Lecture 7

Fronts in the coastal waters: Physics and Biology

Fronts

- **Definition**: Fronts: regions with enhanced horizontal gradients of hydrographic properties; regions where properties change markedly over a relatively short distance.

- **Classification**: Tidal fronts (sea-shelf fronts), shelf-break fronts, upwelling fronts, plume fronts, estuarine fronts, fronts induced by geomorphic features.

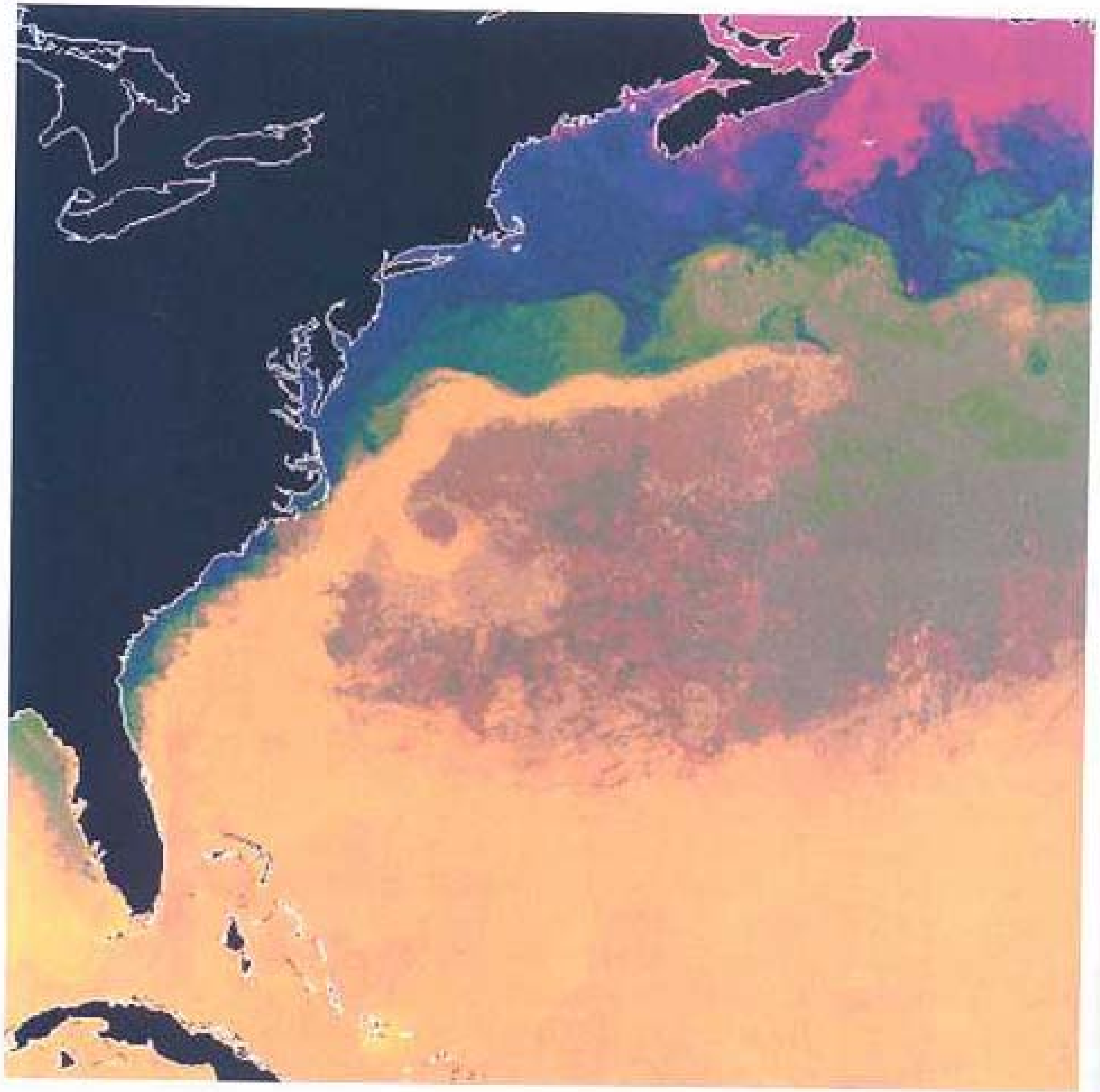
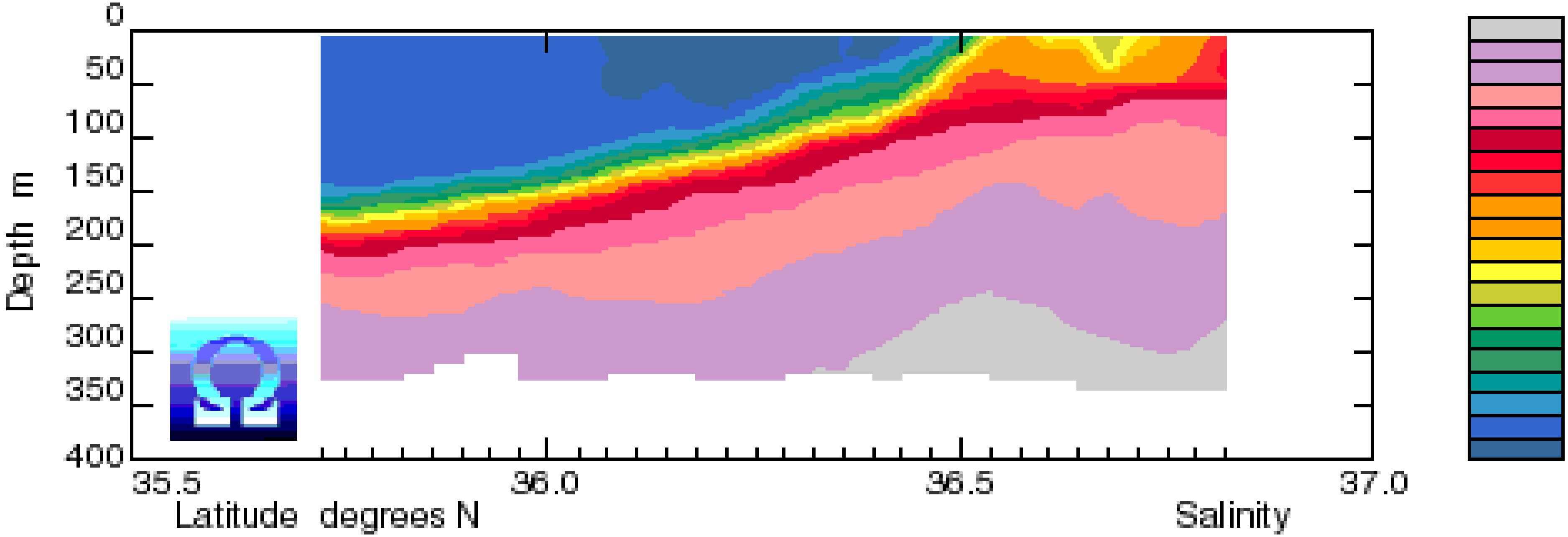


Plate 2 Distribution of surface temperature on the western North Atlantic Ocean on January 19, 1989. Highest temperatures are in the warm (yellow) subtropical waters and in those carried north in the Gulf Stream, where they mix with the colder (green and blue) northern waters. Note the evidence of ring formation on each side of the Gulf Stream. Derived from satellite data, courtesy of NASA and the University of Miami.


0
50
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Depth m
35.5
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36.5
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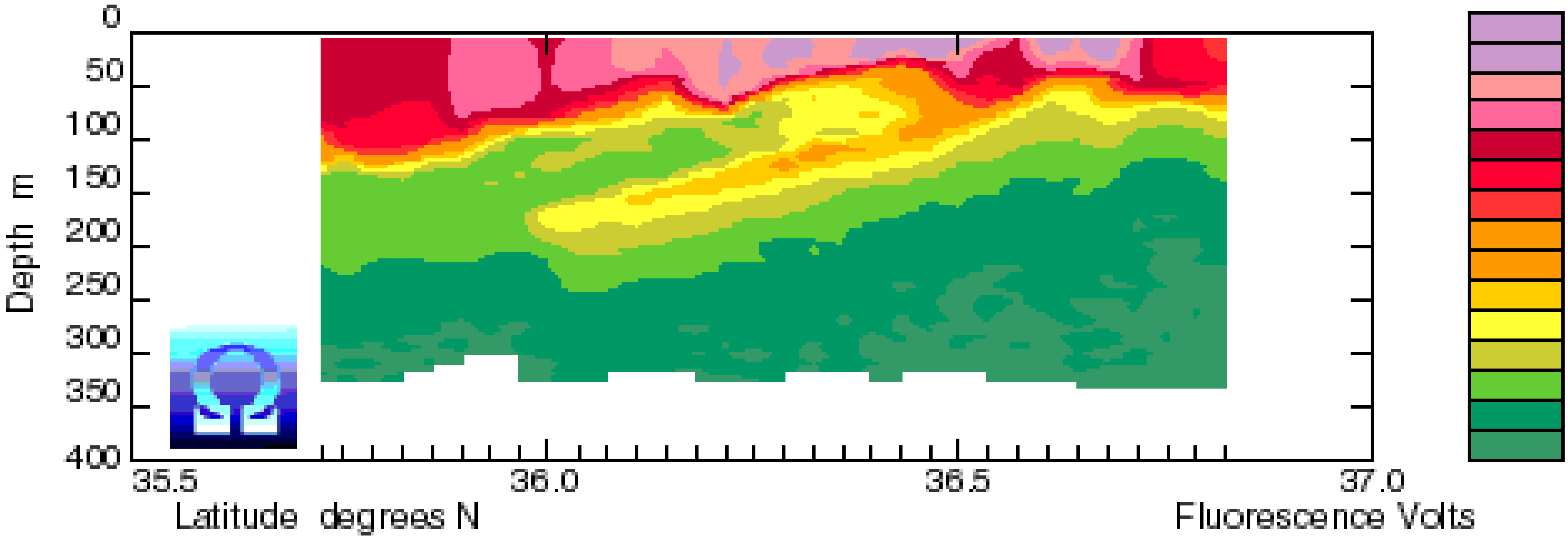
Latitude degrees N
Salinity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Depth m
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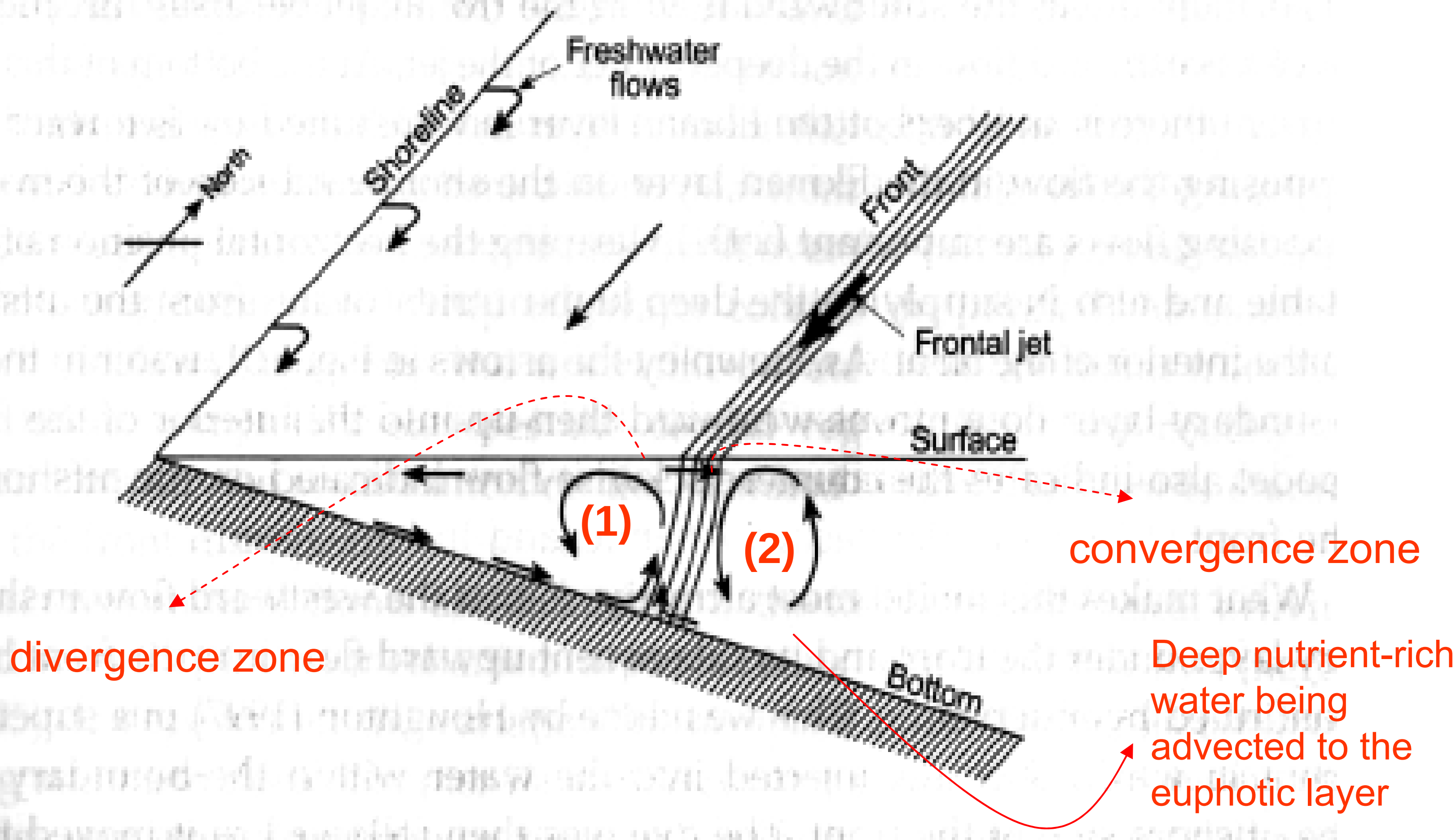
Latitude degrees N
Fluorescence Volts

The Physics of Fronts

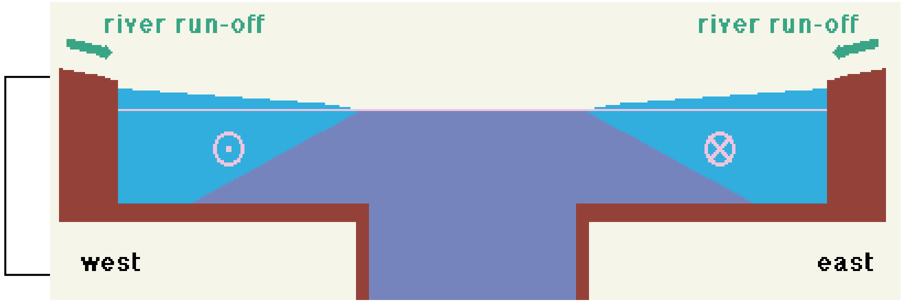


ig. 6.01 Flows associated with a shelf-break front according to the numerical model by hapman and Lentz (1994).

1. Form a jet at the surface with its velocity decreases with depth and reverses direction near the bottom.

2. Current on shoreward of front flows southward with fresher water on its right (in northern hemisphere).

3. Secondary circulations are created on both side of the front.

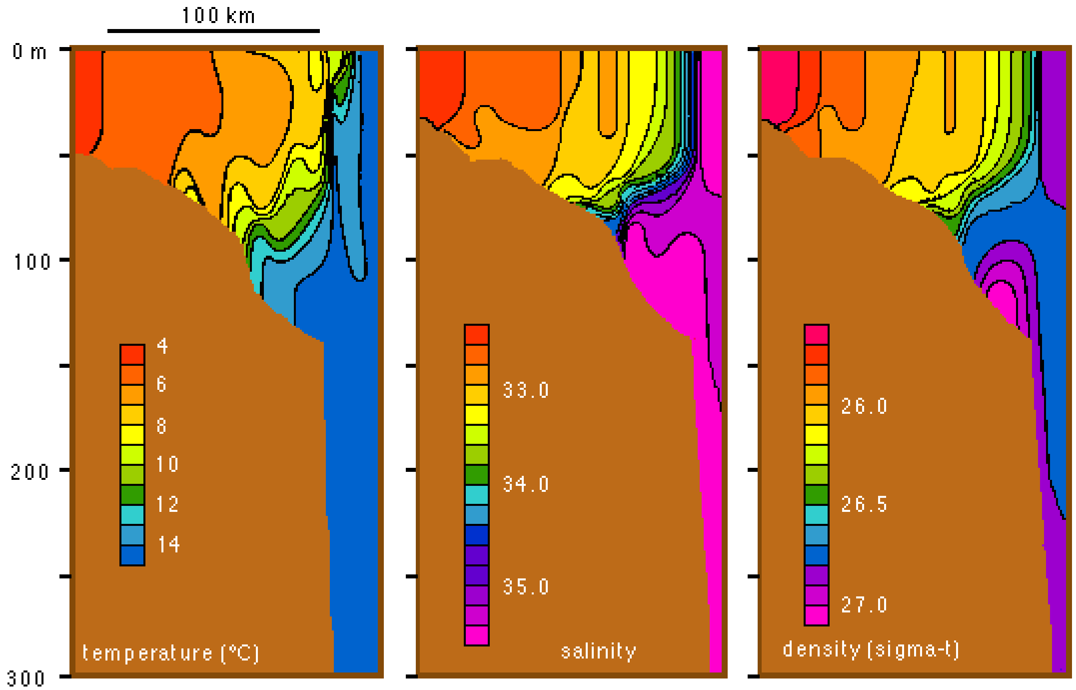


4. On the shore side, 2nd circulation (1) is formed by the northward bottom friction in the southward jet , which creates a eastward Ekman transport at the bottom and compensating flow at the surface.

5. On the offshore side, 2nd circulation (2) is formed because the jet direction is reversed (flows northward) and there is a westward Ekman transport at the bottom and compensating flow at the surface.

(a) Shelf break fronts

- The result of differences in hydrographic properties between the coastal ocean and the open sea
- Geostrophic flow formed by the pressure gradient from two different waters set up a boundary between shelf water and open ocean water and explains the name shelf break front.
- Shelf break fronts are more or less stationary; their mean position is entirely controlled by the location of the shelf break.


100 km
0 m
100
200
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4
6
8
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temperature (°C)
33.0
34.0
35.0
salinity
26.0
26.5
27.0
density (sigma-t)

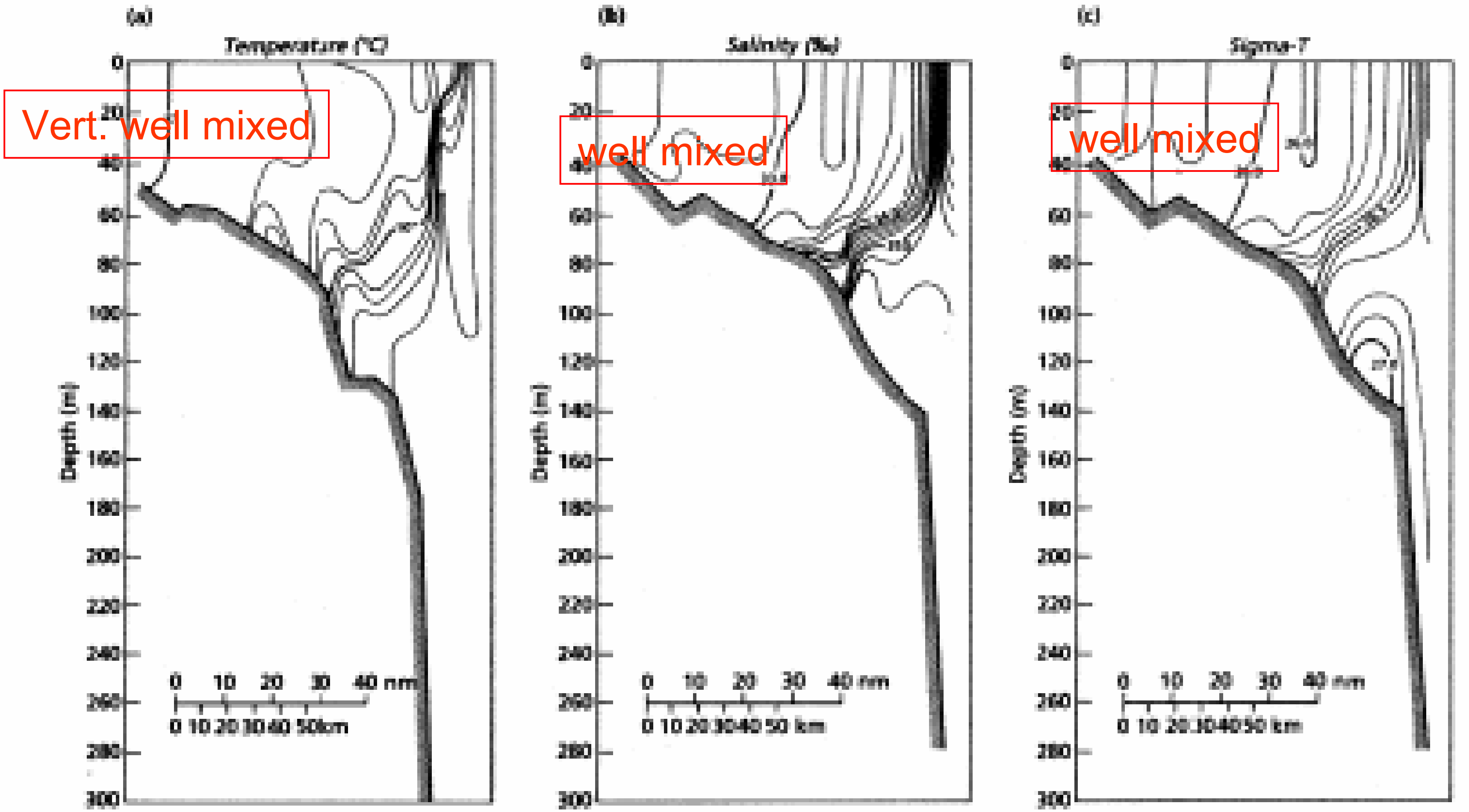


Fig. 6.07 Cross-shelf hydrographic sections south of Rhode Island, United States, April 1974, showing the shelf-break front. From Flagg and Beardsley (1975).

April, Rhode Island

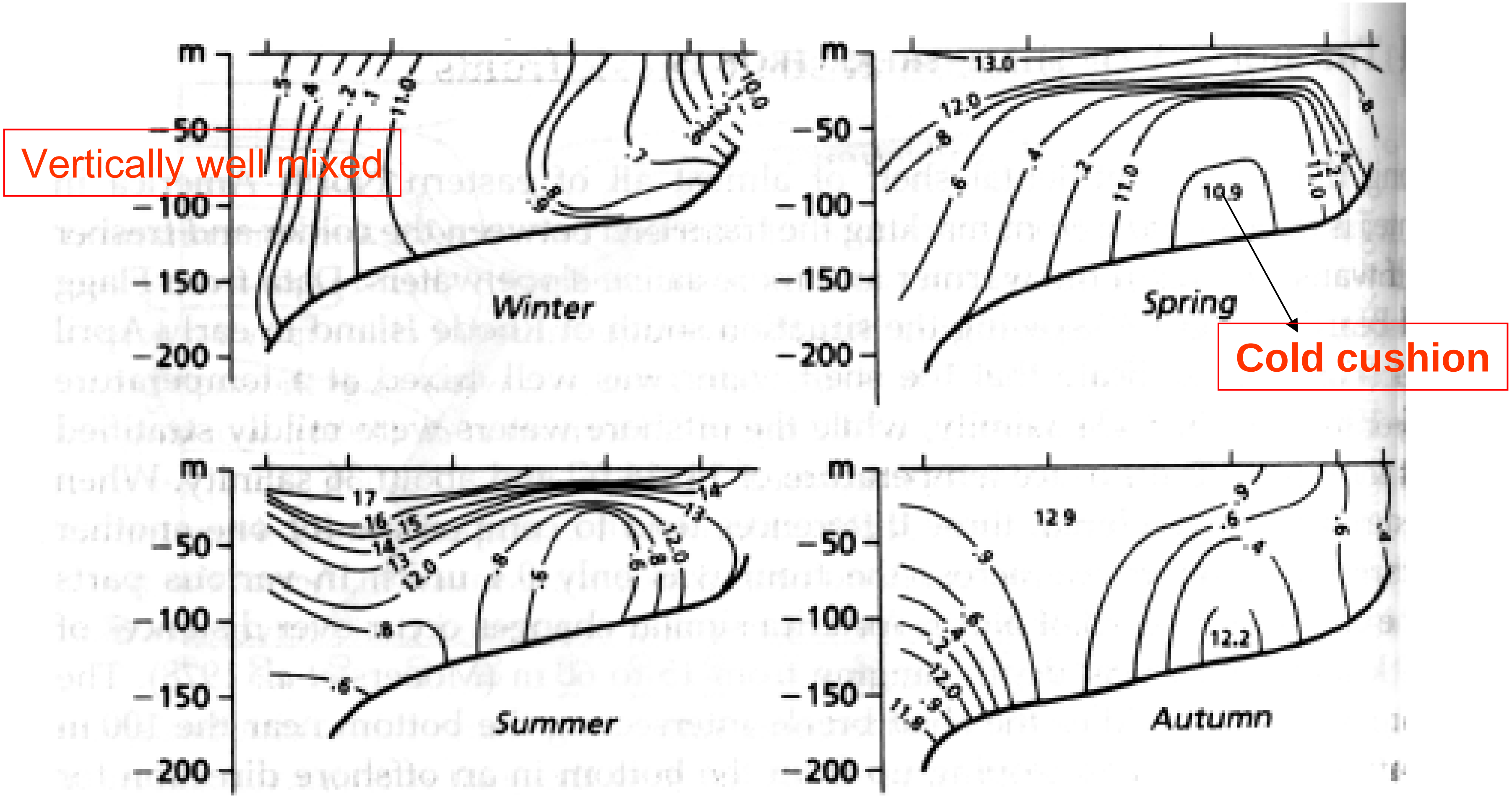


Fig. 6.08 Formation of the "cold cushion" (*bourrelet froid*) on the shelf off Brittany. The structure is visible in spring and becomes warmer and smaller as the seasons advance. Compiled from the data of Le Magueresse and of Vincent and Kurc, by Le Fèvre (1986).

Seasonal variation in northwest Europe

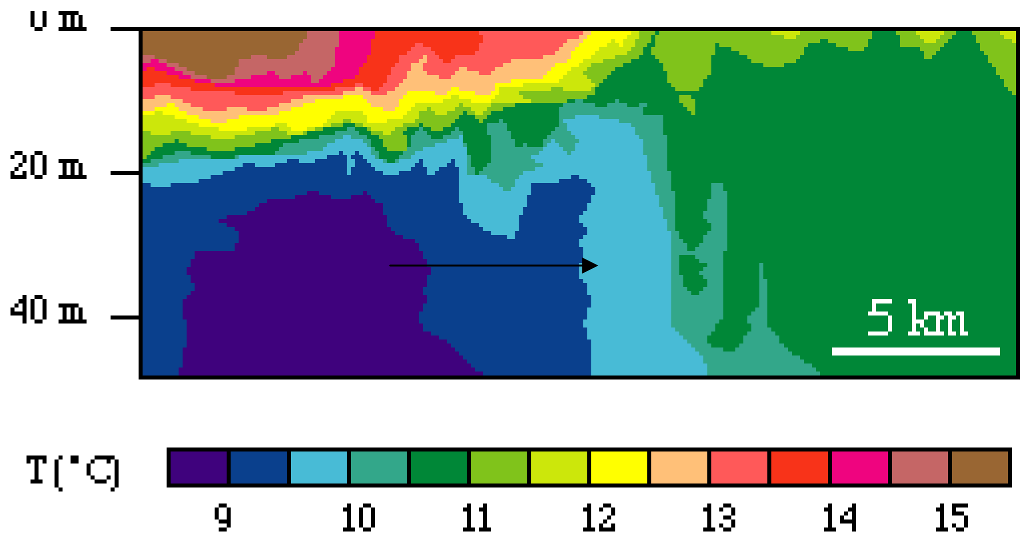
Scale of the front can be estimated by the internal or baroclinic Rossby radius of deformation R_{bc}. The baroclinic Rossby radius is the length scale at which disturbances grow in the oceanic circulation in the presence of stratification. For an ocean consisting of two layers it is given by

$$Rbc=1/f\ (g'D_1)^{0.5}$$

where g = 9.8 m/s^2 is gravity, *f* the Coriolis parameter, D_1 is the upper layer thickness.

(b) Tidal or shelf-sea fronts

- The boundary set up by the heating from atmos. and mixing by the tidal flow is marked by shelf-sea front.



Advance shoreward if tidal strength is weakened

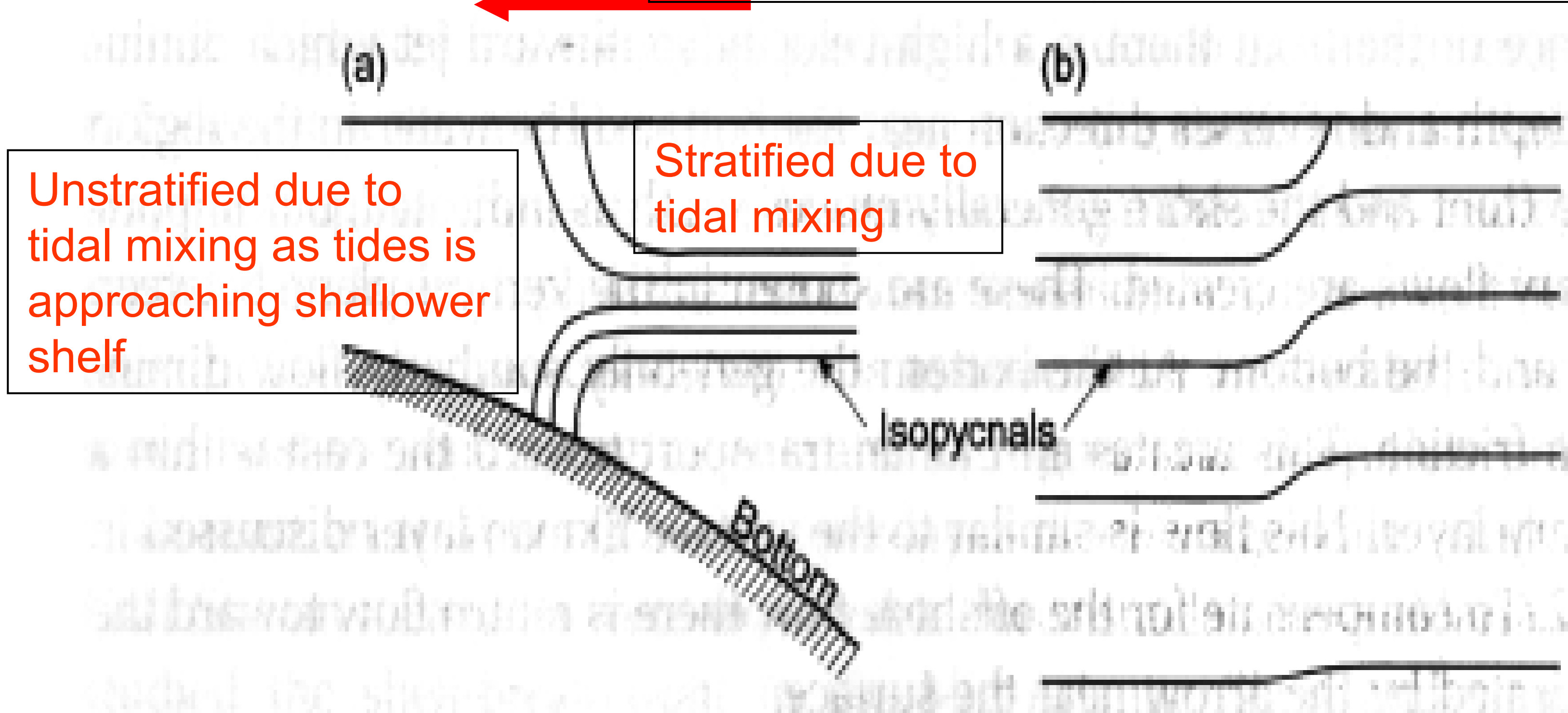


Fig. 6.02 (a) Density section through a tidal front. The region on the left, in the shallower water, is unstratified while the region on the right remains stratified. (b) Density section through a geostrophically balanced current in which the flow is out of the page (in the northern hemisphere) and decreases with depth.

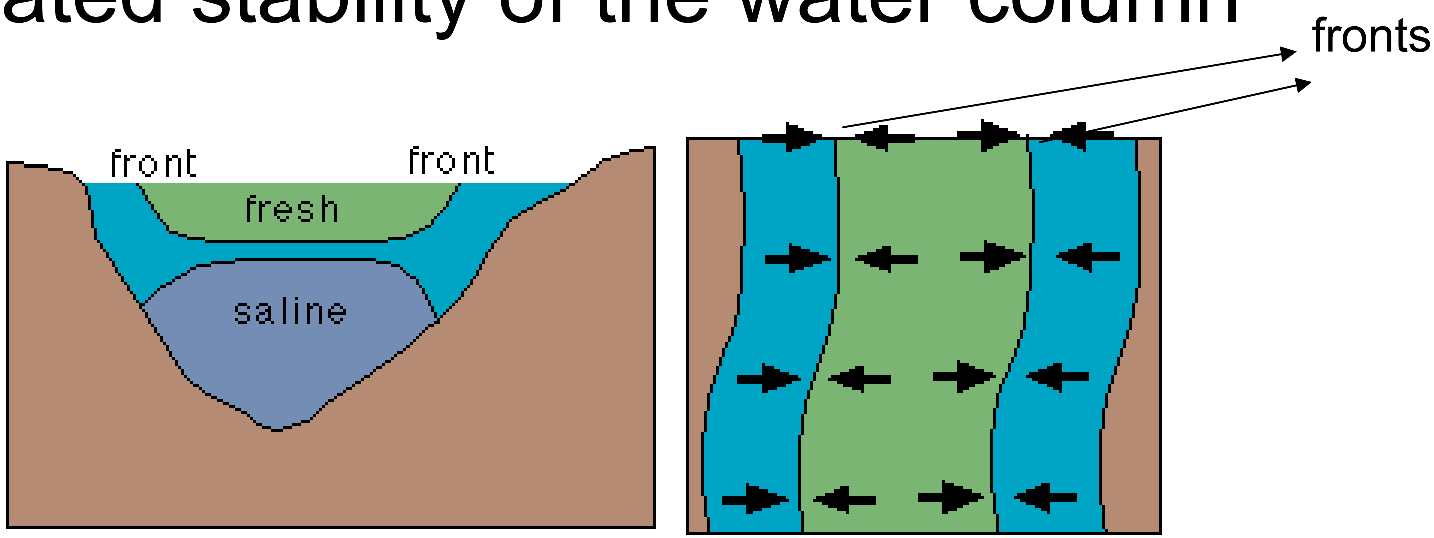
- As one approaches the coastal sea from the deep ocean there comes thus a point where the stratification found in the deep sea can no longer be maintained against the increasingly vigorous tidal mixing.

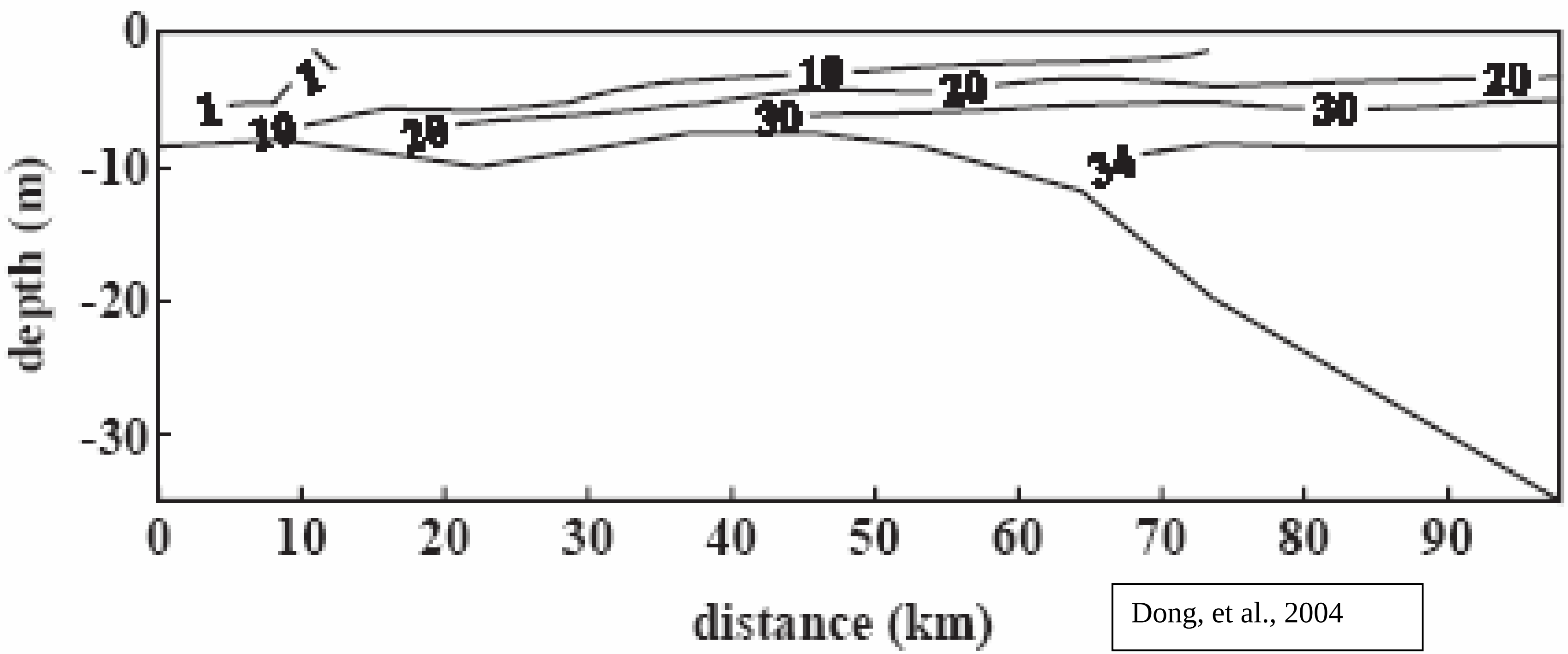
- The front is associated with a density gradient and thus supports a geostrophic jet along it, which causes eddies to form and break off. Like all other fronts it is also linked with a convergence of the surface current.

(c) Fronts in estuaries

- **Plume fronts** form where relatively fresh water reaches the mouth region of an estuary and discharges into the oceanic environment. Front around the plume is strongly convergent and turbulent;
- **Fronts at the interface between tidally mixed and stratified waters** (resembles sea-shelf fronts)

- **Estuarine fronts** a miniature version of the shallow sea front in the sense that tidal mixing competes against buoyancy generated stability of the water column





Dong, et al., 2004

(d) Eddies

$$F_E = \gamma\left(\frac{gD\Delta\rho}{\rho}\right)^{\frac{1}{2}} D\Delta C$$

γ=0.005,D is upper layer thickness,
C is the nutrient.

Eddies: cause water to be exchanged across the front and contribute a significant flux of nutrients (F_E).

The eddies can be generated by the instability at the fronts.

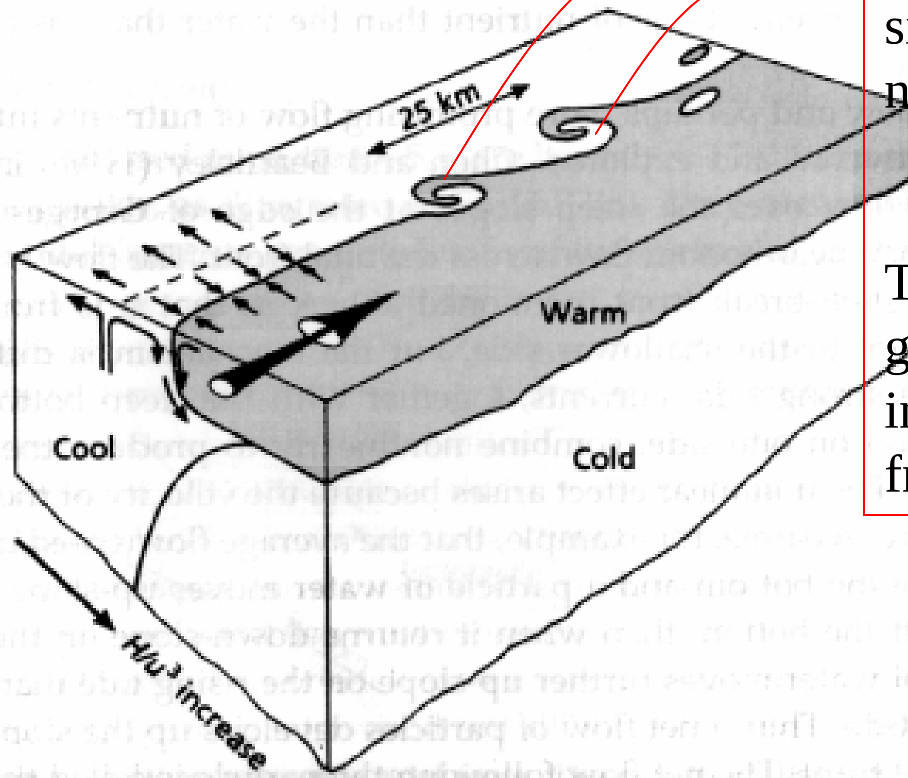


Fig. 6.03 Diagram of the structure and circulation of a tidal front, after Simpson (1981). Note strong along-front mean flow, convergence and downwelling at the front, upwelling on the well-mixed side, and frontal eddies, some of which close on themselves to form isolated patches.

Biology of Fronts

1. The biology of shelf-break fronts

(a) Plankton biomass and production

- Concentration of inorganic nitrate, chlorophyll-a and copepods are found to be much higher at the front than surrounding shelf and slope waters due to the convergence of the waters and upward motion at the front.

- Shelf break fronts show that increased copepod abundance in the frontal region due to the daily augmentation of the nutrients which provides continuously increase in phytoplankton for the copepod population, which is in contrast to the situation at a tidal-mixing front, where the cycle of enhanced production follows the fortnightly cycle of spring and neap tides.

(b) Fish and birds

- The distribution of fish larvae tend to be centered around the shelf-break front.

- The greatest carbon flux to the pelagic food web is found in at the shelf-break front (e.g. in the southeastern Bering Sea) and large concentrations of fulmars aggregate near the front.

- Internal waves often add energy to the mixed layer at the shelf-break fronts, causing a deepening with incorporation of nutrient-rich water from below the nutricline.

2. The biology of tidal fronts

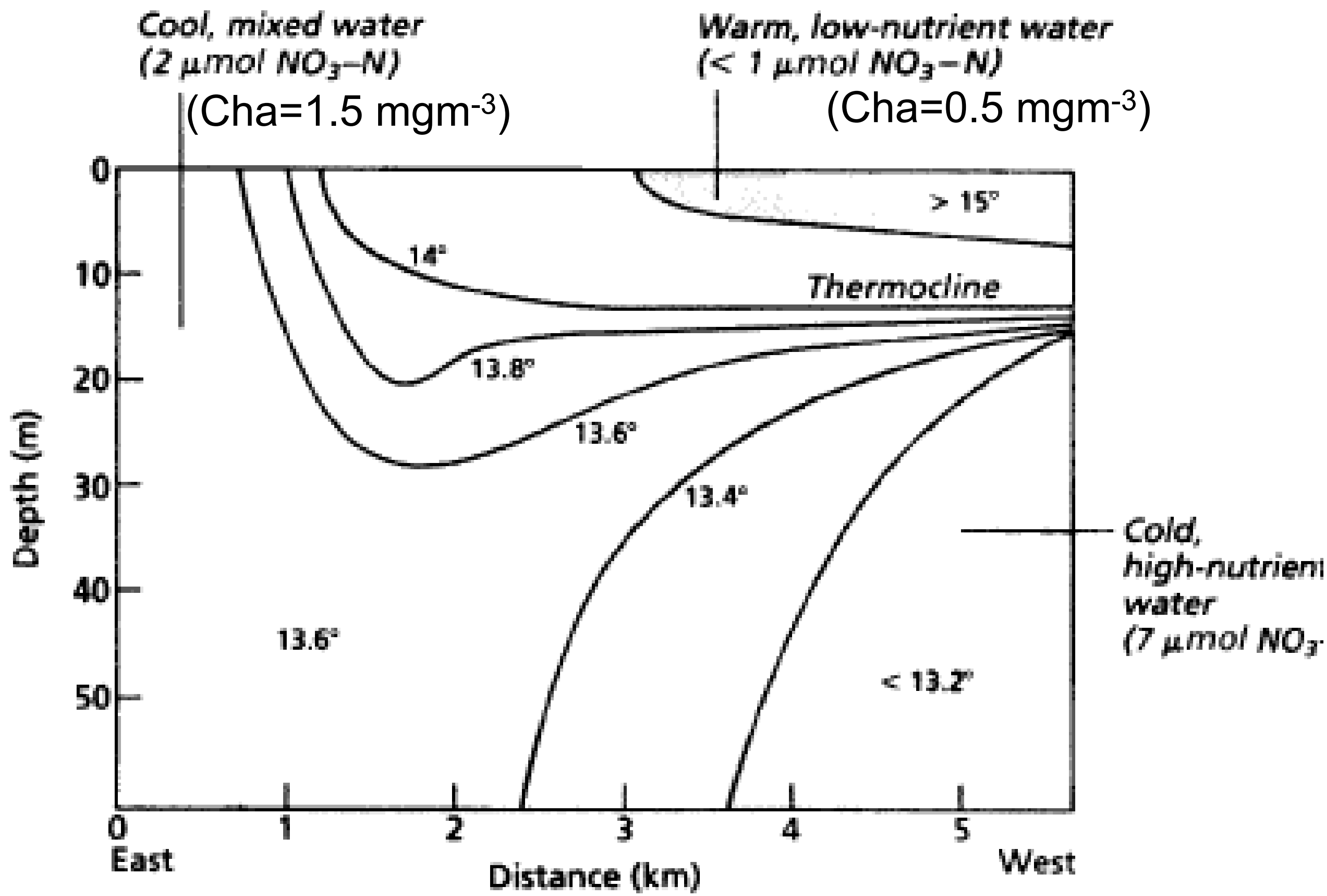


Fig. 6.04 Diagram of the structure of a front in the Irish Sea, based on data in Sin
(1971) and Simpson and Hunter (1974).

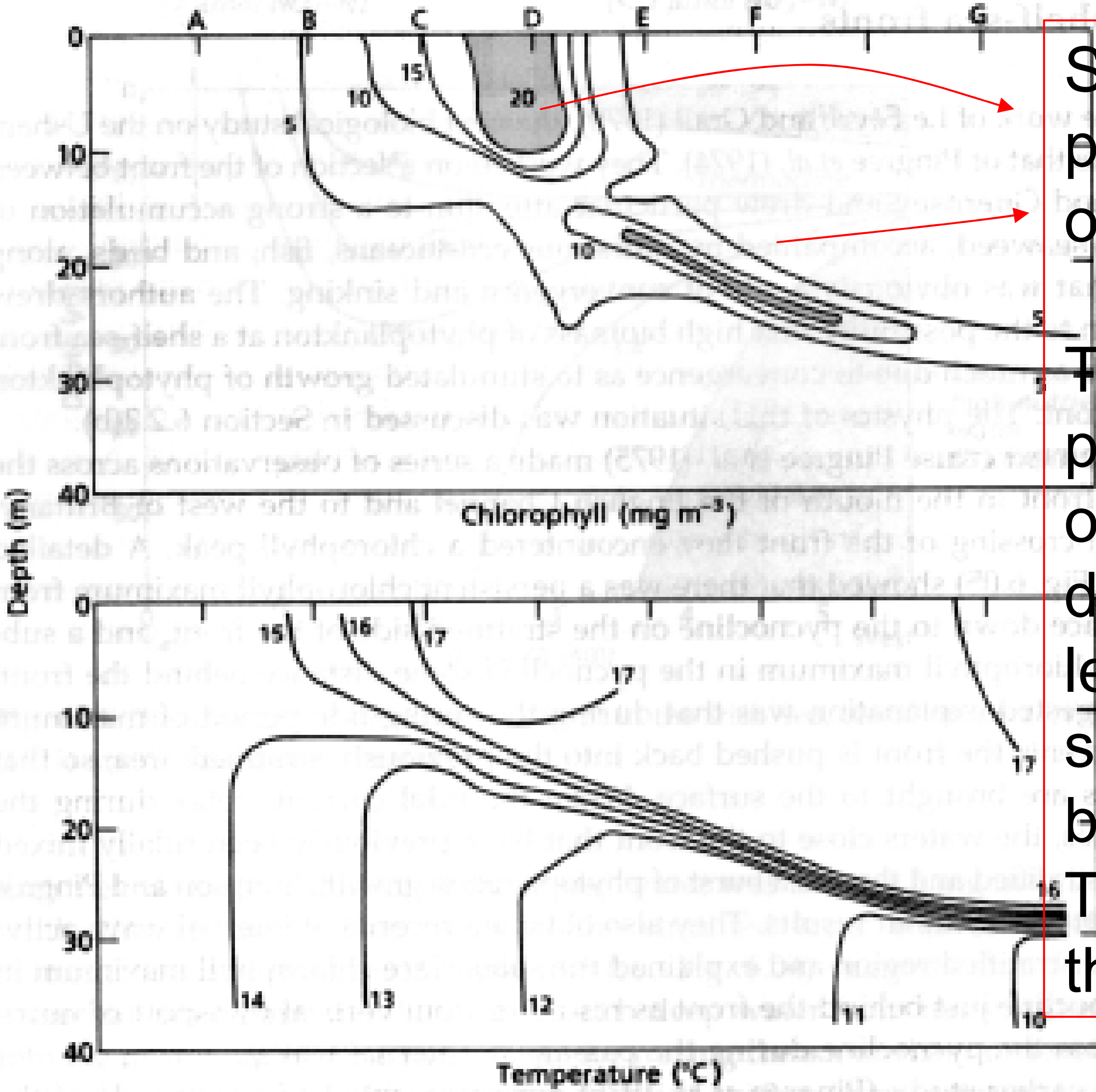


Fig. 6.05 Section through the Ushant front, July 1975, showing a high concentration of chlorophyll near the surface on the stratified side of the front and another high concentration lying just above the thermocline. After Pingree *et al.* (1975).

Subsurface maximum partly due to the passage of internal waves.

The persistent chlorophyll peak is caused by the offshore movement of front during spring tide which leads to the nutrients in the stratified water being brought to the surface. Thus, it forms bloom during the subsequent neap tids.

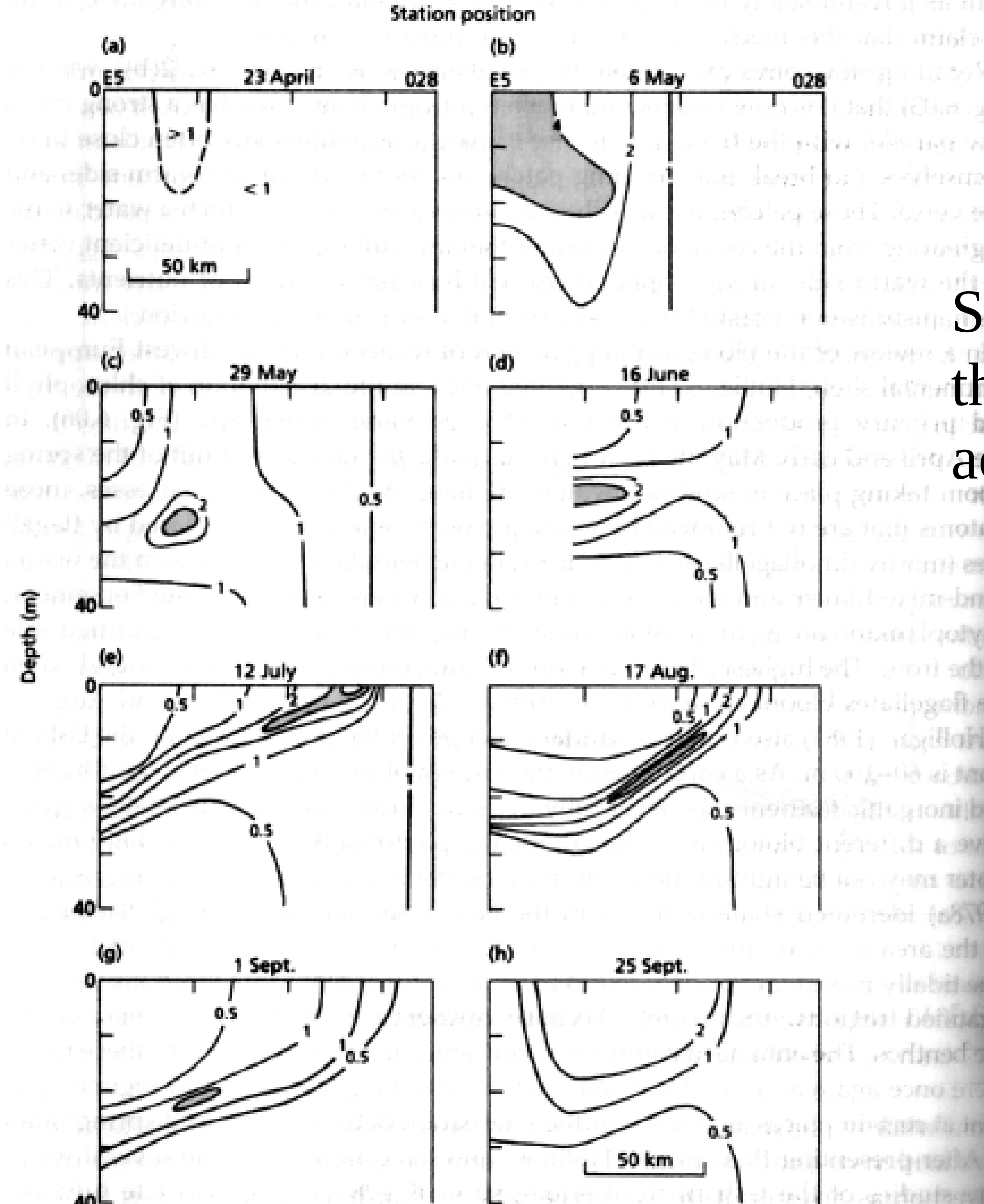


Fig. 6.06 Distribution of chlorophyll-*a* (mg m^{-3}) across the Ushant tidal front on dates given. From Holligan (1981).

Seasonal variation of the Chlorophyll0-a across a front

Remarks:

The dense phytoplankton patches on the sea-shelf fronts is induced by:

(1) Convergence flows which converges the surface high biomass of phytoplankton towards fronts,

(2) Transport of nutrients into the mixed layer of the stratified zone adjacent to the front by:

(a) Spring-neap tidal cycle.

Spring tide-strong mixing with high nutrients-offshore advance of fronts-Neap tide-weak mixing-onshore advance of fronts-bloom of previous high nutrient waters

(b) Baroclinic eddies.

‘Baroclinic’ means density-related. The transport of nutrient across front.

(c) Vertical transport.

$$F_V = K_V\left(\frac{\Delta C}{\Delta Z}\right)L_W$$

K_V: vertical eddy diffusivity (10^{-4} m^{-2} s^{-1}); L_W: the cross-fontal distance.

In general: effect (c)>effect (a)>effect (b)

3. The biology of upwelling fronts

Enhanced biological productivity, high concentration of zooplankton

High nutrient, but light penetration is limited

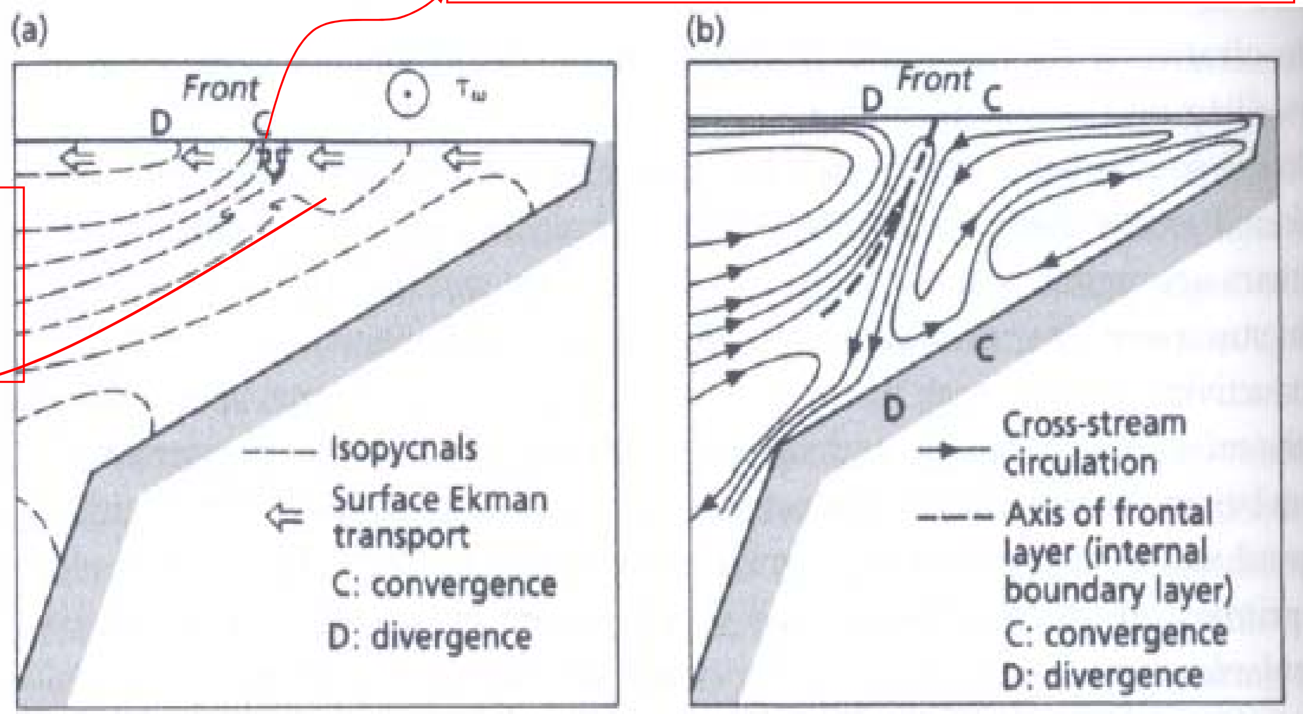


Fig. 6.10 Conceptual model showing (a) density field and (b) cross-shelf circulation in the vicinity of an upwelling front. From Mooers *et al.* (1978).

Thus, across frontal nutrient transport will be crucial to form high productivity

5. The biology of fronts associated with geomorphic features

Surface-dwelling planktonic organisms tend to aggregate here.

Enhanced phytoplankton growth in the regions with irregularities in the sea bed, coastline due to flow-geomorphic interaction.

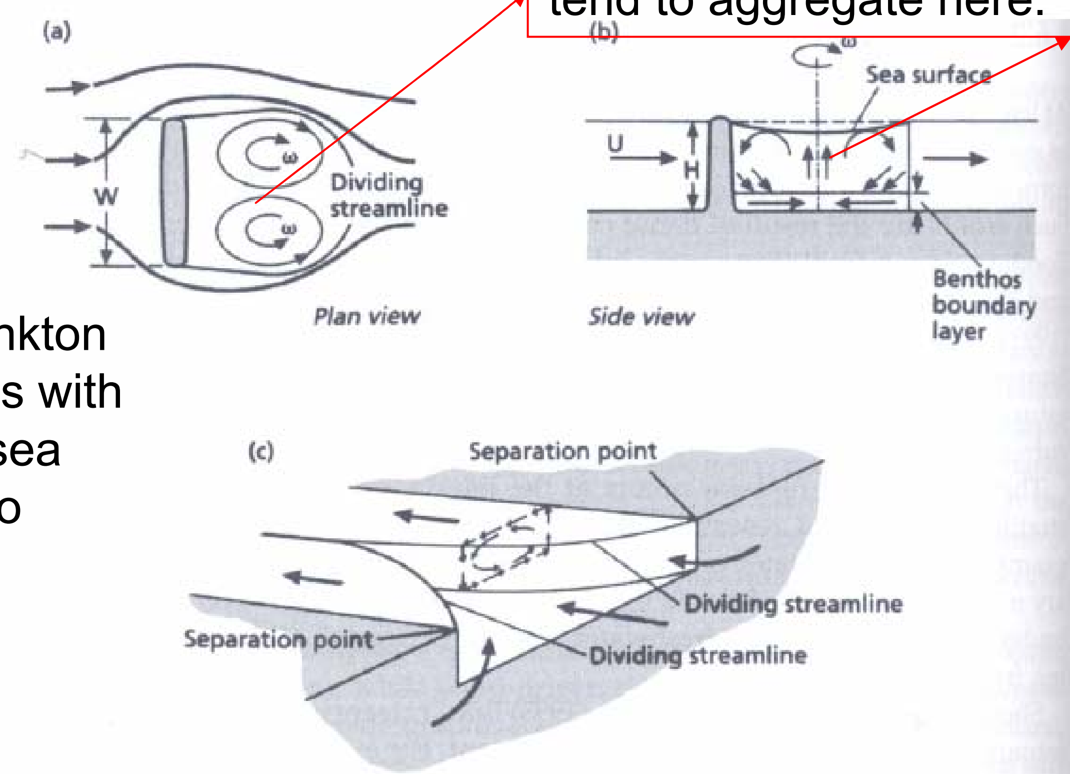


Fig. 6.11 (a) Plan of a commonly occurring flow pattern around a reef in shallow coastal water, showing the front (labeled dividing streamline) separating the area of turbulence in the wake from the less turbulent area beyond. (b) Vertical section showing upwelling produced by the clockwise (southern hemisphere) gyre. (c) Formation of turbulent-mixing region as a tidal stream enters a reef passage. For details see text. From Wolanski and Hamner (1988).

Summary of mechanism that enhanced biological production at the fronts

- 1. The spring-neap tidal cycle. At a fixed point, water may be tidally mixed at one stage of tidal cycle and stratified at another. Nutrients are brought up during the mixing phase and utilized in the upper mixed layer during the stratified phase (see example before).

- 2. Cross-frontal transport. Mechanism that transfers nutrients from the tidally mixed side of the front (phytoplankton is light-limited) to the stratified side of the front. The mechanism can be due to baroclinic eddy.

- 3. Vertical transport. Frontal zone is favorable for the vertical transport of nutrients through the front to the stratified water above, which enhances phytoplankton in the immediate vicinity of the front.