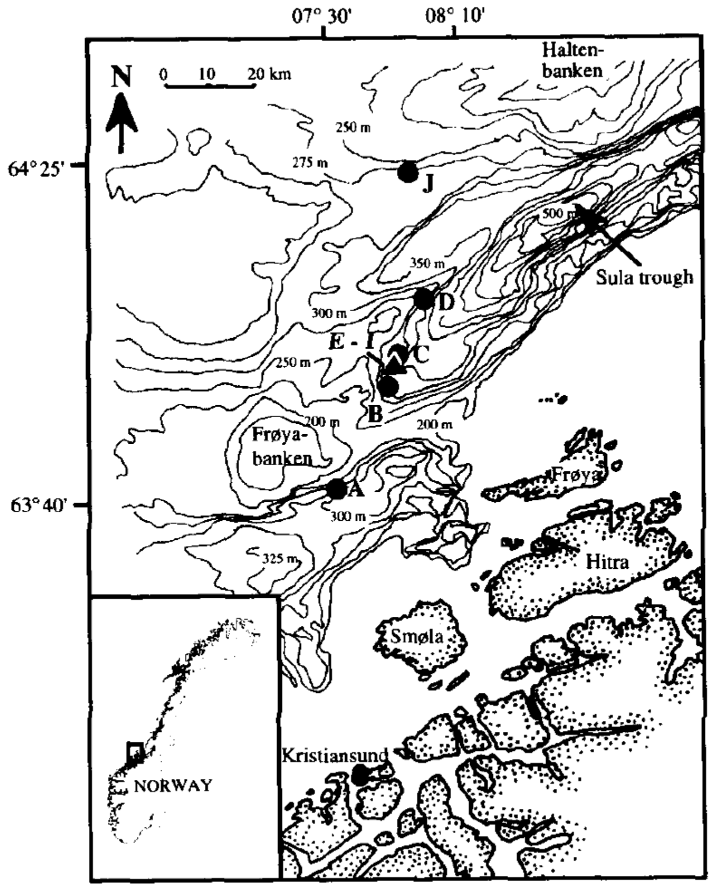
Figure 24: Map of the Haltenbanken-Froyabanken area with coral areas investigated by Mortensen *et al.,* 1995)



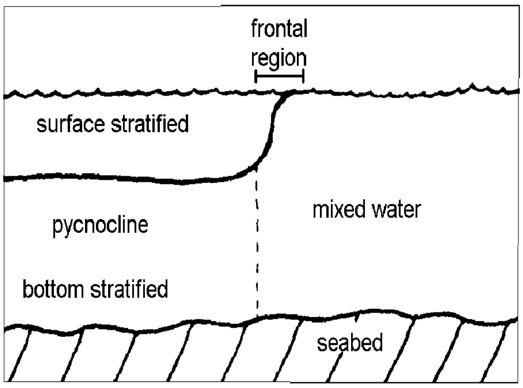
2.6 FRONTS

Fronts are distinctive oceanographic features that mark the boundaries between water bodies with different characteristics. They are lateral zones above or below which there is localised and sometimes vigorous vertical movement of water. Fronts can form at salinity boundaries or where there are temperature differences between two water masses. They may also be caused by topographic features both above and below the surface. The best known fronts are tidal fronts, shelf-break and upwelling fronts, and estuarine fronts which form in coastal areas but deep sea fronts, which form in the open ocean, have also been described (Owen, 1981). Where fronts are vigorous for their size or meet an obstacle, flow becomes unstable and frontal meanders may pinch off and become eddies (see section 2.7).

Fronts occur on a number of scales. They may only be a few meters in extent and persist for hours or, at the other extreme, they may extend for thousands of kilometres and persist for years. The temperature differences which cause tidal fronts are related to the amount of mixing that takes place within coastal and oceanic waters. Coastal waters are greatly influenced by tides and this, combined with their shallow nature, mixes the system. In oceanic waters where tidal stirring is weak, the water column is poorly mixed so during the summer months the upper layers are warmed but remain isolated from the cold bottom waters. The boundary between the upper and lower layers, where the temperature change is greatest, is known as the thermocline, the presence of which indicates that the water has become stratified. Well-mixed waters do not show such marked temperature changes and remain cool throughout. Where these two types of water body meet there is a marked difference in the temperature of surface waters creating a front.

Three distinct water masses can be identified around tidal fronts: surface stratified water, bottom stratified water and mixed water (figure 25) Apart from temperature differences, nutrient levels vary in the vicinity of coastal fronts. The well-mixed coastal waters are rich in nutrients derived from recycling in the sediments, whereas oceanic waters, following nutrient depletion in the spring bloom of plankton are relatively sterile (Beardall *et al.*, 1982).

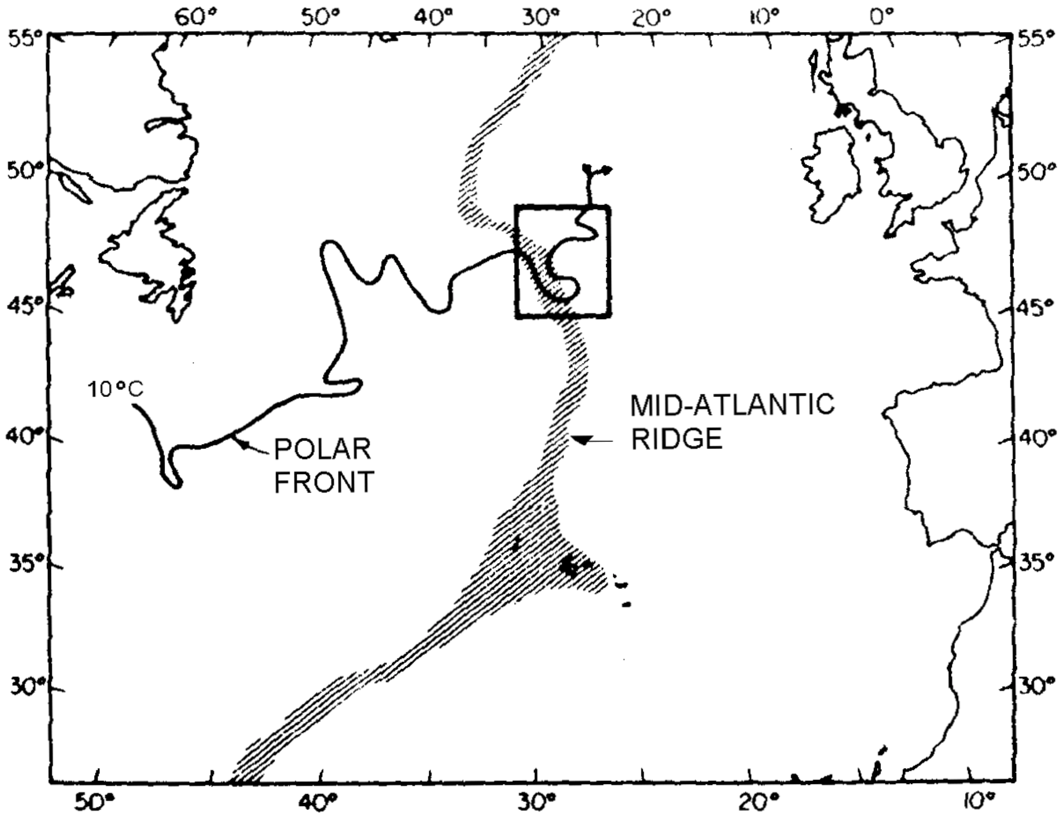
Figure 25: Cross-section through a tidal front showing different water masses (from Fogg *et al.,* 1985)



Another area where fronts form is where the gradient of the continental shelf steepens to become the continental slope. These fronts either separate more saline shelf water from offshore water and arise by upwelling on the continental shelf, or separate less saline shelf water from offshore water and are the result of shelf-water dilution from terrestrial runoff and thus predominate off large coastal watersheds (Owen, 1981). An important aspect of upwelling fronts is their periodic relaxation or breaching and subsequent release into offshore water of nutrients and plankton previously accumulated in the shelf water. This will take place if the upwelling ceases which might occur seasonally or episodically.

Deep sea fronts tend to form when waters of different mixing histories meet. The North Atlantic polar front, which is the product of the seaward extension of the Gulf Stream axis into mid-Atlantic, is one example. This front is defined by the large temperature gradient between cold shelf or sub-Arctic water to the north, and warm Sargasso seawater to the south. There is a marked weakening of the temperature and salinity gradients of the front in the vicinity of the mid-Atlantic Ridge which also causes it to meander at this point (figure 26).

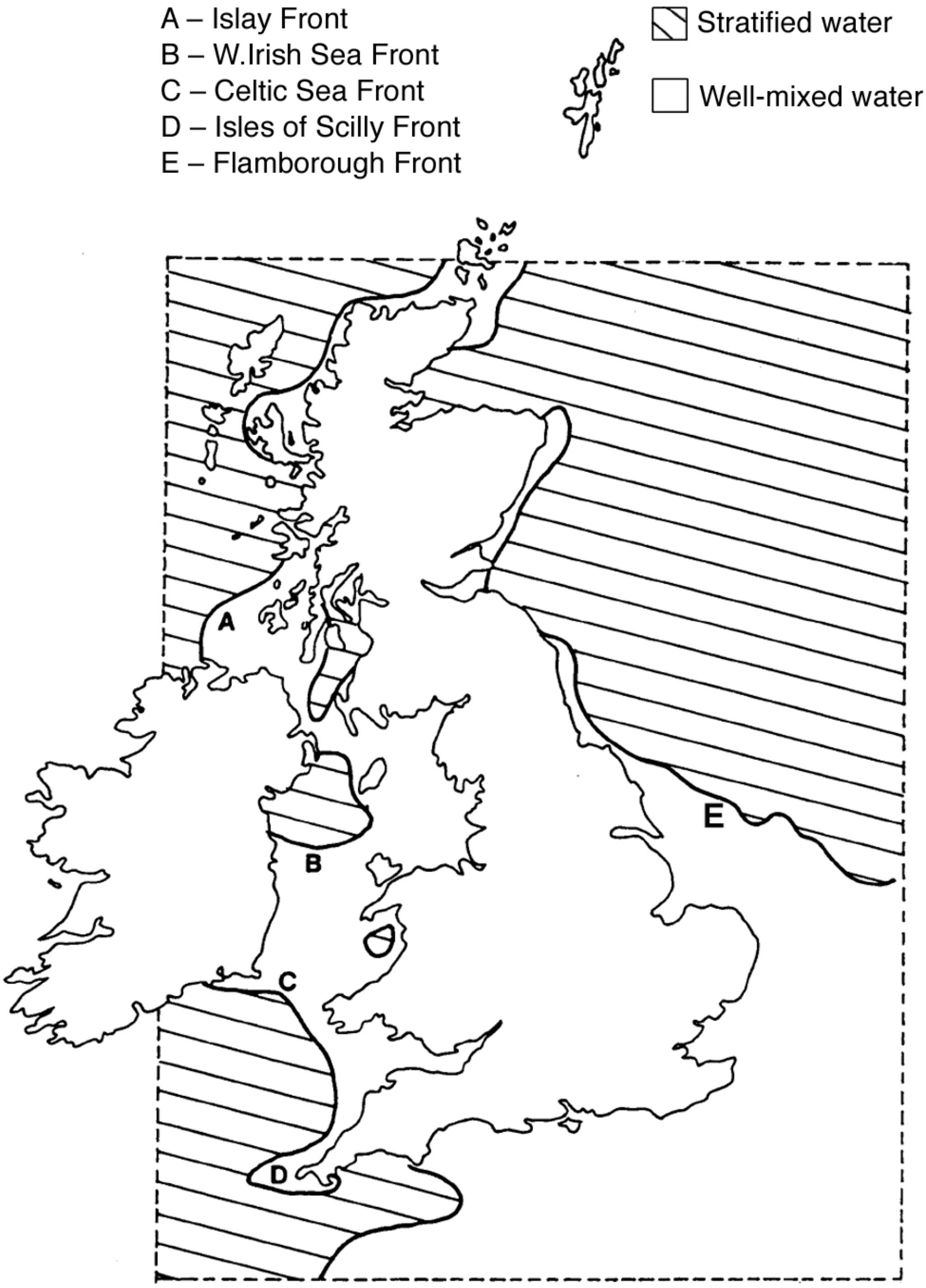
Figure 26: The oceanic polar front (from Dietrich, 1964)



2.6.1 Occurrence in the OSPAR maritime area

Each summer, tidal fronts develop in specific locations which are remarkably constant from year to year. Once developed they are also virtually static (Simpson, 1981). Infra-red satellite imagery has revealed the extent and location of fronts and research vessels have recorded temperature differences of as much as 1°C/m across them (Lee & Ramster, 1981). The positions of the main fronts, which form around the British Isles, are shown in figure 27. Other examples are the fronts which form off the coast of southern Norway, in the vicinity of the shelf-break to the west of Ireland and along the Iberian margin where a permanent subsurface front appears to be present off Cape Finisterre and convergent fronts close to the coast including off Cape Oretgal (Bode *et al.*, 1996).

Figure 27: Fronts which form around the British Isles (from Lee & Ramster 1981)



2.6.2 Marine communities associated with fronts

At a front where the two water bodies meet and where the thermocline is at the surface, eddies and upwellings release nutrients into the surface waters. This availability of nutrients combined with the greater light levels increases phytoplankton production in these areas (Beardall *et al.*, 1982). Zooplankton concentrations have also been observed in these areas. These concentrations are exploited by fish, which appear to congregate near fronts and they, in turn, provide food for birds such as puffin, shearwater and tern which may also concentrate their feeding activity in these areas (Pingree *et al.*, 1974). Rees & Jones (1982) for example recorded rafts of Manx shearwater and razorbill in the immediate vicinity of the western Irish Sea front, whereas there were virtually none of these species in the mixed water areas away from the front. They suggested that the shearwaters were taking advantage of the fact that food concentrated above the thermocline was more accessible, and that the razorbills had easier access to sub-thernmocline food in the vicinity of the fronts.

A more recent study analysed the distribution of seabirds in relation to sea surface temperature and salinity which were taken as markers of the surface features of the Irish Sea front (Begg & Reid, 1997). This confirmed the importance of the area for seabirds as it revealed that Manx shearwater occurred in disproportionately high numbers at the surface expression of the front where the horizontal temperature gradient was greatest. Guillemot and razorbill distributions were more closely related to sea surface salinity. They expressed the view that the distribution of the birds is probably directly related to the distribution of their prey rather than to physical features of this environment.

Marine mammals are also known to exploit the biota of tidal and other fronts. Gaskin (1976) cited feeding by minke whales on herring or capelin aggregated in coastal tide slicks of eastern Canada and fin whales feeding on surface concentrations of euphausiids in a convergence in the Bay of Fundy which had been forced to the surface by mackerel schools. Deep sea fronts also appear to be ‘hotspots’ for marine life. Species which have been reported in high concentrations at various deep sea fronts include squid, flying fish, lantern fish and albacore tuna (Owen, 1981).

The localised enrichment at fronts may also affect the benthos. Investigations of the sea-bed around the western Irish Sea front revealed particularly dense beds of the tubes of the polychaete *Ampharete falcata* (approx 3,000/;m^2) with considerable numbers of *Parviardium ovale* (around 27,000/m^2), *Nucula tenus*, *Abra nitida*, *Pandalus montague* and *Crangon allmani* (Holme & Rees, 1986). This unusual and rich community was restricted to a narrow band of depth and distance.

2.6.3 Conservation issues

The formation, persistence and location of fronts has important ecological implications (box 5). The enhanced productivity and concentration of marine life in these areas makes the associated communities particularly vulnerable to exploitation as well as impacts which might be focused in these areas such as pollution incidents and accumulation of marine litter in the vicinity of fronts which may have a disproportionate impact because of the focus of marine life around fronts.

BOX 5: Ecological effects of fronts and eddies (from Owen, 1981)

Mechanically affect local concentrations of organisms
Juxtapose populations that would not other wise interact
Create new ‘communities’
Conserve and translocate selected species ensembles and concentrations
Attract and sustain large motile animals
Serve as reproduction refuges
Mechanically limit dispersal of meroplankton or neritic populations
Induce/sustain higher local production of organisms
Modify migration patterns as diverse as annual, trans-oceanic
fish movements and diel vertical migrations of motile phytoplankton
Collect surface active and particulate substances.

2.6.4 Conservation actions

Frontal systems are difficult habitats on which to focus conservation measures because they are water column features and also because they are not necessarily present all year round. Because of this, general measures to safeguard water quality where these features form will be important, particularly as pollutants could be retained within frontal systems. The regularity of the occurrence of some fronts in the same location presents the possibility of site protection as well. Measures could be introduced to minimise the risk of pollution incidents by siting offshore operations away from such features or introducing ship’s routeing measures for example, or ensuring that fisheries are not concentrated in these areas. One such site which has been well studied and could be considered as a potential marine protected areas is the western Irish Sea front (Gubbay, 1996).

Western Irish Sea front

The western Irish Sea front forms every year in the late spring (March/April) and persists through the summer until September or October. It marks the boundary between tidally mixed water, to the south-east, and stratified water to the north-west. The front remains in a relatively static position throughout the summer and develops particularly well along the southern and eastern edge. The surface stratified waters appear to be an area of intense biological activity, especially where the front meets the coastal current off the Kish Bank on the Irish coast (Beardall *et al.,* 1982). The regular supply of organic material sinking onto the sea-bed may have enhanced the local richness of the benthos while on the surface the front attracts Manx shearwaters, razorbill and guillemot to feed. Basking shark have also been reported concentrating feeding activity along the front.

2.7 EDDIES

Eddies are localised zones of horizontal water circulation in a relatively closed system where vertical motion is induced or sustained. The vertical water movement compensates for lateral flow into or out of the circulation and is upward in cyclonic eddies and downward in anticyclonic eddies. Another distinction is that cyclonic eddies have cool core temperatures whereas the core in an anticyclonic eddy is warm. The upward water movement in large cyclonic eddies has been estimated to be of the same order as sinking rates of some phytoplankton and detrital particles and on a scale that can transport substantial nutrient