

# PROSPECTING FOR LIFE



Michael Russell, Jet Propulsion Laboratory, California Institute of Technology  
US Government sponsorship acknowledged

<https://www.origins-center.nl/submarine-alkaline-vent-theory/>

“When we are young, the words are scattered all around us. As they are assembled by experience, so are we, sentence by sentence, until the story takes shape.

Plague of Doves, Louise Erdrich

# First Job, Howards of Ilford, England, 1958



**HOWARDS**  
OF ILFORD

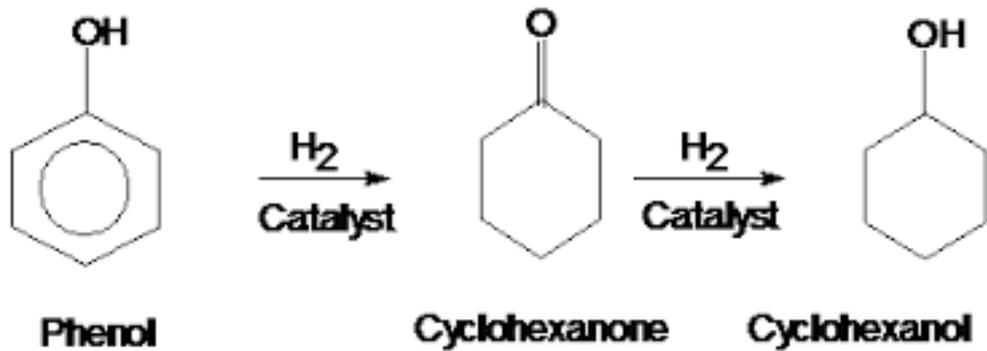
*Manufacturers of solvents,  
fine and technical*

**CHEMICALS**  
*for industrial and  
pharmaceutical purposes*

**HOWARDS**  
OF ILFORD

HOWARDS & SONS LTD · ILFORD NR. LONDON  
*Established 1797*

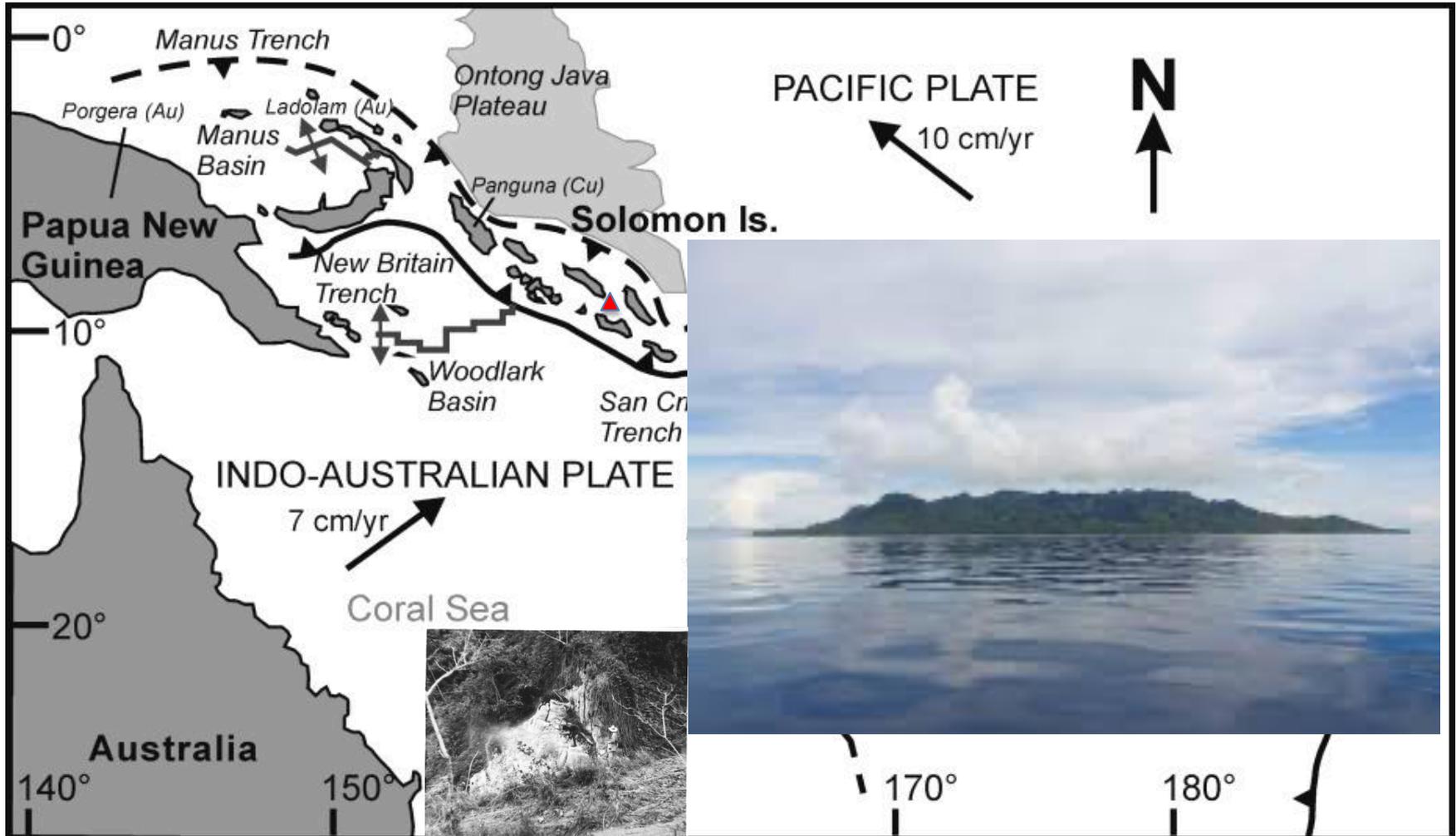
STAND no. B24



Ni catalyst in rocking  
autoclave at 85°C and 3MPa

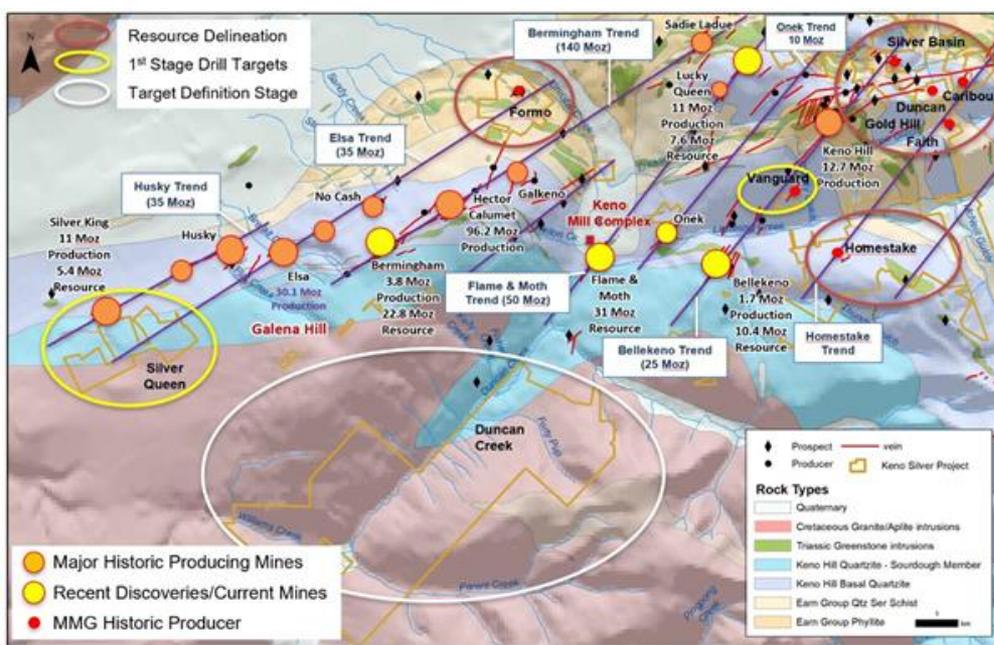


# Solomon Islands, Where geological processes are actual

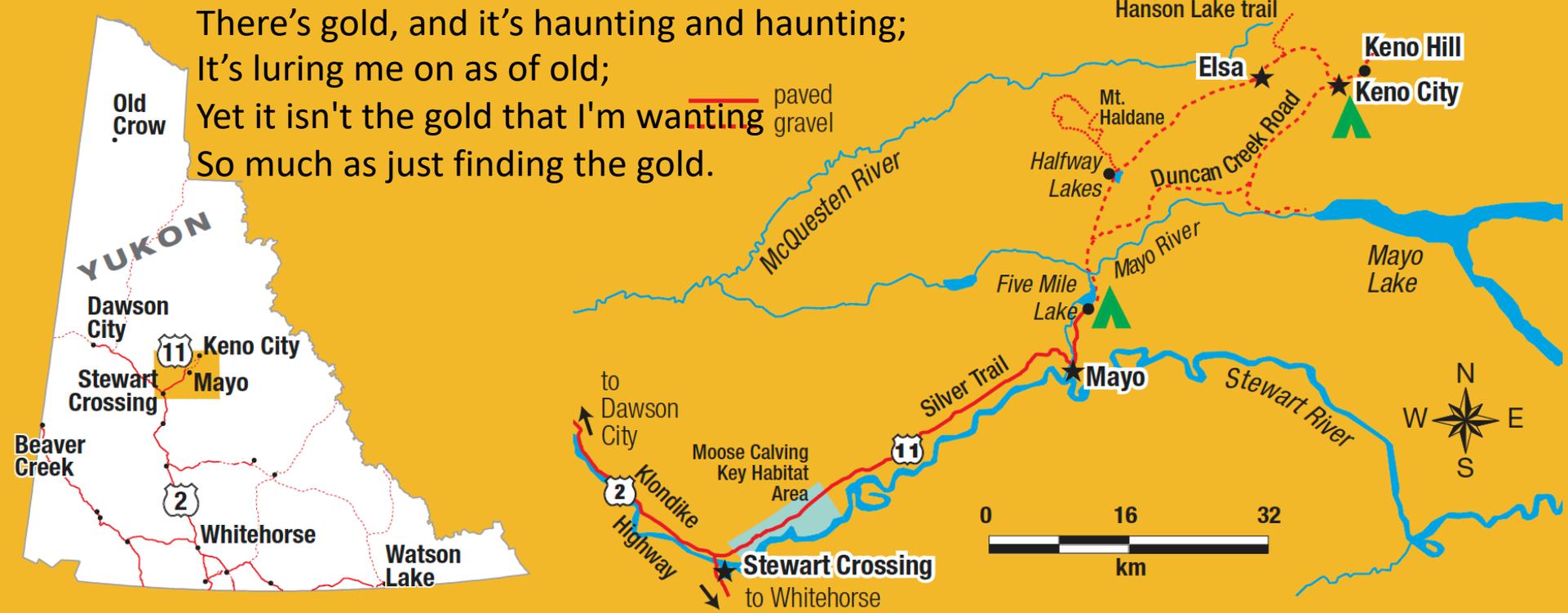






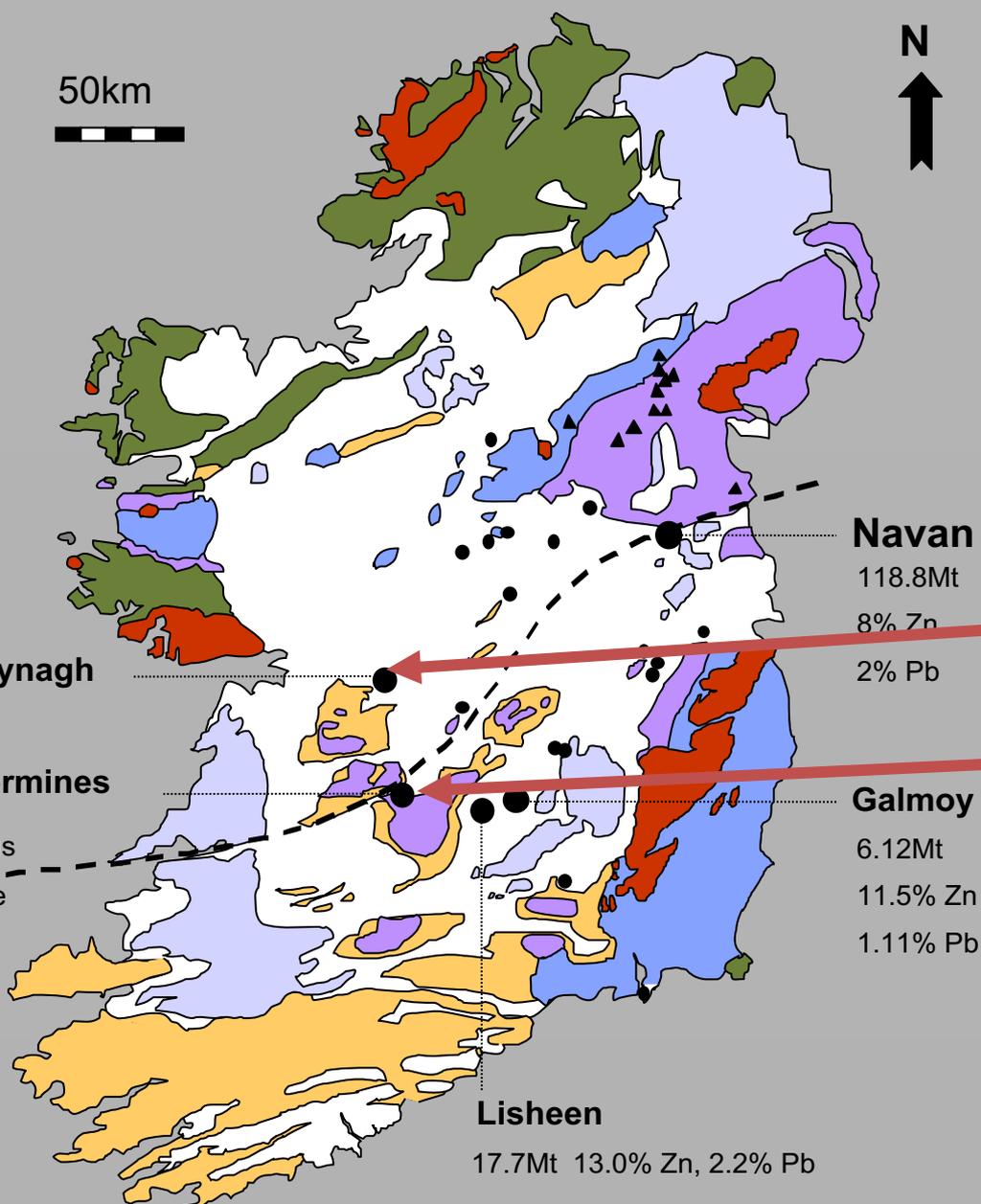


There's gold, and it's haunting and haunting;  
 It's luring me on as of old;  
 Yet it isn't the gold that I'm wanting  
 So much as just finding the gold.



# Geological Map of Ireland

50km



**Navan**  
118.8Mt  
8% Zn  
2% Pb

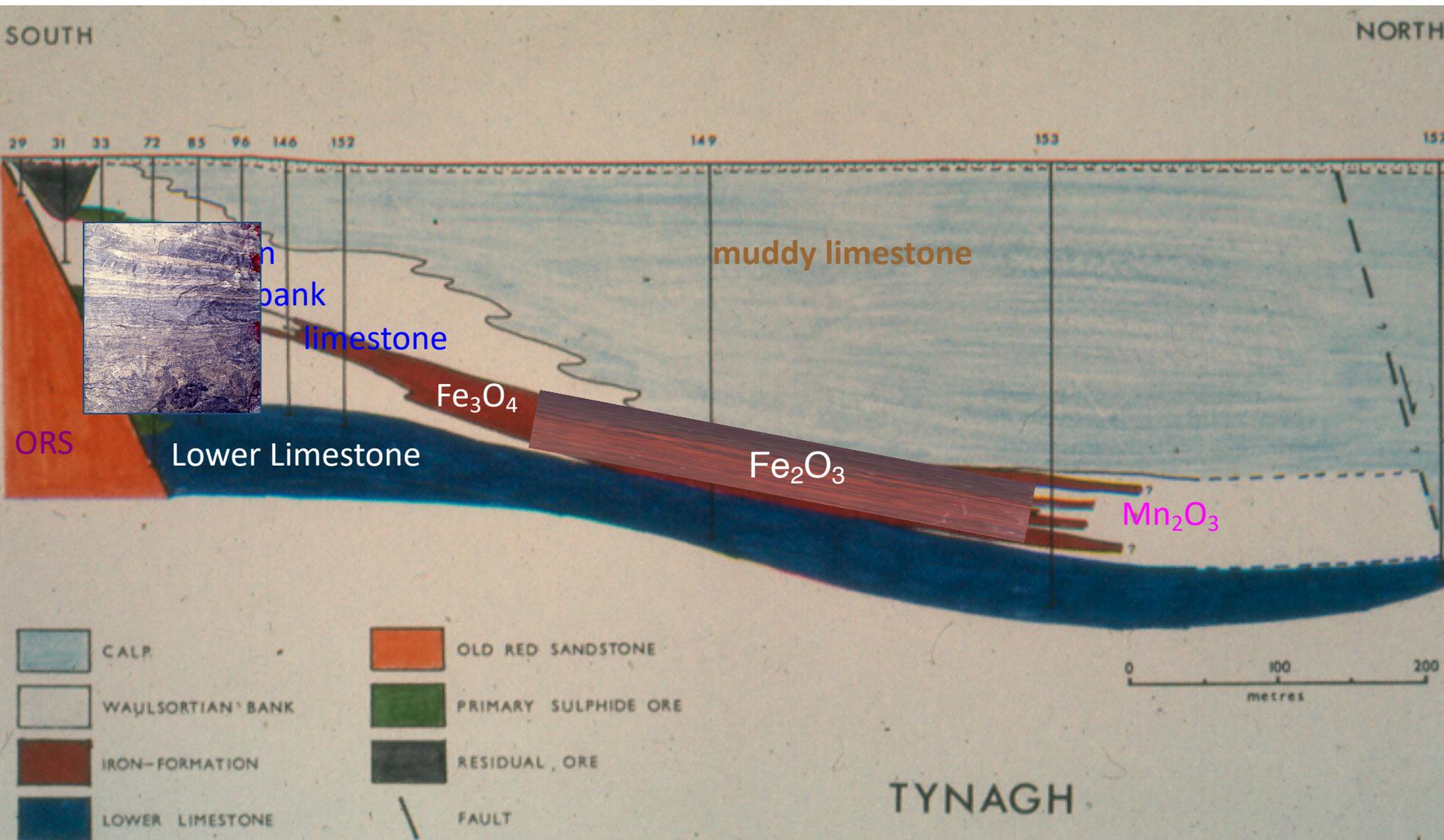
**Galmoy**  
6.12Mt  
11.5% Zn  
1.11% Pb

**Lisheen**  
17.7Mt 13.0% Zn, 2.2% Pb

The Irish orefield hosts the world's largest known concentration of Zn/sq.km

Hydrothermal chimneys and botryoids from the Tynagh Zn+Pb sulfide + BIF orebody and Silvermines Zn+Pb+Fe sulfide orebodies of exhalative affiliation in Mississippian Limestones (~352 Ma)

# TYNAGH Pb+Zn OREBODY



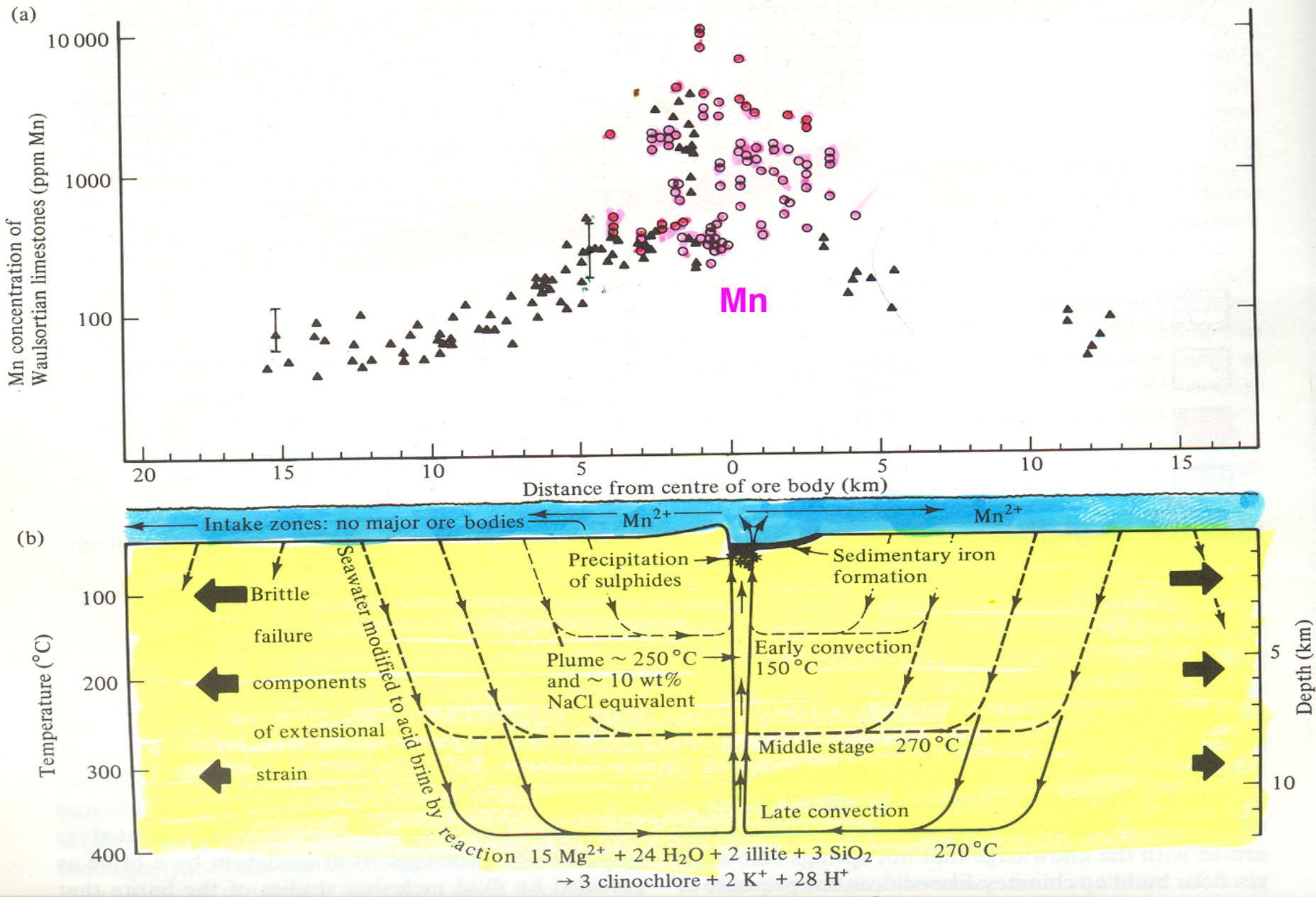
Derry, Clark and Gillat, 1965, Economic Geology 60, 1218

# Tynagh Iron Formation

Bioturbated  
layers of  
magnetite &  
hematite,  
with minor  
chert and tuff



# BIOGENESIS AND SYNGENESIS OF GIANT METAL SULFIDE DEPOSITS RESULTING FROM OPEN SYSTEM HYDROTHERMAL CONVECTION





**Black Smoker**  
**at 360°C, pH ~3.4**  
**East Pacific Rise**

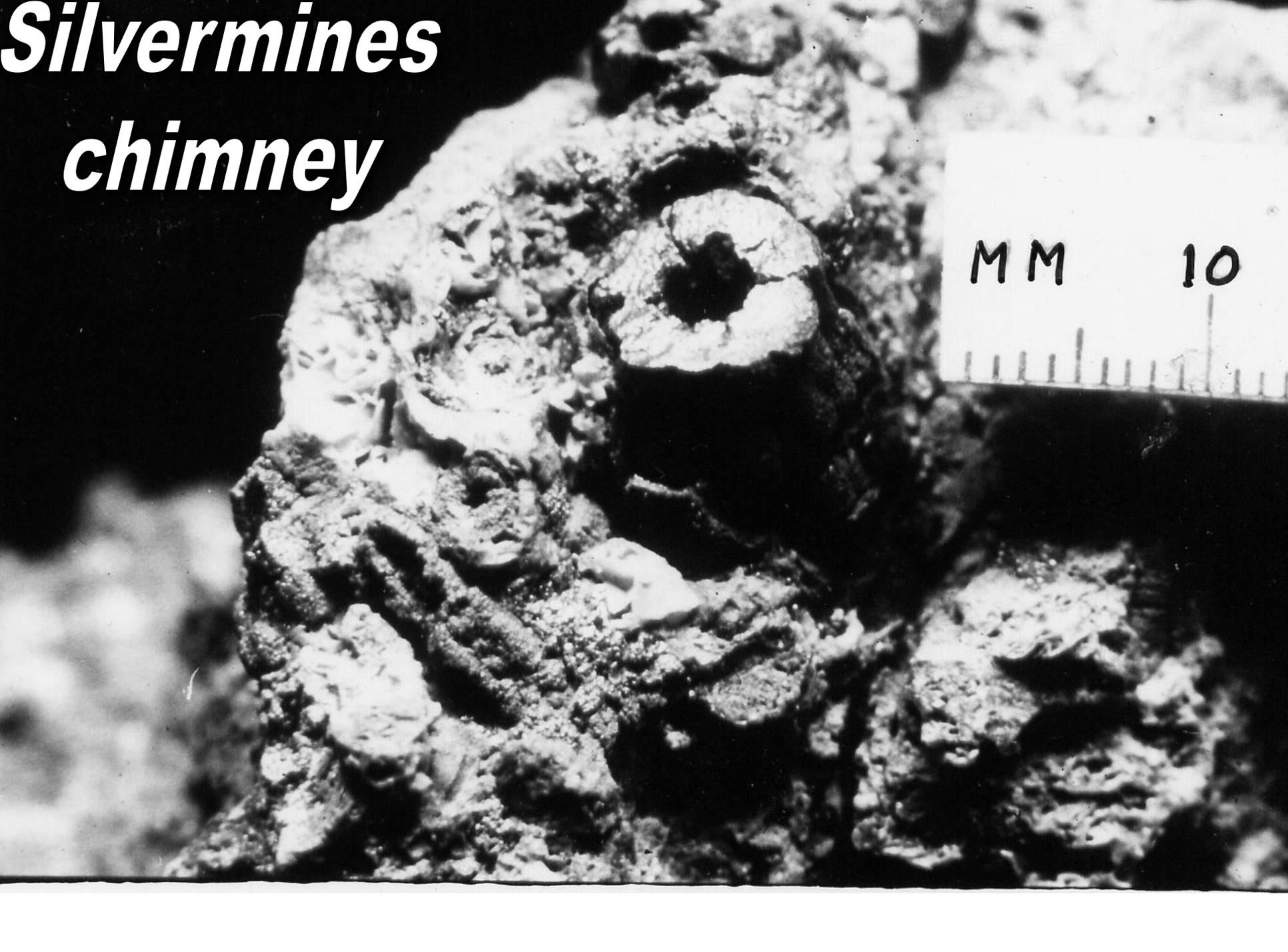
As predicted by Jack Corliss and John Edmond



Michael Russell (left) at the site of the fossil chimney Discovery, Silvermines, Ireland; credit: Garth Earls

*Silvermines*  
*chimney*

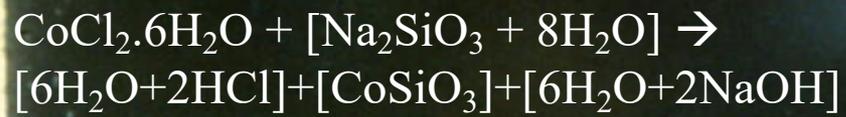
MM 10



# CRYSTAL GARDEN



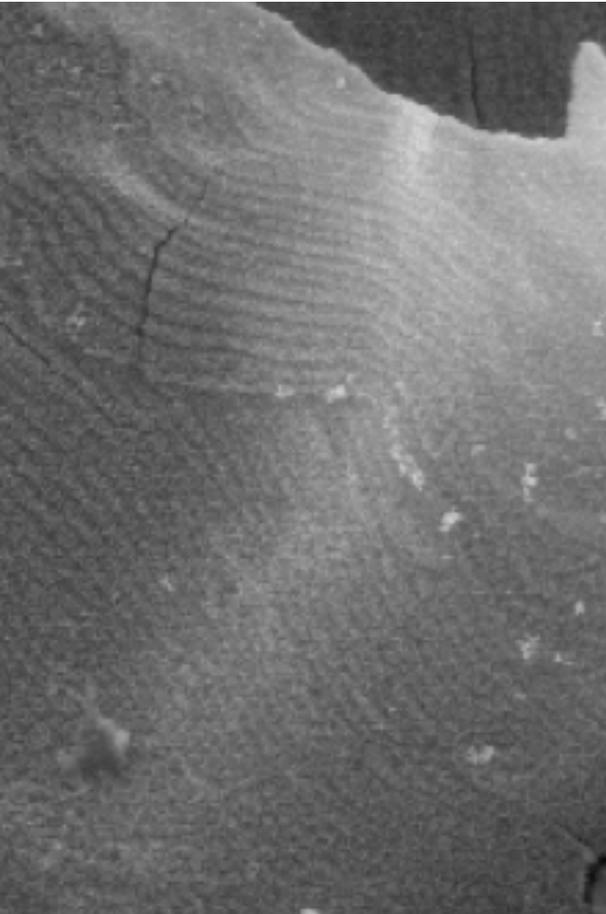
thomas  
salter  
toys



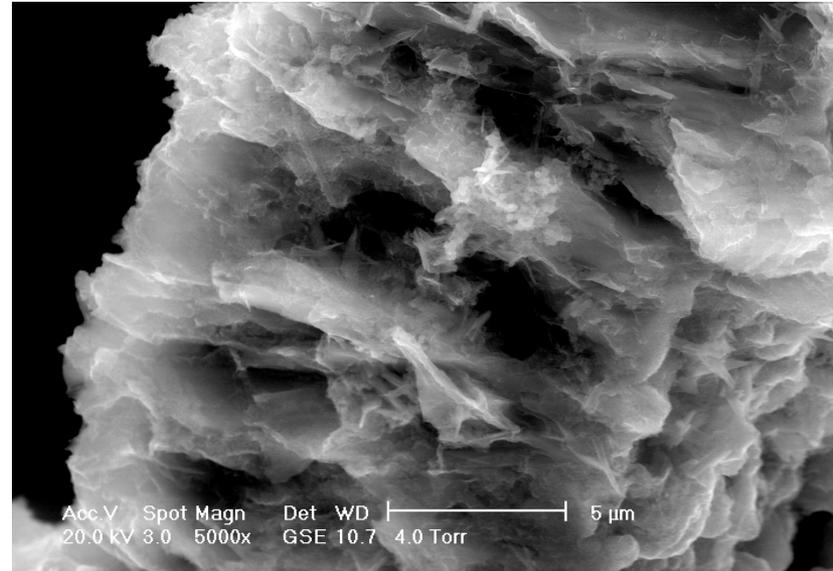
Traube, 1867, Experimente  
zur Theorie der Zellenbildung  
und Endomose. Arch. Anat.  
Physiol., p. 87-165

# Inorganic membrane structure and composition

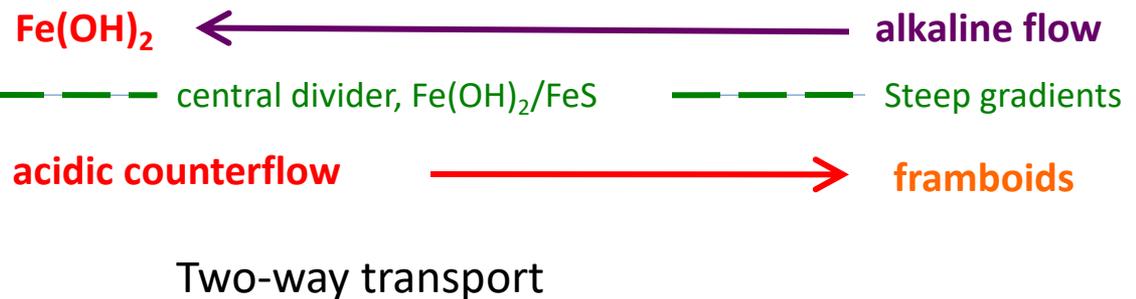
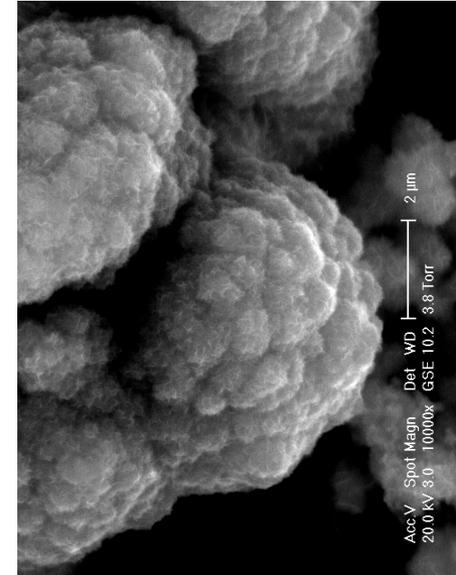
**Fe(OH)<sub>2</sub> flanges to exterior**



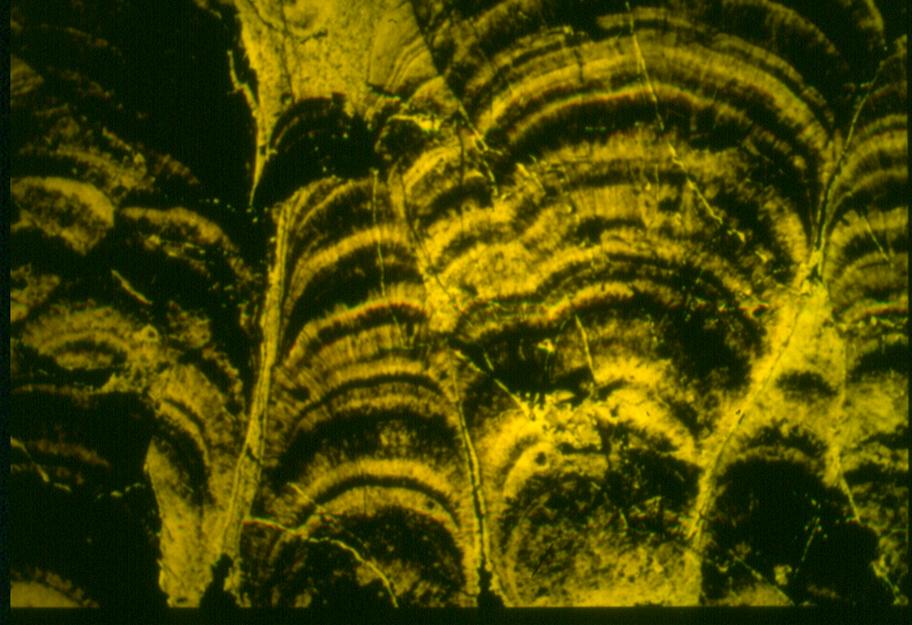
**Porous cross-section of FeS & Fe(OH)<sub>2</sub>**



**Internal Fe<sub>3</sub>S<sub>4</sub> framboids**



Large porous membrane structure prefigures the first biofilms?



3mm

Pyrite microbialite at  
hydrothermal mound,  
Ballynoe open pit barite  
deposit, Silvermines

Russell 1995. *Ore Geol. Rev.*  
v. 10, p. 199-214.



*Parakvinella*  
3 cm long

S. Kim  
Juniper  
et al. Geology  
1992.20. 895

Photo  
A.J. Southw



Banks 1985  
Nature 313, 128



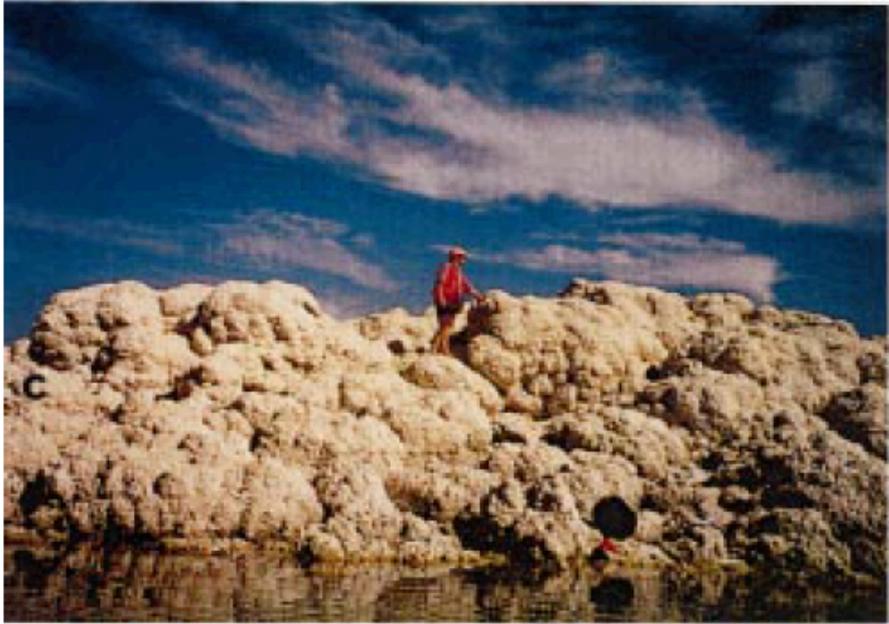
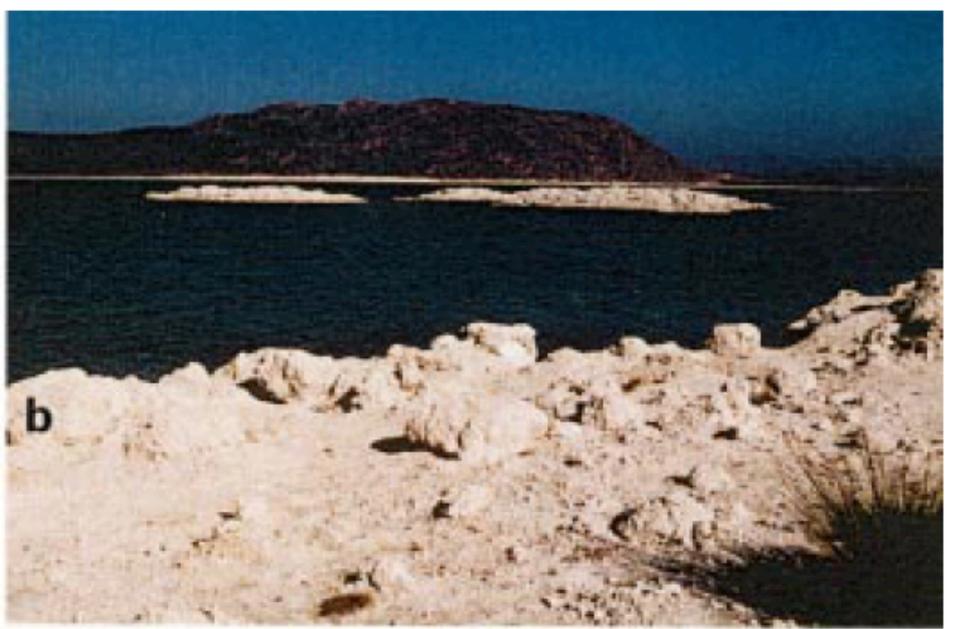
Salda Gölü

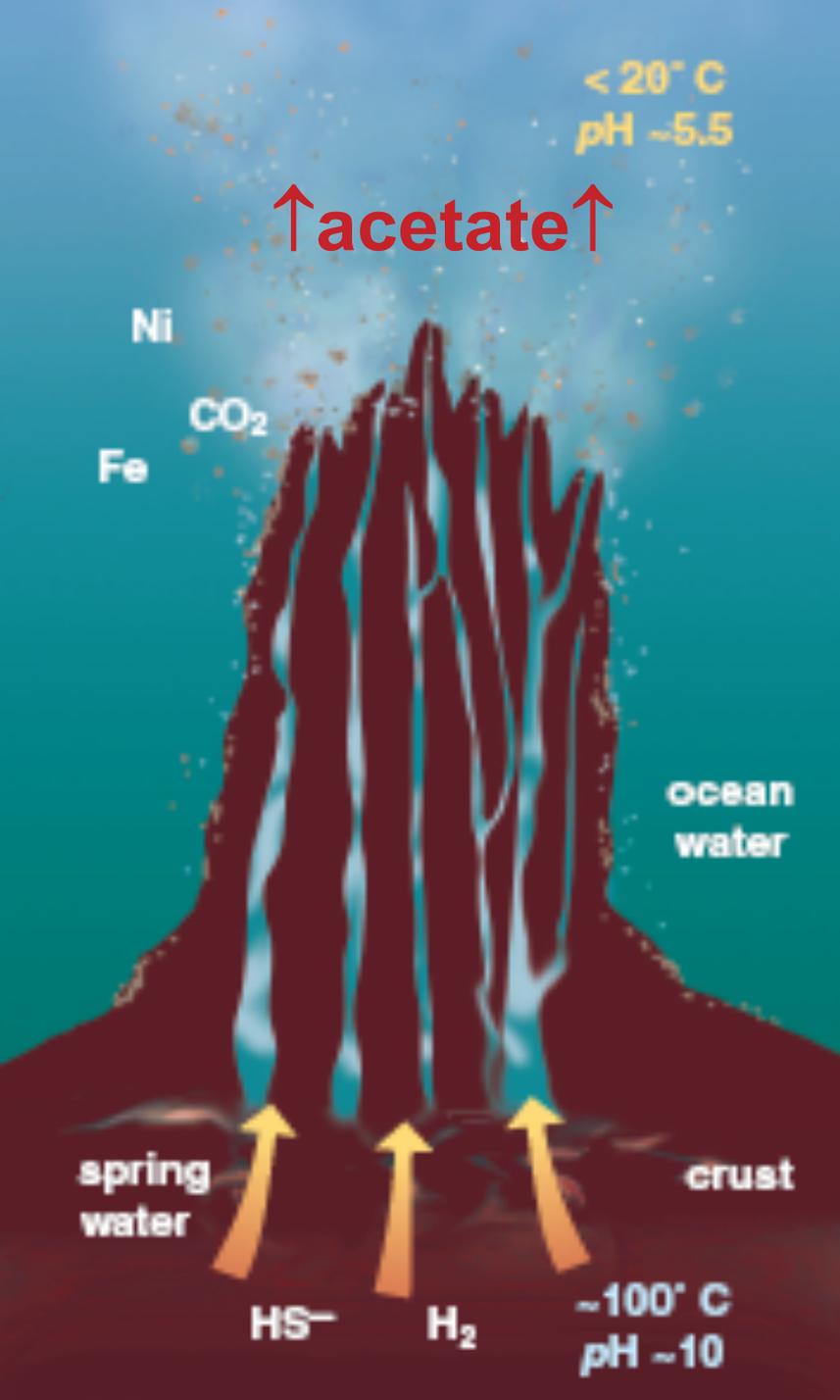
Hydromagnesite  
spring

$\text{CH}_4$

Partially serpentinized ocean floor

7 km





The first microbes were autotrophic, i.e., they used inorganic materials for both energy and structure (HCO<sub>3</sub><sup>-</sup>, NH<sub>3</sub>, H<sub>2</sub>, etc.)

\*\*\*

“By autogeny we understand the origin of a most simple organic individual in an inorganic formative fluid, that is, in a fluid which contains the fundamental substances for the composition of the organism dissolved in simple and loose combinations (for example, carbonic acid, ammonia, binary salts, etc.).”

Ernst Haeckel 1892, p. 414.

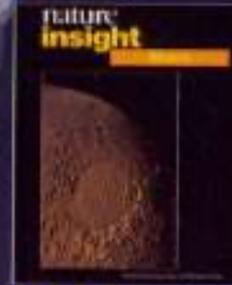
12 July 2001

International weekly journal of science

# nature

ISSN 0028-0825

www.nature.com



Mars  
Nature Insight

compartments



## Hydrothermal vents in the 'Lost City'

**ALKALINE  
SUBMARINE  
SPRING**

**Mg(OH)<sub>2</sub>  
BRUCITE**

**CaCO<sub>3</sub>**

**pH ≤ 11 T ≤ 91°C**

**H<sub>2</sub> ≤ 15mmol**

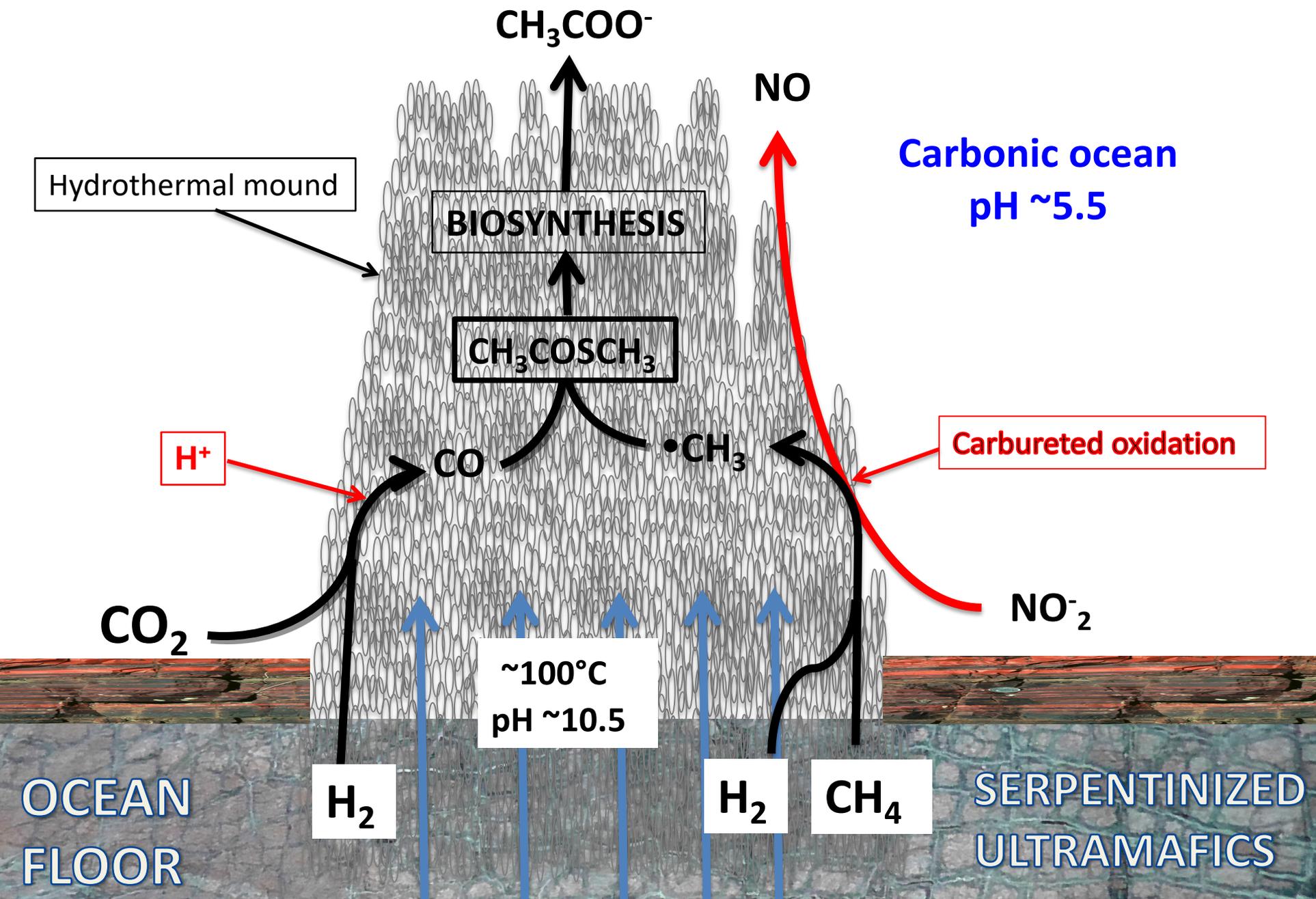
**CH<sub>4</sub> ≤ 2mmol**

**~100,000 years  
(~10<sup>20</sup> nanosecs)**

Kelley et al. 2001,  
Nature **412**, 145  
& Science 2005,  
**307**, 1428-1434.

Martin et al. 2008,  
Nature Microbiol. Rev.  
**6**, 805-814.

# The first metabolic pathway



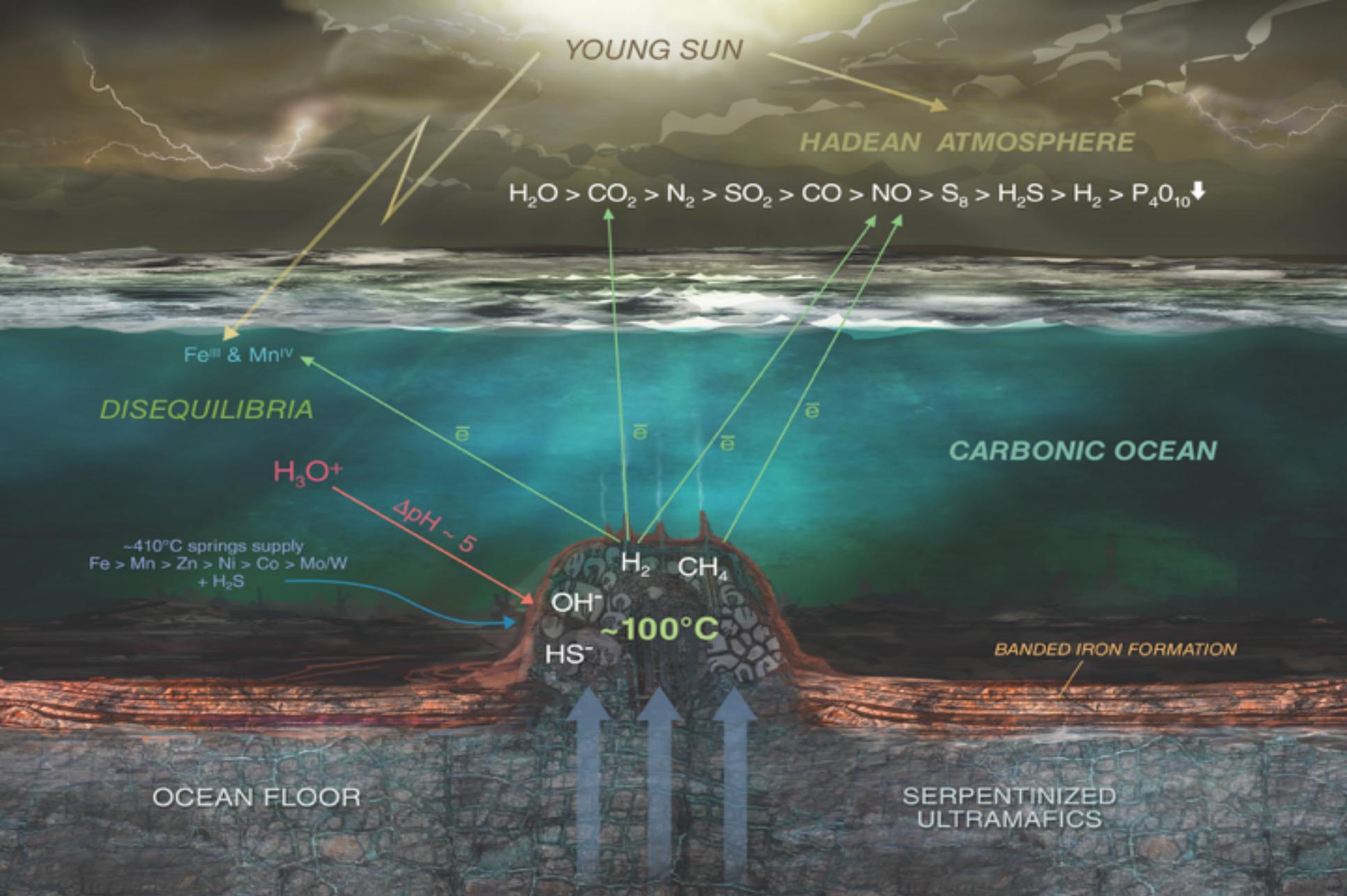
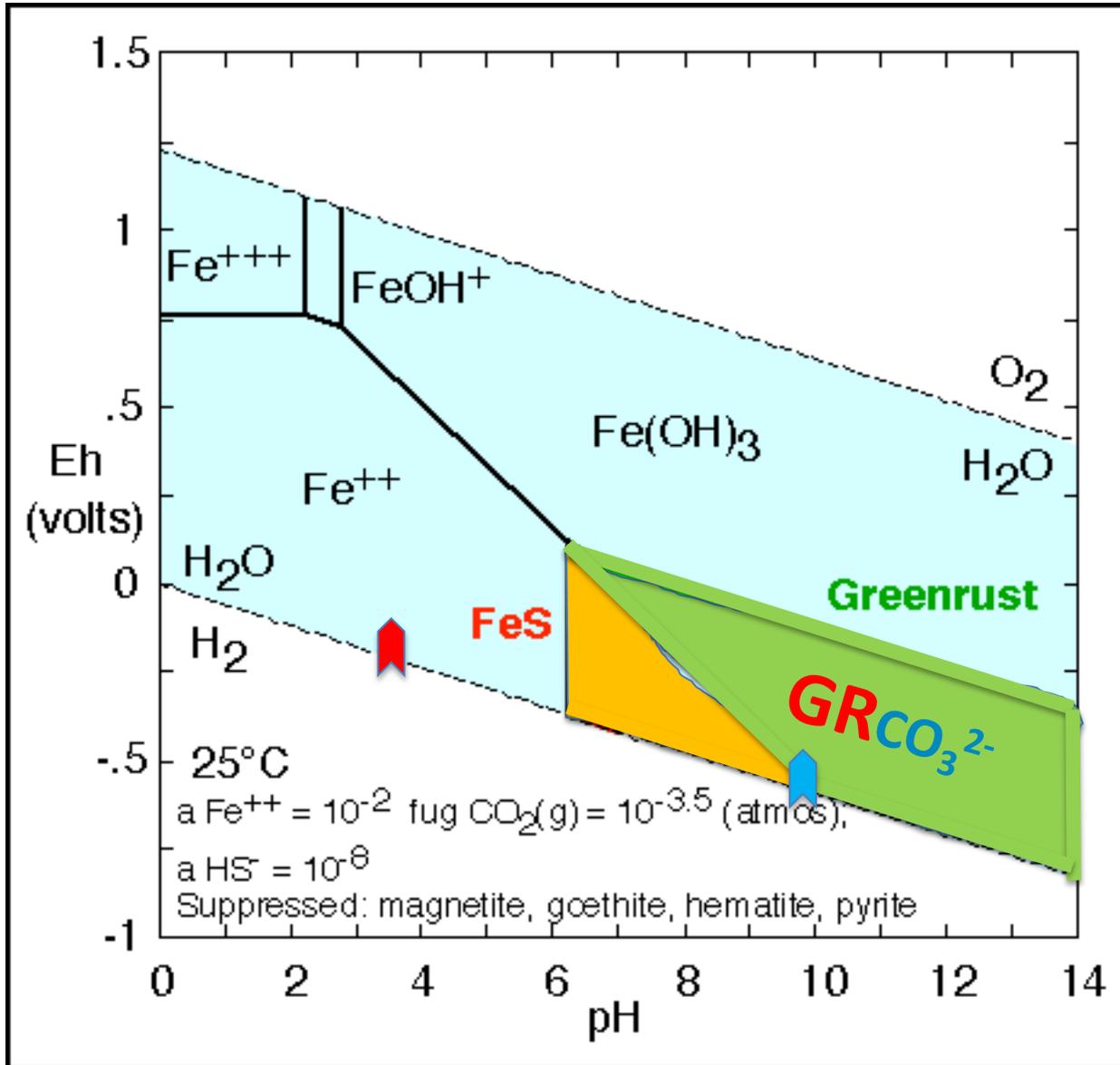


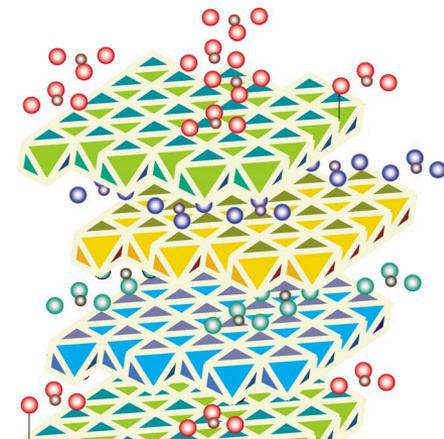
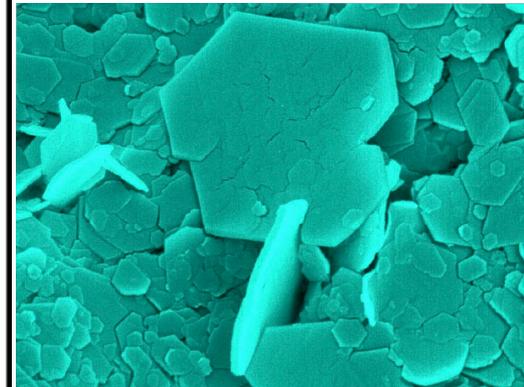
Figure to demonstrate how green rust and Fe-Ni sulfides are precipitated at an H<sub>2</sub>- and CH<sub>4</sub>-bearing alkaline hydrothermal vent on an early ocean floor. High temperature acidic springs (not shown) supply the metals; volcanoes supply the CO<sub>2</sub> while lightning produces NO. Both gases dissolve in the early ocean rendering it mildly acidic and oxidized. The resulting steep redox and pH gradients drive the synthesis of simple organic molecules from the CO<sub>2</sub>, CH<sub>4</sub> and NO<sub>3</sub><sup>-</sup> forced through the green rust interlayers (E. Branscomb, M.J. Russell, *BioEssays* **40**, 1700182, 2018).

# Eh-pH diagram (GW) to demonstrate stability of Green Rust



**NB.** Siderite is strongly oversaturated in Archaean Ocean.

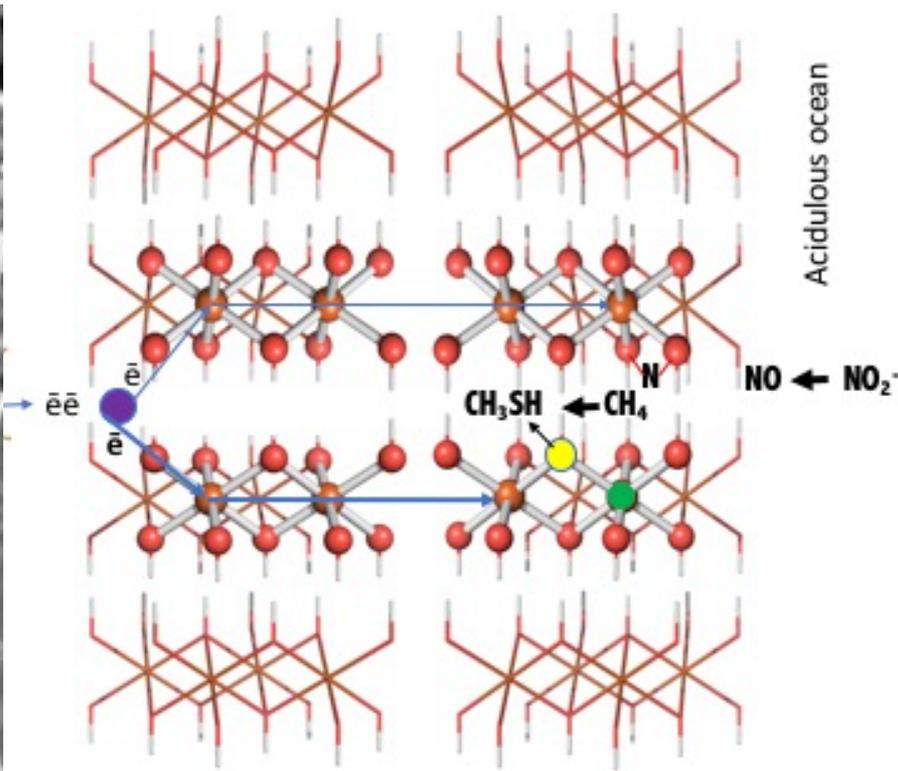
Gäb et al. 2017  
*Geochim Cosmochim Acta* 214: 209-225.



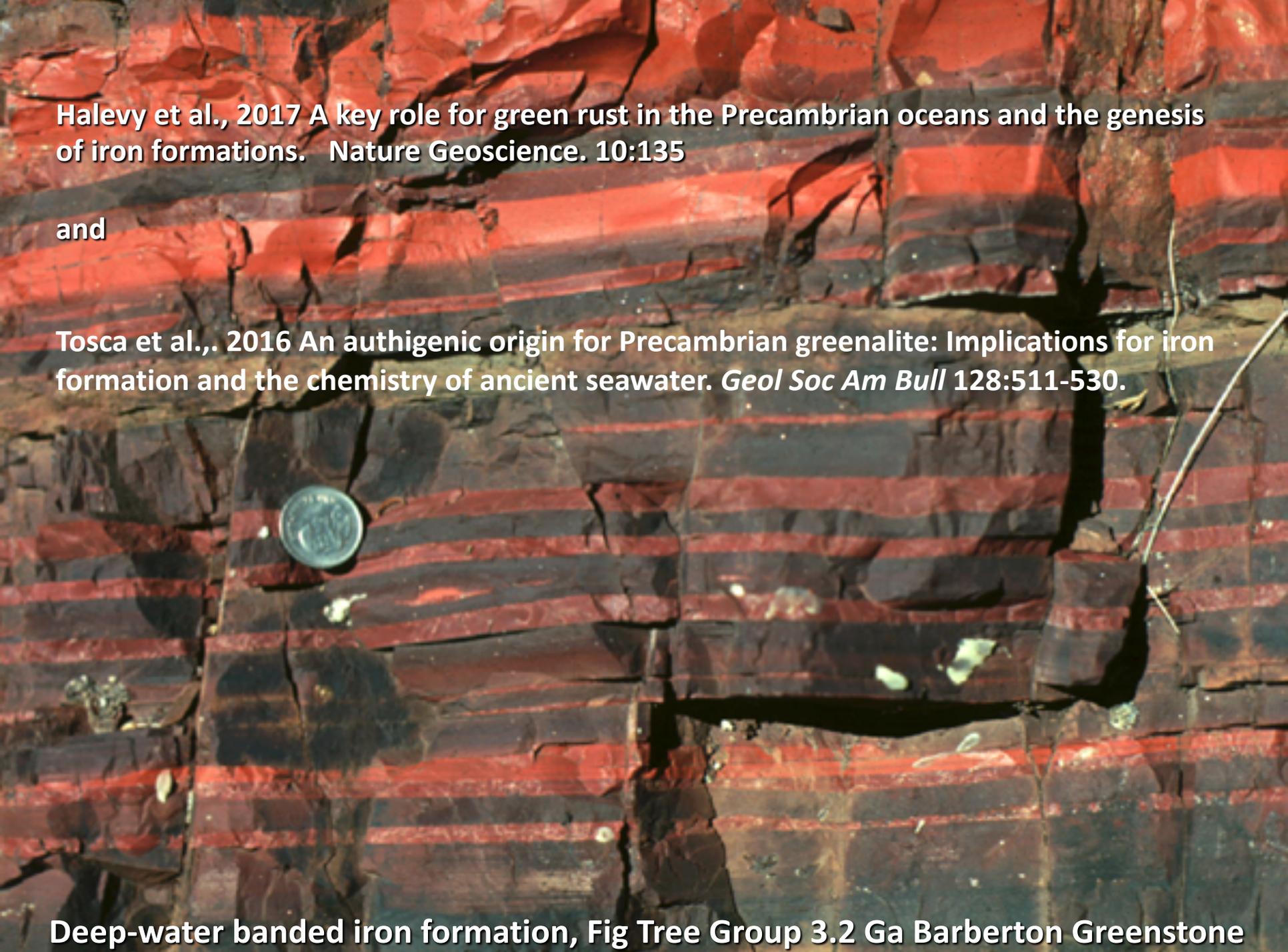
Russell and Hall, 2006, *Geol Soc America Memoir* 198, 1-32

Halevy et al. 2017, *Nature Geosci*, 10(2), 135-139

Green rust, when in the bosom of the ocean deep, appears to have the power, and the art, to gestate the simple organizing 'seed' of all life.



Ferrous-ferric oxyhydroxide



Halevy et al., 2017 A key role for green rust in the Precambrian oceans and the genesis of iron formations. *Nature Geoscience*. 10:135

and

Tosca et al., 2016 An authigenic origin for Precambrian greenalite: Implications for iron formation and the chemistry of ancient seawater. *Geol Soc Am Bull* 128:511-530.

Deep-water banded iron formation, Fig Tree Group 3.2 Ga Barberton Greenstone

exhalation/excretion

$H_2O + NO$  etc.

NO

Carbonic  
ocean  
pH ~5.5

BIOSYNTHESIS

mound & rocket  
are both engines,

Carbureted  
oxidation

$\sim 100^\circ C$   
pH ~11

$H^+ +$   
 $NO_3^-$

$CH_4$

$H_2$

$HNO_3$

CO

$\bullet CH_3$

$NH_3$

$CO_2$

$H_2$

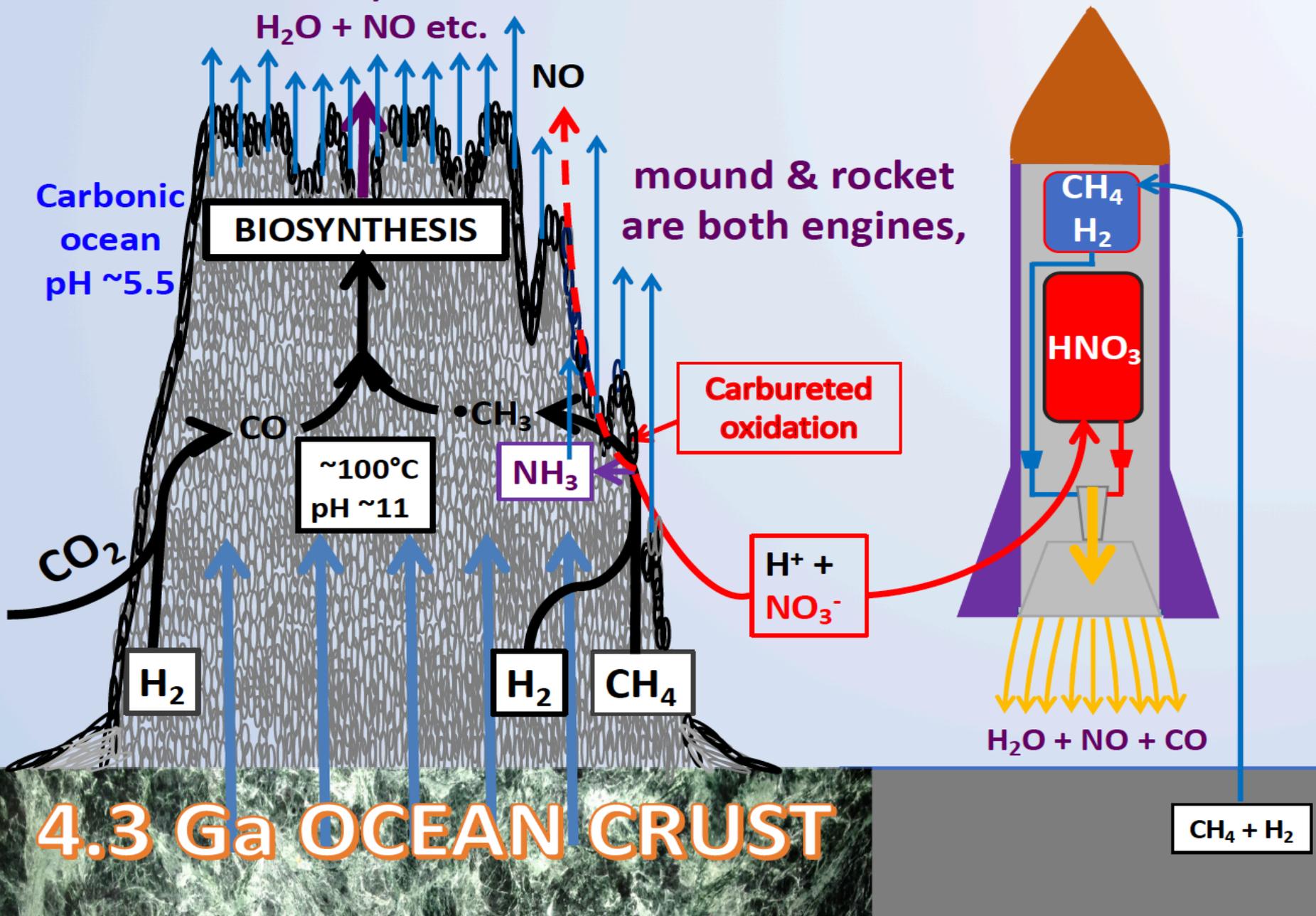
$H_2$

$CH_4$

$H_2O + NO + CO$

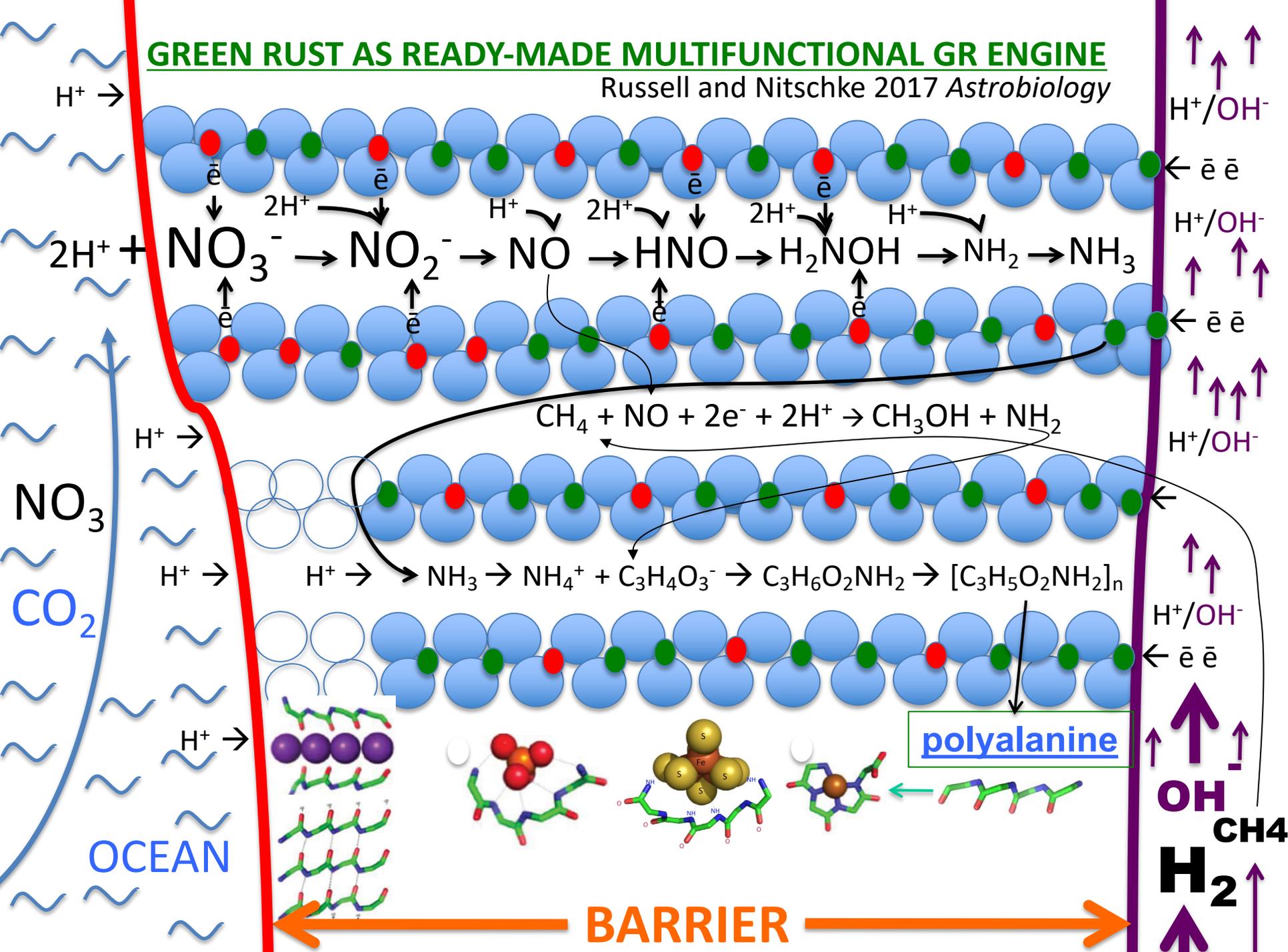
4.3 Ga OCEAN CRUST

$CH_4 + H_2$

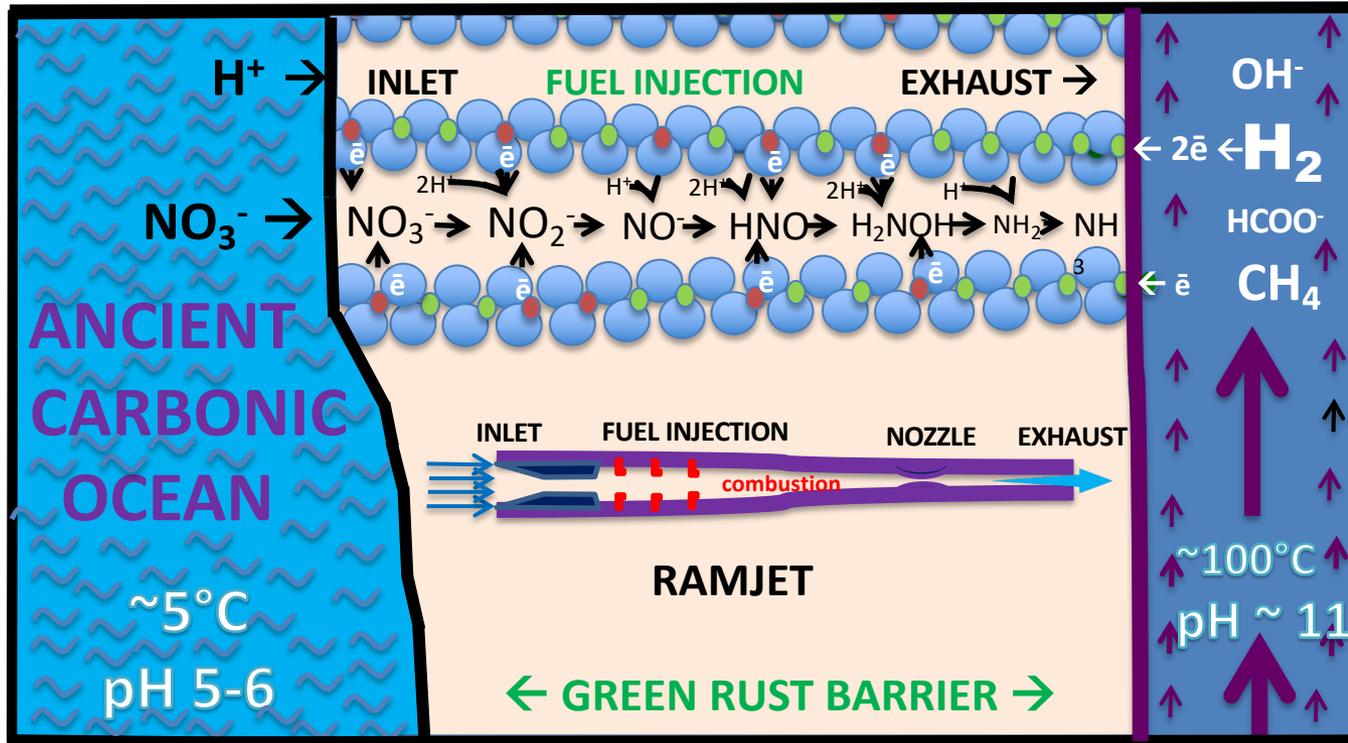


# GREEN RUST AS READY-MADE MULTIFUNCTIONAL GR ENGINE

Russell and Nitschke 2017 *Astrobiology*



# Function follows form

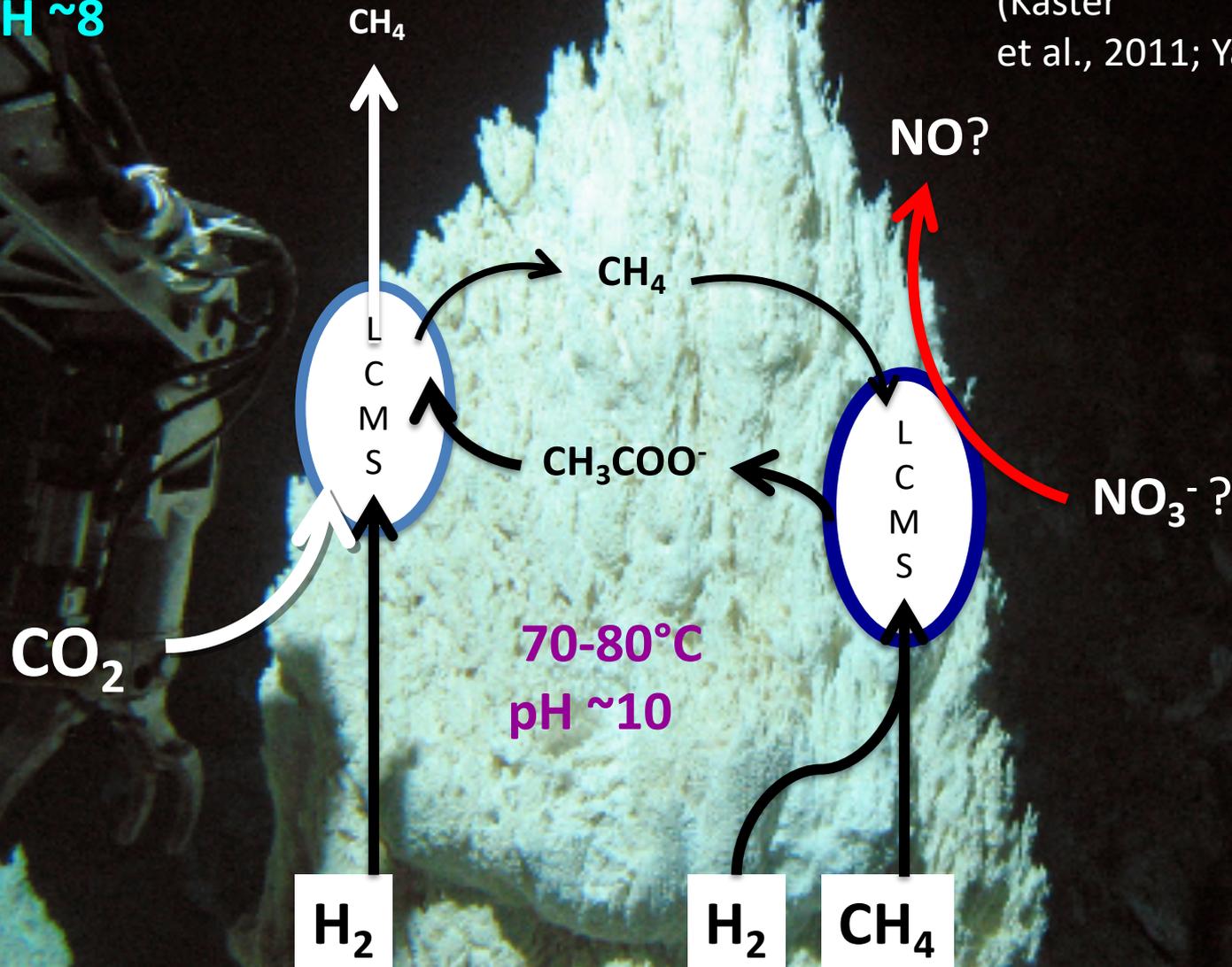


*with apologies to architects everywhere* (Chaisson 2014)

Present day metabolism of *Methanosarcinales* at Lost City (N. Atlantic)

Ocean  
pH ~8

And look out for  
*Methanosarcina acetivorans*  
(Kaster  
et al., 2011; Yan et al., 2017).





Especial thanks to:  
Elbert Branscomb



Wolfgang Nitschke



Michael Wong

Yuk Yung

