Anaerobic Oxidation of Methane

23 Aug ISME16 Montreal
13.30h Room 512

MIKE JETTEN

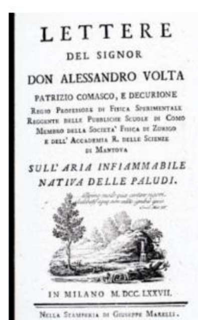
SOEHNGEN INSTITUTE OF ANAEROBIC MICROBIOLOGY

ERC AG 339880 EcoMoM 2014-2018
ERC PoC 713533 Initiator 2016-2017
STW 13184 CH_4 & N removal
Gravitation Grants NESSC & SIAM

Radboud University

www.anaerobic-microbiolog y.eu

1777 Discovery of methane



LETTERE
DEL SIGNOR
DON ALESSANDRO VOLTA
PATRIZIO COMASCO, E DECURIONE
Regio Professore di Fisica Sperimentale
Reggente delle Pubbliche Scuole di Como
Membro della Società Fisica di Zurigo
e dell' Accademia R. delle Scienze
di Mantova
SULL' ARIA INFIAMMABILE
NATIVA DELLE PALUDI.

IN MILANO M.DCC.LXXVII.
Nella Stamperia di Giuseppe Marelli.
Con licenza de' Superiori.

Source: methane-producing archaea

"fat rod" *Methanothrix soehngenii* first observed by Nicolas Soehngen in 1906

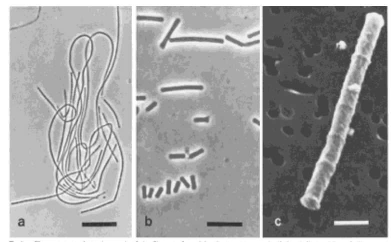


Fig. 1. **a** Phase contrast photomicrograph of the filaments formed by the "acetate organism", bar indicates 4.7 µm. **b** Phase contrast photomicrograph of single cells and short chains, bar indicates 1.9 µm. **c** Scanning photomicrograph of filament fragment, bar indicates 1.2 µm. Micrograph taken by Mrs. D. Metzger, Zürich

$$CH_3COOH \longrightarrow CH_4 + CO_2$$
$$CH_3OH + H_2 \longrightarrow CH_4 + H_2O$$
$$4H_2 + CO_2 \longrightarrow CH_4 + 2H_2O$$

Methane Sinks:

HET ONTSTAAN EN VERDWIJNEN
van
WATERSTOF EN METHAAN
onder den invloed van het
ORGANISCHE LEVEN.
door
NICOLAAS LOUIS SÖHNGEN,
geboren te Oirschot.

DELFT — J. VIS Jr.
1906.

Aerobic oxidation of methane (1906)

$$CH_4 + 2\,O_2 \longrightarrow CO_2 + 2\,H_2O$$

Sulfate dependent AOM (2000)

$$CH_4 + SO_4^{2-} \rightarrow HCO_3^- + HS^-$$

Quest for nitrite/nitrate/iron AOM

Nitrite dependent anaerobic oxidation of methane

$$3CH_4 + 8NO_2^- + 8H^+ \longrightarrow 3CO_2 + 4N_2 + 10H_2O$$

Nitrate dependent anaerobic oxidation of methane

$$5CH_4 + 8NO_3^- + 8H^+ \longrightarrow 5CO_2 + 4N_2 + 14H_2O$$

Iron dependent anaerobic oxidation of methane

$$CH_4 + 8Fe(OH)_3 + 7CO_2 \rightarrow 8\,FeCO_3 + 14H_2O$$

European Research Council erc

(Inter)national Collaboration & Funding

Soehngen Institute of Anaerobic Microbiology
www.anaerobic-microbiology.eu

Talent Grants in & out bound **up to 3 months**
Visiting scientist program **3-6 months at a SIAM host**

Post doc position 2 + 3 y

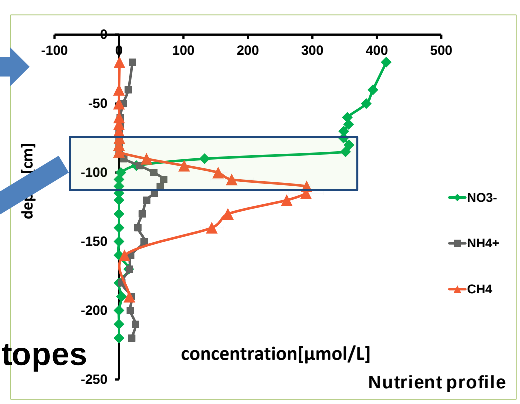
Excellently educated & enthusiastic team members

Lab day out 23 june 2016 including AOM crew:
Arshad, Gambelli, Ghasghavi, Guerrero Cruz, de Jong, Kox, Lueke, Maalcke-Luesken, van Niftrik, Op den Camp, Rasigraf, Slegers, Stultiens, Versantvoort & Welte

Where do we find nitrate/nitrite/iron-AOM?

HIGH NO_3^- due to agricultural run-off /ground water
HIGH reactive iron in sediment
HIGH CH_4 production in sediment

Depth Profile of Nitrate & Methane



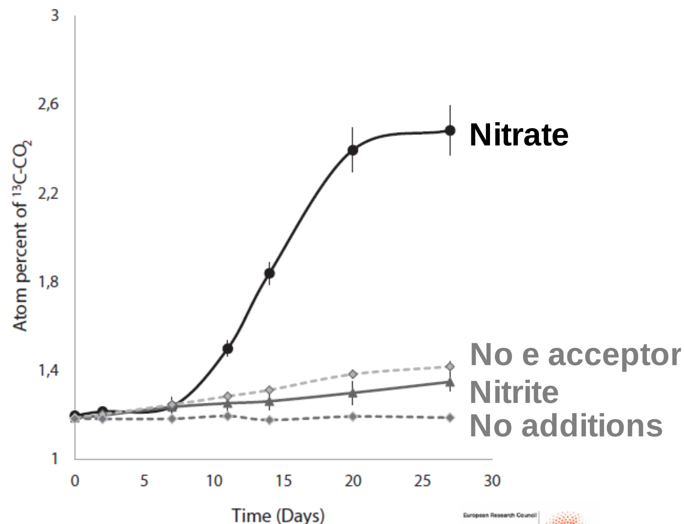
Activity tests
^{13}C & ^{15}N Stable isotopes
qPCR & FISH
Enrichment
Metagenome

$^{13}CH_4$ activity test Paddy field soil Italy

Annika Vaksmaa

Anaerobic Soil Slurry
$^{13}CH_4$ (10%)
Nitrate/Nitrite/controls
GC-IR-MS $^{13}CO_2$

qPCR
AOM archaea 10^7/g
AOM bacteria 10^4/g

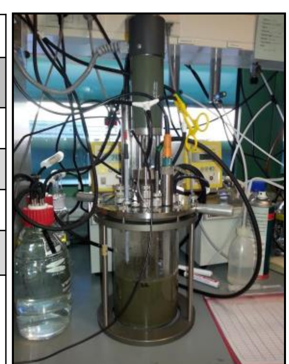


Vaksmaa et al (2016) FEMS Ecology accepted

Enrichment Culture CH_4 & Nitrate

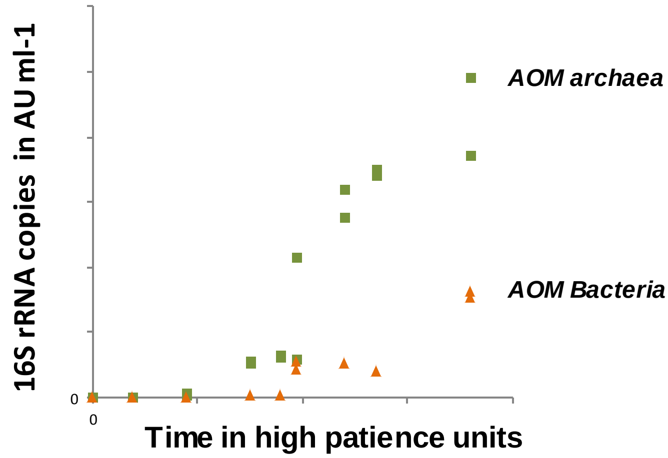
Annika Vaksmaa

	Vercelli
Inoculum	Paddy field soil
Electron donor	CH_4
Electron acceptor	$NaNO_3$
Type	Continuous SBR
In operation	A very long time
Monitoring	qPCR batch experiments nitrate, nitrite measurements Metagenome analysis



Vaksmaa et al (2016) in prep

qPCR Monitoring of enrichment culture for AOM archaea & bacteria



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Vaksmaa et al (2016) in prep

European Research Council erc

FISH analysis

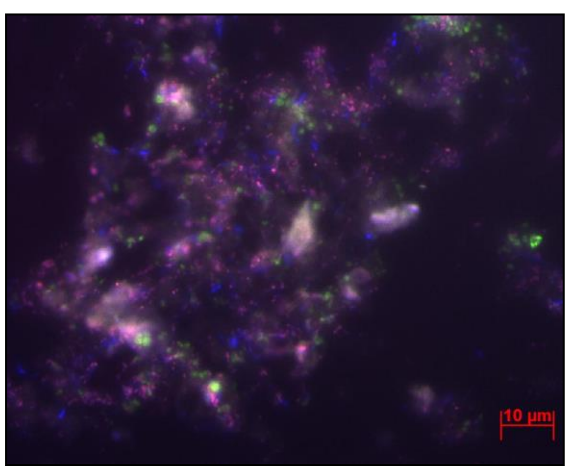
M. oxyfera bacteria

M. nitroreducens archaea

Metagenome analysis

M. oxyfera bacteria 6%

M. nitroreducens archaea 15%



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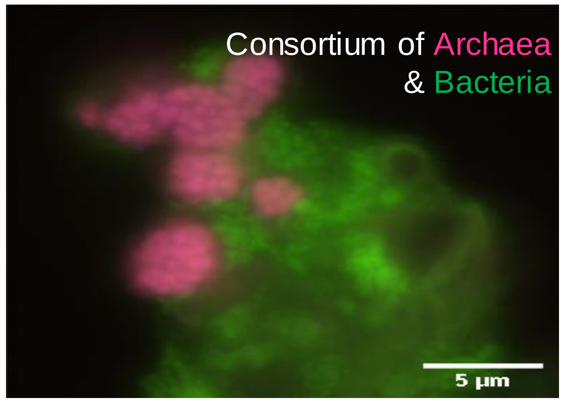
European Research Council erc


nature Vol 440|13 April 2006|doi:10.1038/nature04617

LETTERS

A microbial consortium couples anaerobic methane oxidation to denitrification

Ashna A. Raghoebarsing[1], Arjan Pol[1], Katinka T. van de Pas-Schoonen[1], Alfons J. P. Smolders[2], Katharina F. Ettwig[1], W. Irene C. Rijpstra[3], Stefan Schouten[3], Jaap S. Sinninghe Damsté[3], Huub J. M. Op den Camp[1], Mike S. M. Jetten[1] & Marc Strous[1]



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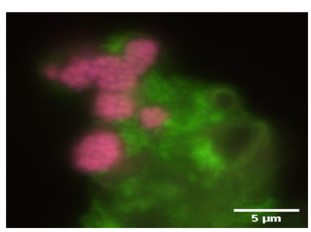
Raghoebarsing et al 2006 Nature



+ Nitrate

+ Nitrite

Archaea
Methanoperedens
Mechanism?

Haroon et al 2013 Nature

Bacteria
Methylomirabilis
NO dismutase?

Physiology
Genome
Stable isotopes

Raghoebarsing et al 2006 Nature
Ettwig et al 2010 Nature

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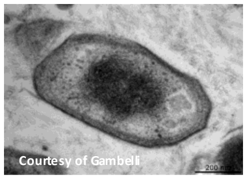
Methylomirabilis oxyfera



Visit me at poster 072A

Karin Stultiens

Some strains only have xoxF

Rubisco

Ks values ?

hunting for putative NO dismutase

by membrane proteomics

$2NO \rightarrow N_2 + O_2$

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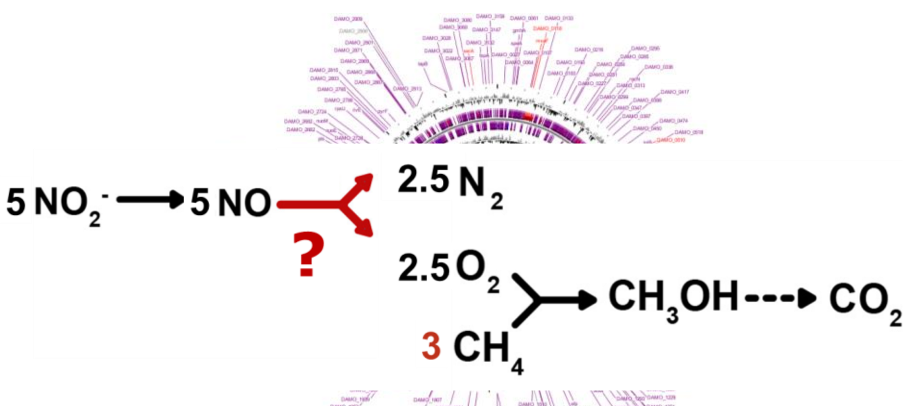
Stultiens et al (2016) in prep

Genome of *Methylomirabilis oxyfera*



pathway of (aerobic) methane oxidation
Incomplete denitrification
Putative NO dismutase

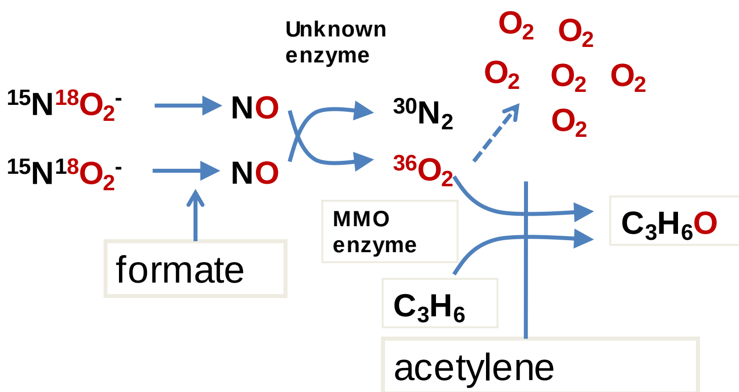
www.anaerobic-microbiology.eu

Ettwig et al 2010 Nature

Possible mechanisms of *M. oxyfera*

Can oxygen be released?

Tested with suicide substrates, inhibitors and $^{15}N^{18}O$ nitrite



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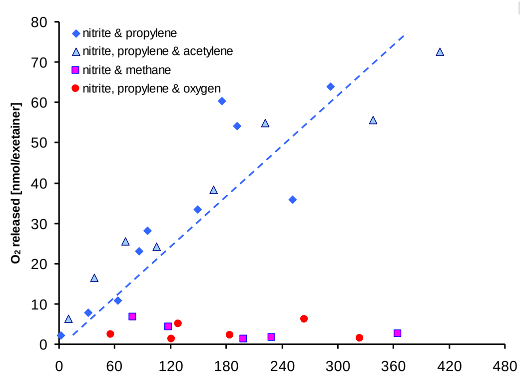
Ettwig et al 2010 Nature

Methylomirabilis oxyfera putative NO dismutase

$$2NO \rightarrow N_2 + O_2$$



ARTICLES

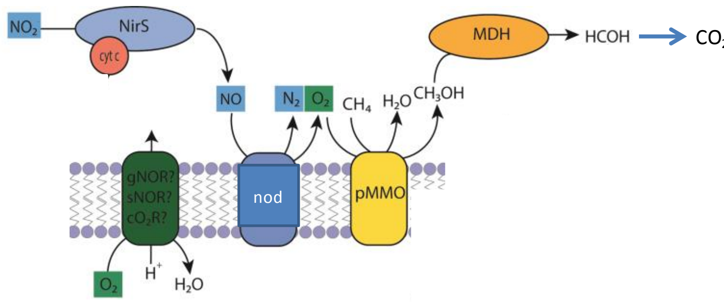
Nitrite-driven anaerobic methane oxidation by oxygenic bacteria

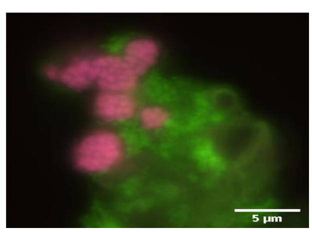
$^{15}N^{18}O$ experiments show: Oxygen Production

www.anaerobic-microbiology.eu

Ettwig et al 2010 Nature

Proposed mechanism for nitrite-dependent methane oxidation





+ Nitrate

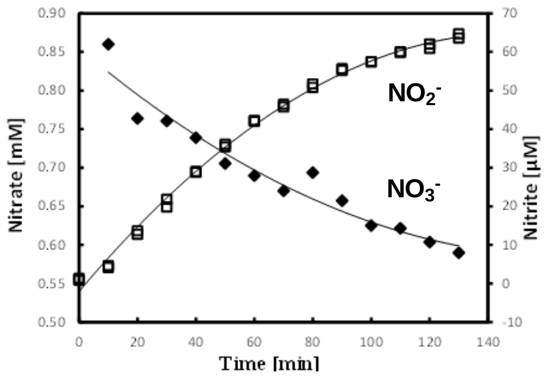
+ Nitrite

Archaea
Methanoperedens?
Mechanism?

Bacteria
Methylomirabilis
NO dismutase
pmoCAB

metagenomics
Physiology & Biochemistry

Nitrate-AOM by Methanoperedens Archaea



In co culture with nitrite scavengers M. oxyfera or anammox
Up to 2 mM NH_4^+ (10% of total N)

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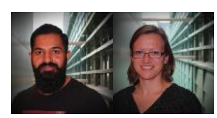
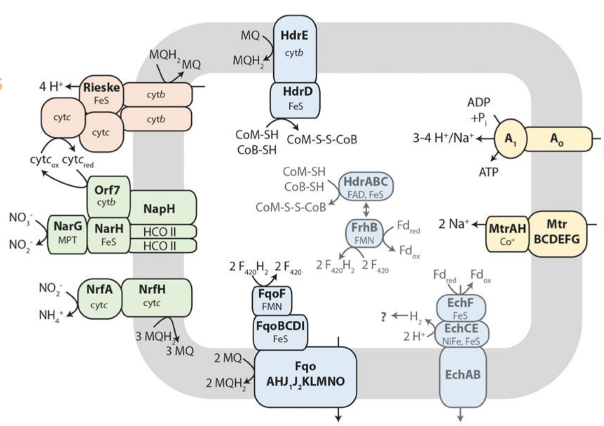
Zhu et al 2014

Genome inventory Methanoperedens



Arslan Arshad Cornelia Welte

Complete reverse CH_4 pathway
HDR complex
FQO complex
Many cytochrome c genes
bc_1 complex
Nitrate reductase narGH
Nitrite reductase nrfAH



Arshad et al 2015 Frontier in Microbiology
http://journal.frontiersin.org/article/10.3389/fmicb.2015.01423/full

SIAM PhD vacancy
Biochemistry of AOM

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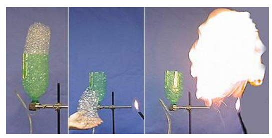
Anaerobic Oxidation of Methane

- Nitrite selects for *M oxyfera*
- *M oxyfera* makes O_2 from NO
- Novel nitrate reducing AOM archaea
- AOM present in many ecosystems
- Remaining : The Quest for iron-AOM



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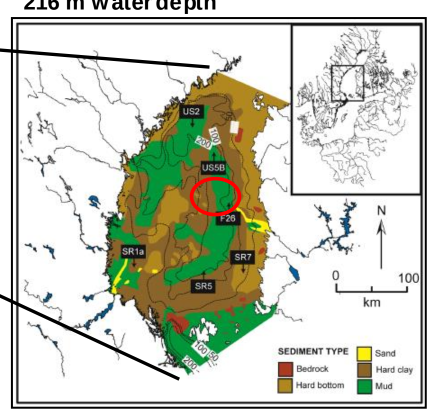
Sampling site: Bothnian Sea

Olivia Rasigraf

216 m water depth



Matthias Egger & Caroline Slomp

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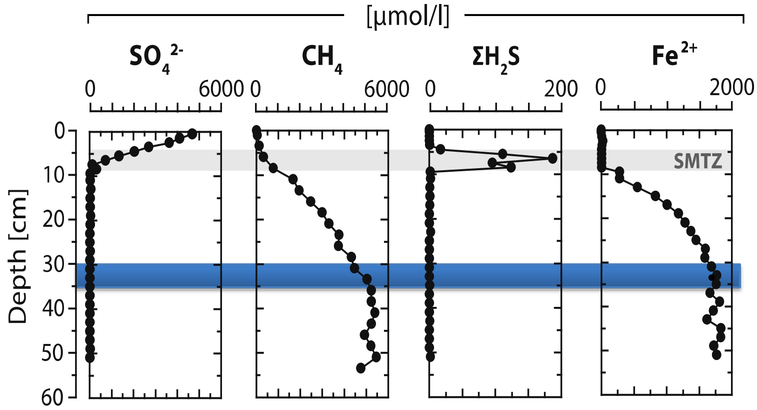
Sediment biogeochemistry

Olivia Rasigraf



iron-AOM

$CH_4 + 8Fe(OH)_3 + 7CO_2 \rightarrow 8\ FeCO_3 + 14H_2O$

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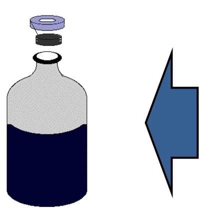
Universiteit Utrecht

Incubation set up

Anaerobic set-up



Sediment slurry in mineral medium

$Fe(OH)_3$ or MnO_2 nanoparticles

$^{13}CH_4$ (~50%)

$^{12}CO_2$ (~5%)

Headspace gas analysis: GC-MS

Ion measurements: ICP-OES

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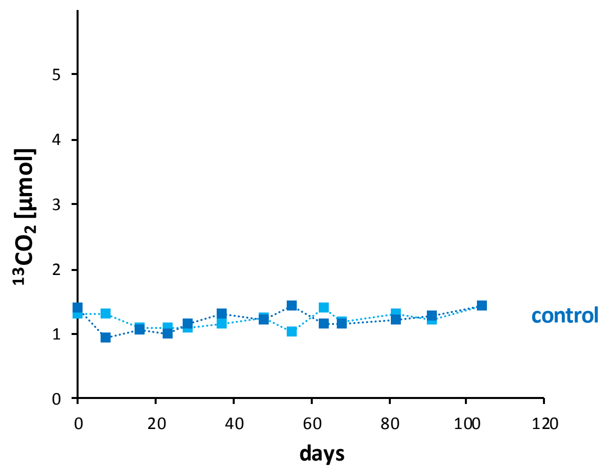
$^{13}CH_4$ oxidation to $^{13}CO_2$ coupled to Fe^{3+} reduction



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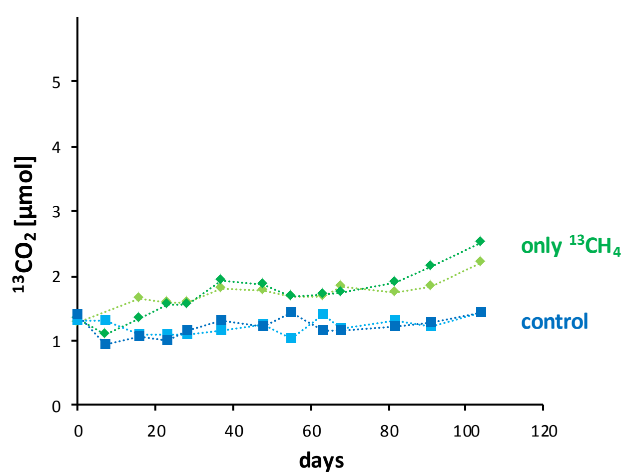
NESSC
NETHERLANDS EARTH SYSTEM SCIENCE CENTRE
Egger, Rasigraf et al 2015 EST

$^{13}CH_4$ oxidation to $^{13}CO_2$ coupled to Fe^{3+} reduction



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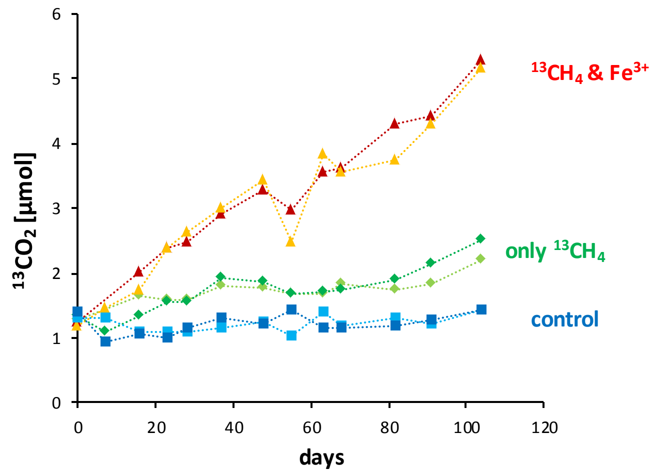

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Egger, Rasigraf et al 2015 EST

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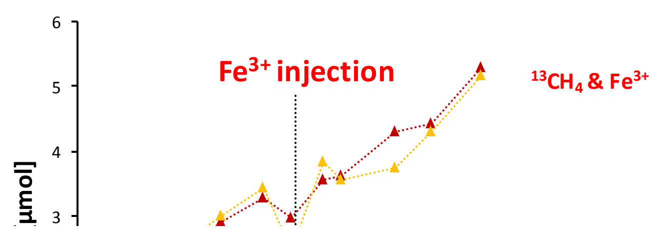

only $^{13}CH_4$

control

120

Environmental Science & Technology

Article

pubs.acs.org/est

Iron-Mediated Anaerobic Oxidation of Methane in Brackish Coastal Sediments

Matthias Egger,[*,†] Olivia Rasigraf,[‡] Célia J. Sapart,[§,∥] Tom Jilbert,[†,⊥] Mike S. M. Jetten,[‡] Thomas Röckmann,[§] Carina van der Veen,[§] Narcisa Bândă,[§] Boran Kartal,[‡,#] Katharina F. Ettwig,[‡] and Caroline P. Slomp[†]

[†]Department of Earth Sciences - Geochemistry, Faculty of Geosciences, Utrecht University, Budapestlaan 4, 3584 CD Utrecht, The Netherlands

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[∥]Laboratoire de Glaciologie, Université Libre de Bruxelles, 50 Avenue F. D. Roosevelt, B-1050 Bruxelles, Belgium

[#]Department of Biochemistry and Microbiology, Laboratory of Microbiology, Ghent University, K. L. Ledeganckstraat 35, 9000 Gent, Belgium

More Evidence for iron AOM

Soo et al. Microb Cell Fact (2016) 15:11
DOI 10.1186/s12934-015-0397-z

Microbial Cell Factories

RESEARCH — Open Access

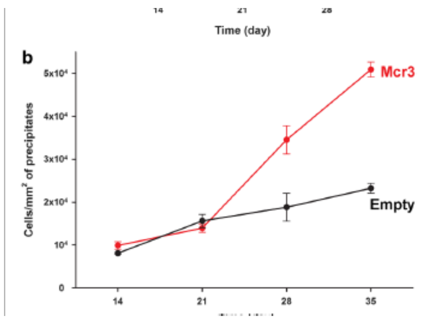
Reversing methanogenesis to capture methane for liquid biofuel precursors

Valerie W. C. Soo[1†], Michael J. McAnulty[1†], Arti Tripathi[1], Fayin Zhu[1], Limin Zhang[2,6], Emmanuel Hatzakis[3], Philip B. Smith[5], Saumya Agrawal[7], Hadi Nazem-Bokaee[1], Saratram Gopalakrishnan[1], Howard M. Salis[1], James G. Ferry[4], Costas D. Maranas[1], Andrew D. Patterson[2] and Thomas K. Wood[1,4*]

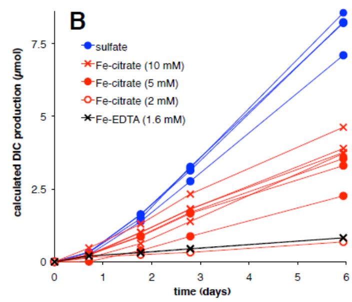
MICROBIAL PHYSIOLOGY

Artificial electron acceptors decouple archaeal methane oxidation from sulfate reduction

Silvan Scheller,* Hang Yu, Grayson L. Chadwick, Shawn E. McGlynn,† Victoria J. Orphan*



Growth of engineered Methanosarcina On Methane & 10 mM $FeCl_3$



Activity of AOM On Methane & 10 mM Fe-Citrate

SIAM

www.anaerobic-microbiology.eu

FOX NEWS.com

New (an)aerobic C1 microbes could save the world

Wednesday, November 14, 2007

By Jeanna Bryner

LiveScience

Unique bacteria hiding out in a witches' brew of anoxic water not only thrive in cold wetlands and oceans but also chow down its C1 compounds

Thank you !

European Research Council erc

SIAM

European Research Council erc

stw

NESSC NETHERLANDS EARTH SYSTEM SCIENCE CENTRE

NWO Netherlands Organisation for Scientific Research

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TUDelft