Ocean Sequestration of CO_2

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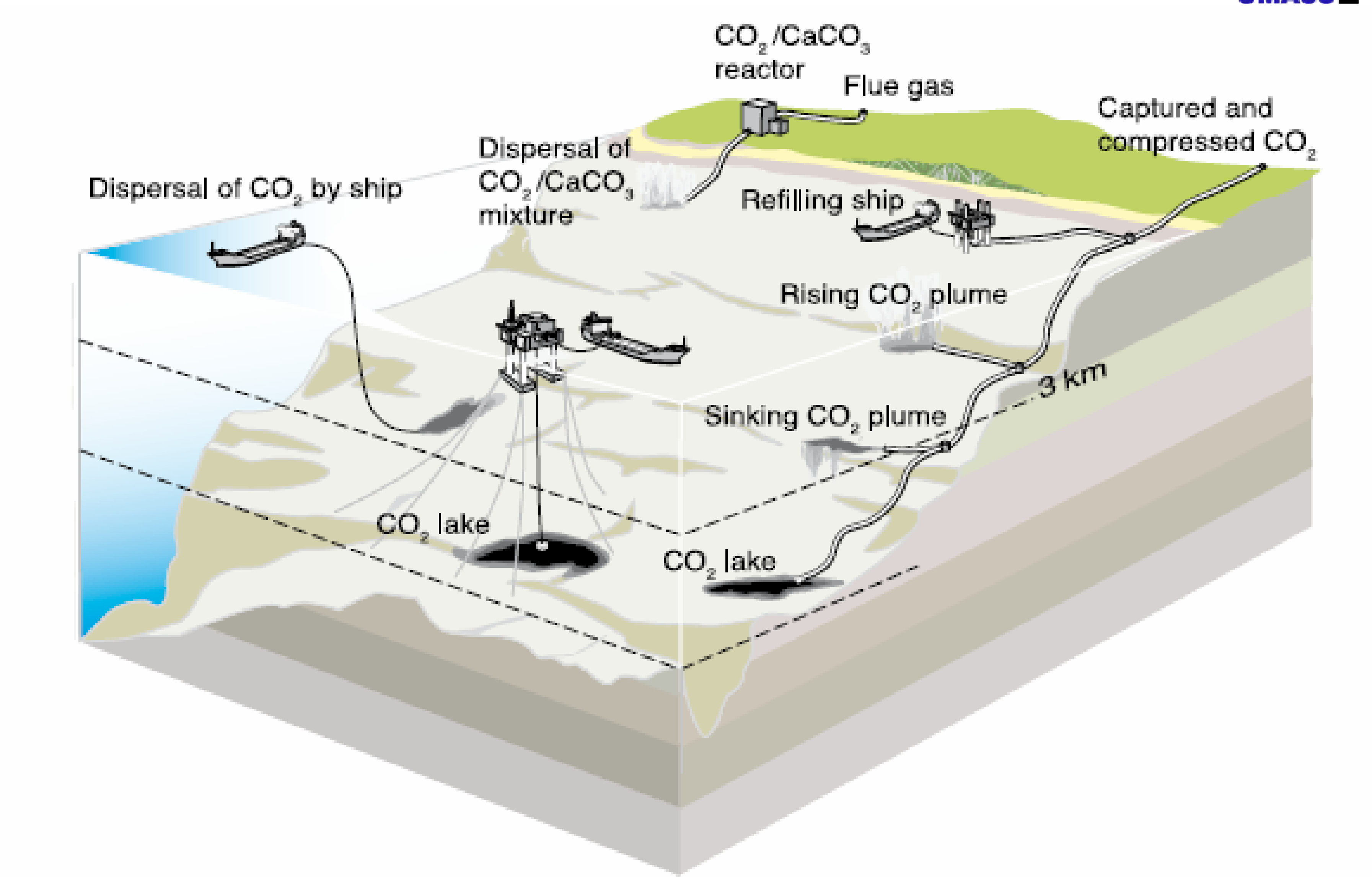
Ocean sequestration options

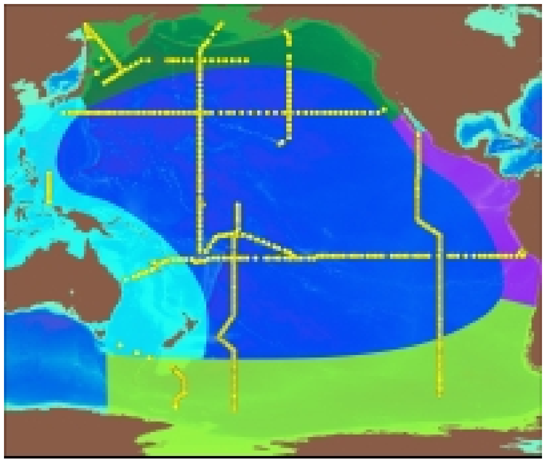


Source: IPCC Special Report on CC&S, 2005

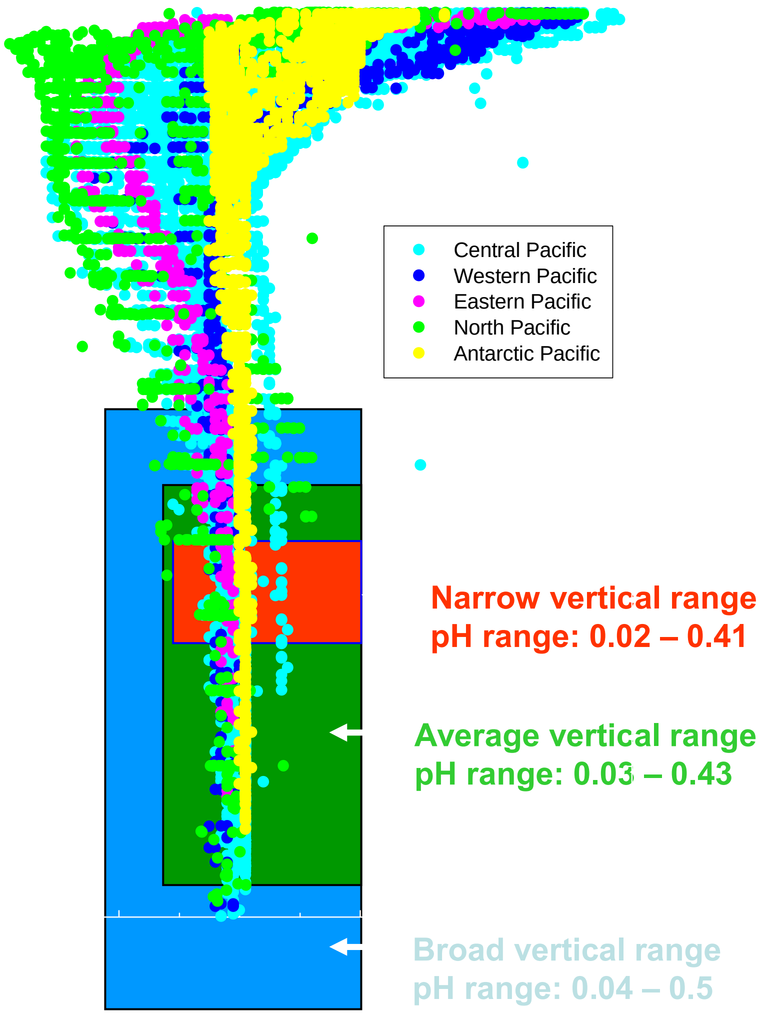
Problems with Scenarios for Ocean Sequestration of CO_2

- High Costs - exclusive of capture
- Proximity of Sources to Ocean
- Ecological Effects
  - Physical Impact of Immiscible Liquid
  - Chemical Impacts
    - pH
    - Carbonate hot spots
- Long Term Uncertainty
  - Chemical Effects
  - Lake Nyos Syndrome
- London Convention 1972

Ecosystem Impacts: Variation in Deep-Ocean pH across Zoogeographic Regions & Bathymetric Ranges



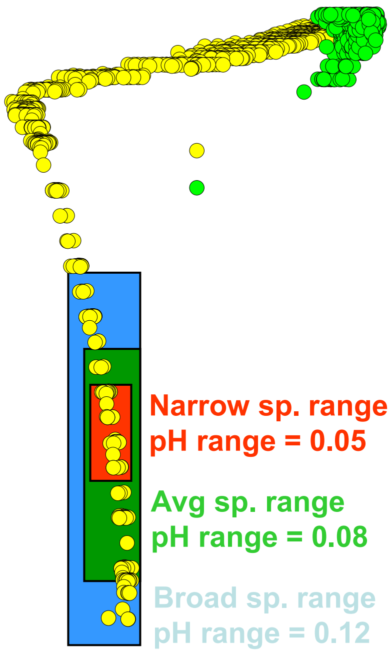
JGOFS/WOCE
pH stations +
zoogeographic regions
(Mironov, 1987)



Source: Barry et al. 2005 (AGU Fall Meeting)

Summary of pH variations

Variation at one station

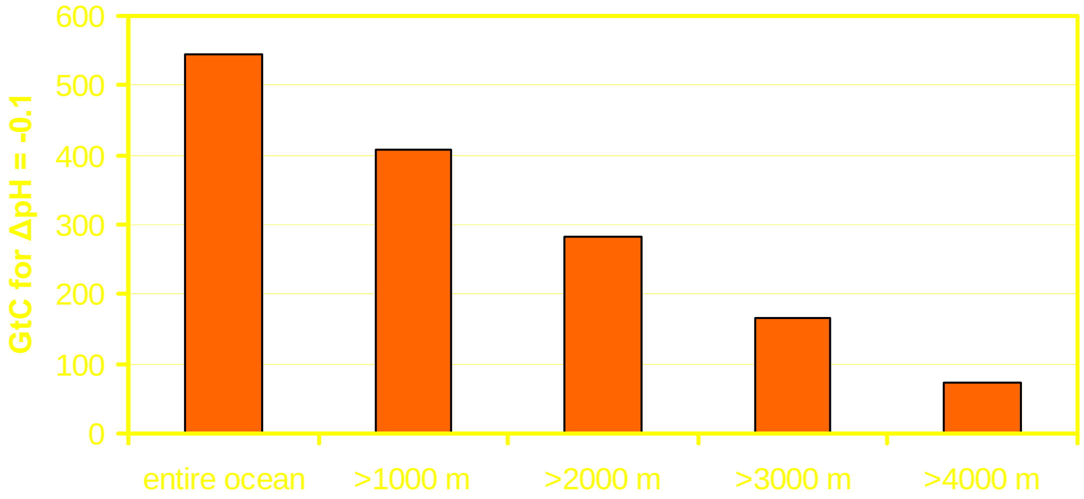


Species Range	Horizontal & Vertical pH Range (Zoographic Regional Mean)	Vertical pH Range (One Station: HOTS)
Narrow	0.16	0.05
Average	0.18	0.08
Broad	0.24	0.12

Assume |ΔpH| < 0.1 ➔ "no ecosystem impact"

Source: Barry et al. 2005 (AGU Fall Meeting)

How much C could “fit” into a ΔpH of -0.1?



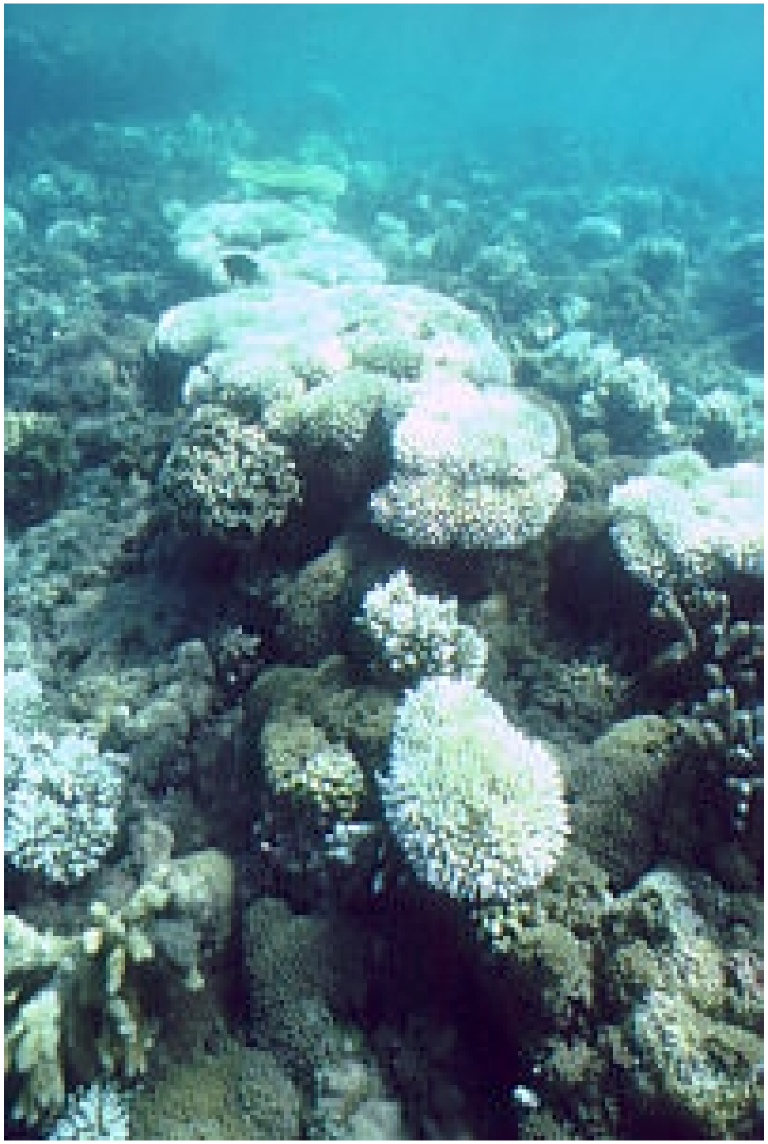
Assuming well-mixed ocean

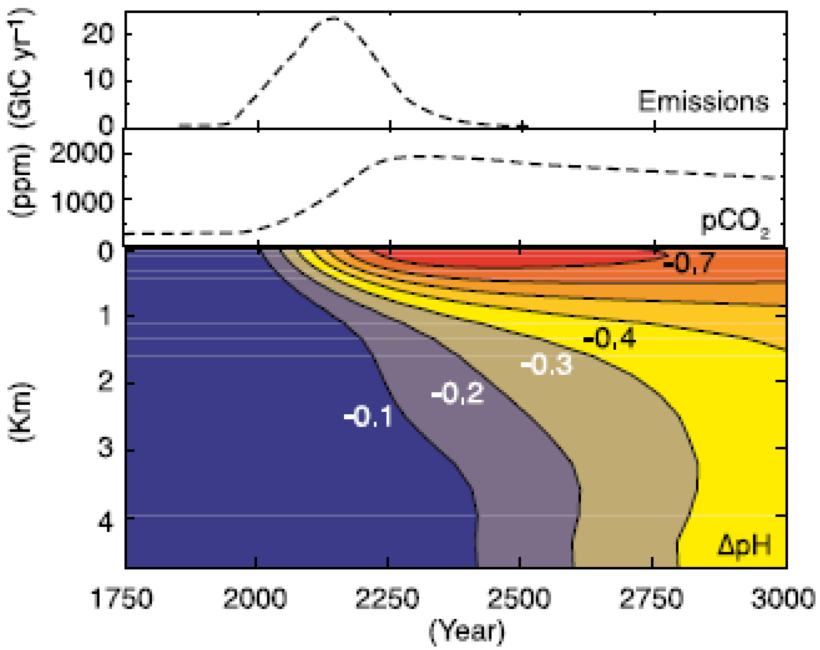
Entire 175 GtC could be stored < 2500 m with ΔpH = -0.1

Corresponds to ~4,000 500-MW coal plants (100 kgCO_2/s each) for 50 yr

This is “ecosystem impact”; more on plume effects (mixing zones) later

Predicted changes in ocean pH via C storage



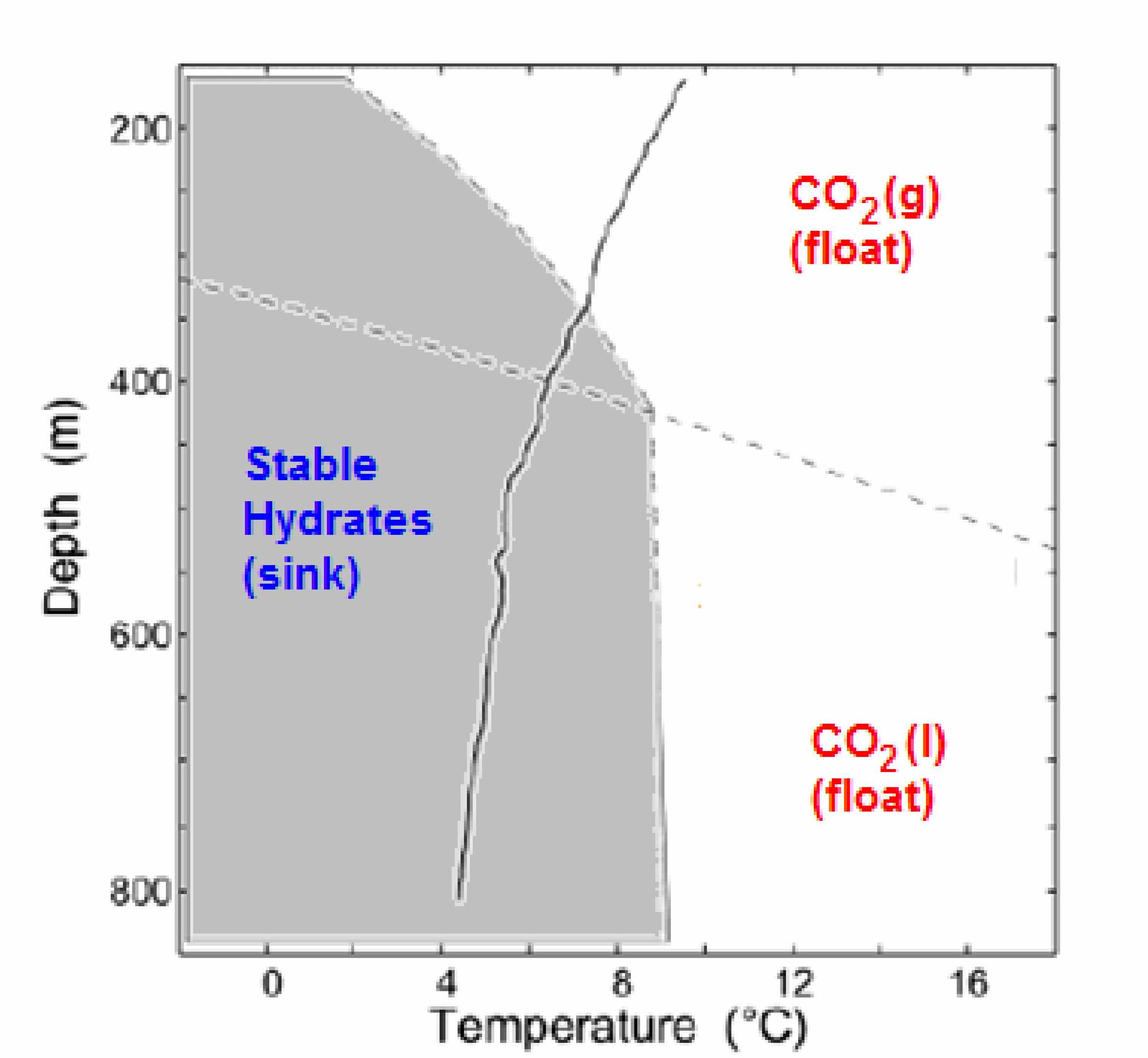


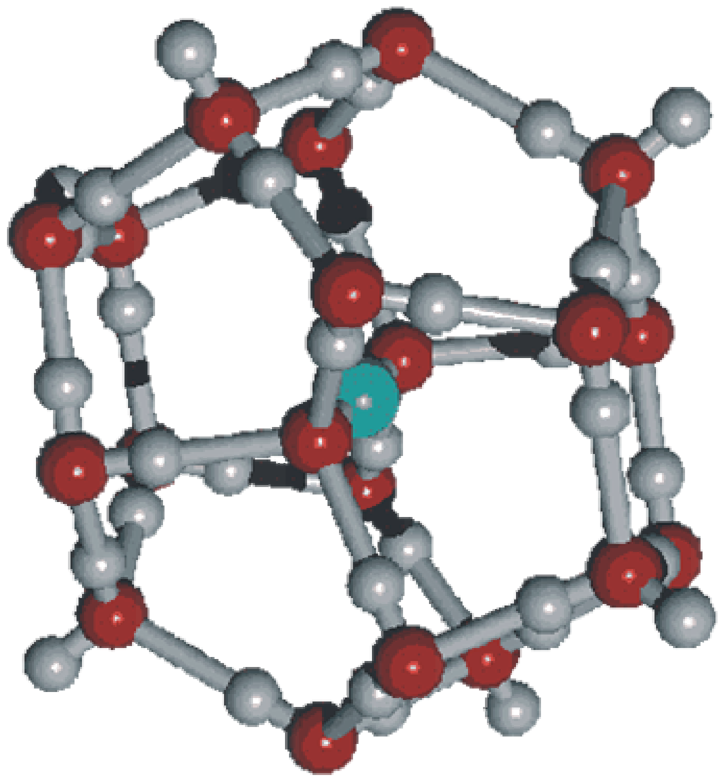
Sources: Caldeira & Wickett 2005;
IPCC Special Report on CC&S, 2005

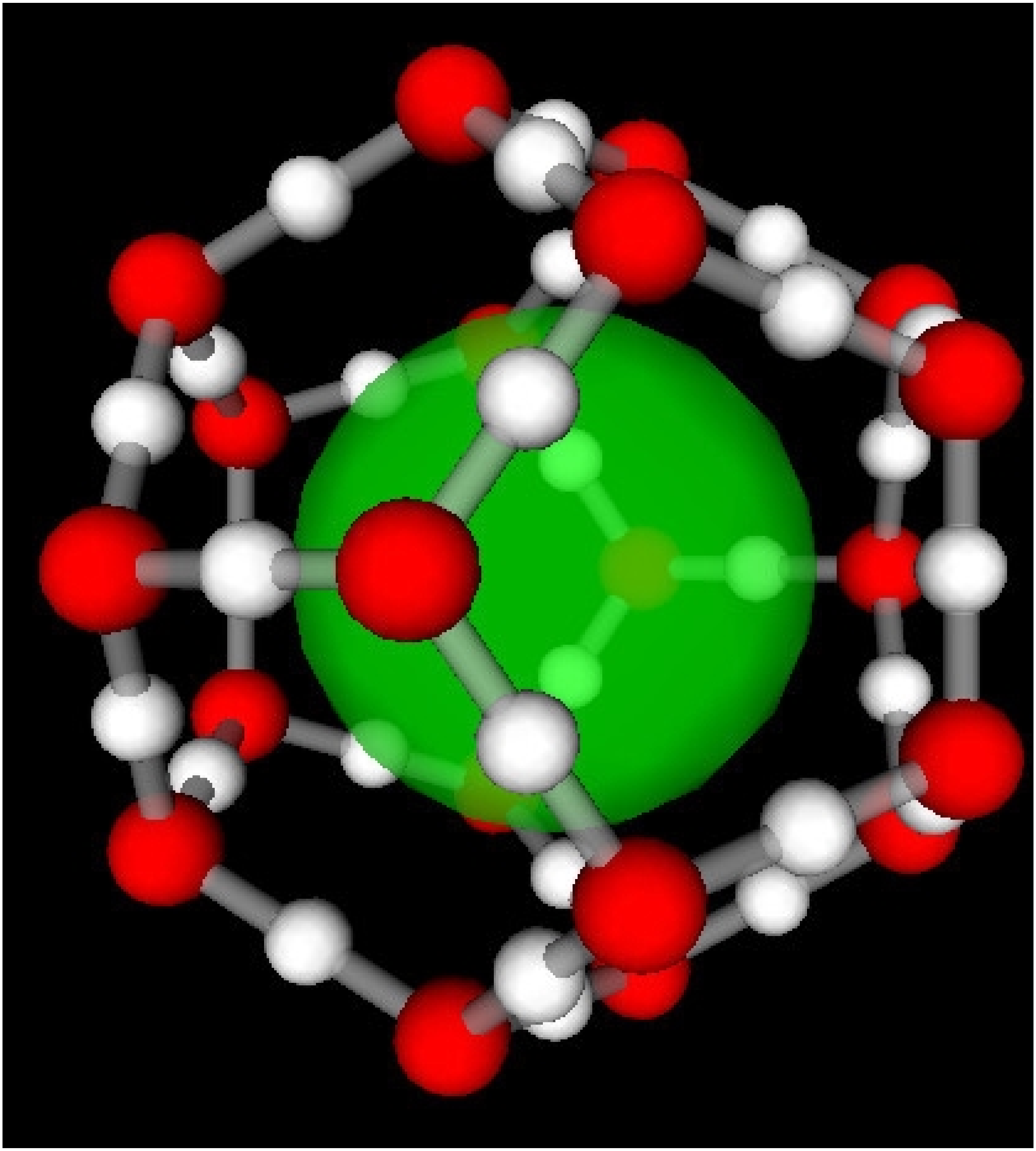
Negatively buoyant forms of CO_2

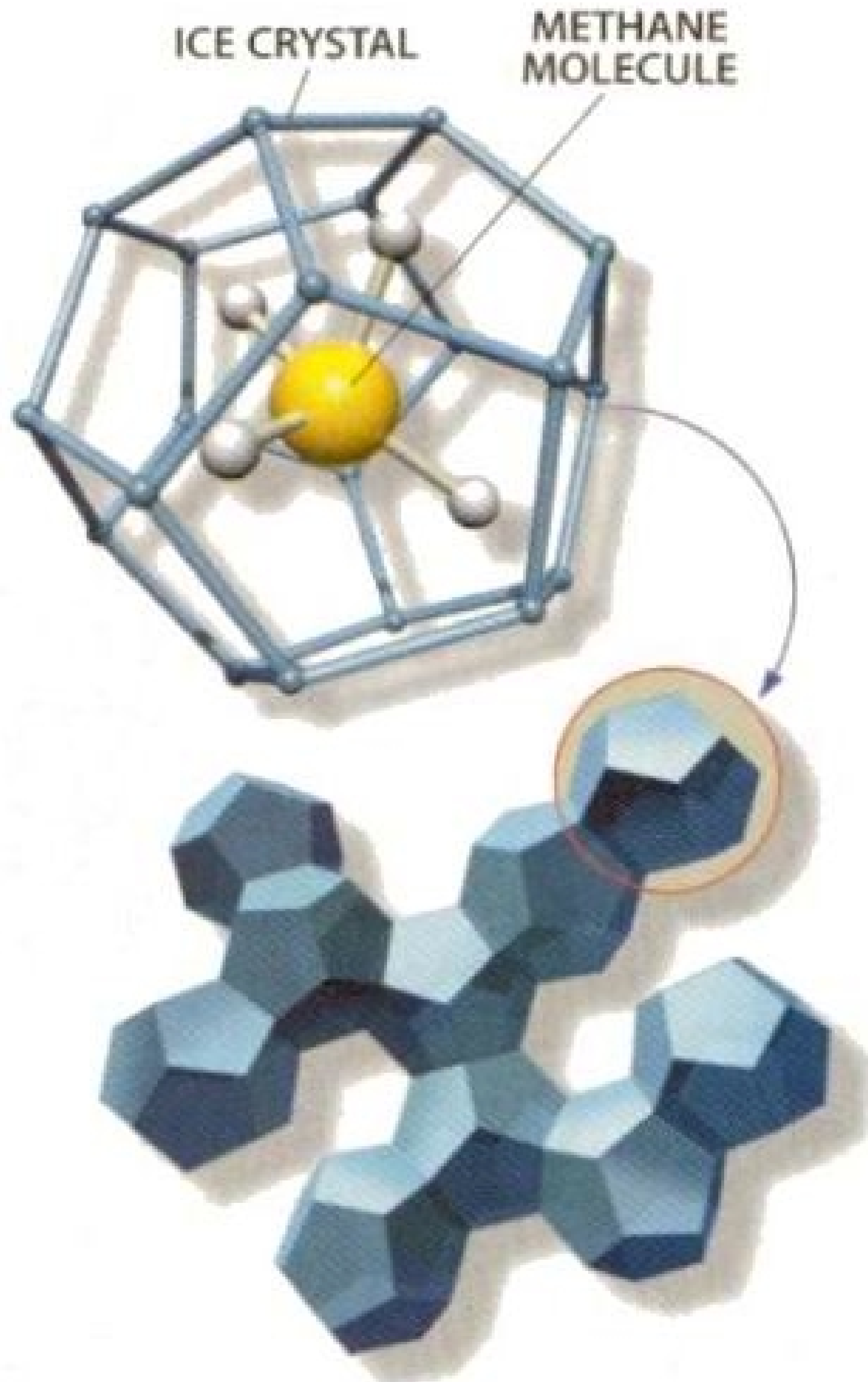
	Composition	CO_2 mass fraction, f (%)	Density excess, $\Delta\rho/\rho$ (%)	Disp/diss phase buoy $R = (5.3/f)\Delta\rho/\rho$
CO_2 Hydrates	$CO_2 \cdot 6H_2O$	30	10	1.8
Liquid CO_2 w/ hydrate particles	CO_2 & $CO_2 \cdot 6H_2O$	55-70	3-5	0.3 -0.4
Dry Ice	Frozen CO_2	100	55	2.9
COSMOS (cold CO_2)	CO_2	100	10	0.5
CO_2 /$CaCO_3$ Solutions	$CO_2/H_2O/CaCO_{3(s)}$ $H_2O/Ca^{2+}/2HCO_3^-$	35-60	0.5-10	0.1-0.9
Dense CO_2 solutions	CO_2/H_2O	100	~0.5	0

CO_2/seawater phase diagram

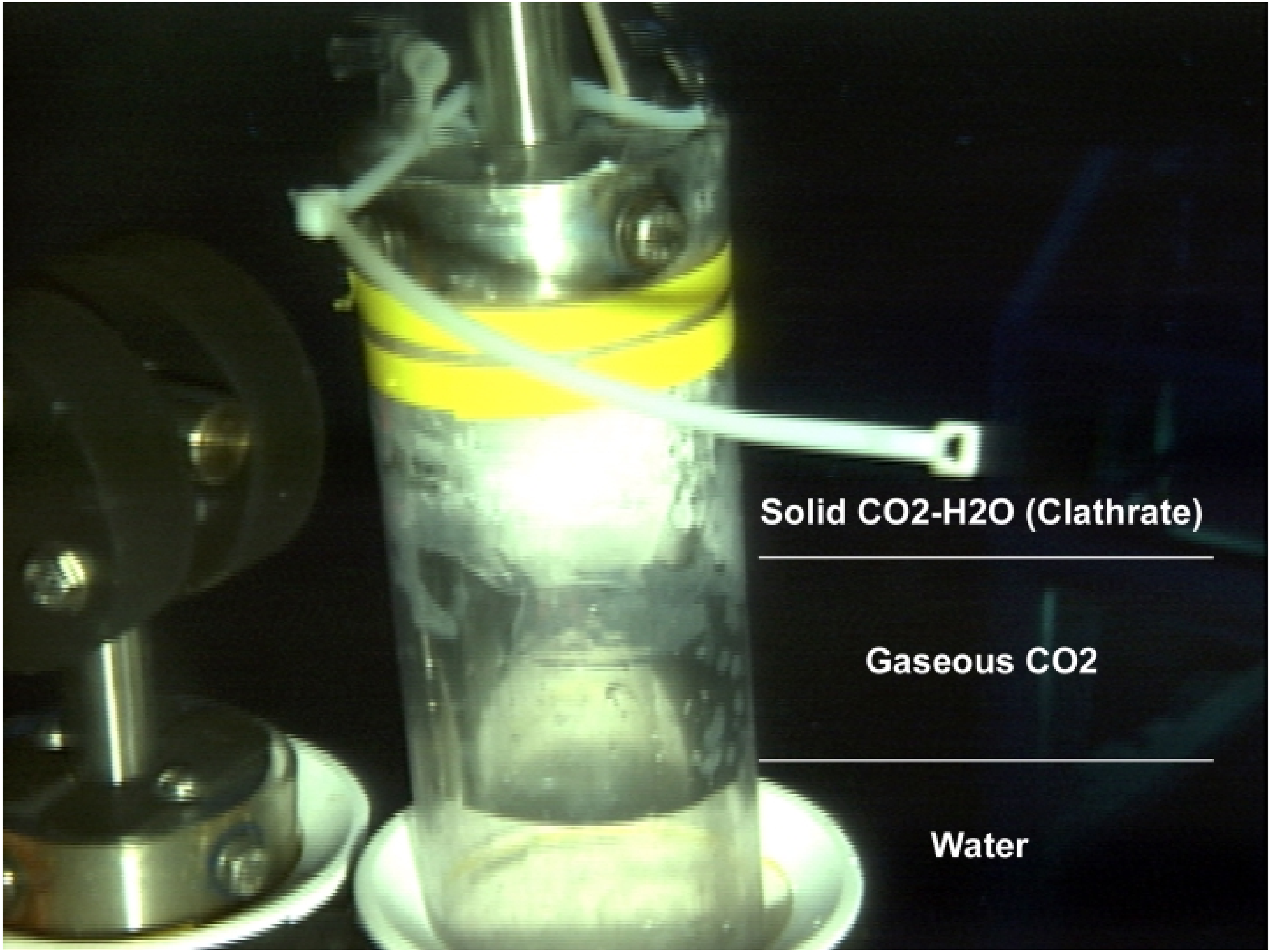








Natural gas hydrate structure


Solid CO2-H2O (Clathrate)
Gaseous CO2
Water

Burning natural gas hydrate

MBARI Videos of Liquid CO_2 in Deep Ocean

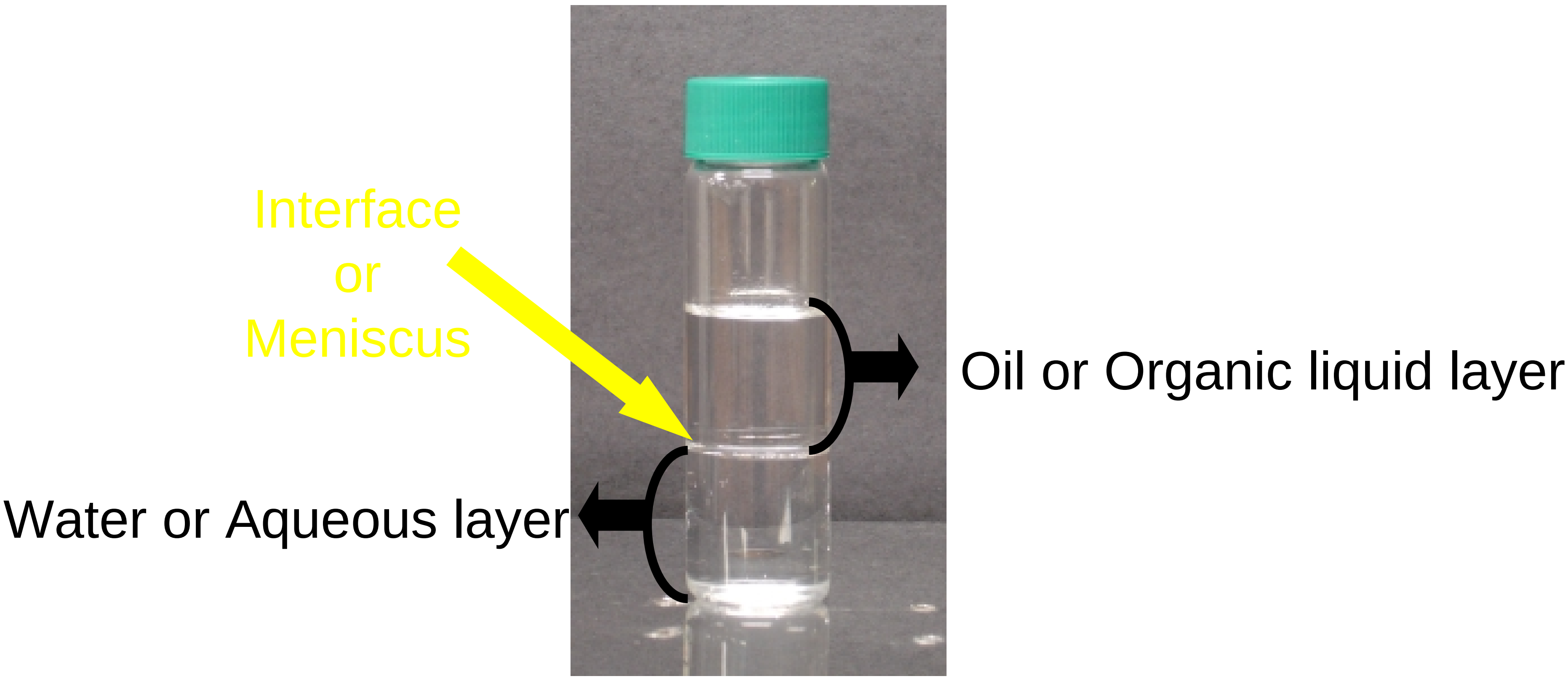
http://www.mbari.org/ghgases/movies.htm

Our Discovery

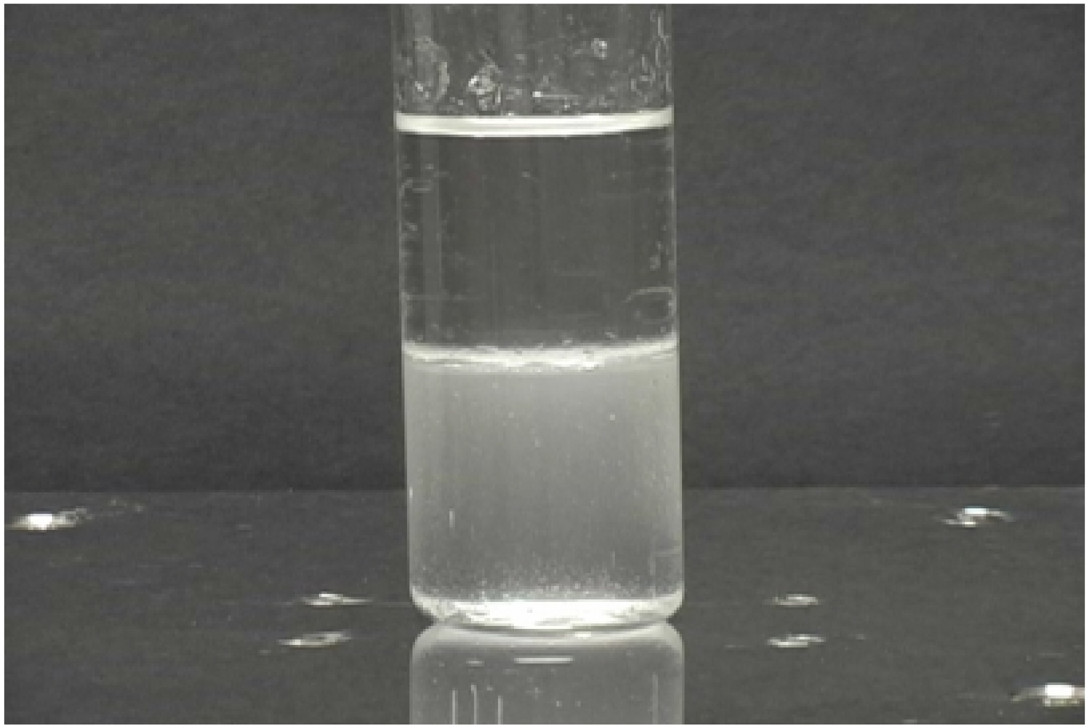
In 2001 we discovered how to make emulsions of liquid CO_2 and water stabilized by fine particles

Some simple chemistry

- Immiscible liquids form two layers with an **interfacial tension** or force between them



Applying shear force or mixing creates a dispersions



Droplets of a dispersion quickly coalesce to larger & larger drops resulting in two layers once again

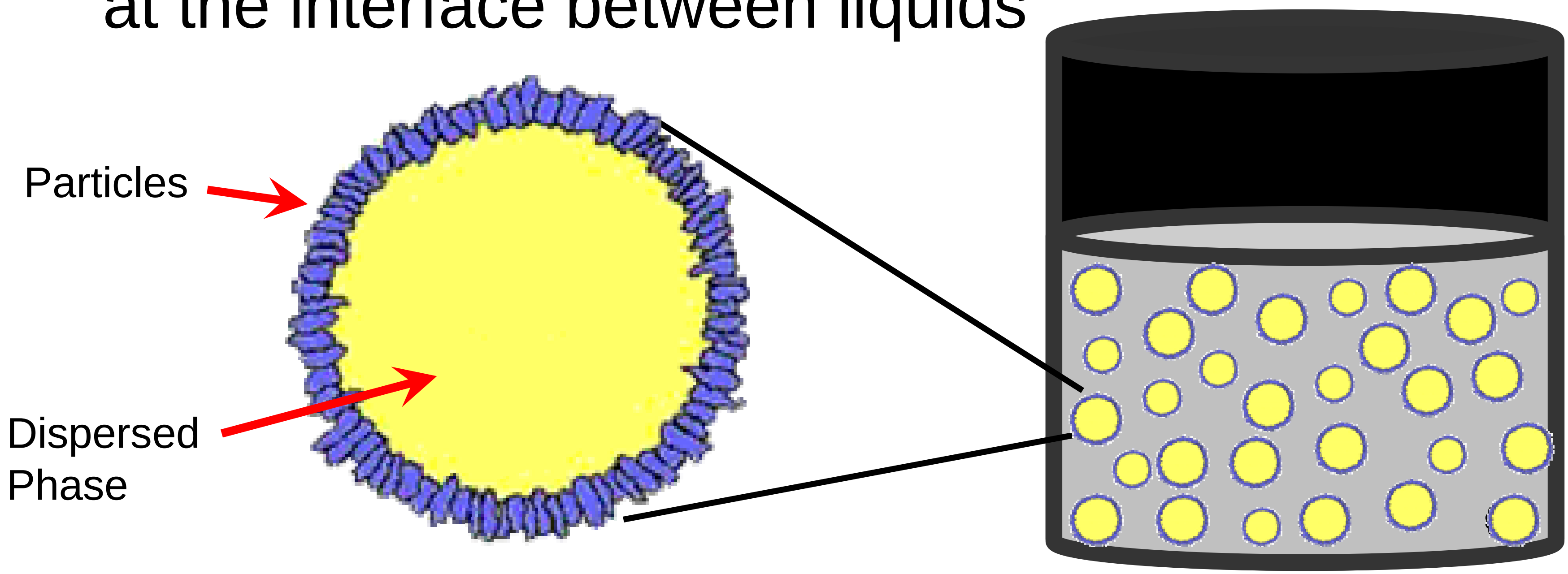
Emulsions

- When an **emulsifying agent** is added to a two phase system, interfacial tension is greatly reduced allowing formation of <u>stable</u> dispersions or emulsions

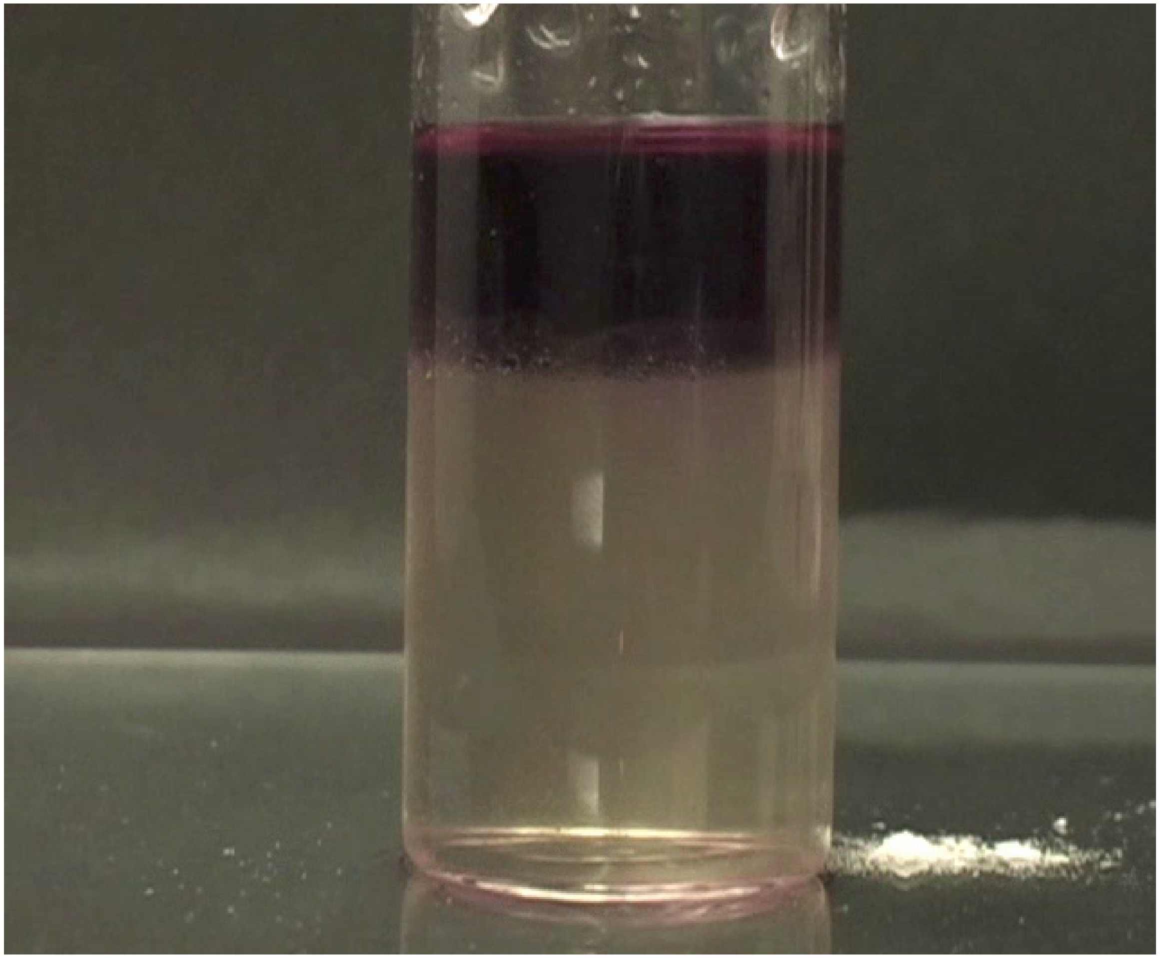
- Emulsions can be either **macroemulsions** or **microemulsions** depending on droplet size

Particle Stabilized Emulsions
(also called Pickering Emulsions)

- Very fine particles can act as emulsifying agents, though more common emulsifiers are surfactants like soaps and detergents
- Emulsifying agents work by arranging themselves at the interface between liquids



Particle Stabilized Emulsions

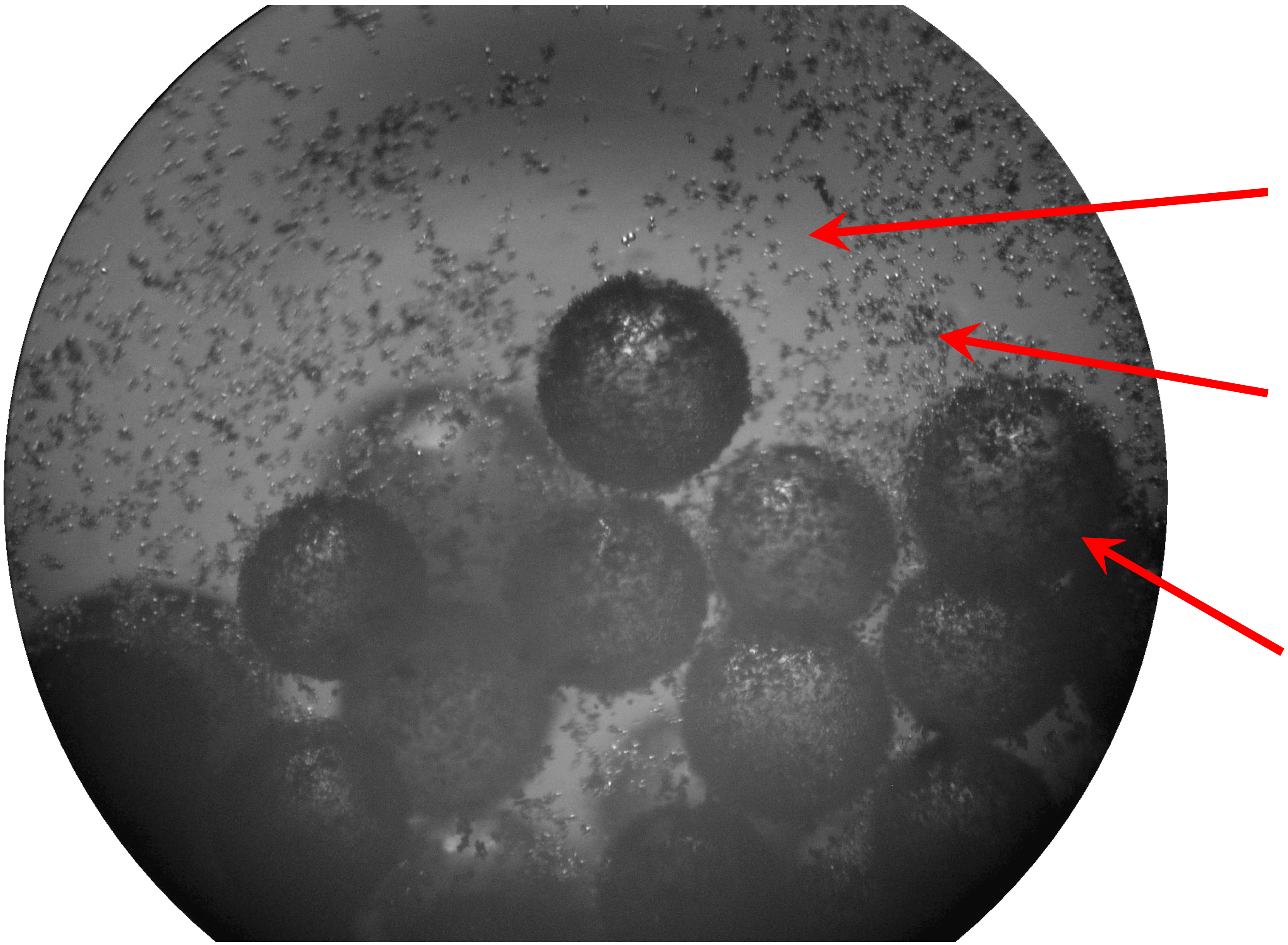


Particle Stabilized Emulsions

- **Hydrophilic particles** form oil-in-water emulsions:
  - Calcite ($CaCO_3$)
  - Pulverized sand (SiO_2)
  - Lizardite & other minerals

- **Hydrophobic particles** form water-in-oil emulsions:
  - Carbon black
  - Pulverized coal
  - Teflon particles

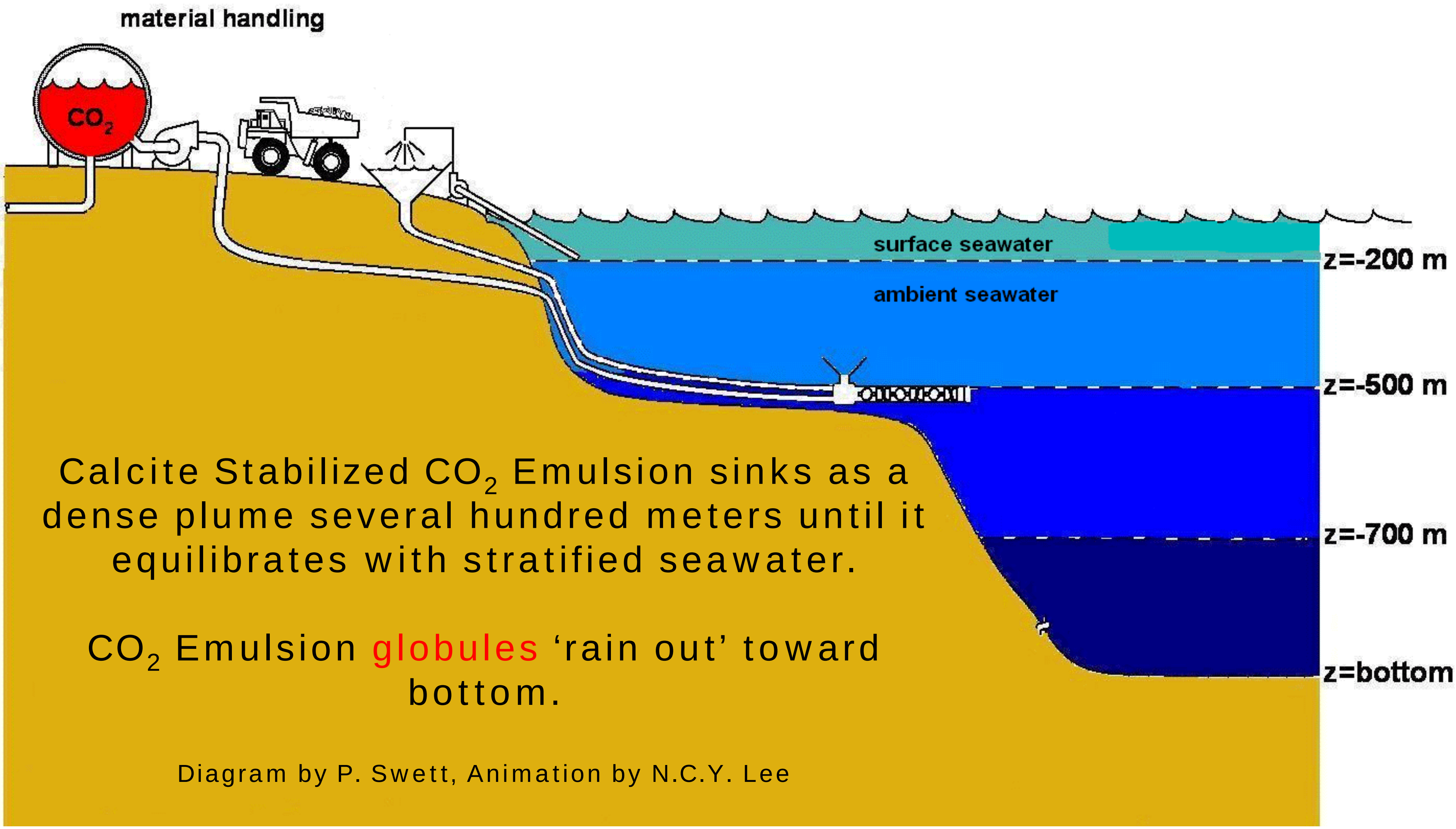
Liquid CO_2/Seawater/$CaCO_3$ Macroemulsion (a.k.a. Globulsion)



~200 µm droplets (globules)

The Grand Finale

Ocean Sequestration Scenario



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Ocean Sequestration of Carbon Dioxide: Modeling the Deep Ocean Release of a Dense Emulsion of Liquid CO_2-in-Water Stabilized by Pulverized Limestone Particles

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