# Plankton Respiration and vertical Carbon Flux in the Ocean

By
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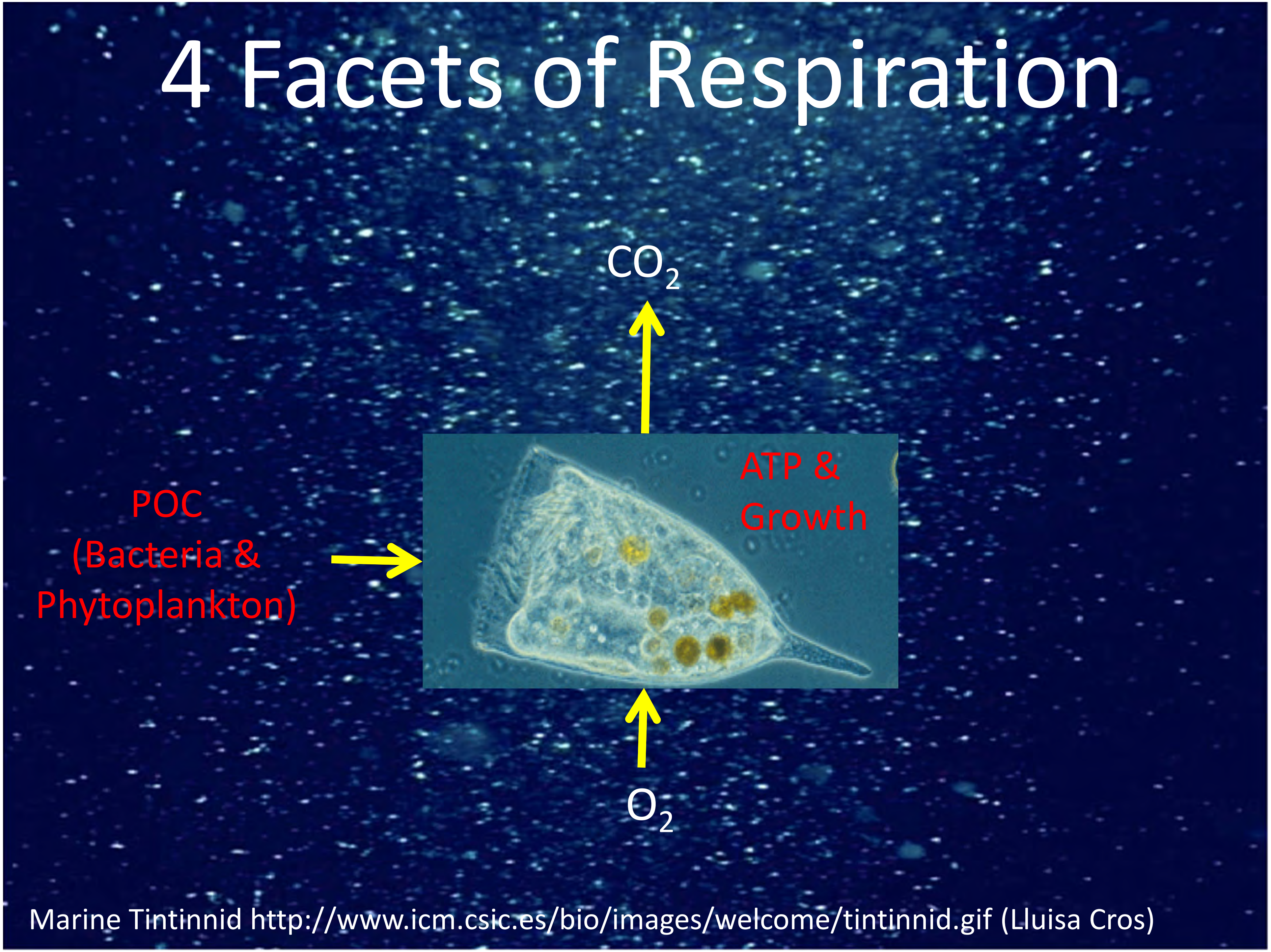
http://www.seos-project.eu


4 Facets of Respiration
$CO_2$
POC
(Bacteria &
Phytoplankton)
ATP &
Growth
$O_2$
Marine Tintinnid http://www.icm.csic.es/bio/images/welcome/tintinnid.gif (Lluisa Cros)

# 4 Facets of Respiration

1. POC & DOC Consumption (Organic matter degradation, Decay)

2. $CO_2$ Production & Krebs Cycle Decarboxylases & $CO_2$ removing dehydrogenases

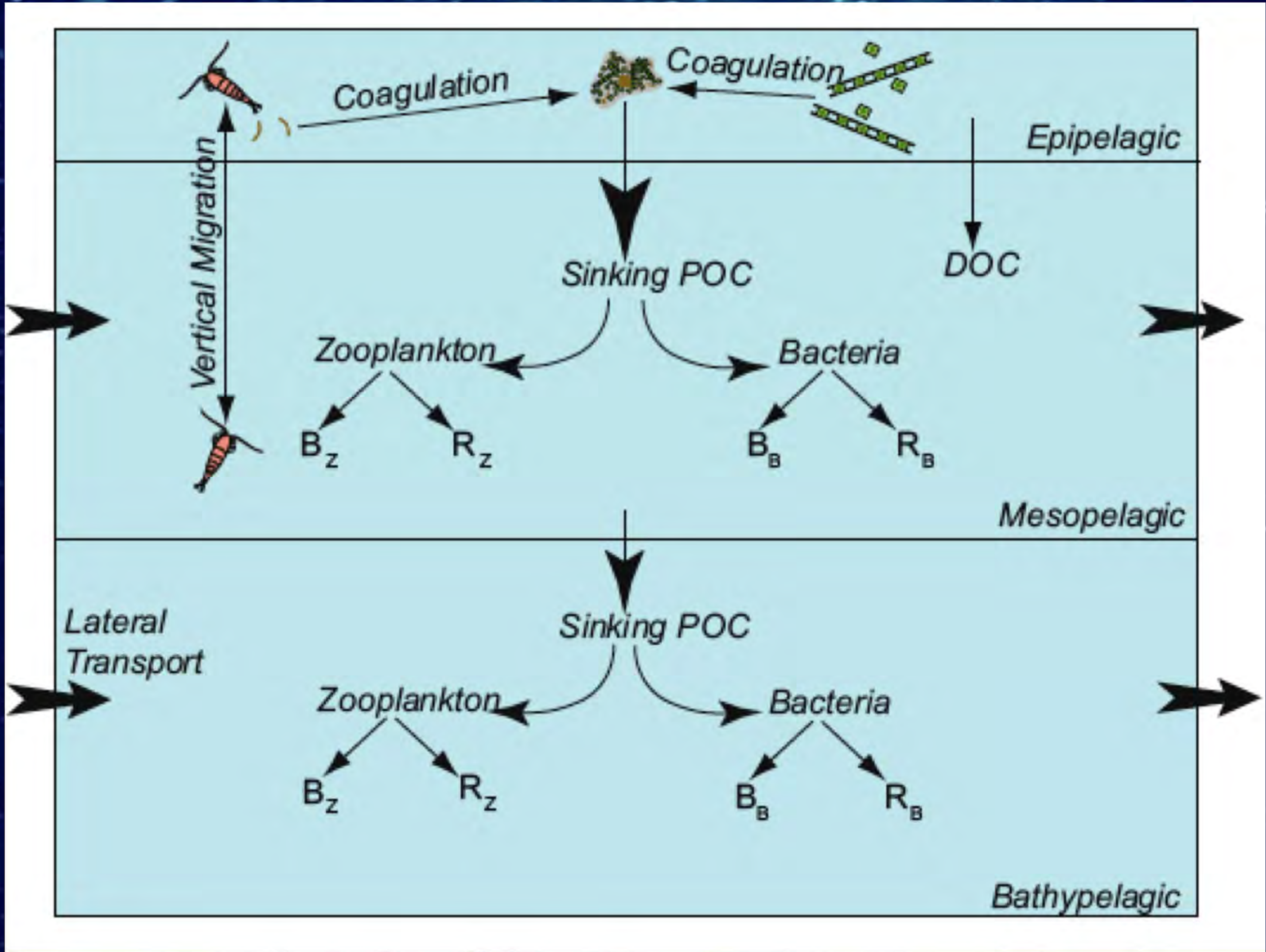
3. $O_2$ Consumption & the Respiratory Electron Transport System (ETS)

4. Biological Energy Formation, the production of ATP during Oxidative Phosphorylation & Growth

# Facets of Carbon Flux

Lateral advection

Lateral advection




Burd et al. 2010

# 4 Facets of Carbon Flux

1. Passive Sedimentation (Sediment traps, respiration of microplankton & zooplankton)

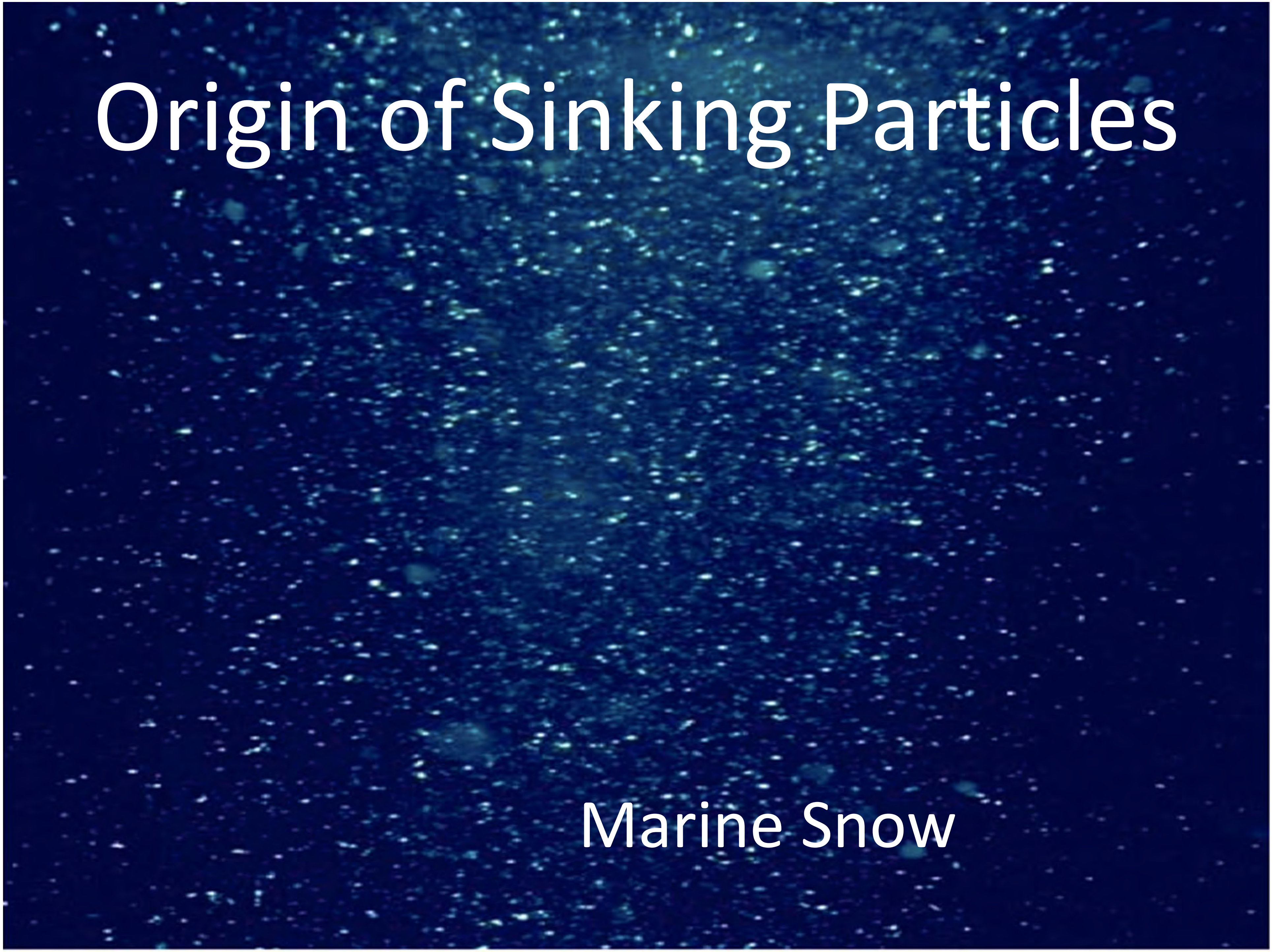
2. Active Flux via zooplankton vertical migration (Day-night biomass, gut-contents, & respiration differences)

3. DOC entrainment and mixing (downwelling, convergence zones, winter mixing)

4. Lateral advection (Off shelf transport, turbidity flows)

# Origin of Sinking Particles

# Origin of Sinking Particles



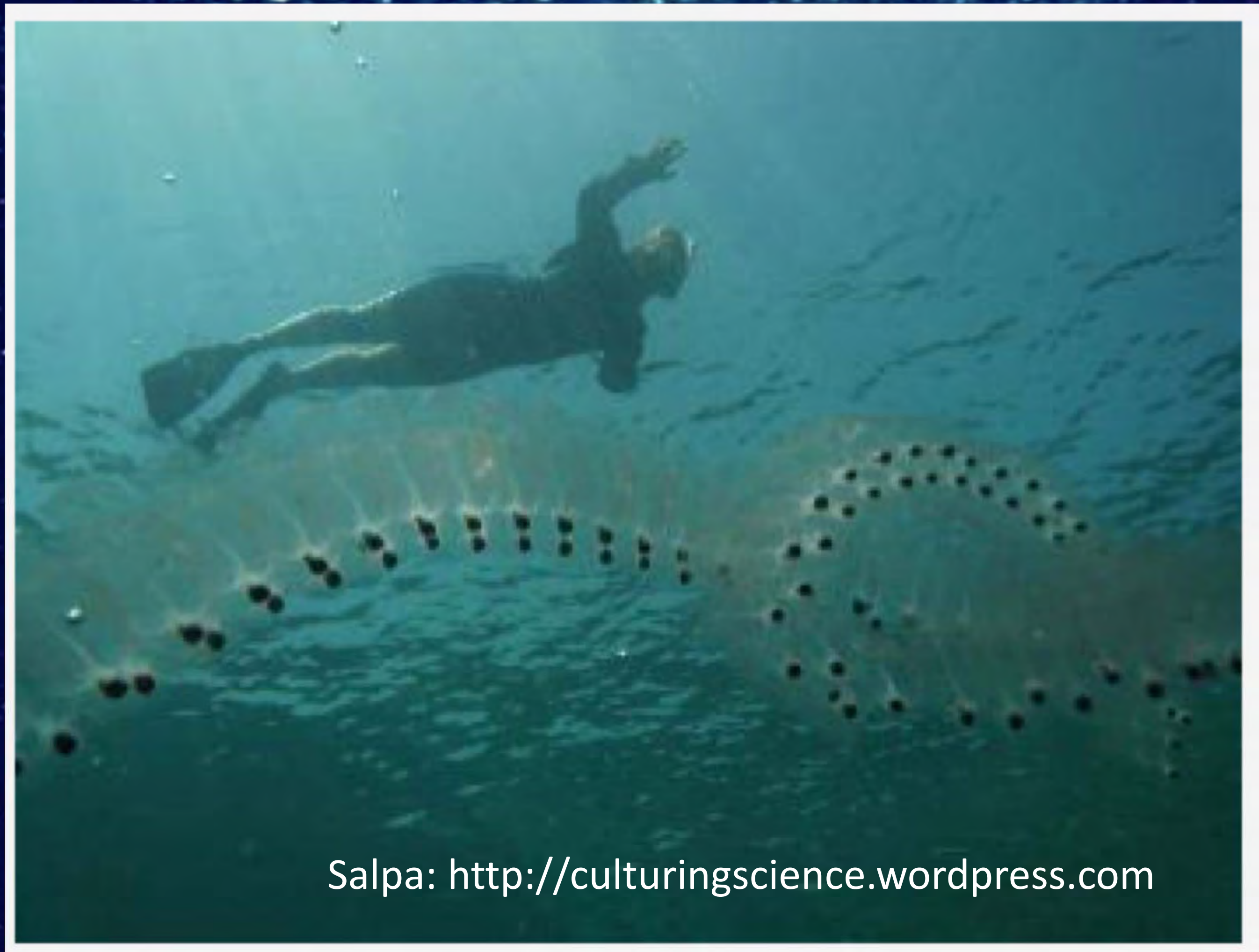
# Origin of Sinking Particles





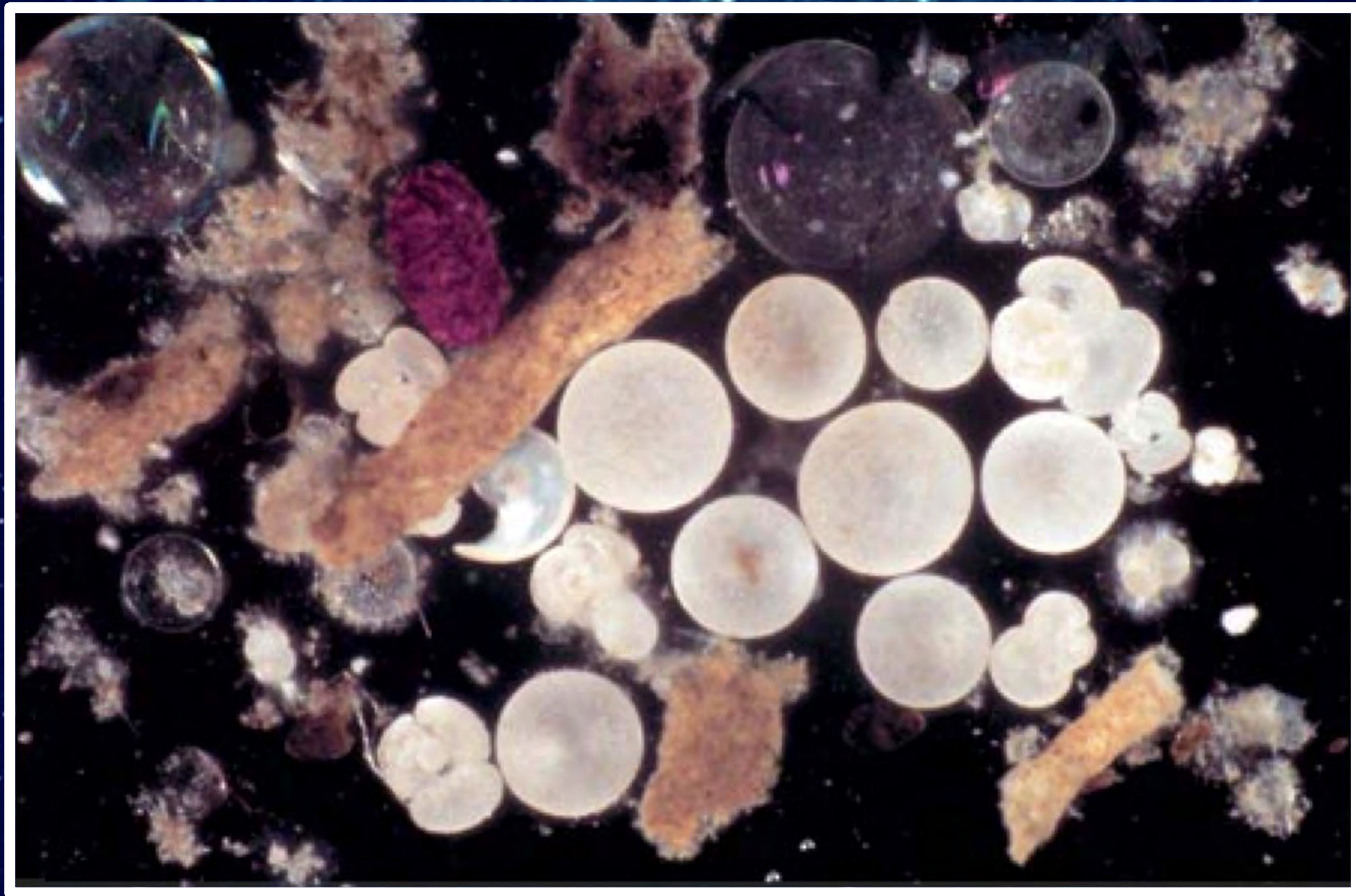
Gracias a: Russ Hopcroft

# Origin of Sinking Particles

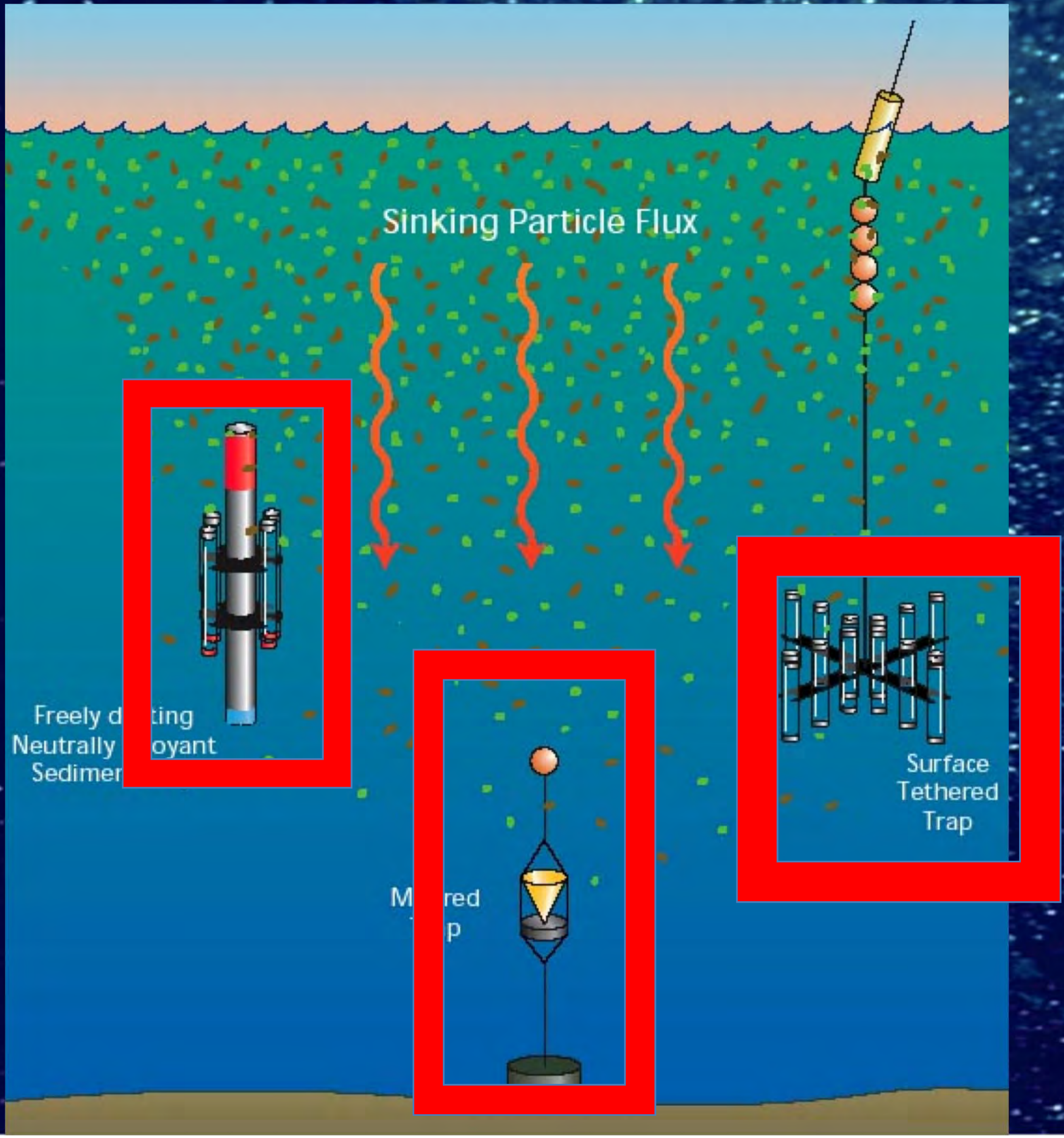


Salpa: http://culturingscience.wordpress.com

# Origin of Sinking Particles



http://www.whoi.edu/cms/images/lstokey/2005/1/v40n2-honjo1en_4948.jpg




# Different Types of Sediment Traps

http://www.whoi.edu/instruments/

# Mismatch: sediment trap & classic R-based C-flux measurements

esearch II 57 (2010) 1557–1571 1563

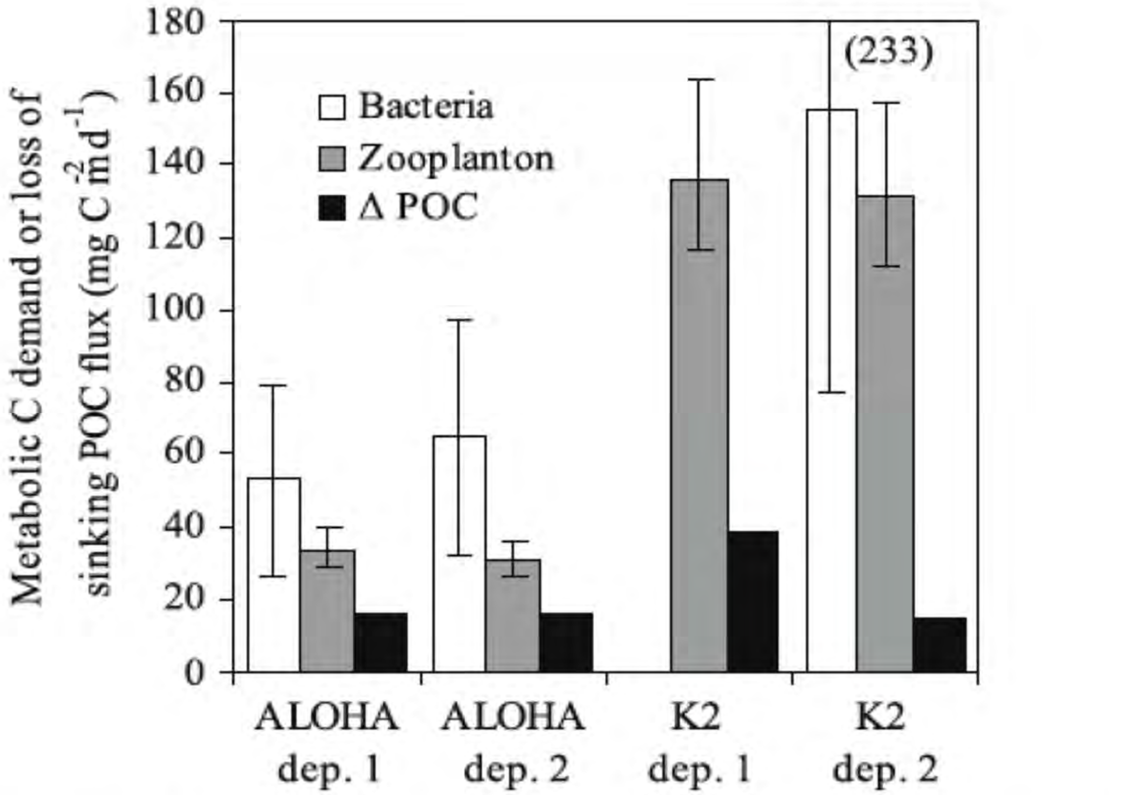



**Fig. 3.** Metabolic carbon demand and loss of sinking POC at stations ALOHA and K2 as measured during the VERTIGO program (figure from Steinberg et al, 2008).

Burd et al., 2010

Long before JGOFS,I had been looking for the signature and the impact of carbon flux.

Signature: CRD Deep-sea Max; NW Africa Benthic Metabolism; Peru Current offshore variation as Productivity decreases; Alboran Sea OMZ and convergence from Alboran gyre; MW Med Deep metabolism and canyon turbidity currents.

XIE ET AL.

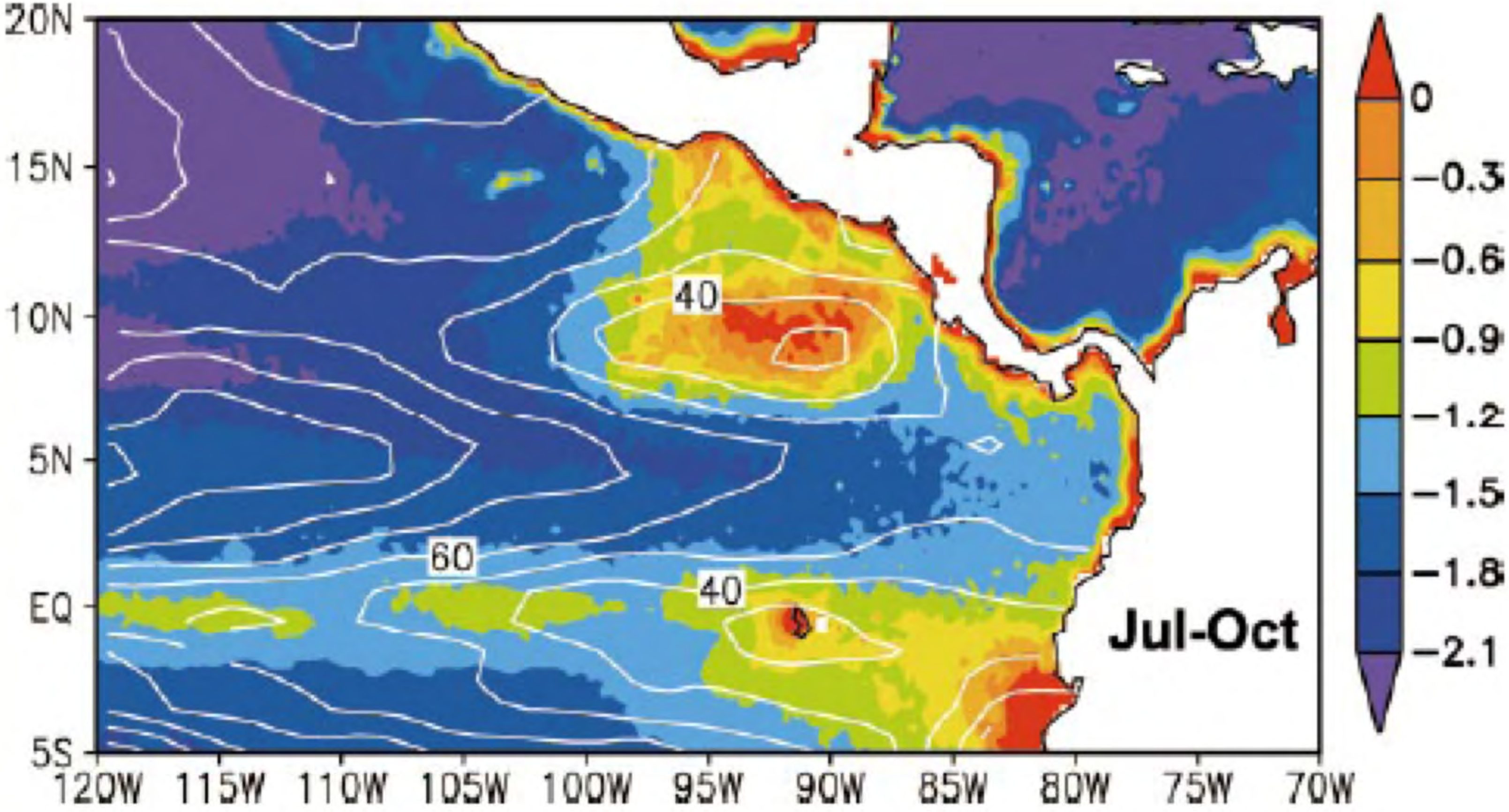
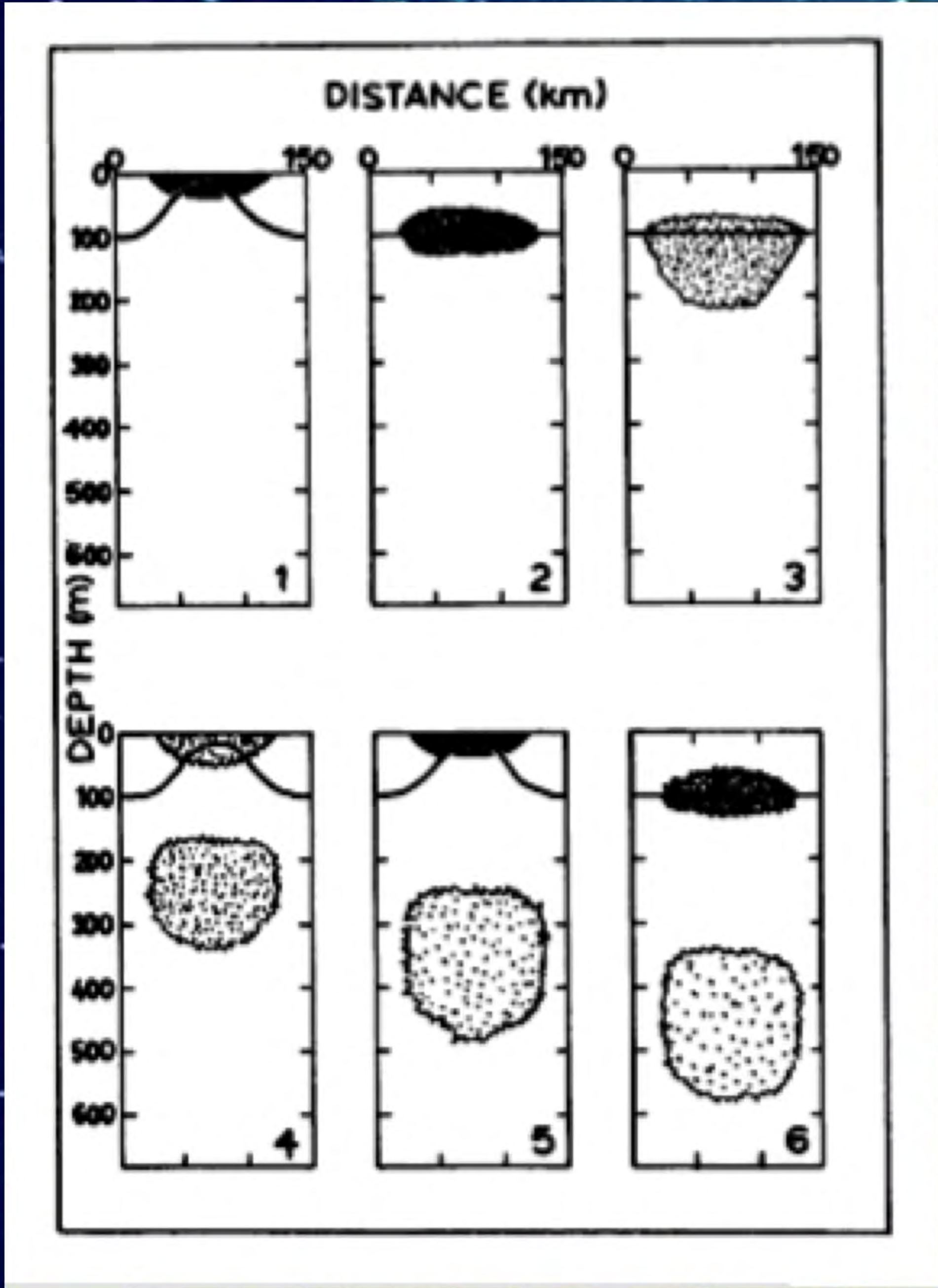


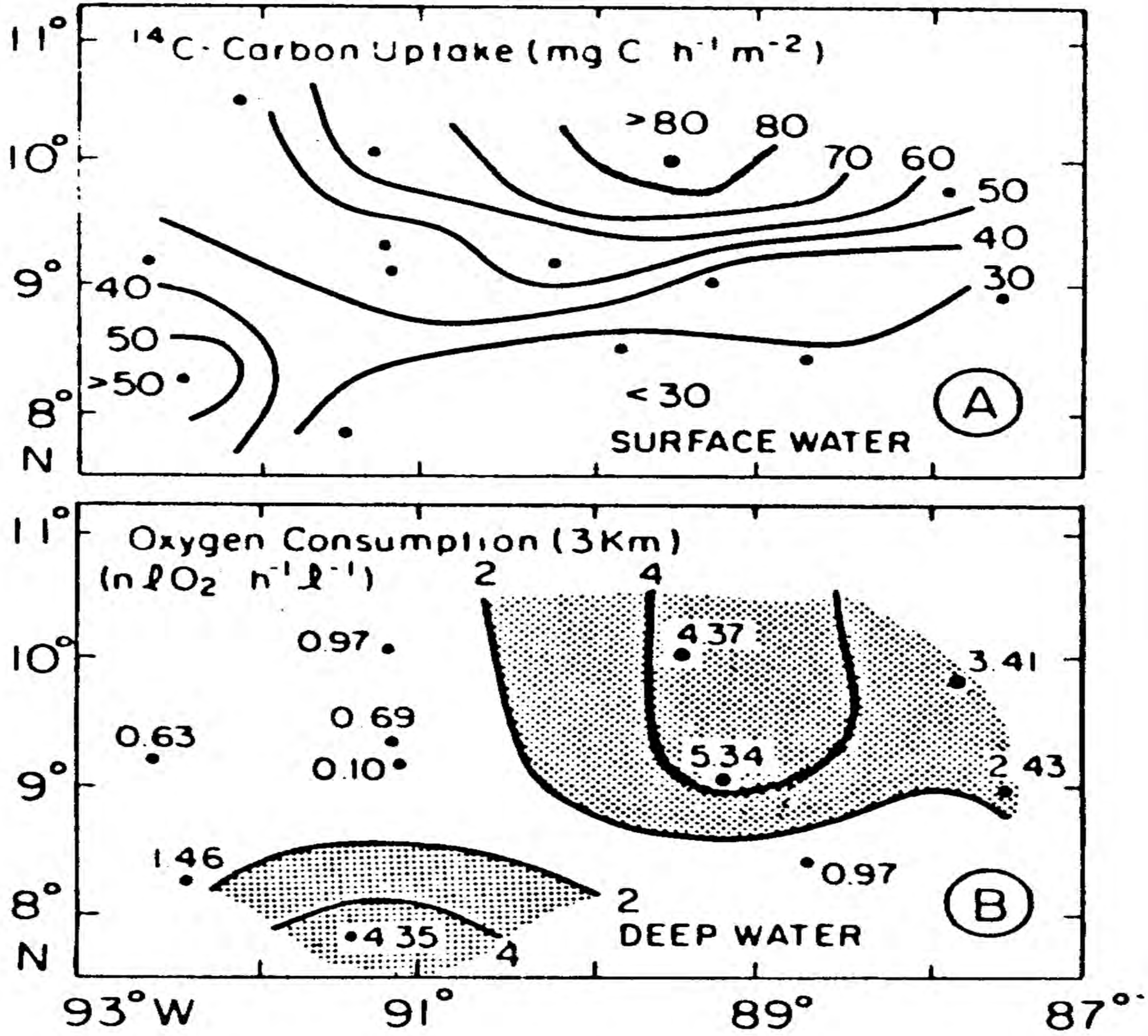

FIG. 7. SeaWiFS chlorophyll in natural logarithm (shade; mg $m^{-3}$) and 20°C isothermal depth (contours; m) climatology for Jul–Oct.

# Signature of carbon flux: Costa Rica Dome




Carbon pumping due to isopycnal relaxation under the Costa Rica Dome (9° N, 89° W)

(Packard et al., 1977)



¹⁴C-Carbon Uptake (mg C h⁻¹ m⁻²)
>80
80
70
60
50
40
30
40
50
>50
<30
A
SURFACE WATER
Oxygen Consumption (3Km)
(n ℓ O₂ h⁻¹ ℓ⁻¹)
2
4
4.37
3.41
0.97
0.69
0.63
0.10
5.34
2.43
1.46
0.97
2
4.35
4
B
DEEP WATER
11°
10°
9°
8°
N
93°W
91°
89°
87°

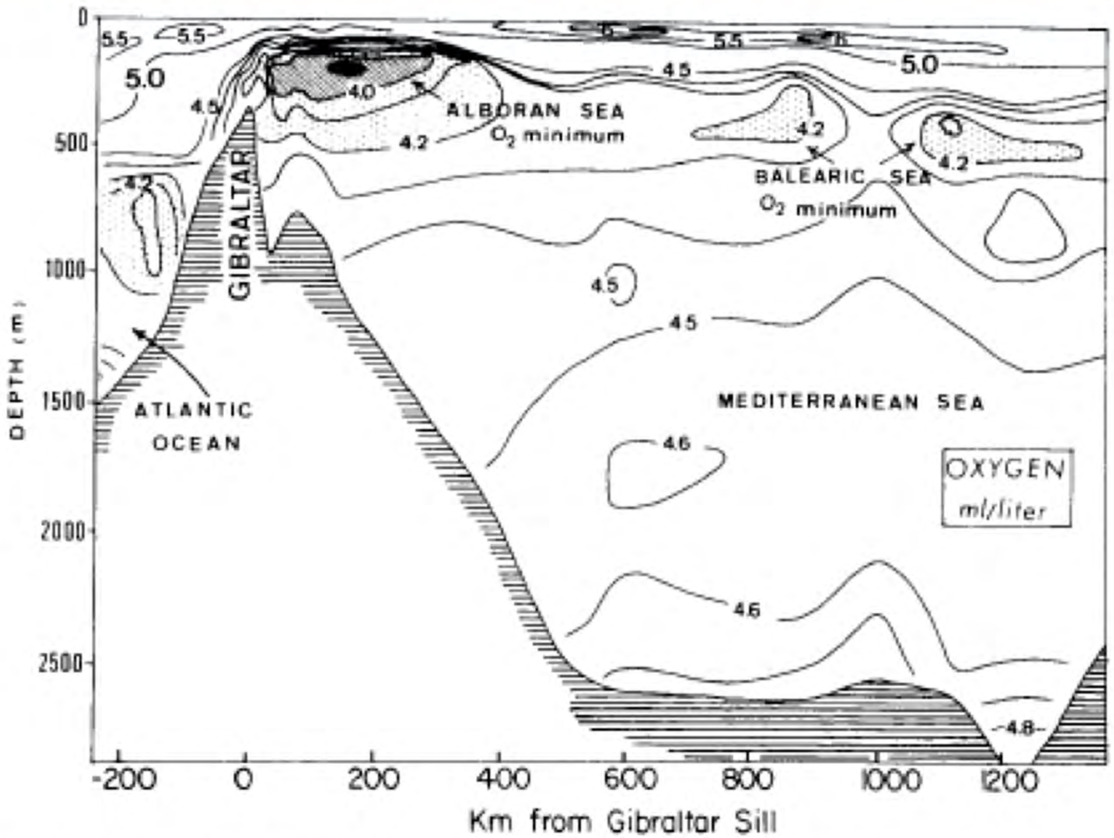



Fig. 2. The oxygen minimum in the Alboran and Balearic seas as determined on the *Médiprod IV* cruise (GROUPE MÉDIPROD, 1984).

# Signature of carbon flux: Alboran Sea Story

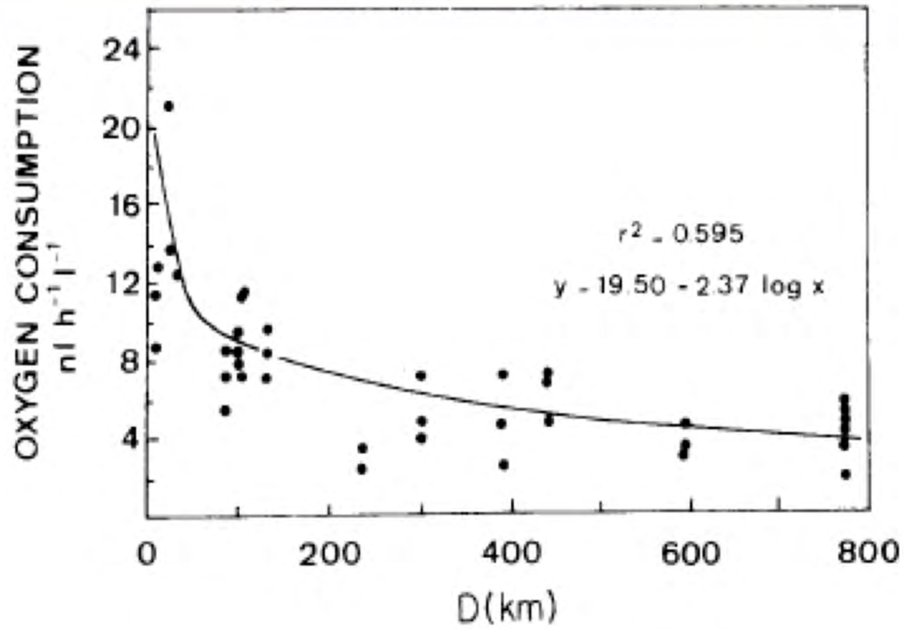
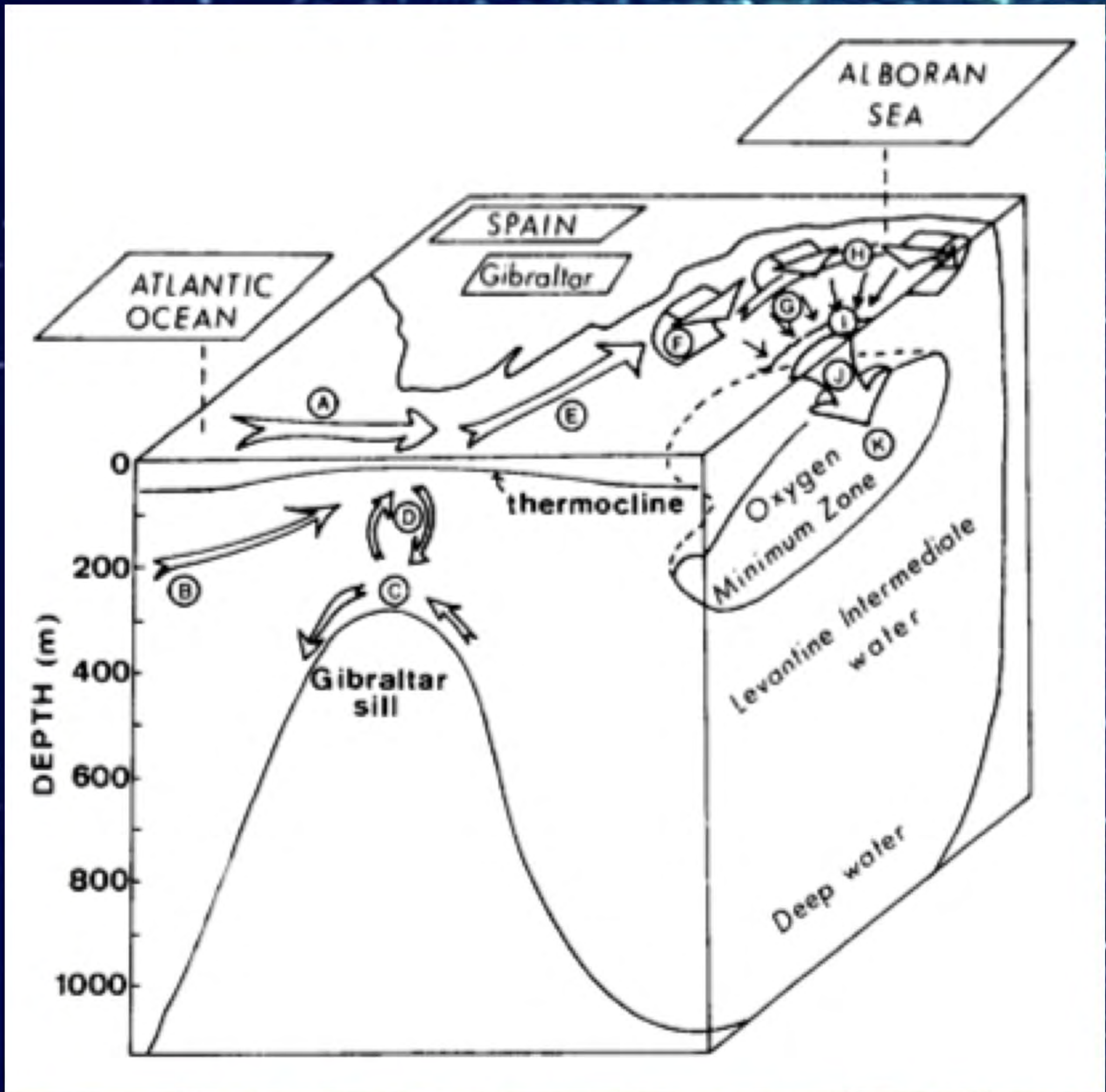



Fig. 3. The decrease in the oxygen utilization rate between 250 and 350 m on a transect from the Strait of Gibraltar to the Strait of Sicily (*Varifront* 6 cruise). D is distance from Gibraltar.

High Respiration in core of the Alboran OMZ.
Carbon fluxing in from where?




Carbon Flux through Convergence in the Alboran Gyre

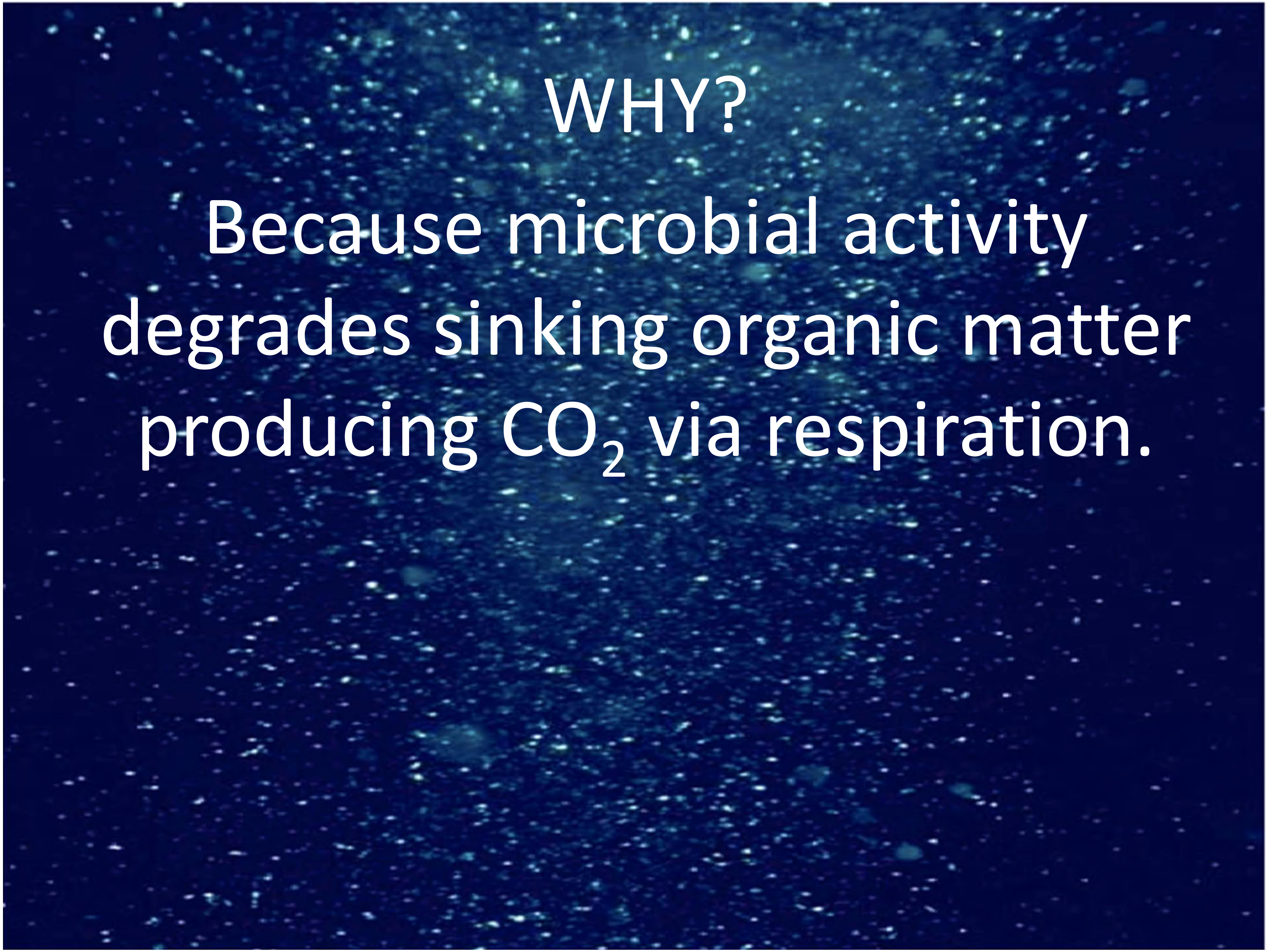
Packard et al, 1988

# Back to Carbon Flux, Itself.

Concentration of sinking organic matter decreases with depth.

Why?

Caveat: POC can be produced in situ via nitrification and agglutination reactions. They are not quantified yet, but considered minor.


WHY?
Because microbial activity degrades sinking organic matter producing $CO_2$ via respiration.

# Deep ocean respiration is based on advected organic matter

If horizontal fluxes are small or cancel,
Respiration ≈ Δ vertical flux. (Burd et al (2010) argues they are minor. )

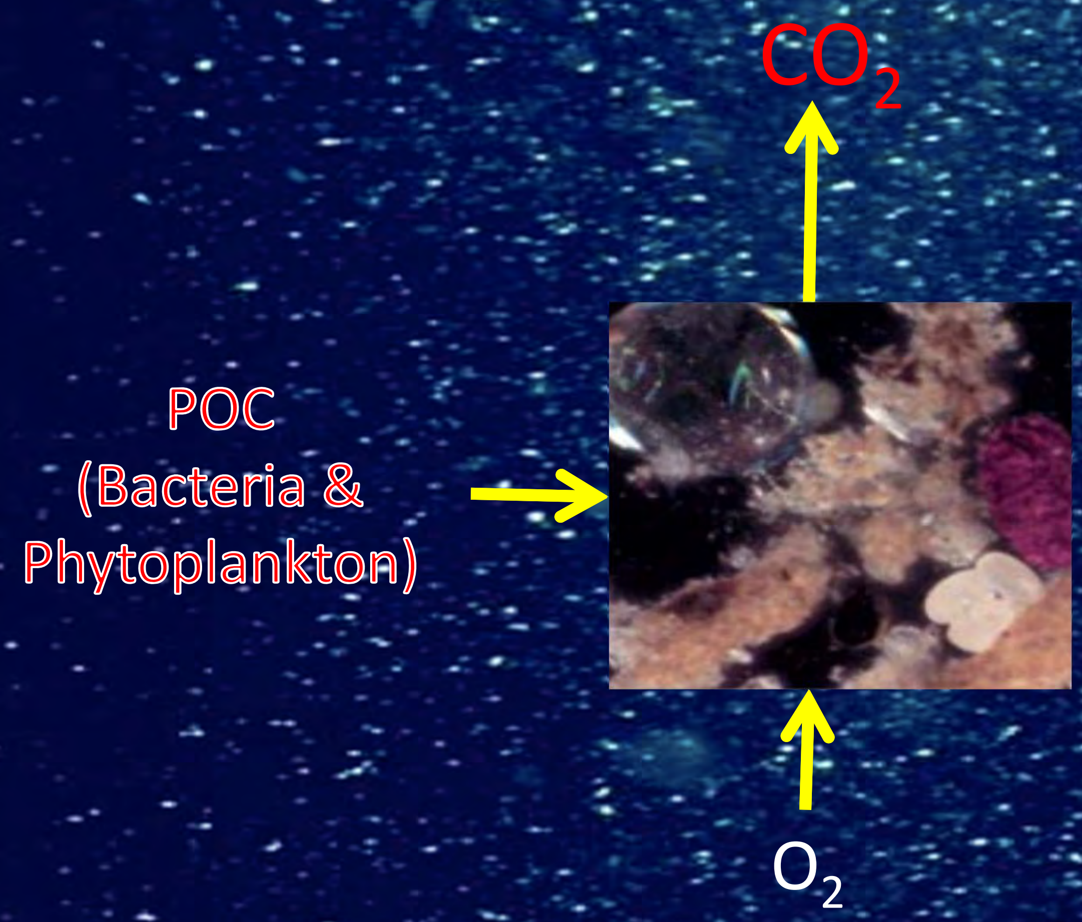
Caviat: Near coasts horrizontally advected POC is an additional source (Walsh, Alonso-González & Arístegui).

## Respiration ≈ Δ vertical flux

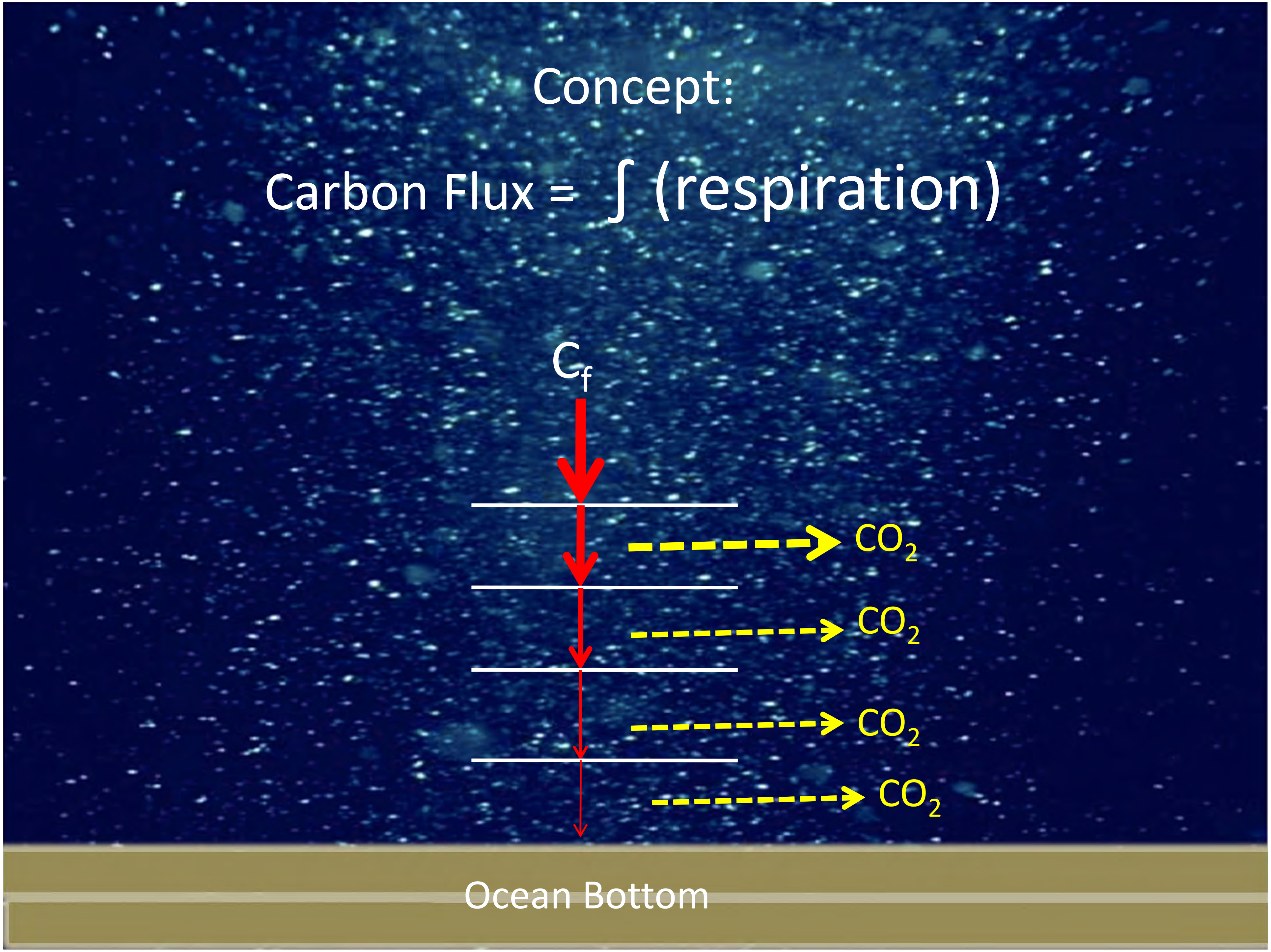
## Vertical flux ≈ ∫ Respiration

Since respiration is so difficult to measure in ocean waters, ETS activity is measured as a proxy. Thus ETS profiles of microplankton or zooplankton become measures of carbon flux.

# Microbial activity degrades sinking organic matter producing $CO_2$ via respiration.




Marine Tintinnid http://www.icm.csic.es/bio/images/welcome/tintinnid.gif (Lluisa Cros)



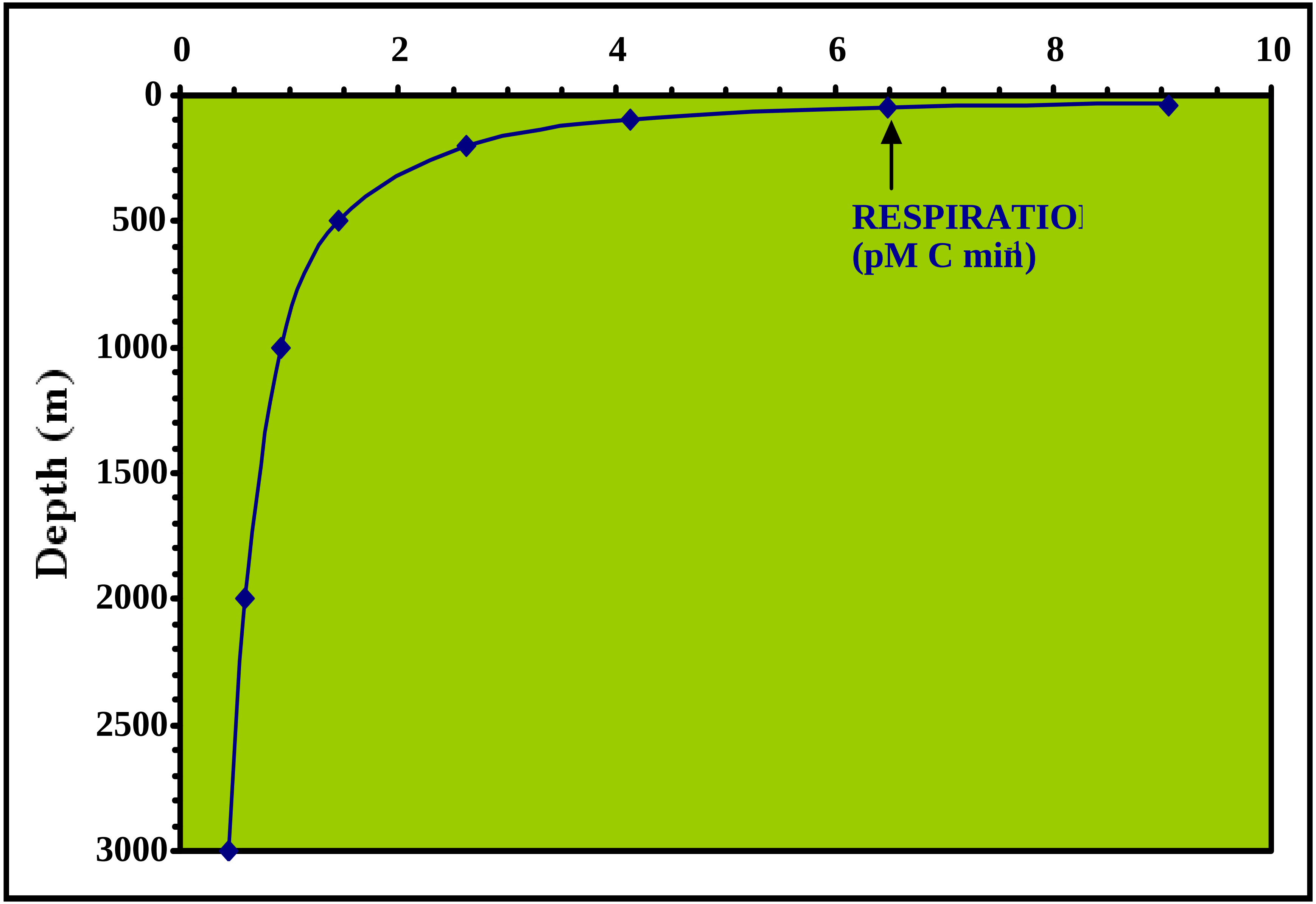
Concept:
Carbon Flux = ∫ (respiration)
C_f
CO2
CO2
CO2
CO2
Ocean Bottom

For carbon flux ($C_f$ ) depth profiles where $C_f = f_C(z)$, the respiration equation will be: $R = \partial(f(z))/\partial z$ (Suess, 1980).

For R depth profiles, where

$R = f_R(z)$, the $C_f$ equation will be:

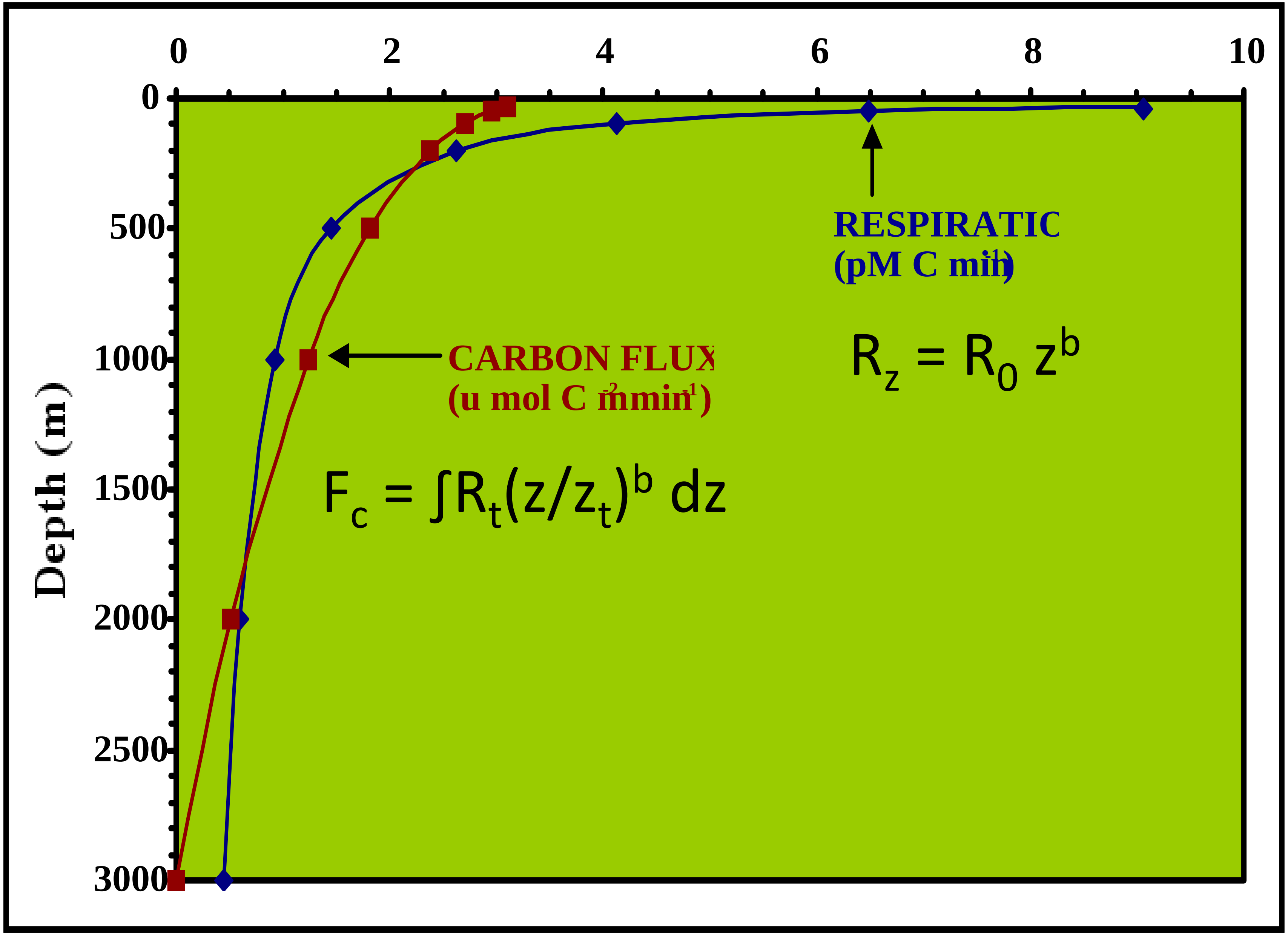
$$C_f = \int(f_R(z))\partial z$$



0
2
4
6
8
10
0
500
1000
1500
2000
2500
3000
Depth (m)
RESPIRATIO
(pM C min-1)

R = f(z) can be described by power functions ($R_z = R_0 z^b$), by depth-normalized power functions ($R_z = R_t(z/z_t)^b$) and by exponential functions ($R_z = R_0 e^{bz}$). However, because the modelled $R_{O2}$ at $z = z_t$ is close to the measured value at $z_t$ we calculate carbon fluxes with the depth-normalized power function:

$$R_z = R_t(z/z_t)^b \ .$$



0
2
4
6
8
10
0
500
1000
1500
2000
2500
3000
Depth (m)
RESPIRATIC
(pM C min-1)
CARBON FLUX
(u mol C m-2 min-1)
$R_z = R_0 z^b$
$F_c = \int R_t (z/z_t)^b dz$

The indefinite integral of $R_z = R_t(z/z_t)^b$ with respect to depth (z) is:

$$F_c = \int R_t(z/z_t)^b \, dz = [R_t /((b+1)(z_t)^b)] \, z^{b+1} + C$$

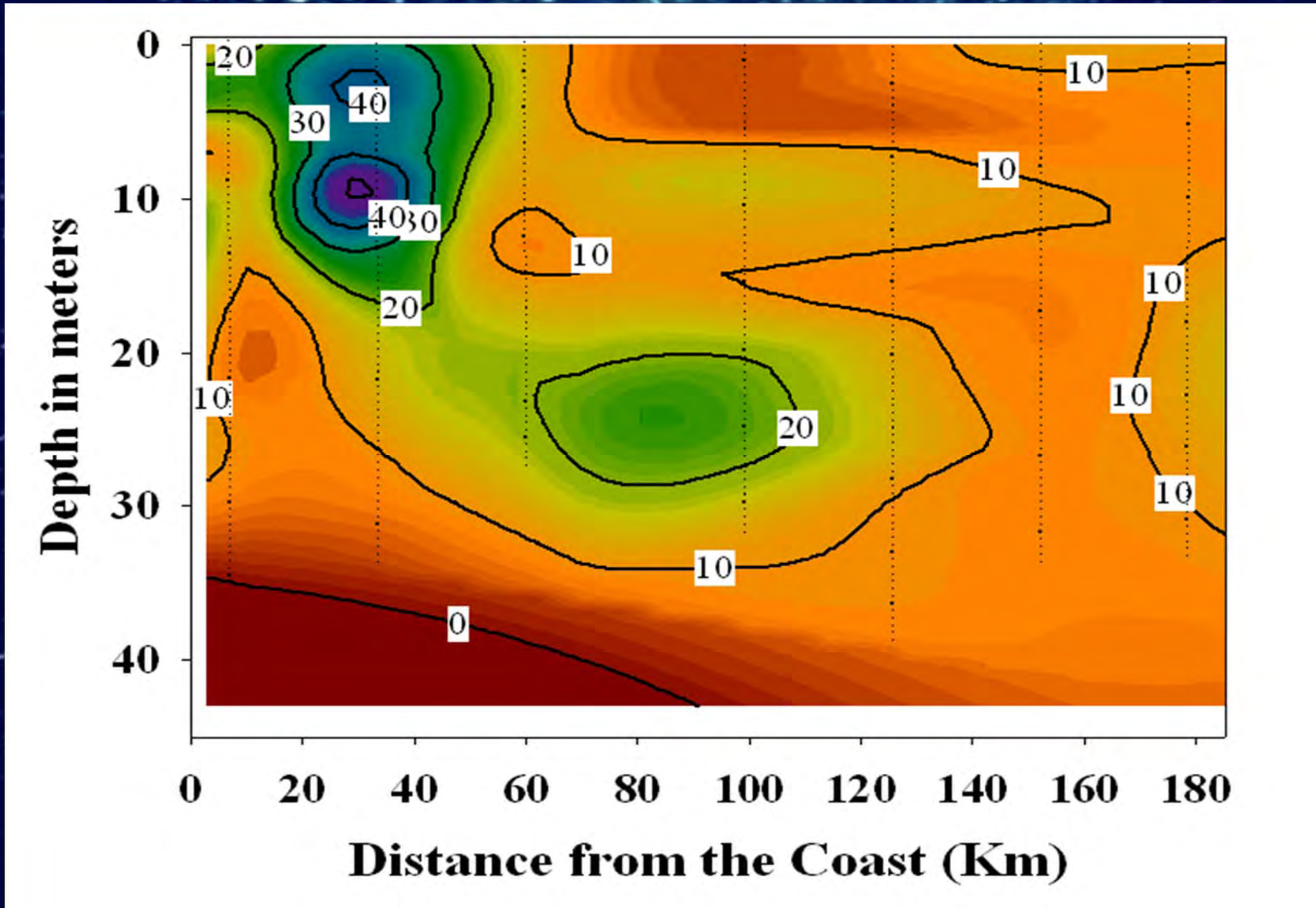
To calculate the delta flux ($F_{t-s}$) between $z_t$ and $z_s$ we solve $R_z = R_t(z/z_t)^b$ as a definite integral between these two boundary conditions.

$$F_{t-s} = \int_{z_t}^{z_s} R_t(z/z_t)^b \, dz = [R_t /((b+1)(z_t)^b)] \, [(z_s^{\,b+1}) - (z_t^{\,b+1})]$$

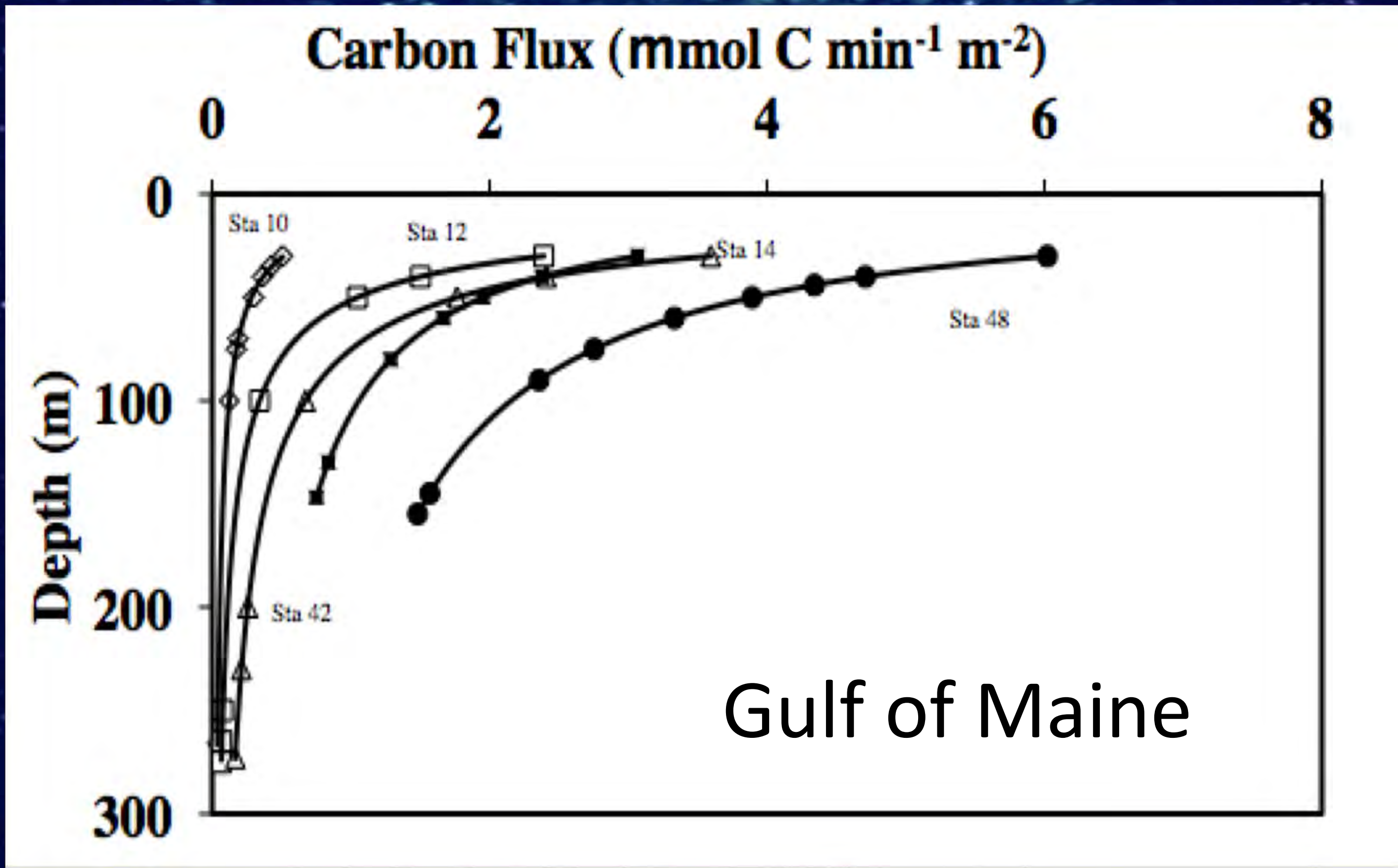
To calculate the carbon flux from $z_t$ to infinity ($F_\infty$), we find that in the limit as $z_s$ goes to infinity, $[R_t /((b+1)(z_t)^b)] [(z_s^{b+1})]$ goes to zero. Thus

$$F_\infty = \int_{z_t}^{\infty} R_t(z/z_t)^b \, dz = [R_t /((b+1)(z_t)^b)] [-z_t^{b+1}]$$

# ETS activity (nmol e$^-$ min$^{-1}$ L$^{-1}$) along the C-Line (13-20 Sept 1976)



# Microplankton Passive Flux From ETS Activity



# Carbon Flux

## (g C $m^{-2}$ $y^{-1}$)

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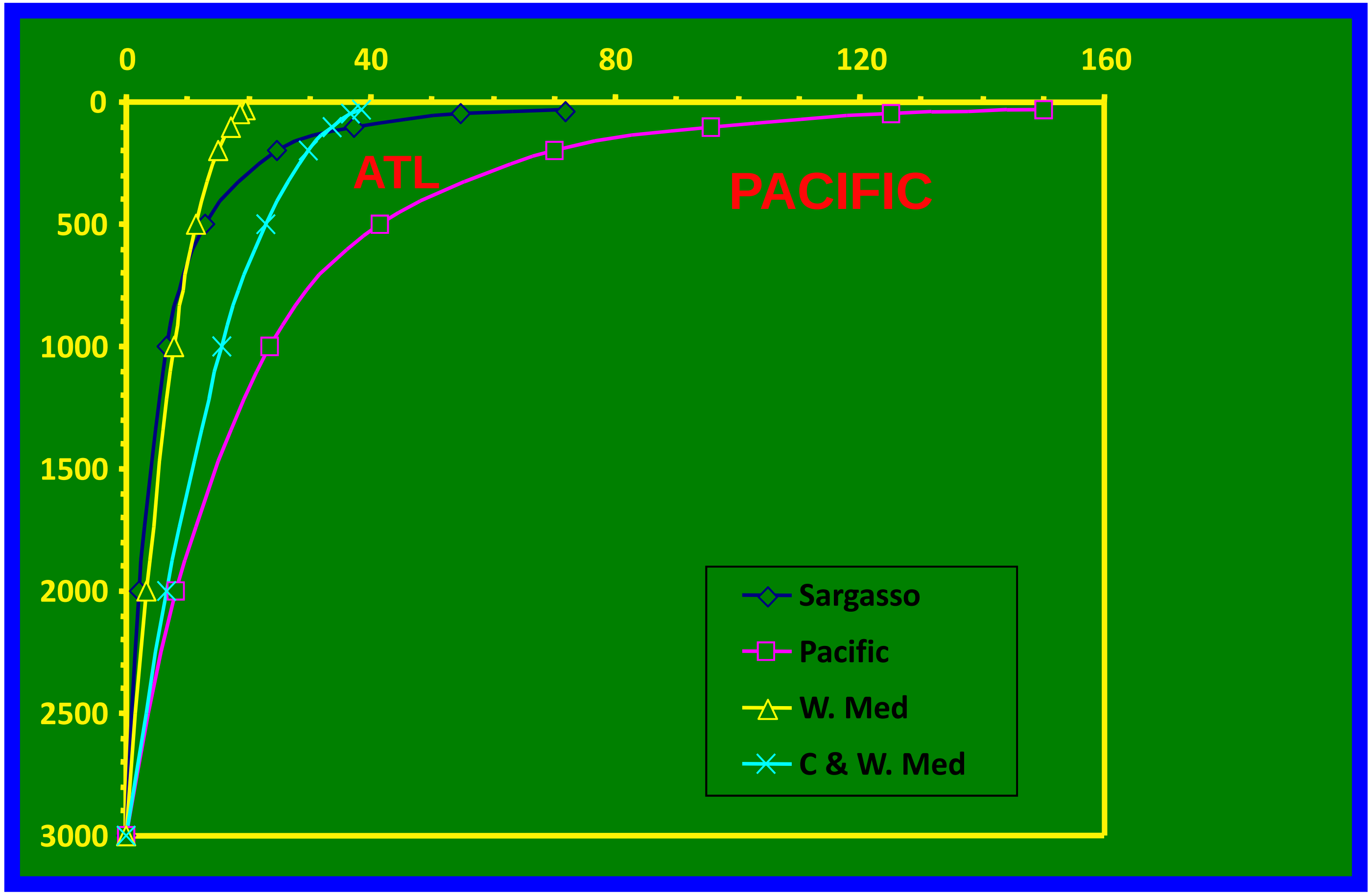


# Classic Carbon Flux at 100 m ($mgC\ m^{-2} day^{-1}$)

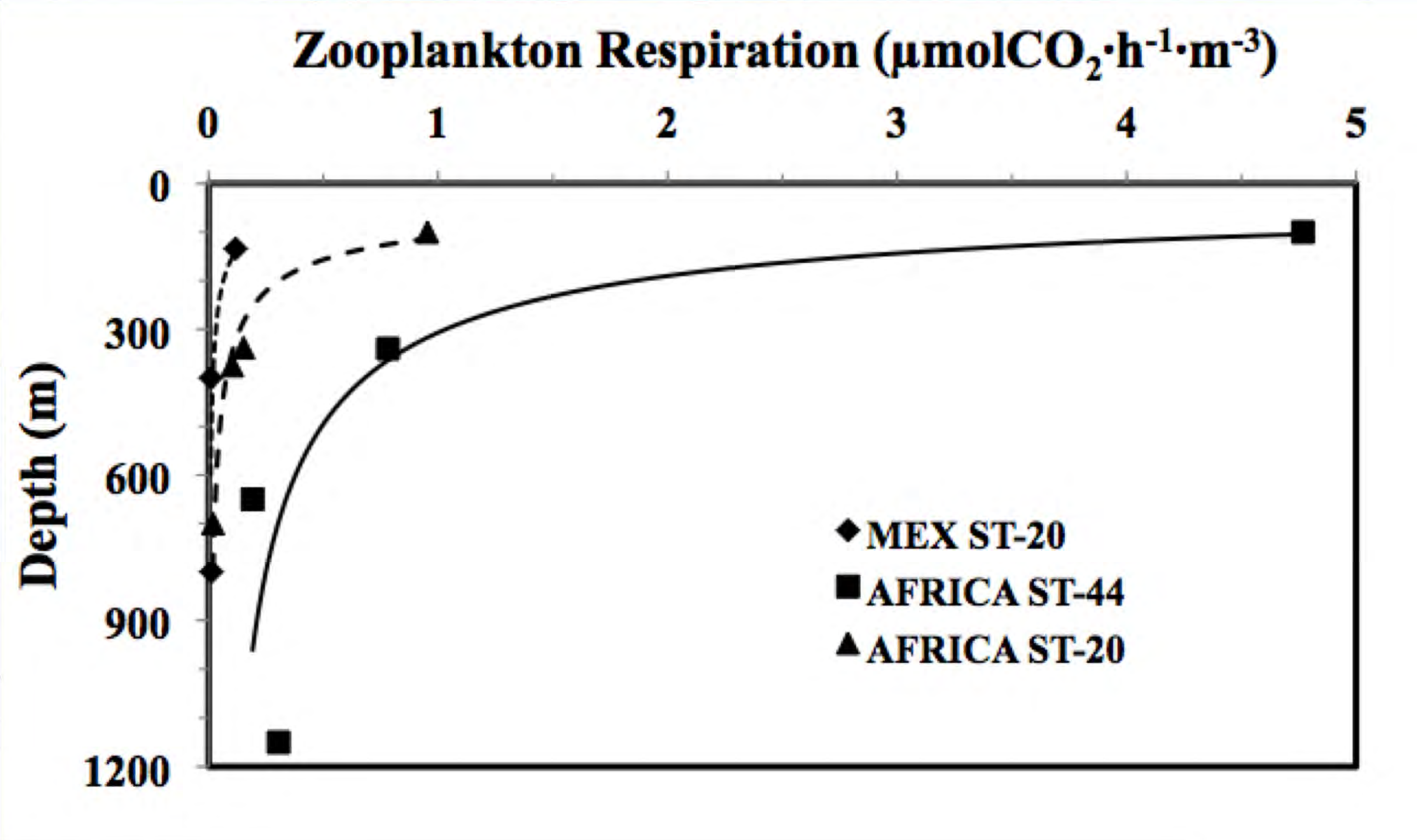
UNIVERSIDAD DE LAS PALMAS DE GRAN CANARIA

- Peru Current (Sept)
  - Offshore 85
  - Upwelling Edge 544
- Central Pacific 263
- Sargasso Sea 101
- Western Mediterranean 93
- Note! Negative fluxes not included here.

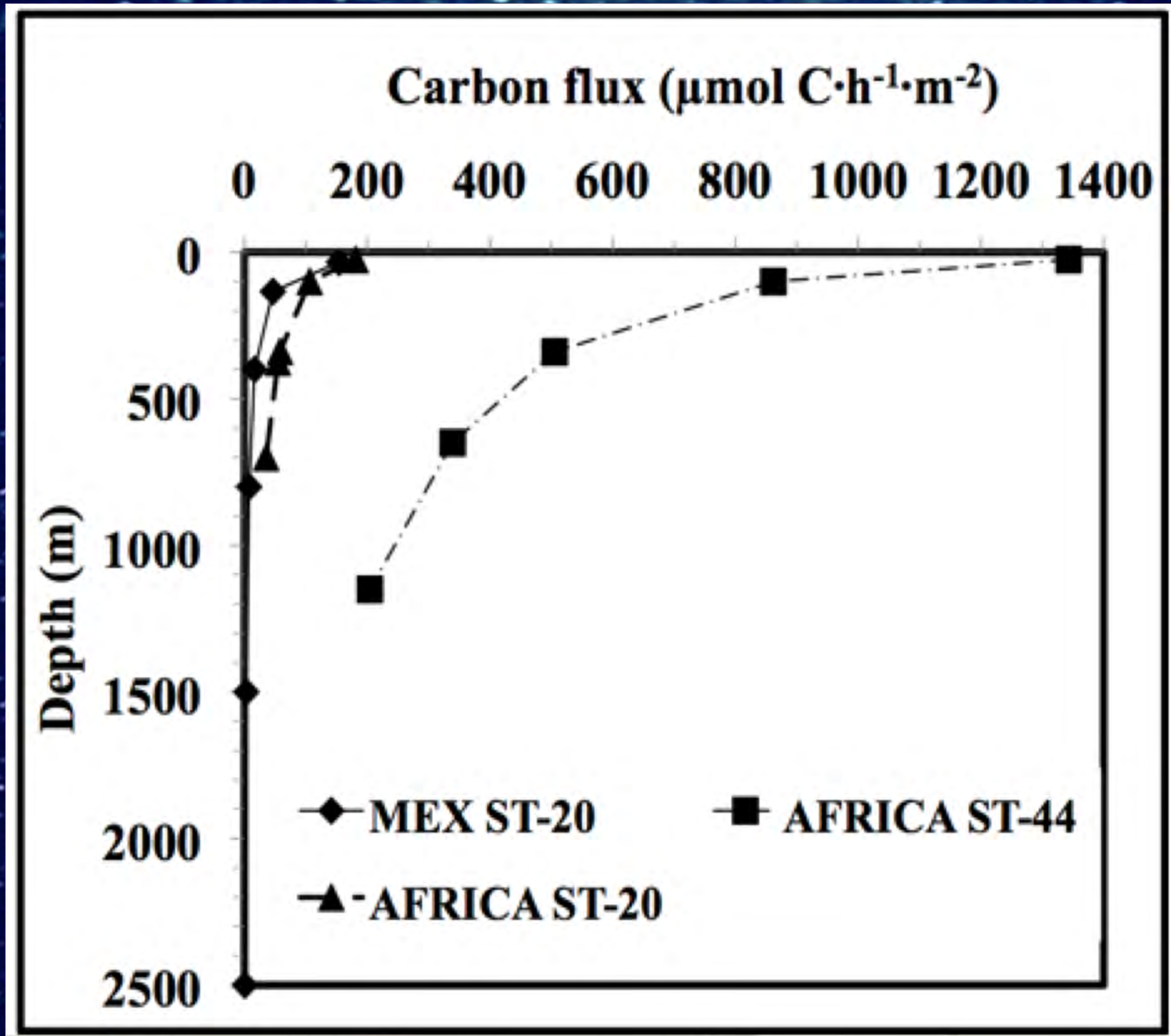
# Canary Island Microplankton Passive C-Flux

| Reference | Location | Date | Depth (m) | Carbon Flux mmol C $day^{-1}$ $m^{-2}$ |
|---|---|---|---|---|
| Alonso-González et al.(2010b) BGS 7 | Canarian eddies | Aug, 2006 | 150 | 9.7 ± 2.0 |
| Alonso-González et al.(2010b) BGS 7 | NW African-Atlantic | Aug, 2006 | 150 | 5.8 ± 0.3 |
| Alonso-González et al.(2010a) GRL 37 | Canarian eddies | June-Dec, 2005 | 260 | 0.48 ± 0.02 |
| Alonso-González et al.(2010a) GRL 37 | Canarian | Dec 2005-June 2006 | 260 | 0.43 ± 0.03 |
| Alonso-González et al.(2010a) GRL 37 | Canarian eddies | June 2006 Dec 2006 | 260 | 0.14 ± 0.01 |
| Alonso-González et al.(2010c) PNAS | E Atlantic & Can. eddies | June 2005 to Dec 2006 | 500 | 0.08 ± 0.01 to 2.05 ± 1.44 |
| Alonso-González et al.(2010c) PNAS | E Atlantic & Can. eddies | June 2005 to Dec 2006 | 1000 | 0.18 ± 0.09 to 1.78 ± 2.27 |

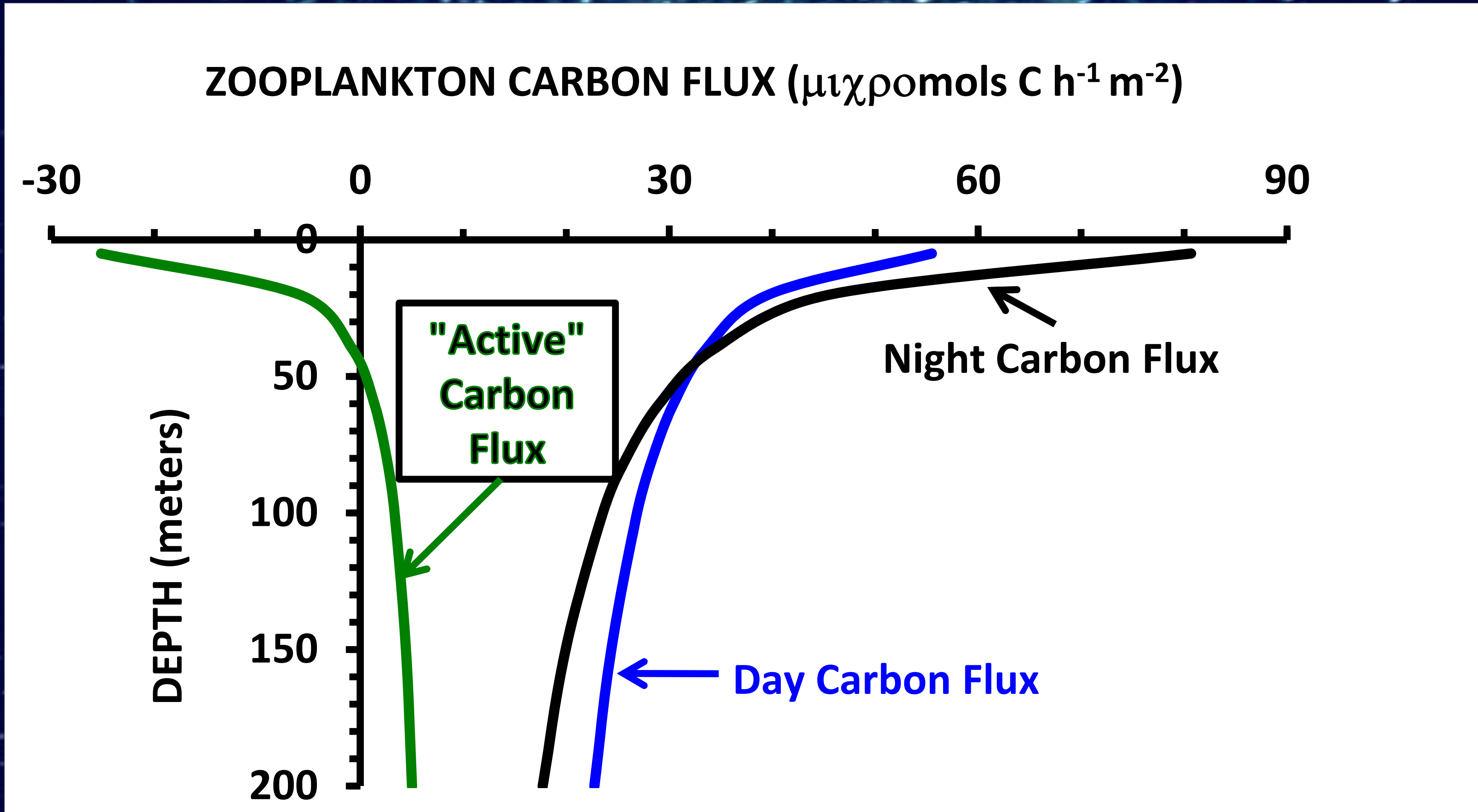
# Zooplankton Respiration



# Zooplankton Passive Flux



# Active Flux (via vertical migration)



# ACTIVE CARBON FLUX

Zooplankton vertical migration daily transports carbon from the surface to depth

HISTORY: Ketchum refers to this it in 1957. Since JGOFS Longhurst, Dam, Steinberg, Hernández-León, Morales, Putzeys, et al. have measured it.

Hernández-León’s group at ULPGC: first to use ETS in the calculations of carbon flux.

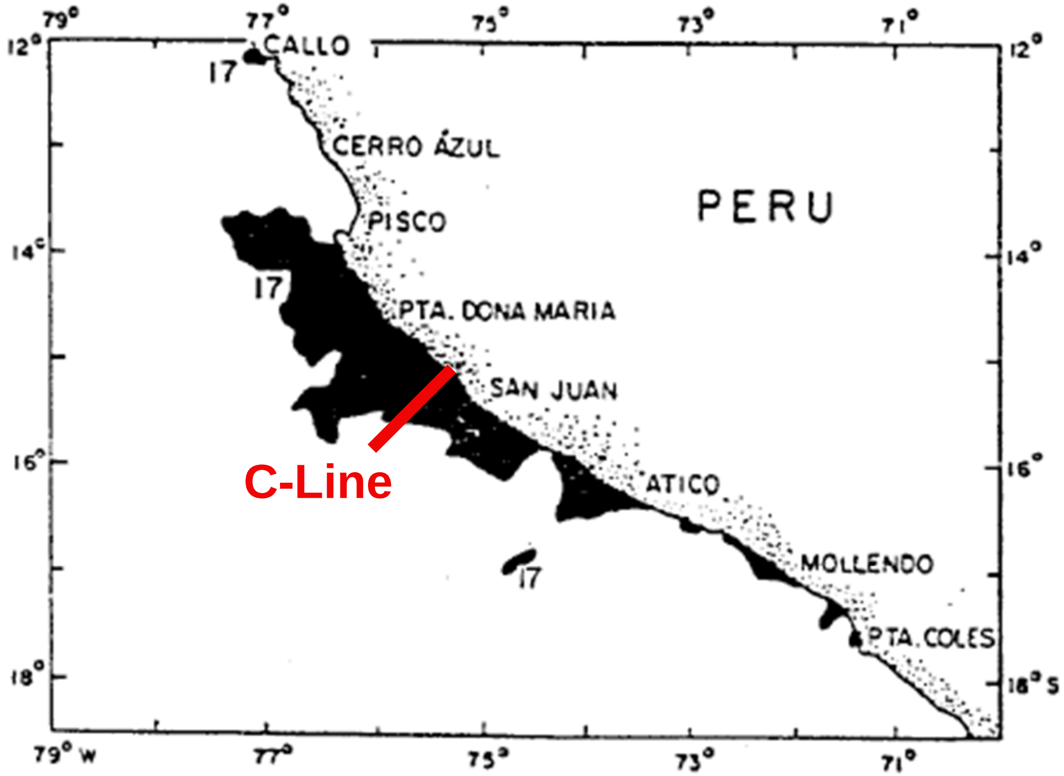



Fig. 1. The maxima and minima of upwelling intensity within a coastal upwelling system. This entire coast of southern Peru is characterized by upwelling, but during this period (28-30 May 1974) centers of intense upwelling occurred at Callao, San Juan, Atico and Mollendo. This figure is redrawn from Zuta et al. (1978).

Upwelling revealed from microplankton ETS : A story.

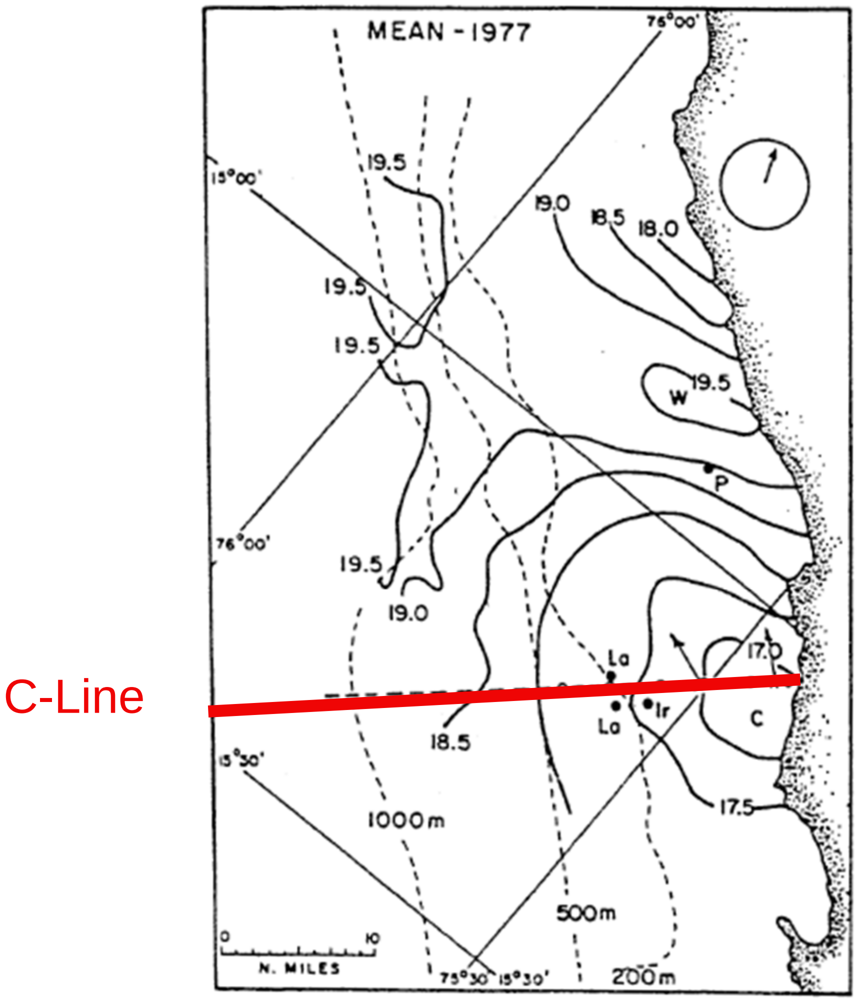



Fig. 3. The plume at 15°S in the Peruvian upwelling system. The contours depict the mean sea surface temperatures as measured from aircraft flying at 150 m above the ocean (redrawn from Brink et al., 1981).

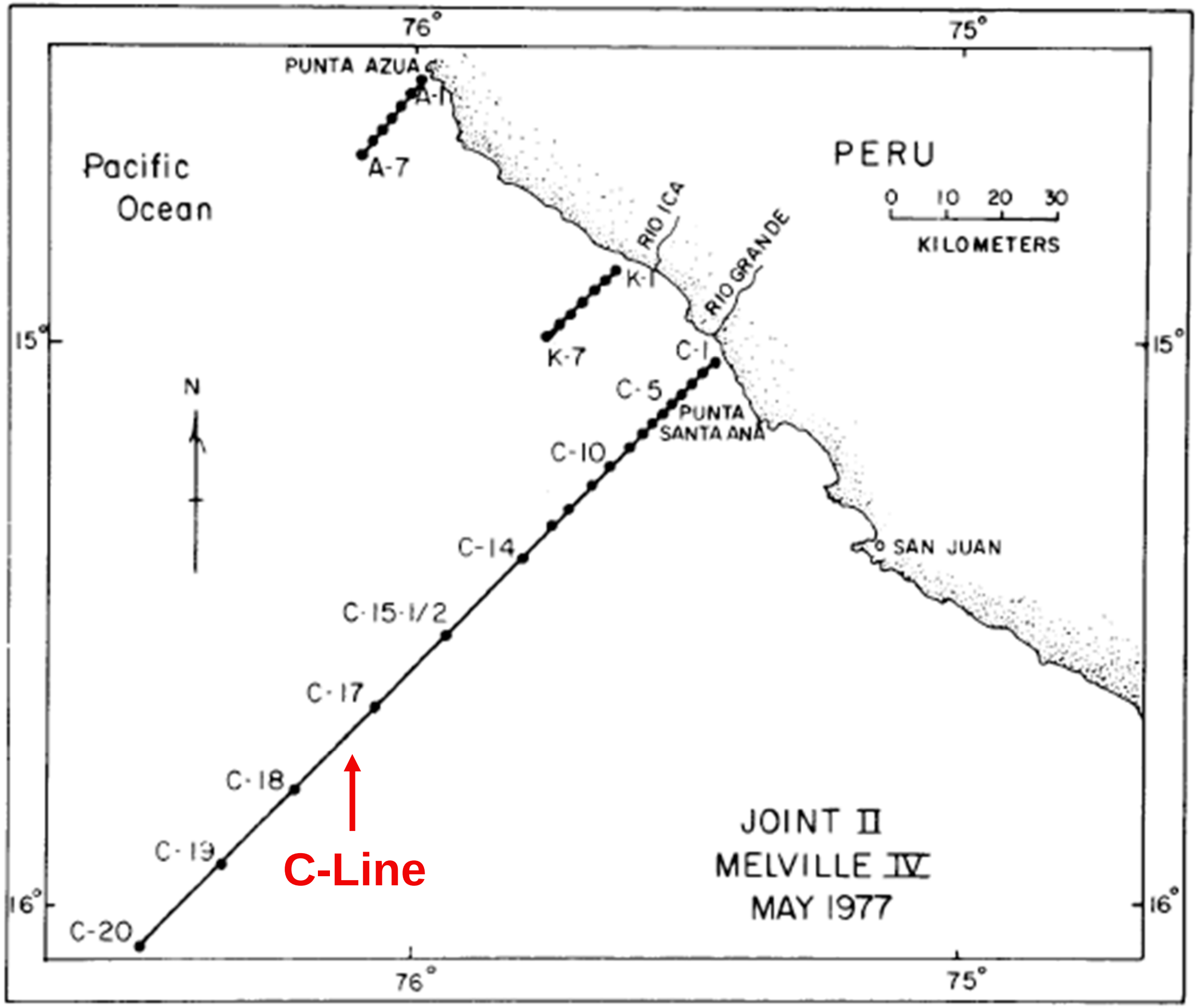
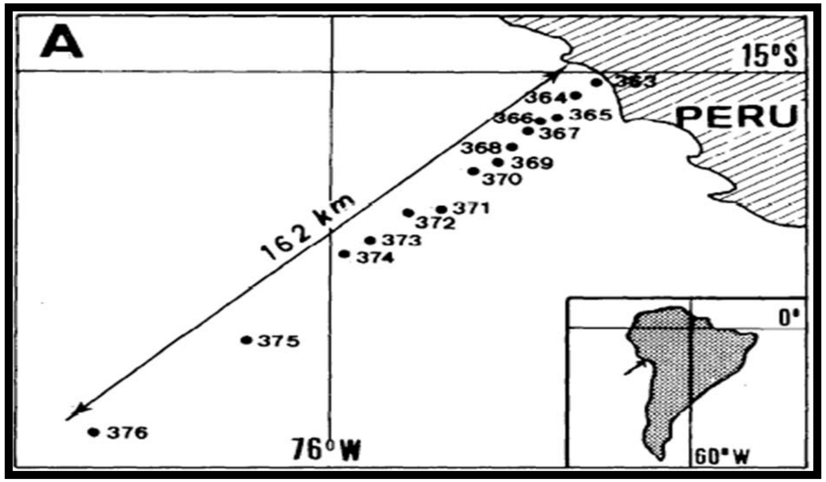
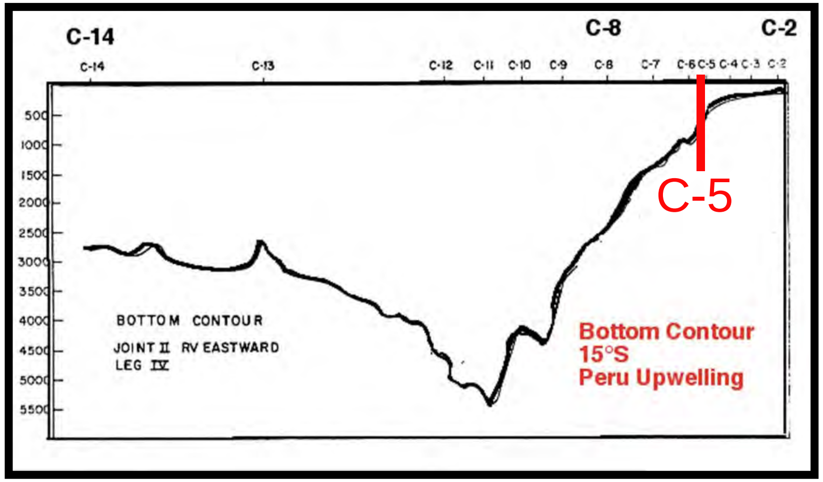



Fig. 1. Station locations along A-, K- and C- (15°S) lines during the R/V *Melville* Leg IV (May, 1977).

# Peru Trench



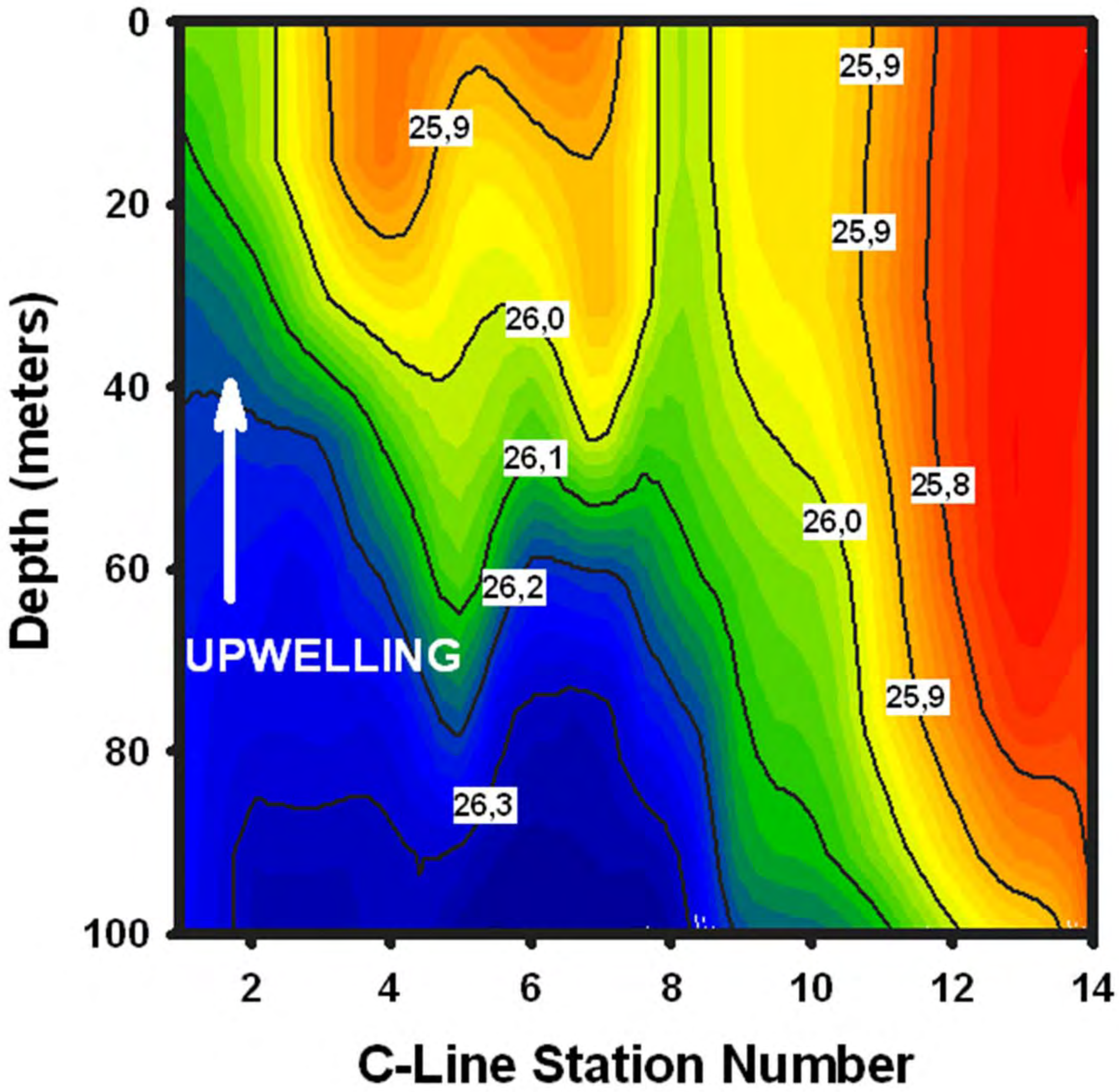

CUEA "C"-Line

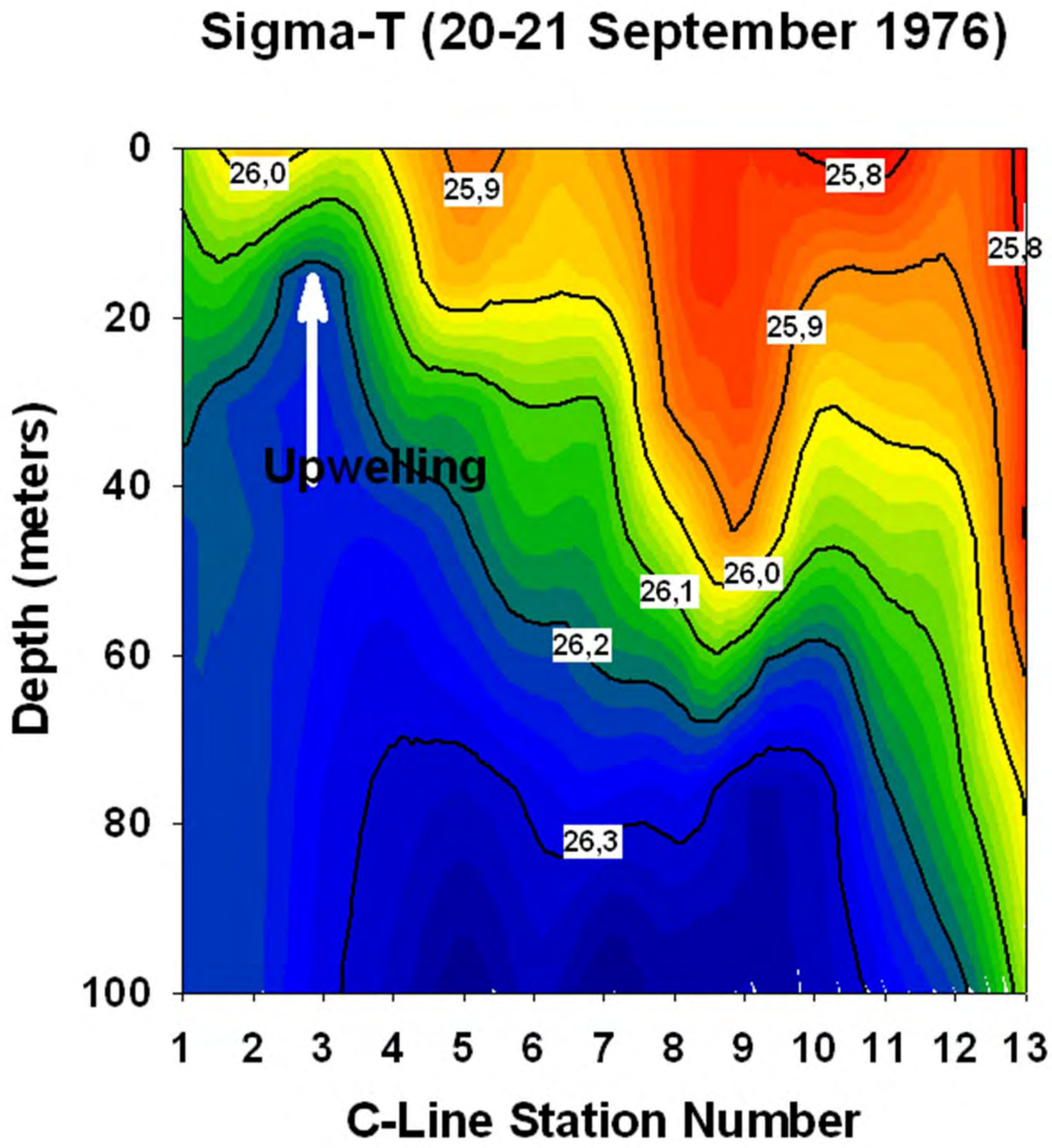
CUEA Cruise

JASON Sept 1976

Stations 1-14

# Sigma-t (10-11 Sept 1976)




Sigma-T (20-21 September 1976)
Depth (meters)
0
20
40
60
80
100
C-Line Station Number
1
2
3
4
5
6
7
8
9
10
11
12
13
Upwelling
26,0
25,9
25,8
25,8
25,9
26,0
26,1
26,2
26,3

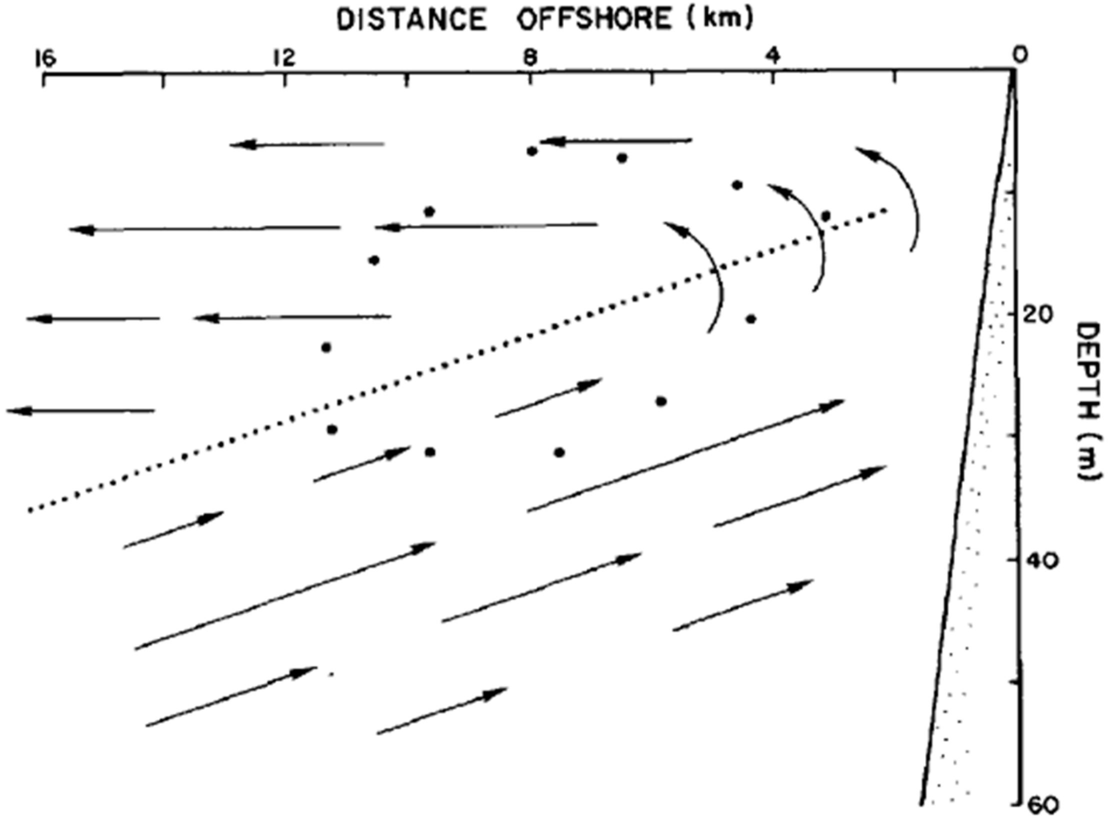
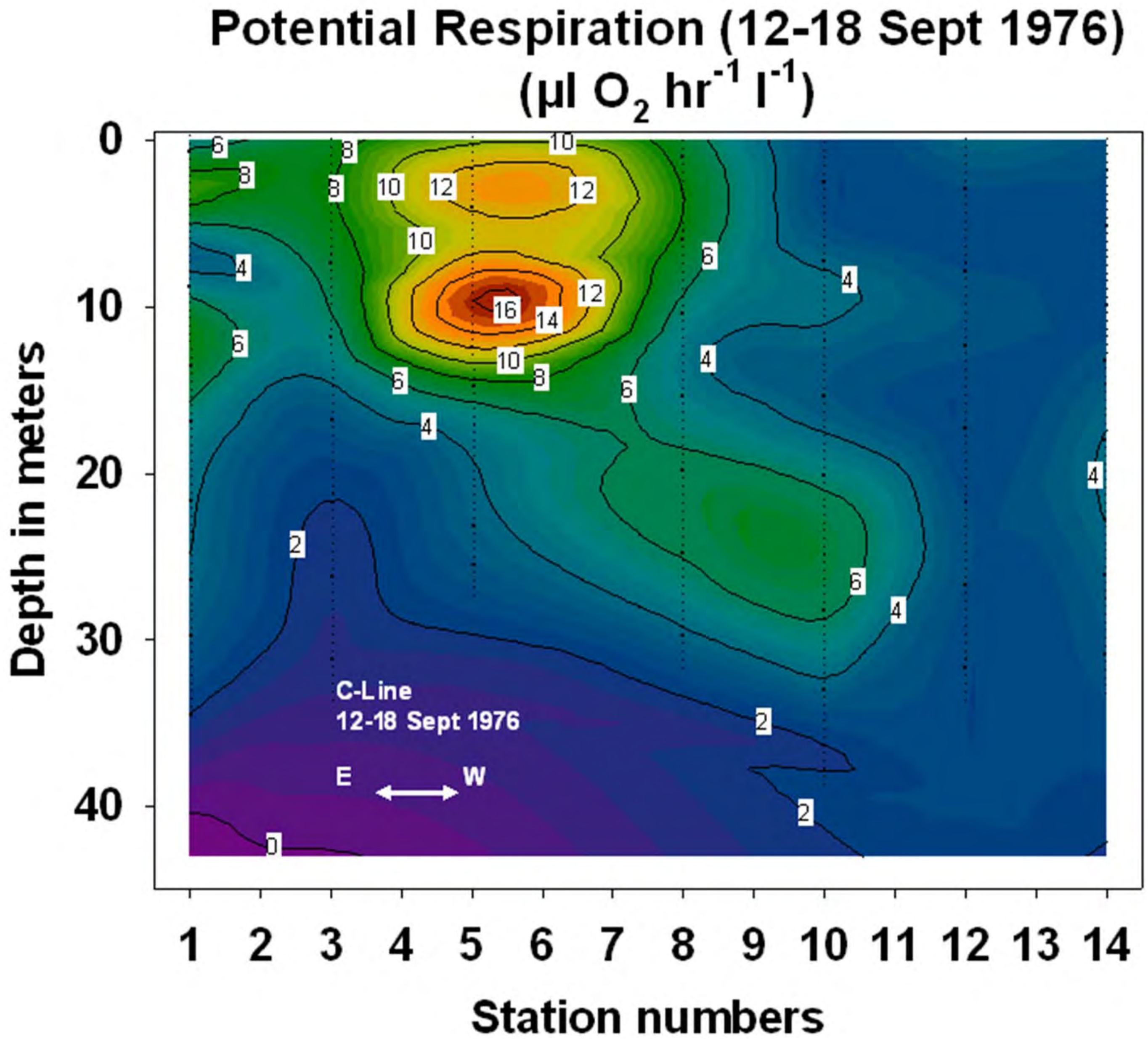
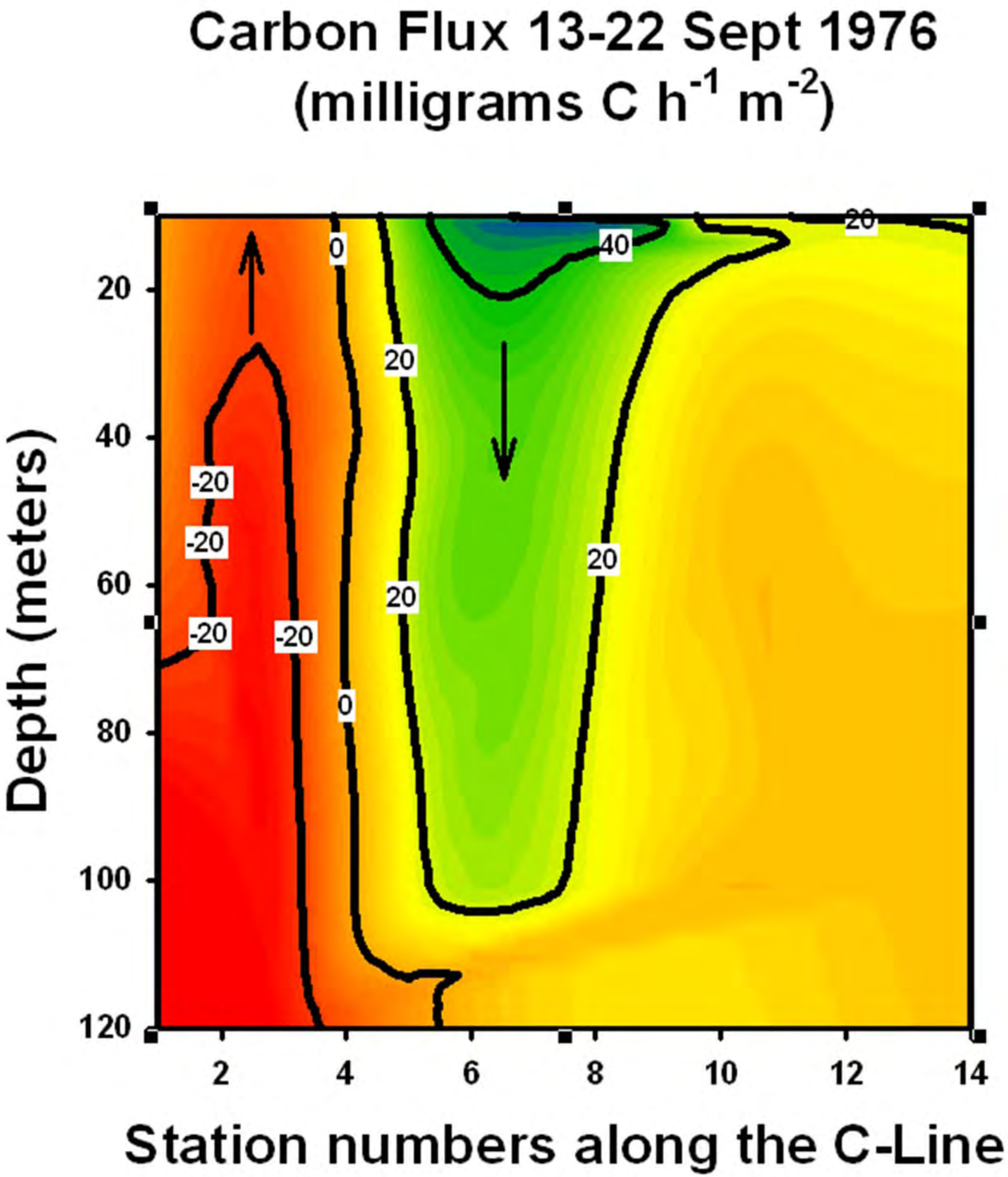



Figure 3. Hypothetical cross-shelf reseeding mechanism. Phytoplankton (solid circles) are advected offshore in the surface layer but sink into the onshore-flowing layer. They then are moved inshore and upwelled to the surface where a new bloom is initiated. The dotted line represents the observed mean depth of zero onshore/offshore motion.

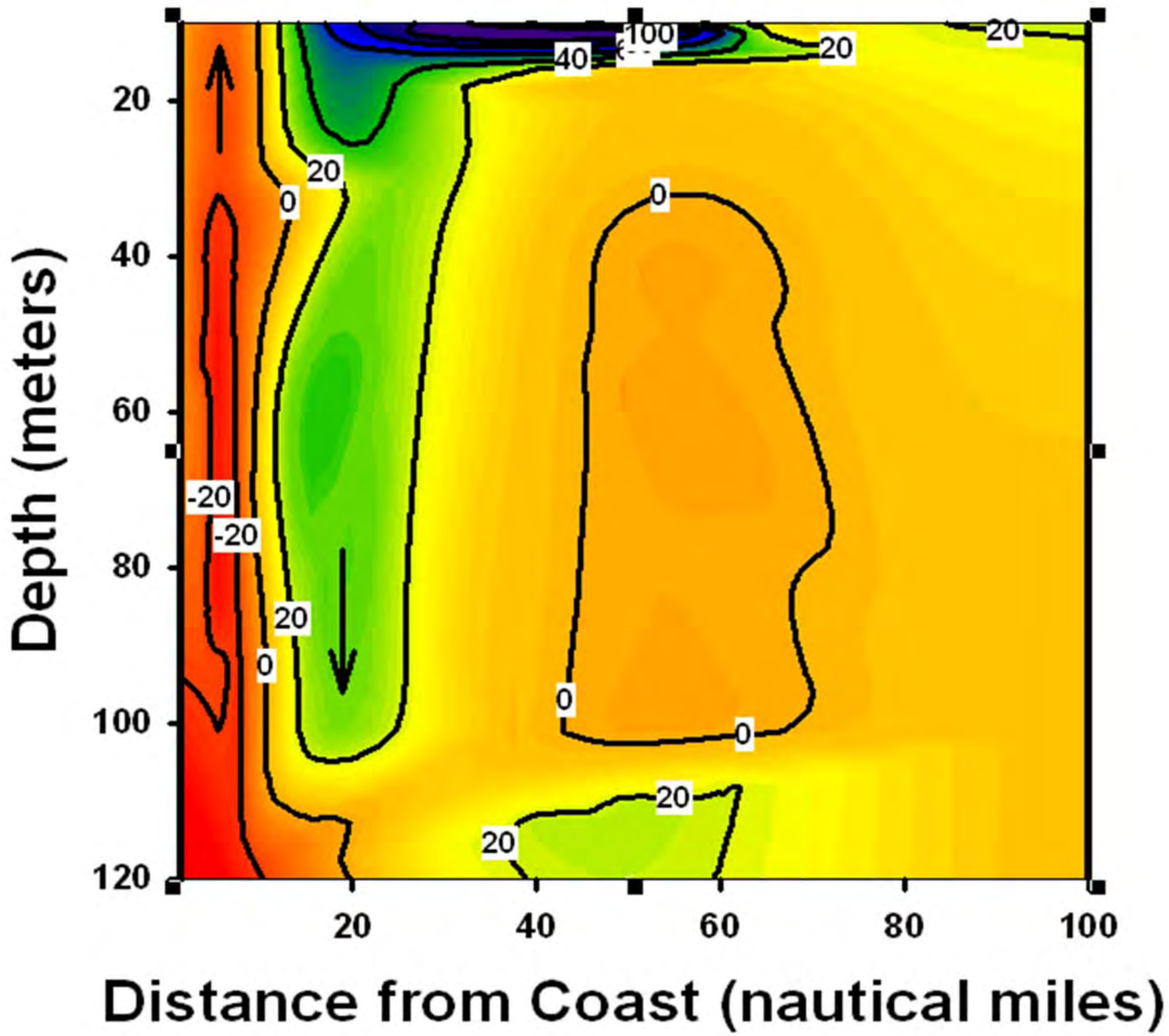
THIS IS A PREDICTION OF NEGATIVE C-FLUX!



Potential Respiration (12-18 Sept 1976)
(µl O2 hr-1 l-1)
Depth in meters
0
10
20
30
40
Station numbers
1 2 3 4 5 6 7 8 9 10 11 12 13 14
C-Line
12-18 Sept 1976
E
W


Carbon Flux 13-22 Sept 1976
(milligrams C h-1 m-2)
Depth (meters)
20
40
60
80
100
120
2
4
6
8
10
12
14
Station numbers along the C-Line
0
20
40
-20

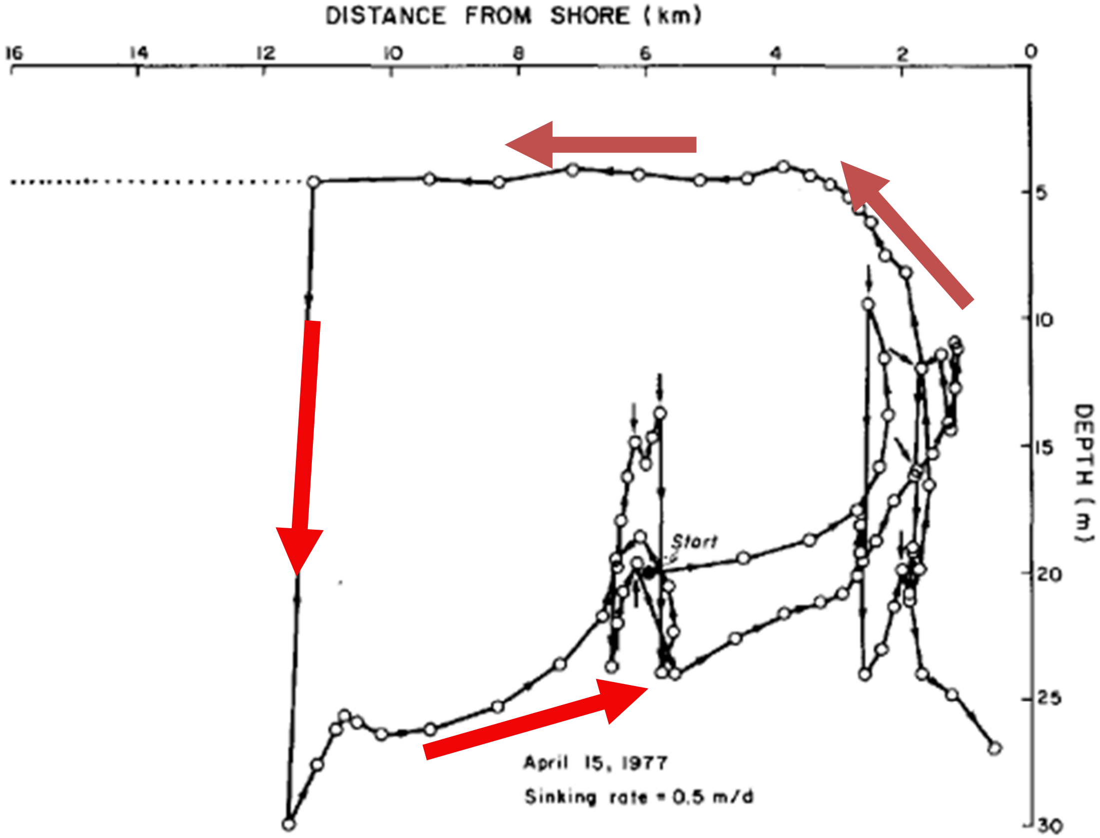
# Carbon Flux 13-22 Sept 1976
(milligrams C $h^{-1}$ $m^{-2}$)



The vertical velocity of water was much greater than the sinking rates of particles during the 52 day period, so that the net vertical transport of particles was controlled by the vertical velocity of the water. – Smith et al., 1983

The water was upwelling!

1983] *Smith et al.: Physical control of phytoplankton communities* 549




Phytoplankton upwell with the seawater!

# Conclusions 1

✧All measurements associated with ocean carbon flux are flawed and need serious refinement.

✧Carbon flux profiles can be calculated from ETS activity profiles.

✧**Time-dependent variability of carbon flux can be studied now, because the ETS-measurement time-scale is minutes.**

# Conclusions 2

✧ Carbon flux can be profiled, it can be studied in time-series, and its negative values can be demonstrated using ETS-based rrespiration ocean profiles.

# Conclusions 3

- ✧ Coordinated measurements of microplankton, microzooplankton, & net-zooplankton ETS profiles plus sediment trap profiles at the same ocean location are desperately needed.

- ✧ Laboratory studies, carefully refining the methodology in all facets of carbon flux studies (BGE, thymidine & leucine conversion factors, cell carbon quotas, R.Q.s, & R/ETS ratios) are critical for future advances.

# Acknowledgements

In different ways each of these people helped me in this research: FA Richards, C. Barnes, ML Healy, HJ Minas, LA Codispoti, JP Christensen, A Devol, Q Dortch, M Estrada, PG Coble, FD King, NR Anderson, BJ Zahuranec & MM Gómez. I thank them all.

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G. McNamara on 27 m wave, Nazare Canyon, Portugal, 11-11-11, www.guardian.co.uk