Microbial metabolism of contaminants: from oil and pesticides in Ecuador to selenium in California's largest lake, the Salton Sea

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Outline

- Ecuador, oil, pesticides
- Selenium in the Western US
- Selenium accumulation in Salton Sea sediment: differences by geographical location and depth
- Isolating selenate reducers
- Engineering the microbiome to address chemical contamination

Ecuador

- Oil, ~60% of national income, lax to non-existent environmental regulations
- Aguinda vs. Chevron, 1993: US$20 billion
- Assessing cancer risk in workers from the flower and petroleum industry
- Microbial enrichments: chlorpyrifos, aldicarb, pentachlorophenol, benzene

Ecuador: assessing risk, exploring solutions

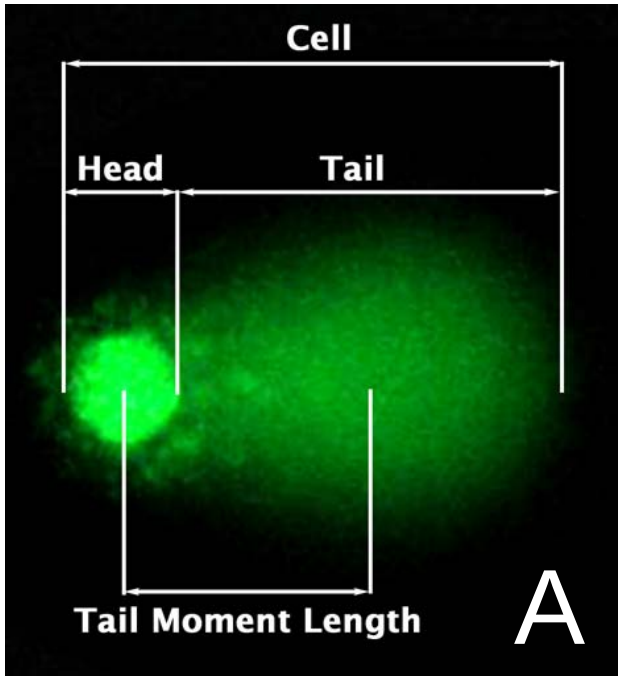

Image credits: CellBiolabs Inc. 2016

Outline

- Ecuador: development, lax environmental regulations
- Idaho, California: Selenium
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Selenium (Se)

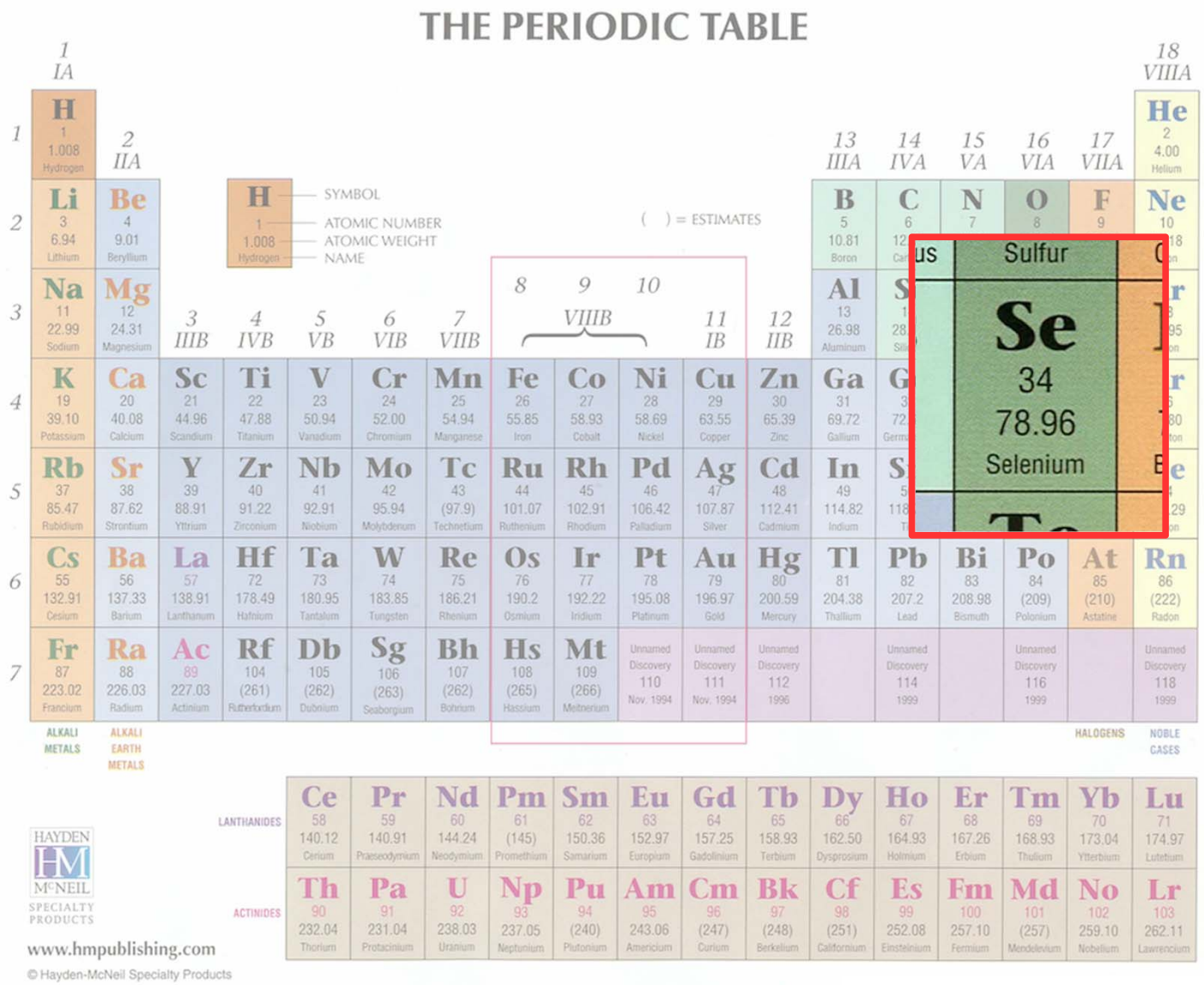
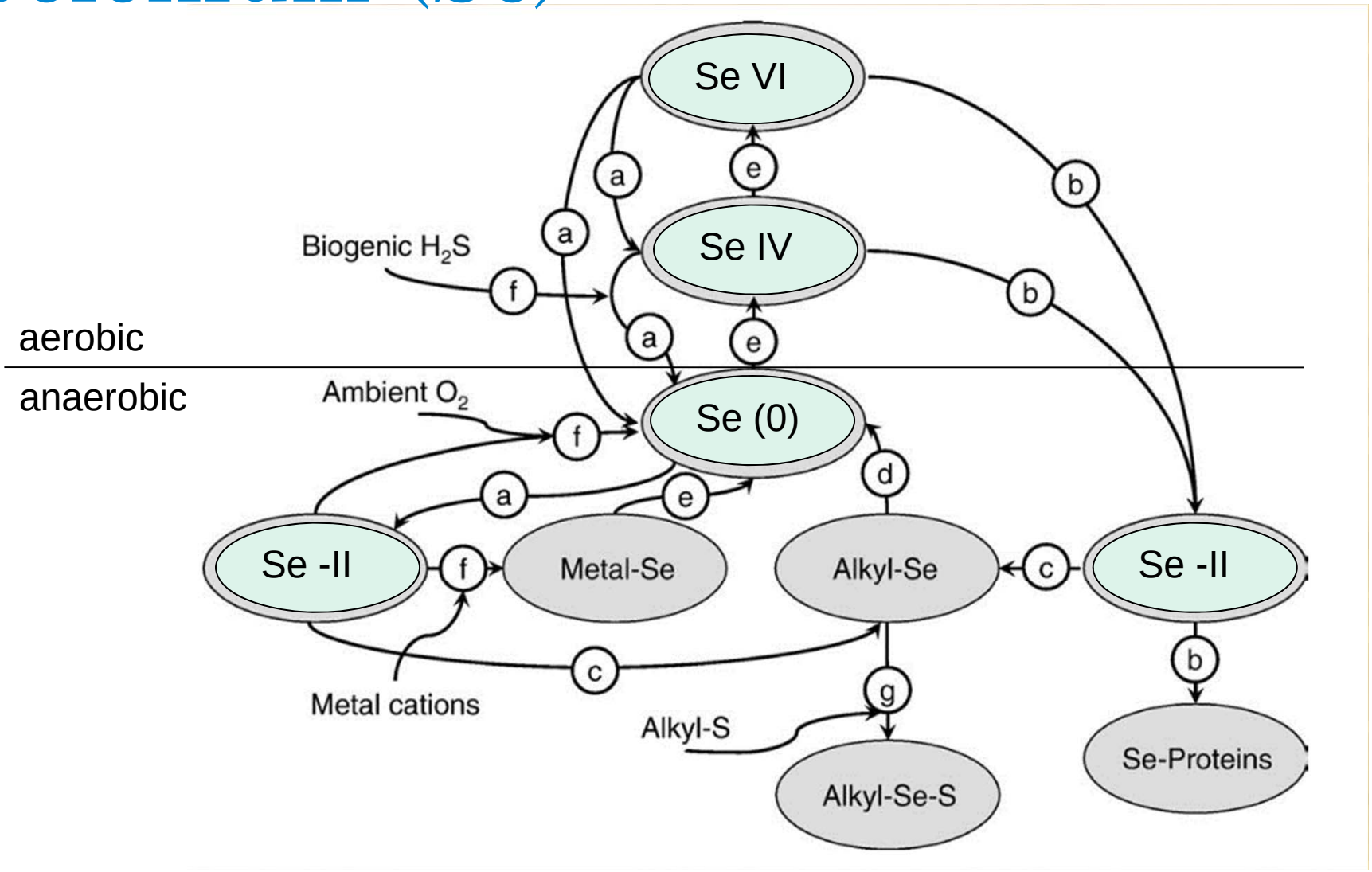


Image credits: HM Publishing, 2016; Nature's Way, 2016

Selenium (Se)

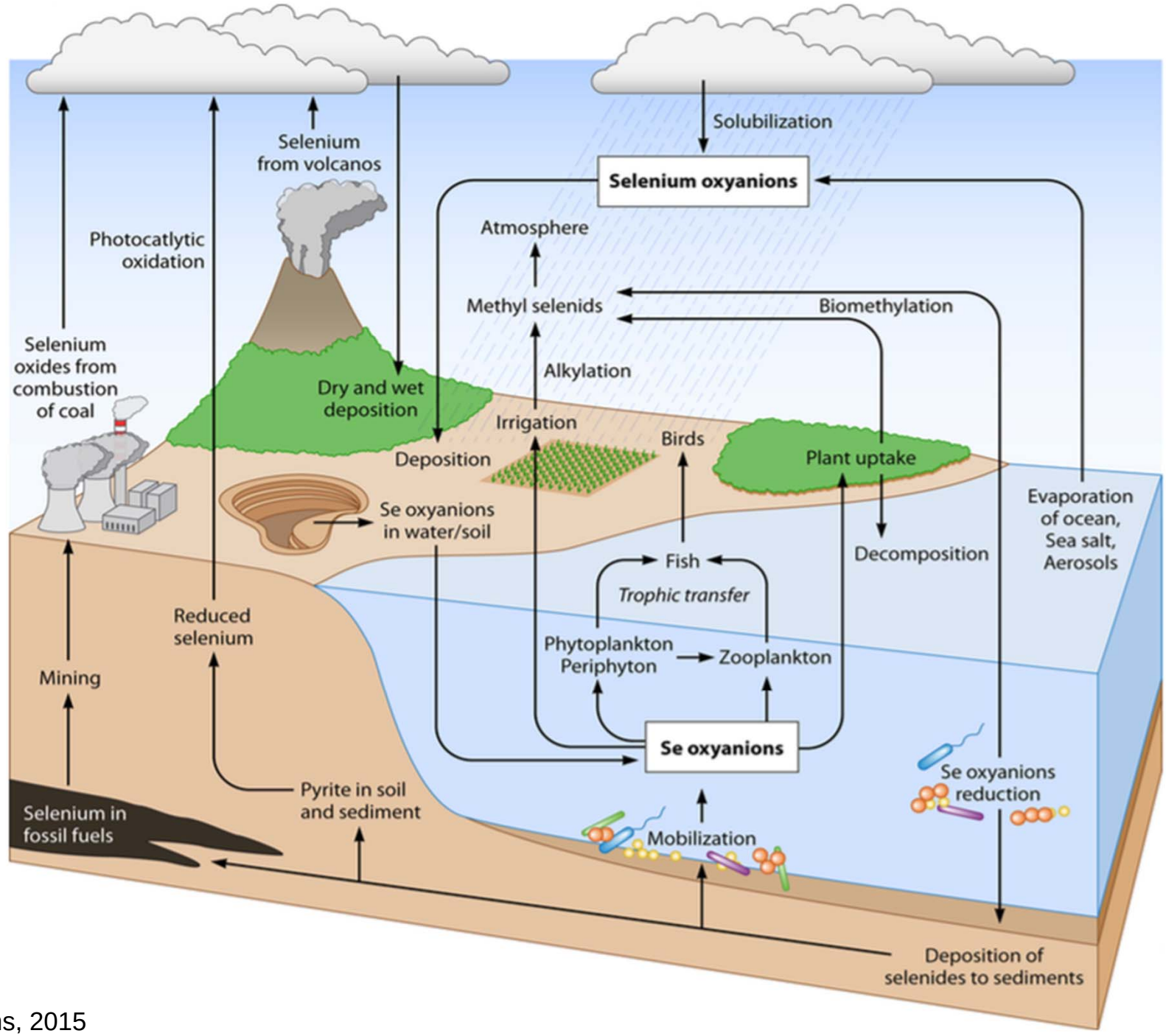
Image credits: Waterkeeper Alliance, 2014; Presser & Ohlendorf, 1987

Selenium (Se)



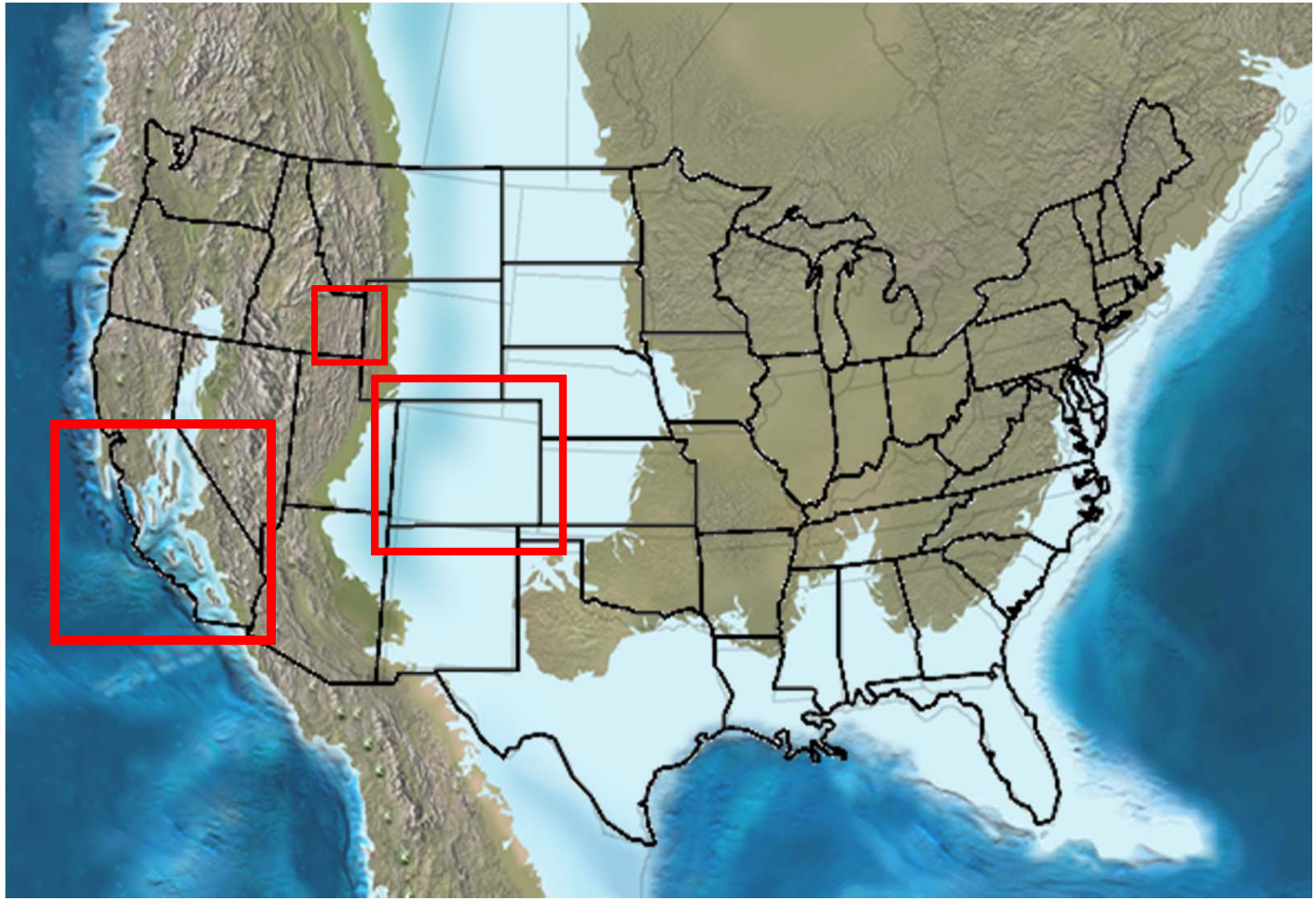
Lenz & Lens, 2009

Se



Nancharaiah & Lens, 2015

Se in the Western US



North America, Cretaceous period, 85 Ma

Image credits: Ron Blakey, Colorado Plateau Geosystems Inc.

The Salton Sea, CA

- SW U.S.
- 980 km^2
- 8 m average depth
- Eutrophic
- Highly productive
- Hypersaline

Image credits: Wikimedia Commons

The Salton Sea, CA

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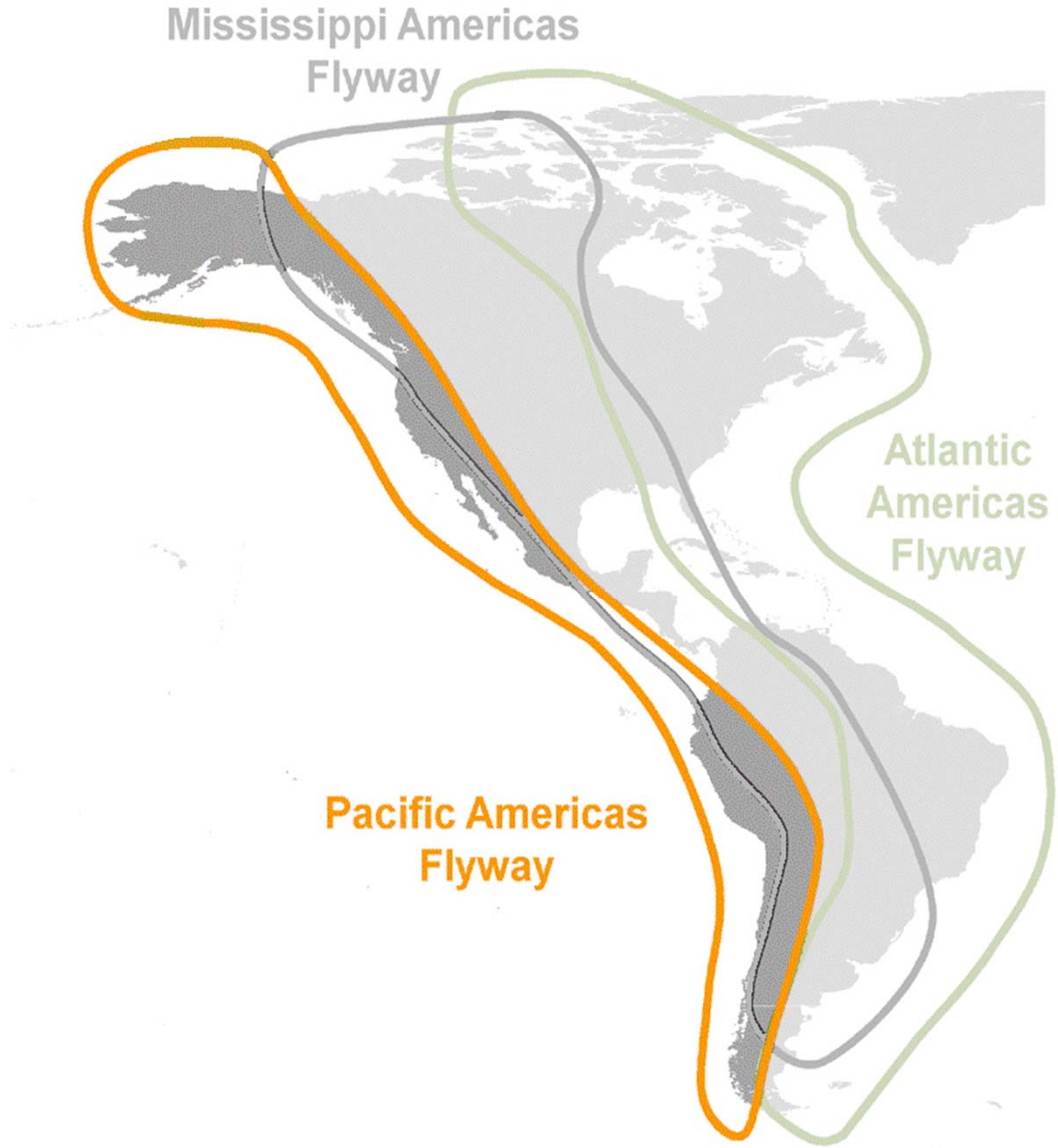

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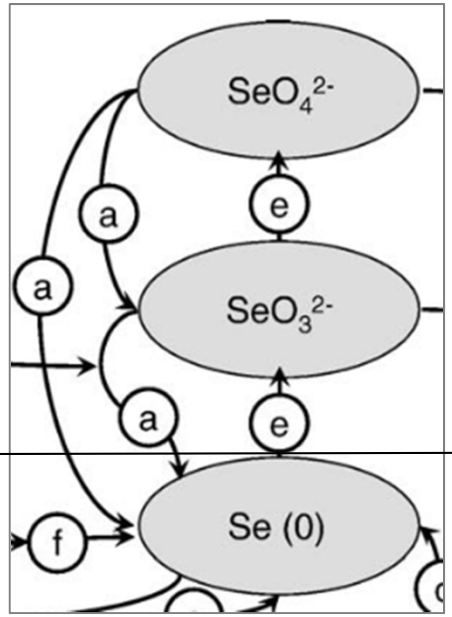
Se in sediment

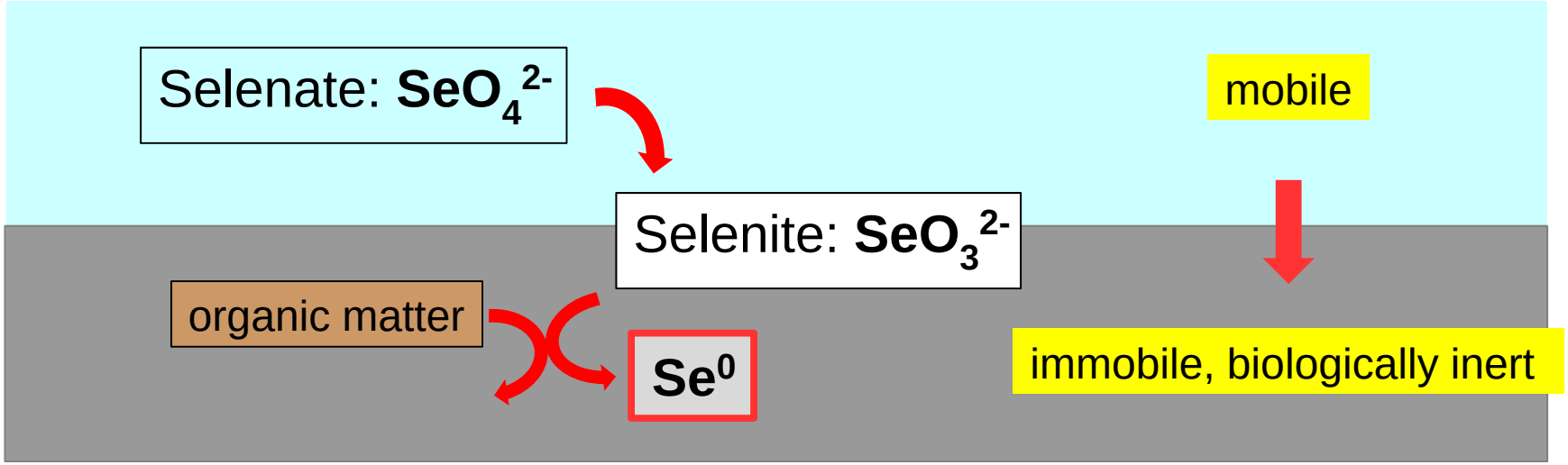


Se VI: selenate

aerobic

anaerobic

Se^0: elemental



Lenz & Lens, 2009

Selenium (Se) in the Salton Sea

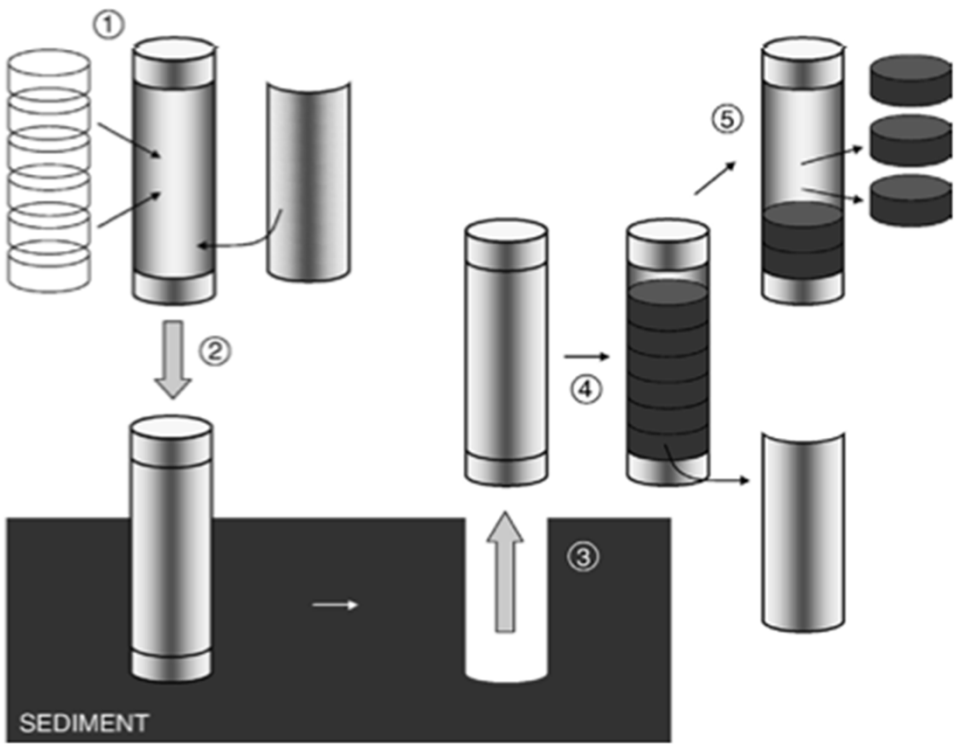
- 5 µg L^{-1} (water); 5 mg kg^{-1} (soil)
- Se is the most notable inorganic pollutant of concern
- Se is an imminent threat to birds
- Littoral sediments will be affected by a reduction in the size of the lake

Research objectives

- Evaluate differences in littoral sediment across geographical locations, depth
- Quantify selenate reduction rates and kinetic parameters for selenate reduction
- Identify the sediment parameters that control Se retention at the centimeter scale

METHODS

Flow-Through Reactors (FTRs) to sample, characterize sediment @ cm scale



- Particle size, surface area
- C_{org}, N_{TOT}, Se content
- Abundance of selenate reducers (MPN)
- Sorption
- Selenate reduction rates
- K_m , R_{max} for selenate reduction

Pallud et al., 2007

FTR

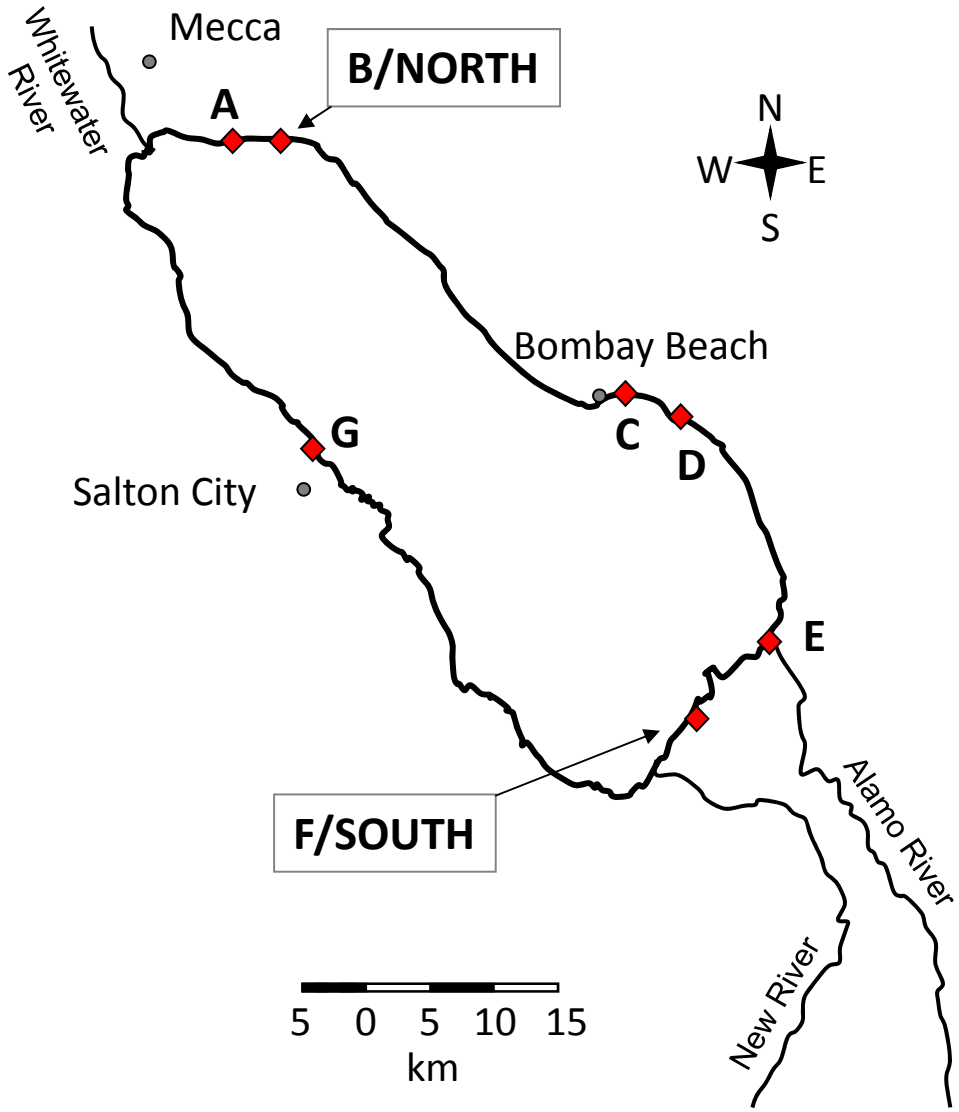


Image credits: Céline Pallud, 2015; Juan VillaRomero, 2011

Kinetics of selenate reduction, differences with depth

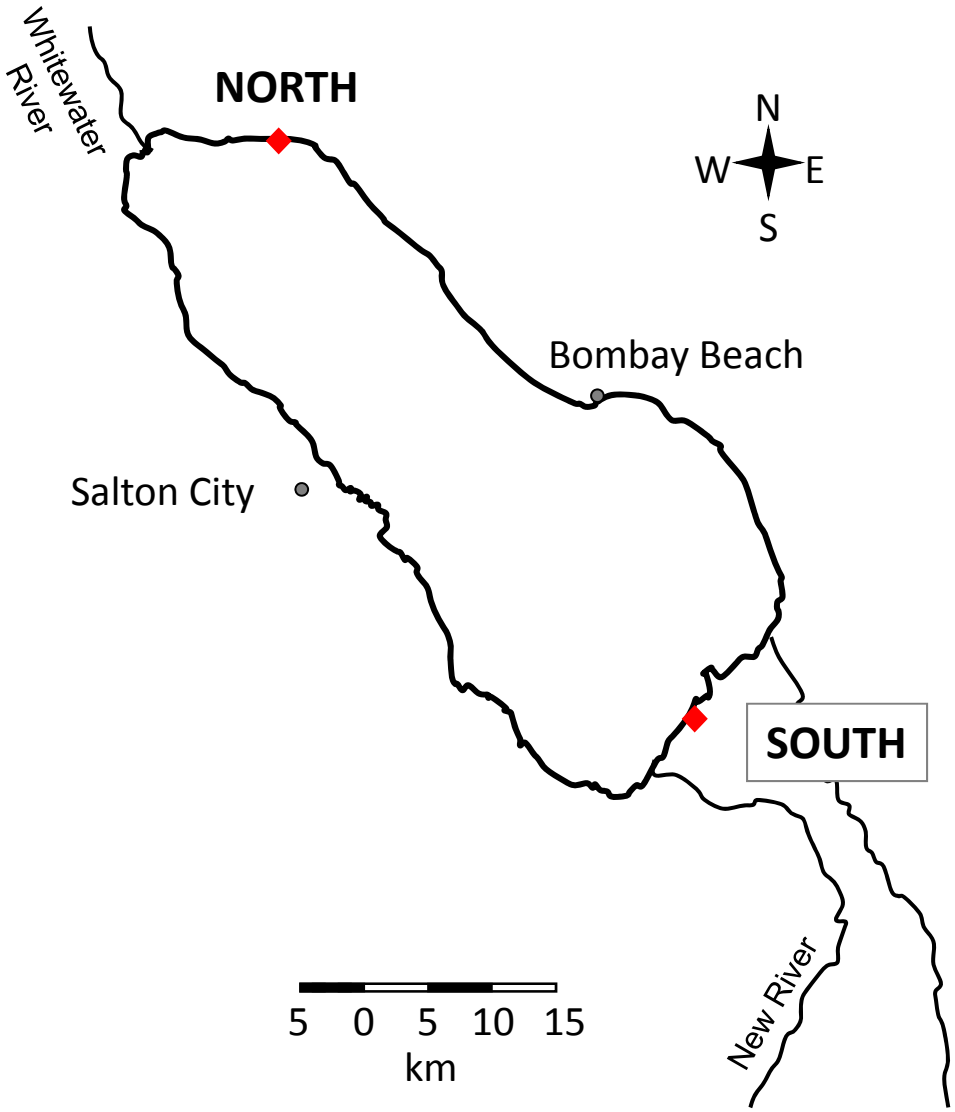
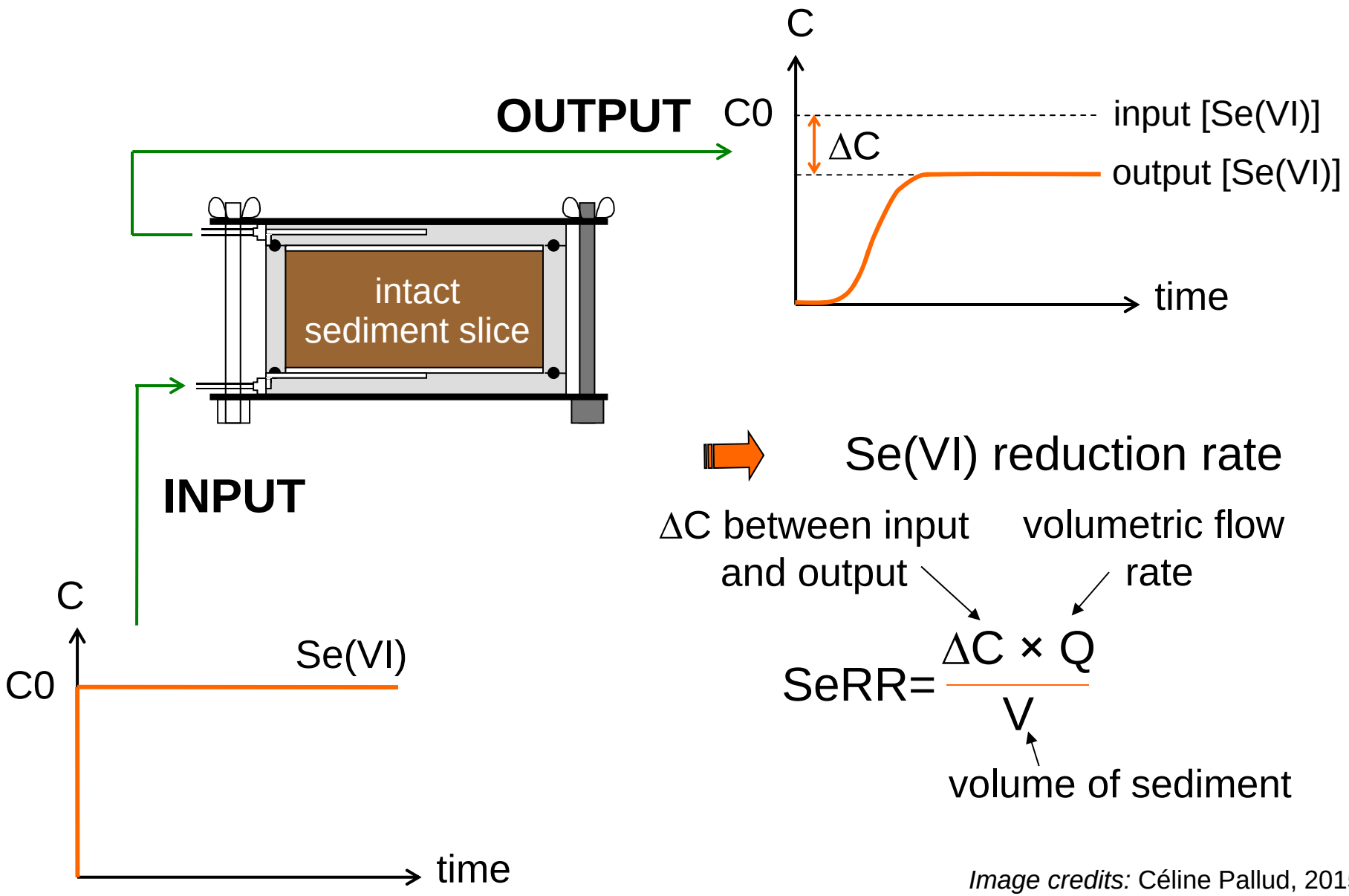


Image credits: Céline Pallud, 2015; Juan VillaRomero, 2011

FTRs: calculating rates of SeVI reduction



Se(VI) reduction rate

ΔC between input and output

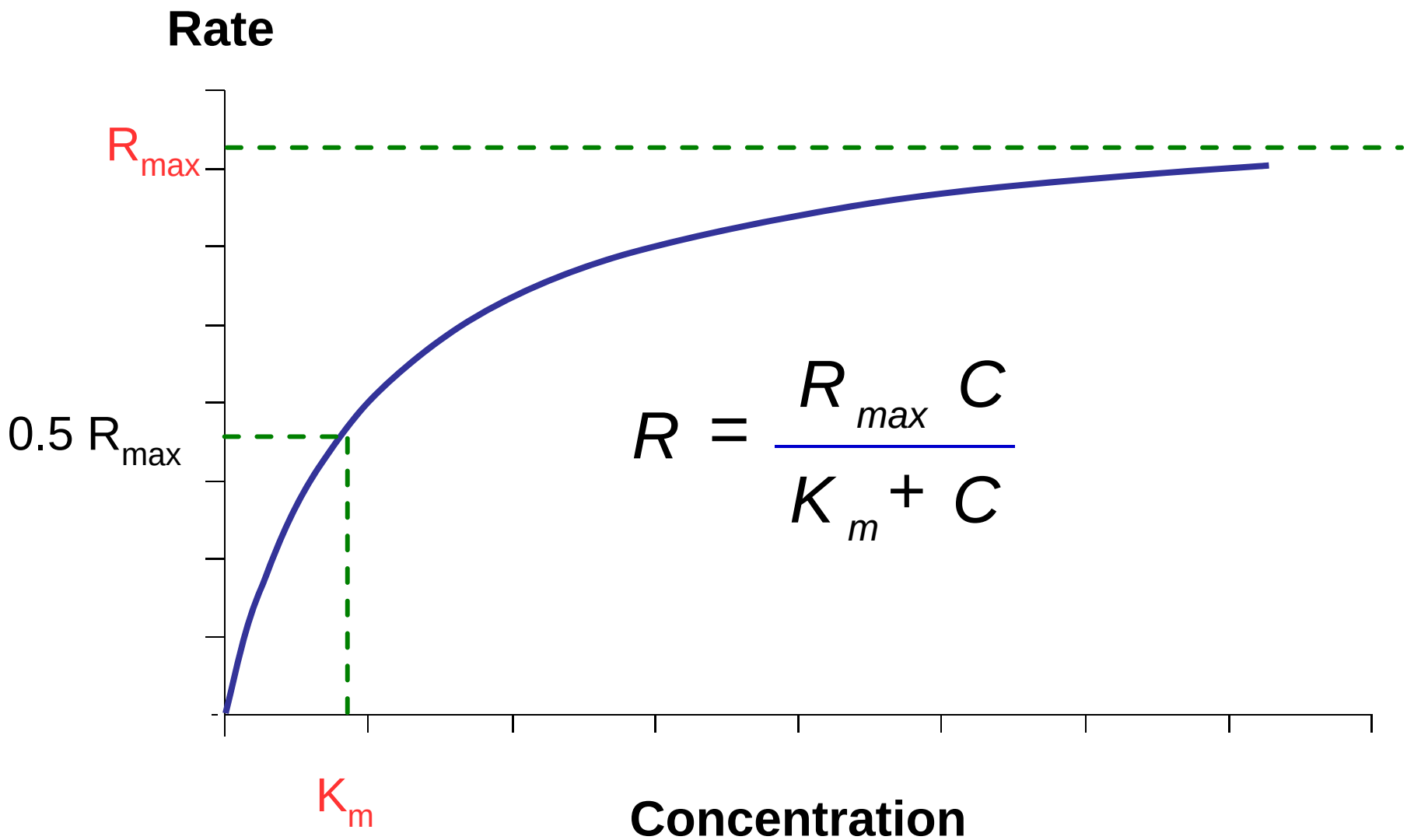
volumetric flow rate

$$SeRR = \frac{\Delta C \times Q}{V}$$

volume of sediment

Image credits: Céline Pallud, 2015

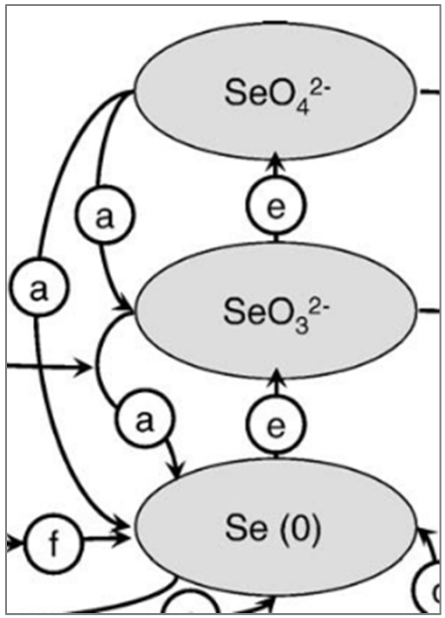
FTRs: C vs. C/R → K_m, R_{max}



$$R = \frac{R_{max}\, C}{K_m + C}$$

Image credits: Pallud et al., 2007; Céline Pallud, 2015

Most Probable Number (MPN)



$$SeO_4^{2-} + 6\ e^- \longrightarrow \mathbf{Se^0}$$

Abundance estimates: number of replicates, dilutions and positives

Image credits: Lenz & Lens, 2009; Wikimedia Commons

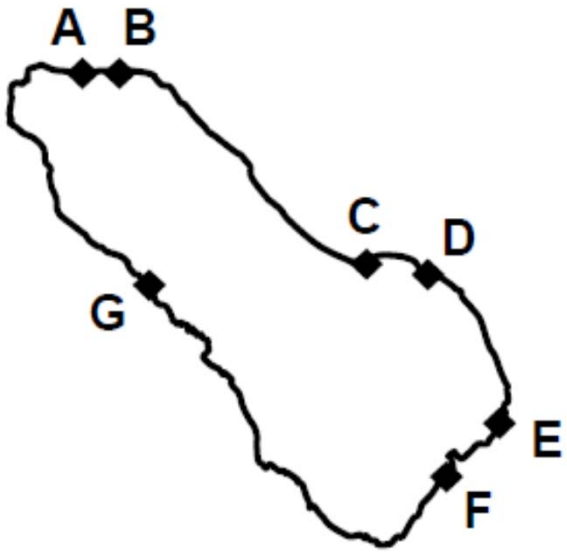
Most Probable Number (MPN)

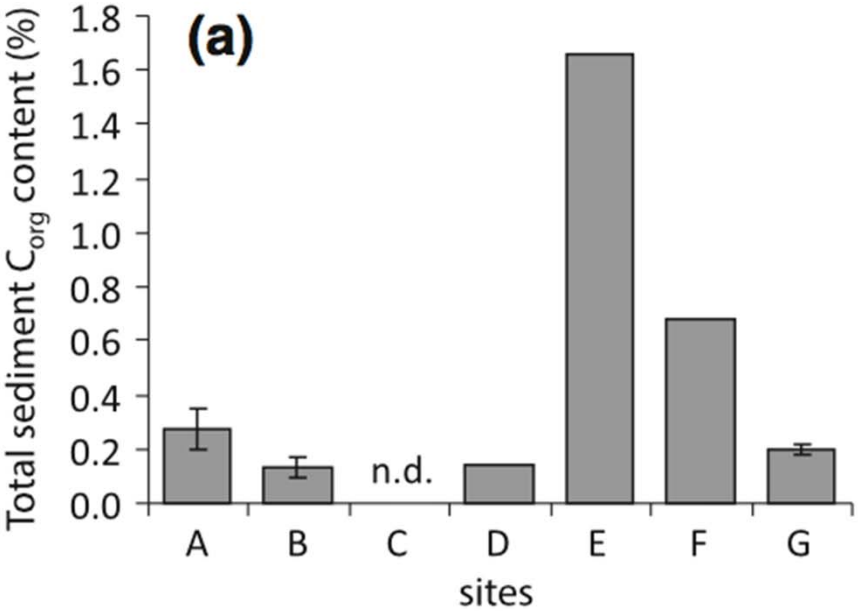
SS-1

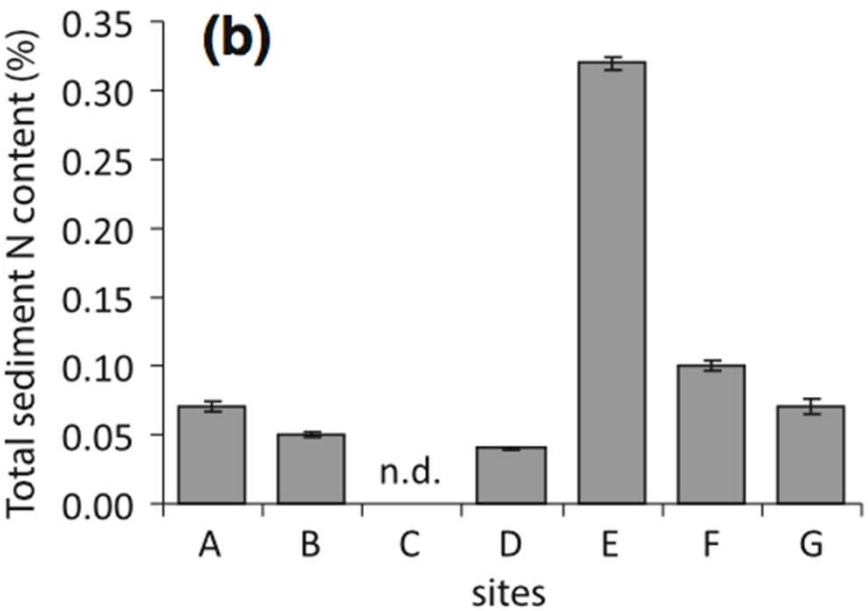
Image credits: Google Earth, JF VillaRomero

RESULTS

By geographical location







VillaRomero et al., 2013

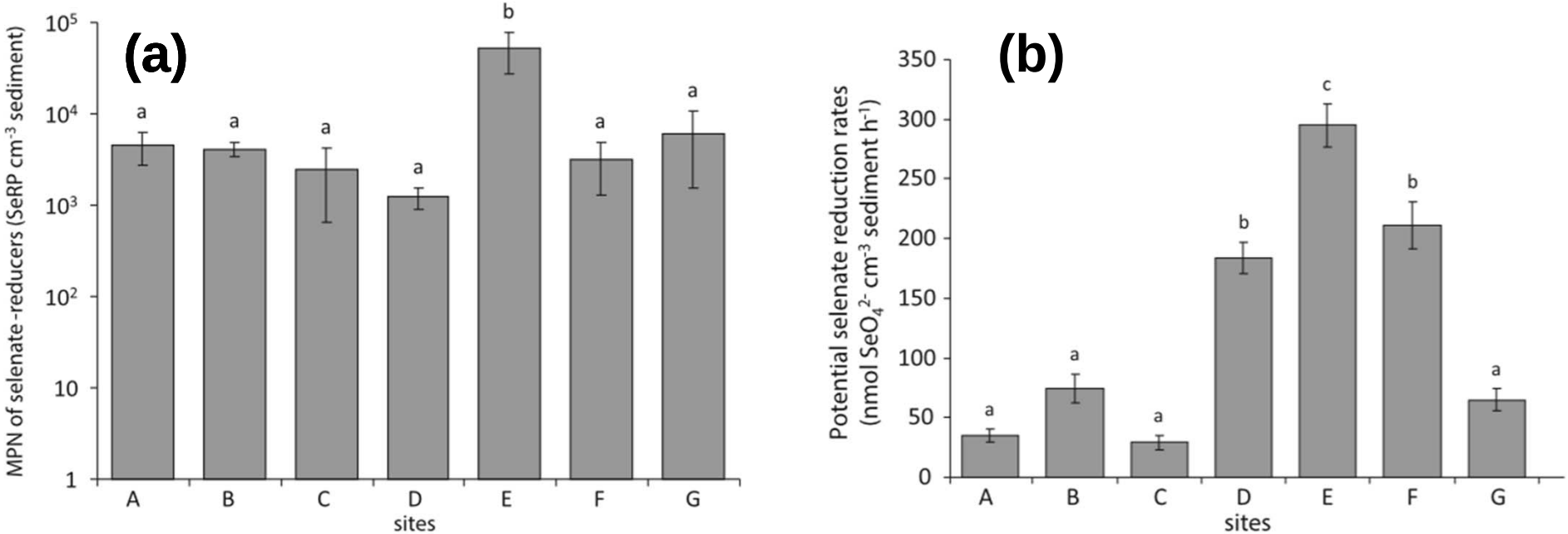
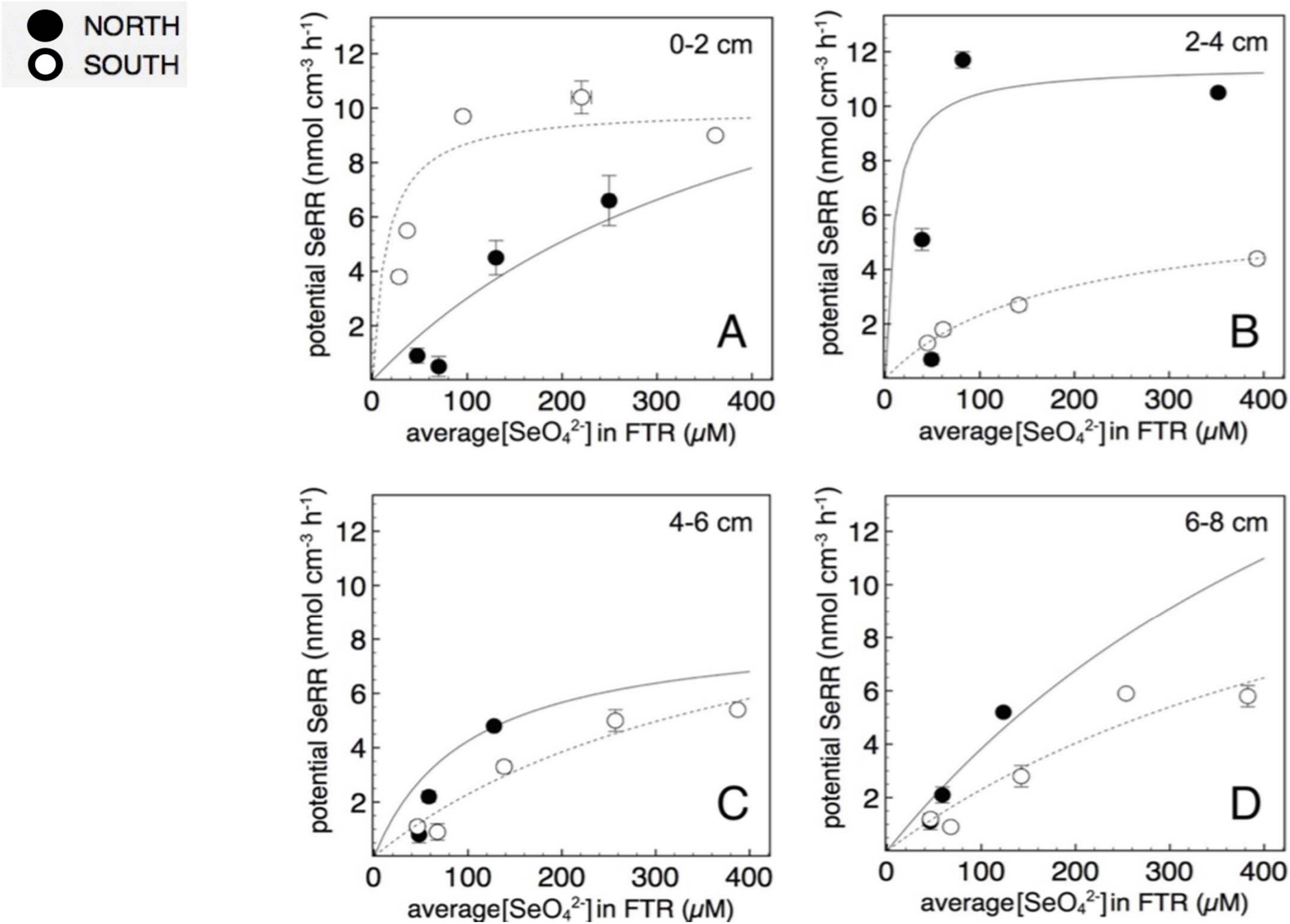


Table 1 K_f and nf parameters calculated from isotherm data fitted to the Freundlich model for our seven study sites sampled in July 2011

Sites	K_f	nf
A	bdl	bdl
B	1.42	0.8
C	0.53	1.0
D	0.22	0.5
E	bdl	bdl
F	0.61	0.7
G	1.07	0.8

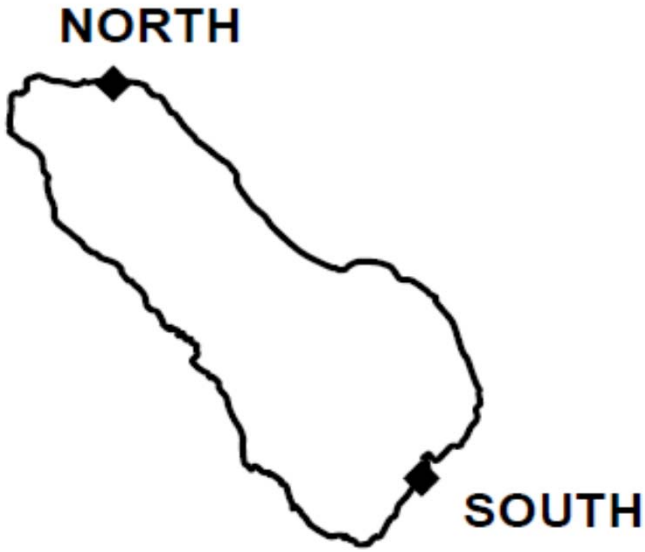
bdl below detection limits

VillaRomero et al., 2013



VillaRomero 2015, in preparation

Kinetic parameters: K_m, R_{max} by depth



		K_m	R_{max}
	cm	µM	nmol/h/cm³
NORTH	**0-2**	448.6	16.6
	2-4	10.0	11.5
	4-6	100.0	8.5
	6-8	661.0	29.2
SOUTH	**0-2**	15.0	10.0
	2-4	173.8	6.4
	4-6	420.8	11.9
	6-8	616.1	16.5

VillaRomero 2015, in preparation

Kinetic parameters: K_m

TABLE 2. Potential rates of selenate reduction in surficial sediments at 25°C and apparent K_ms for selenate

Site	Total selenium (μmol kg^{-1})	Selenate reduction (μmol l^{-1} h^{-1})	K_m (μM SeO_4^{2-})
Massie Slough	48 ± 0	22.07 (expt 1)	62[a]
		10.65[b] (expt 2)	720[b]
Big Soda Lake[c]	19 ± 0	3.57	34
Lead Lake	1 ± 0	3.01	16
Searsville Lake	19	1.91	20
Hunter Drain	14 ± 1	0.74	7.9
June Lake	5 ± 0	0.51	ND[d]
San Francisco Bay	4	0.41	22
Big Soda Lake[e]	140 ± 0	0.21	ND
San Francisco salina	2	0.12	ND
Mono Lake[e]	9 ± 0	0.07	ND
Roadside salina	8 ± 0	<0.01	ND

Steinberg & Oremland, 1990

Selenium accumulation in Salton Sea littoral sediments - conclusions

- Littoral sediment is biogeochemically diverse: parameter, location, depth
- Potential selenate reduction rates are six orders of magnitude greater than selenium input. Virtually all Se remains sequestered in sediments
- Potential selenate reduction rates, highest in site with the highest C_{org} and N content. Role of salinity, microbial reduction vs. abiotic sorption.
- Highest selenate reduction potential and highest R_{max} do not coincide spatially

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Microbial metabolism: ~4 BY

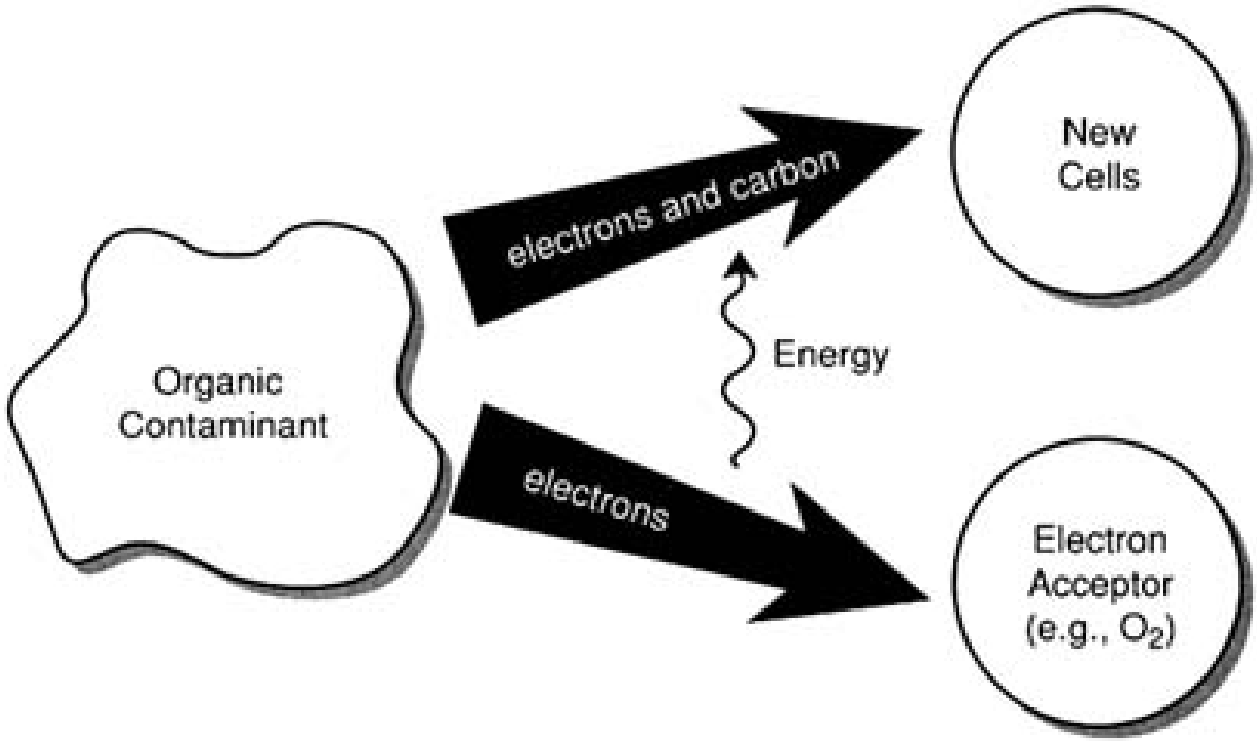


Image credits: In-situ bioremediation, National Academy Press, 1993

Microbial metabolism: ~4 BY

Environment International

Volume 61, November 2013, Pages 98–114

Review

Microbial degradation of polyfluoroalkyl chemicals in the environment: A review

Jinxia Liu[a], Sandra Mejia Avendaño[b]

Finding microbes

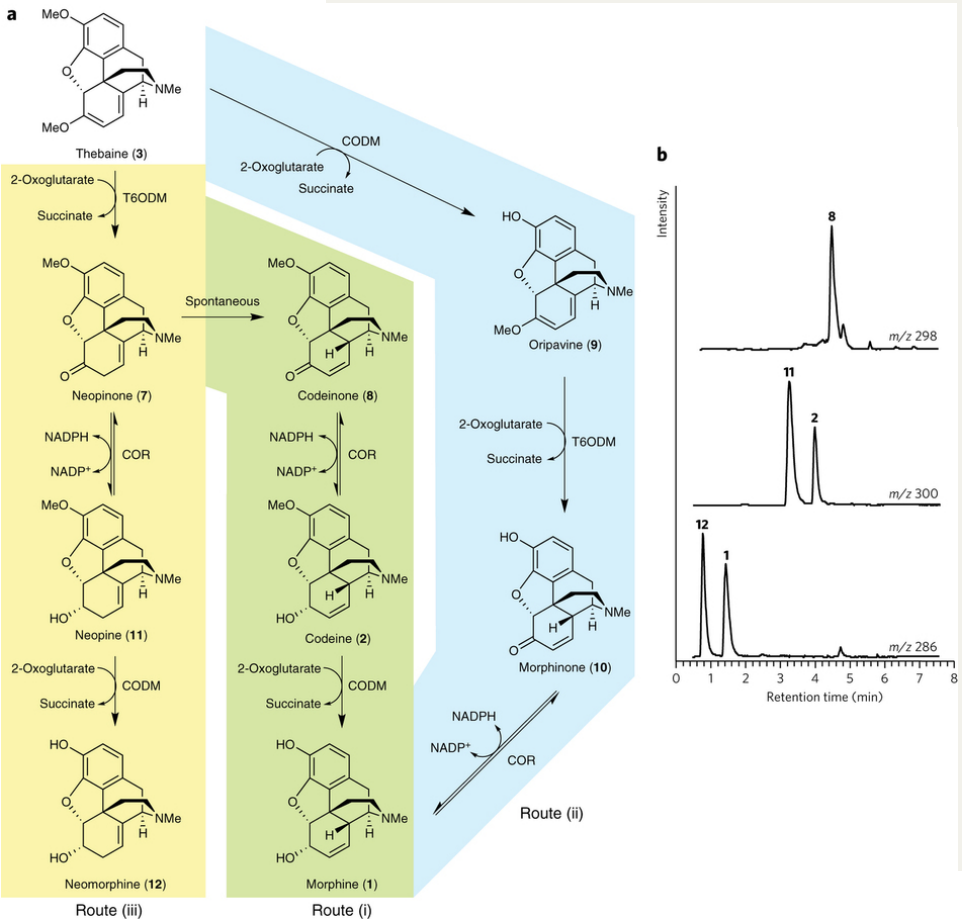
SS-1

Image credits: Google Earth, JF VillaRomero

Engineering microbes

AUGUST 13, 2015

Stanford researchers genetically engineer yeast to produce opioids



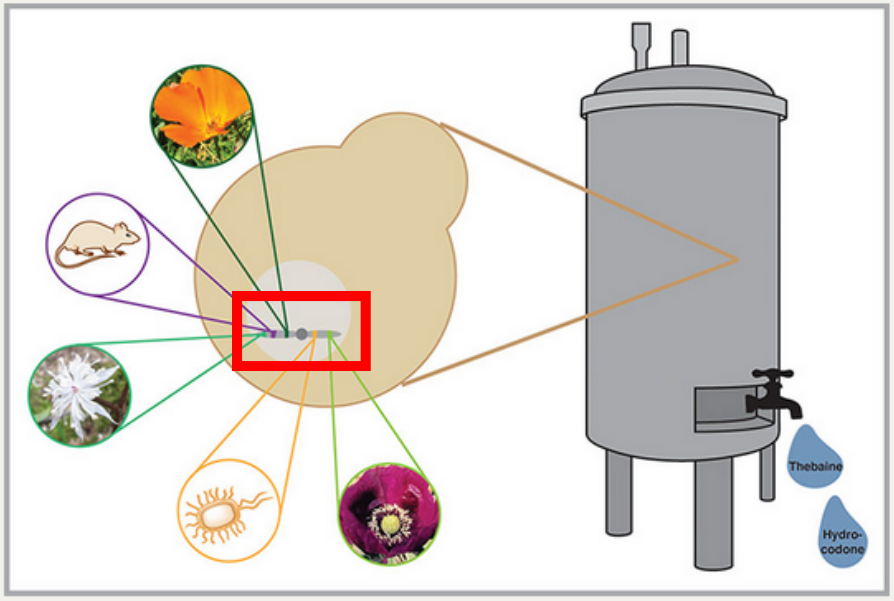
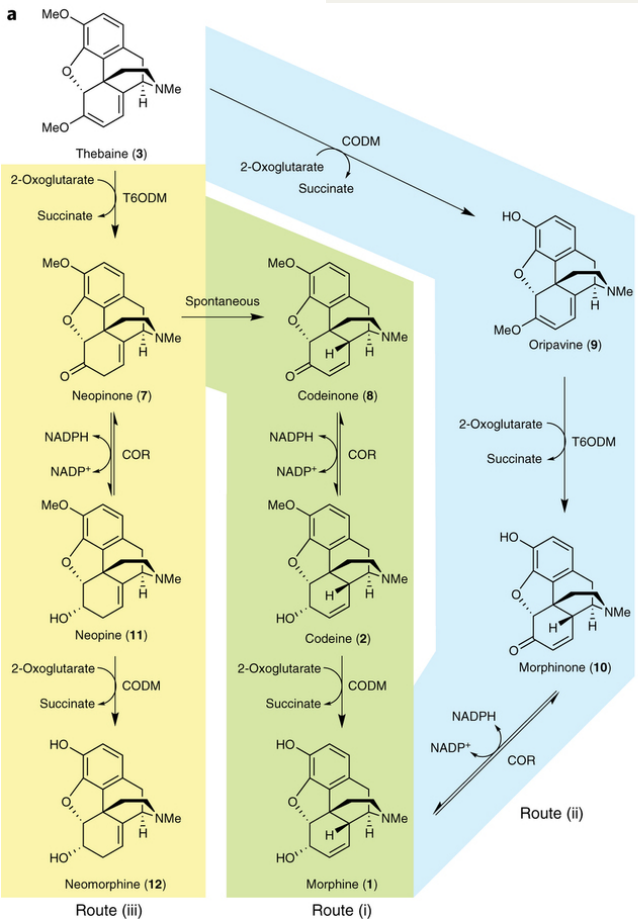


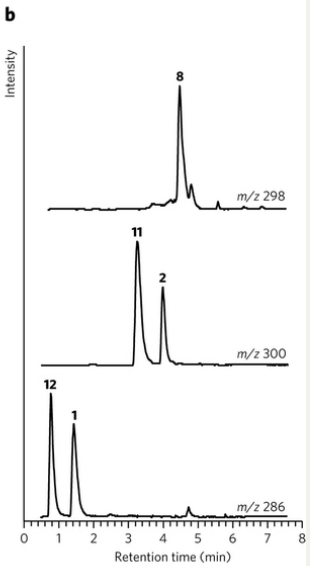
Image credits: Thodey et al., 2014; Stanford University, 2016

Engineering microbes

AUGUST 13, 2015

Stanford res[illegible]rche[illegible] genetically engineer yeast to produce [illegible]pioids





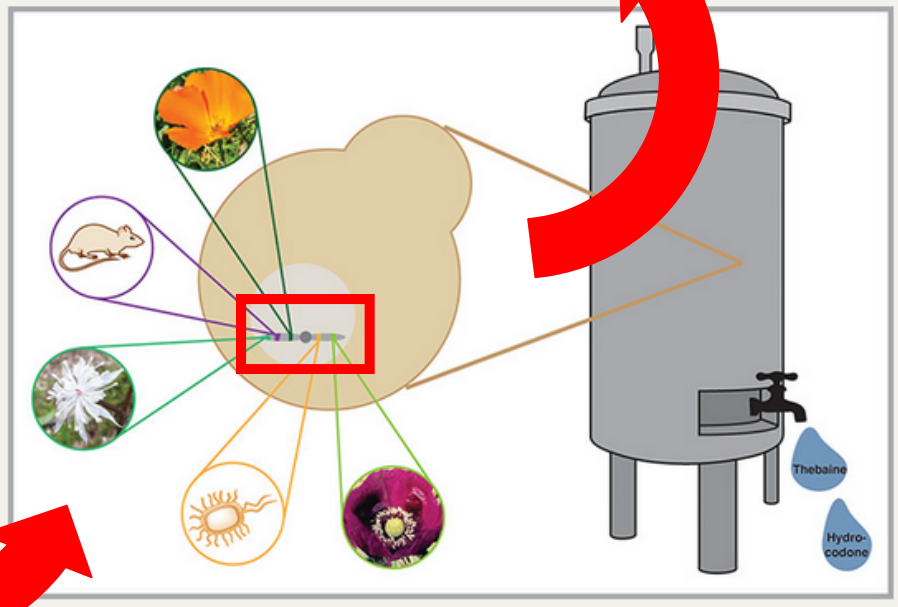


Image credits: Thodey et al., 2014; Stanford University, 2016

Engineering microbes

Trends in Biotechnology

Cell PRESS

Volume 23, Issue 3, March 2005, Pages 135–142

Accessing microbial diversity for bioremediation and environmental restoration

Debarati Paul, Gunjan Pandey, Janmejay Pandey, Rakesh K. Jain

Harnessing microbial gene pools to remediate persistent organic pollutants using genetically modified plants—a viable technology?

Elizabeth L. Rylott*, Emily J. Johnston and Neil C. Bruce

+ Author Affiliations

* To whom correspondence should be addressed. E-mail: liz.rylott@york.ac.uk

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First published online: August 17, 2015

Microbial removal of Se

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Image credits: SiREM, 2016

Engineering the human microbiome to eliminate pollutants?

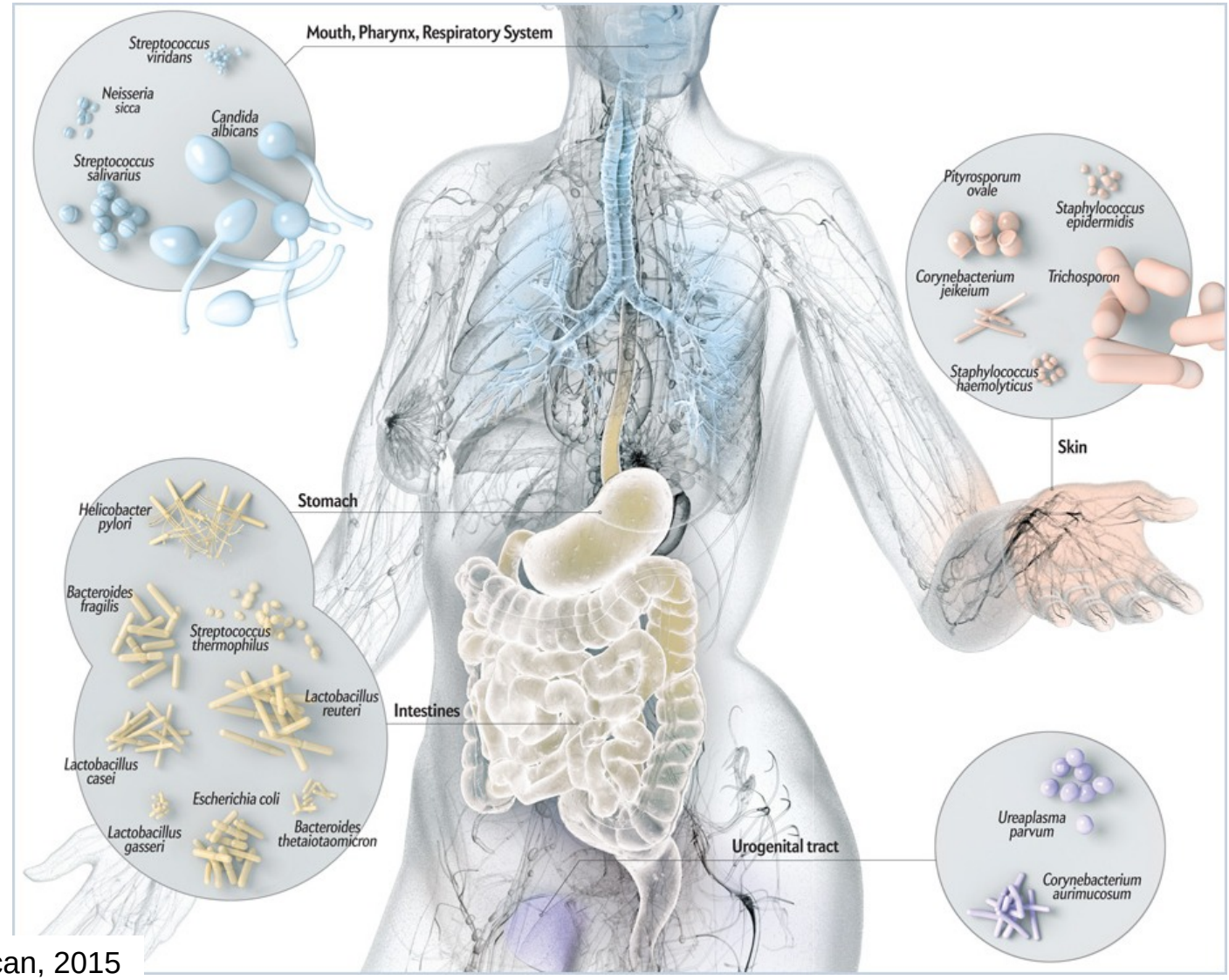

Image credits: Scientific American, 2015

Acknowledgments

- Céline Pallud & Pallud Lab of Soil Biogeophysics and Biogeochemistry
- Department of Plant and Microbial Biology, University of California, Berkeley
- Environmental Protection Agency Grant STAR FP-91727201

Questions?

Image credits: Juan VillaRomero, 2012