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A HYPOTHESIS ABOUT DISCONTINUITY LAYERS

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A HYPOTHESIS ABOUT DISCONTINUITY LAYERS

During the summer very sudden vertical changes in temperature are often observed and this feature is usually called a discontinuity layer. In the North Sea, it can be of the order of 5°C in less than 2 m and a good indication of its distribution is given by Dietrich (1954), Fig.1. His results show that the discontinuity can be just as strong in comparatively shallow water of 50 m as in the deeper water to the north of the area. In particular, in the southern area called the Austern Grund, there seems to be either a sharp thermocline or none at all.

Such marked changes seem rather at odds with the usually expected effects of turbulence in a region where there can be considerable tidal and wind mixing since these could be thought to produce a more gradual gradient of temperature. This expectation of a shallow slope to the thermocline depends on the assumption that vertical mixing must everywhere tend to lessen the steepness of the thermocline. If, however, vertical mixing increased the slope under certain conditions, then a mechanism would exist which would lead to the formation of discontinuity layers. It is the purpose of this note to suggest that such a mechanism seems possible within the accepted ideas about the relation between vertical mixing and stability.

It is generally assumed that for a given velocity gradient there is a level of stability above which turbulence is inhibited (Sverdrup, Johnson & Fleming, 1942, p.476). As no adequate form is known for the relationship between turbulence and stability, the simplest method is to assume a linear relation. Also, for simplicity, temperature rather than density changes will be considered. On this basis the coefficient of eddy conductivity, A_T , takes the form

$$\frac{A_T}{\rho} = a + b \frac{\partial T}{\partial z}, \quad 0 \leq -\frac{\partial T}{\partial z} \leq \frac{a}{b} \quad (1)$$

$$= 0, \quad -\frac{\partial T}{\partial z} > \frac{a}{b}$$

where a and b are positive functions of the velocity gradient.

The equation governing the turbulent mixing of temperature is generally taken to be the simple "momentum" form,

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial z} \left(\frac{A_T}{\rho} \frac{\partial T}{\partial z} \right) \quad (2)$$

but it should be remembered that the application of this to conditions of great stability is rather doubtful.

Using (1) and (2), and assuming that the velocity gradients change slowly,

$$\frac{\partial T}{\partial t} = (a + 2b \frac{\partial T}{\partial z}) \frac{\partial^2 T}{\partial z^2} \quad \text{for } 0 \leq -\frac{\partial T}{\partial z} \leq \frac{a}{b}$$

$$= 0 \quad \text{for } -\frac{\partial T}{\partial z} > \frac{a}{b}$$

Consider now a typical thermocline as shown by the continuous line in Fig.1, where z_0 is the depth of the point of inflection. In the region below z_0 ,

as $z \uparrow$, $\frac{\partial T}{\partial z} \uparrow$

and $\frac{\partial^2 T}{\partial z^2} > 0$ except at z_0 where $\frac{\partial^2 T}{\partial z^2} = 0$

Suppose that at z_0

$$\begin{aligned} & -\frac{g}{2b} < -\frac{\partial T}{\partial z} < \frac{g}{b} \\ \text{then } & \frac{\partial T}{\partial z} > 0 \quad \text{for } -\frac{\partial T}{\partial z} < \frac{g}{2b} \\ & \frac{\partial T}{\partial z} < 0 \quad \text{for } \frac{g}{2b} < -\frac{\partial T}{\partial z} < \frac{g}{b} \\ \text{and } & \frac{\partial T}{\partial z} \rightarrow 0 \quad \text{as } z \rightarrow z_0. \end{aligned}$$

Thus the change in temperature must be towards the broken line in Fig.2. By similar reasoning, if there were no interchange of heat through the sea surface, then there will be a similar type of change from the surface to z_0 . The combined result is that in the neighbourhood of z_0 there is an increase in the steepness of the thermocline. Obviously further changes will tend to increase the steepness of the thermocline even more.

In this model therefore it is not necessary that stability should occur initially for the discontinuity to develop in this way; all that is required with these particular conditions is that the steepness of the thermocline should be at least half that at which stability would occur. Again, for this model, the value of a half is critical since above it mixing will tend to produce a discontinuity layer while below it mixing will tend to eliminate the thermocline.

In the shallower parts of the North Sea such a tendency to extremes appears to occur (for this region there will often be a salinity gradient which will help to increase the stability but which will not alter the principles discussed here). The possible explanation of this is that in early summer there is a relatively calm period when the velocity shears are low. In some areas the thermocline will be sufficiently steep to produce an accelerating process towards a discontinuity which cannot be broken down by later increases in mixing; in other areas, with a smaller thermocline, mixing will tend to lessen the slope and later mixing will carry this on to give vertical homogeneity. In this way the situation found in Dietrich's chart between Dogger Bank and Terschelling will be produced.

This hypothesis about discontinuity layers is based on what is probably a far too simple linear relation between mixing and stability with zero turbulence at a particular value of stability. It is intended merely to indicate the direction which temperature changes may possibly take under these types of conditions. In reality the situation will be far more complex and this model may be invalidated by other factors neglected here. One of these has been mentioned already; it is the effect of varying velocity gradients which probably approach their maximum at the maximum stability thus tending to prevent a reduction in turbulence. Further, the fact that in a density gradient the coefficient of eddy conductivity is lower than the coefficient of eddy viscosity (Taylor, 1931) may also prevent the occurrence of a sufficiently low level of mixing. Yet a postulate seems necessary to explain the presence of a discontinuity layer and perhaps also the similar pattern found laterally in the Pacific and termed an "oceanic front" (Cromwell & Reid, 1956). This one is given in the certainty that others will improve on it.

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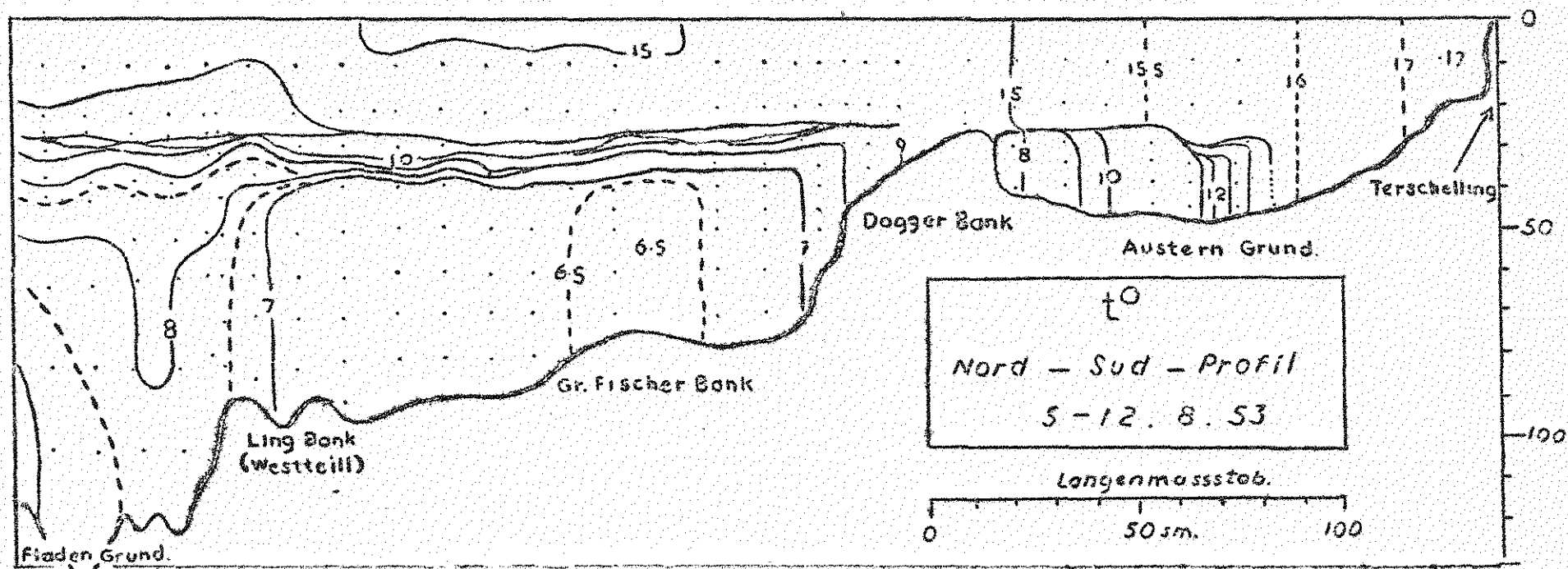


FIG. 1. (modified from Dietrich, 1953, Fig.5)

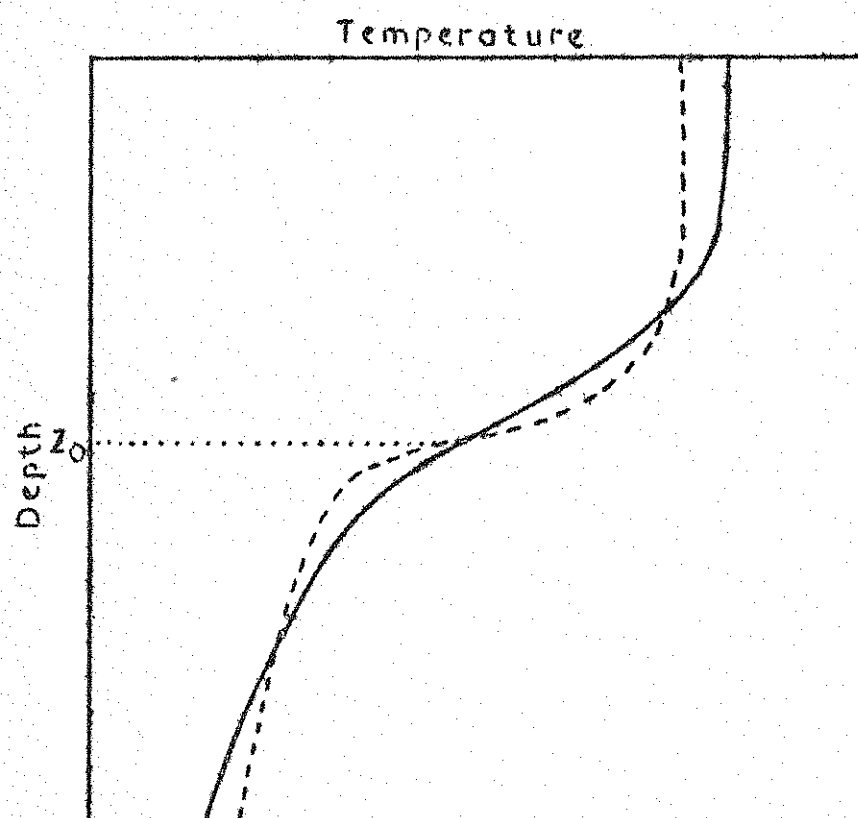


FIG. 2.