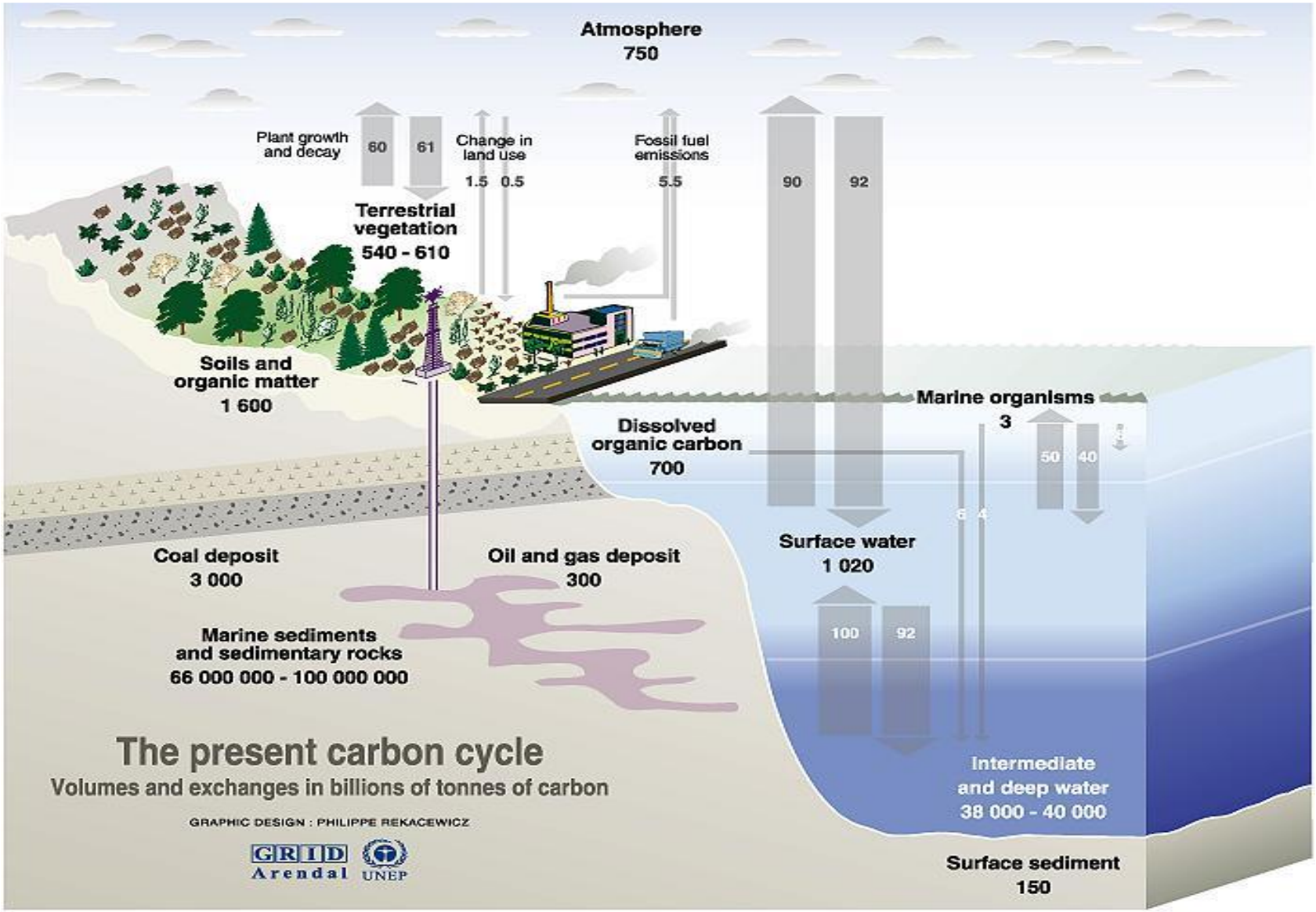
Some challenges and opportunities in our quest to understand and monitor carbon cycling

Are we responsible for current global warming??

Even if climate change is not anthropogenic, should we still monitor carbon?

CARBON CYCLING <u>KNOWN KNOWNS</u>:



Sources: Center for climatic research, Institute for environmental studies, university of Wisconsin at Madison; Okanagan university college in Canada, Department of geography; World Watch, November-December 1998; Climate change 1995, The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge press university, 1996.

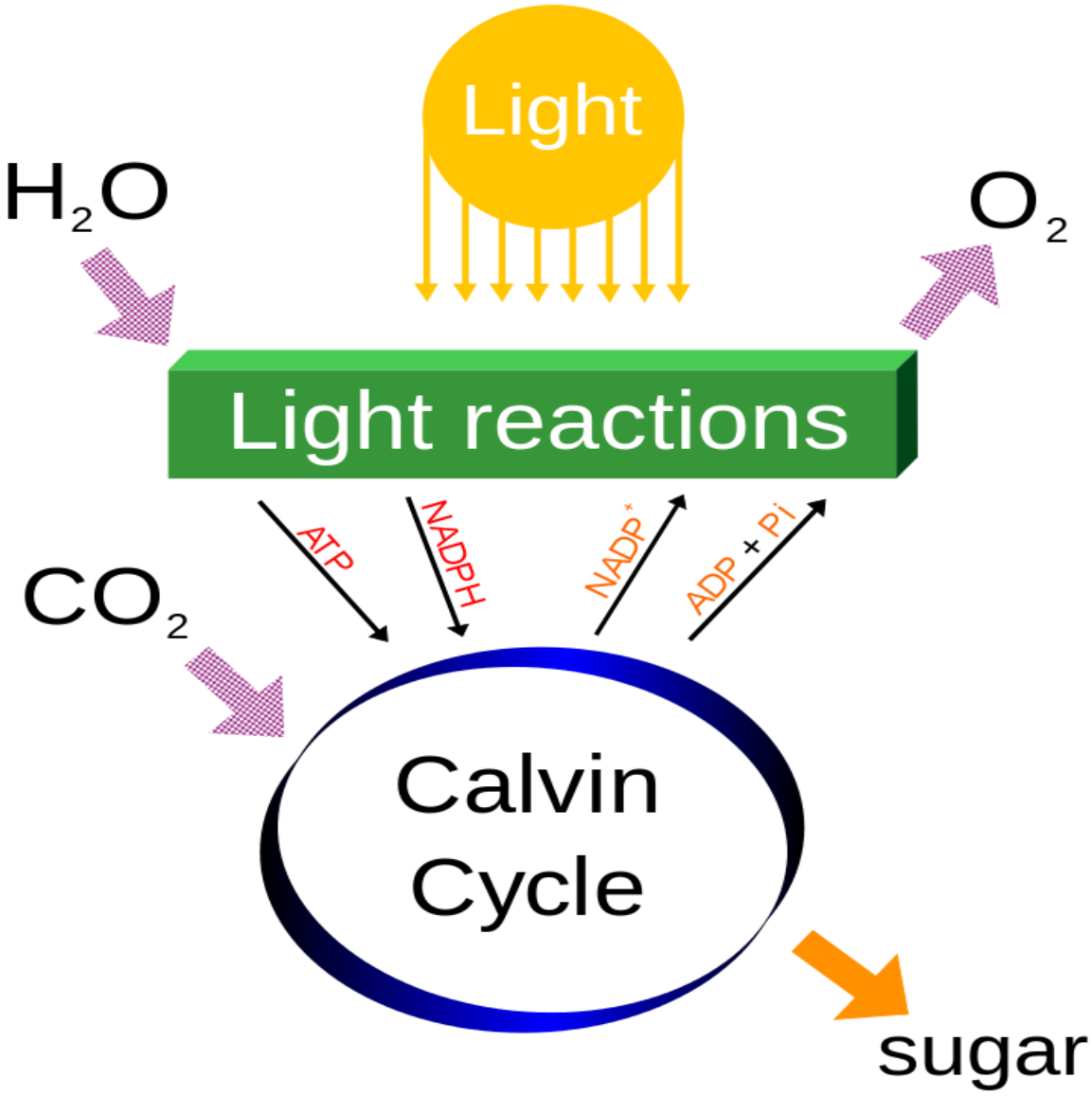
CARBON CYCLING KNOWN UNKNOWNS:

~ 25% of anthropogenic CO_2 is "missing"!

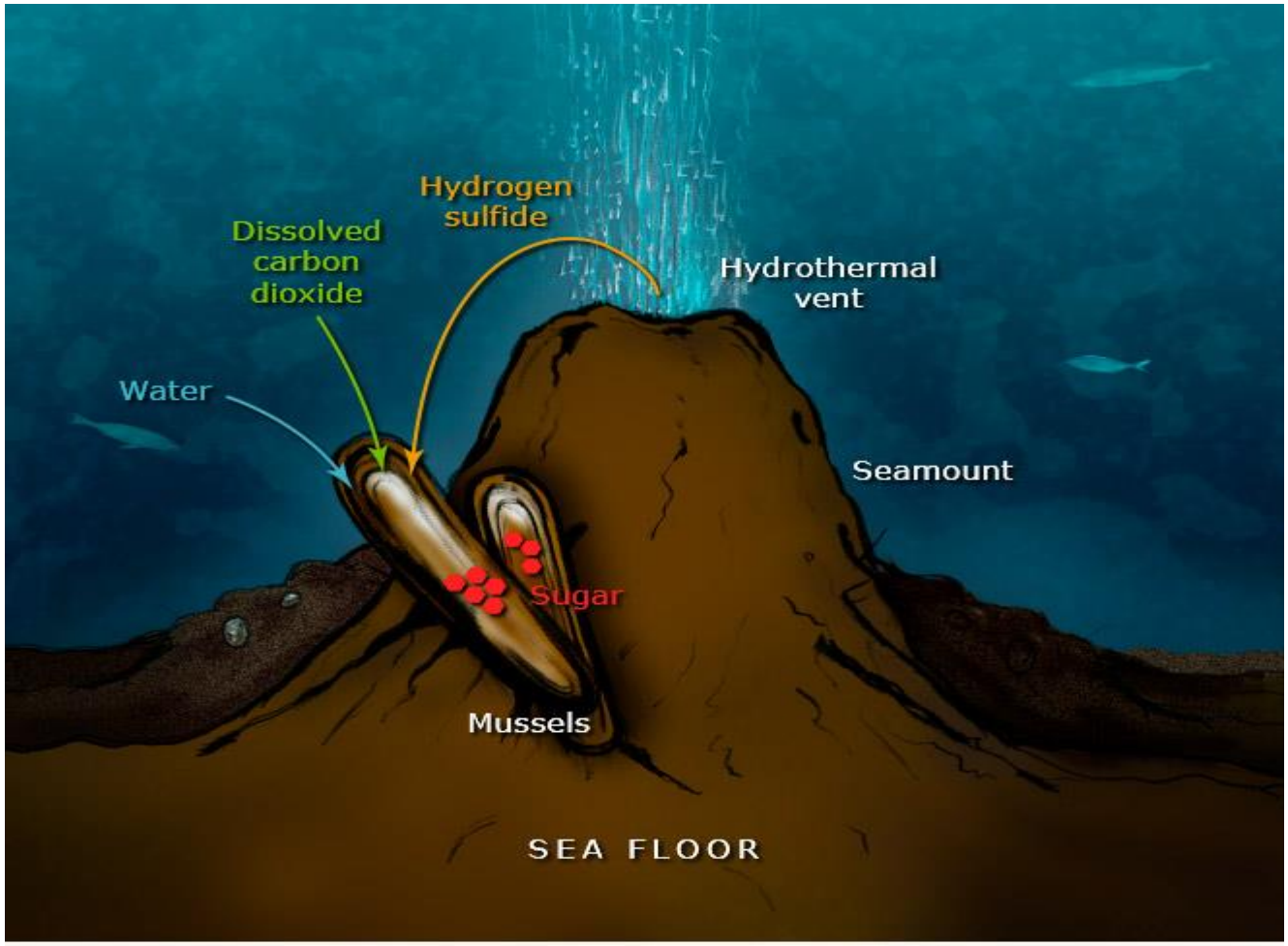
CARBON CYCLING <u>UNKNOWN UNKNOWNS</u>:

??????????????????????????????

A major component of the carbon cycle**: Photosynthesis**



Chemosynthesis



$$6CO_2 + 6H_2O + 3H_2S \longrightarrow C_6H_{12}O_6 + 3H_2SO_4$$

Carbon dioxide + Water + Hydrogen sulfide ⟶ Sugar + Sulfur compounds

Chemosynthesis is not everywhere, it's only found deep in the ocean, near thermal vents!!!!!!!!!!!!!!!!!

The Grand Prismatic Spring, Yellowstone National Park

"*we know more about the movement of celestial bodies than the soil underfoot*". **Leonardo Da Vinci**

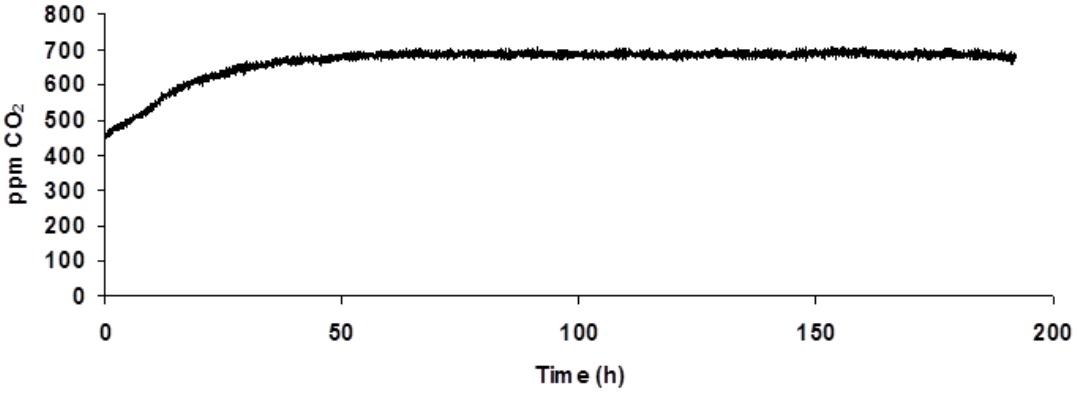
Soil Chemosynthesis??

- We investigated how the addition of elemental sulfur (Sº) affects an agricultural soil by incubating both an unaltered and an Sº amended arable soil.
- The incubations were carried out in both $^{12}CO_2$ and $^{13}CO_2$ atmospheres under close to natural CO_2 concentrations (400ppm).
- The efflux (CO_2 production through respiration and degradation), CO_2 uptake and net change in atmospheric CO_2 caused by the incubated soils was continuously measured.
- The $^{13}CO_2$ experiments facilitated the combination of Stable Isotope Probing (SIP), Nuclear Magnetic Resonance (NMR) and phospholipid fatty acid (PLFA) analysis with compound specific stable isotope mass spectrometry that we use to track the fate of atmospheric CO_2.

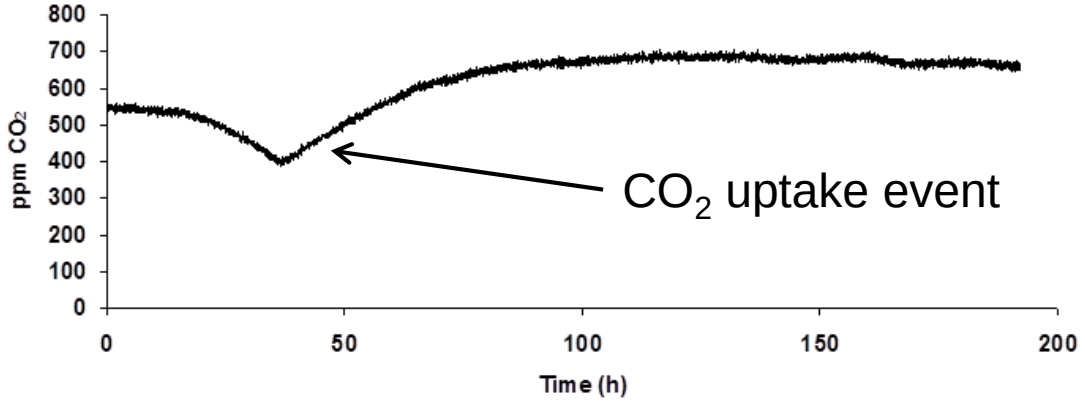
CO_2 uptake Investigations

An order of magnitude increase in CO_2 assimilation in soil occurred when conditions for chemosynthesis existed.

No electron donor



Sulfur added as an electron donor



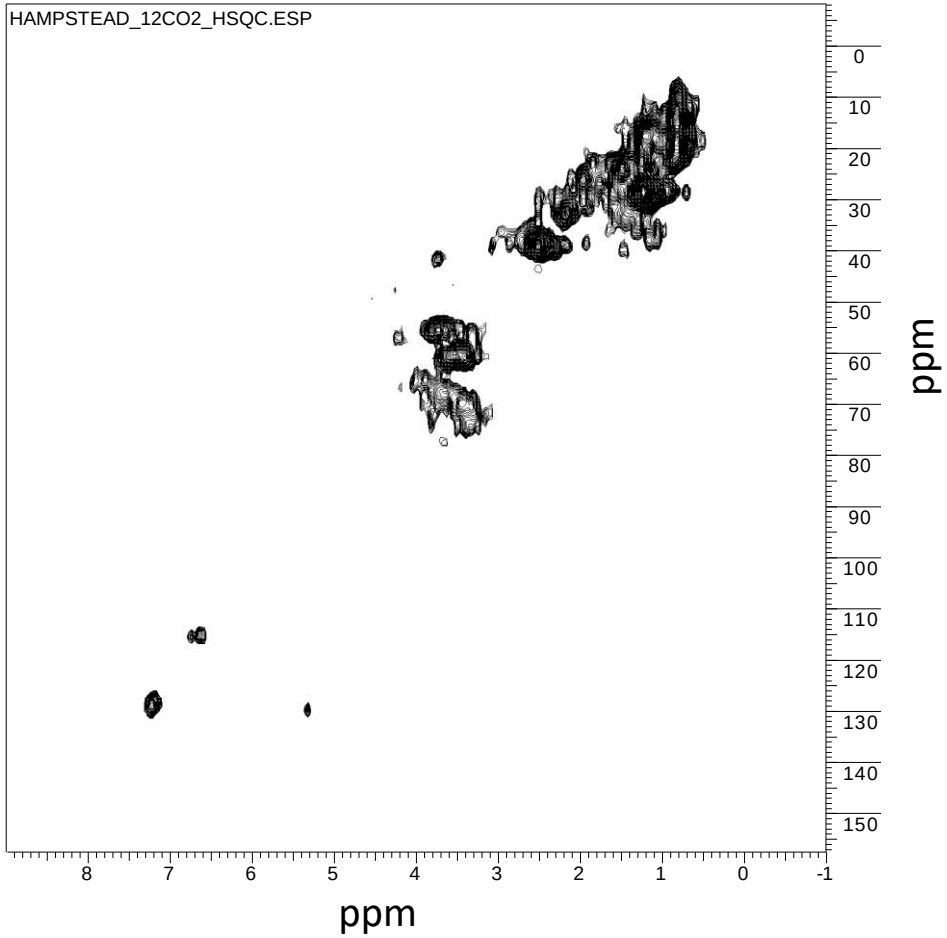
K. M. Hart, S. F. Oppenheimer, B. W. Moran, C. C.R. Allen, V. Kouloumbos, A.J. Simpson, L. A. Kulakov, L. Barron, B. P. Kelleher. 2013. *Soil Biology & Biochemistry*. 57, 615-624.

Tracking the fate of chemosynthetic uptake of atmospheric CO_2 in soil:

- NMR analysis of soil organic matter before and after the application of electron donor in atmosphere enriched with $^{13}CO_2$
- Comparison of the 1D solid phase CP-MAS ^{13}C NMR spectra before and after labeling allows us to quantify the increase in total carbon signal in the soils due to uptake of $^{13}CO_2$.
- By subtracting the NMR spectra of the $^{12}CO_2$ from the $^{13}CO_2$ incubations we can see carbon incorporated into soil as a result of chemosynthesis.

K. M. Hart, C. C. R. Allen, A. J. Simpson, S. F. Oppenheimer, P. V. Flanagan, B. T. Murphy, B. P. Kelleher. Tracking the fate of microbially sequestered carbon dioxide in soil organic matter. *Environmental Science & Technology.*, 47, 5128-5137. 2013.

^{1}H–^{13}C HSQC NMR analysis of soil organic matter before the application of electron donor in atmosphere enriched with $^{13}CO_2$



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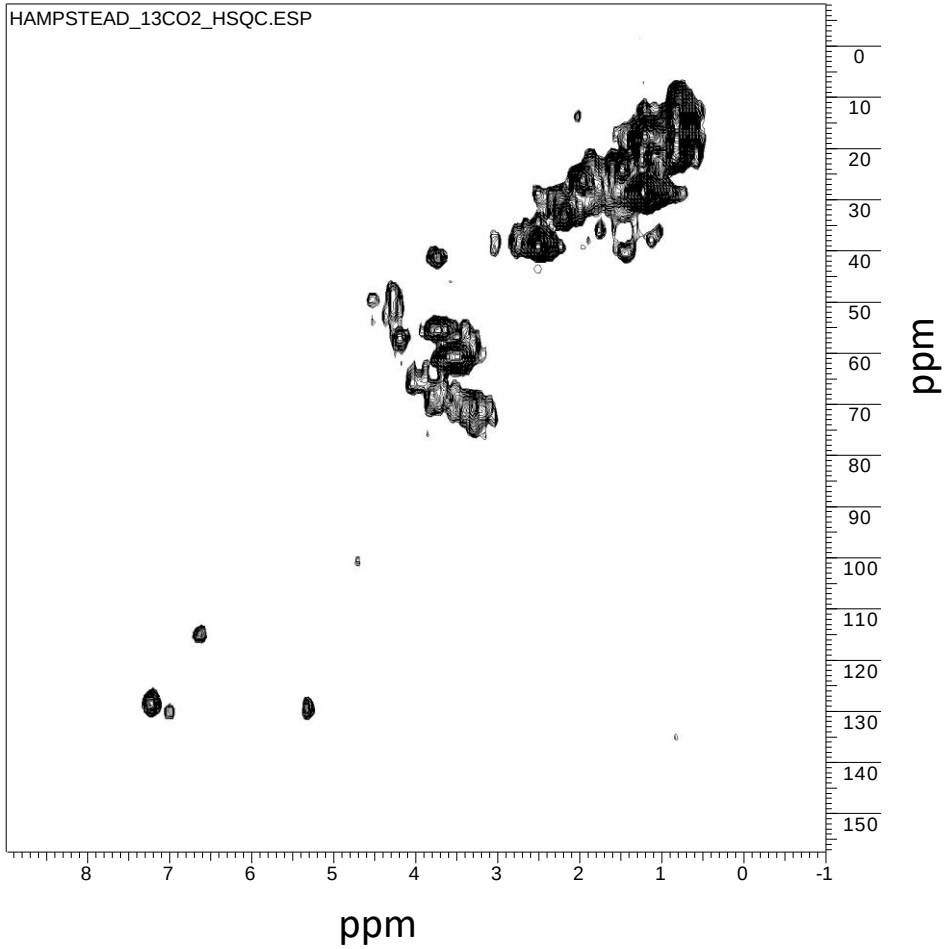

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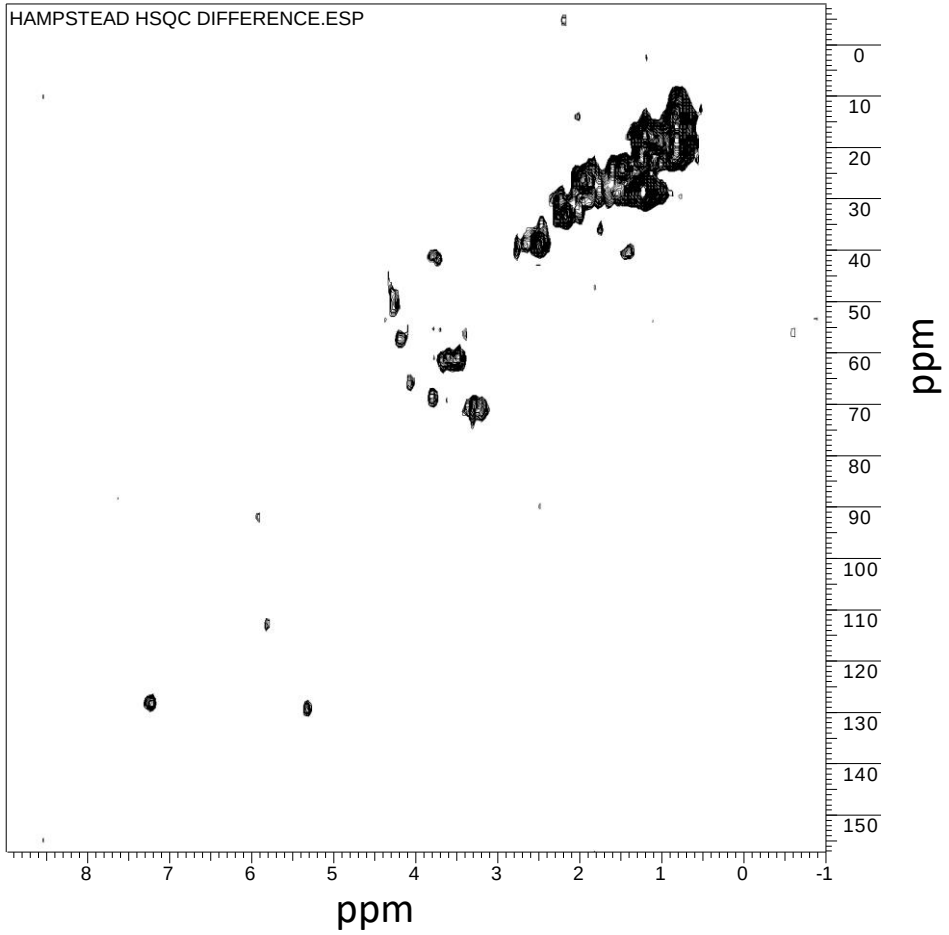
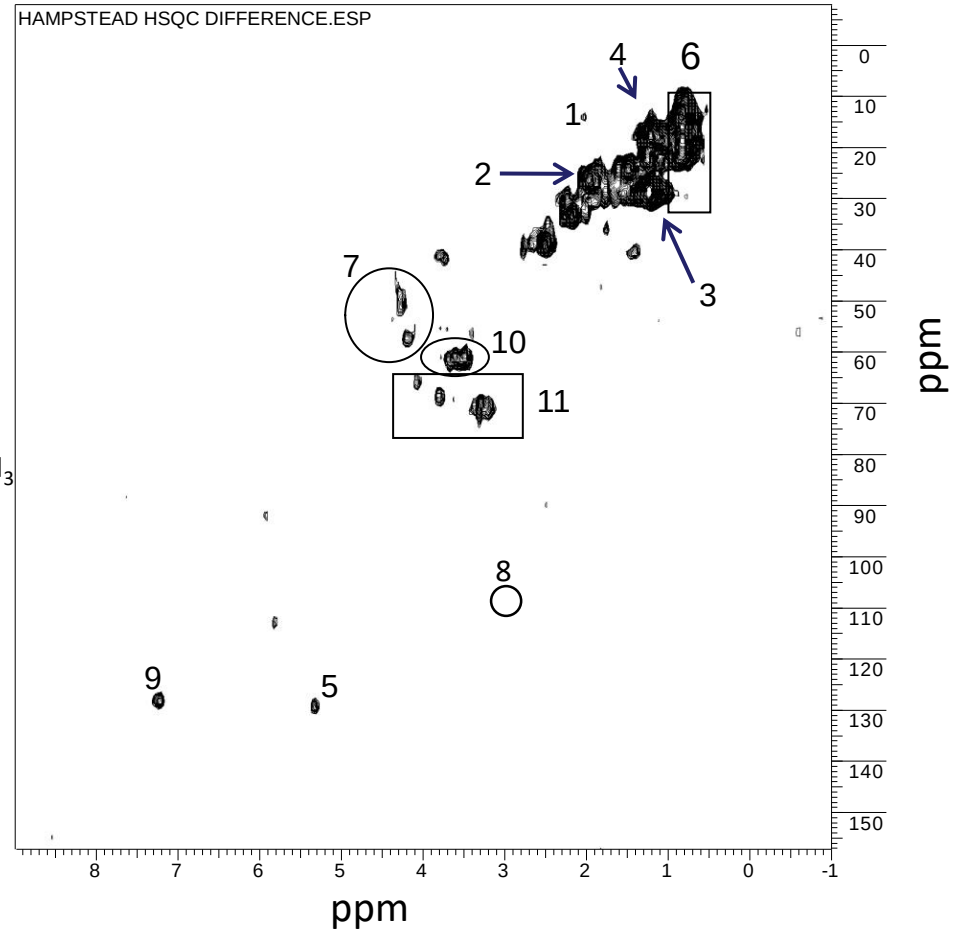


^{1}H–^{13}C HSQC Difference – I.E. soil that has been ^{13}C enriched

1 = Acetyl group.
2 = R-**CH_2**-COOH in lipids
3 = R-**$(CH_2)_n$**-R main chain in lipids
4 = R-**CH_2**-CH_2-COOH in lipids
5 = Unsaturation in lipids
6 = Overlap of CH_3 from lipids and CH_3 in amino acids in protein side chains
7 = α H-C units in peptides/proteins
8 = Tyrosine - missing
9 = Phenylalanine
10 = CH_2 in carbohydrates
11 = CH in carbohydrates



Latest experiments show that soil organic matter increases by approximately 64% over 12 weeks as a result of the addition of an electron donor, in this case sulfate, to soil.

If we underestimate chemosynthetic contributions to soil organic matter, do we also underestimate Its contribution to carbon cycling??

- We now know that ~50% of all the Earths biomass is present in soils and sediments as bacteria,
- It is certain that much of this biomass is comprised of CO_2 fixing potential.

Prediction of Irish Coastal Transformations.

Integrating multidisciplinary geoscientific data into forecasting models to monitor and predict coastal change: Proof of concept in Dublin Bay.

Background:

- **Satellite-based environmental data is an important asset** and a major tool that we can use to address societal challenges such as coastal flooding, port security or marine pollution.

- **However, extensive validation is required** not only for improvement of model performance but also for accurately quantifying the errors and consistency of the predictions.

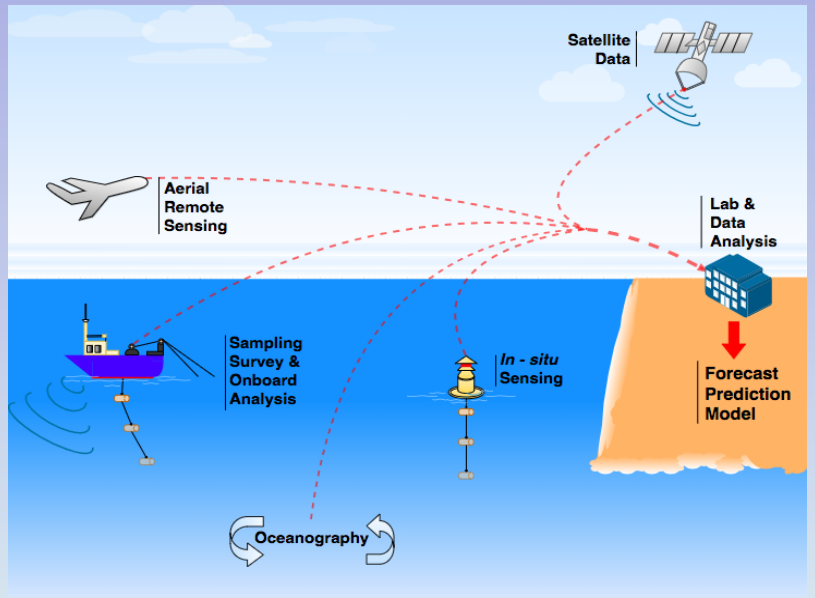
Objectives:

- **A coordinated program of coastal ocean observations** that will be used to validate, calibrate and extract as much information as possible from satellite earth observation data

.

- We will **integrate these datasets to generate models** that can be used to predict environmental change.

- The project aims to provide experimental proof-of-concept in Dublin Bay that can be extrapolated to a range of environments.



- All data and models produced will be made publicly available.

- The project is multidisciplinary and will integrate mathematical modelling, remote and in-situ sensing, physical and chemical oceanography and seabed mapping.

Academic Partners:

DCU Ollscoil Chathair Bhaile Átha Cliath Dublin City University

Geological Survey Suirbhéireacht Gheolaíochta Ireland | Éireann

Maynooth University National University of Ireland Maynooth

UCC Coláiste na hOllscoile Corcaigh, Éire University College Cork, Ireland

Funded through SFI IvP:

Science Foundation Ireland sfi For what's next

Marine Institute Foras na Mara

Geological Survey Suirbhéireacht Gheolaíochta Ireland | Éireann

Rialtas na hÉireann Government of Ireland

Geochemical mapping of inner Dublin Bay and Bull Island

Introduction

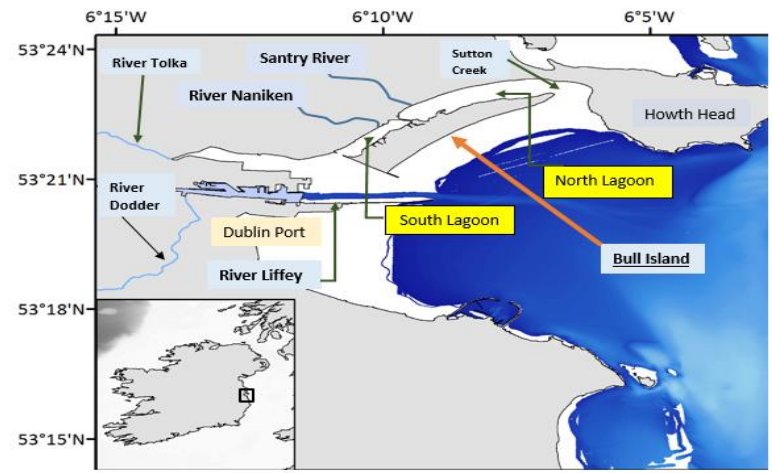
- Bull Island (BI) is situated in Dublin Bay on the east coast of Ireland (Figure 1).
- man-made island as it formed in response to the construction of the Great South Wall in the 1700s and North Wall in the 1800s.
- Special Area of Conservation under the EU Habitats Directive

Objectives

- Provide baseline information for future studies that investigate environmental change over time.
- Use data to validate, calibrate and extract information from satellite earth observation data.
- long-term provision of such datasets is required to generate models that can be used to predict environmental change.

Physical analysis	Chemical analysis
• Particle Size Analysis (PSA):	• Total nitrogen content (%TN)
○ % Clay	• Electrical conductivity (EC)
○ % Silt	• PAHs
○ % Sand	• Total organic carbon content (%TOC)
• Average Particle Size	• Fe, Cr, Al, Cr, Pb, Ca
	• pH
	• Organic matter content (%OM)

Table 1: Analysis carried out in this Bull Island study



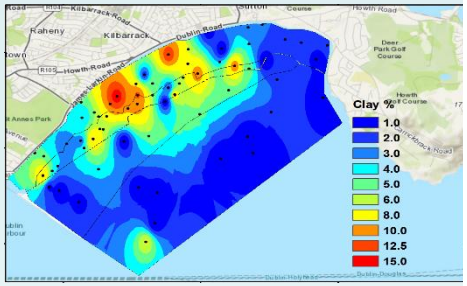
Map of Dublin Bay and Bull Island with sampling zones and points.

Sampling, mapping and analysis

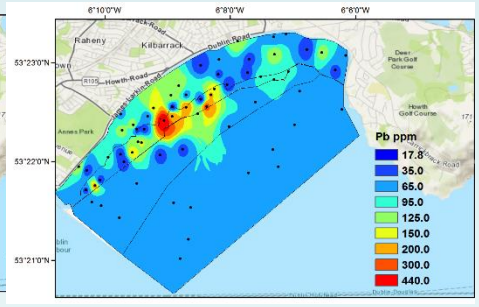
- The sampling plan was produced using R Statistics and ArcGIS software.
- The sampling area was divided into; salt marsh, bull mudflats, Bull island and intertidal.
- ArcGIS was used to map results

RESULTS

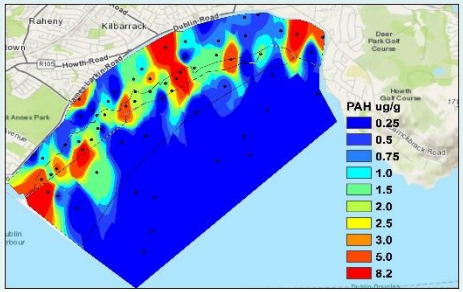
- depositional zone in the salt marsh/mud flat area where PAHs, lead and chromium concentrate.
- primary source of PAHs is the combustion of fossil fuels
- C:N ratios show that high pollutant concentrations are mainly due to terrestrial anthropogenic activity.
- Principal component analysis (PCA) indicates strong linear relationships between PAH and lead with TOC.



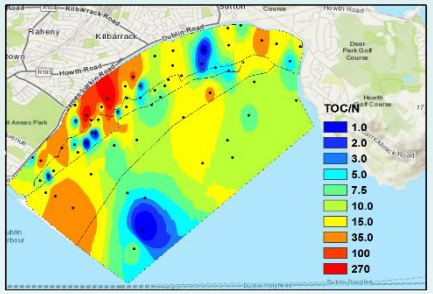
Intepolated map of clay distribution in Bull Island



Lead distributions

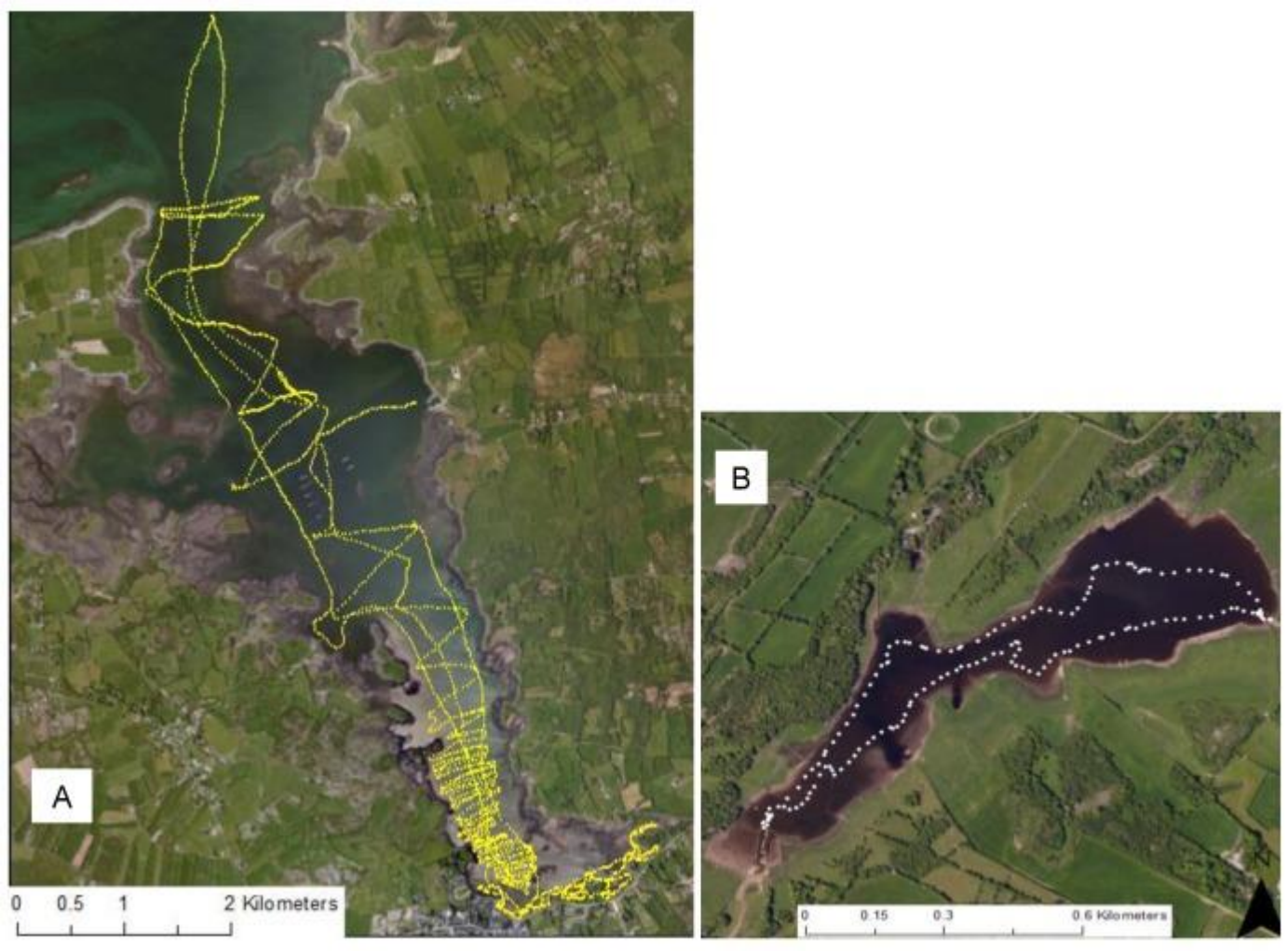


PAH distributions



C:N ratio distribution

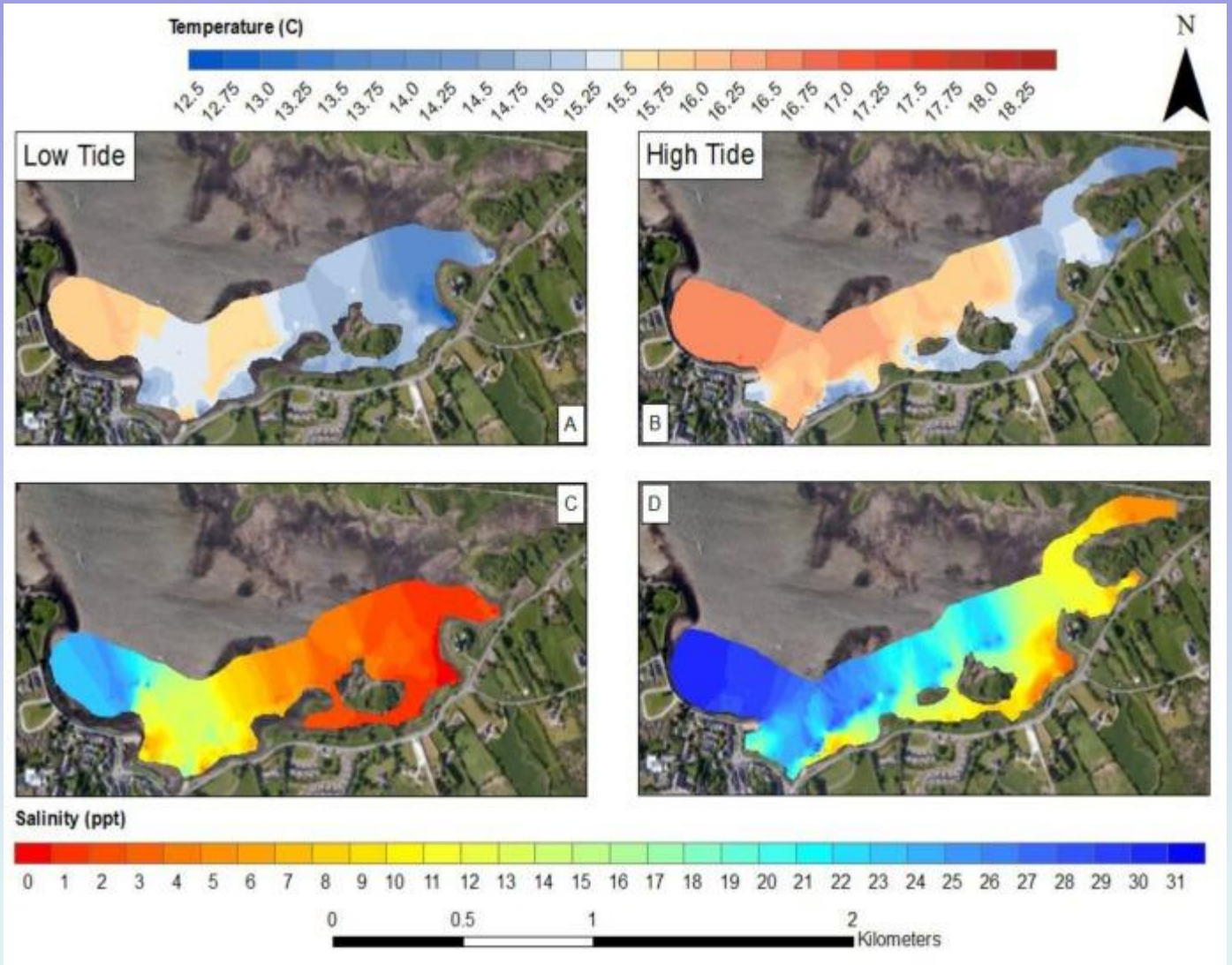
Combining Remote with in-Situ Sensing



Location of in-situ data points collected over a four-day sampling campaign in (**A**) Kinvara Bay and (**B**) Cahergluassuan Turlough (25–28 August 2015).

McCaul et al, *Sensors*. 2016. 16(9). Pii E1 402

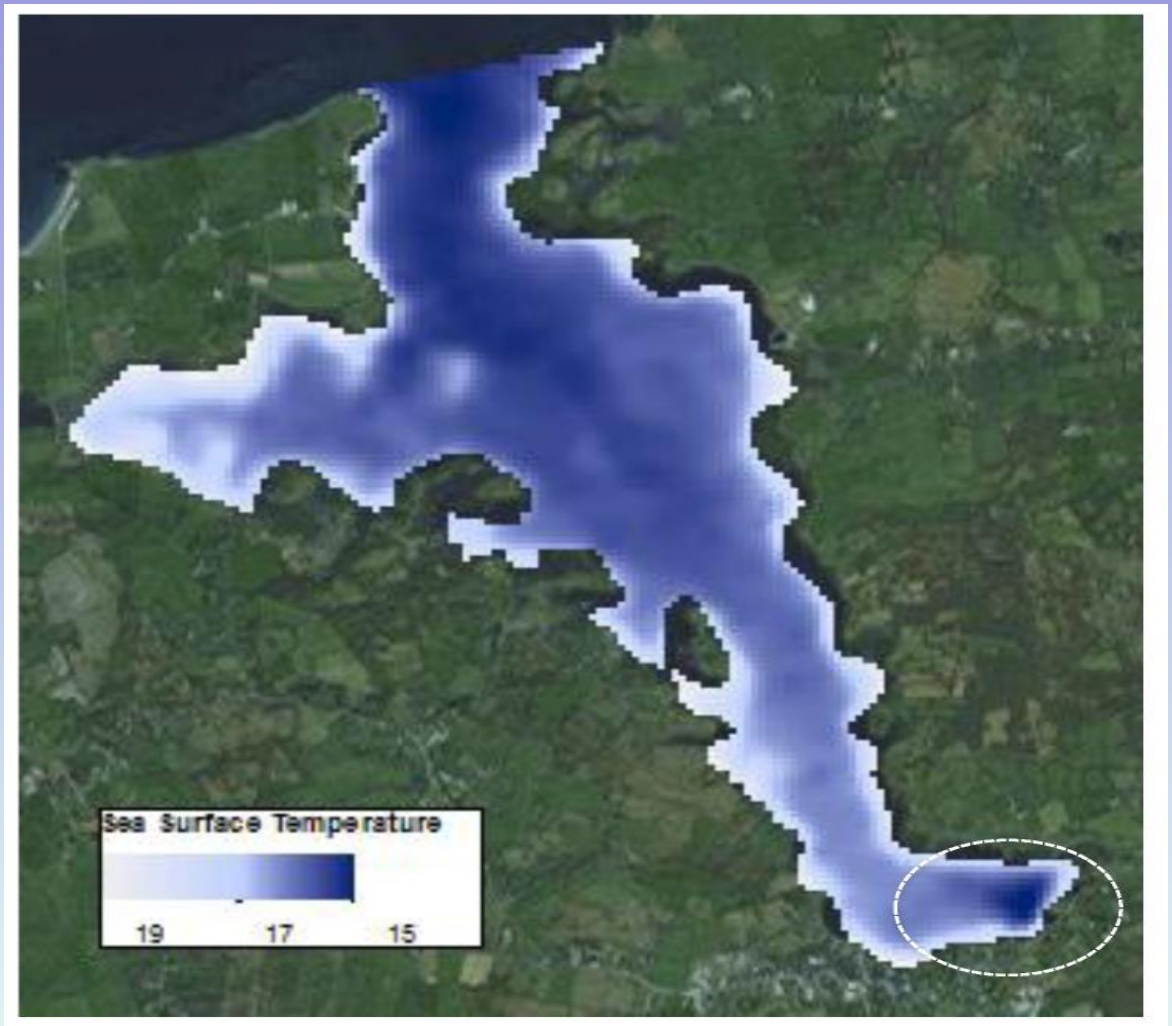
This research was carried out by PREDICT partners, Margaret McCaul an Dermot Diamond



Sea surface temperature and salinity maps of southern Kinvara Bay interpolated from in-situ data (**D**).

McCaul et al, *Sensors*. 2016. 16(9). Pii E1 402

This research was carried out by PREDICT partners, Margaret McCaul an Dermot Diamond

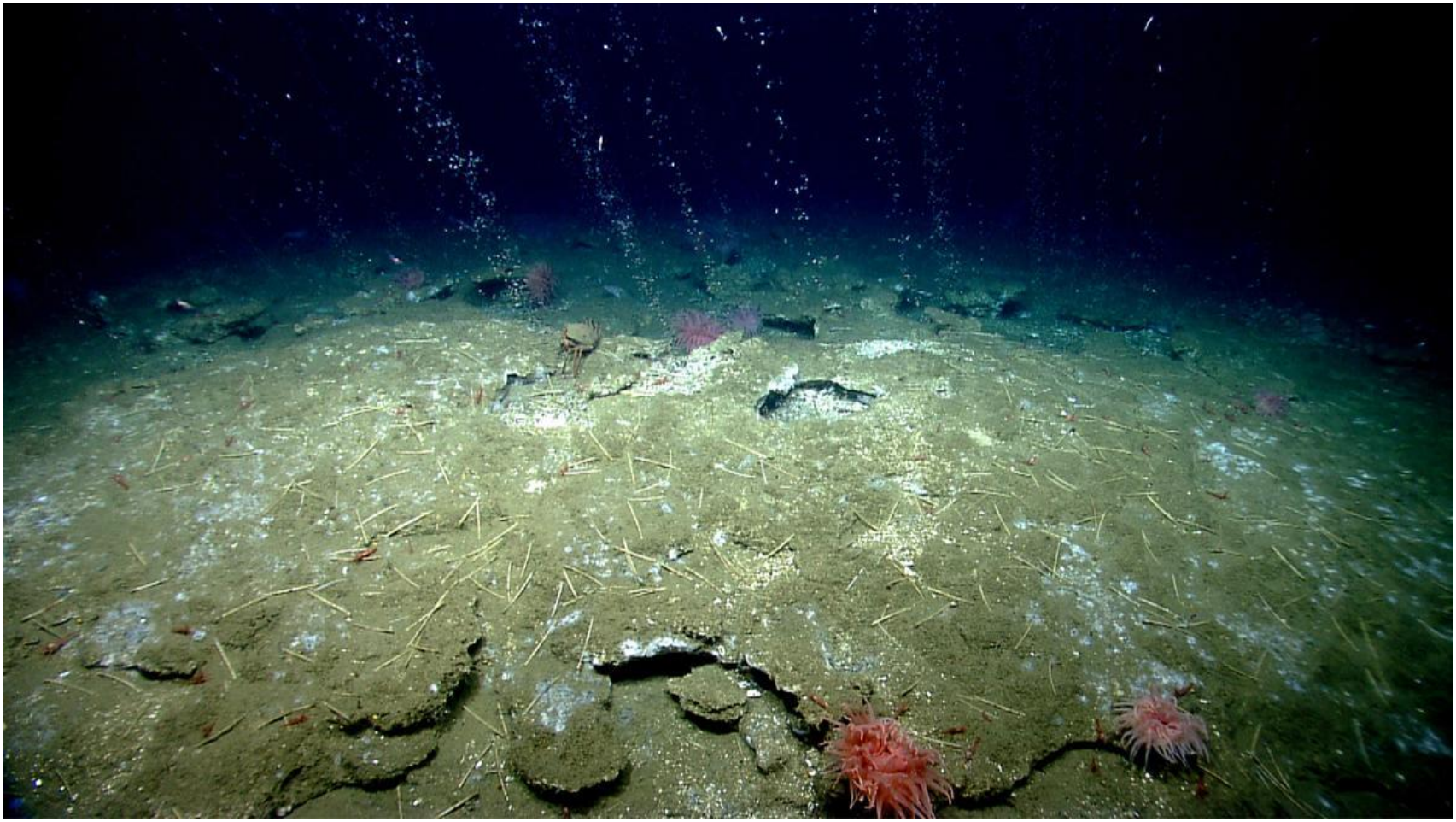


Sea surface temperature map of Kinvara Bay generated from Landsat 8 satellite imagery

McCaul et al, *Sensors*. 2016. 16(9). Pii E1 402

This research was carried out by PREDICT partners, Margaret McCaul an Dermot Diamond

Marine Methane.



Widespread methane leakage from the sea floor on the northern US Atlantic Margin

Skarke at al, Aug 2014 · Nature Geoscience

Methane Seepage Features in Irish Waters

Recent discoveries:

Irish Sea

- Codling Fault MDAC mounds
- Irish Sea pockmarks,

Malin Sea:

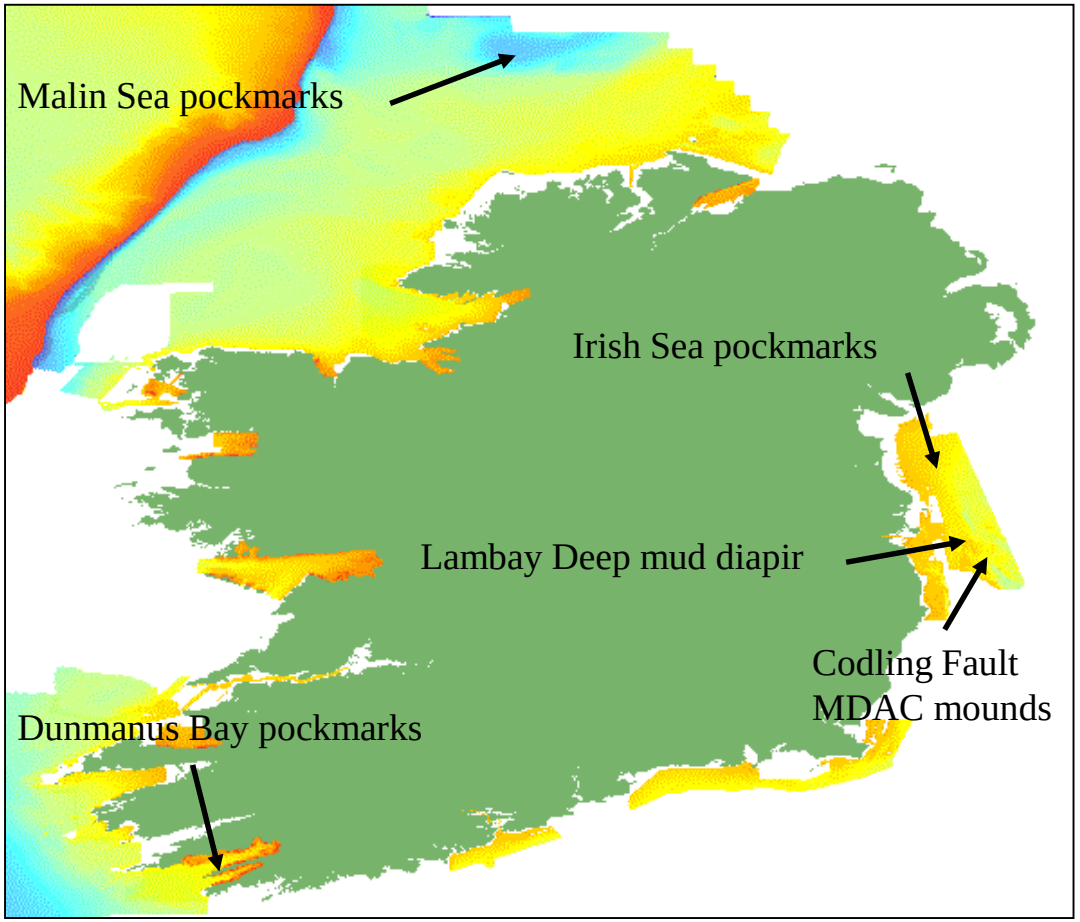
- Malin Shelf Giant Pockmark,

Dunmanus Bay:

- Dunmanus Bay micro-Pockmarks.

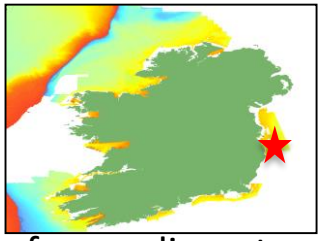
Bantry Bay:

- Pockmarks,
- Constant gas seepage

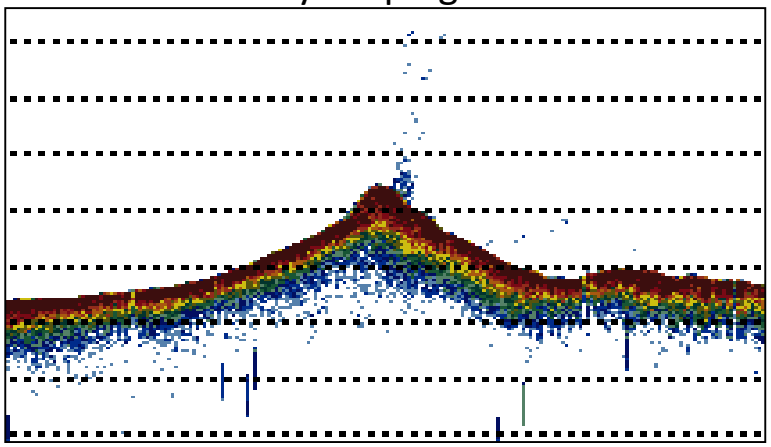


- Szpak, M. T., et al Geophysical and geochemical survey of a large marine pockmark on the Malin Shelf, Ireland. *Geochemistry, Geophysics, Geosystems*. 2012. 3, Q01011, doi:10.1029/2011GC003787.
- Szpak, M. et al. Occurrence, characteristics and formation mechanisms of methane generated micro-pockmarks in Dunmanus Bay, Ireland. *Continental Shelf Research*. 2015, 103, 45-59.
- Shane S O'Reilly, et al. Estuarine, *Coastal and Shelf Science*. 136, 157-171, 2014.
- S. S. O'Reilly, et al. *Continental Shelf Research*, 113, 1-9, 2016.

Codling Fault Methane Derived Authigenic Carbonate mounds (MDAC)

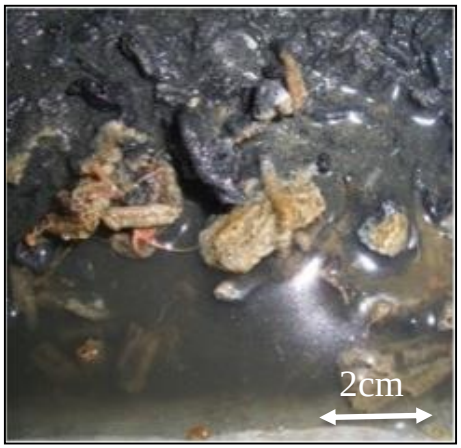


Actively seeping mound

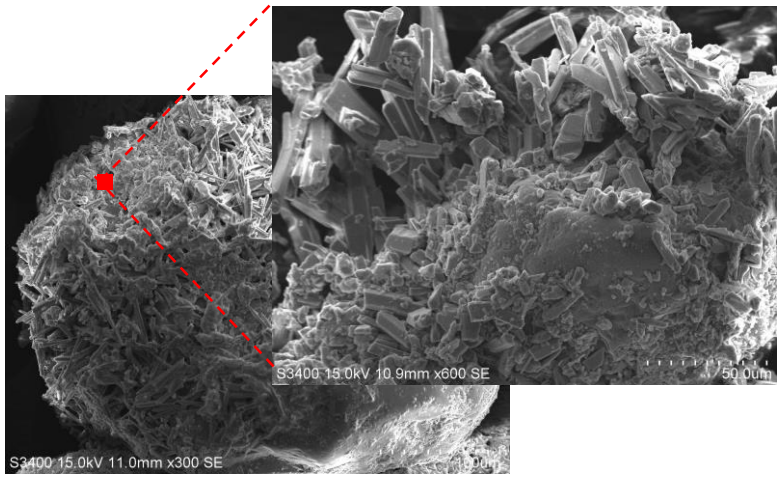


Pavement stacking

Anoxic surface sediment

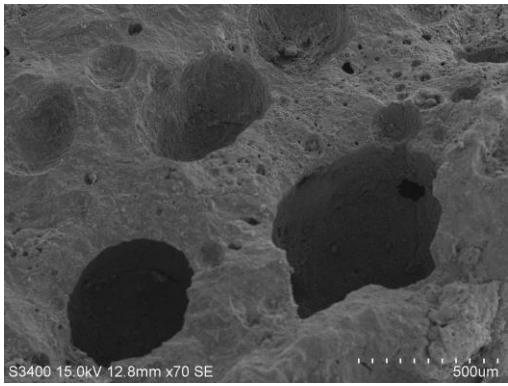


Carbonate & pyrite encrusted quartz grain



Microbial structures

Fluid flow pores



S. S. O'Reilly, et al, **Shallow water methane-derived authigenic carbonate mounds at the Codling Fault Zone, western Irish Sea.** *Marine Geology*, 357, 139-150 2014.

Thank you

Past & Present PGs and PDs:

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Shane O'Reilly,
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Andre Simpson (University of Toronto),

DCU School of Chemical Science technicians.

GSI Geological Survey of Ireland Suirbhéireacht Gheolaíochta Éireann www.gsi.ie

epa Environmental Protection Agency

INFOMAR Integrated Mapping for the Sustainable Development of Ireland's Marine Resource

DCU

Marine Institute Foras na Mara

PIP Petroleum Infrastructure Programme

ENTERPRISE IRELAND where innovation means business

Science Foundation Ireland sfi For what's next

IRCSET Investing in People and Ideas
Irish Research Council for Science, Engineering and Technology