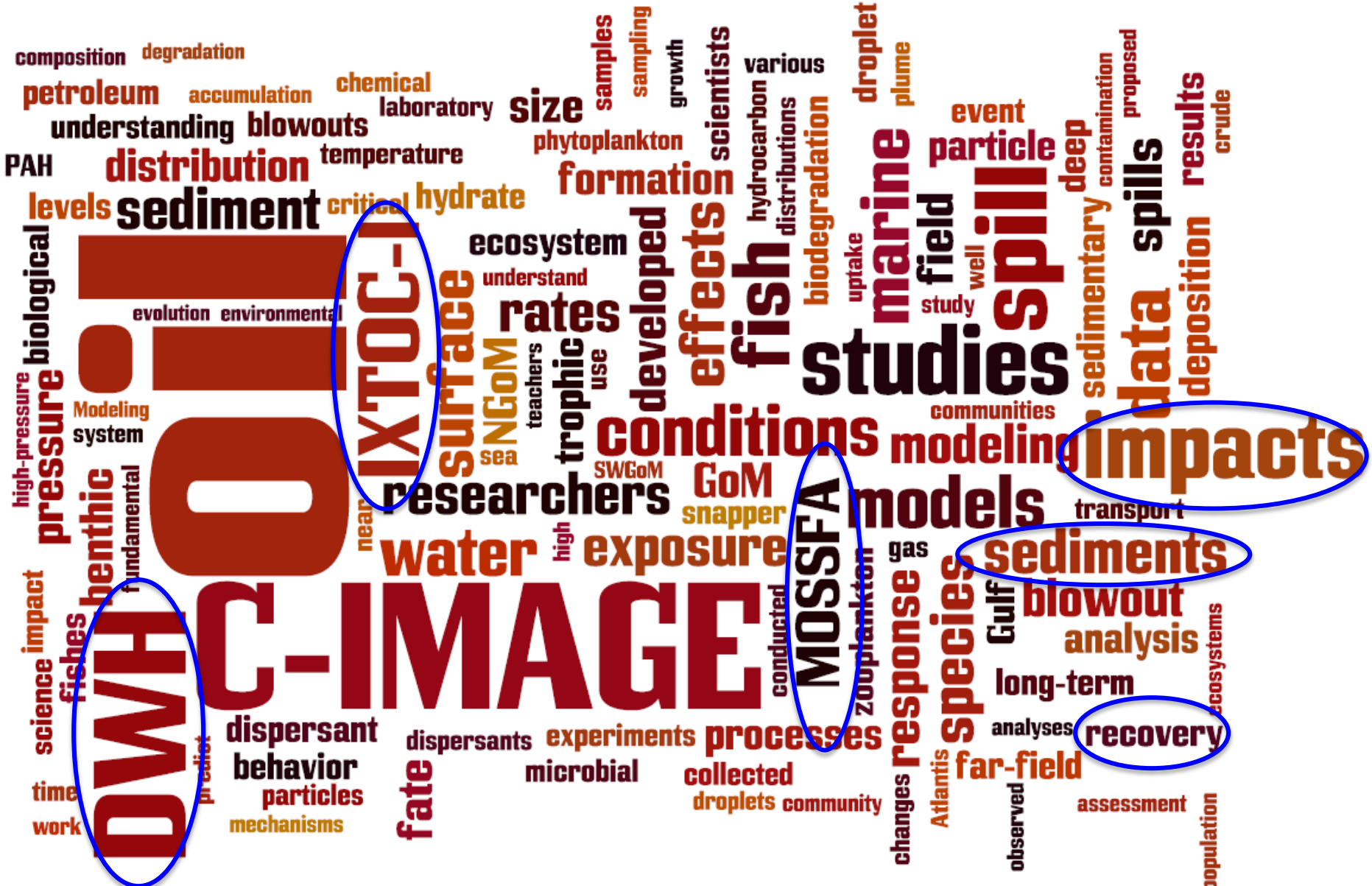
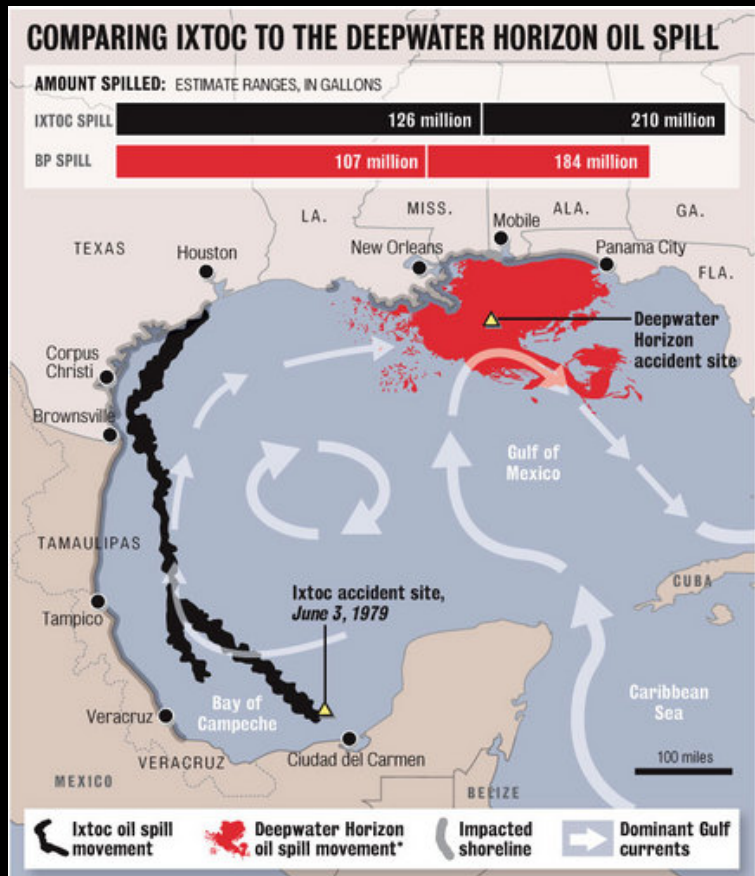
What is C-IMAGE II doing 2015-2017?



Marine Oil Snow Sedimentation & Flocculent Accumulation MOSSFA Events—The Rule or the Exception to the Rule?

Comparative Analysis of the Deepwater Horizon & IXTOC-1 Blowouts

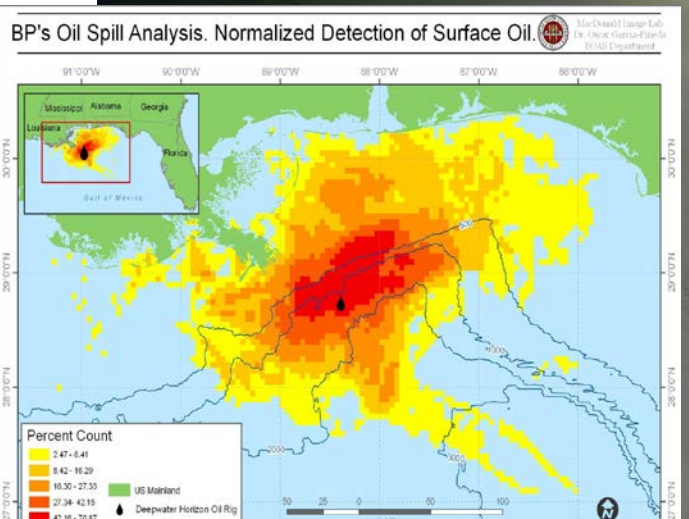
David J. Hollander, M.-L. Machain-Castillo, A. Gracia, E.G. Escobar-Briones, S. Murawski, H.A. Alexander-Valdés, S. Bosman, G.R. Brooks, J. Chanton, K. Freeman, D. Hastings, J. Kostka, R.A. Larson, S. Lincoln, P. Montagna, T. Oldenburg, I.C. Romero, I.C., A.C. Ruiz-Fernández, J. Sánchez-Cabeza, P.T. Schwing,



UNAM Workshop: Ecosystem Impacts and Recovery From Petroleum Exploration and Extraction

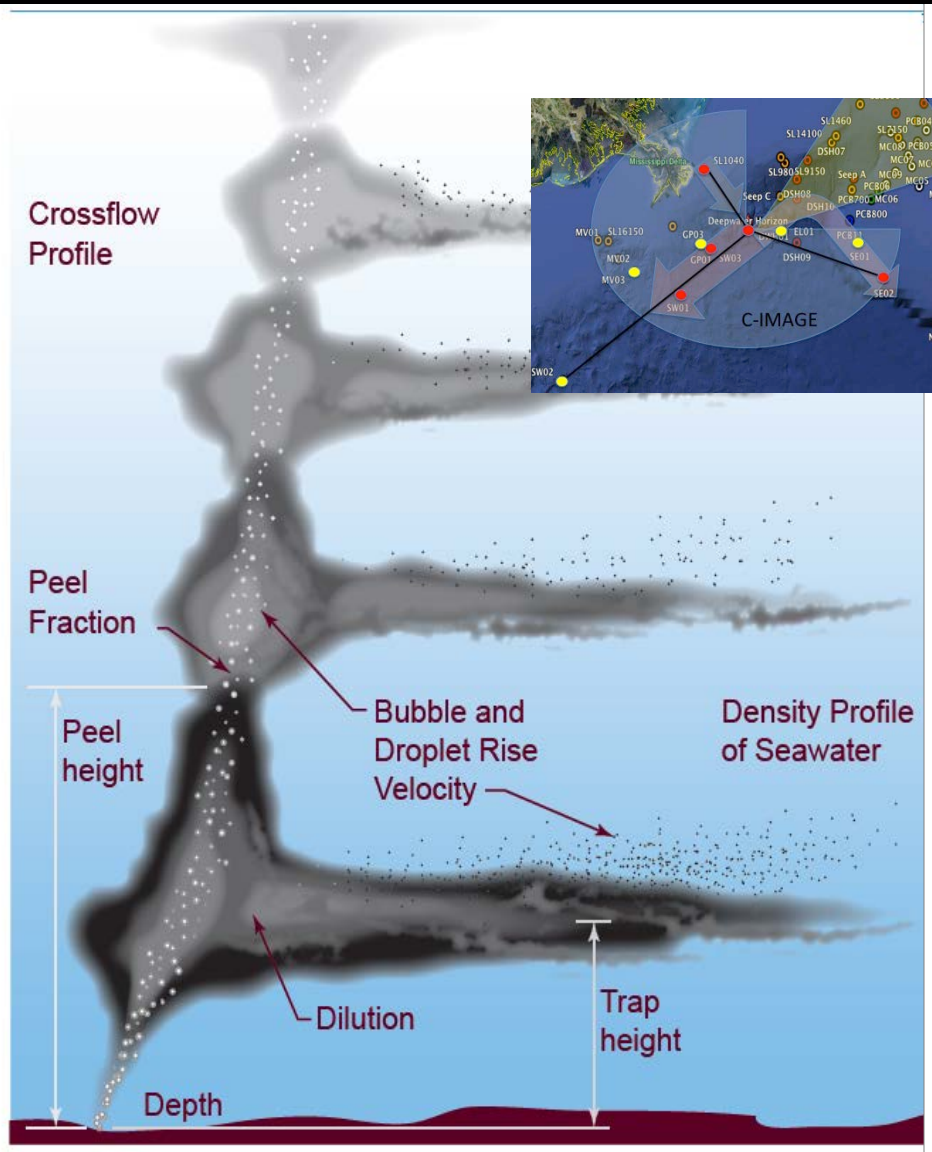
4 May 2016

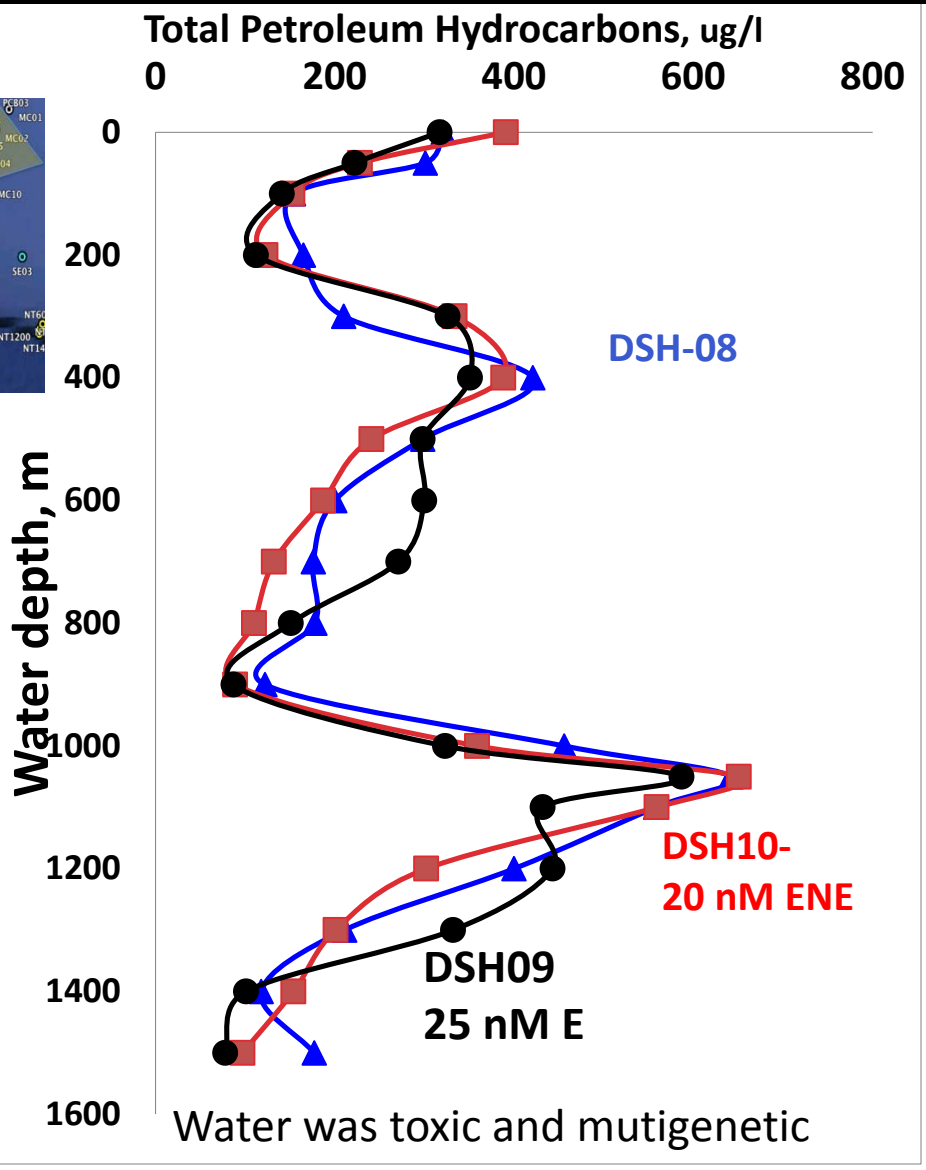
Oil Spill from Space—A 2-Dimensional Disaster
Surface Coverage 68,000 Sq. Mi. – Size of FL



- High Resolution Satellites and Aircraft can be used both to find surface oil and to measure its thickness and therefore quantity

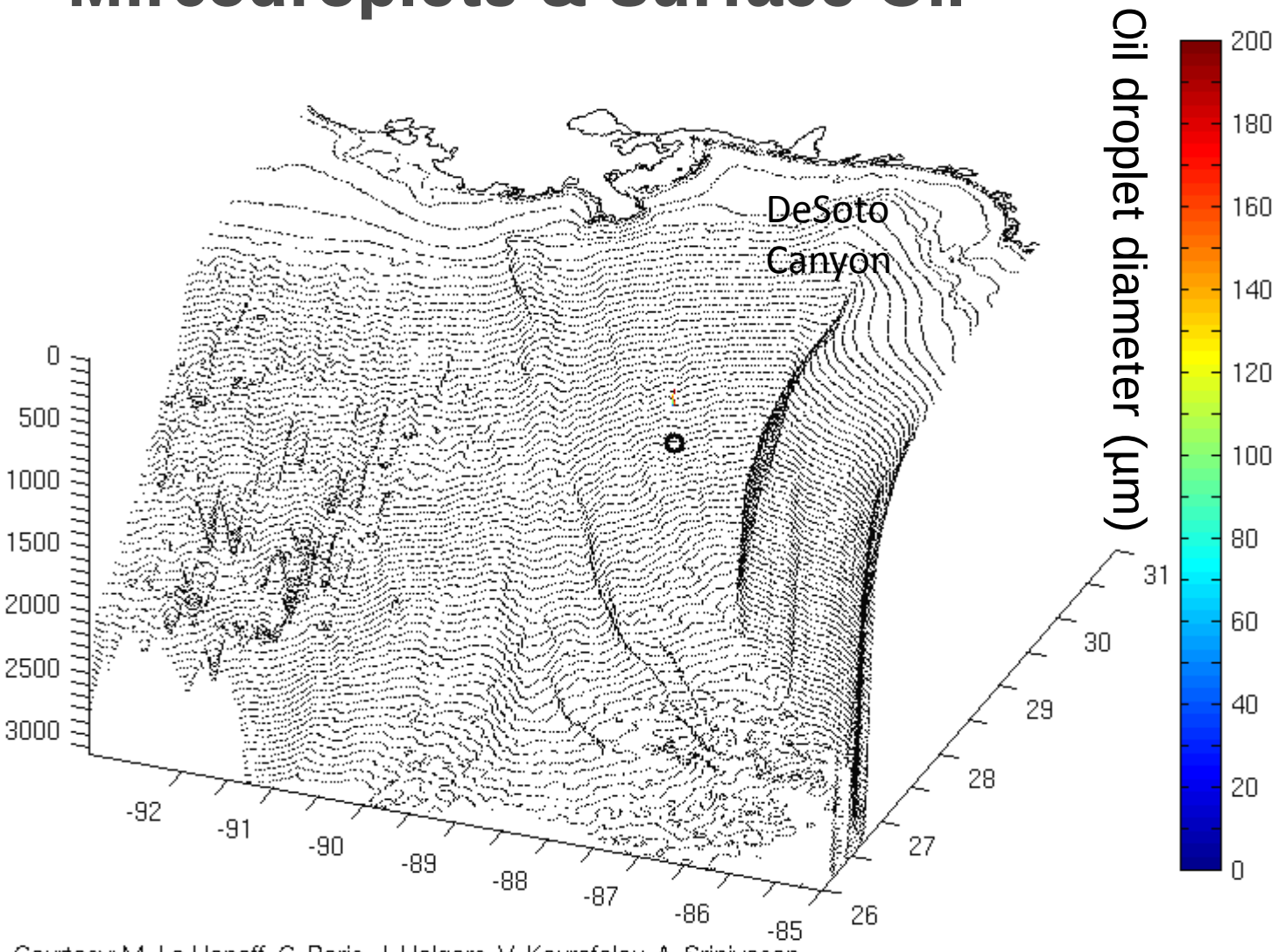
Deep-water Blowout is a 4-Dimensional Catastrophe
Chemistry & Physics of Submarine Oil Release





SUBSEA: 3D animation of the Macondo well blowout from Apr. 20 to Sep. 6, 2010

Distribution and Transport of the Subsurface Oil Mircodroplets & Surface Oil



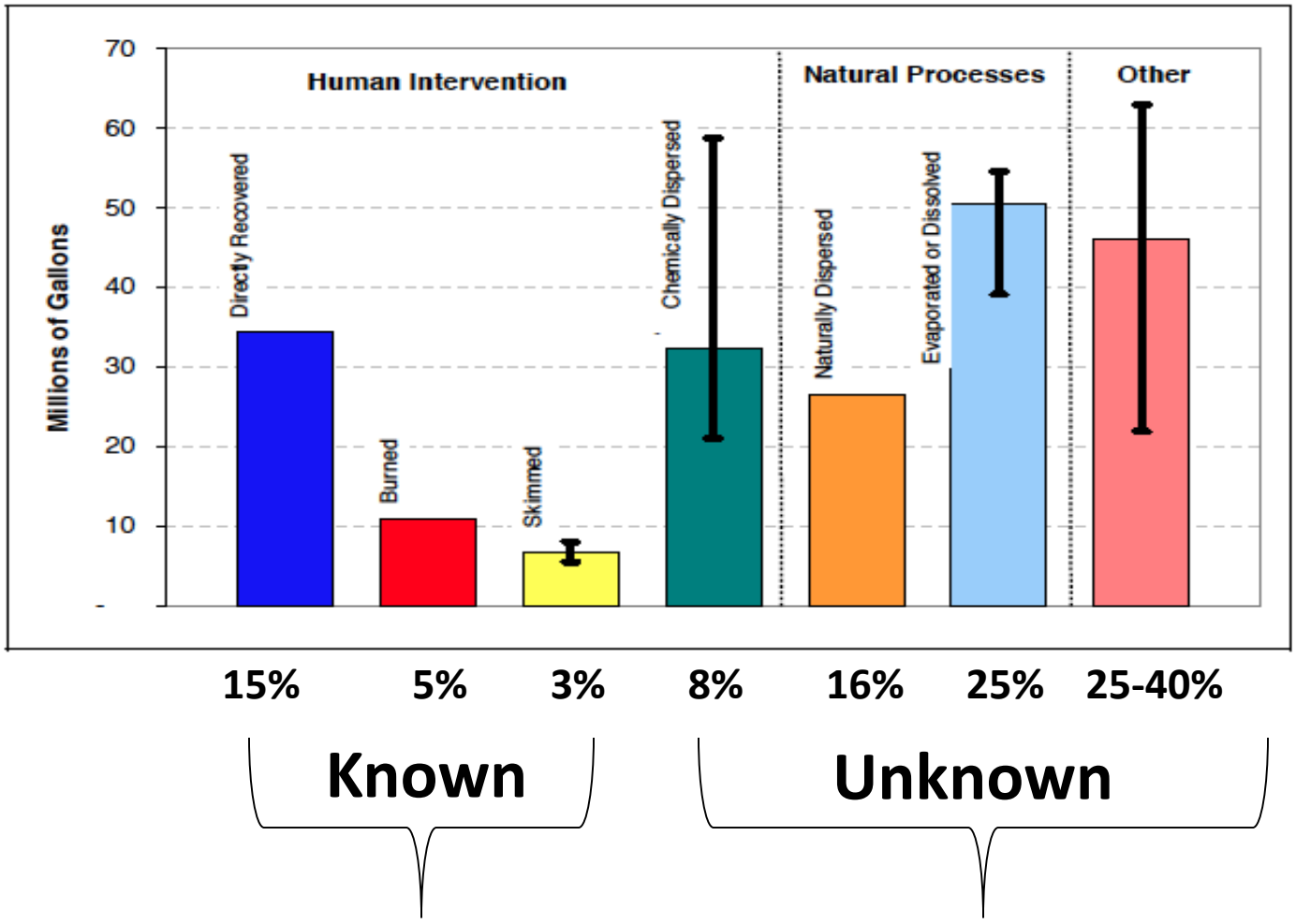
Courtesy: M. Le Henaff, C. Paris, J. Helgers, V. Kourafalou, A. Srinivasan

UNIVERSITY
OF MIAMI

Oil Budget Released by NOAA August 4, 2010

Figure 5. Federal Government Oil Budget Estimates and Ranges of Uncertainty

Based on July 14, 2010 Estimates



~ 75% not accurately accounted for

So where did it really go?? Sediments?

Sediment Cores- August and December, 2010
1000-1200 m. “Plume Depth”

1047m Sediments
PCB-06 DeSoto Canyon
70 nm ENE of DWH

1115 m Sediments
DSH 08 (N-S line)
20 nm NE of DWH

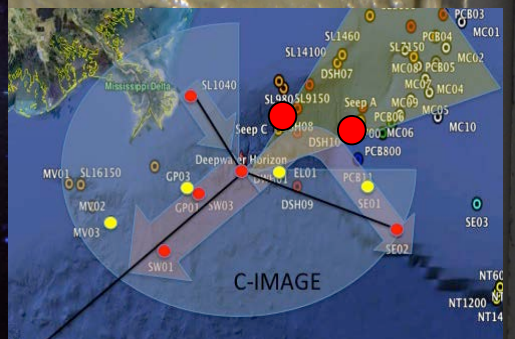
2–2.5m

5 cm

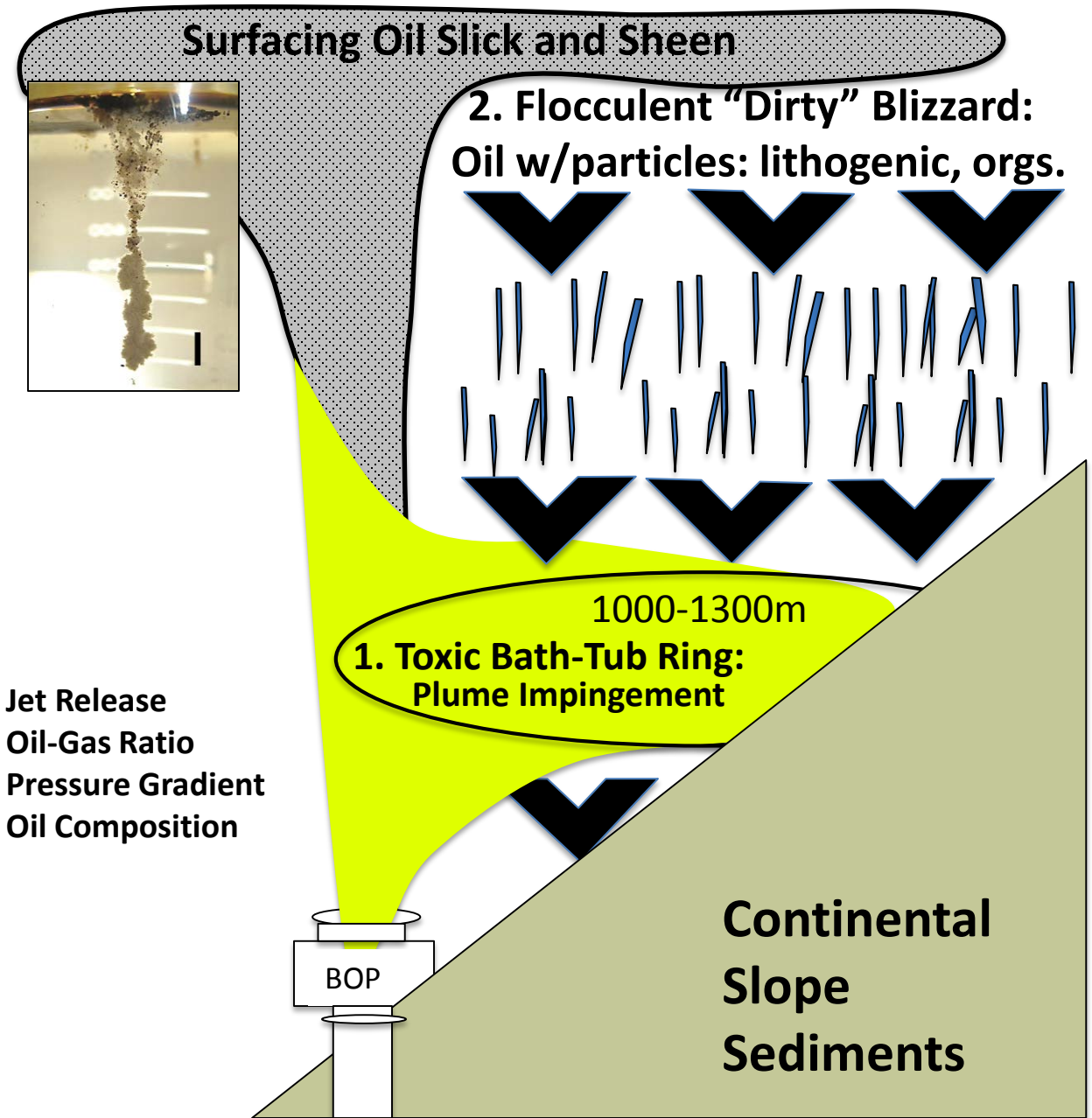
Why no Bioturbation?

Sheen on Surface Sediment

UV fluorescing particles & sheen



Two Possible Mechanisms of Sedimentary Oil Deposition



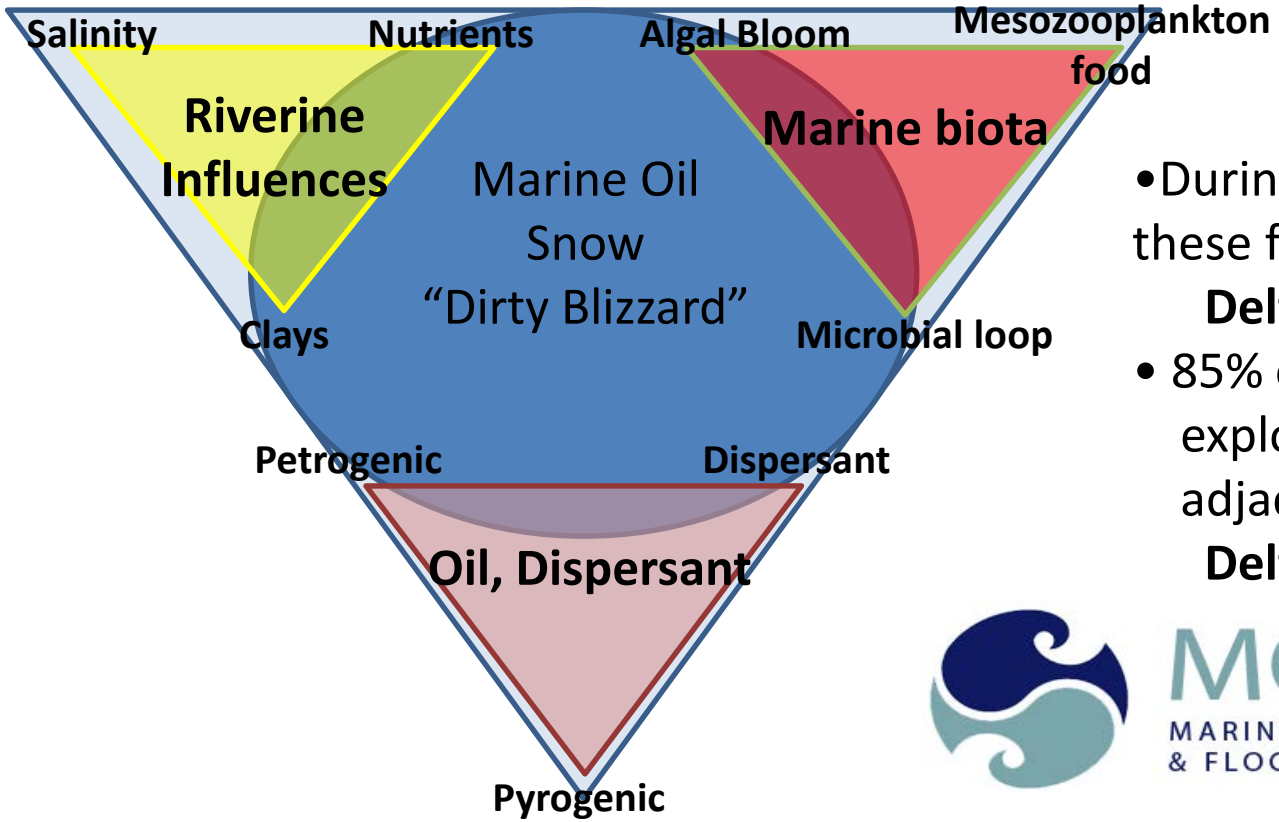
- **1-Toxic Bath-Tub Ring:**

  Plume impinges on the sediment directly; poisoning the benthic ecosystem with BTEX, PAHs.

- **2-Flocculent Blizzard:**

  Rapid flocculation and sinking of clay, algae, bacteria- oiled aggregates (weathered oil, pyrogenic PAHs, dispersant) aggregates; rapid pulsed sediment accumulation of surfacing oil-dispersant

WHAT factors control the formation sinking of oil-associated particles (Marine Oil Snow Sedimentation)?

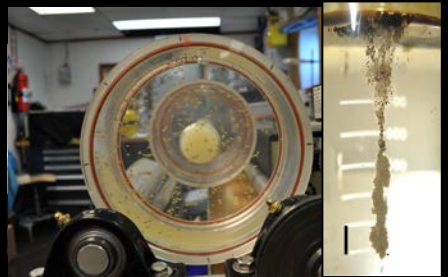


- During an oil spill, where can these factors come together?
  Deltaic Systems
- 85% of all deep-water exploration is occurring adjacent to:
  Deltaic Systems

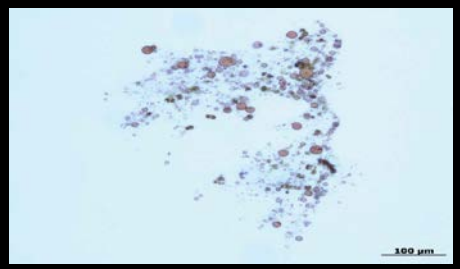
MOSSFA
MARINE OIL SNOW SEDIMENTATION & FLOCCULENT ACCUMULATION

Microbial mucus snow

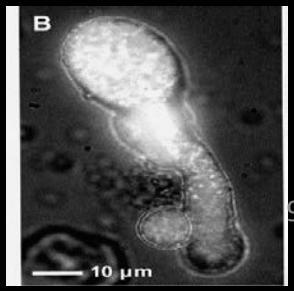
Aggregates coagulation of particles



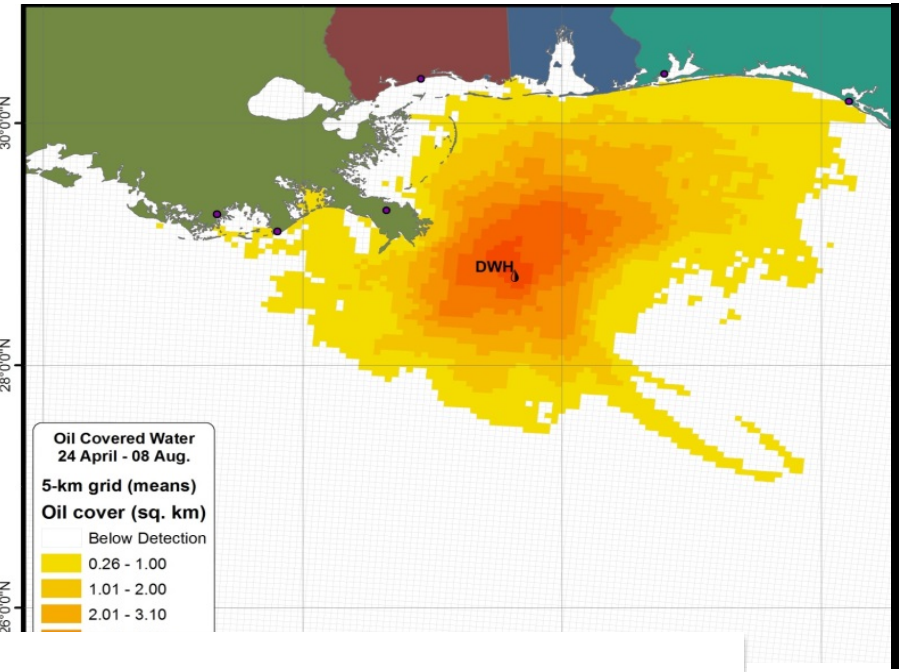
Zooplankton Activity



OMA:
Oil mineral aggregates

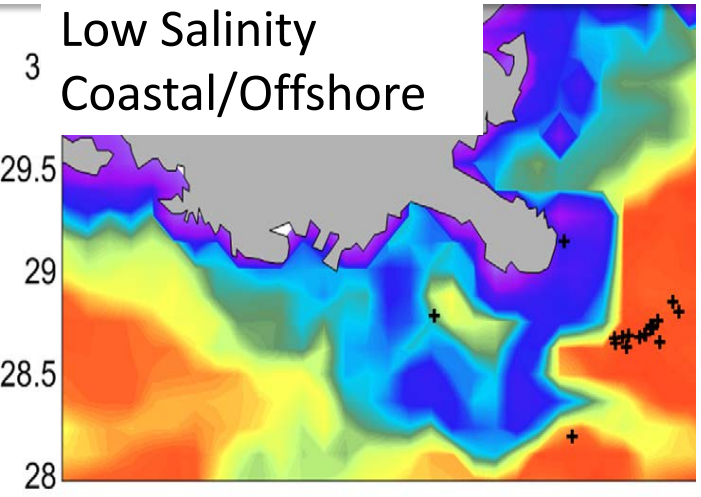


Did mitigation strategies of surface oil intensify Marine Oil Snow Sedimentation & increase the "footprint" of sedimentary oil deposition?

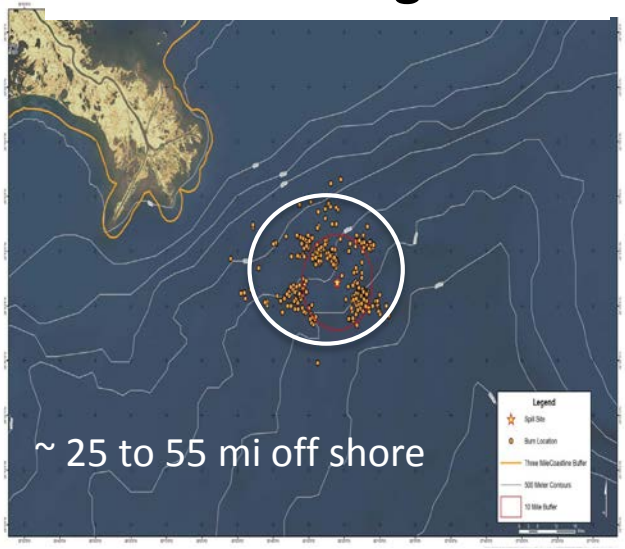


1. River discharge releases clays & nutrients and freshwater to offshore
2. Dispersant application decreases oil droplet size and facilitates oil binding with clays, algae and bacteria
3. Algae-bacteria exposed to oil dispersant form biopolymers (stress-response) that flocculates and traps clays, oil & plankton
4. Oil burning produces pyrogenic PAHs and soot particles

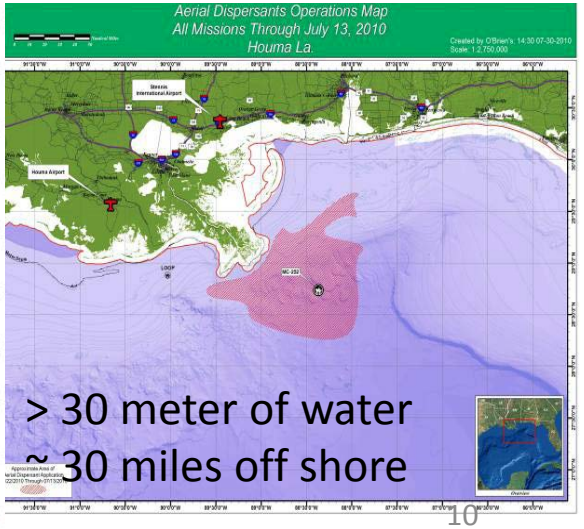
Freshwater Discharge



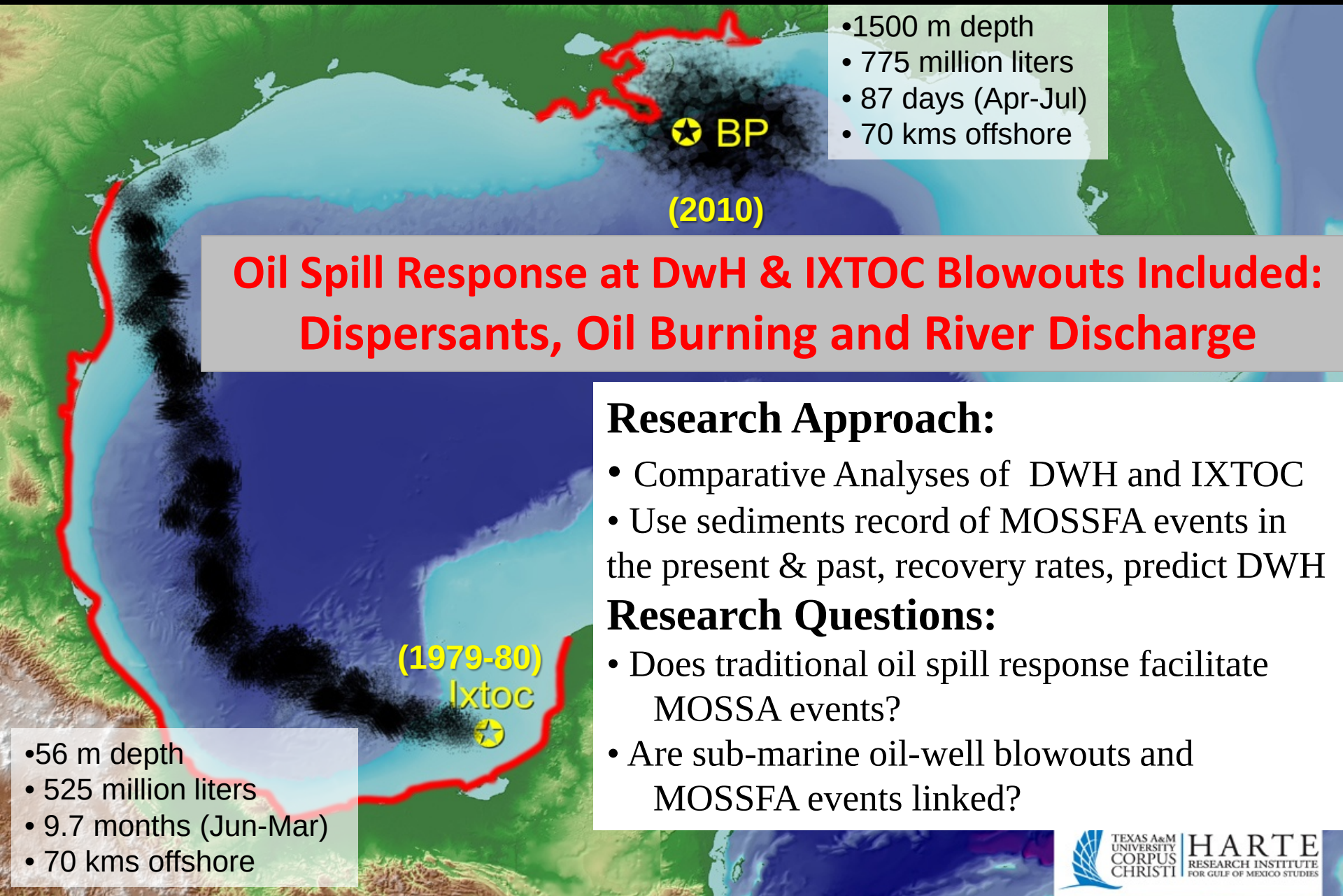
In Situ Burning



Area of Dispersant



Deepwater Horizon (2010), not the first submarine blowout
It was IXTOC-1 (1979-1980), Bay of Campeche, Offshore MX



Oil Spill Response at DwH & IXTOC Blowouts Included: Dispersants, Oil Burning and River Discharge

Research Approach:

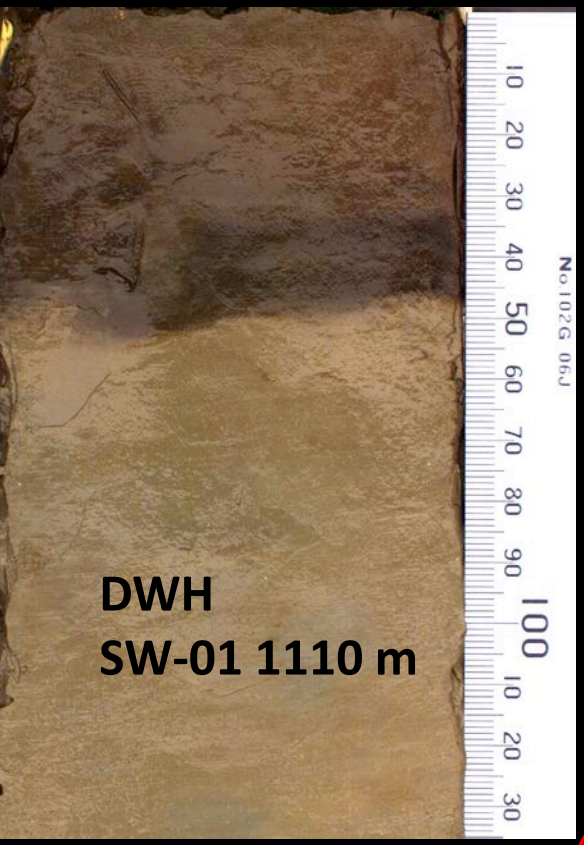
- Comparative Analyses of DWH and IXTOC
- Use sediments record of MOSSFA events in the present & past, recovery rates, predict DWH

Research Questions:

- Does traditional oil spill response facilitate MOSSA events?
- Are sub-marine oil-well blowouts and MOSSFA events linked?

TEXAS A&M UNIVERSITY CORPUS CHRISTI | HARTE RESEARCH INSTITUTE FOR GULF OF MEXICO STUDIES

Sediment Core Comparison DwH-IXTOC Laminated Facies



DWH NGoM

2010

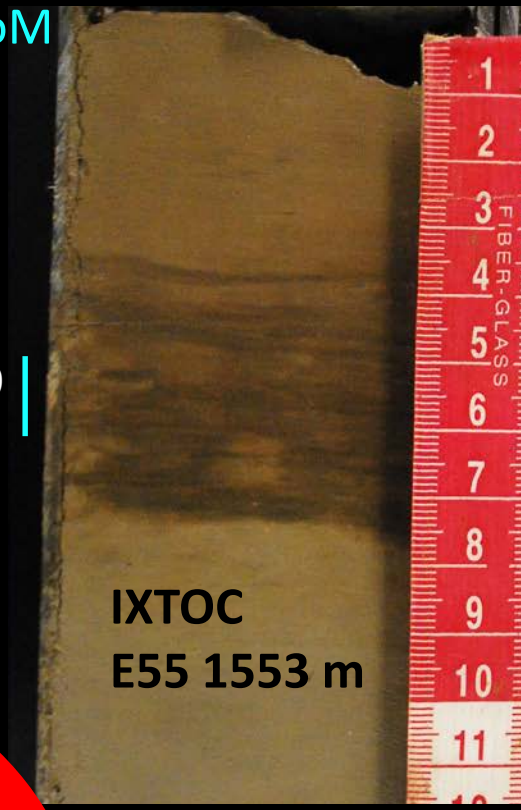
DwH Influence

Influences Seen Above and Below Actual Date of Event Due to Carbon Loading, Redox Changes, and Redeposition

IXTOC SW GoM

IXTOC-1 Influence

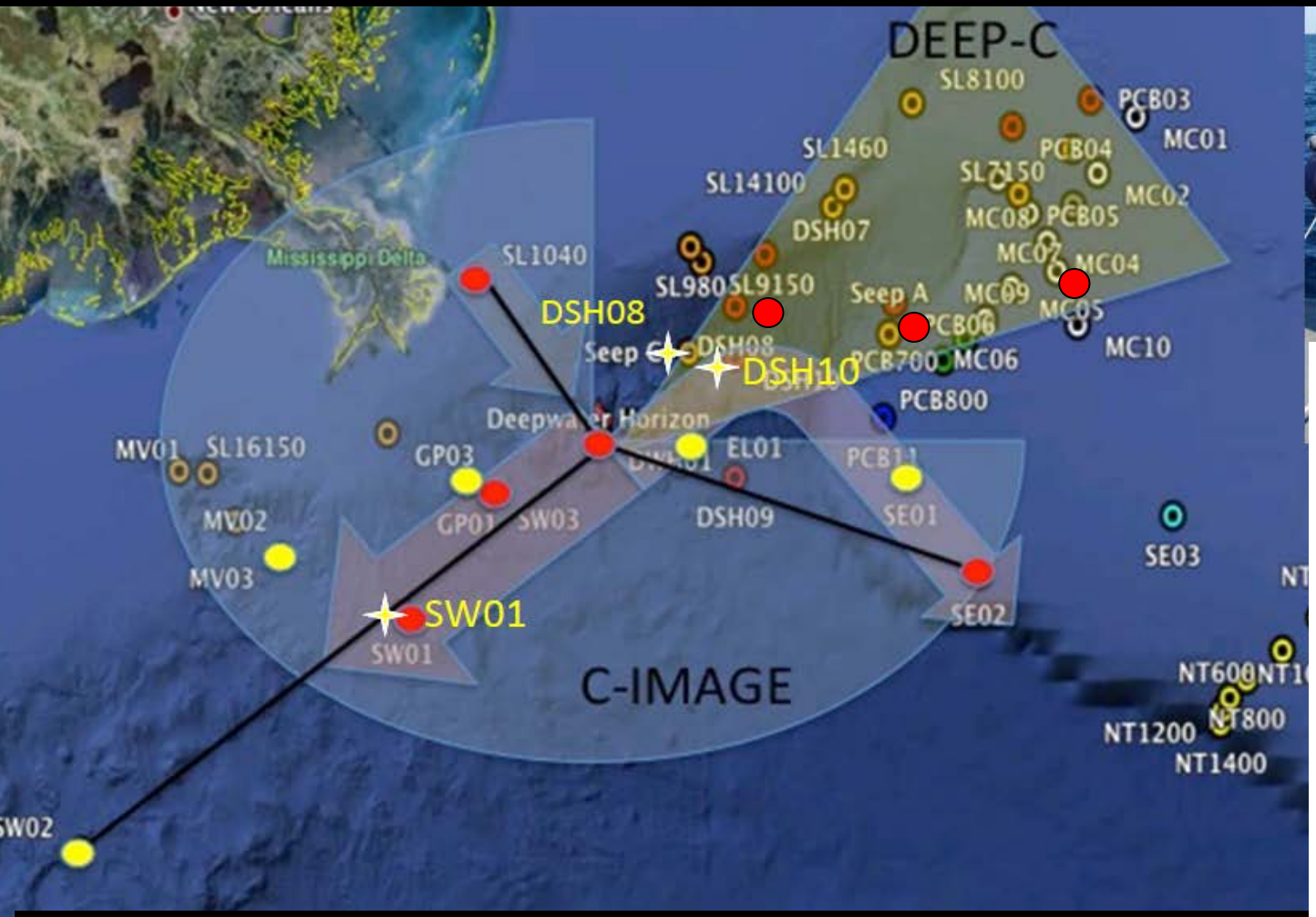
1979



"The present is the key to the past and the past is a window to see into the future"

Ixtoc (past)	DWH (present)	Can we predict DWH recovery (future)?

Sediment Coring Sites and Analytical Methods



Cores extruded @ high resolution
- 2 mm to 20 cm, 5 mm to 60 cm

Methods:

1. **Geochronology**
   (**^{234}Th, ^{210}Pb, MAR-gm/cm^2/yr**)
2. **Sedimentology**
   (**Grain size , clays**)
3. **Organic Geochemistry**
   (**Org-C, aliphatic, PAH, polars**)
4. **Benthic Foraminifera**
   (**mortaility, recovery**)
5. **Microbial Ecology**
   (**community structure**)
6. **Redox metal chemistry**
   (**MnO_2- oxic, Re- anoxia**)
7. **Bulk ^{14}C**
   (**Org-C source indicator**)

November 2010
December 2010/February 2011
June 2011
September 2011
April 2012
October 2012
August 2012

C-IMAGE primary site
C-IMAGE secondary site

Sediment Cores- August and December, 2010
1000-1200 m. “Plume Depth”

1047m Sediments
PCB-06 DeSoto Canyon
70 nm ENE of DWH

1115 m Sediments
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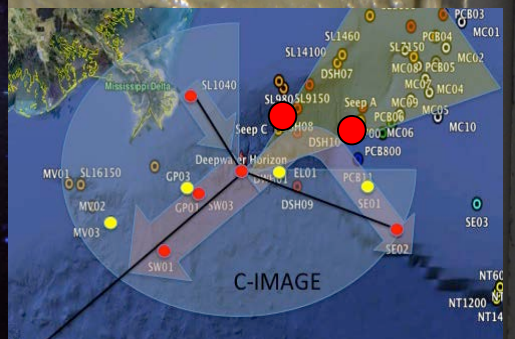
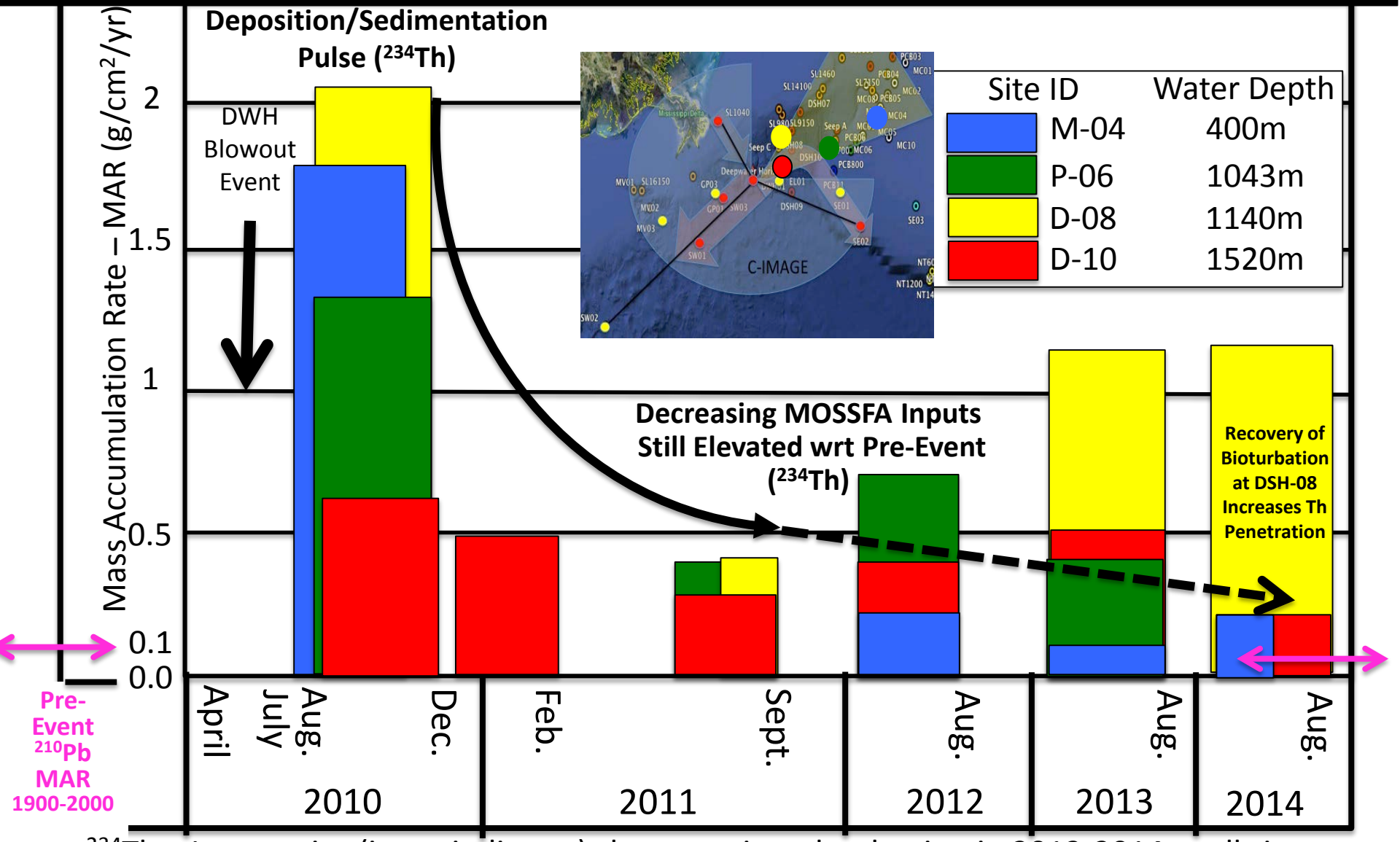


Sediment Pulse Event During the DWH

- ^{234}Th-Mass Accumulation Rate Define Sediment Event (MOSSFA)

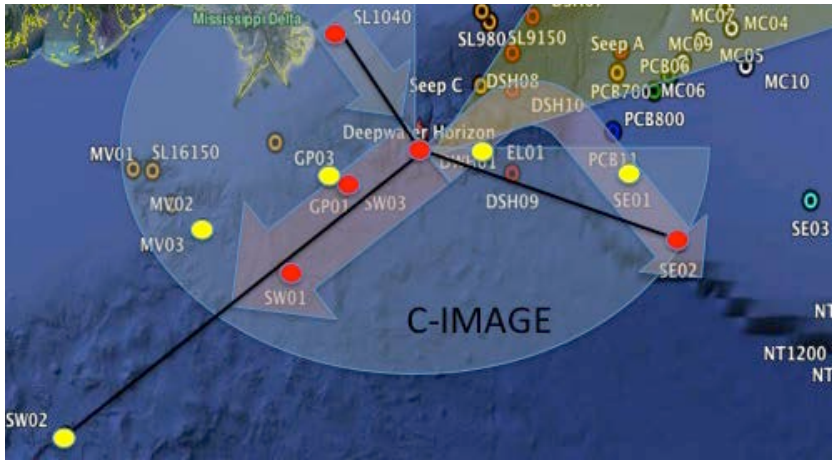


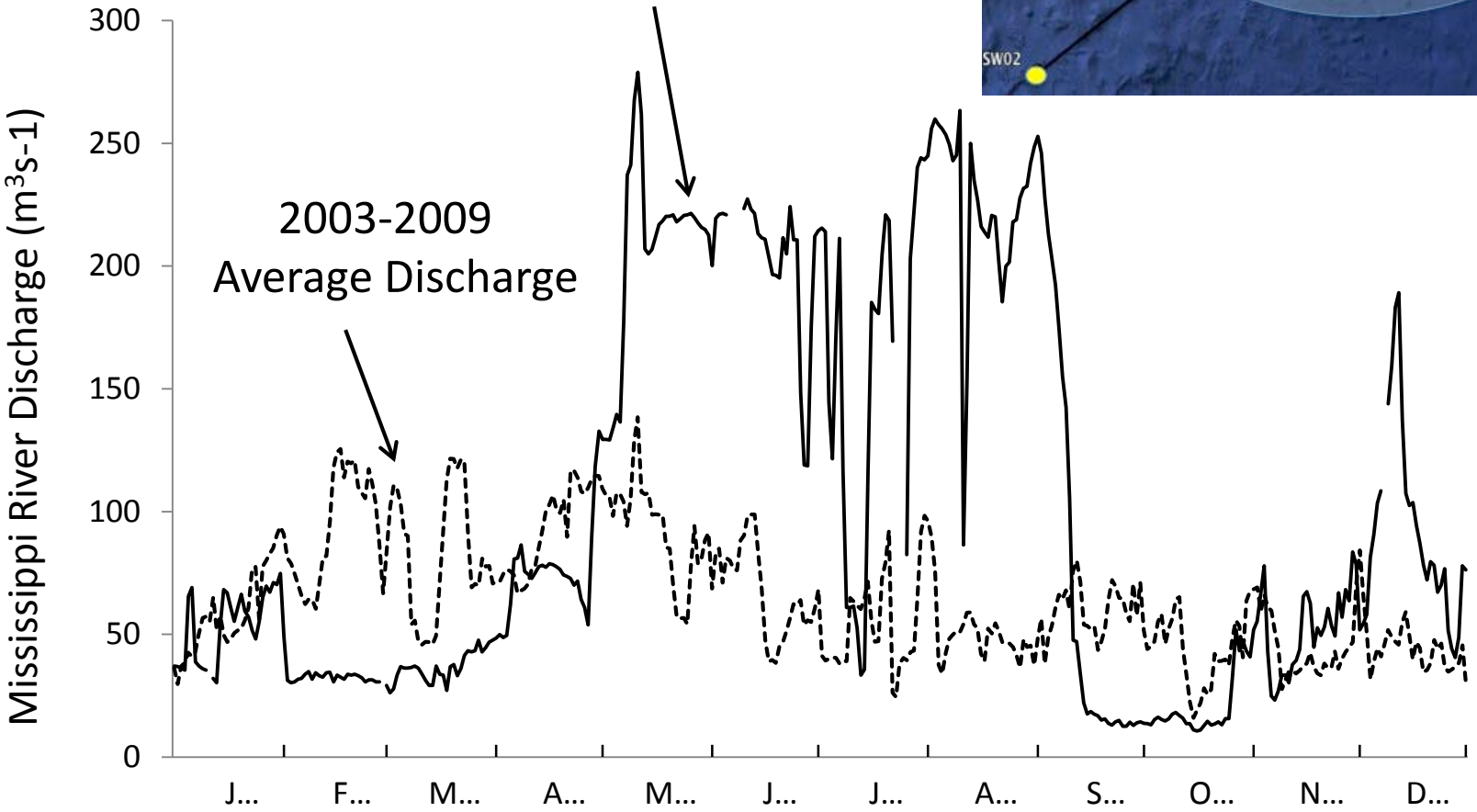
^{234}Th – Inventories (input indicator) show continued reduction in 2013-2014 at all sites

At DSH-08 a return of sediment bioturbation is controlling increasing ^{234}Th MAR

Elevated Discharge Mississippi River & Diversionary Channels To Push Oil Offshore and the Purge Marsh of Oil

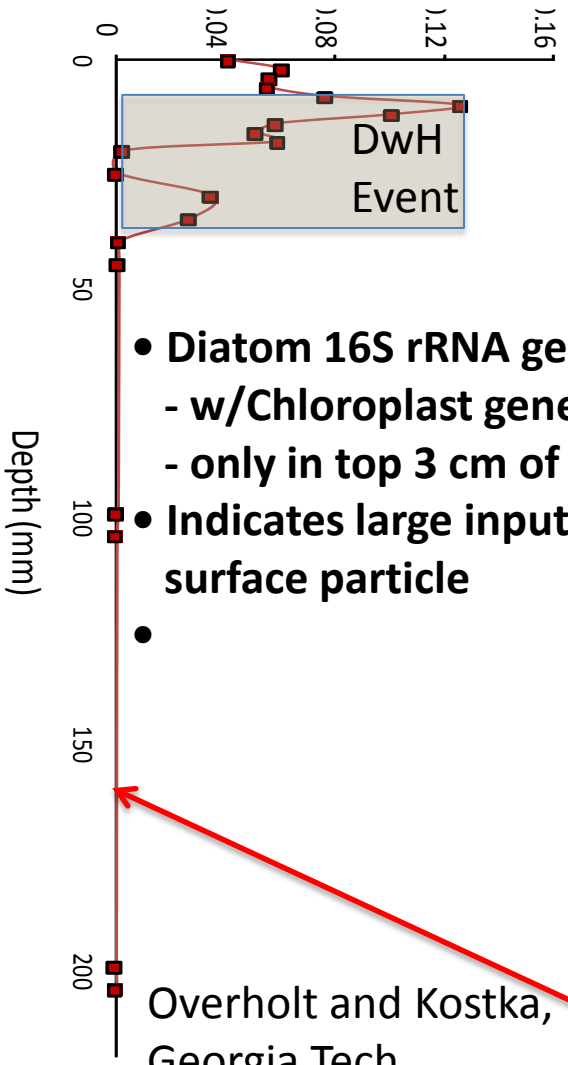
DwH





DWH Surface Produced Microbial Sources and EPS Preserved in Deep-Sea Sediments

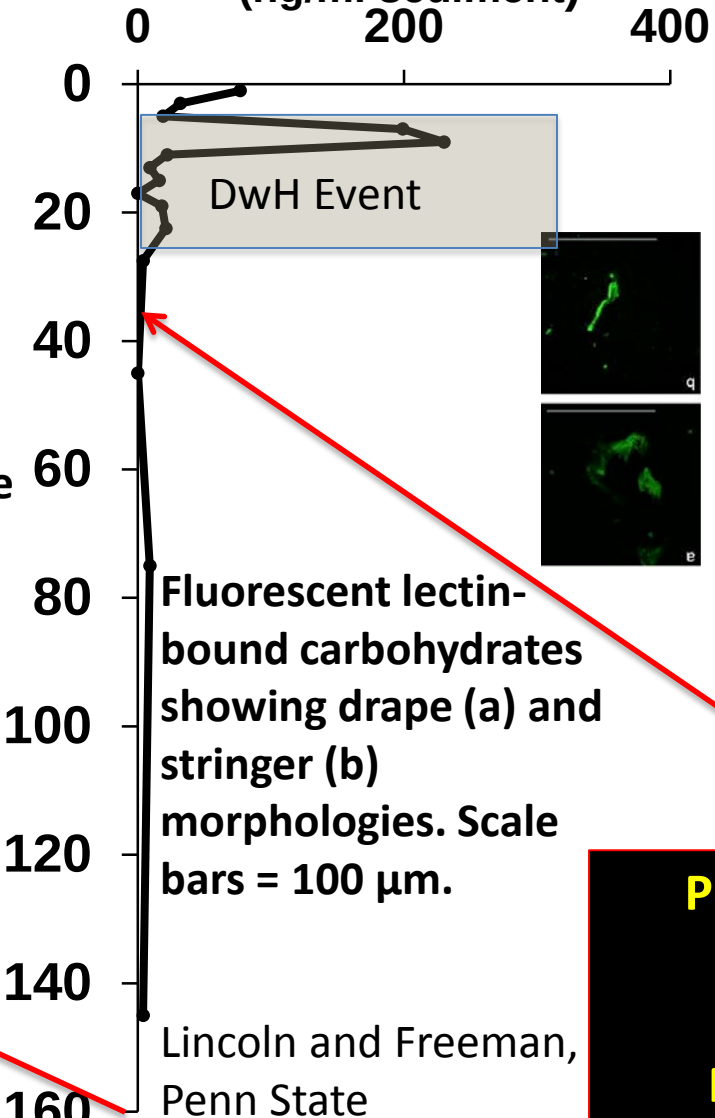
Diatom 16S RNA Sequences



- Diatom 16S rRNA genes
  - w/Chloroplast genes
  - only in top 3 cm of core
- Indicates large input of surface particle
-

Overholt and Kostka, Georgia Tech

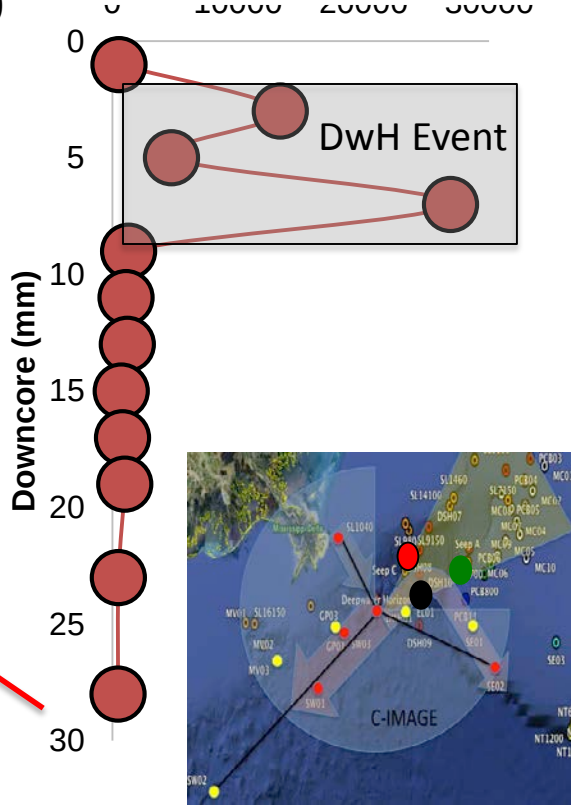
Bulk polysaccharides (ng/ml sediment)



Fluorescent lectin-bound carbohydrates showing drape (a) and stringer (b) morphologies. Scale bars = 100 µm.

Lincoln and Freeman, Penn State

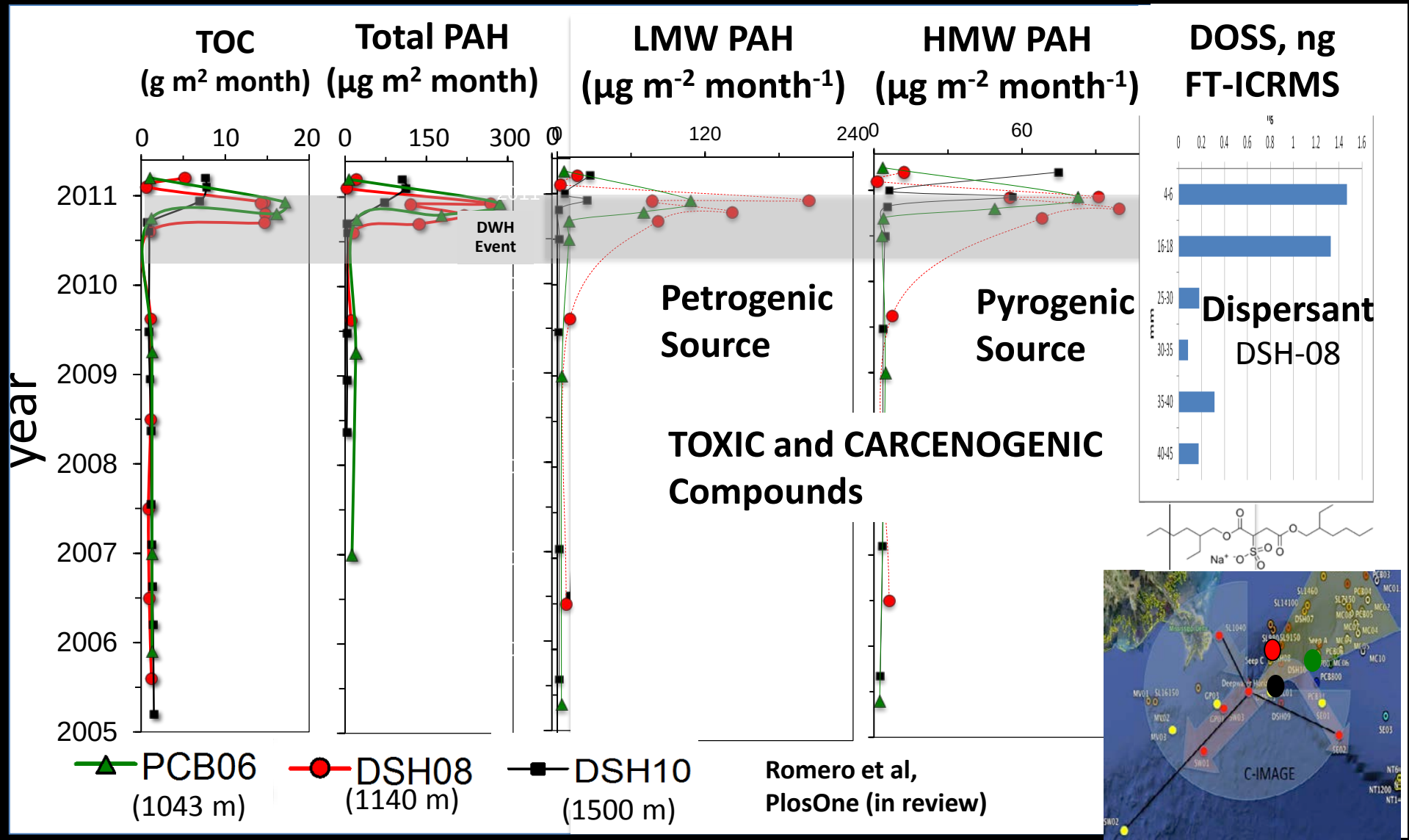
Planktic Foram. Accum. Rate (F/cm2/yr)



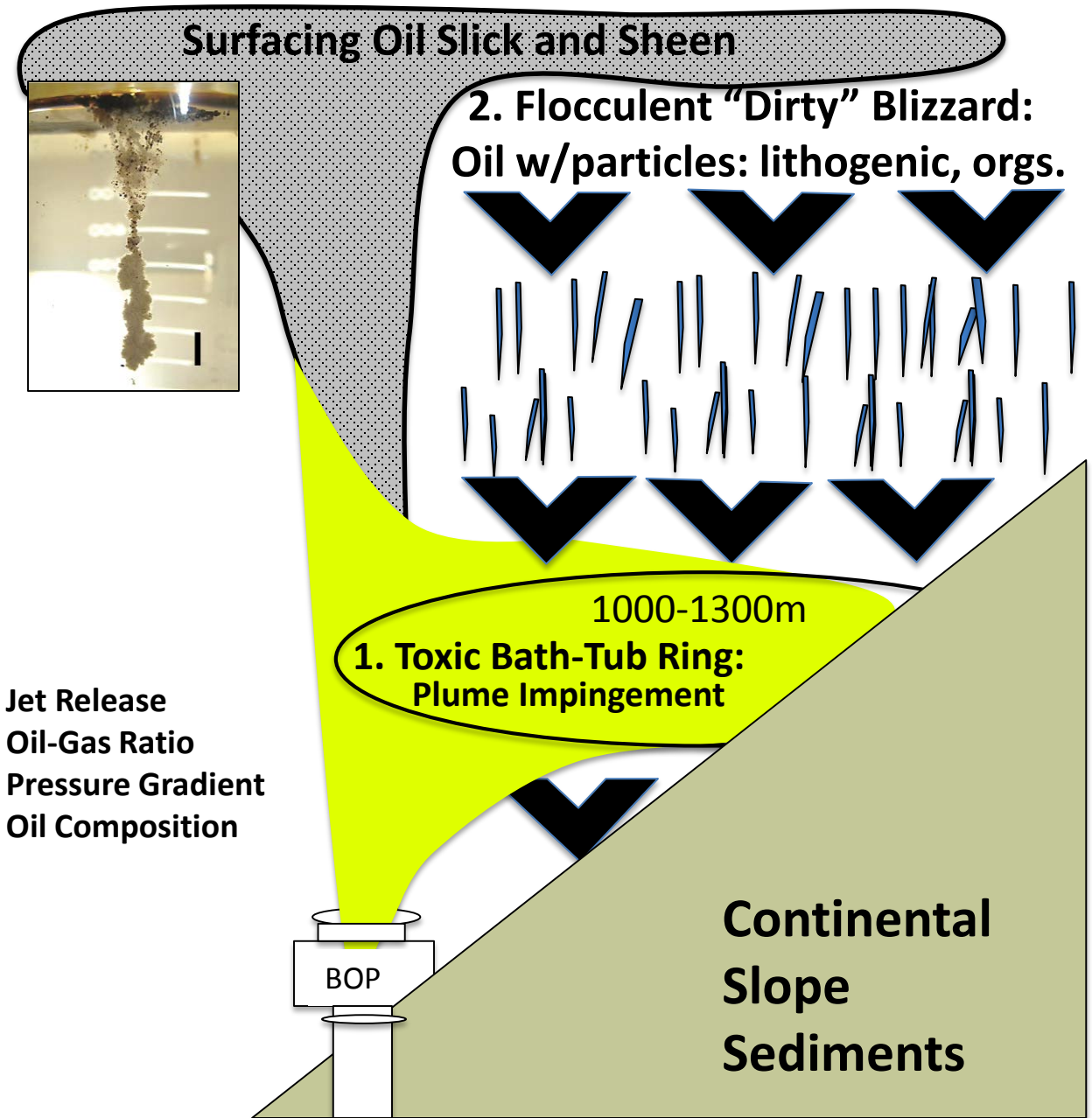
Phytoplankton and EPS Inputs are evidence for the MOSSFA Phenomena

DWH Hydrocarbons, Dispersant in Sediments

- High Accumulation Rates of Organic-C & PAHs During DwH
- LMW- Petrogenic & HMW- Pyrogenic Sources, DOSS-Dispersant



Two Possible Mechanisms of Sedimentary Oil Deposition



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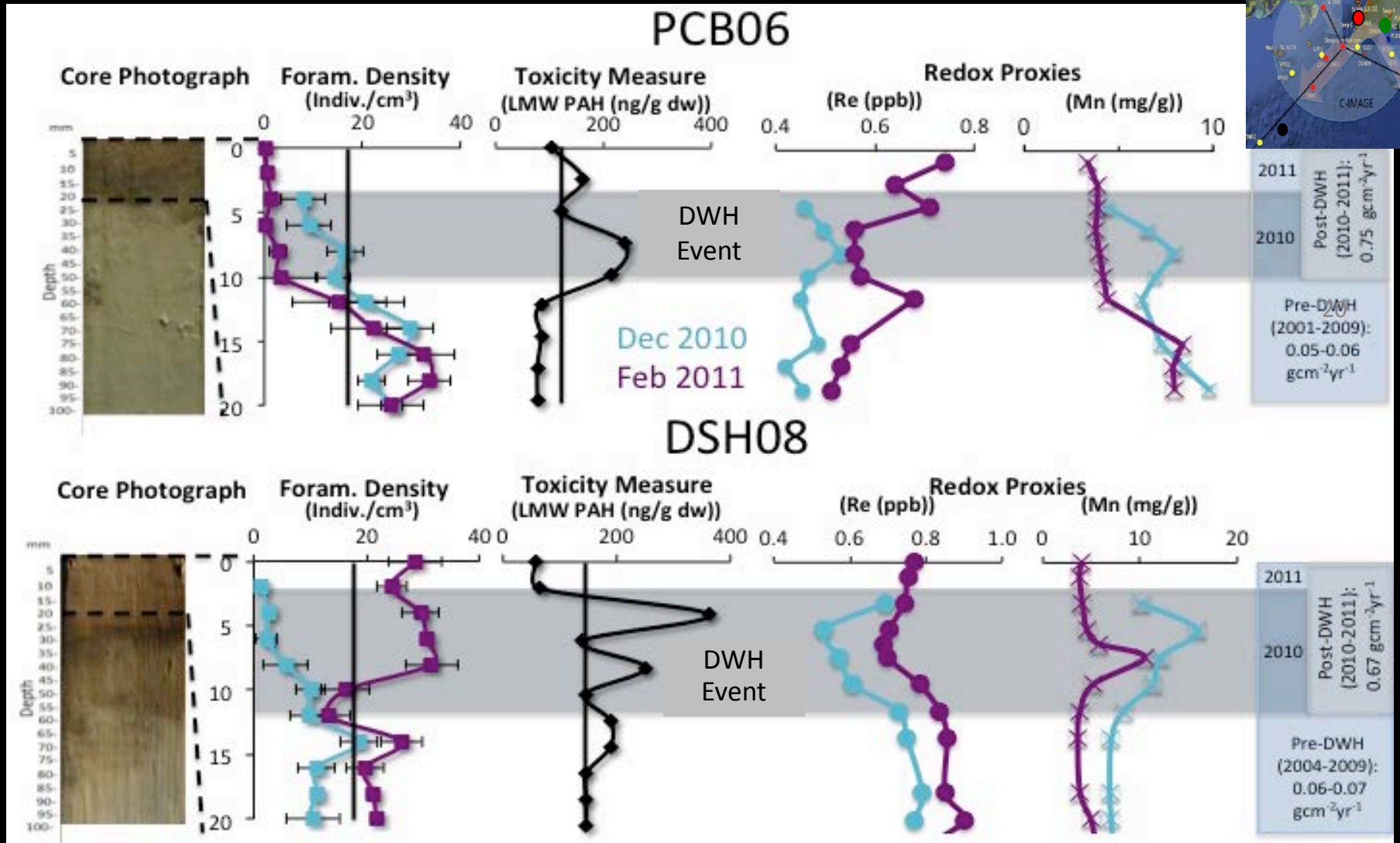
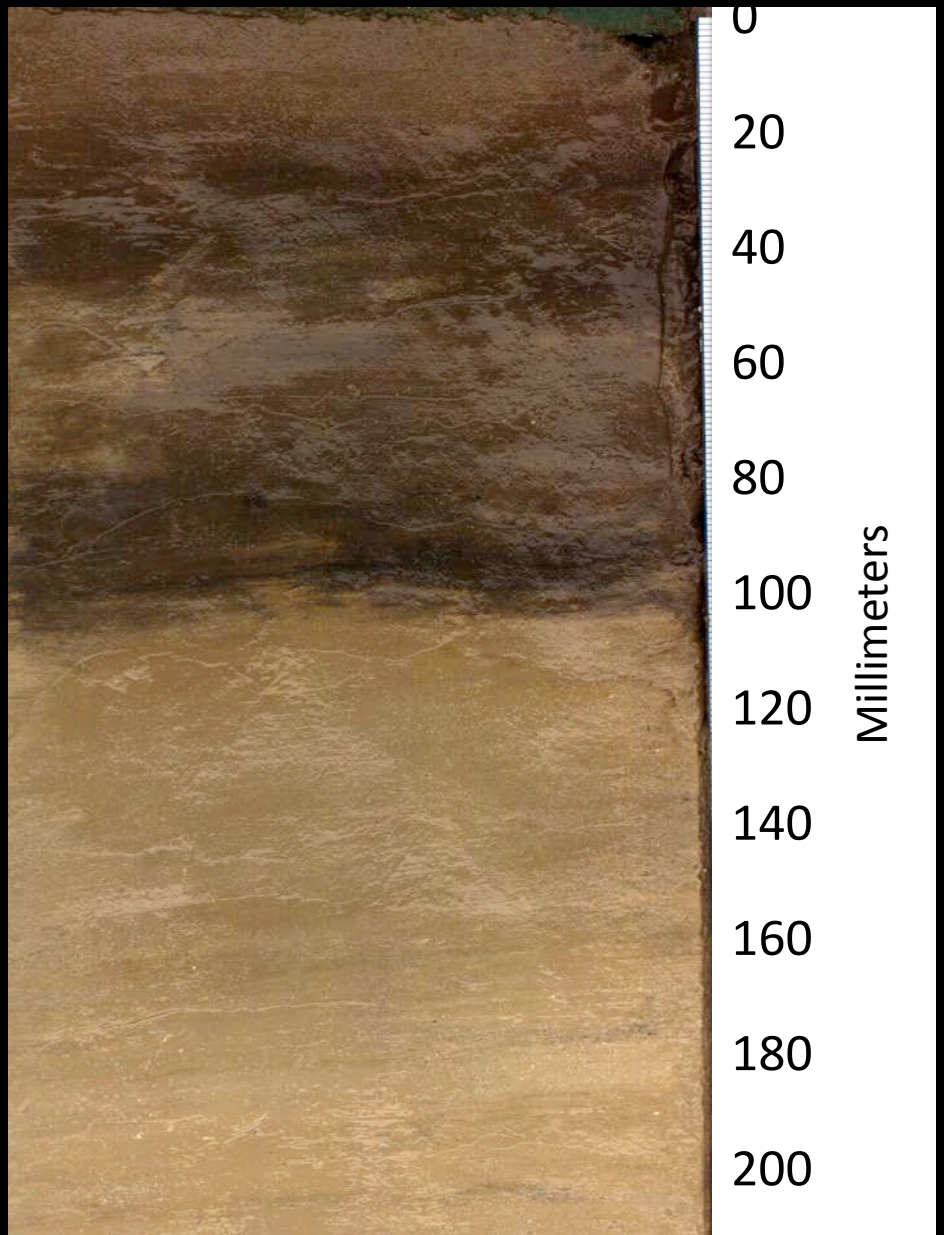
Benthic Habitat Changes and Organismal Decline

- Oil sedimentation causes changes in toxicity, chemical conditions and widespread mortality of benthic fauna
- Benthic Foram Die-off: What is the cause? How is recovery?

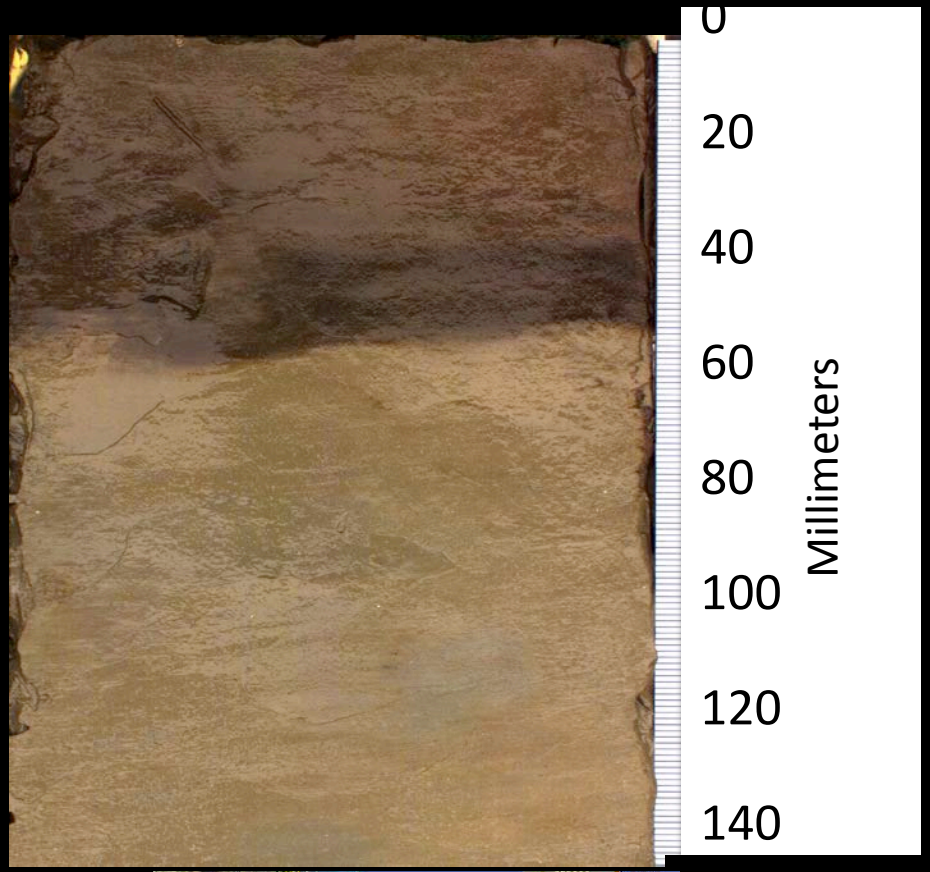


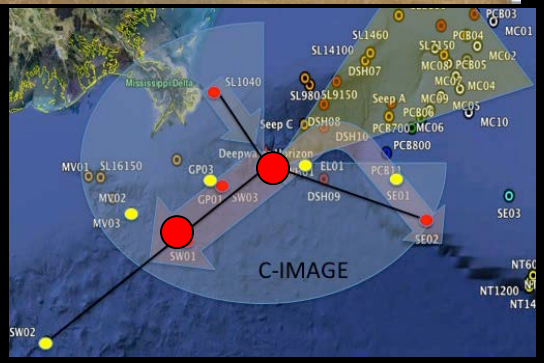
Spatial Footprint of “Flocculent Blizzard” is Expansive, August 2012

3 km from Wellhead, 1508 m



120 km southwest,1187 mwd

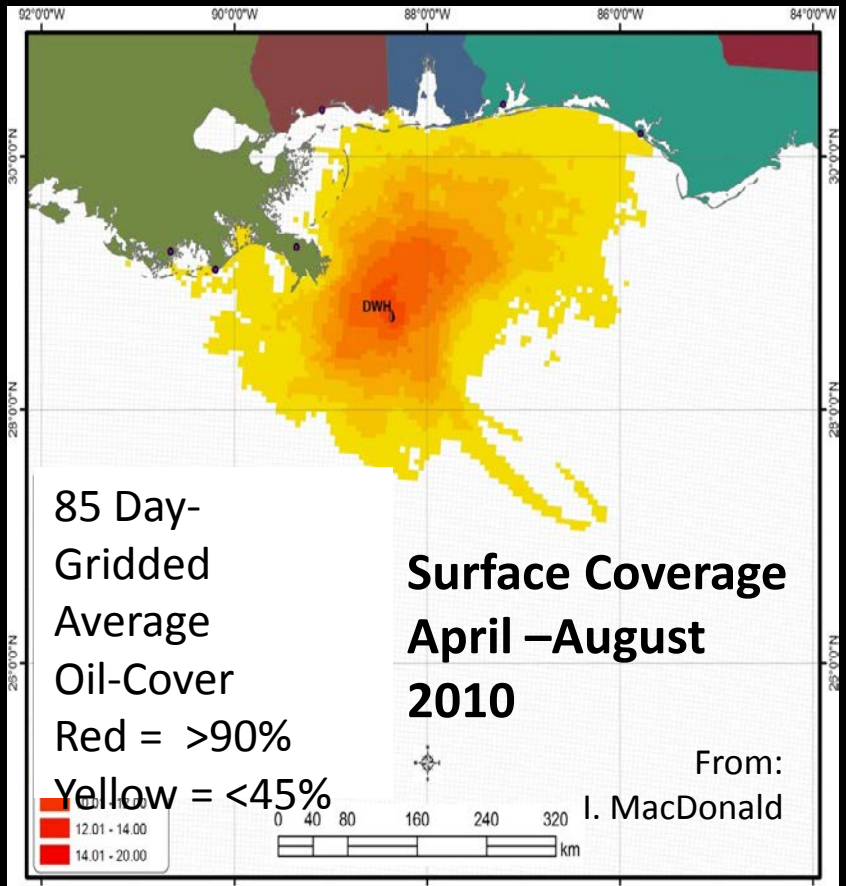


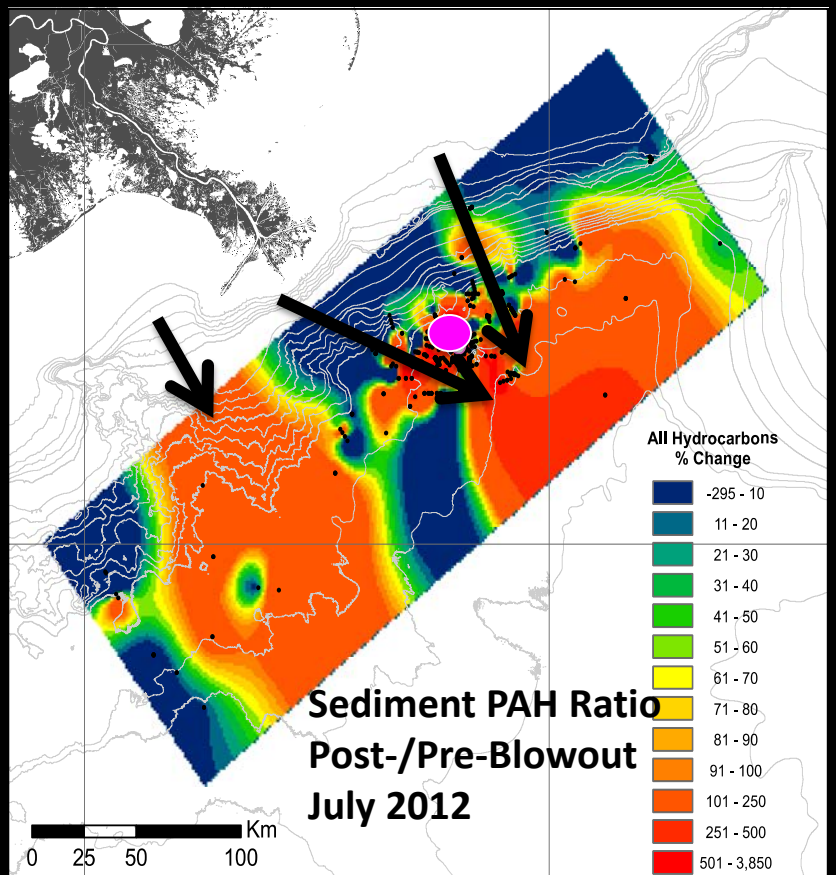


Resuspension and Downslope Transport of DWH Oil-Associated Sediment

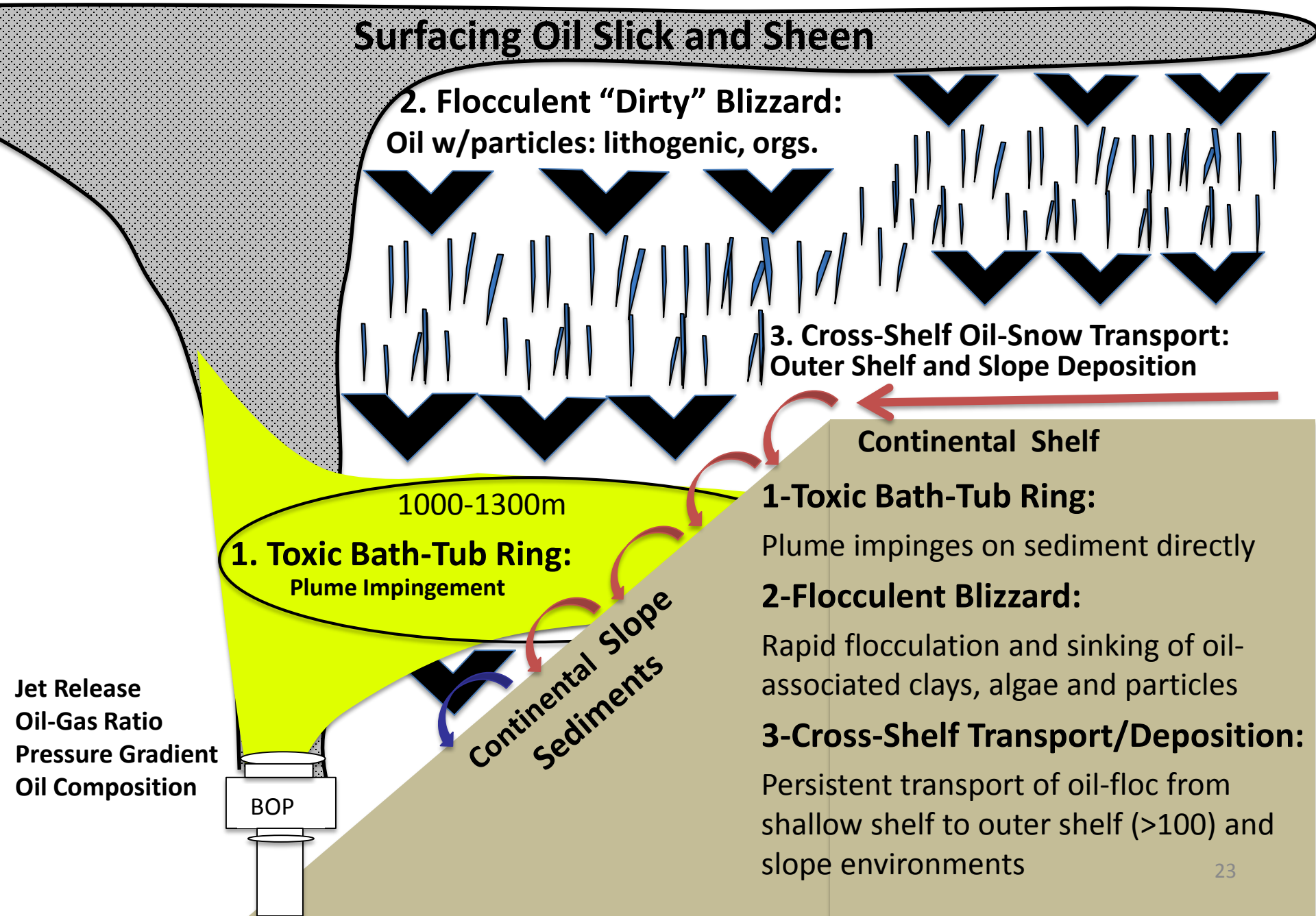
Spatial & temporal offset between surface water oil coverage And "foot-print" of sedimentary oil deposition

Significant quantities of oil remain trapped in deep-sea sediments (4-10% of the total oil released to the ocean)





Three Mechanisms of Sedimentary Oil Deposition:



1-Toxic Bath-Tub Ring:

Plume impinges on sediment directly

2-Flocculent Blizzard:

Rapid flocculation and sinking of oil-associated clays, algae and particles

3-Cross-Shelf Transport/Deposition:

Persistent transport of oil-floc from shallow shelf to outer shelf (>100) and slope environments

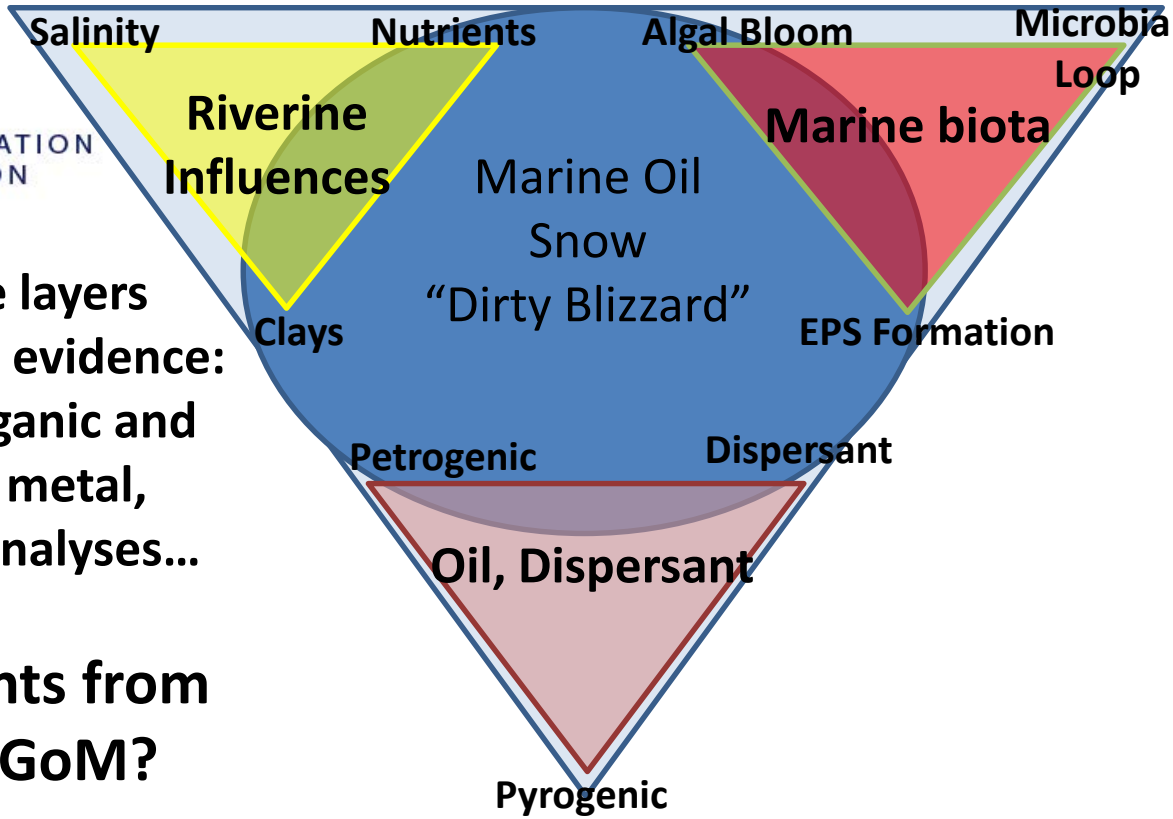
Environmental factors that control MOSSFA and the formation and sinking of oil-associated particles

MOSSFA
MARINE OIL SNOW SEDIMENTATION & FLOCCULENT ACCUMULATION

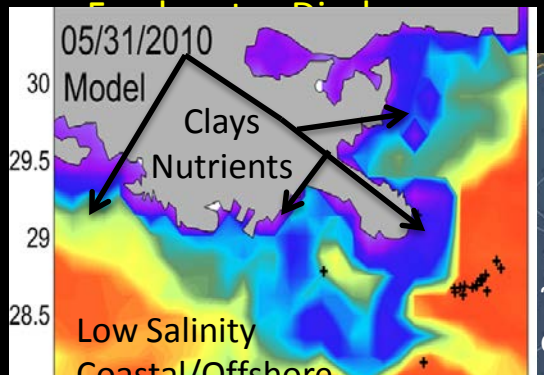
Oil Can Sink…

At DwH, oiled-sediment pulse layers confirmed through multiple lines evidence: sedimentological, biological, organic and inorganic geochemical, redox metal, micropaleontological, isotopic analyses…

What do we see in sediments from the IXTOC region in the SGoM?



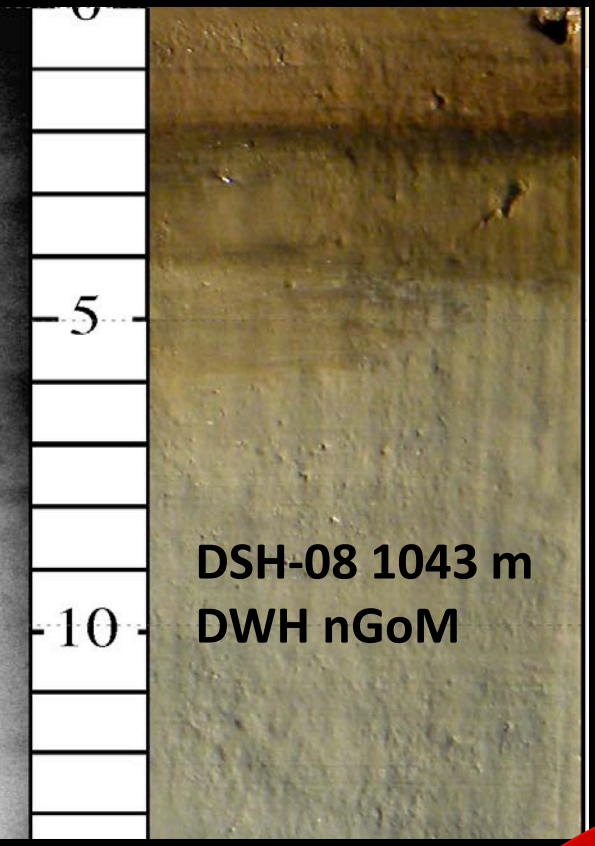
Response strategies intensified MOSSFA and increased the "footprint" of sedimentary oil deposition?



In Situ Burning

Area of Dispersant

Sediment Core Comparison: DwH vs IXTOC Redox Jump Facies



DWH
NE GoM

2010

DwH Influence

Influences Below and Above Actual Date of Event Due to Carbon Loading, Redox Changes and Redeposition

IXTOC
SW GoM

IXTOC-1 Influence

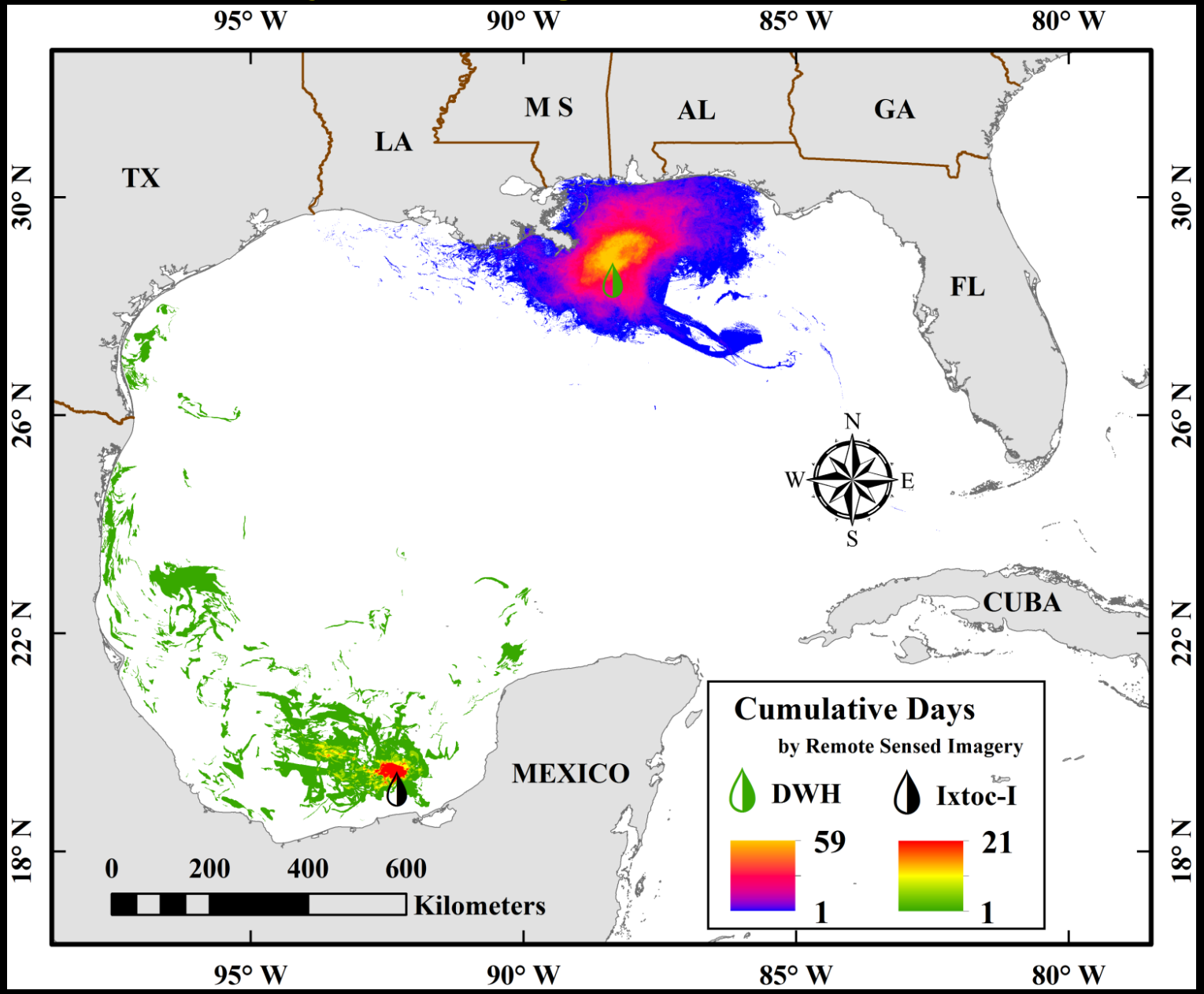
1979

"The present is the key to the past and the past is a window to see into the future"

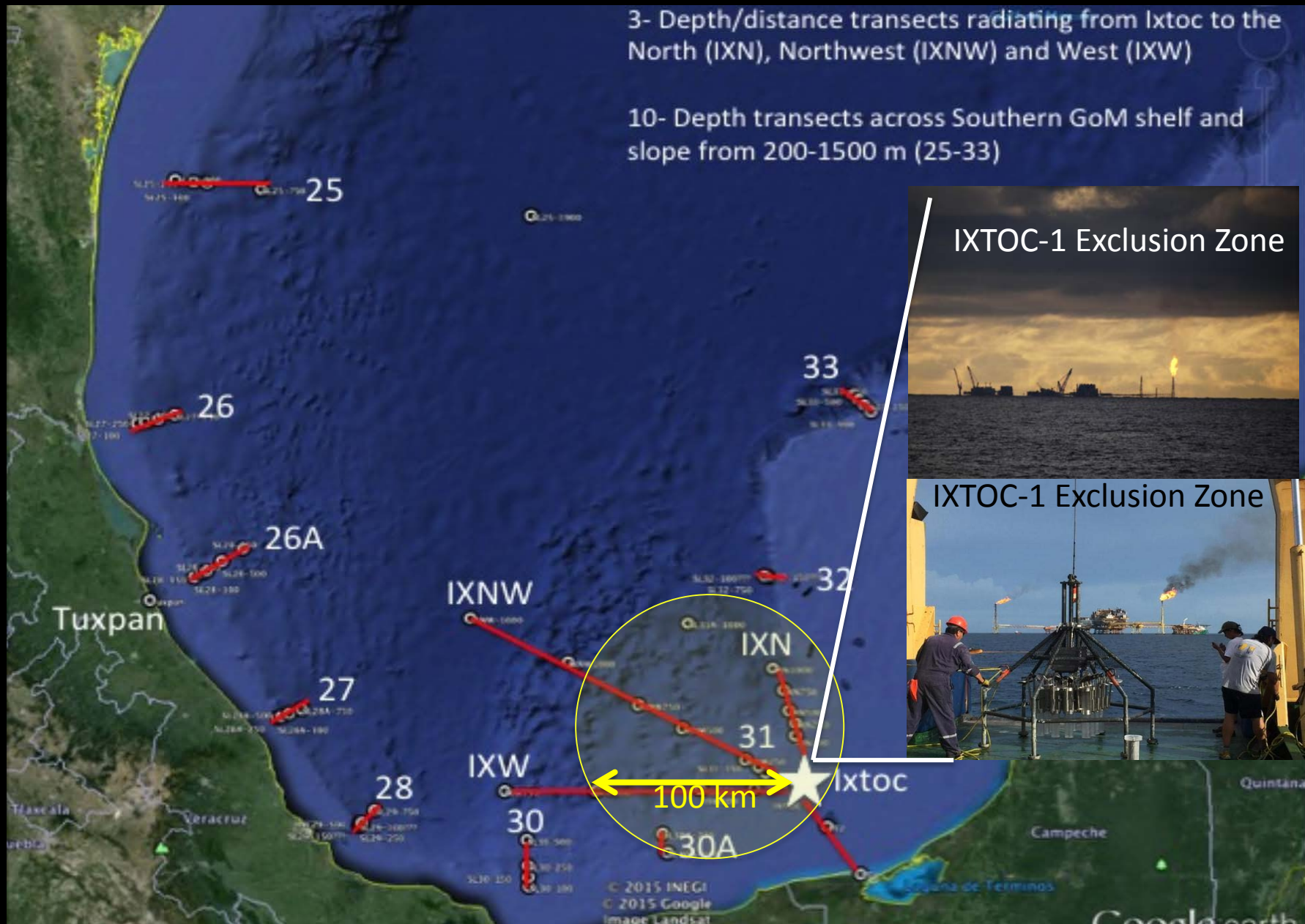
Ixtoc (past)	DWH (present)	Can we predict DWH/other spill (future)???

Surface oil footprint and trajectory of the Ixtoc-I oil spill

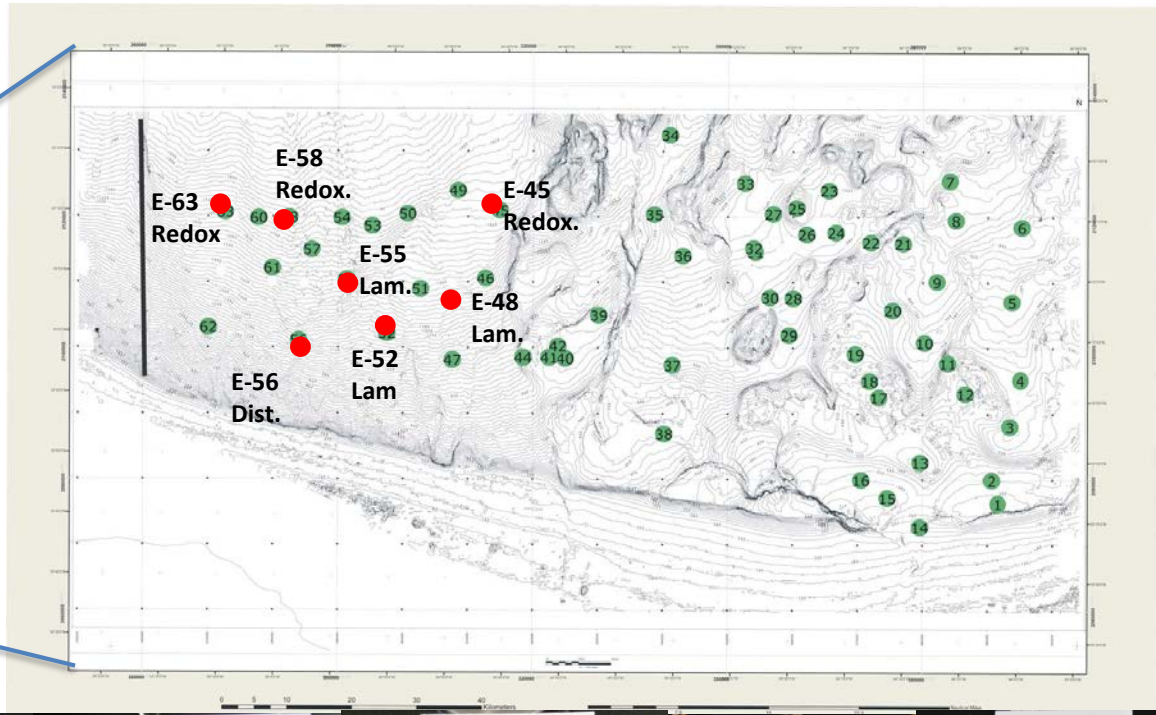
Cummulitive Days Coverage of IXTOC and DWH oil spill

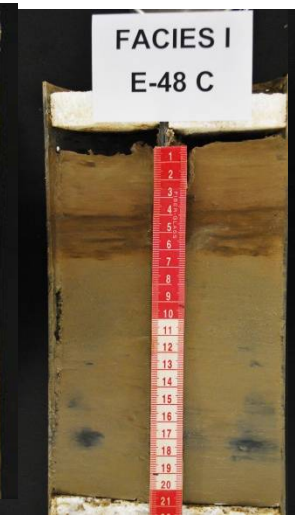


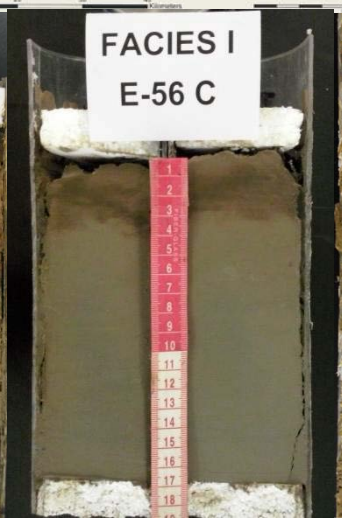
IXTOC Cruise 2015:
Sediment Coring & Water Sampling Transects

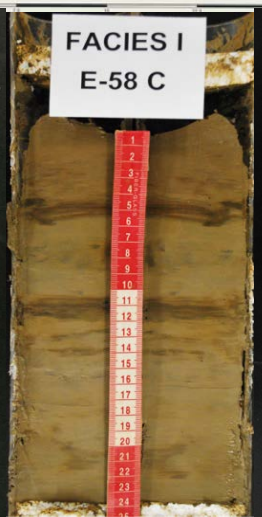


SEDIMENT CORES «FACIES I»



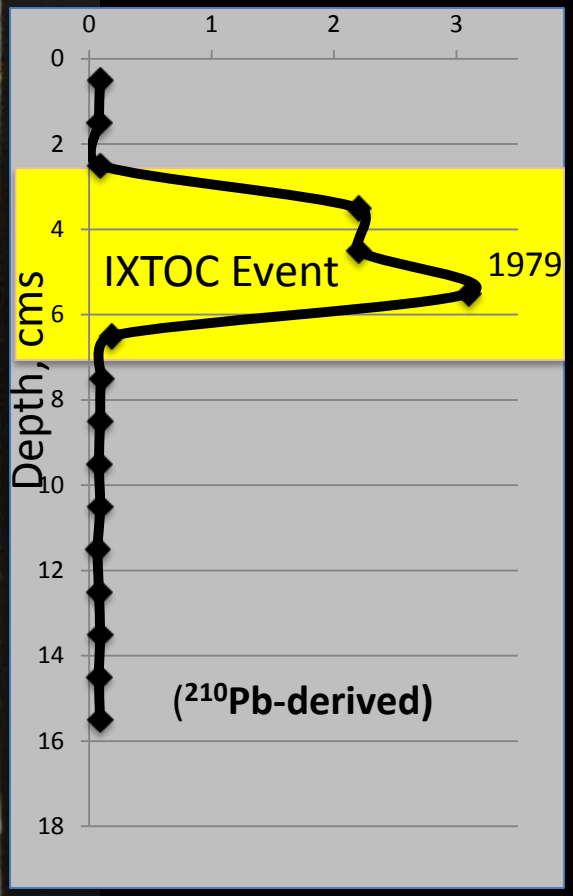






IXTOC Sediments: Mass Accumulation Rate Increases

IXTOC Sediment
Mass Accumulation Rate
g/cm2/yr

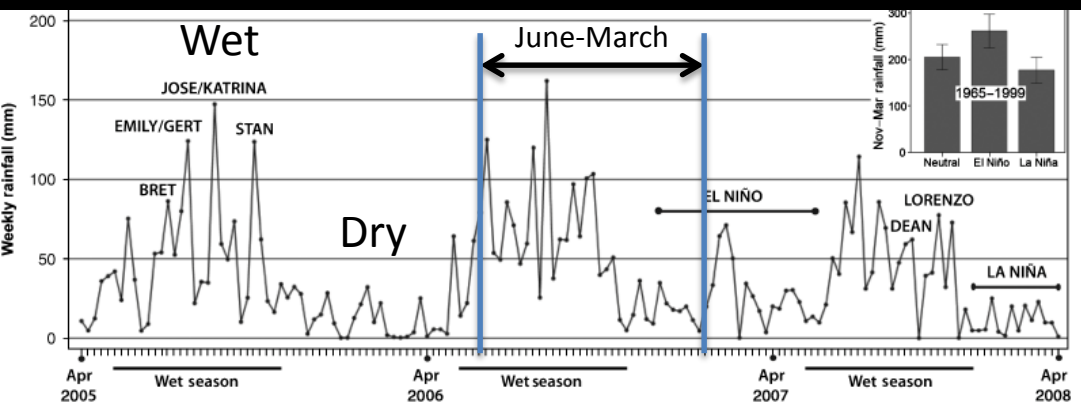


IXTOC Event
MAR increase
by ~3.5-fold
0.9 to 3.2 g/cm2/yr
(DWH Event increases
by 2.5 fold)

MAR increase is synchronous with date of IXTOC blowout, 1979, but elevated MAR extends for years after event ends.

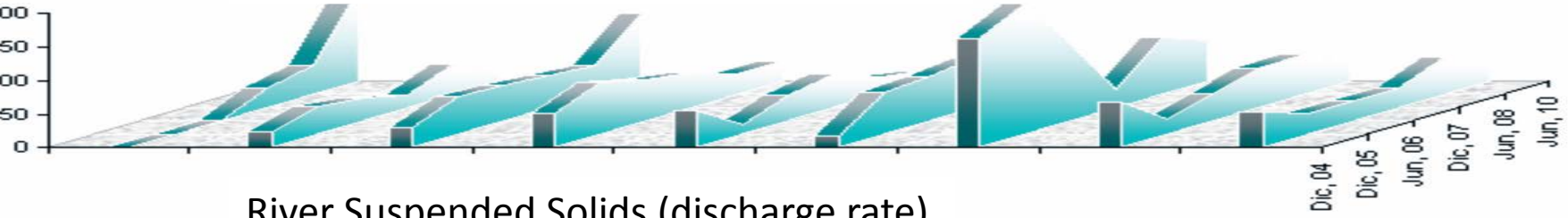
The prolonged IXTOC MAR is similar to that seen after DWH event

Seasonal Rainfall Pattern and River Discharge of Suspended Solids in the Vera Cruz-IXTOC Region



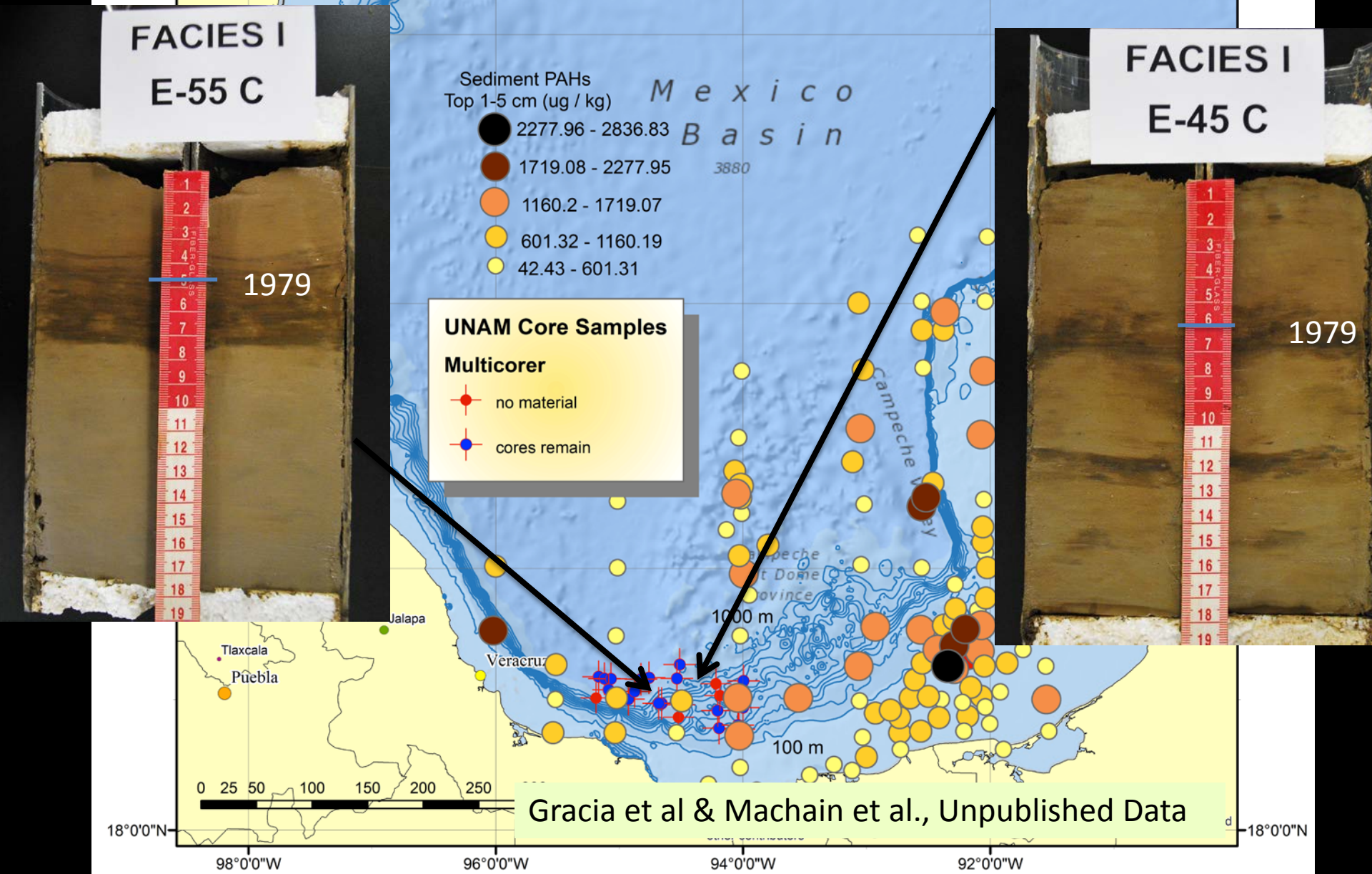
- **Majority of Wet-Season Overlaps with Timing of IXTOC Event, June - March**
- **Rivers Adjacent to IXTOC Contain Abundant Suspended Particles and Nutrients**

River Suspended Solids (concentrations)



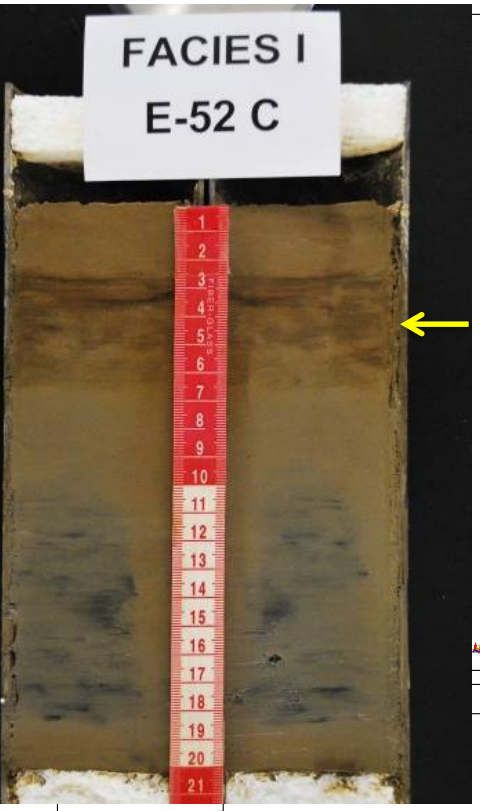
River Suspended Solids (discharge rate)

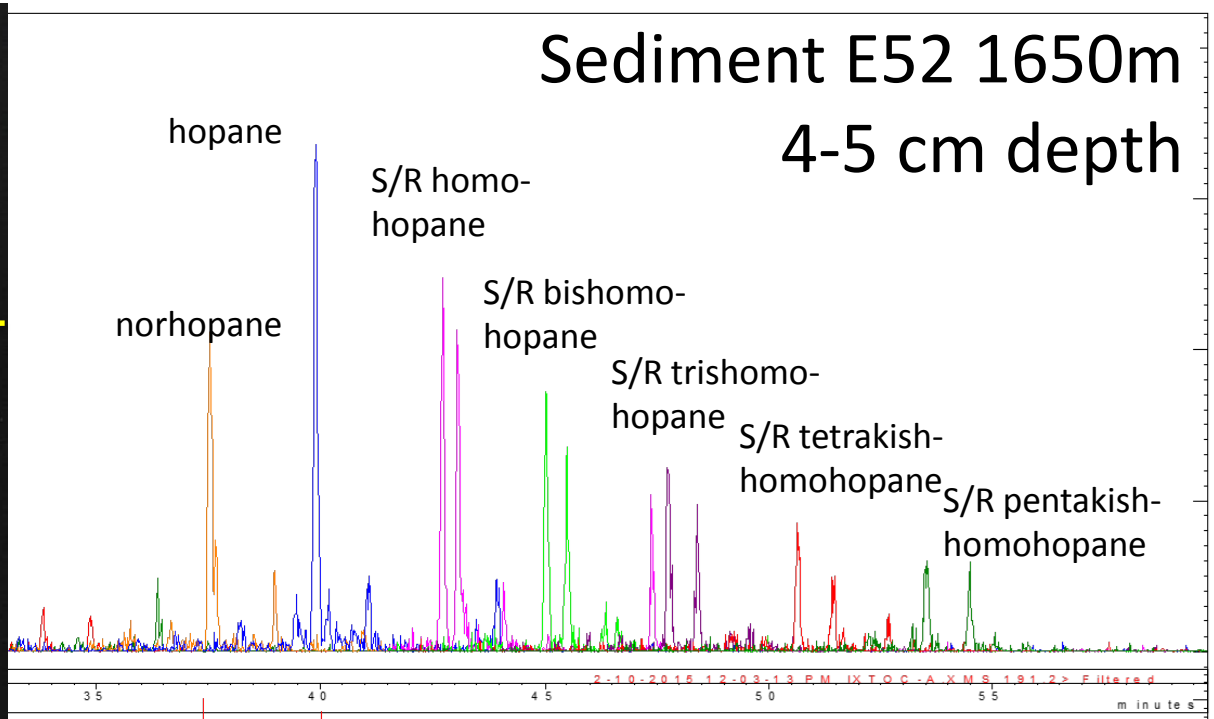
IXTOC Sediment Core Locations
Surface Sediment PAH Distribution & Concentrations

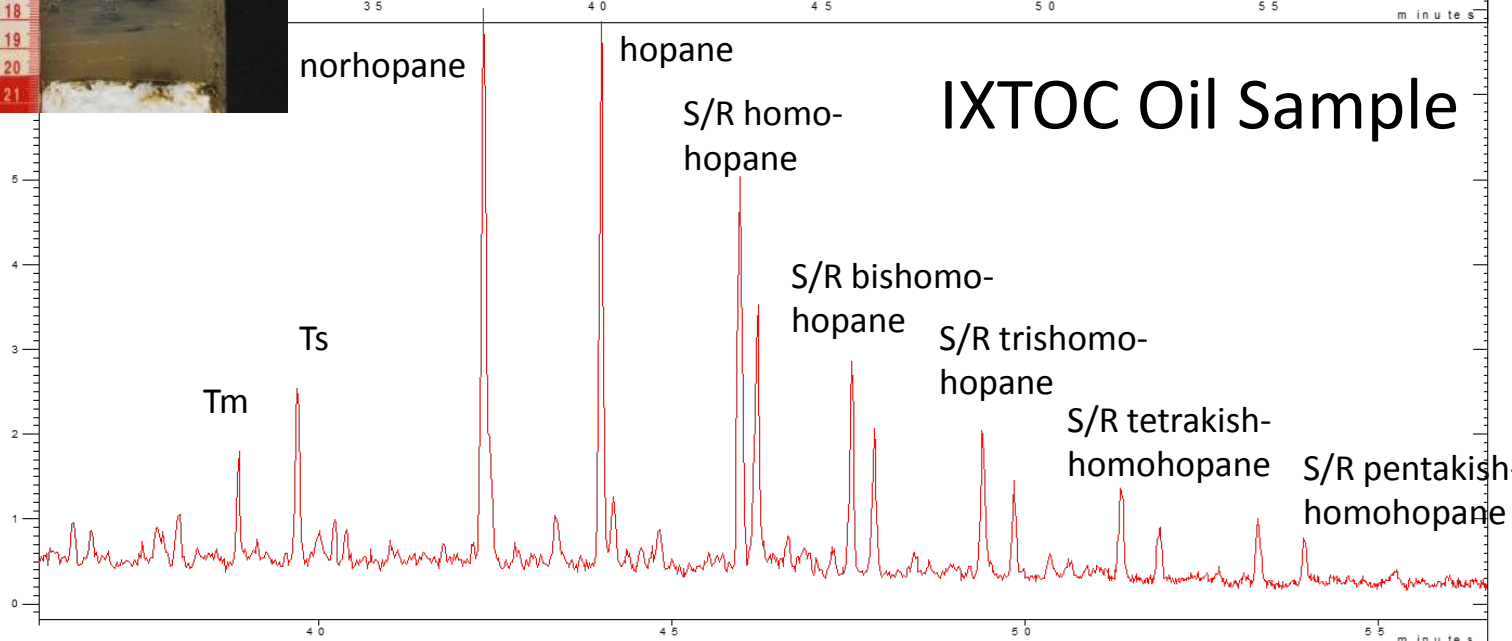


Gracia et al & Machain et al., Unpublished Data

Correlation of IXTOC Oil and Sediment: HOPANES M/Z 191



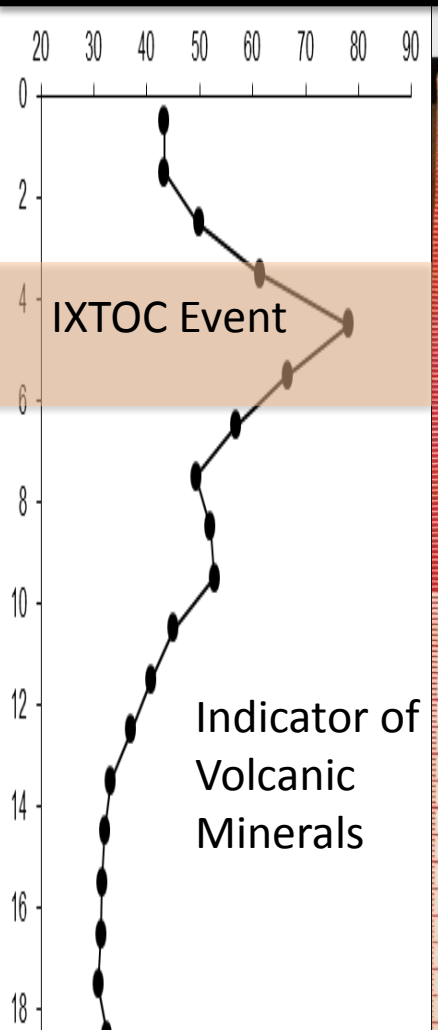




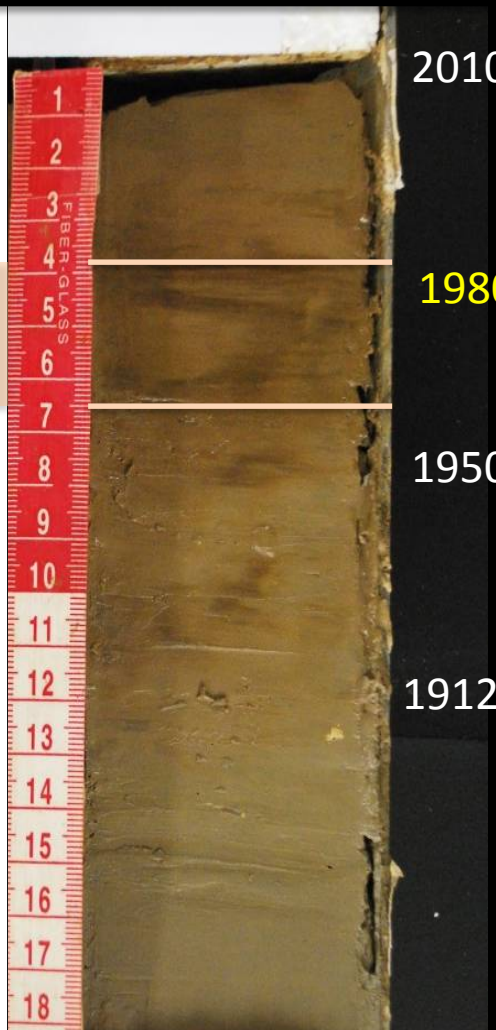
IXTOC Blowout Event Recorded in Sediments-1600 mwd

Changes in Sediment type, Foram Abundance, Redox, HC Inputs

Magnetic Susceptibility



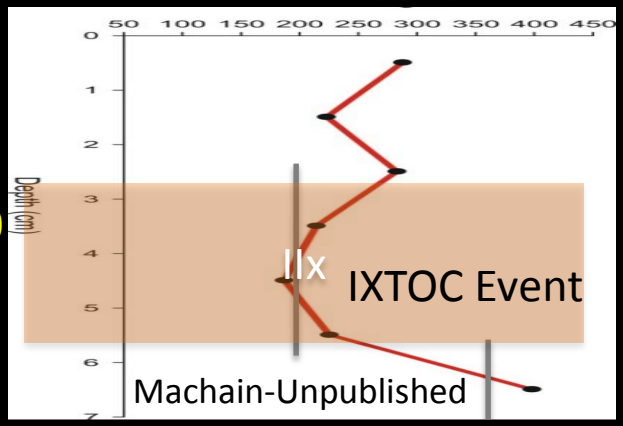
Core 63
1650 mwd



Age
^{210}Pb

2010
1980
1950
1912

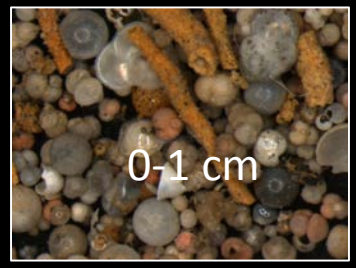
Foraminifera
Abundance (tests/g)
50 200 400

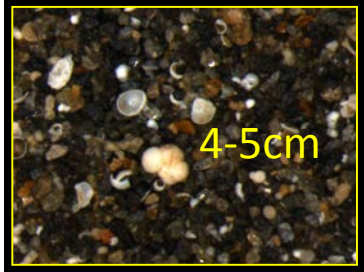


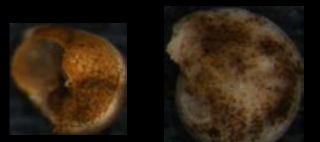
IXTOC Interval

- **Organic-rich sediment**
- **Hydrocarbon Staining**
- **Benthic Meiofauna are Scarce & Fragmented**
- **Altered Community**
- **Redox Changes**
- **High lithic component Input**

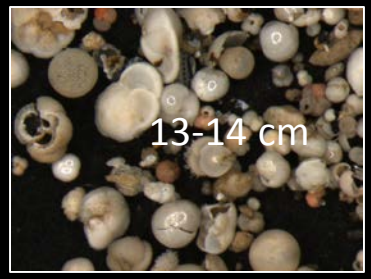
Sediment
> 63 uM





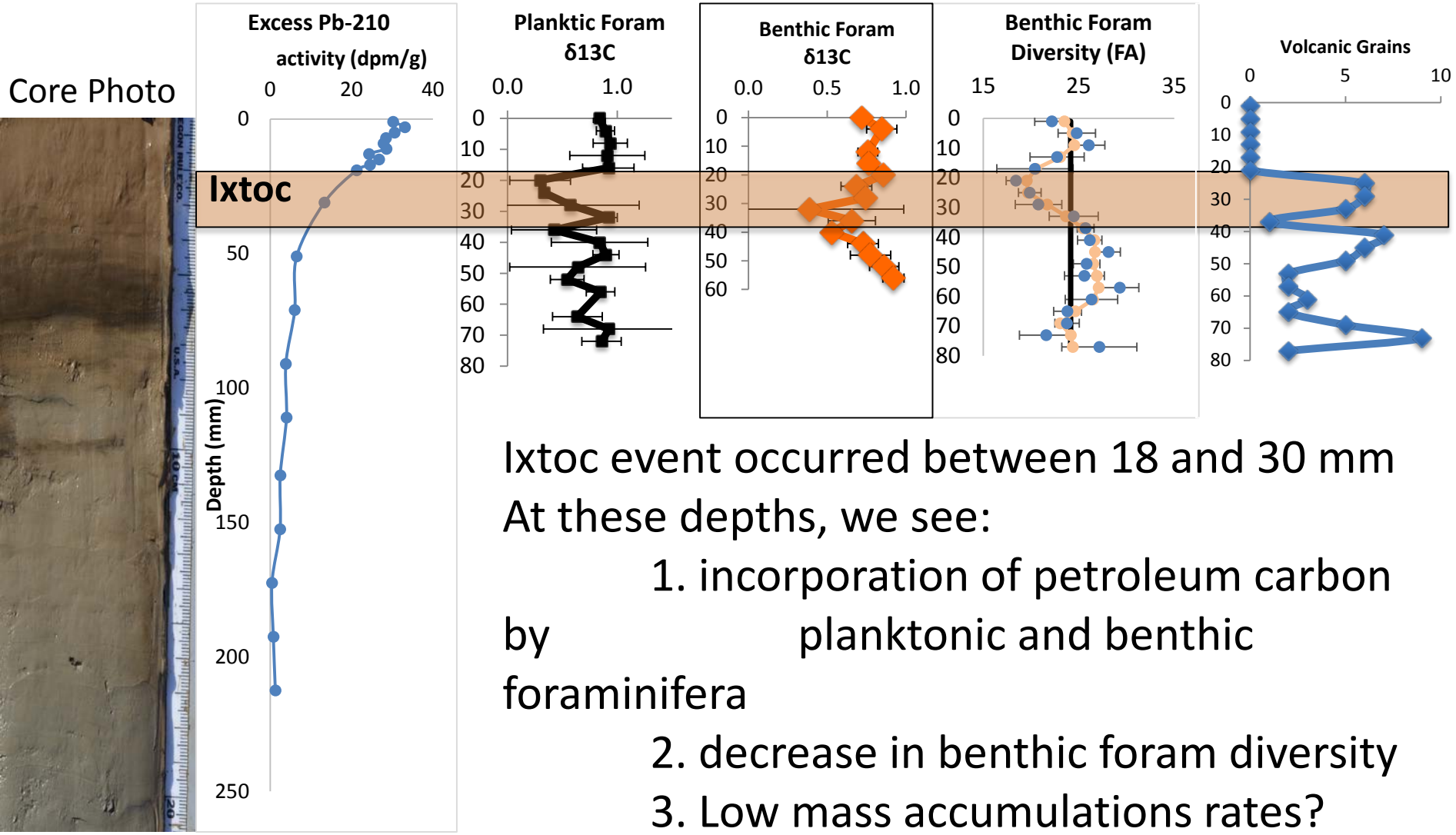


Hydrocarbon Stained Foram Tests



Response of Planktonic & Benthic Forams to IXTOC Event
IXW-500 Site, ~ 100 km from IXTOC Site

Core Photo



Ixtoc event occurred between 18 and 30 mm

At these depths, we see:

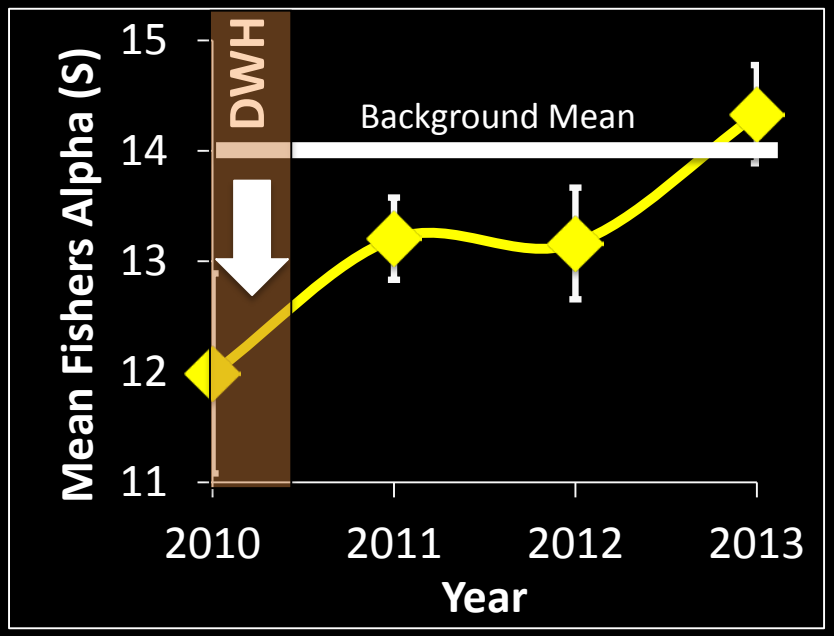
1. incorporation of petroleum carbon by planktonic and benthic foraminifera
2. decrease in benthic foram diversity
3. Low mass accumulations rates?

Schwing, Brooks, Larson, et al.

Volcanic records: good for geochronology

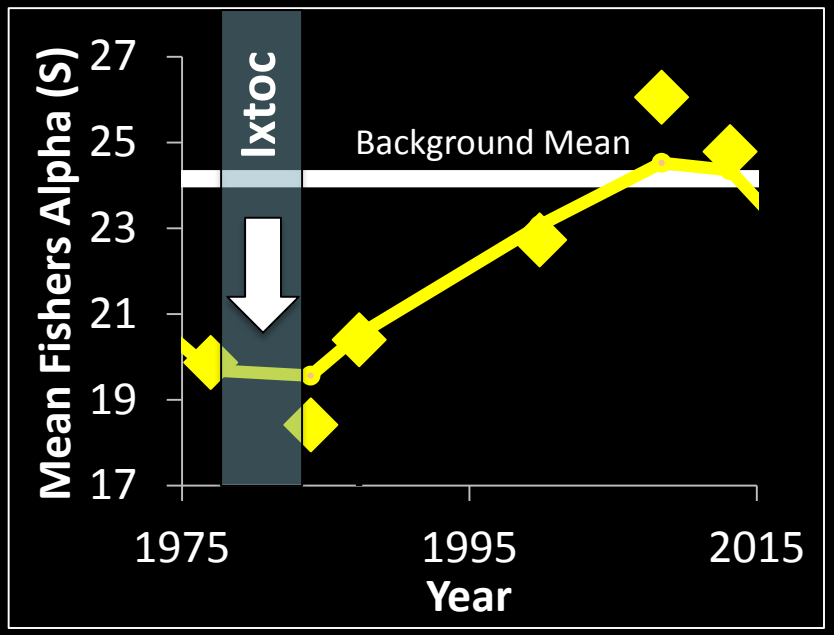
Benthic Recovery Rate

NGoM- DWH



- NGOM: Diversity from 8 sites took 3 years to recover following DWH, (resembles ^{234}Th evidence of bioturbation)
- Majority of site show that Mieofauna and macrofauna not yet recovered

SGoM- IXTOC-1



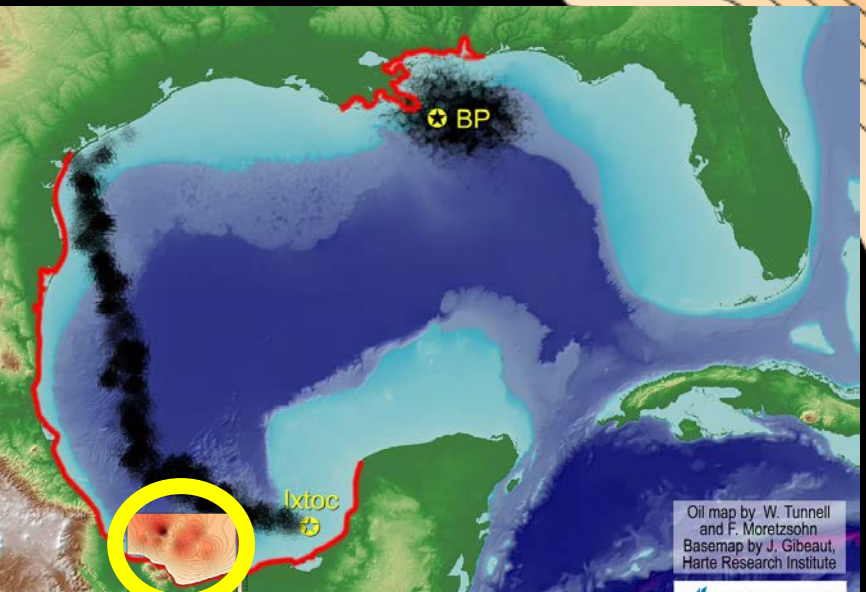
- SGOM: Diversity from 1 site suggests recovery took ~20 years following Ixtoc

Recovery of benthic estimated between 3 and 20 yrs

Need more sites to validate?

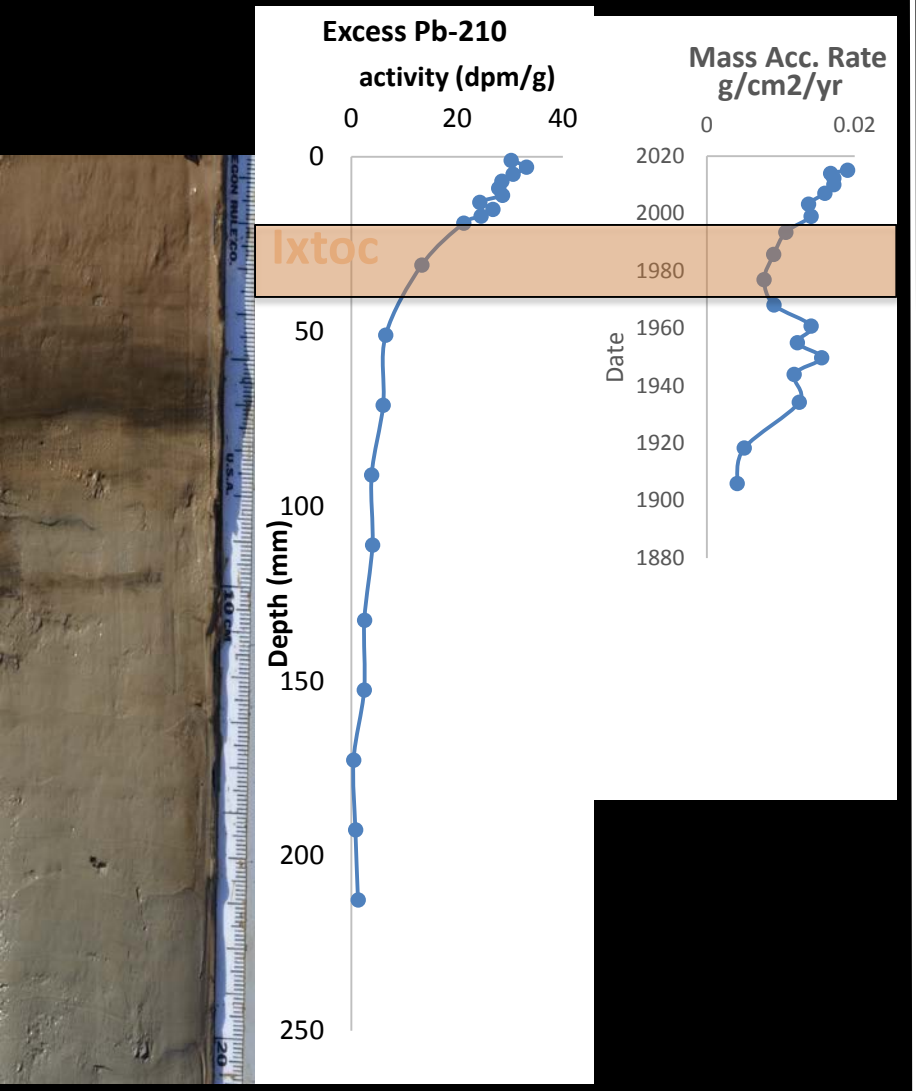
^{210}Pb-Sediment Accumulation Rates in 2011:

Did Sediment Depocenters focus MOSSFA Event after IXTOC Event?



Coatzacoalcos River

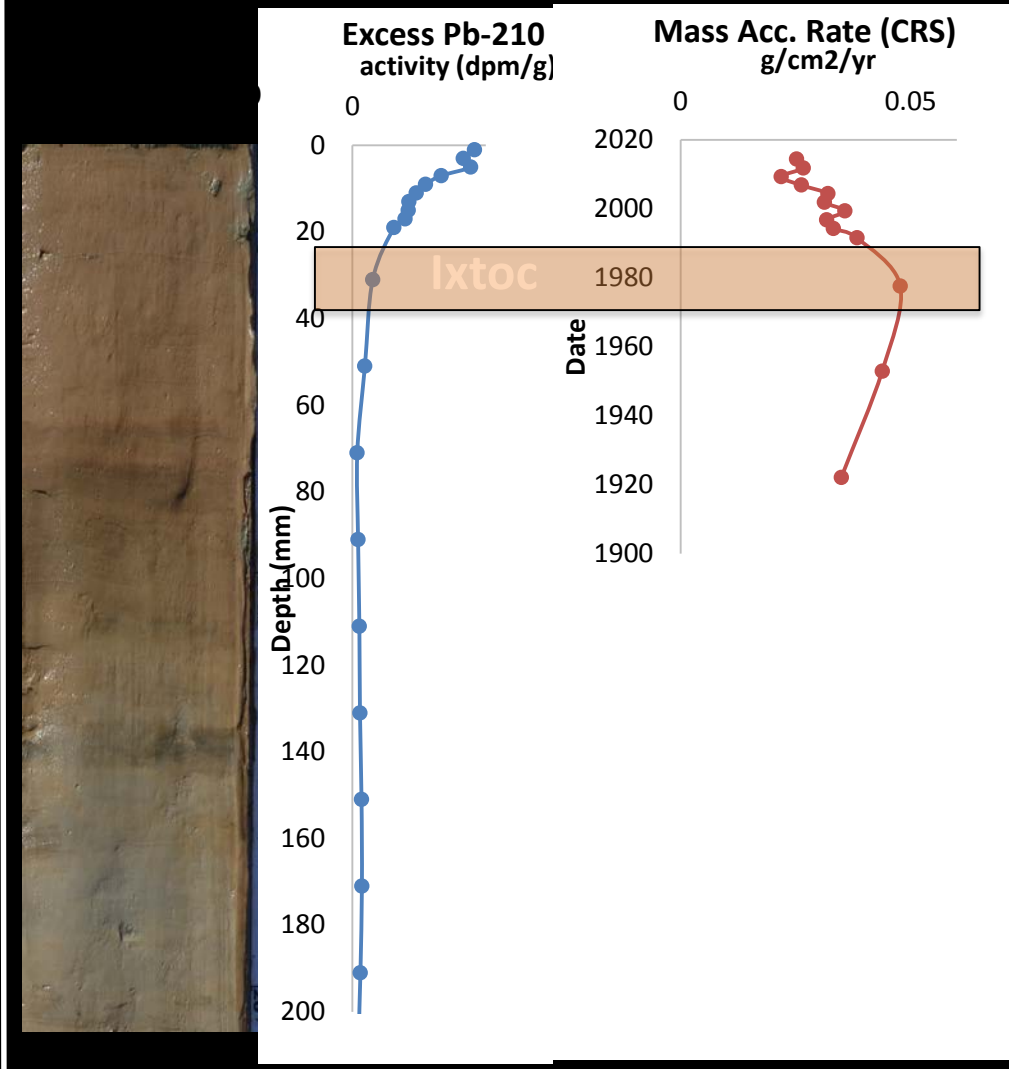
IXW-500



Decreasing Mass Accum. Rates during IXTOC Event

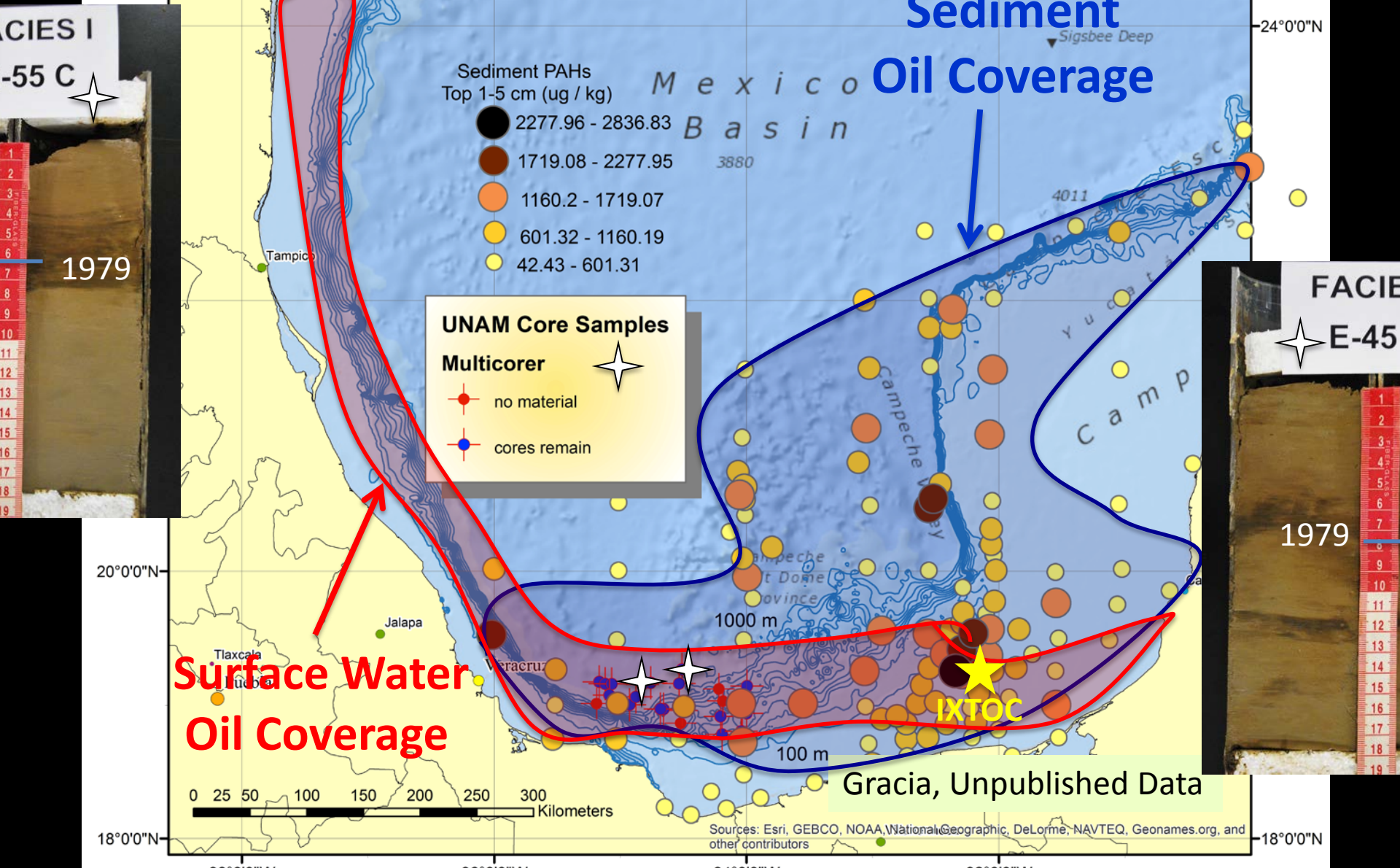
Schwing, Brooks, Larson, et al.

IXW-750

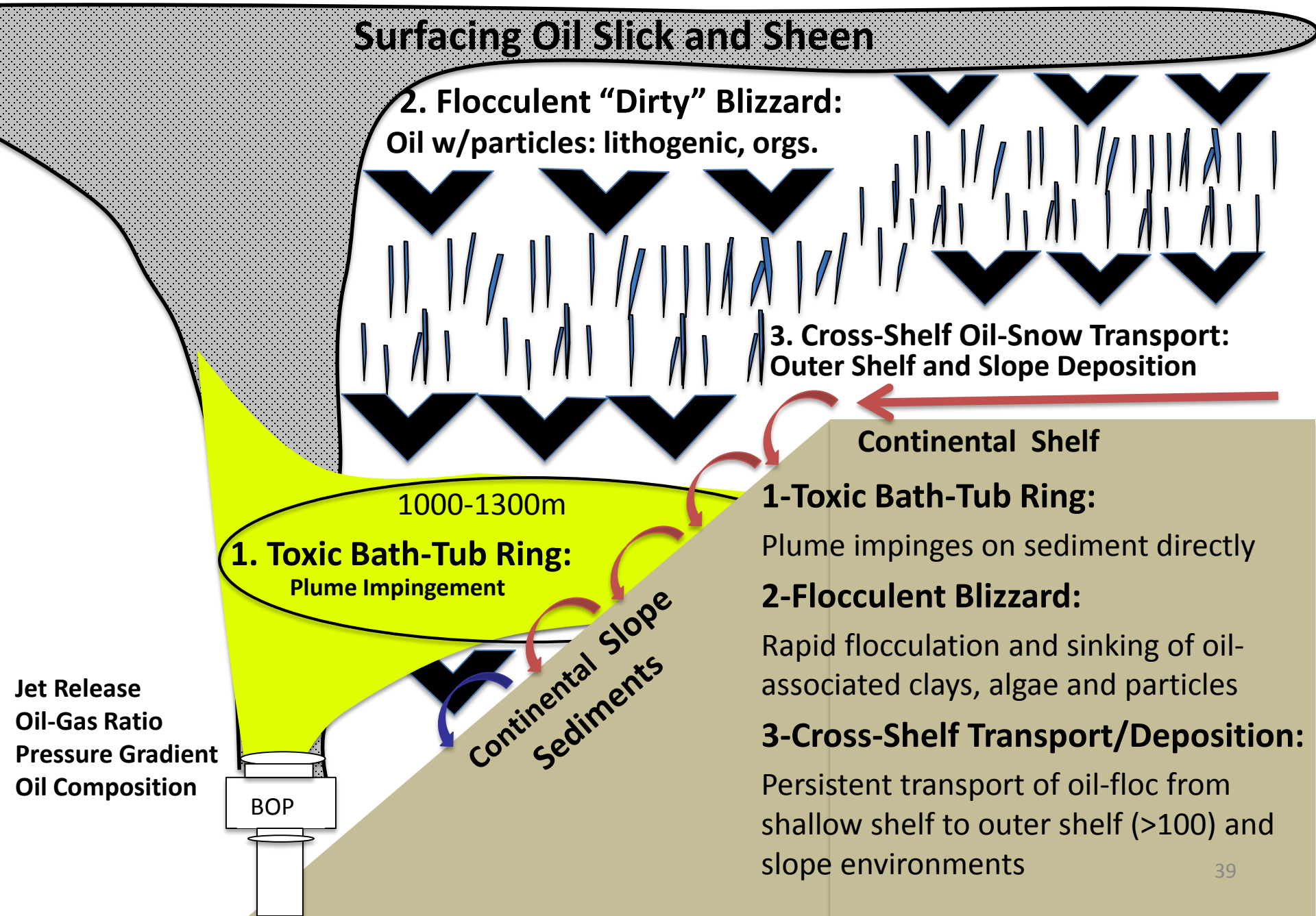


Increasing Mass Accum. Rates during IXTOC: Sediment Remobilization to Depocenter?

Spatial Offset Between Surface Water & Sediment Oil Coverage
MOSSFA processes after IXTOC : Deposition in Deepsea



Three Mechanisms of Sedimentary Oil Deposition:



1-Toxic Bath-Tub Ring:

Plume impinges on sediment directly

2-Flocculent Blizzard:

Rapid flocculation and sinking of oil-associated clays, algae and particles

3-Cross-Shelf Transport/Deposition:

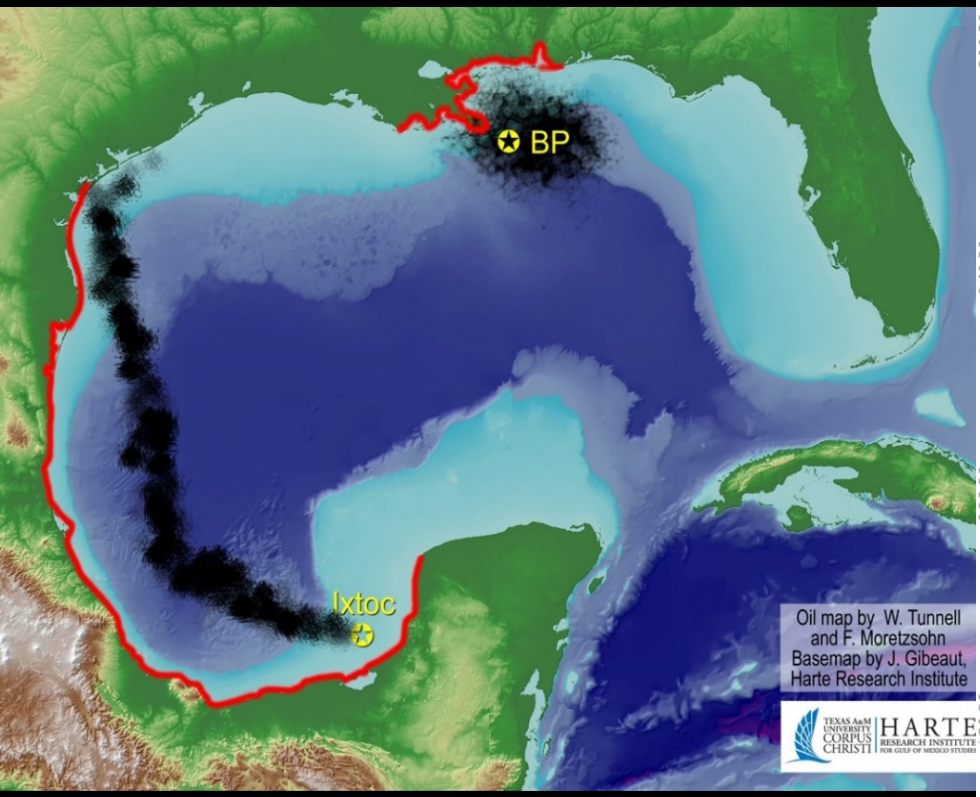
Persistent transport of oil-floc from shallow shelf to outer shelf (>100) and slope environments

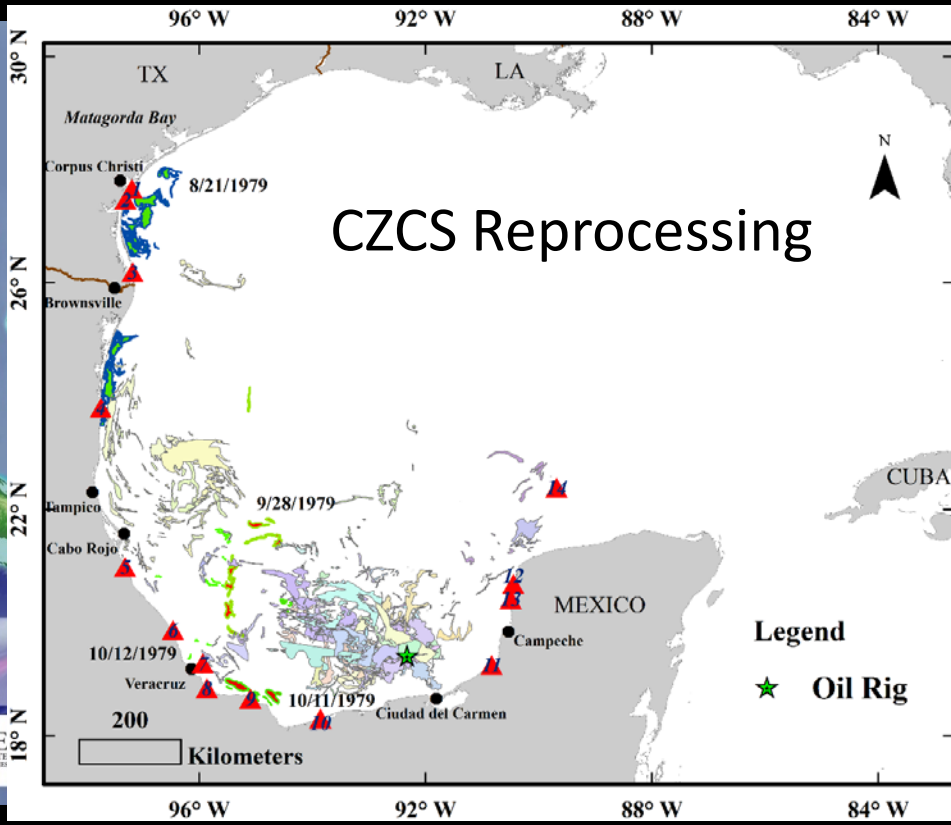
Significance and Implication of a MOSSFA Event: Oil Spill Response and Long-Term Consequences

- A "new" consideration for real-time oil spill response
  - Concentrating mechanism of mineral-oil-biota aggregates (MOBAs)
  - Predict MOBA formation mechanisms: spatial-temporal
  - Formation, in part, related to traditional response strategies: Freshwater discharge (clays/nutrients), burning and dispersant application
  - Target for real-time collection and cleanup

- Widespread MOBA sediment deposition- Benthic Impacts
  - Long-term persistence in the benthic environment, up to 20 years
  - Important for calculations of the final oil budget
  - Predict area of benthic ecosystem impact
  - If transported to slope and buried, may be best alternative to remove oil from biologically active areas and minimize impact to economically important species

Tracking the IXTOC Oiling of the SGoM Shoreline-Reprocessing of Coastal Zone Color Scan (CZCS) Satellite Images After 35+ years





Red triangles show locations of coastal oiling during IXTOC

Many diverse environments in the SGoM

Summer 2016: Coastal-Shoreline SGoM Sampling
Mangrove, Beach Rocks, Laguna Terminus Enmido Reefs

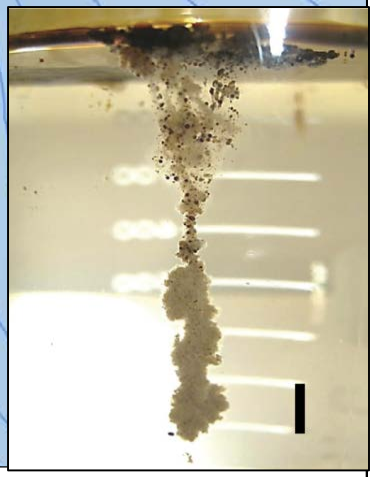
Remnants of Ixtoc tar mat first observed and photographed in 1979; remnant in 2010

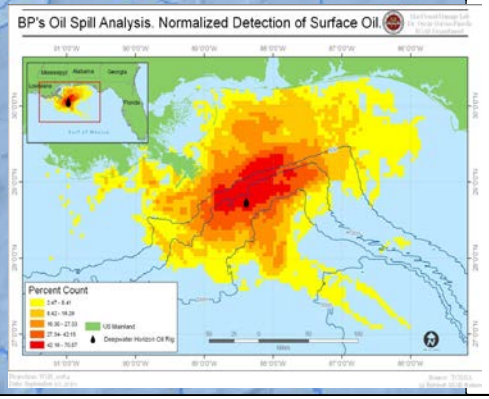
Unusual bare areas in mangrove forest revealed thin layer of tar with mangrove roots growing though it at edges

Document changes in chemical composition and toxicity associated with the weathering of coastal oil

MOSSFA Time in the nGoM, Sunset May 22, 2010

2010 Map of Sediment Flocculent Thickness- nGoM



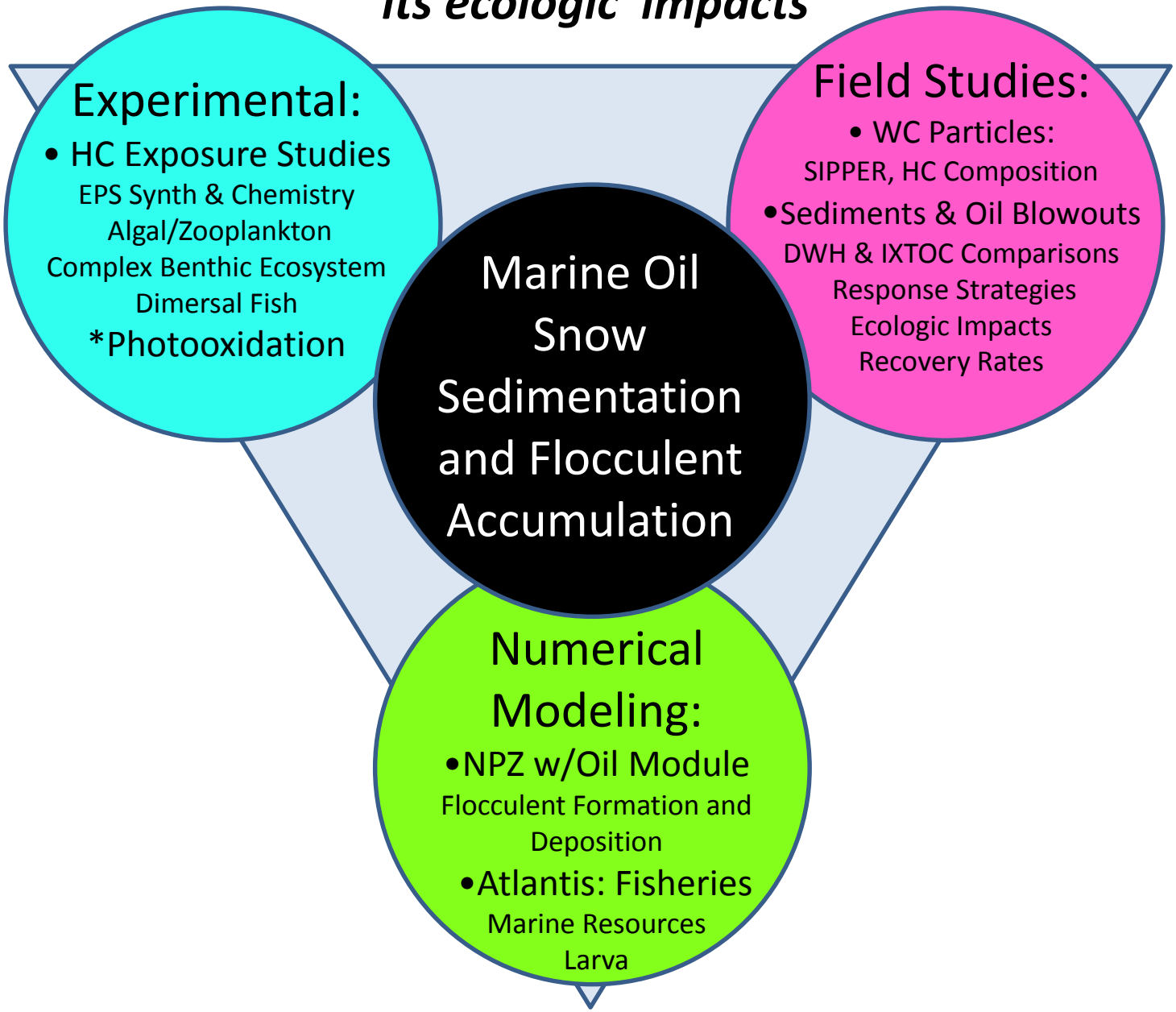


Observed floc depth on surface sediment samples (cm)

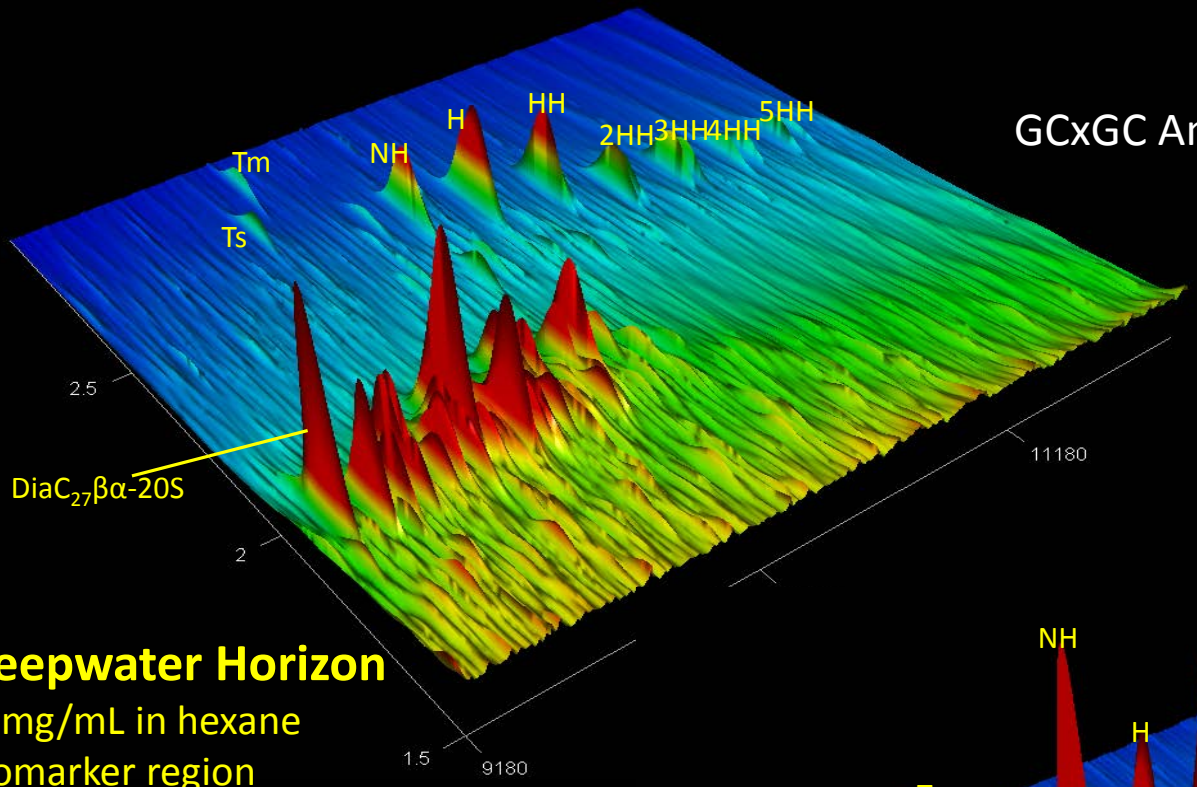
- No Data
- 0.0 - 0.5
- 1.0 - 2.0
- 2.5 - 4.0
- 5.0 - 7.0
- Macondo Wellhead
- Select Depth Contours
- Cruise Leg 1 Sept. 19 - Oct. 8
- Cruise Leg 2 Oct. 9 - Oct. 18

C-IMAGE II

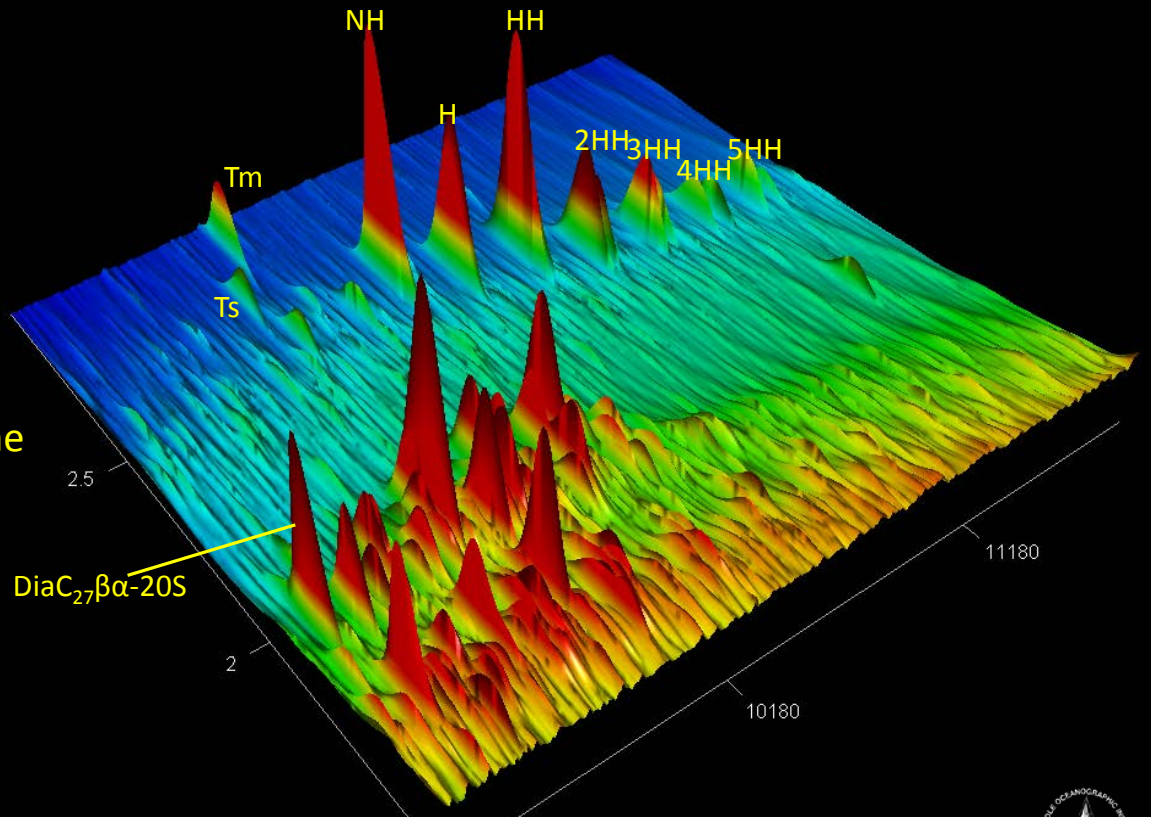
Factors affecting formation of marine oil snow, its deposition its ecologic impacts



GCxGC Anaysis of DWH and IXTOC Oil



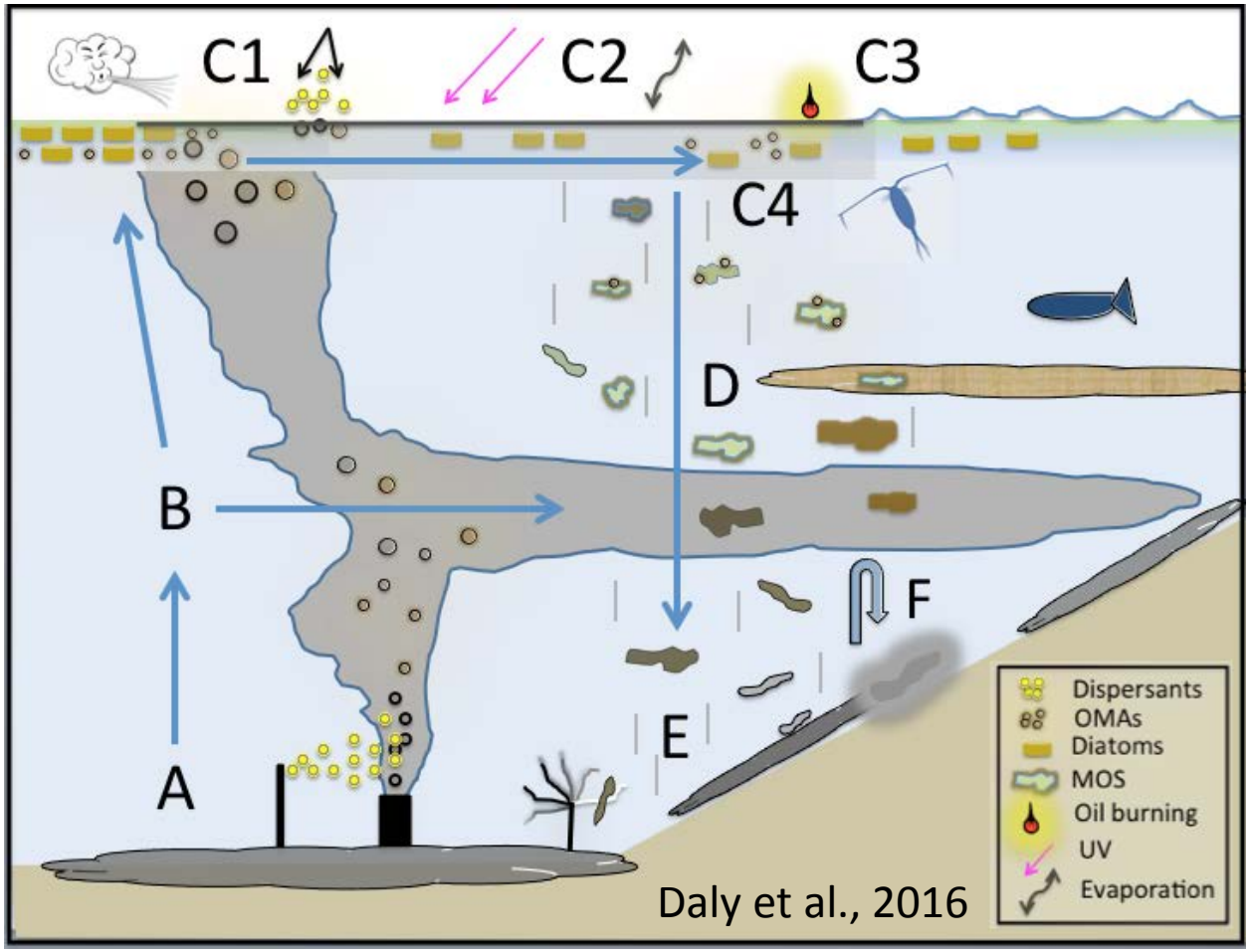
Deepwater Horizon
15mg/mL in hexane
biomarker region



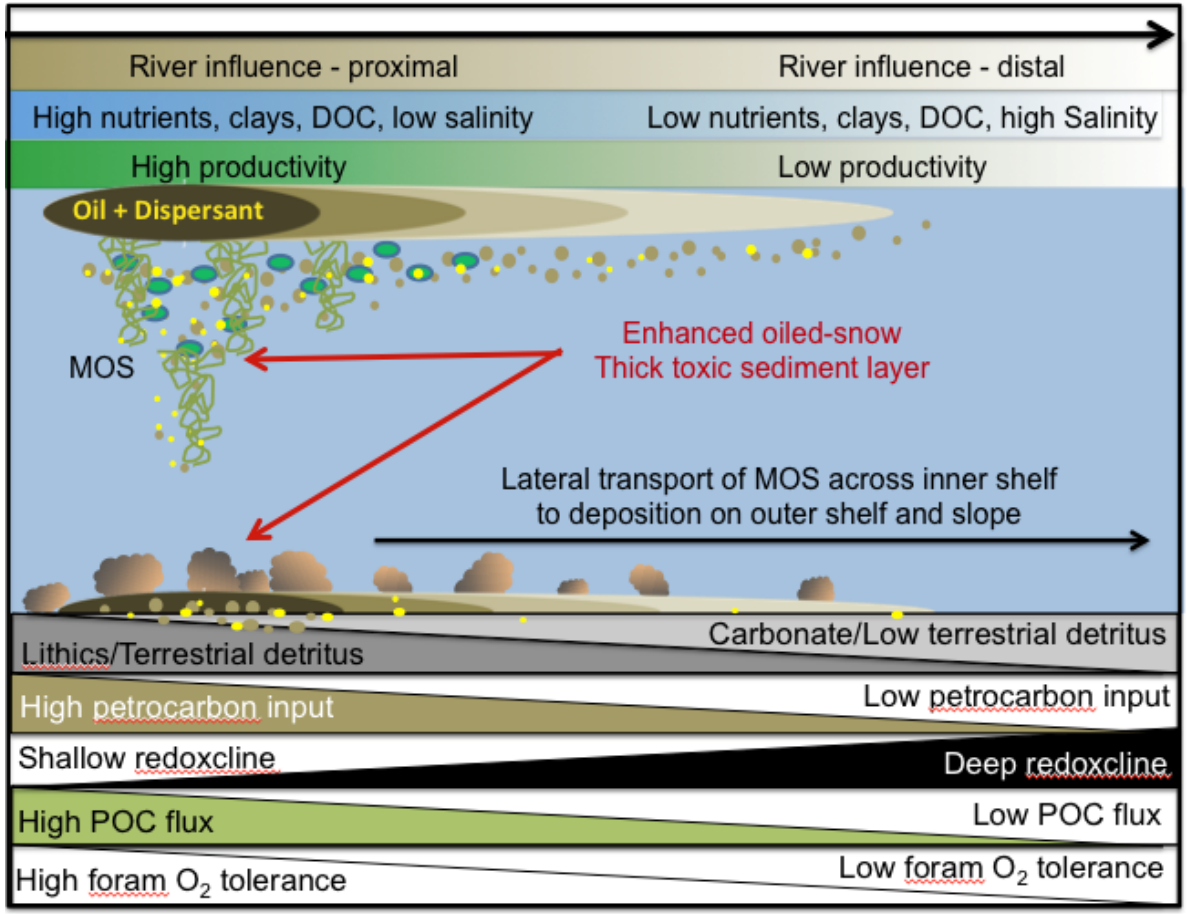
Ixtoc
15mg/mL in hexane
biomarker region

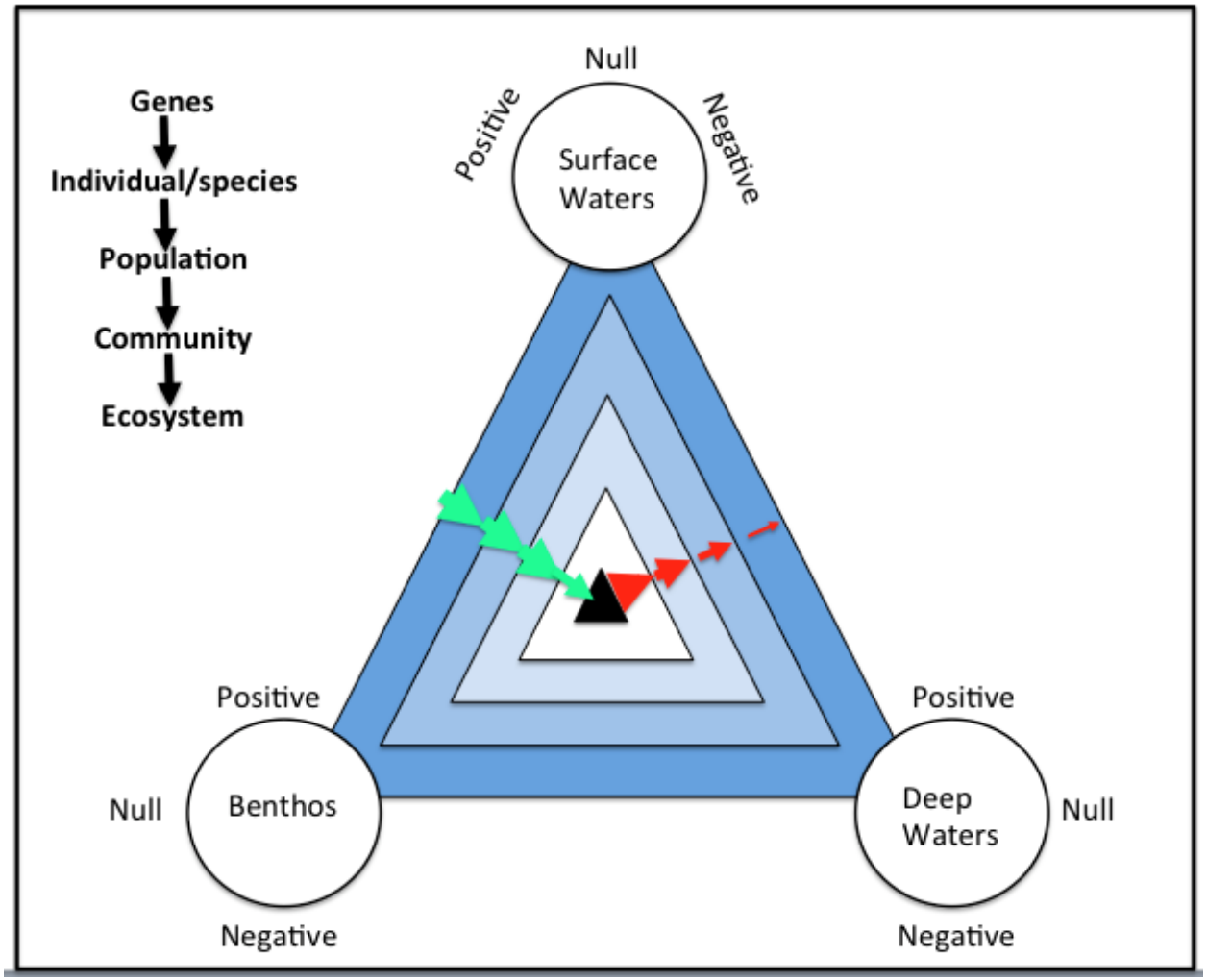
Conceptual Diagram of MOS Related Processes

From the source of oil discharge to the fate of hydrocarbons in sediments



C) Shows surface processes & formation of MOS: (C1) wind, diatom bloom, application of surface dispersants, (C2) oil transformation due to UV light and evaporation, (C3) role of aerosols & oil burning, new material sources, (C4) sinking MOS particles
(D) a benthic nepheloid layer and deep oil plumes. (E) benthic sedimentation of MOS and flocculation onto corals, (F) resuspension of oiled sediments due to turbulence.


River influence - proximal
River influence - distal
High nutrients, clays, DOC, low salinity
Low nutrients, clays, DOC, high Salinity
High productivity
Low productivity
Oil + Dispersant
MOS
Enhanced oiled-snow
Thick toxic sediment layer
Lateral transport of MOS across inner shelf
to deposition on outer shelf and slope
Lithics/Terrestrial detritus
Carbonate/Low terrestrial detritus
High petrocarbon input
Low petrocarbon input
Shallow redoxcline
Deep redoxcline
High POC flux
Low POC flux
High foram O_2 tolerance
Low foram O_2 tolerance


Genes
Individual/species
Population
Community
Ecosystem
Null
Positive
Negative
Surface Waters
Positive
Null
Negative
Benthos
Positive
Null
Negative
Deep Waters

What is C-IMAGE II doing 2015-2017?