Recent iron-rich sediments in the Skjernå river system and in Ringkøbing fjord. (Iron pollution of the river Skjernå and Ringkøbing fjord, Western Jutland)

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Preliminary results of an investigation of the iron pollution of the Skjernå river system and Ringkøbing fjord are presented. The pollution is caused by human activity (mining of brown coal, drainage of meadows, straightening of rivers). The results indicate a deterioration of life conditions for the makrobenthos in Ringkøbing fjord caused by the supply of iron. At present no quantitative statement concerning the relative importance of human intervention on the iron supply to the fjord can be given.

During 1974 and 1975 an investigation of water and sediment chemistry in the river Skjernå and in Ringkøbing fjord, Western Jutland, has been carried out at the Geochemical Department of the Geological Survey of Denmark. The main purpose of this research was to obtain precise information on the extent and the reasons for iron pollution in the area, which has been claimed to be responsible for a decrease in the yield of fishing and angling. The iron pollution is the result of human activities, the most important of which are the mining of brown coal, drainage of meadows (especially the area west of Skjern and Tarm) and straightening of meandering rivers. The investigation is not yet completed, but some preliminary results are presented in this paper and in two other publications (Kristiansen, 1976 and Jacobsen, 1976).

Outline of the geology and geochemistry of the investigated area

The Skjernå river, including its tributaries, drains an area of about 2200 km^2 in which the Quaternary deposits include the following main types (see fig. 1):

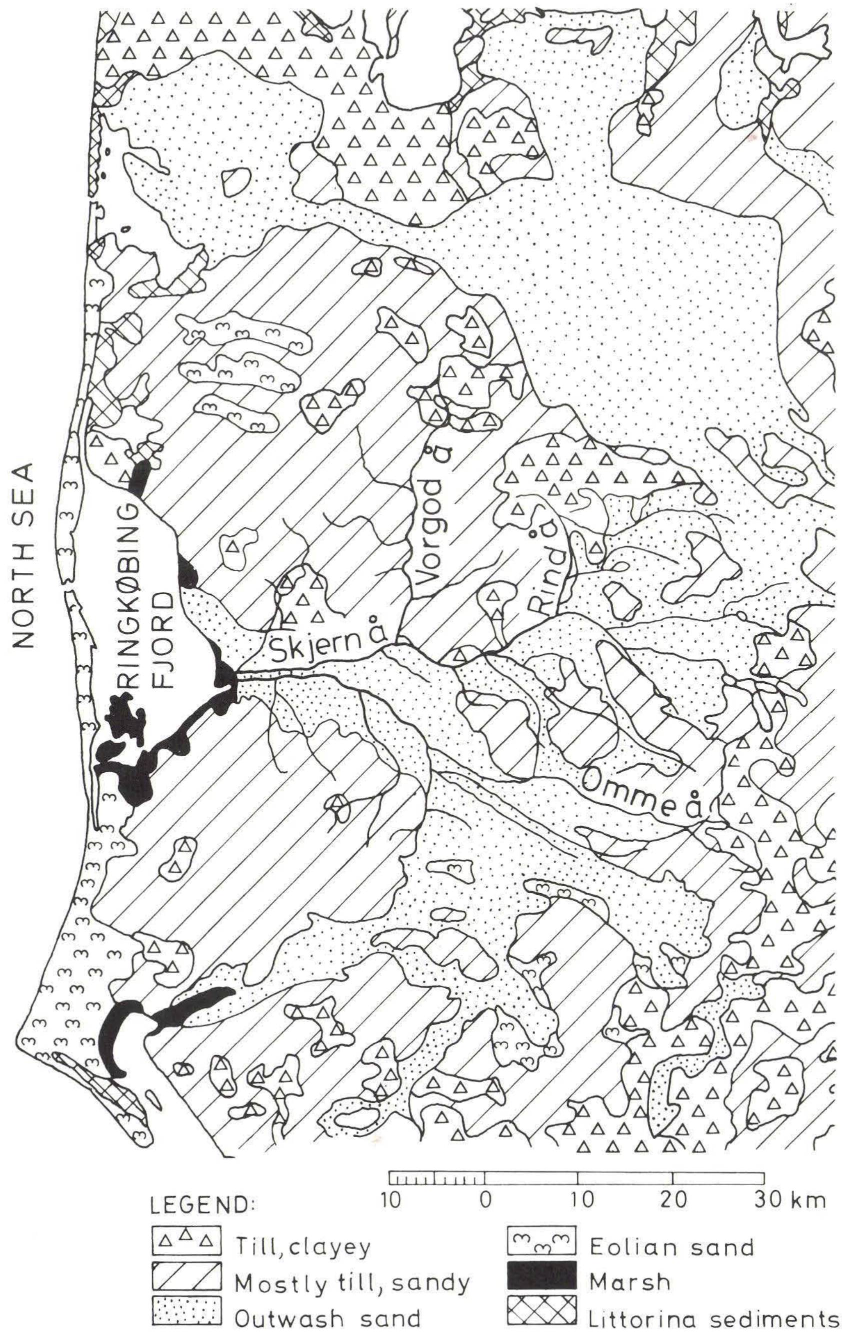

Fig. 1. Generalized map of Quaternary sediments in Western Jutland (after K. Milthers, 1954).

1. hill islands (mainly till and diluvial sand)
2. outwash plains (sand)
3. bogs and meadows (organogenic deposits, especially peat and marsh).

The areas which are built up of till and diluvial sand are generally referred to the Riss glaciation. Due to the topography these areas have been named hill islands, lying as erosional remnants in the younger outwash plains. The outwash plains were formed during the melting periods following the Riss glaciation (i.e. mainly before and after the Weichsel glaciation during which Western Jutland was not covered by ice). The outwash plains consist mainly of sand. During the Holocene freshwater organogenic sediments were formed in bogs and meadows in the area. Generally these deposits are rich in organic matter (peat etc.) with a variable admixture of clastic components. In the western part of the area, around Ringkøbing fjord, surface deposits of marsh sediments occur.

Geochemically the upper metres of the investigated area can be classified as being intensively weathered, which is the result of the combined effects of age, climatic conditions, hydrology, and the original geological composition. This means that the upper metres of the sediments are more or less free of lime, and that the surface water is characteristically low in alkalinity, pH, and hardness (Ca and Mg content is low). However, in the deeper-seated parts of the hill islands as well as in the low-lying meadows a certain amount of lime is still present. Manganese and iron which are released by the weathering processes have been deposited along the rivers, for example in organic-rich sediments as bog iron ore or in the transition zone between freshwater and marine water in the area west of Skjern and Tarm (in the so-called Skjernå delta).

The Pre-quaternary sediments of the area are mainly Miocene quartz sand containing layers of brown coal (see for example Koch et al., 1973). The brown coals have formerly been mined from open pits, but today the mining has ceased. The brown coals are interbedded with layers of clay for which the depositional environment has allowed an accumulation of metal sulphides, the most important being iron sulphides. As a result of the brown coal mining these deposits have been piled up and thereby exposed to oxidation. The ground water within the area studied reflects partly the above-mentioned intense weathering of the surface and partly the geology of the deeper-lying sediments, thus giving a characteristic water chemistry: low hardness, alkalinity, and pH; and high concentrations of excessive CO_2, iron, and manganese. In the deeper ground water reservoirs more alkaline water is present.

Geology of the Skjernå delta

Geological information on the low-lying area between Ringkøbing fjord and a point slightly to the east of Skjern and Tarm (the Skjernå delta) (fig. 1) has been taken from files in the Well Record Department, Geological Survey of Denmark, and supplemented by some 15 small borings carried out during this investigation to obtain samples for chemical analyses. Sediments from the upper 30–50 m within the area are dominated by thin layers of sand and clay deposited in a fluviatile environment. The upper few metres have been called diluvial deposits (Quaternary), while the deeper sediments have earlier been referred to the Tertiary, based on their content of mica or rebedded brown coal material. Investigations of the foraminiferas from a few borings in the area indicate, however, that this stratigraphic division is invalid (pers. comm. A. Dinesen and F. N. Kristoffersen, 1975). It seems more likely that the fluviatile sediments rich in mica and brown coal are rebedded by the Quaternary meltwater streams.

Above the fluviatile sediments in the Skjernå delta a series of Holocene deposits rich in organic matter is present. Freshwater sediments (peat) are found at levels ranging from -10 to -5 m below sea level, and as these deposits are overlain by marine (*Littorina*) sediments, they are assumed to have been formed early in the Holocene in the so-called Continental Period. The level for the peat gives an indication of the level of the Skjernå delta at that time which is in general agreement with earlier findings (Mertz, 1924). Above the peat (which is normally less than ½ m thick), and sometimes interlayered with it, marine (*Littorina*) sediments are found. The *Littorina* deposits are up to 2–3 m thick. The precise demarcation of the area transgressed by the *Littorina* sea is not yet known, but it seems most likely that only a narrow zone around the present Skjernå river was covered by the *Littorina* sea. According to Andersen (1963) the *Littorina* sea seems to have covered this area for only a short period of time, and therefore it is natural that Holocene freshwater sediments dominate the upper 5–6 m of the sequence in the Skjernå delta. In the western part of the Skjernå delta these youngest deposits consist almost exclusively of sand, while eastwards there is an increasing content of organic matter in the sediments. The western sand zone is presumably the result of beach-ridge formation in Ringkøbing fjord and sedimentation of suspended material from the river Skjernå. Behind this sand zone conditions were favourable for peat formation and sedimentation of more fine-grained material (silt and clay) around the meandering Skjernå river.

Chemical composition of sediments from the Skjernå delta

The chemical composition of sediments from the Skjernå delta is highly variable. Sediments rich in sand and silt are almost insoluble in aqua regia, giving an insoluble residue of 95–98 ‰ (d.m.). The remainder is Fe_2O_3 and loss on ignition. The clay sediments have about 85 ‰ insoluble residue (including SiO_2 from acid-soluble silicates), and normally a considerable loss on ignition (organic matter, chemically combined water). The sulphur content (total S) varies from 0.2 to 3–4 ‰, highest in samples rich in organic matter. The Al_2O_3 content is about 0.5 ‰. The peat has an insoluble residue of 20–30 ‰, but deviations from this value are common due to variations in the admixture of sand. Loss on ignition is often around 50 ‰, and the Fe_2O_3 content is between 10 and 15 ‰. Total S content is 1–9 ‰, most of which is found as reduced sulphur compounds (e.g. sulphides). The content of CaO is about 1 ‰, MgO 0.5 ‰, and Al_2O_3 1–3 ‰.

Recent iron-rich sediments in Vorgodå and Sydlige parallelkanal

During 1975 the recent river sediments in most of Vorgodå and Sydlige parallelkanal (fig. 1 and 2) were mapped, and a few samples from the river Skjernå were taken for comparison. The purpose of this was to study a possible effect of the river-water chemistry (cf. Jacobsen, 1976 and Kristiansen, 1976) on the sediments and thereby a.o. to estimate the extent of the iron pollution of the river bottom.

Vorgodå

Bottom sediments in the river Vorgodå are normally sandy but vary in composition within very small distances downstream as well as across the river due to local differences in stream velocity (for example erosion at one side of the river, sedimentation at the other).

The overall impression is that the iron content in the sediments is higher in Vorgodå south of the stream Rimmerhus bæk than in Skjernå river, and that the iron occurs mainly as one of the following three main types in Vorgodå:

1. coatings on sand grains
2. loose ochre
3. more or less reduced iron compounds.

Sand grains coated with iron are especially common in the upper part of Vorgodå, from the outlet of the stream Rimmerhus bæk (see fig. 1 in Jacobsen, 1976) and a few km downstream. The coating has a characteristic yellow colour. Loose ochre layers are found mostly within approximately the same part of Vorgodå, but ochre is also present in the remaining part of Vorgodå south of the outlet of Rimmerhus bæk. At some localities the ochre is found as a thin, hard crust, or is mixed up in the upper 5–10 cm sand. Iron, in a more or less reduced state, grey to black in colour, occurs in quiet environments associated with organic material, or a few cm below the oxidized river bottom. No iron sulphide reflections could be obtained from the material by X-ray diffraction.

Chemical analyses (aqua regia treatment) of 12 samples from 7 different localities in Vorgodå show that sand grains coated with iron might contain about 2 % Fe_2O_3, while the loose ochre and ochre crusts have 3–8 % Fe_2O_3. The reduced iron-rich sediments contain 2–10 % Fe_2O_3 but only up to 0.7 % S, and their Al_2O_3 content is 1–4 %, which is rather high. Loss on ignition varies between 4 and 14 % for the reduced iron-rich sediments. At one locality the reduced iron-rich sediment had extremely high contents of Fe_2O_3 (29.1 %) and Al_2O_3 (17 %). These preliminary results from Vorgodå indicate that sediments containing more iron and aluminium than normal river sediments from the area are being deposited today, especially in the quietest environments in the river. The sediments thus seem to reflect some of the changes in river water chemistry in Vorgodå (cf. Jacobsen 1976). Still the question remains open, as to what extent these unconsolidated deposits will be transported further downstream towards Ringkøbing fjord (in suspension etc.) as no information on the suspended sediment load in the river system is available at present.

Sydlige parallelkanal

River bottom sediments from Sydlige parallelkanal are much more muddy and richer in iron than sediments from Vorgodå. In contrast to sediments from Vorgodå the deposits in Sydlige parallelkanal often have iron in the reduced state at the sediment-water boundary. In the vicinity of the outlets from the five pumping stations (see Kristiansen, 1976, fig. 1) the river sediment normally has a high ochre content giving a red colour on the sediment surface some distance downstream. However, this type of deposit is rapidly (within a few hundred metres) replaced by a muddy deposit, grey or black in colour, containing reduced iron. Reduced sediments quite often occur on one side of the river, while oxidized sediments are present on the other. Reduced iron compounds are found everywhere in Sydlige parallelkanal a few cm below the sediment surface in the areas where ochre is present at the surface.

This reduced environment (low redox potential) in the sediment is probably caused, at least partly, by the supply of sewage to Sydlige parallelkanal from, for example, the small river Ganerå (cf. Kristiansen 1976).

The iron-rich sediment vary in thickness from a few cm to ½ m (locally more). In many cases the deposit is relatively homogenous, but at a number of localities there are vertical profiles with layers of iron-rich sediment a few centimetres thick separated by thicker sand layers. This layered sediment sequence is present within the westernmost 2–3 km of Sydlige parallelkanal, but does not occur at all localities. Normally, only a single iron-rich layer is found, but up to 4 layers, separated by distinct sand layers, occur in the vertical sequence at some localities. The iron-rich deposits are almost free of sand, and are accordingly assumed to represent a quiet sedimentary environment in Sydlige parallelkanal, where the normal pumping activity has supplied the sediment with iron. The separating sand layers, which are relatively thin (20–30 cm), are well-sorted, coarse sand. The sand layers are therefore believed to correspond to shorter periods where the depositional environment was agitated (for example during storms). It seems surprising that the unconsolidated, muddy iron-rich deposits were not removed or at least mixed with sand when (or before) the sand layers were formed. No explanation can be given to this at present. It does not seem likely that the well-sorted, coarse sand material which is found 2–3 km from Ringkøbing fjord has been supplied to the river bottom from the fjord. Another possibility which must remain open at present is that the sand originates from the dikes which surround Sydlige parallelkanal.

Chemical analyses of the bottom sediments from Sydlige parallelkanal show that the ochre contains 6–21 % Fe_2O_3, about half of which is ferrous iron. The Al_2O_3 is 1–2 %; S (total) ca. 0.2 %; and loss on ignition 12–24 %. The reduced iron sediments have slightly higher loss on ignition (20–30 %), but considerable deviations from this average are common. The iron and aluminium contents are similar to the values found for the ochre, but ferrous iron here makes up ¾ of the total iron content. The sulphur content is normally less than 1 %, but higher values (ca. 2 %) are found locally.

The recent bottom sediments in Sydlige parallelkanal reflect an intense supply of iron (both ferri- and ferrous iron) which originates from the drained Skjernå delta (see Kristiansen, 1976). Shortly after the iron is deposited in Sydlige parallelkanal it is reduced to ferrous iron, which may permit higher concentrations of iron in solution to be transported further downstream towards Ringkøbing fjord as ferrous iron is more soluble. No quantitative data on the transport of suspended material through Sydlige parallelkanal is available, and it is therefore uncertain if the iron-rich bottom material is transported to the fjord.

Recent sediments from Ringkøbing fjord

Mapping of the bottom sediments in Ringkøbing fjord has until now only included about a third of the fjord area, namely its south eastern part adjacent to the outlets of Skjernå and Sydlige parallelkanal. Fig. 2 shows the localities of sampling, the lithology, and the thickness of the upper sediment layers. It appears from the map that the coarsest material occurs around the outlet of river Skjernå and otherwise at near-shore localities. The iron content in these coarse deposits (gravel, sand) is normally low and often only visible as a slight brownish colour on the grain surfaces. Outside this zone the grain size decreases, as could be expected, and silt and clay sediments are dominant. Corresponding to the decrease in grain size an increase in the iron (ochre) content is observed. The ochre is found as a very loose and flaky deposit; at some localities part of this material was suspended in the lowermost 10–15 cm of the water column. The loose ochre layer is normally about 2 cm thick (locally up to 4–5 cm).

The general impression is that the iron-rich sediments from the southern part of the investigated area (Falen Dyb) have the lowest content of silt and fine grained sand, presumably because this area is relatively protected against water exchange between the fjord and the North Sea (fig. 1). Fig. 2 only gives a poor impression of the correspondance between water depth and sediment type, mainly because the depth contours do not show the actual depths (the last measuring was carried out in 1884–85). Instead the reader is referred to the cross sections fig. 3–7, where the actual depths are shown. The locations of the cross sections are indicated on fig. 2. Figs. 3–7 show that the most fine grained sediments and the highest iron contents occur in the deepest parts of the fjord, and that admixtures of silt and sand are common in shallow areas. Deposition of the fine grained ochre accordingly requires a quiet environment, and it is assumed that the same iron-rich deposit is also present in large parts of the remaining fjord area which has not yet been mapped. Figs. 3–7 also give an impression of the sediments just below the fjord bottom. Immediately under the zone containing ochre reduced iron compounds are present giving the sediments a dark grey to black colour. At this boundary between the oxidized and the reduced zone (Eh discontinuity layer, Fenchel and Riedl 1970) burrows from polychaete worms are common. The burrows reach to some 20 cm depth in the reduced zone, and they are normally covered by an oxidized crust of iron hydroxides. At the Eh discontinuity layer there is in most cases also a distinct lithological change, as the reduced sediment contains much more clay and silt than the oxidized zone. In the reduced sediment many dead *Mya* specimens are found in life position. These bivalves are distributed with the youngest (smallest) specimens immediately below the zone containing

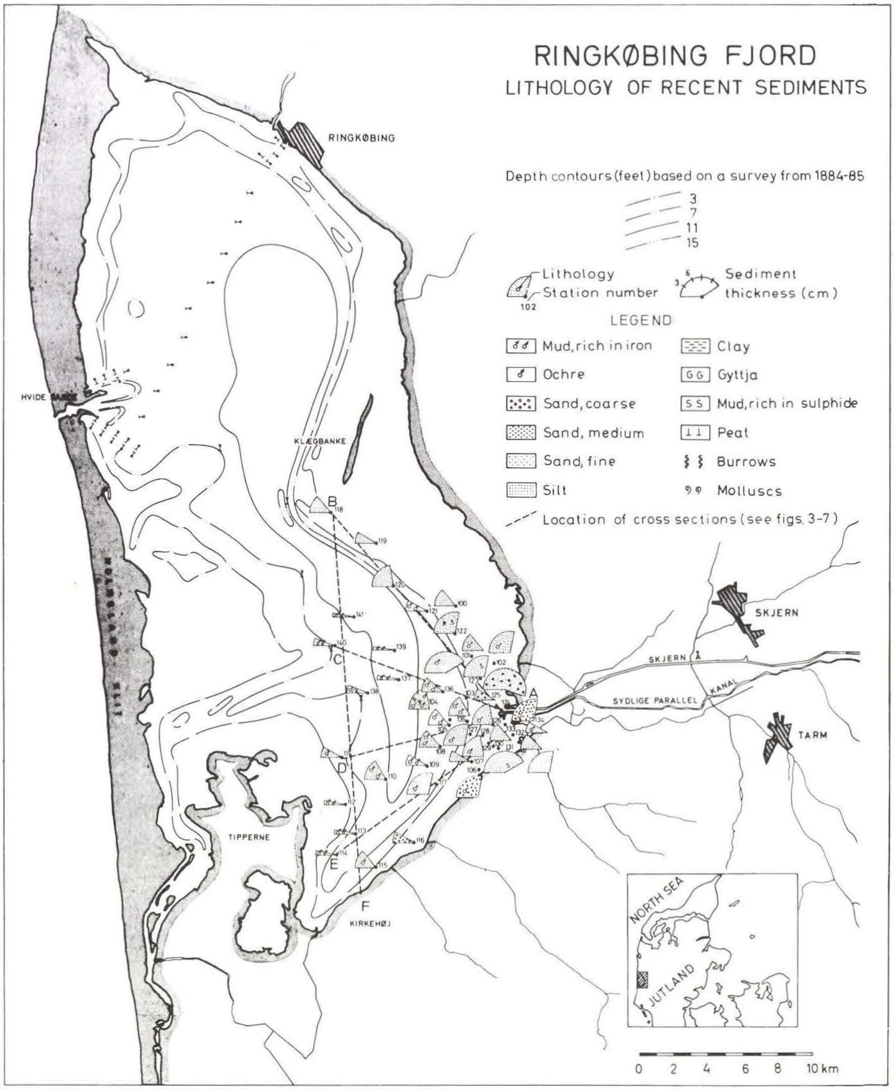

Fig. 2.

ochre while larger individuals are found at greater depths (down to 10–15 cm). The distribution of the molluscs is presumably characteristic for an earlier normal life situation at the fjord bottom, which has now deteriorated. Almost nowhere were living individuals found during this investigation, and it seems reasonable to suggest that the ochre pollution of the fjord might be responsible for the decrease in the makrobenthonic life. At present no age determinations on the yongest ochre-rich sediment have been carried out.

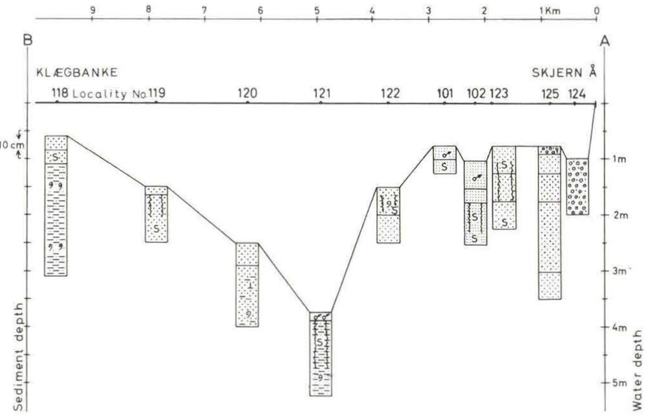

Fig. 3. Ringkøbing fjord. Cross section A-B, see fig. 2.

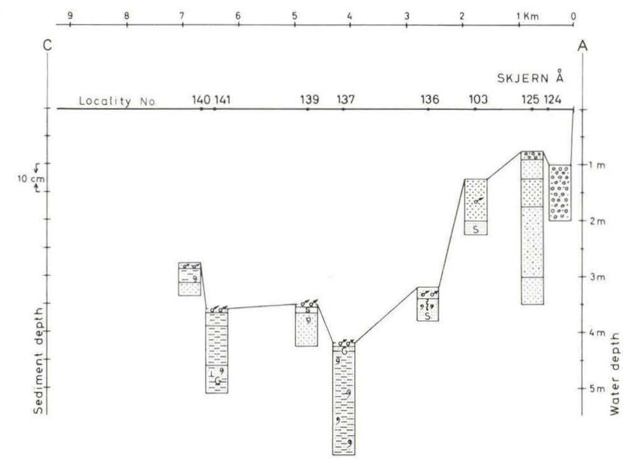

Fig. 4. Ringkøbing fjord. Cross section A-C, see fig. 2.

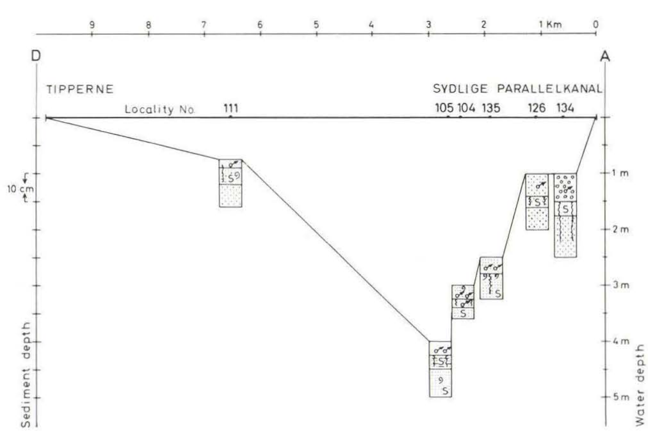

Fig. 5. Ringkøbing fjord. Cross section A-D, see fig. 2.

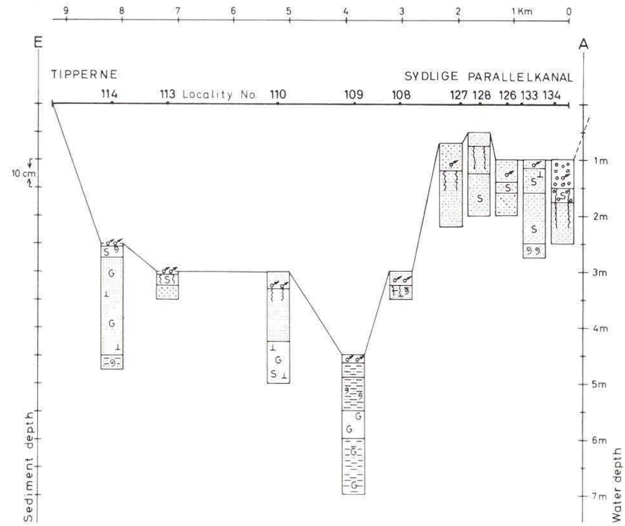

Fig. 6. Ringkøbing fjord. Cross section A-E, see fig. 2.

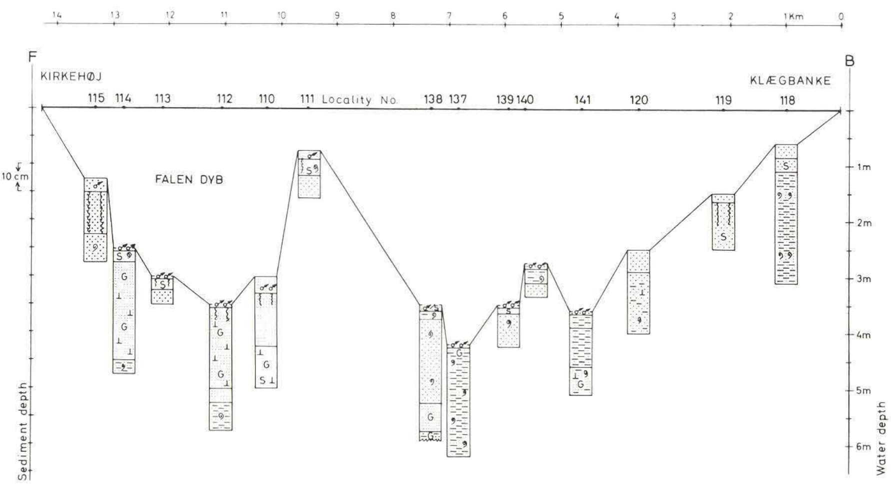

Fig. 7. Ringkøbing fjord. Cross section B-F, see fig. 2.

Chemical analyses (aqua regia) of sediments from Ringkøbing fjord have until now only been performed on the main sediment types. The iron content in a silty ochre deposit was 2.4 % Fe_2O_3; in a reduced iron rich mud 3.2 % Fe_2O_3; in gyttja, rich in iron, 3.3 % Fe_2O_3 was found. The more clastic sediments which occur a few cm below the ochre layer only contain 1 to 2 % Fe_2O_3. The iron content in the ochre layer is surprisingly low, and this underlines the need for more chemical data to supplement the field observations. The samples contain a little Al, presumably from the badly crystallized clay minerals which are soluble by the aqua regia treatment. Loss on ignition shows some variation (up to 6.4 ‰). The highest content of total S is 0.5 ‰. No pyrite peaks could be obtained by X-ray diffractometry.

Conclusions

The preliminary results of the sediment investigation show that an increased content of iron is present in the youngest deposits in Vorgodå, Sydlige parallelkanal, and Ringkøbing fjord. Concerning the rivers no evidence can at present be given for a possible effect of the increased iron content on the biological environments. In Ringkøbing fjord the iron seems to have worsened life conditions for part of the makrobenthos within the total area so far mapped. Further quantitative data of river discharge and suspended load are needed in order to decide the importance of the different iron sources to the iron pollution of the fjord.

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Dansk sammendrag

DGU's undersøgelser af vandløbsvand og sedimenter i Skjernå systemet og Ringkøbing fjord iværksattes med henblik på at afklare omfanget af og årsagerne til den okkerforurening af området, som i den offentlige debat har været gjort ansvarlig for bl. a. en nedgang i fjordfiskeriet. Hovedårsagerne til jernforureningen skal søges i de menneskelige indgreb i området, hvoraf de vigtigste er den nu afsluttede brunkulsbrydning, afvanding af engarealerne vest for Skjern (Skjernå deltaet) og udretning af vandløb. Nærværende afhandling må ses i sammenhæng med Jacobsens (1976) og Kristiansens (1976) publikationer, som giver de foreløbige resultater af de hydrokemiske undersøgelser i området. Vestjyllands specielle kvartærgeologiske og forvitringsmæssige forhold har resulteret i, at åerne har en karakteristisk vandtype med lav pH, lav hårdhed og højere jern- og manganindhold end i hovedparten af det øvrige Danmark. Dette har ført til, at betydelige mængder af jern og mangan i tidens løb er transporteret med vandløbene og afsat eksempelvis i Skjernå deltaet. Den miocæne, brunkulsførende serie, der findes under kvartærlagene i store dele af det undersøgte område, afsattes i et iltfrit sedimentationsmiljø, og her har betingelserne for akkumulering af f. eks. jernsulfidmineraler været gode. Ved brunkulsbrydningen og engafvandingen er der sket en kraftig oxydation af disse sedimenter med bl. a. et kraftigt pH fald til følge, som på en række måder kan spores i overfladevandets kemiske tilstand (se Jacobsen, 1976 og Kristiansen, 1976). Ved undersøgelser af bundsedimenterne i nogle af vandløbene og i fjorden kan effekten af de ændrede kemiske tilstande tydeligt spores. I Vorgodå forekommer således unormalt høje jernindhold og stedvis også høje aluminiumskoncentrationer i bundaflejringerne. – I Sydlige parallelkanal er påvirkningen af jernudledningen fra pumpestationerne endnu tydeligere. Jernets tilstandsform ændres hurtigt i bundsedimenterne (okkeren reduceres) sandsynligvis delvis på grund af den spildevandstilførsel, Sydlige parallelkanal modtager fra Skjern by. – I Ringkøbing fjord findes et slamagtigt okkerlag over den del af fjordbunden, der hidtil er kortlagt (ca. ⅓ af fjordens areal, omkring udløbet af Skjernå og Sydlige parallelkanal, se fig. 2). Jernindholdet i okkerlaget er forbavsende lavt (2–3 %), men dog højere end i det lidt ældre sediment. Det synes påfaldende, at der lige under okkerlaget ret udbredt forekommer døde sandmuslinger, som er fordelt vertikalt i sedimentet efter størrelse (de mindste individer sidder øverst). Muslingerne formodes at repræsentere et normalt livssamfund, som ikke har kunnet overleve den seneste tilledning af okker. Alderen af okkerlaget er endnu ikke kendt. På de foreliggende data kan det ikke afgøres, hvor stor en del af jernet i fjorden der er tilført via henholdsvis Sydlige parallelkanal og Skjernå.

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