

# Influence of Suspended and Dissolved Matter on the Transparency of Sea Water

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## Abstract

The transparency at different levels in the sea as recorded by means of a transparency-meter is compared with the distribution of suspended particles studied with the aid of a Tyndall-meter. A simple procedure is used to distinguish between different components of light extinction and to derive values of the content of the dissolved yellow substance. The distribution of yellow substance is illustrated for the transition area between the Baltic and the Skagerrak and for the outflow of the Göta Älv. It is emphasized that the content of yellow substance may often be considered as a characteristic property of a water mass.

The transparency of the sea is generally studied *in situ* by means of a transparency-meter which, when standardized (JERLOV, 1944), records the true light extinction, *i.e.*, the sum of absorption and scattering. The extinction is caused by the water itself, by suspended particles, and by dissolved substances, chiefly yellow substance. Studying the extinction by unfiltered and Berkefeld-filtered samples of sea water it is possible to distinguish between the extinction due to particles and that due to dissolved matter (JAMES and BIRGE, 1938; CLARKE and JAMES, 1939). This procedure is, however, too laborious to be used conveniently in routine work at sea.

A great deal of interest has been directed to the particle component in the sea, in particular from a biological point of view (see KREY, 1949; ARMSTRONG and ATKINS, 1950). In an earlier report the present author has described a method of studying the distribution of particles in the sea with the aid of a Tyndall-meter (JERLOV, 1951). The method offers the possibility of characterizing water masses and studying horizontal and vertical movements in the sea by means of the particle content,

which is expressed as a scattering coefficient (conveniently in  $\text{km}^{-1}$ ).

On the other hand, the transparency of the sea as measured by means of a transparency-meter can be used for identifying a water mass (JOSEPH, 1950; WYRTKI, 1950; JERLOV, 1951; KREY, 1952). Alone transparency measurements, even if made for different colours, do not furnish sufficient data to distinguish between the extinction due to particles and that due to dissolved substances, as the absorption by particles as well as that by yellow substance exerts a selective action on the transmitted light.

It is obvious, however, that if the particle content is studied together with the selective light extinction the task of distinguishing between different components of extinction would be highly facilitated. An attempt to realize this is made below.

## Particle distribution

Coastal waters, as a rule, contain more suspended particles than do ocean waters, due to a richer plankton population and a

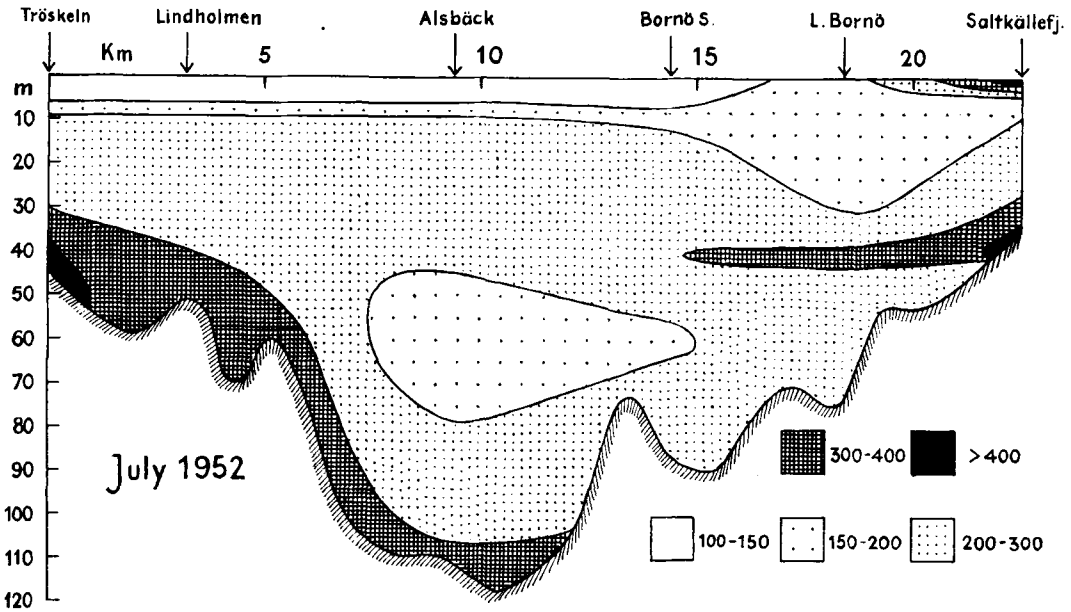


Fig. 1. Particle distribution in the Gullmar Fjord on the 18th July 1952.

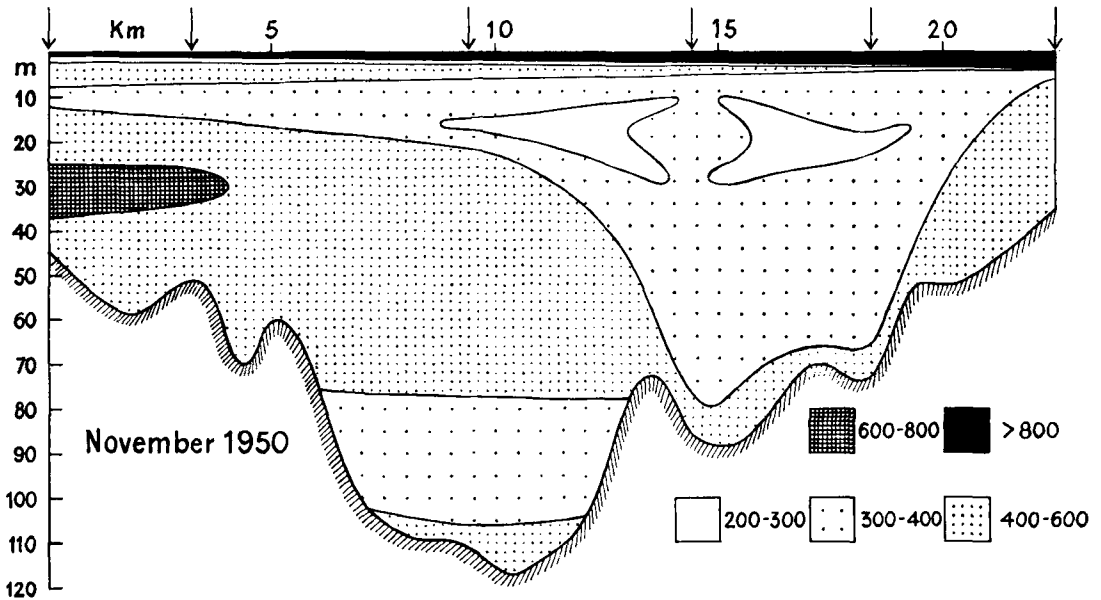


Fig. 2. Particle distribution in the Gullmar Fjord on the 20th November 1950.

larger amount of *detritus* and of inorganic matter derived from land or from the bottom. The clearness of deep ocean samples is illustrated by a particle content of 20 (JERLOV,

1951) whereas the Kattegatt and the Skagerrak are seldom lower than 100 in particles. In order to define our problem of distinguishing between different components of light ex-

tioning it is pertinent to give some aspects on the particle distribution in the stratified water at the Swedish west coast.

A section from the Gullmar Fjord run on the 18th July 1952 is shown in fig. 1. On this occasion, after a period of strong northwestern winds, the fjord was filled with high-salinity water, the upper layers were well mixed, and the thermocline was as deep as at 40 m. The particle content at the surface was low but increased toward the innermost part of the fjord. The main body of fjord water was characterized by a particle value of 200—300. Only near the bottom at the shallowest stations particles were more abundant, which is attributed to sediments being whirled up. Owing to this effect the clearest water is on an average present at mid-depths in the fjords (JERLOV and KOCZY, 1947).

Quite another situation, which sometimes occurs in the autumn or in winter in the Gullmar Fjord, is illustrated in fig. 2. This section was run in November 1950. The fjord was covered with a turbid layer of low salinity, due to river water and precipitation, and spread over the salt water under the prevailing calm conditions. The layer decreased in thickness toward the mouth of the fjord but its terrigenous material supplied the entire basin with an abundance of particles (the scale is here twice as large as in fig. 1) which, judging from the Tyndall observations, were definitely brown at all levels.

As first observed by HANS PETERSSON (1934) with the aid of optical instruments an accumulation of suspended matter is generally present in or near a density discontinuity layer in the sea. Such a distribution appears in fig. 1 at 40 m but more clearly in fig. 3 for the international P-section, Pater Noster-Skagen (at the boundary between the Kattegatt and the Skagerrak). In particular, the discontinuity, when close to bottom, is connected with an abundance of particles probably stirred up by vertical oscillations in the layer, due to the tides.

The rivers carry considerable amounts of sediment, most of which flocculates and settles rapidly. An example of these conditions is given in fig. 8 showing the outflow from the Göta Älv. The penetration of salt water as a deep layer from outside into the Göteborg Harbour is also clear from this fig. The par-

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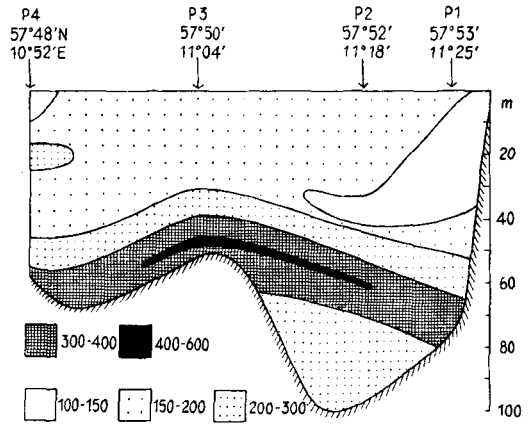


Fig. 3. Particle distribution in the P-section (boundary between the Kattegatt and Skagerrak) on the 25th July 1952.

ticle contamination is as high as 3,000 at the Free Port (Frihamnen) where the river enters. Further it is observed that sediment is whirled up from the bottom especially in the shallow waters of the inner harbour. Accordingly, the clearest water is present as a tongue which reaches bottom at the Free Port.

### Components of light extinction

Adopting the following notations.

- $c$  = total extinction coefficient
- $c_w$  = extinction coefficient by the water itself
- $a_p$  = absorption coefficient by suspended particles
- $a_y$  = absorption coefficient by yellow substance
- $s$  = scattering coefficient by suspended particles

We have

$$c - c_w = a_p + a_y + s, \quad (1)$$

where  $c_w$  is known (CLARKE and JAMES, 1939),  $c$  is measured by means of the transparency-meter, and  $s$  by means of the Tyndall-meter.

As a matter of routine the extinction was determined with different colour filters, viz. RG 1 (655  $m\mu$ ) and UG 1 + BG 12 (380  $m\mu$ ), sometimes also with BG 12 (440  $m\mu$ ). The absorption of red light by yellow substance in concentrations found in the sea is practically

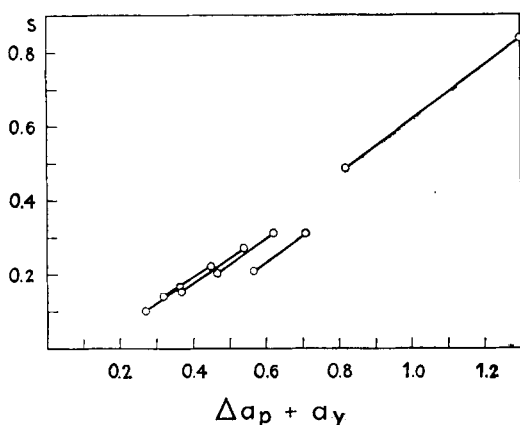


Fig. 4. Relationship between scattering by particles,  $s$ , and selective absorption,  $\Delta a_p + a_y$ .

nil. Hence, we can write the difference  $\Delta$  between coefficients for  $380\text{ m}\mu$  and for  $655\text{ m}\mu$  in the following way.

$$\Delta(c - c_w) - \Delta s = \Delta a_p + (a_y)_{380\text{ m}\mu} \quad (2)$$

The factor  $\Delta s$  is small, if the particles are not strongly coloured, and does not exceed the experimental errors in the determination of  $c$ . Nevertheless the factor is taken into account below.

The absorption of red light by particles comes out directly from equation (1) as  $a_y = 0$ . Apparently it is proportional to the scattering by the particles but the values are too low to permit any definite conclusions. But there is every reason to believe, that the absorption,  $a_p$ , for a given wave-length is a function of scattering,  $s$ , even if the relationship may be different for a different average size and colour of particles in the sea. We consider the difference  $\Delta a_p$  and let the experiments decide whether  $\Delta a_p$  is a function of  $s$  or not. Therefore, the left member in equation (2) containing the measured quantities should be plotted against the particle scattering  $s$  for depth intervals where the content of yellow substance is expected to be constant.

The fact that yellow substance apparently is a stable soluble product points to it being a conservative concentration. This could not hold true in a strict sense, as a production of yellow substance normally takes place wherever organic matter in the sea decomposes to which

should be added that a certain consumption would seem probable, but the assumption is fully acceptable for Swedish coastal waters which are rich in yellow substance largely supplied by fresh water outflow. The consequence would be that content of yellow substance and, for instance, salinity are intimately connected. KALLE (1949) has proved this relationship to exist by studying the yellow substance in filtered water-samples, collected in the Gulfs of Bothnia and of Finland. The work by JOSEPH (1950) and by KREY (1952) points in the same direction.

Therefore, in water columns of constant salinity the yellow substance is likely to show small variations. Fig. 4 is prepared in view of this. At different localities in off-shore as well as in fjord waters, two levels are selected which display almost the same salinity but different particle content. Straight lines connect the pairs. Most of these depths are above the thermocline. Surface observations have been avoided as they are often effected by contaminations from the ship.

The diagram in fig. 4 shows the selective absorption to be strongly influenced by particle scattering. The factor  $\Delta a_p$  is responsible for this selective action. As the lines are practically parallel,  $\Delta a_p$  can be expressed by the relation

$$\Delta a_p = 1.5 s \quad (3)$$

This simple formula is found for the western Swedish areas at the end of July 1952. It is not expected to be of general application as the relationship between absorption and scattering by particles is dependent on their average size and colour.

This attempt to interpret the role of particle absorption enables us to find from equations (2) and (3) values of yellow substance expressed as absorption coefficient for  $380\text{ m}\mu$ . Then, all components involved in the extinction are obtained from equation (1), for ultra-violet light as well as for red light.

The resolved components for  $380$  and for  $655\text{ m}\mu$  and their variations with depth are set out in fig. 5. The long wave-lengths are to a higher degree scattered than absorbed, whereas the case is opposite for the short wave-lengths. Because of particle accumulation in the discontinuity layer below  $30\text{ m}$ , all factors increase toward the bottom except

yellow substance, which shows a slight decrease. This brings us over to the distribution of yellow substance.

**Vertical and horizontal distribution of yellow substance**

Another illustration of the fall off in concentration of yellow substance in the discontinuity layer is given in Table I for the inter-

**Table I. Extinction components. Section P1—P4 on the 25th July 1952**

Depth m	655 m $\mu$			380 m $\mu$			
	$c - c_w$	$s$	$a_p$	$c - c_w$	$s$	$a_p$	$a_y$
0	0.21	0.17	0.04	0.56	0.18	0.28	0.10
10	19	12	7	55	15	29	11
20	20	15	5	57	18	29	10
30	15	14	1	49	16	23	10
40	18	17	1	52	19	27	6
50	26	24	2	67	26	39	3

national P 1—P 4 section. The upper layers, which are mixed with Baltic water, display a yellow value of 0.10 which drops to 0.03 at

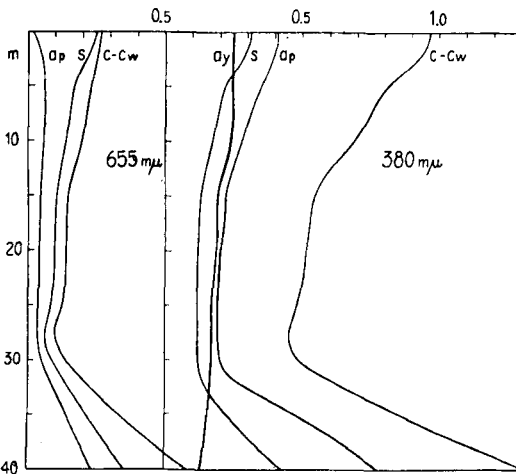


Fig. 5. Extinction components for 380 m $\mu$  and for 655 m $\mu$  in the Kattegatt (57° N; 12° E) on the 24th July 1951. Total extinction coefficient =  $c$ ; extinction coefficient by the water itself =  $c_w$ ; absorption coefficient by suspended particles =  $a_p$ ; absorption coefficient by yellow substance =  $a_y$ ; scattering coefficient by suspended particles =  $s$ .

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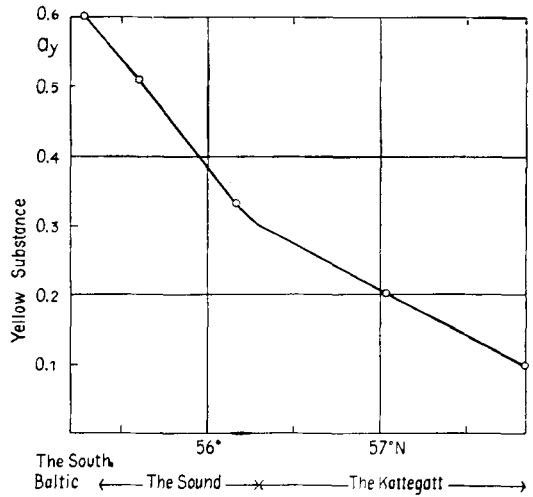


Fig. 6. Decrease of the content of yellow substance in the upper layers, toward the north in the Transition Area.

50 m where North Sea water is present. The density increase between 30 and 50 m is associated with the usual richness in particles as already shown (fig. 3).

The considerable difference between the Baltic and the Skagerrak as to the content of yellow substance is also demonstrated in fig. 6 which refers to measurements at depths above the thermocline carried out at the end of July 1952. The Baltic water becomes rapidly intermixed in the Sound. There is a marked bending of the curve where the Sound opens out into the Kattegatt. The decrease of yellow substance is more gradual in the Kattegatt where an additional amount of yellow substance is furnished by rivers. On the whole, the distribution of yellow substance characterizes the hydrographic situation, and the yellow colour identifies the Baltic water when it spreads toward the north.

An intensification of the yellow colour is often a local phenomenon due to outflow of fresh water. Particularly in the fjords, where the low turbulence favours a very pronounced stratification, a layer of low salinity is frequently formed over saltier water. This layer does not only contain an abundance of particles but has also a high content of yellow substance. Values of  $a_y = 1.0$  are often observed at Bornö Station.

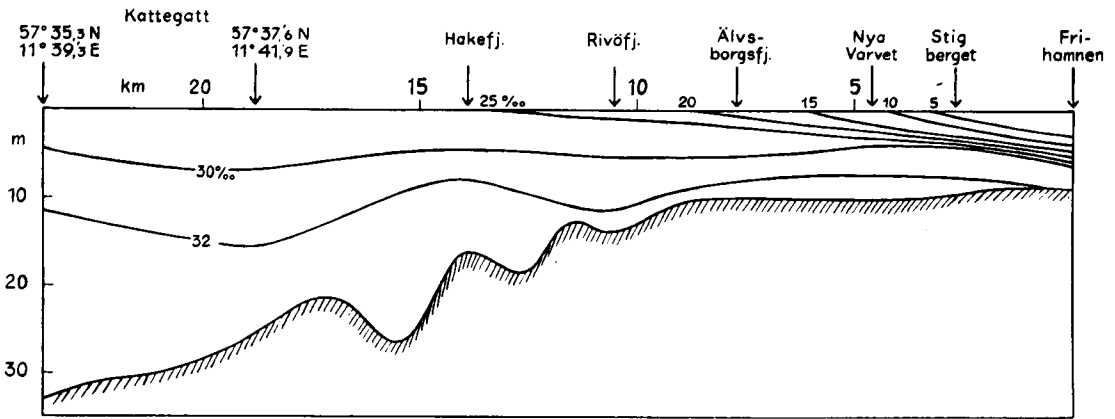


Fig. 7. Salinity distribution at the outflow of the Göta Älv.

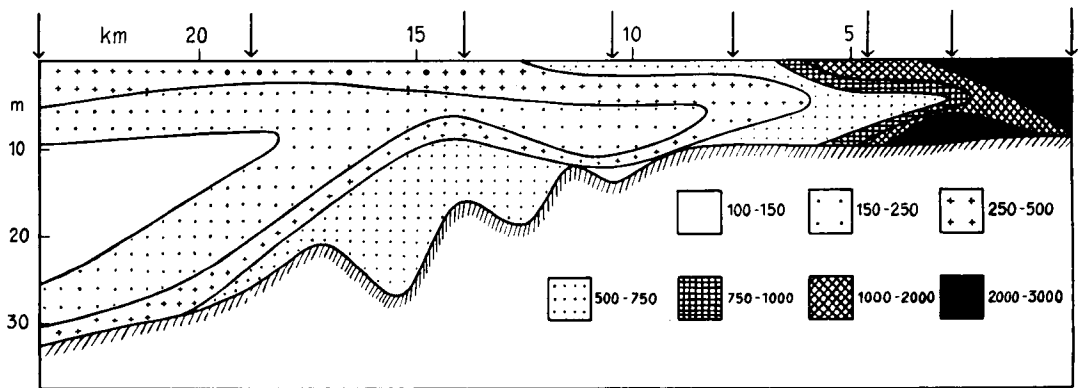


Fig. 8. Particle distribution at the outflow of the Göta Älv.

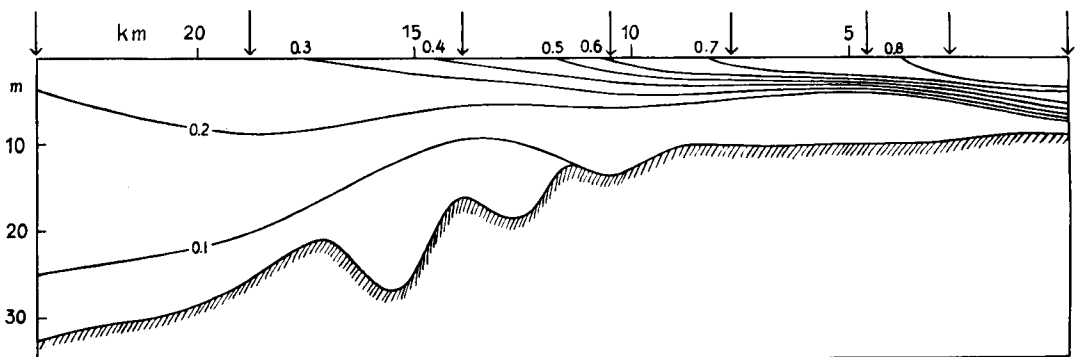


Fig. 9. Distribution of yellow substance at the outflow of the Göta Älv.

When we discuss the role of rivers for the colour of the sea it is worth while to ascertain whether the yellow substance may be used as an indication of water from the Göta Älv. In view of the high extinction in the river, the

measurements were carried out for blue light as well as for red light, and the content of yellow substance is expressed as the absorption coefficient for  $440\text{ m}\mu$ . The values of  $a_y$  found in the inner harbour are somewhat un-

certain as equation (3) possibly does not hold true for particles abundant in the river water (fig. 8). This is characterized by a yellow value of 0.8 which corresponds to about 1.6 for 380 m $\mu$ . The penetration of sea water as a deep layer into the innermost harbour and the mixing boundary appear clearly in fig. 9. The inflowing deep current retains its colour remarkably well, whereas the yellow substance in the outflowing river water is rapidly reduced seawards by the addition of salt water from below and by horizontal diffusion. At a distance of 20 km from the mouth of the river the content of yellow substance is not far from normal for the off shore water. The trend of the isopleths for yellow substance and for salinity (fig. 7) are in good agreement.

The distribution of yellow substance may be used as an indication of fresh water, in particular where it flows out into sea water of low salinity which cannot be determined with accuracy. This discussion and also the German investigations emphasize the point that the yellow substance in certain cases may be considered as a characteristic property of a water mass. It is observed that the particle scattering found by the Tyndall-meter needs to be known only in relative units. Transparency measurements in coastal waters should preferably be made with the aid of a transparency-meter with a light path of two metres and with an automatic device for changing colour filter. They do not require any additional time at the stations as they can be conducted at the same time as the routine serial observations.

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