rocks are formed by or are adjacent to igneous rocks[5,6], and a potential source of CH_4 on other planets, such as Mars[6,7]. In addition to submarine serpentinization, driven by seawater at mid-ocean ridges and subduction zones (see the literature on Lost City and other seafloor hydrothermal fields[1]), a wide body of research has recently demonstrated the importance of active (present-day) serpentinization driven by meteoric water, occurring in peridotites already emplaced on the continents, in ophiolites, peridotite massifs or intrusions. Abiotic gas in these land-based sites has been discovered in an increasing number of countries, beginning from the 1980s with the pioneering works on springs and seeps in the Philippines, New Zealand and Oman[8-10]. In the last five years the list of the sites with surface manifestations of methane in serpentinized peridotites (MSP) increased considerably, including today at least 16 countries. Here is a brief but updated overview on the MSP distribution, seepage, isotopic composition and origin.

2. Surface manifestations of MSP: classification and distribution

Surface manifestations (i.e. seepage) of MSP are typically located in correspondence with faults or at the intersection of more faults, often in tectonic contact between ultramafic rocks and carbonate-rich rocks (limestone, metasedimentary rocks). Four types of MSP emissions can be distinguished:
(a) Gas bearing hyperalkaline springs (HS); (b) Gas vents, without water discharge (GV); (c) miniseepage: diffuse exhalation from the ground (peridotite outcrops and organic soil) around the springs or vents; (d) microseepage: diffuse exhalation from the ground far or independent from springs or seeps. HS and GV are a form of "macro-seepage" as they refer to visible fluid manifestations[6]. Hyperalkaline waters, with pH >9 and $Ca\text{-}OH^-$ chemistry, are characteristic of active serpentinization as they result from the liberation of OH^- and Ca^{2+} during the hydration of olivine and pyroxenes. They reflect a relatively deep hydrologic circulation, with ages in the order of a few thousands years[6,11,12]. MSP has been reported in tens of HS, distributed in 16 countries (Fig. 1).

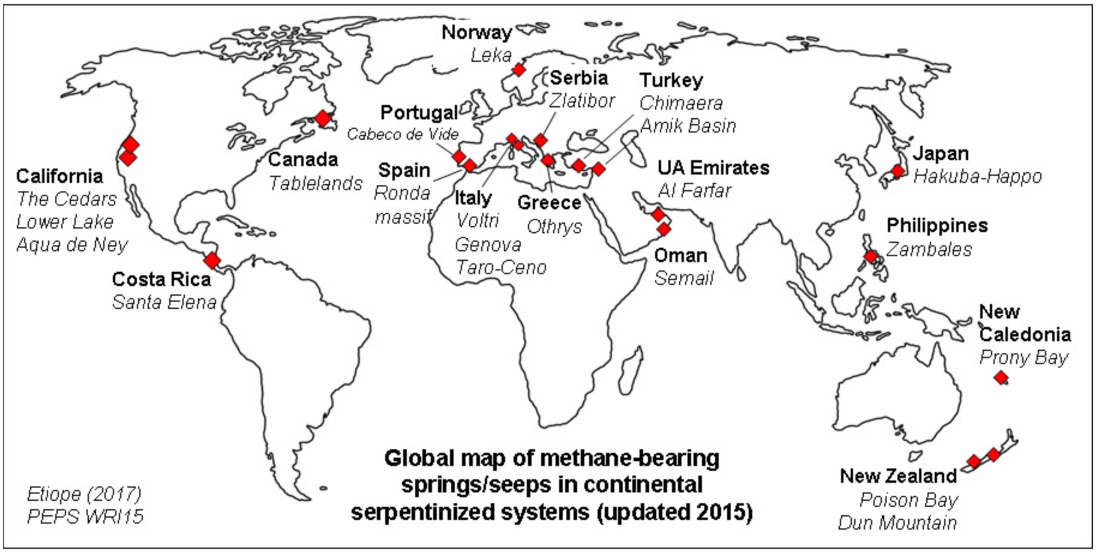

Fig. 1. Global distribution of continental MSP sites (references of the sites are in[6] and[14]). Dominantly abiotic methane, determined by complete C and H isotopic analyses, is documented in countries reported in Fig. 2. All sites refer to ophiolites, except Spain, Japan (peridotite massifs) and Portugal (peridotite intrusion)