Potential CH_4 seepage on Mars

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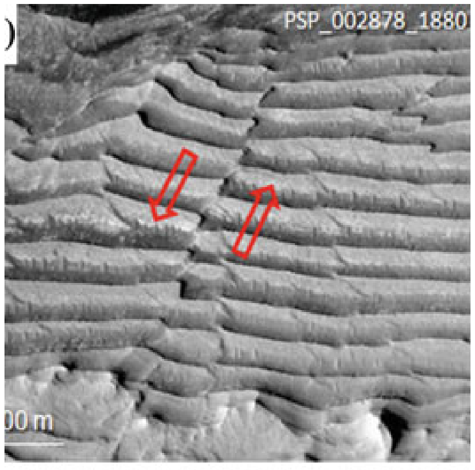
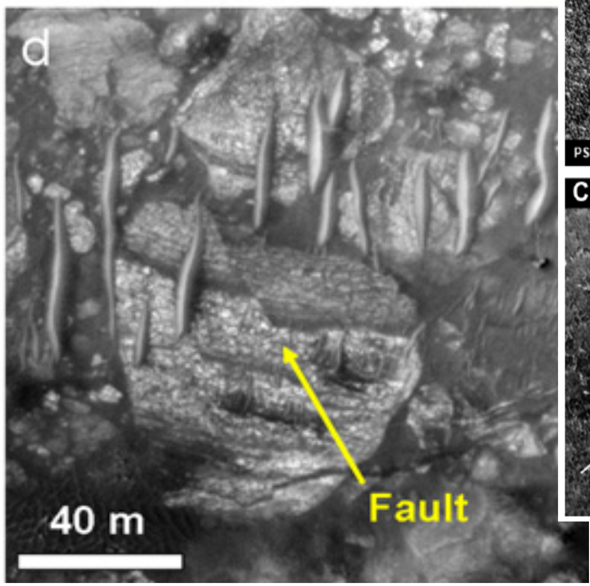
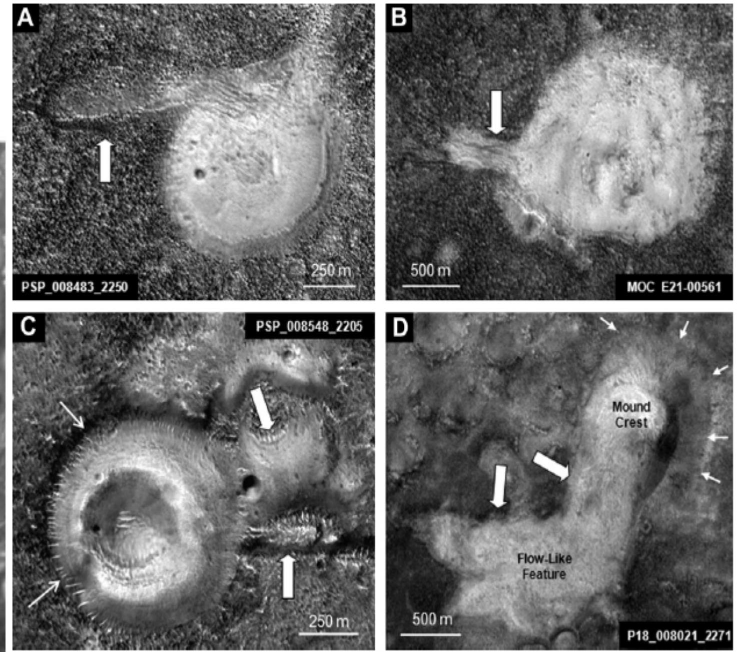


Arabia Terra
(*Etiope et al. 2011*)



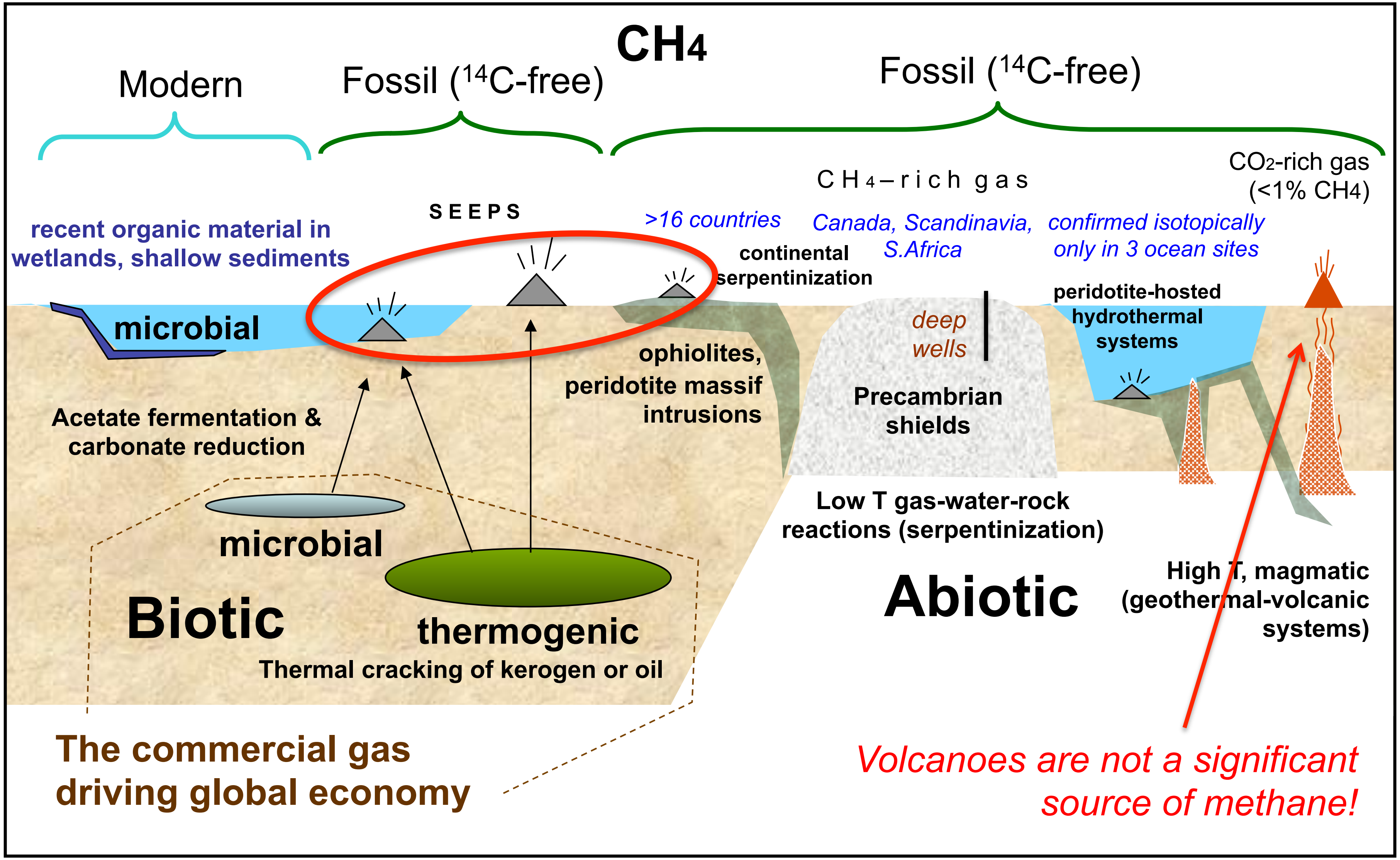
Nili Fossae
(*Wray and Ehlmann, 2011*)



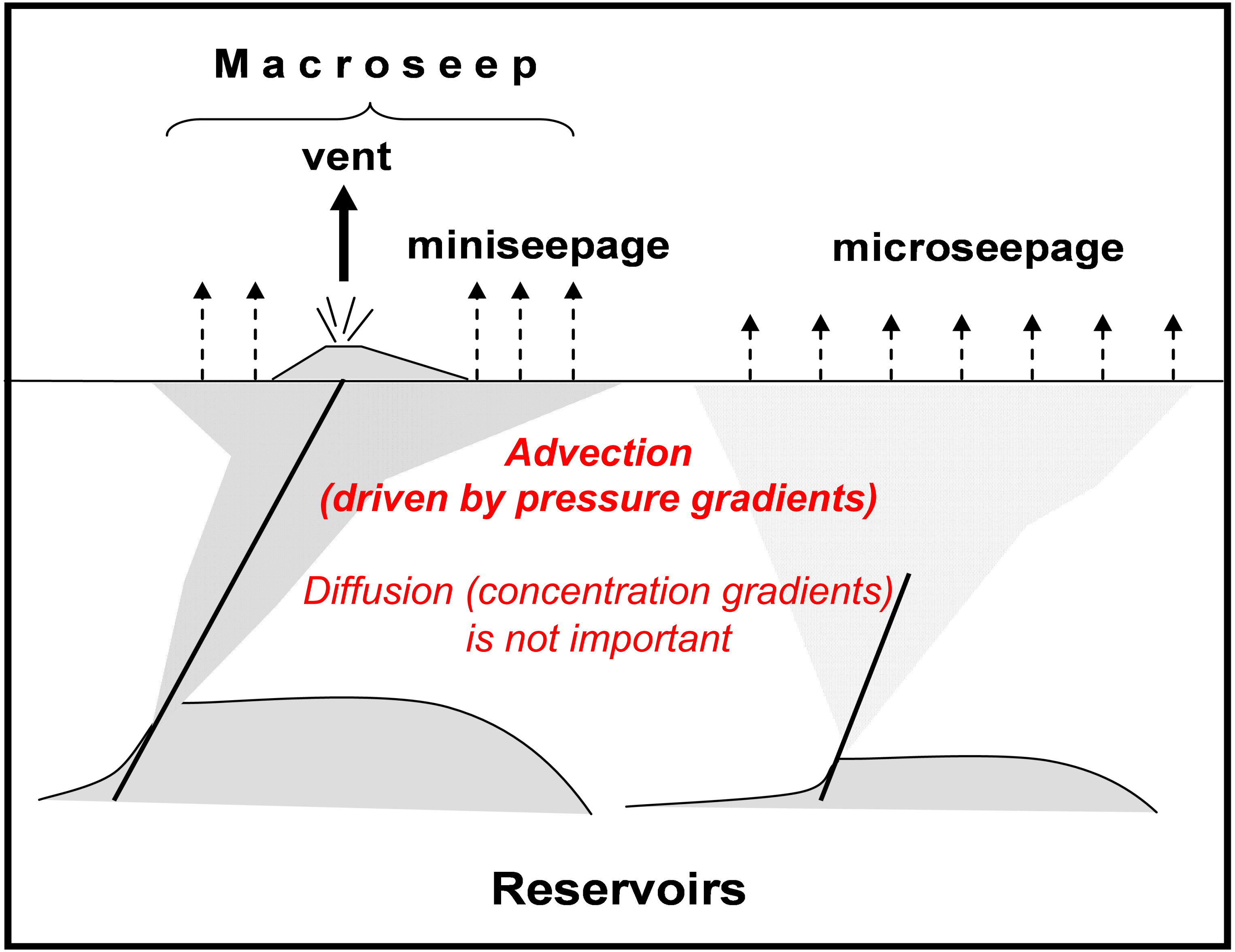
Acidalia Planitia
(*Oehler and Allen, 2010; Etiope et al. 2011*)

SEEPAGE ON EARTH

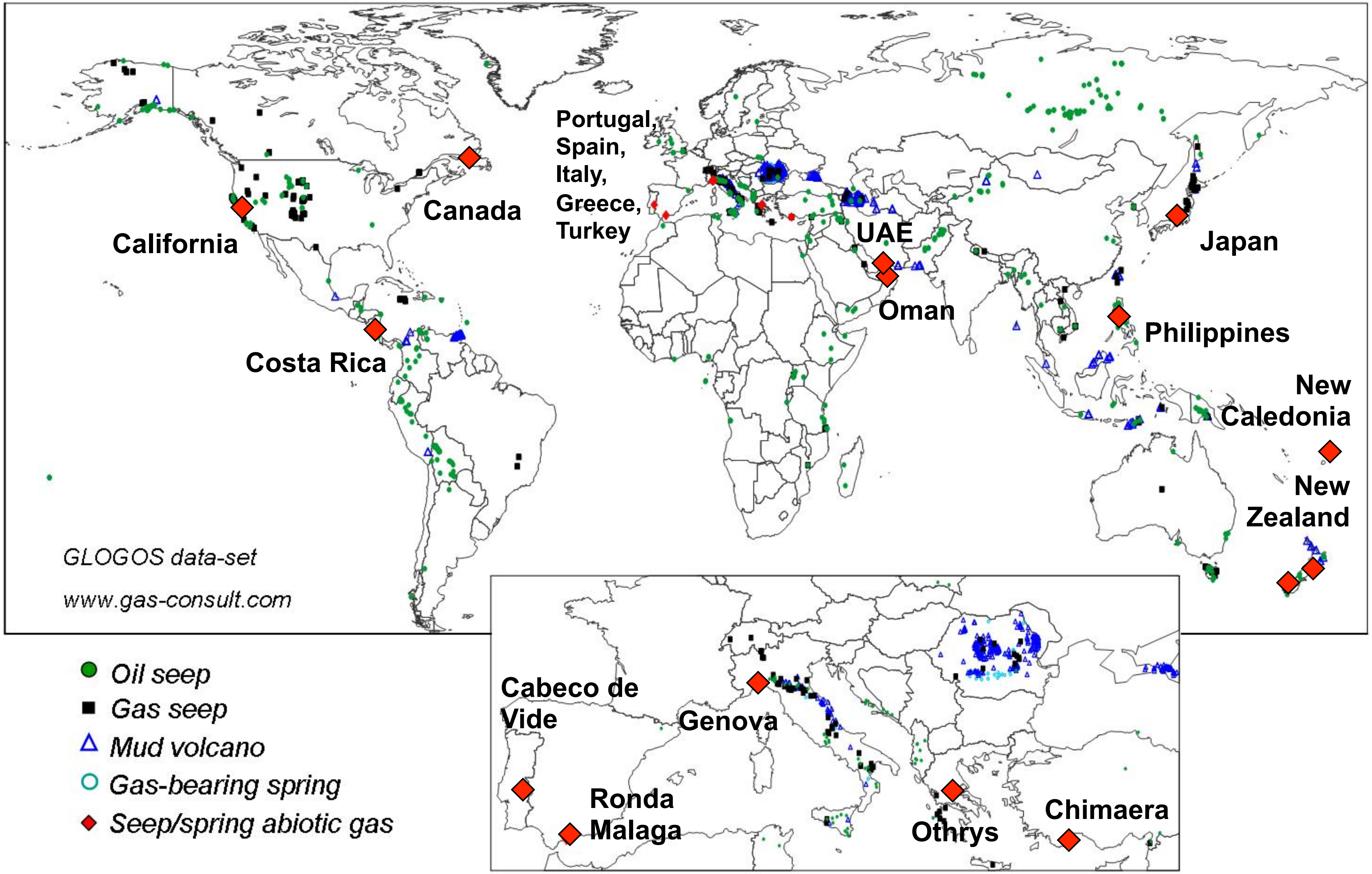
Methane origin on Earth



Gas seepage can be visible or invisible, focused or diffuse over large areas



BIOTIC and ABIOTIC METHANE SEEPS



Gas seeps and “eternal” fires

Release from 1 to 1000 ton CH_4 per year


Eternal fires and Zoroastrianism
Azerbaijan (Yanardag)

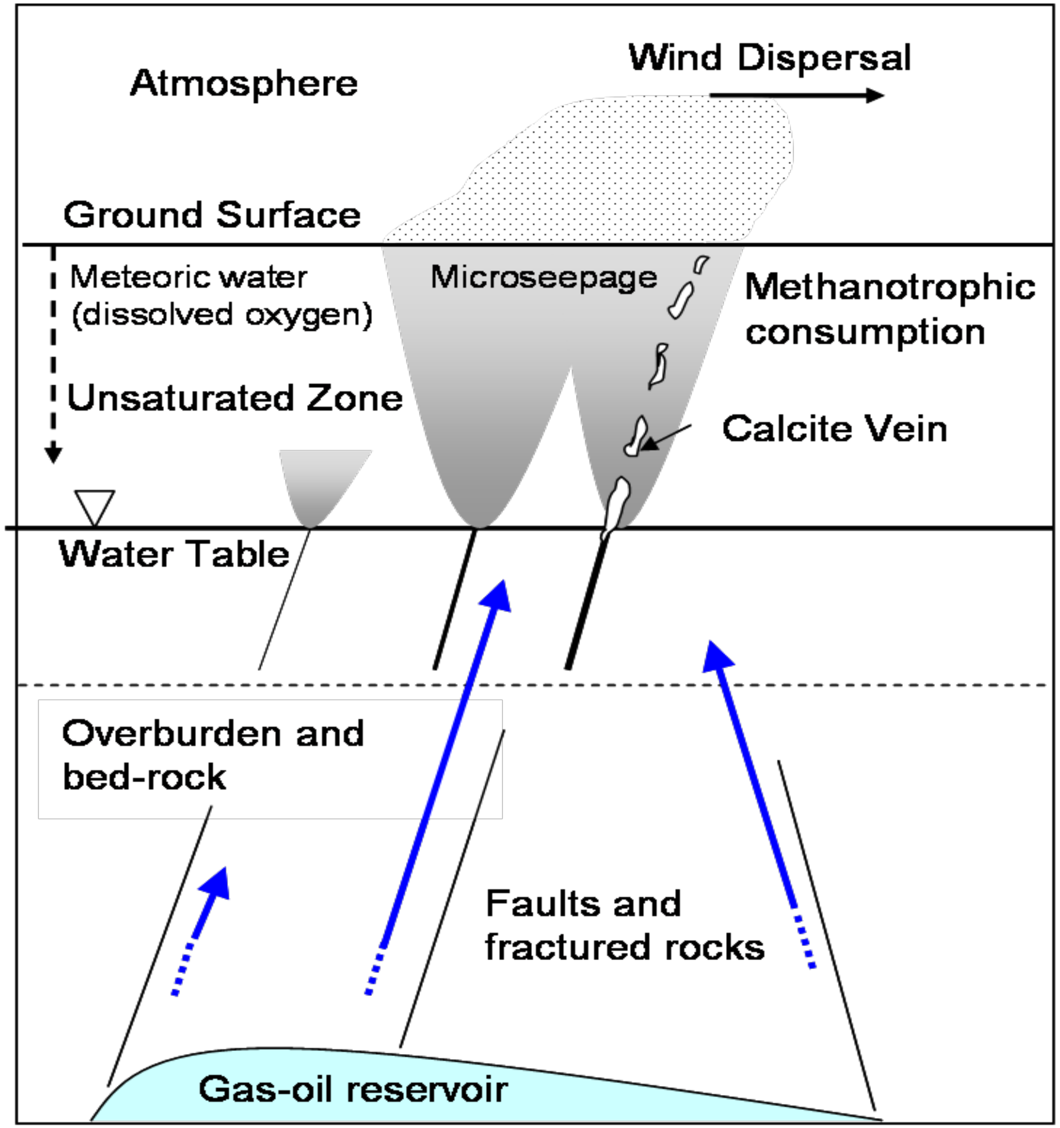
Mud volcanoes

Release from 1 to 500 ton CH_4 per year

Sedimentary volcanism, 3-phase system : gas-water-sediment

Mud volcanoes – Azerbaijan

MICROSEEPAGE



Widely used for petroleum exploration

Etiope and Klusman (2010)

Potential microseepage area

~ 4-8 million km^2

(Etiope and Klusman, 2010)

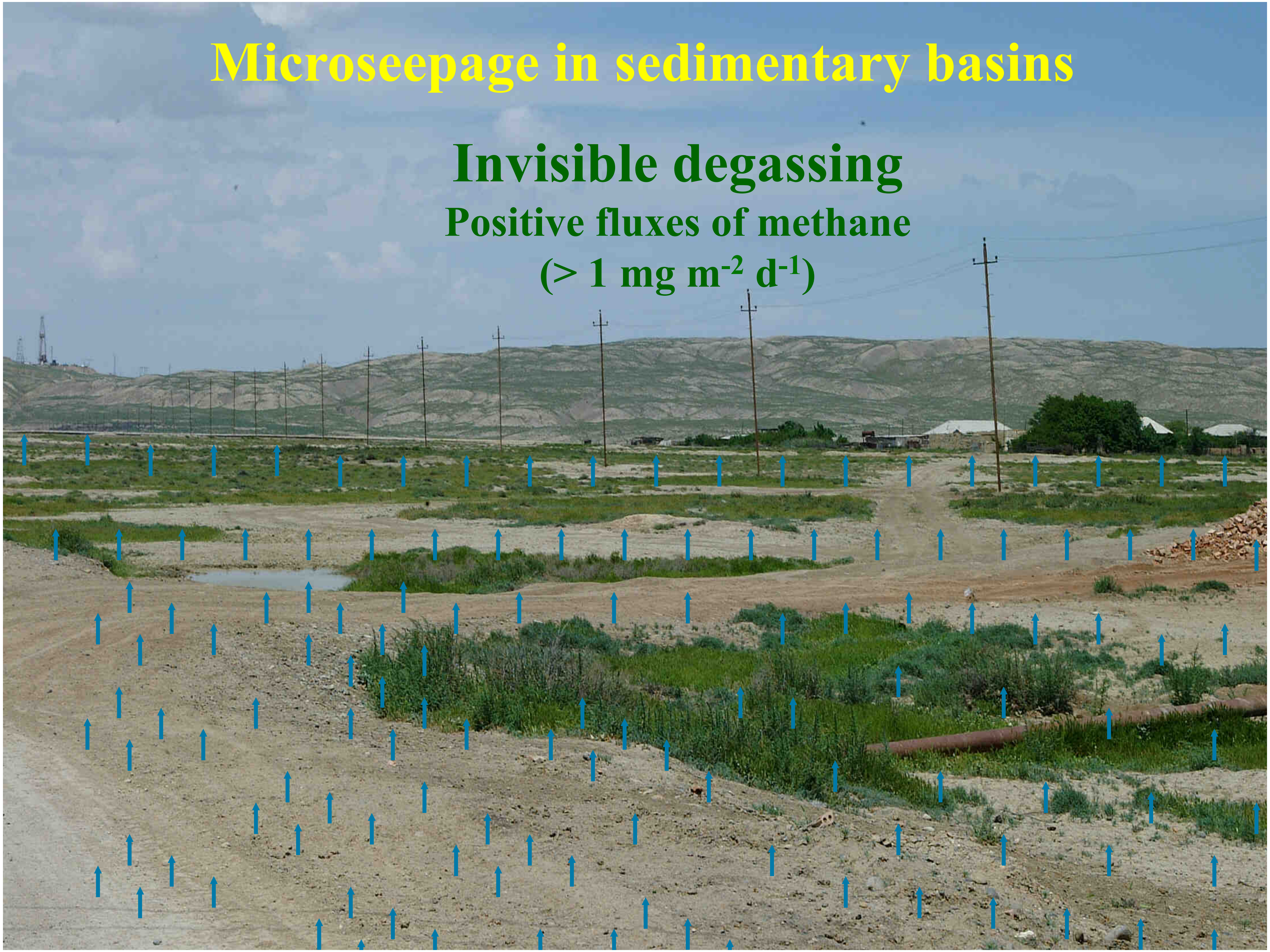
Sedimentary basins and petroleum-producing areas of the world (from *Britannica Online for Kids*. Web. 11 Mar. 2014).

Microseepage in sedimentary basins

Invisible degassing

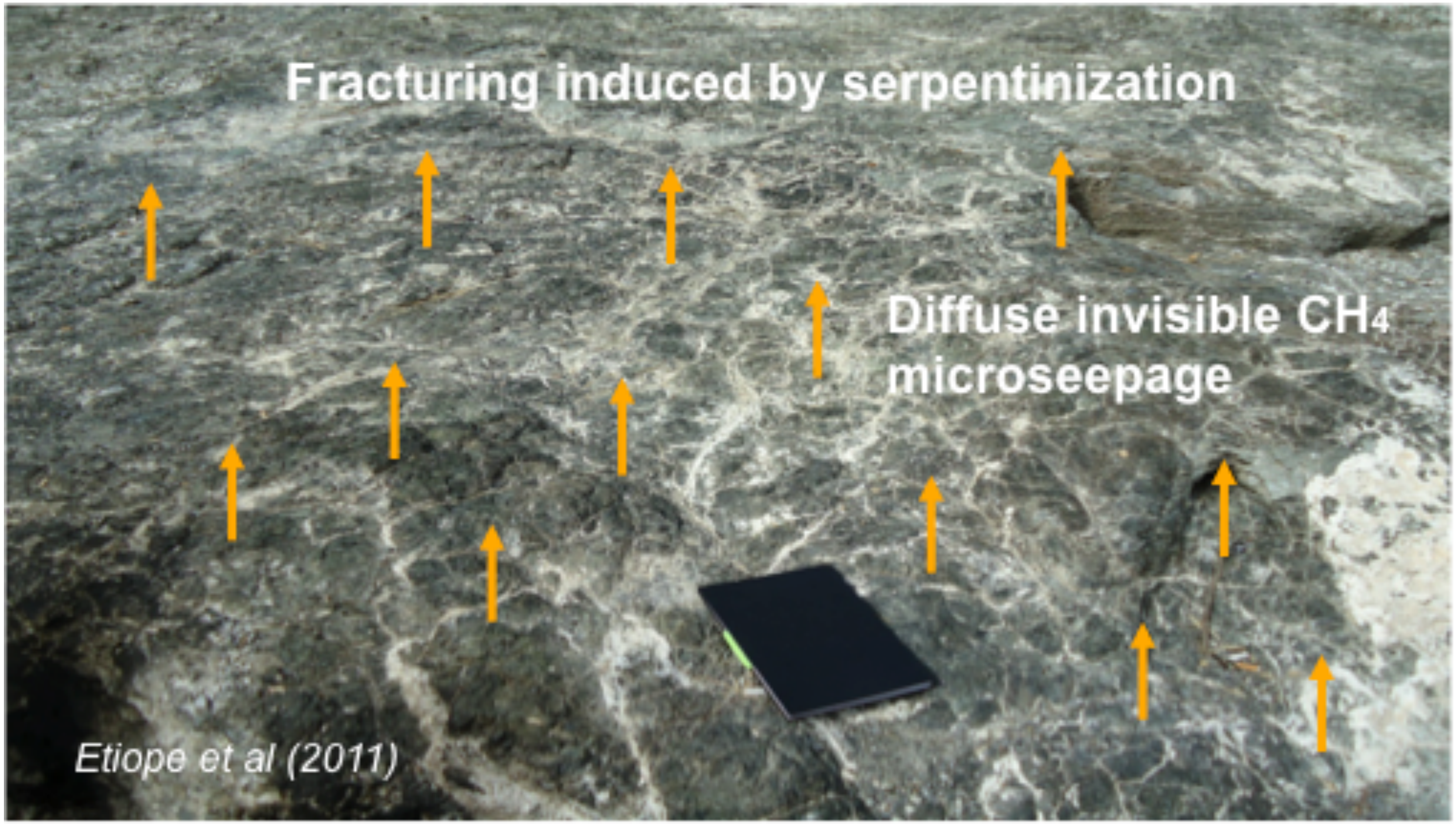
Positive fluxes of methane

(> 1 mg m^{-2} d^{-1})

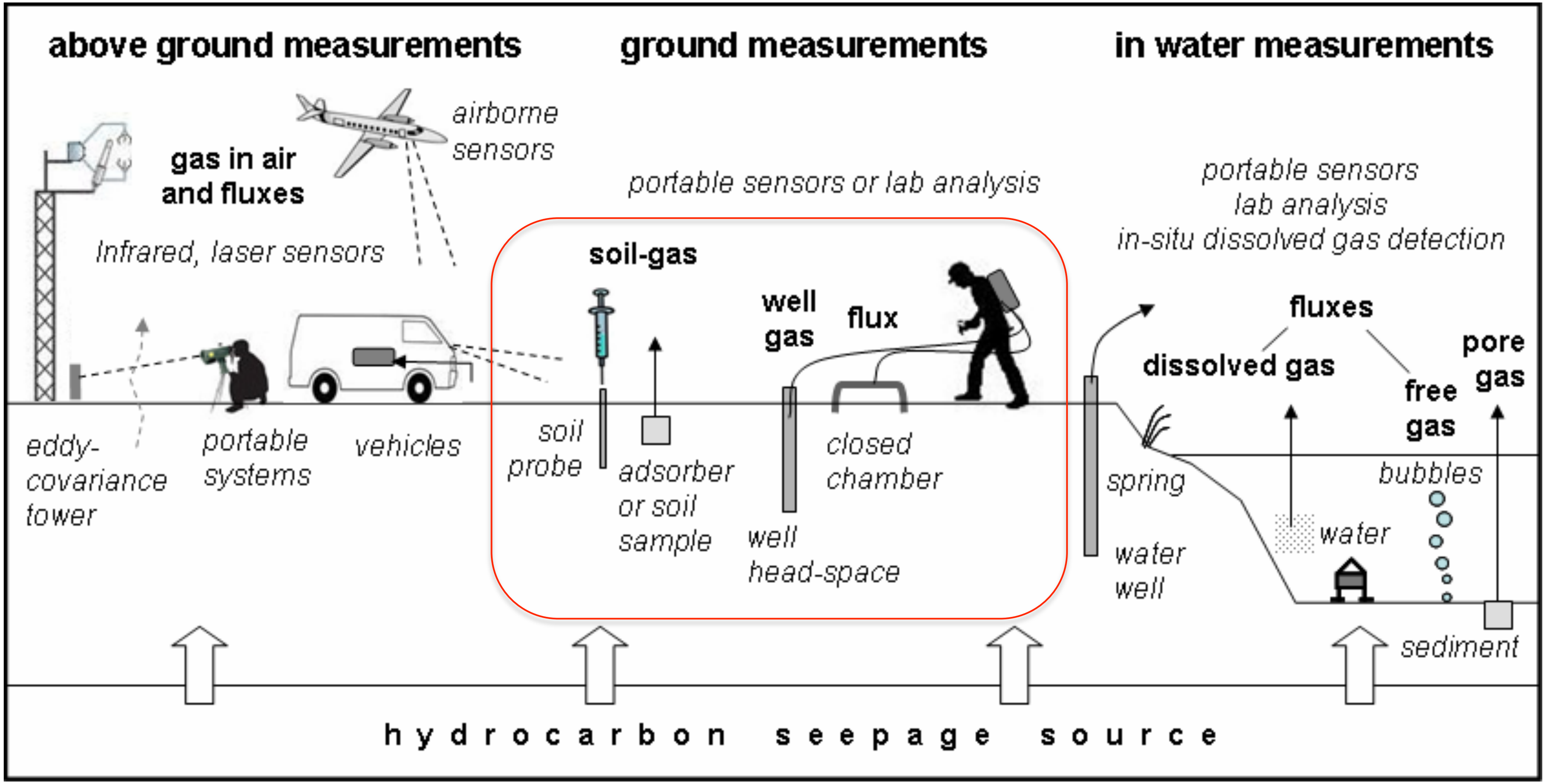


MICROSEEPAGE IN OLIVINE-RICH ROCKS (PERIDOTITES)

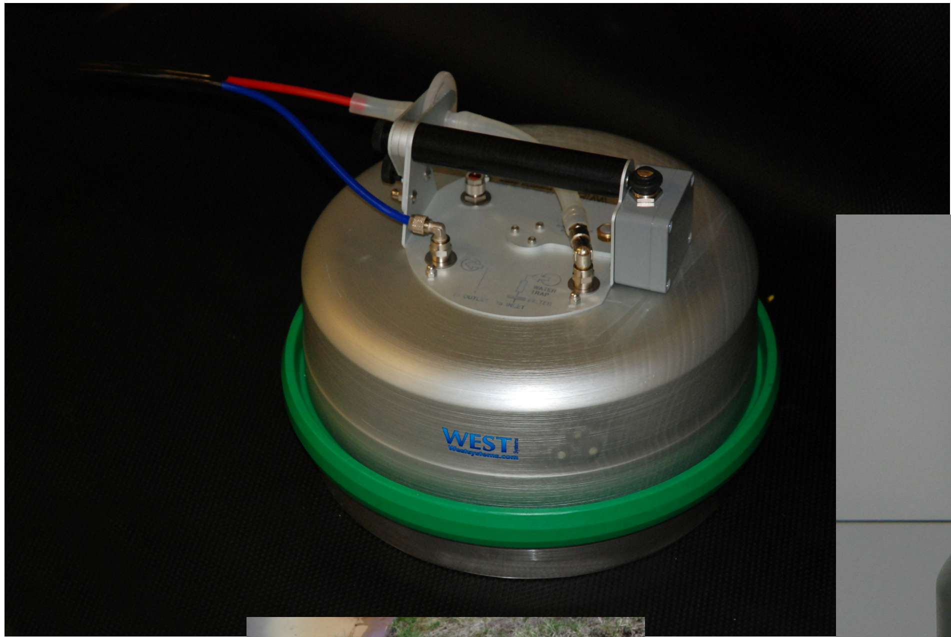
from 1 to 10^3 mg m^{-2} day^{-1}

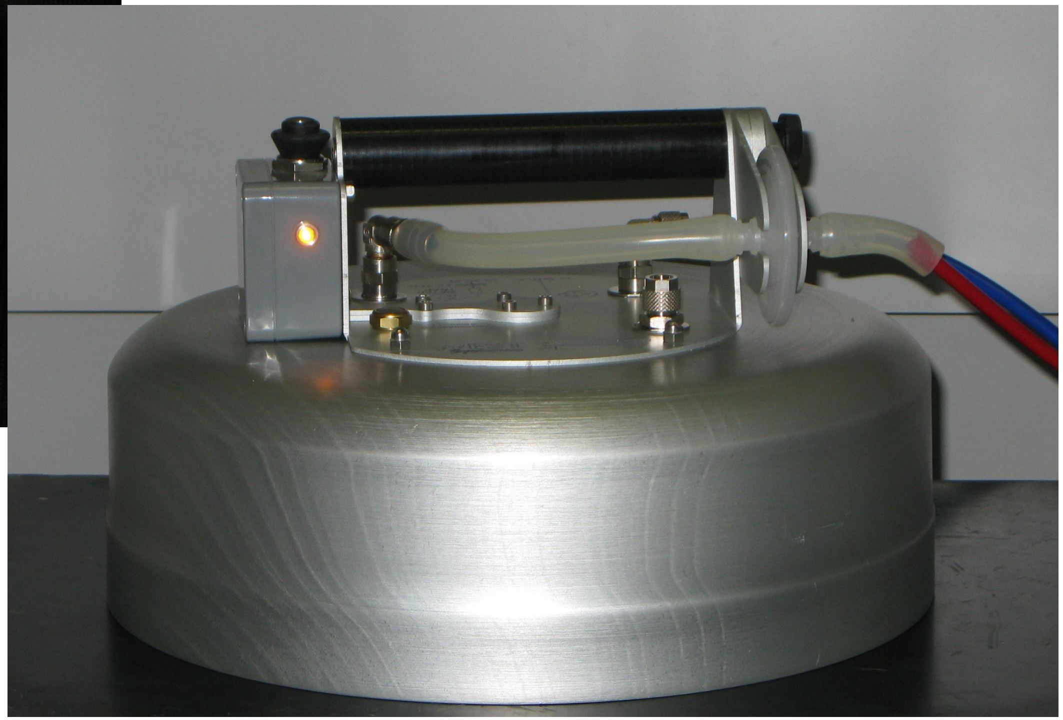


How to detect and measure gas seepage



CLOSED-CHAMBER SYSTEM
for microseepage





Widely used for soil-respiration, gas fluxes from wetlands, rice paddies and permafrost.

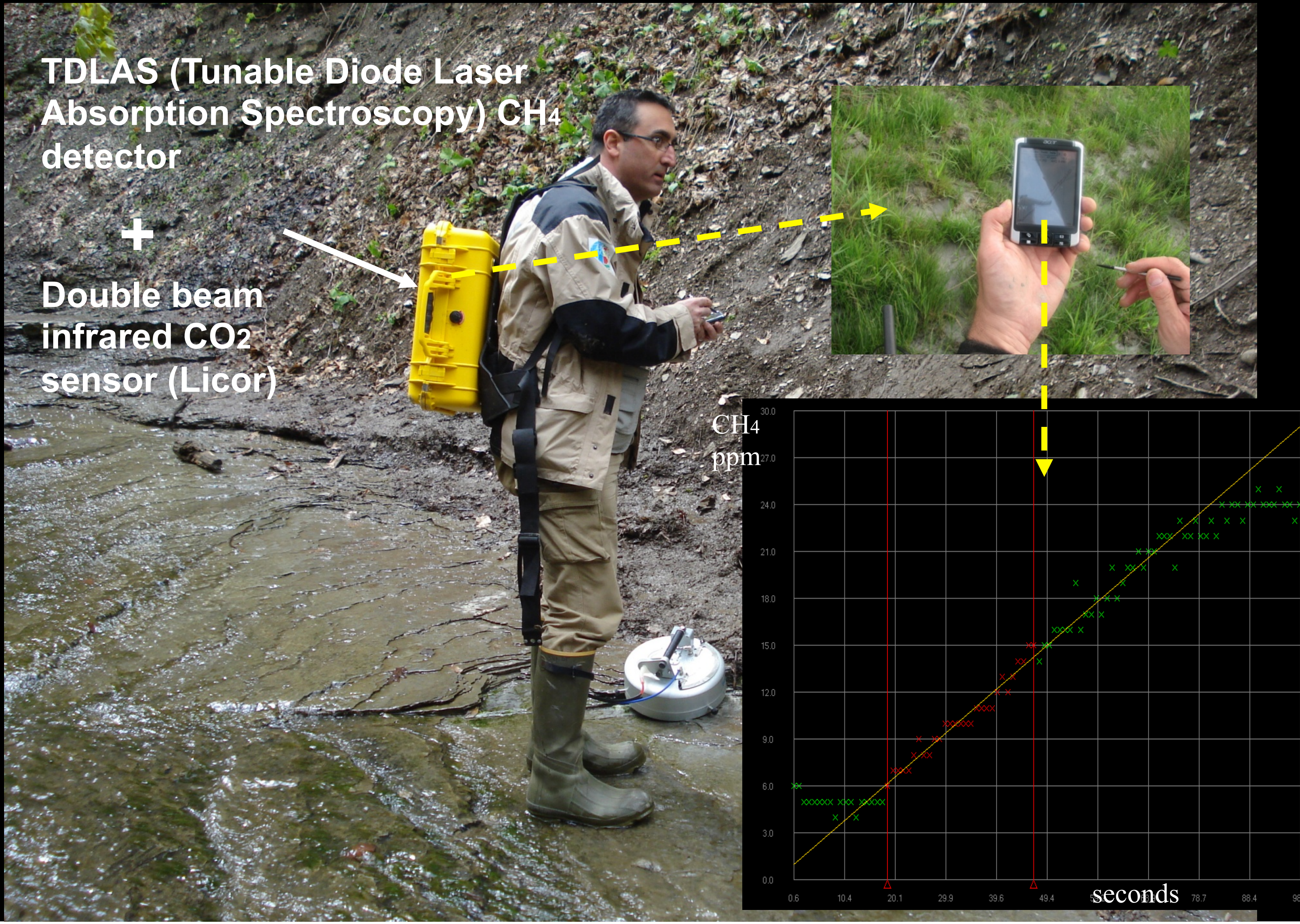
Gas flux Q is expressed in terms of mg m^{-2} day^{-1} by the eq.:

$$Q = \frac{V_{FC}}{A_{FC}} \cdot \frac{c_2 - c_1}{t_2 - t_1} \quad \left[\frac{mg}{m^2 * d}\right]$$

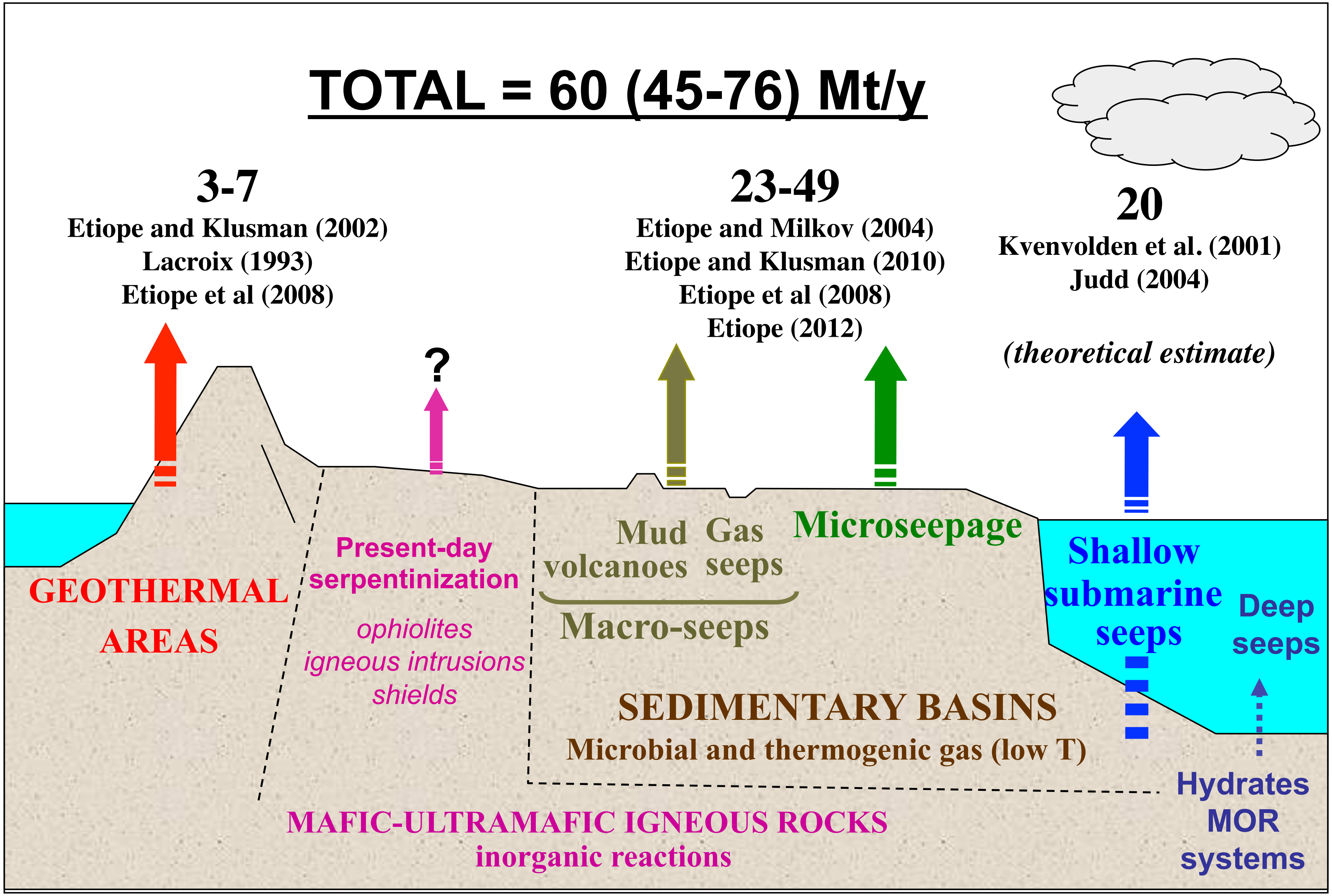
V_{FC} (m^3) chamber volume
A_{FC} (m^2) chamber area
c_1 - c_2 (mg/m^3) methane concentrations at times t_1 - t_2 (days).

Photo: Charlotte Sigsgaard

GAS DETECTION AND FLUX MEASUREMENTS WITH A NEW GENERATION OF SENSORS



GEOLOGIC METHANE EMISSIONS

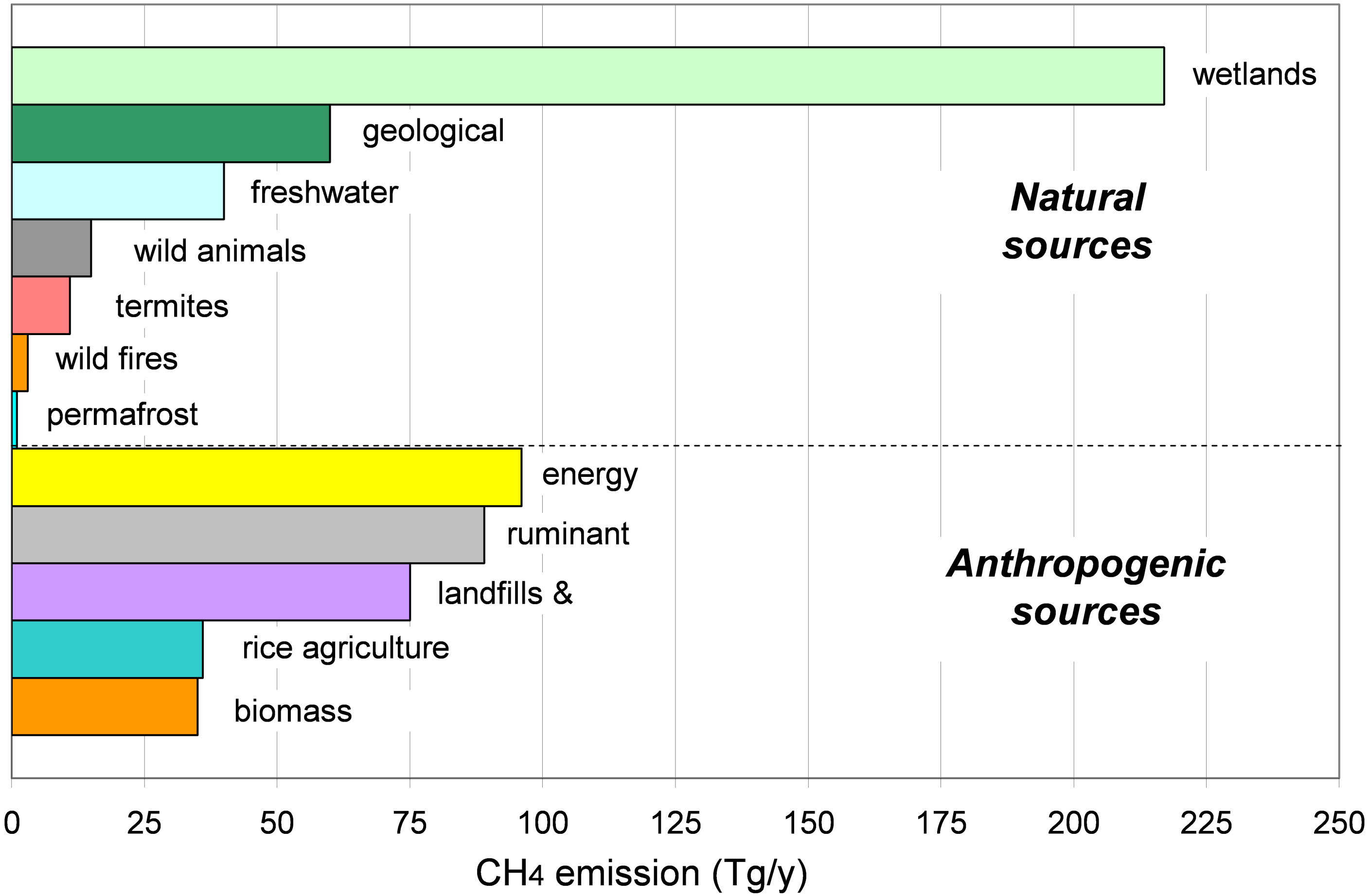


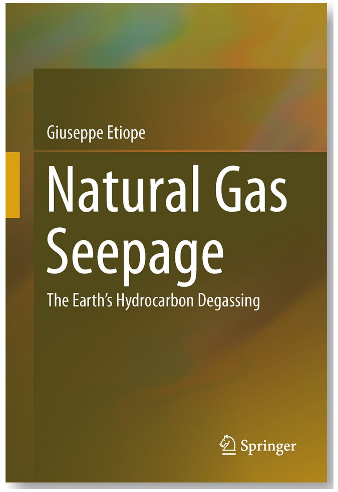
Geological CH_4

2^{nd} natural CH_4 source

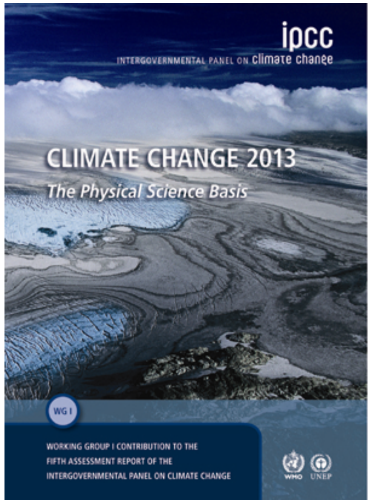
10% of total CH_4 source

Etiope and Ciccioli 2009 (Science)
Etiope, 2012 (Nature Geosci.)





(Etiope, 2015)



(IPCC, 2013)

POTENTIAL SEEPAGE ON MARS

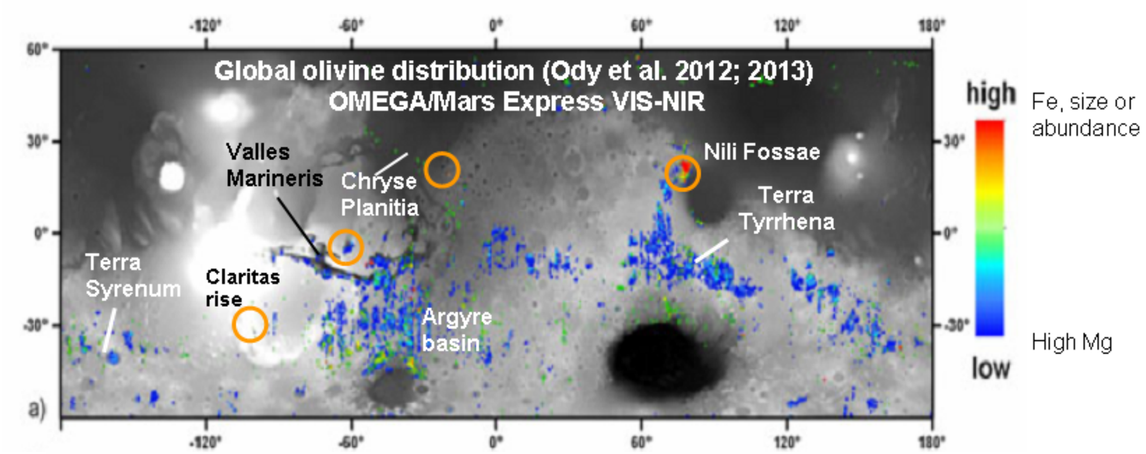
where are the best chances of finding methane?

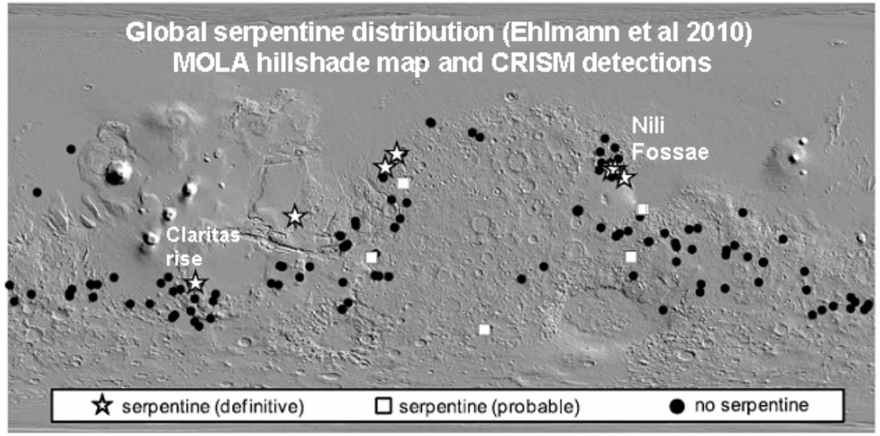
Analog seepage sites

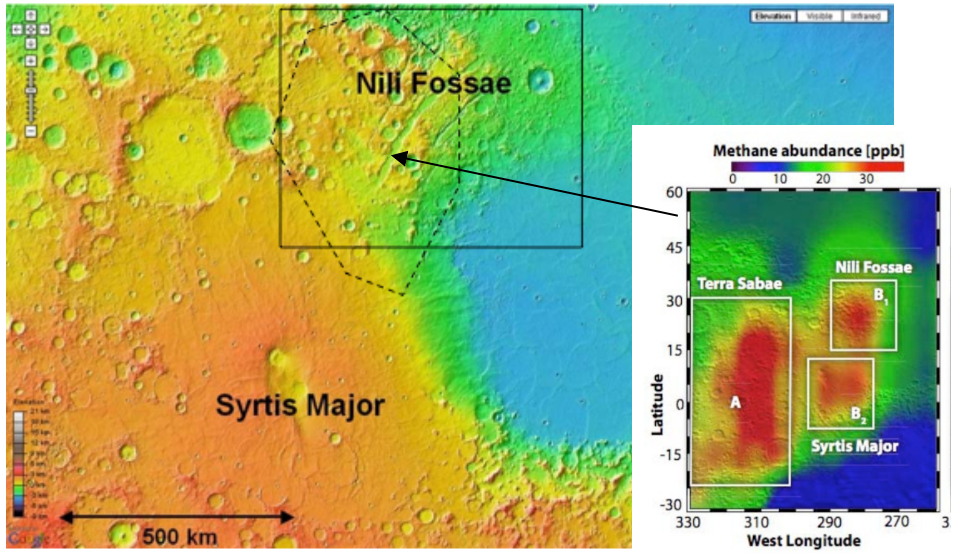
faulted/fractured ultramafic/serpentinized rocks
faulted/fractured sedimentary basins (mud volcanoes, mounds)

Olivine-rich and serpentinized areas on Mars

Serpentine occurs in Mars’ ancient Noachian terrains, Nili Fossae, Syrtis Major, Claritas Rise

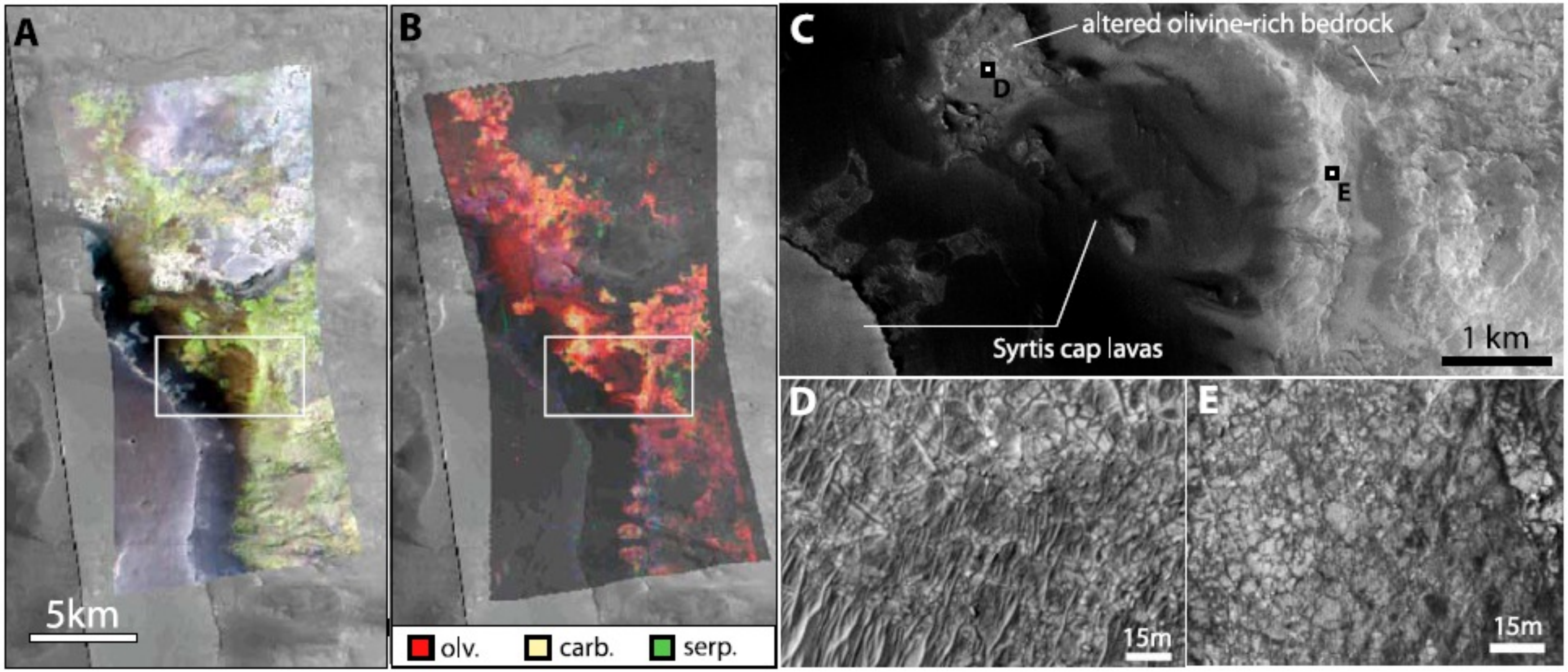






30,000 km² olivine-rich outcrop (*Hoefen et al 2003*)

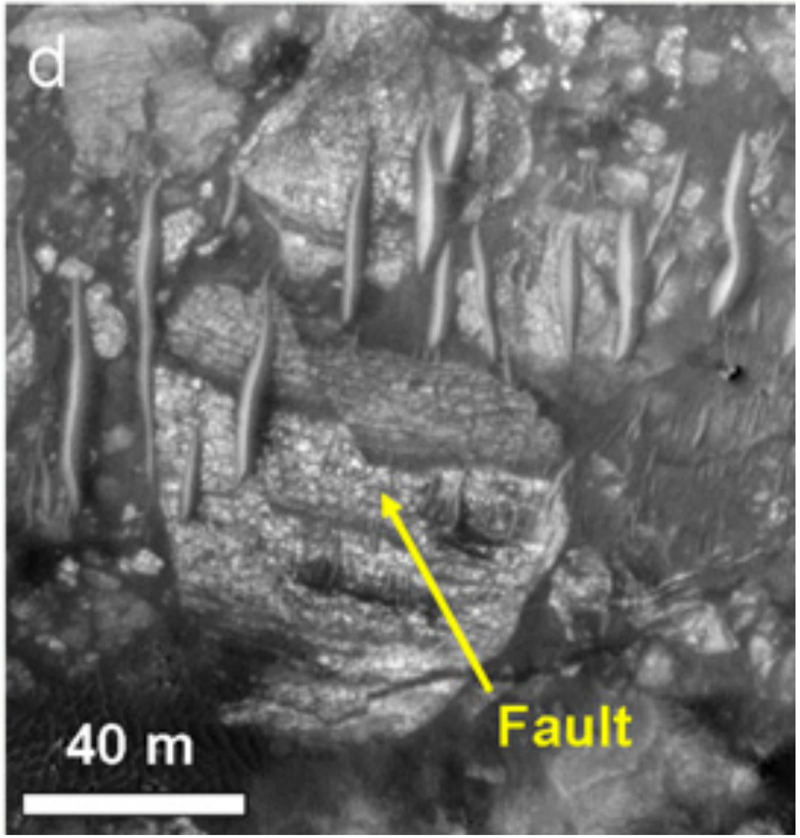
Nili Fossae



Ehlmann et al (2010)

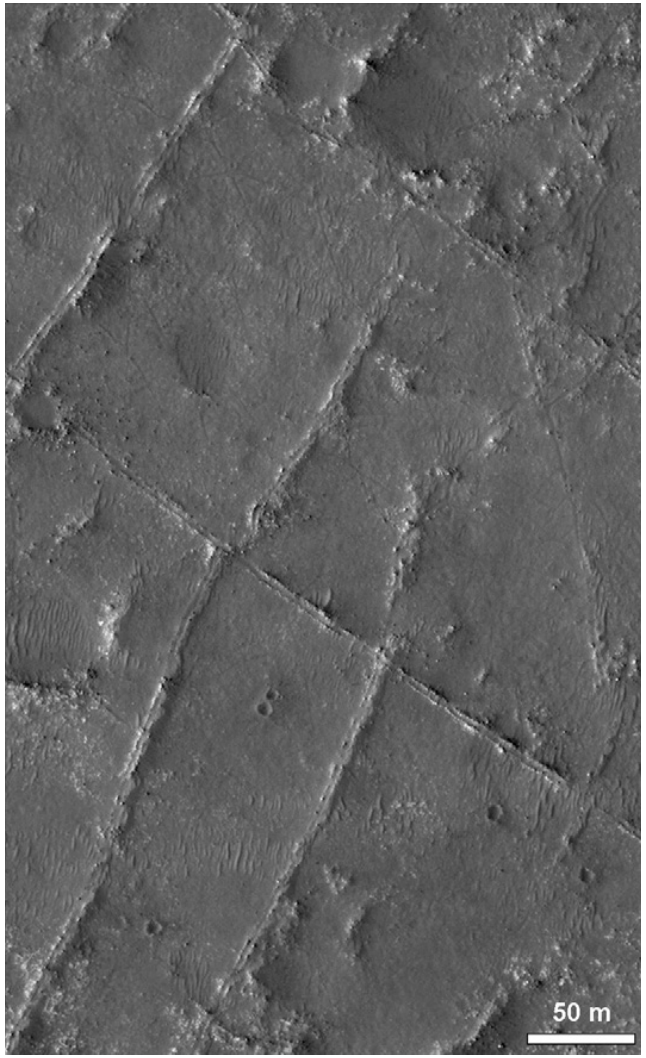
North of the Noachian-Hesperian contact (17.3°N, 77.2°E), erosion exposes a >150 km^2 olivine-rich, highly fractured outcrop, partially altered to serpentine

Nili Fossae



Fault at Nili Fossae, from PSP_006923_1995 (19.381N, 76.421E)

Wray and Ehlmann (2011)



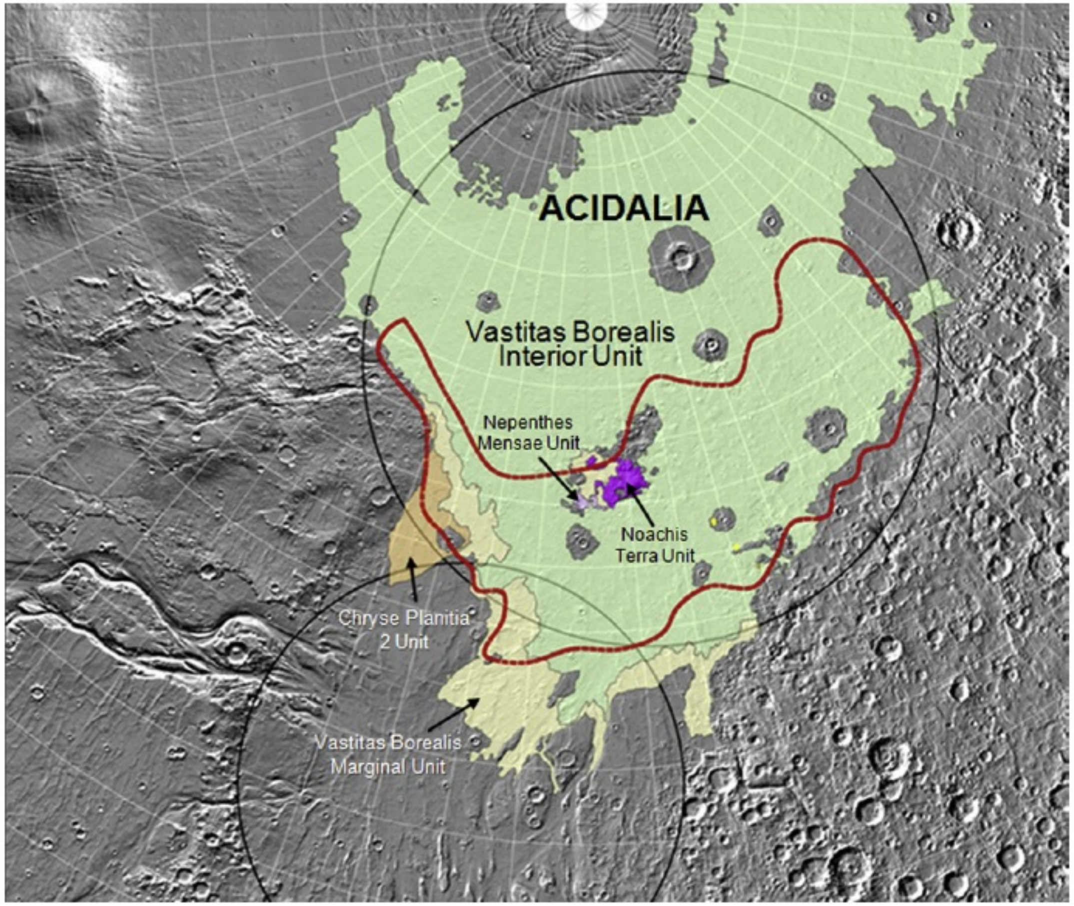
Fluid-precipitation filled fractures on the floor of Jezero crater, eastern Nili Fossae

Potential mud volcano-like seeps

Candidate mud volcanoes reported from Utopia, Isidis, northern Borealis, Scandia, Chryse–Acidalia region (*Davis and Tanaka, 1995; Tanaka, 1997, 2005; Tanaka et al., 2000, 2003, 2008; Farrand et al., 2005; Kite et al., 2007; Rodríguez et al., 2007; Skinner and Tanaka, 2007; Allen et al., 2009; Oehler and Allen, 2009; Skinner and Mazzini, 2009; McGowan, 2009; McGowan and McGill, 2010*)

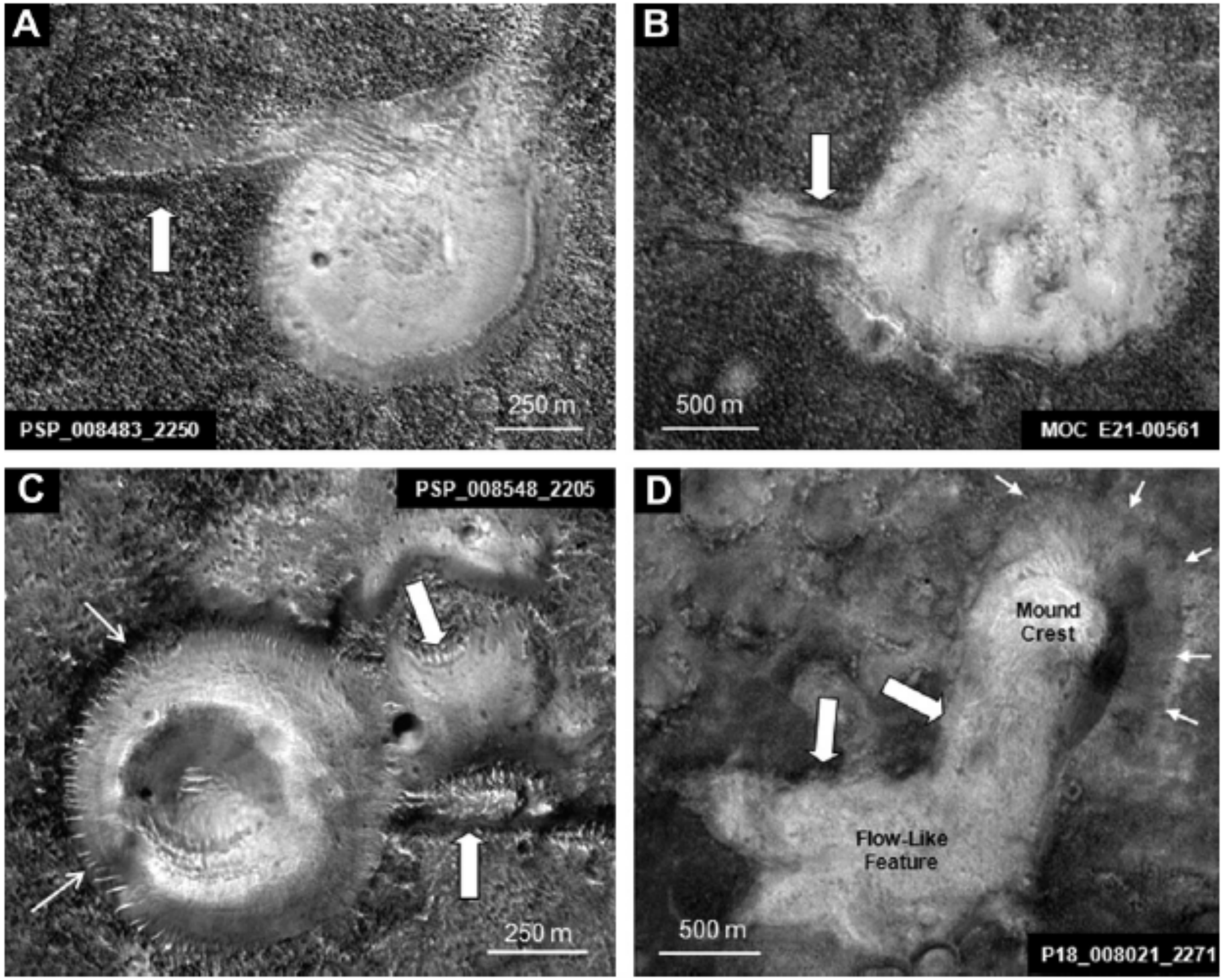
>40000 estimated

(18000 mapped)
in Acidalia Planitia
(*Oehler and Allen, 2010*

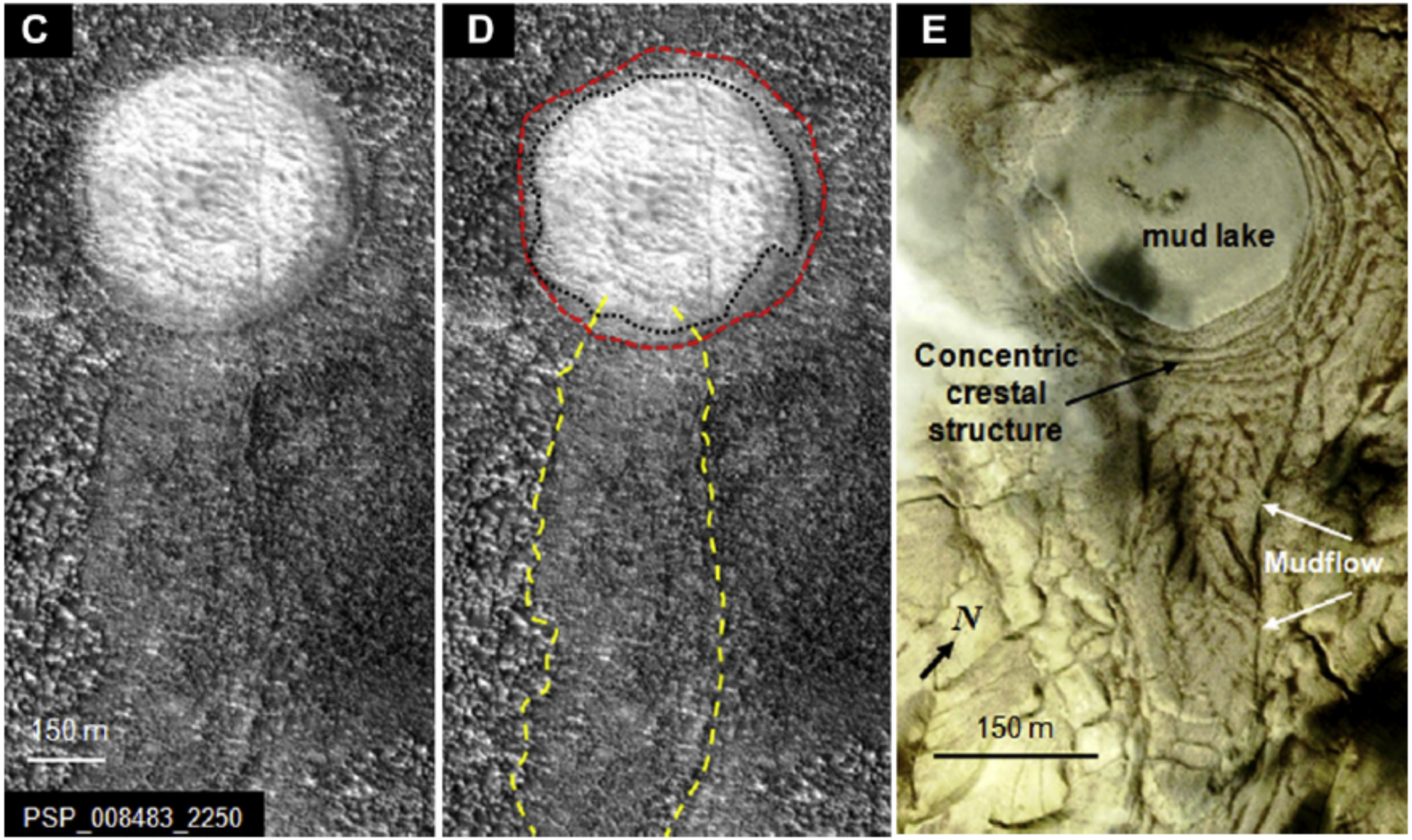


Potential mud volcano-like seeps Acidalia Planitia

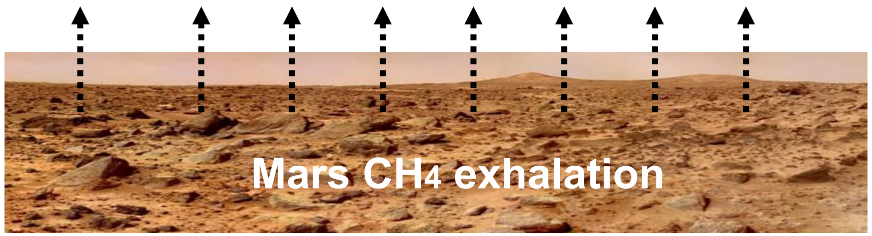
(*Oehler and Allen, 2010; Etiope, Oehler, Allen 2011*)



Potential mud volcano-like seeps Acidalia Planitia (*Oehler and Allen, 2010; Etiope et al. 2011*)



A FEW MARTIAN SEEPS or WEAK MICROSEEPAGE CAN SUSTAIN THE ATMOSPHERIC CH_4 LEVEL (and the Mumma's plume)



the CH_4 plume on Mars reflects an episodic emission of ~19,000 t CH4 yr−1 (Mischna et al., 2011) or ~150,000 t CH4 yr−1 (Lefevre and Forget, 2009)

equivalent to a diffuse microseepage of ~10-100 mg $m^{-2}d^{-1}$ from an area of 500 to 5000 km^2

If the whole 30000 km^2 olivine outcrop at the Nili Fossae (Hoefen et al., 2003) is assumed to exhale, a microseepage of 2 mg $m^{-2}d^{-1}$ (the lowest level detected in terrestrial peridotites) would be sufficient to support the plume

If a global Martian CH_4 source of around 100-300 t yr^{-1} is required to maintain the 10 ppb atmospheric level (Atreya et al, 2007), one large mud volcano or a few small mud volcanoes, or just a very weak microseepage, sparse in different zones of Mars, would be sufficient.

Etiope, Oehler, Allen (2011)
Etiope, Ehlmann, Schoell (2013)

A NOTE ON ABIOTIC METHANE PRODUCED AT LOW TEMPERATURES

Low T abiotic methane

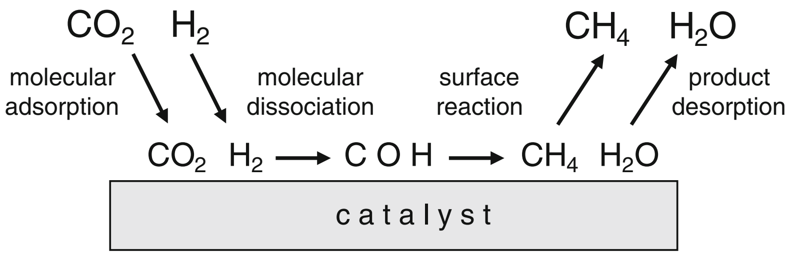
SABATIER REACTION

$CO_2 + 4H_2 = CH_4 + 2H_2O$

The simplest way to form abiotic methane

A fundamental reaction for life origin *(H_2-CH_4 = energy sources for microbes)*, the transition from inorganic to organic chemistry (Russell et al. 2010)

So far considered to take place at T>200°C



Geofluids (2014)

Low-temperature catalytic CO_2 hydrogenation with geological quantities of ruthenium: a possible abiotic CH_4 source in chromitite-rich serpentinized rocks

G. ETIOPE[1,2] AND A. IONESCU[2]

Abiotic CH_4 can be rapidly produced at low T (<100°C)

Fast production of considerable amounts of CH_4 via Sabatier reaction at 90, 50 and 25°C, using small concentrations of ruthenium (Ru) equivalent to natural amounts in chromitites

inorganic to organic transition at T<100°C

no need to invoke hydrothermal systems for life origin

Ruthenium exists on Mars….

…so CH_4 may originate at T<100°C

Ruthenium (PGE, Platinum Group Elements) and other siderophile elements, associated to chromium minerals, can be particularly enriched in martian mantle rocks (*Jones et al., 2003*).

About 16 ppb of Ru were detected in the Chassigny meteorite (*Jones et al., 2003*), belonging to the SNC (Shergotty, Nakhla, Chassigny) meteorites, which are derived from martian mantle.

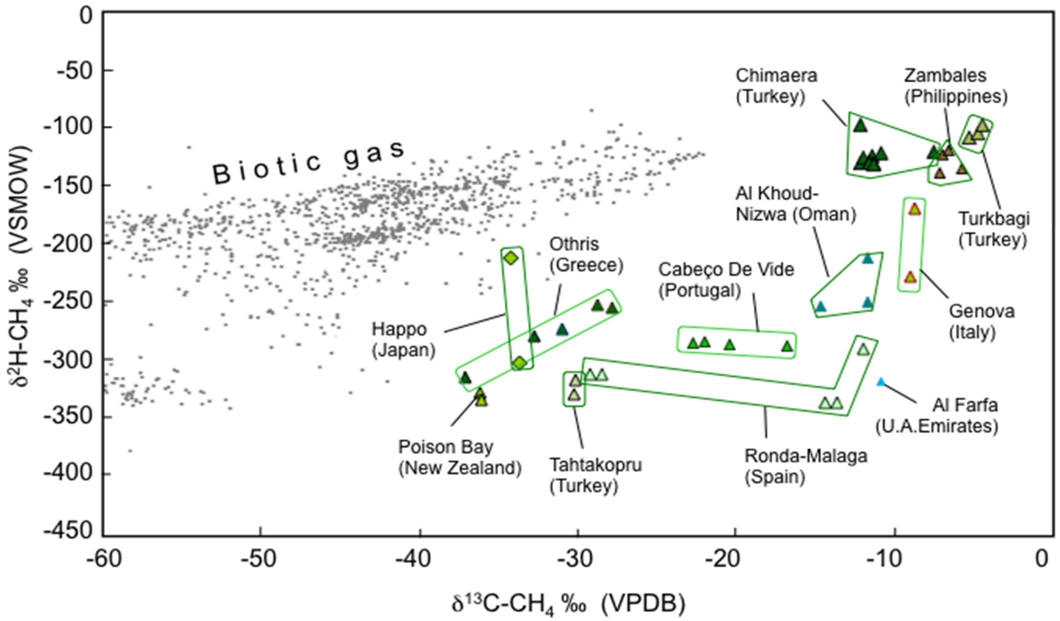
Such a concentration is within the typical range observed in terrestrial chromitites, including those in methane-bearing ultramafic rocks

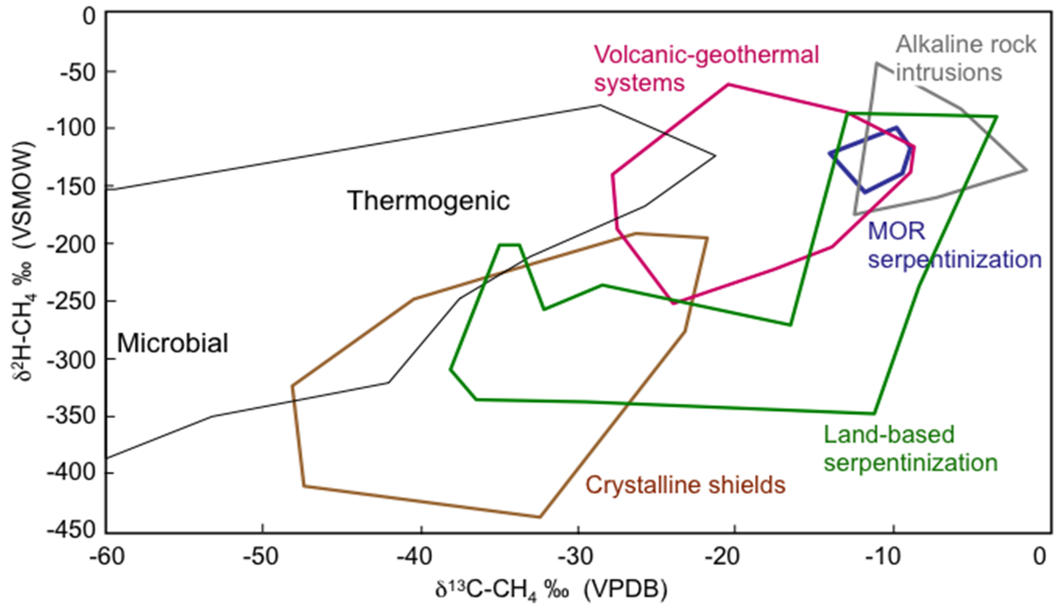
no need of hydrothermal or magmatic systems to generate abiotic CH_4 on Mars

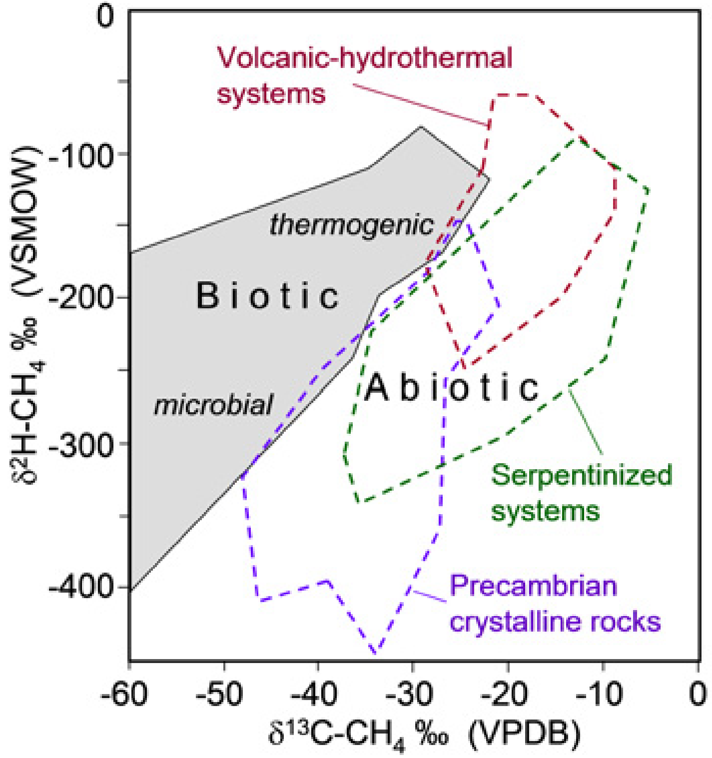
CH_4 ISOTOPIC COMPOSITION ON EARTH

Abiotic vs biotic methane

well distinguished by C and H isotopic ratios







Etiope and Schoell (2014)
Etiope (2015)

CH_4 ISOTOPIC COMPOSITION ON MARS?

Potential C–H isotopic signatures of abiotic CH4 on Mars

Martian C feedstock: - atmospheric fractionated CO_2 ($\delta^{13}C$: +46 ‰; *Webster et al 2013*)
- atmospheric unfractionated CO_2 ($\delta^{13}C$ -20‰ to 0‰; *Niles et al., 2010*)
- magmatic CO_2 (Zagami meteorites, $\delta^{13}C$: -10 to -20‰)

$\delta^{13}C$-CH_4 can be similar to that observed on Earth only if it derives from unfractionated CO_2

Martian H feedstock: - atmospheric H_2
- H in minerals (meteorites)

} extrem. enriched in deuterium δ^2H up to +4000‰ *Leshin, 2000; Sugiura and Hoshino, 2000* due to atmospheric escape fractionation processes

- subsurface waters ???
- magma : low δ^2H; initial δ^2H similar to Earth; *Boctor et al., 2003; Lunine et al., 2003*
- igneous rocks: olivine, δ^2H: -60 to -280 ‰ *Gillet et al. 2002*

A wide range of δ^2H could be measured for martian CH_4, far outside terrestrial variations

Martian δ^2H–CH_4 values could be within the terrestrial range if the precursor hydrogen derives from primordial, unfractionated, magmatic gas or is similar to that of martian olivine.

Main messages

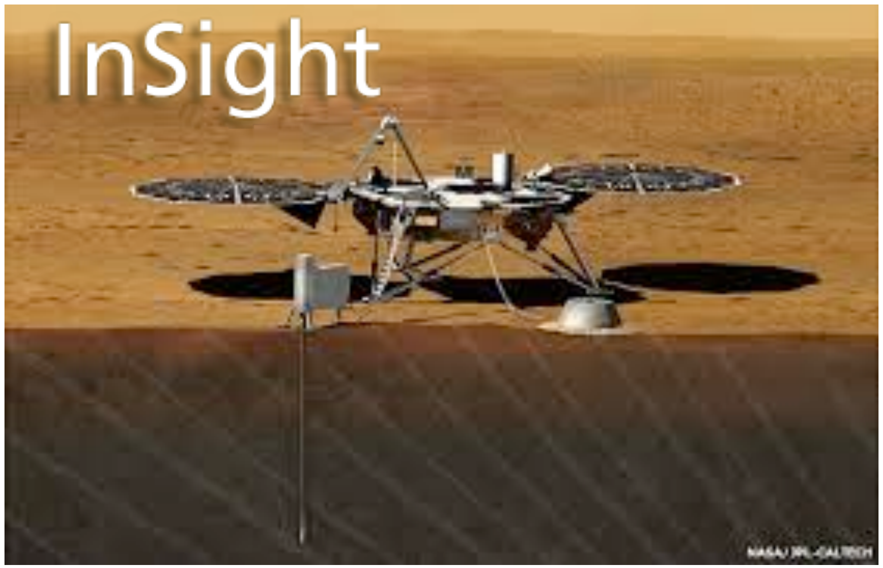
Observations of terrestrial gas seepage, in sedimentary basins and serpentinized rocks, can be used to infer forms and magnitude of potential seepage on Mars

Low microseepage, sparse in different zones of Mars, would be sufficient to sustain methane observed in the atmosphere

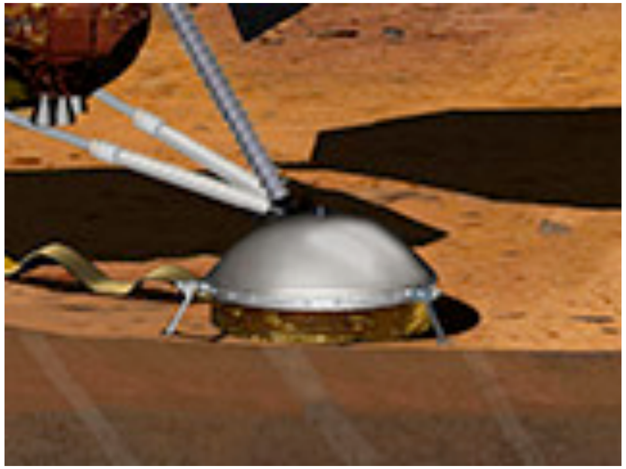
BUT, as on Earth, CH_4 microseeping on Mars cannot be detected a few cm above the soil, because of winds and dilution of the leaking gas

Abiotic methane can be generated at very low T by Sabatier reaction ANYWHERE H_2, CO_2 and platinum group elements (Ru) are available

Geologic CH_4 on Mars should be searched in the regions with olivine-bearing rocks, preferably above or near faults or at apparent mud volcanoes, ideally by drilling into the soil, or using accumulation chambers on the ground

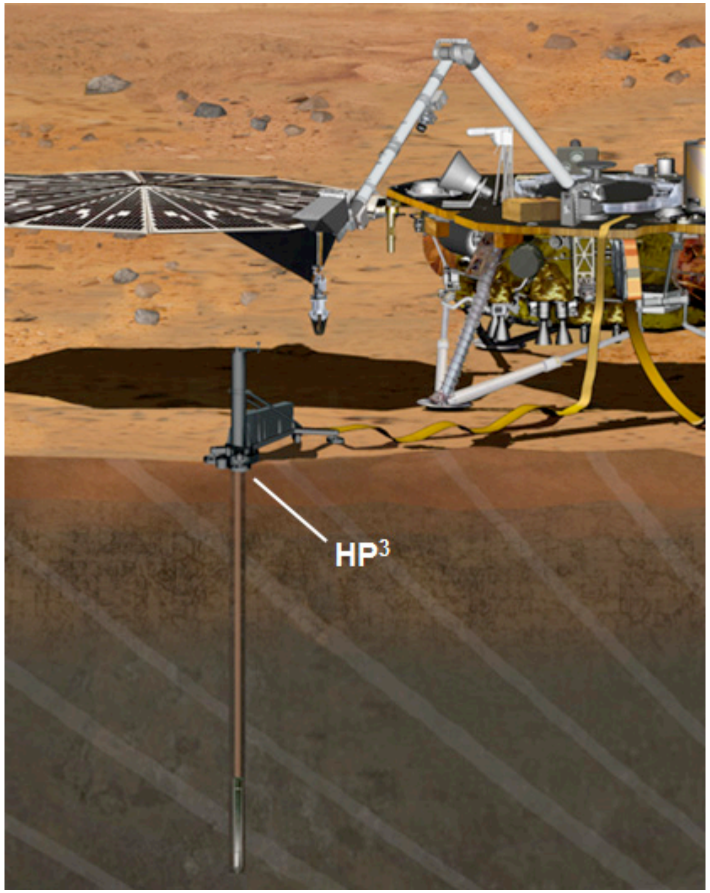


INSIGHT landing site:
Elysium Planitia



SEIS seismometer

A similar arm could be used for positioning a closed-chamber



HP3 (Heat Flow and Physical Properties Probe)

CONNECTING A GAS SENSOR TO THESE PROBES WOULD BE A GREAT OPPORTUNITY TO RELIABLY DETECT METHANE SEEPAGE