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14689

Investigation of the ore potential in black shales of the Upper Permian Ravnefjeld Formation in Scoresby Land and on Traill Ø, central East Greenland
Fieldwork in August 1996

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Copenhagen
06-11-1997

DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 1997/124

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Introduction

Field work was carried out in the North-East Greenland sedimentary basin on Scoresby Land and Traill Ø during a three weeks period in August 1996. The aim of the work was to investigate the black shales of the Upper Permian Ravnefjeld Formation from an ore geological point of view. The logistics in the field period was arranged by the TUPOLAR project who operated out of Mesters Vig. The field group consisted of the assistant Mikkel Kreimer-Møller and myself.

The entire marine Upper Permian Foldvik Creek Group in Scoresby Land and Jameson Land is known to be thoroughly mineralised with base metals and barite (+/- Ag) (Harpøth *et al.*, 1986). Lead and zinc mineralisation in the shales of the Ravnefjeld Formation was first discovered by Nordisk Mineselskab A/S during reconnaissance work in 1968 (Lehnert-Thiel, 1968; Lehnert-Thiel & Walser, 1968) and was subject to more detailed investigations in 1969 and 1979 (Peball *et al.*, 1970; Thomassen & Svensson, 1980). The mineralisation was interpreted as syngenetic with reference to the similarities with the Kupferschiefer of Central Europe (Thomassen, 1973; Harpøth *et al.*, 1986).

The Ravnefjeld Formation has so far not been found to be mineralised outside the Wegener Halvø area, and only limited work was carried out by Nordisk Mineselskab on the formation in other parts of the basin. Because the shale-hosted type of mineralisation is easily overlooked in the field, the presence of mineralised areas in other parts of the basins can not be excluded. One of the aims of the 1996 fieldwork was therefore to visit some of the exposed parts of the shale unit north of Scoresby Land in order to evaluate the ore potential. Furthermore a more scientific approach to the known mineralisation was planned. The intention was to delineate the structures that control the known mineralisation on Wegener Halvø and last but not least to get a hold on the timing of mineralisation. Although a syngenetic model has been proposed, putting the mineralisation event to Upper Permian, it was originally my feeling that this idea should be reviewed. The main reason was that more recent work by Stemmerik (1991) had shown the mineralisation in some Upper Permian carbonate reefs on Wegener Halvø to post-date hydrocarbon migration, meaning that the mineralisation was most probably related to thermal event that accompanied the opening of the North Atlantic ocean in the late Paleocene.

The field campaign

The plan was to start the work around the known mineralisation on Wegener Halvø in order to get a feeling for the look of the mineralised blocks in the field. Bad weather the first week, however, prevented access to Wegener Halvø, so the first camp was consequently put at Rubjerg Knude on Traill Ø (Fig. 1). The bad and foggy weather impeded the work a bit and furthermore made the stay on the locality last a week rather than the planned 3-4 days. This unfortunately prevented visit to more localities north of Kong Oscars Fjord.
On August 10th the camp was moved to Wegener Halvø, where two camps were made in the next 9 days with the purpose of investigating the known mineralisation in this area. The

local camp-move on the 16th of August was combined with a 1 1/4 hours helicopter reconnaissance to more remote parts of Wegener Halvø and Depotø.

On August 19th we moved back to Mesters Vig in order to make one-day trips in the area around Blyklippen and Blyryggen where the Ravnefjeld Formation is also found. This resulted in a total of three days work in the area before the season ended on August 22nd.

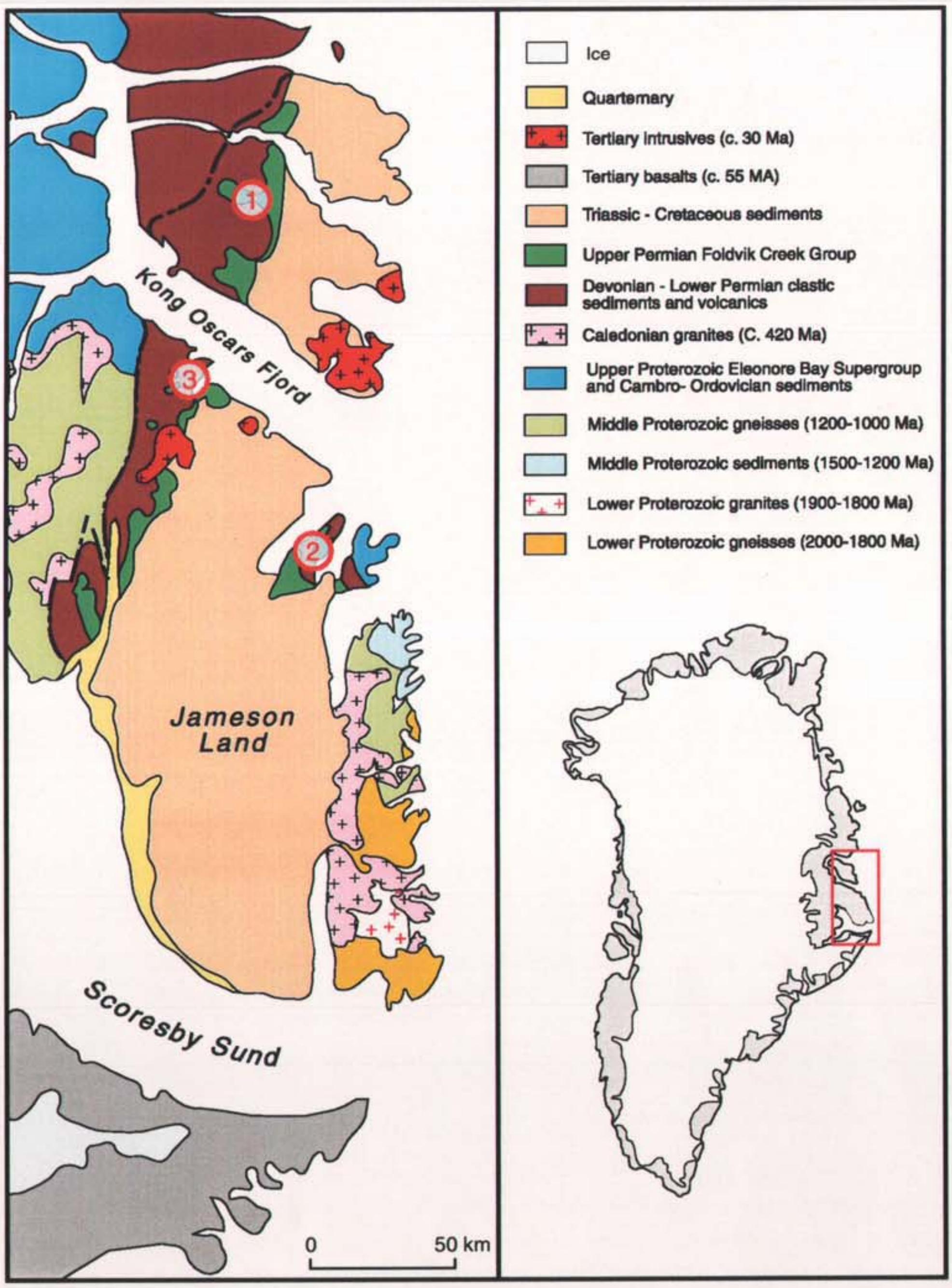

Figure 1. *Generalised geological map of central East Greenland. The areas that were visited during fieldwork in '97 is marked by numbers; 1, Rubjerg Knude; 2, Wegener Halvø; 3, Mesters Vig.*

Geological setting

The *Ravnefjeld Formation* is found in most parts of the c. 400 km long North-East Greenland depositional basin, which is situated inside the frames of Caledonian Fold belt (Fig. 2). The formation is part of the Upper Permian *Foldvik Creek Group*, a marine unit deposited unconformably on top of deformed and tilted Devonian - Lower Permian coarse grained, continental, clastic sediments which attains thicknesses in excess of 13.000 m in the Jameson Land basin.

The *Foldvik Creek Group* was deposited during an Upper Permian transgressive event, in which the basin formed a bay, closed in the south and open towards the east-northeast where it was in contact with the rifted seaway between Greenland and Norway (Christiansen *et al.*, 1993).

The basal part of the *Foldvik Creek Group* is constituted by the *Huledal Formation*, a fluvio-marine conglomerate which can be found in most of the basin (Surlyk *et al.*, 1986). The *Huledal Formation* is very thick on Rubjerg Knude where it is occasionally Cu-mineralised, but is only scarcely distributed in the Wegener Halvø area.

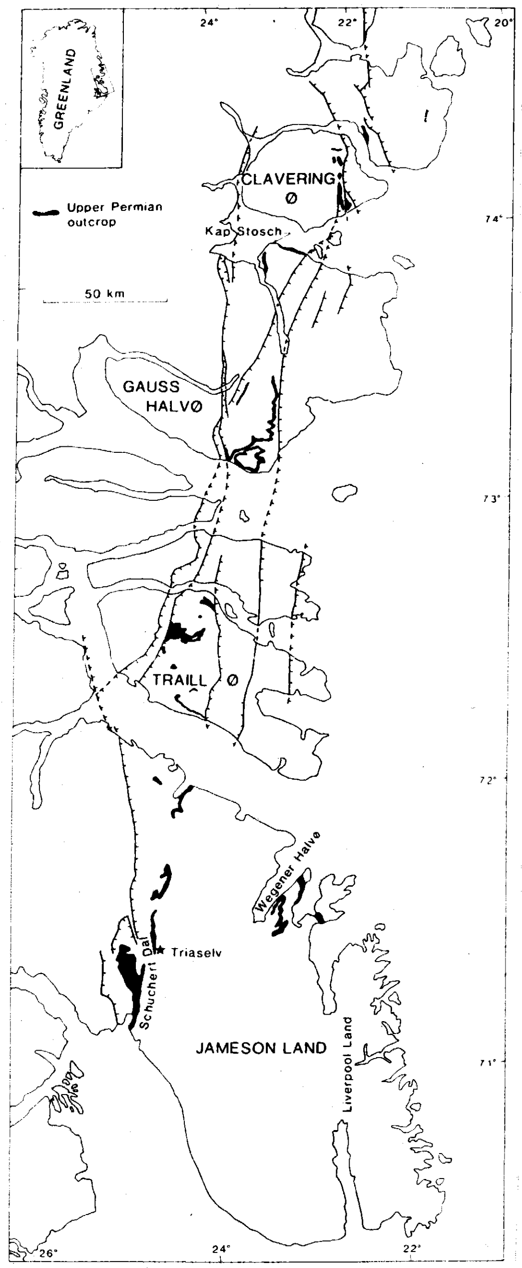

Figure 2. *Map of central East Greenland showing the distribution of Upper Permian outcrops (from Piasecki & Stemmerik, 1991)*

The *Huledal Formation* is overlain by the *Karstryggen Formation* (Fig. 3), a marine carbonate and evaporite sequence, mainly distributed along the margins of the basin. The *Karstyggen Formation* is karstified during at least two episodes of subaerial exposure giving rise to development of karstic breccias, sink holes and variable topography.

The *Karstryggen Formation* is overlain by the *Wegener Halvø Formation* that forms platform deposits along the western margin of the basin and reef structures on top of the karstic palaeo-highs in the Wegener Halvø area.

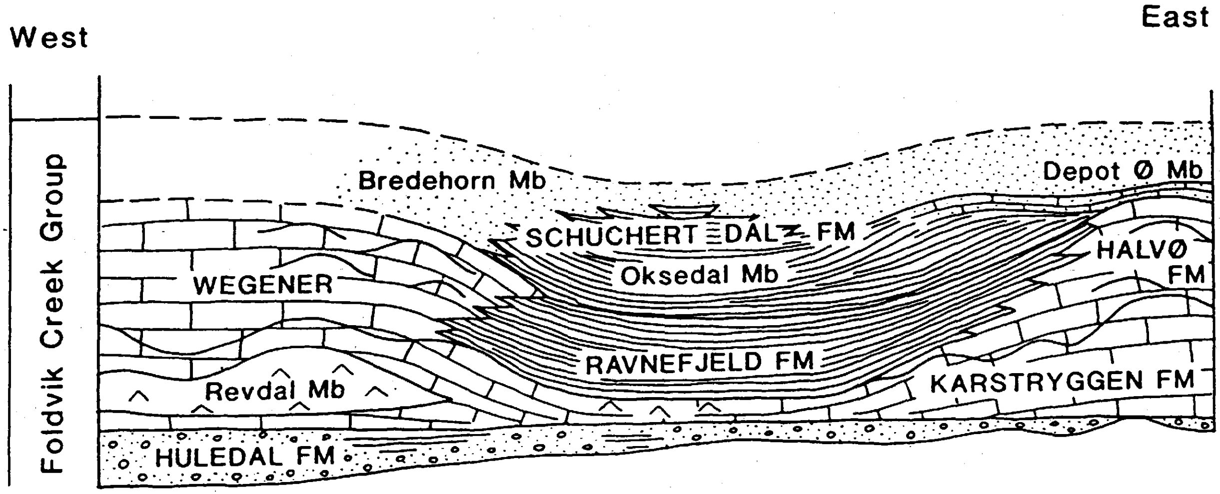

Figure 3. *Simplified cross section of the Upper Permian Foldvik Creek Group (from Surlyk et al., 1986).*

The *Ravnefjeld Formation* is contemporaneously with the *Wegener Halvø Formation*, interfingering with this on the basinwards side and filling the inter-reef basins in the Wegener Halvø area. The *Ravnefjeld Formation* is dominated by black bituminous shales, which in most of the basin can be subdivided into three bioturbated and two laminated units (Piasecki & Stemmerik, 1991). Along the western margin of the basin, the Ravnefjeld is more sandy than in the eastern part.

The *Ravnefjeld Formation* is in many places overlain by the more sandy *Schuchert Dal Formation* which again is overlain by Triassic deposits, but is in other places directly overlain by Triassic shales making the boundary harder to define.

Mineralisation

The mineral deposits in central East Greenland area have been collectively described by Harpøth *et al.* (1986). The *Foldvik Creek Group* is the most thoroughly mineralised group in the basin. Besides the stratiform Pb, Zn and Cu occurrences in the *Ravnefjeld Formation* which will be described later, sporadic Cu and Pb mineralisation in the *Huledal Formation* occur on Traill Ø and in the Karstryggen area and widespread stratabound Pb, Zn and barite mineralisation occur in the *Karstryggen and Wegener Halvø Formations* along the eastern and western basin margins.

Results of Fieldwork

Traill Ø - Rubjerg Knude

The general stratigraphy of the Upper Permian succession at Rubjerg Knude is shown on Fig. 4. The most striking feature is the thickness of the basal Huledal Formation conglomerate which attains thicknesses up around 65 m. This again is overlain by a c. 60 m thick sandstone unit, which is not found in any of the localities in Jameson Land and Scoresby Land. Overlying the clastic sequences is a gypsiferous horizon (15-20 m), a carbonate unit of varying thickness (usually less than 10 m) and on top of that the Ravnefjeld Formation shales (80-100 m). The borders between the latter three units may be more or less gradually. The gypsiferous horizon of the Karstryggen Formation often contains carbonate and shale beds and the lower part of the Ravnefjeld Formation locally contains gypsum and carbonate intercalation.

The entire area is intruded by numerous basaltic sills and dykes.

The area in reach from the camp site was traversed, but no mineralisation was observed in the Ravnefjeld Formation. In two cases Cu-mineralisation within the Huledal Formation conglomerate was detected. The mineralisation is in the form of Cu-minerals in the cement and on coatings on detrital grains. Both showings were minor and showed signs of being controlled by fractures.

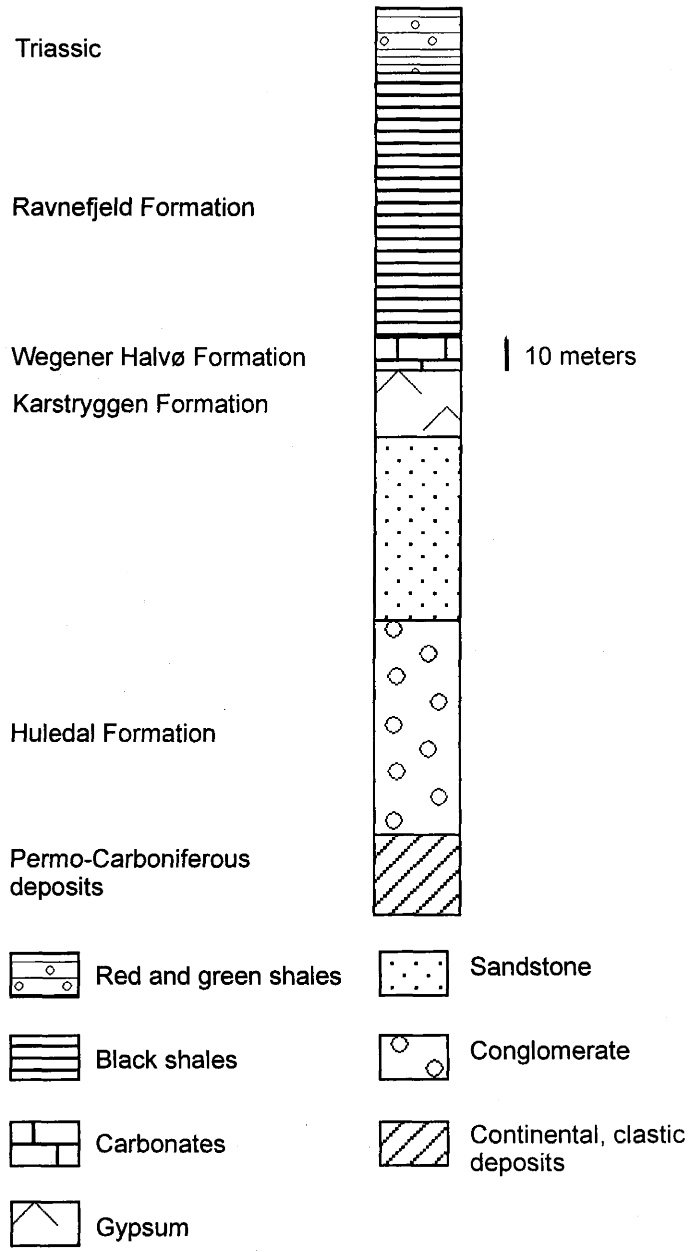

Figure 4. *The Upper Permian stratigraphy in the Rubjerg Knude area.*

Two vertical sections through the Karstryggen and Ravnefjeld Formations were systematically sampled in order to make geochemical profiles through the Formation.

Wegener Halvø

The Upper Permian stratigraphy on the Wegener Halvø area is dominated by carbonate buildups belonging to the Karstryggen and Wegener Halvø Formations. These have grown on the south-eastern part of a tilted and fault-bounded shelf-platform (Fig. 5), which nowadays is more or less outlined by the coastline of Wegener Halvø.

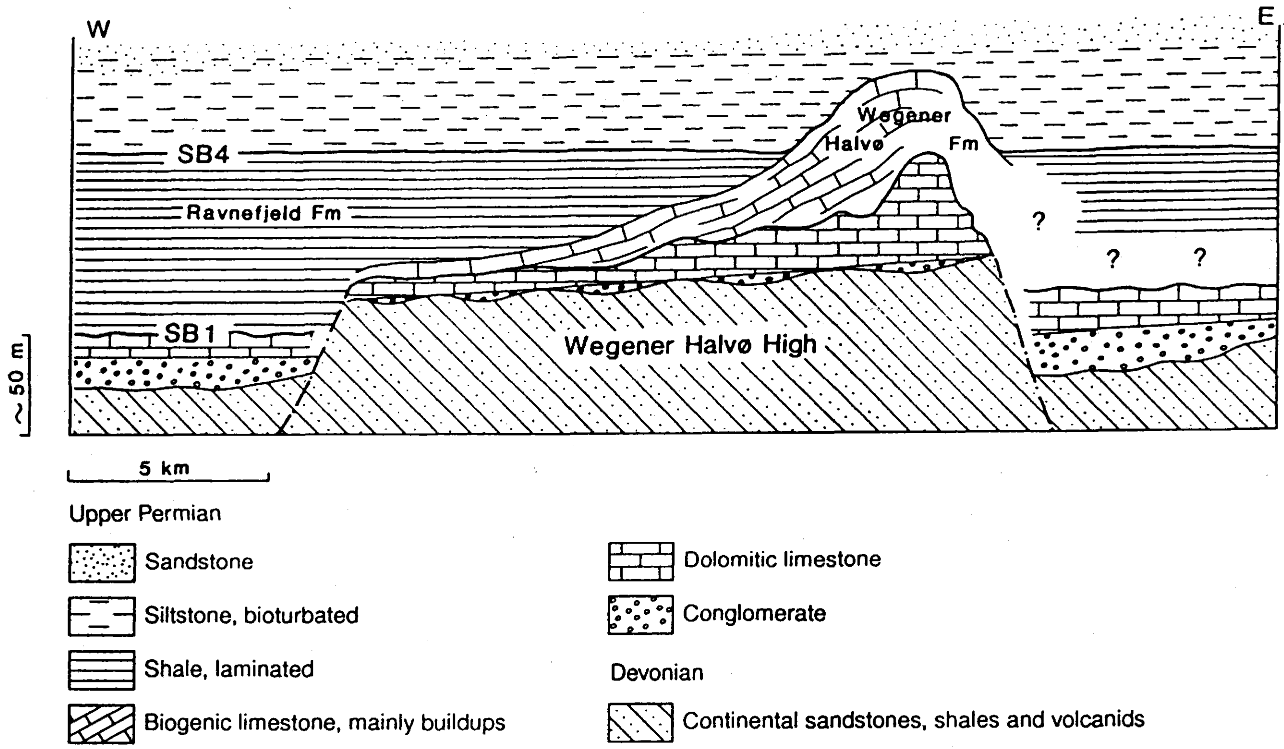

Figure 5. *Schematic cross section of Upper Permian depositional units on Wegener Halvø. Note location of carbonate buildups over crest of faulted block and the successive thicker shale units towards the west (from Stemmerik et al., 1997).*

The Huledal Formation is only scarcely found in the area. In most places, the Upper Permian transgressive succession is deposited on top of folded and eroded Devonian sandstones and volcanics and occasionally on Permo-Carboniferous clastic sediments.

Black, bituminous shales of the Ravnefjeld Formation partly overlie the buildups and partly interfinger with the Wegener Halvø Formation on the western basinwards side of Wegener Halvø (Fig.5). On most of Wegener Halvø, the shales fill karstic palaeo-depressions and inter-reef depressions in the carbonate units (Fig. 6). On the north-western shore of Wegener Halvø, a more thick and consistent shale-sequence is found, representing the more deep-water type, which is expected to exist in most of the central parts of the basin.

The Ravnefjeld Formation is overlain by the Schuchert Dal Formation, a carbonate-rich sandstone in which abundant shell fragments are found as clasts in some places.

Figure 6. *The south-side of the Vimmelskaft valley showing karstic relief in the carbonates filled with black shales of the Ravnefjeld Formation. (Ore minerals were found in the lower part of the shale sequence in all localities visible on the photo.)*

Ore mineral showings in the Ravnefjeld and Wegener Halvø Formations are widespread on Wegener Halvø. Mineralisation in the carbonates are confined to the upper part of the buildups and consist mainly of chalcopyrite and barite with less amounts of galena and sphalerite.

Mineralisation within the Ravnefjeld Formation were found over an extensive area (Fig.7). Ore minerals are mainly sphalerite and galena, but occasionally chalcopyrite was found (especially in the north-western showings). In most places, mineralisation is confined to the lowermost part of the shale sequence, where it occurs in various lithologies. Usually the lowermost concretionary layers or lenses and cemented packstone layers are certain hosts of ore minerals (Fig. 8c-e), but also more loose shale material can host sulphides. Galena and sphalerite are often found to replace small fossils, but in hardly cemented concretions, small (1-3 mm) disseminated crystals are more common. Replacement of pyrite has also been observed in a few cases.

A remarkably rich locality was reported by Thomassen & Svensson (1980) on the southern slope of Lille Ravnefjeld. A visit to this locality led to the finding of a new thoroughly mineralised zone on the northern slope of Lille Ravnefjeld during fieldwork in 1996. The rich mineralisation is confined to deep and relatively narrow shale basin in a karstic trough cut down into the carbonates near the top of Lille Ravnefjeld (Fig. 8a and 9). The basin is cut along the axial plane by a north-south running dyke. A North-South running fault has formerly been mapped in the zone (see geological map: Flemming Fjord 71Ø. 1 Nord, 1: 100.000). No displacement of significance has, however, been noticed along the zone in the Upper Permian sequence. The presence of off-set in the underlying Devonian could not be deter-

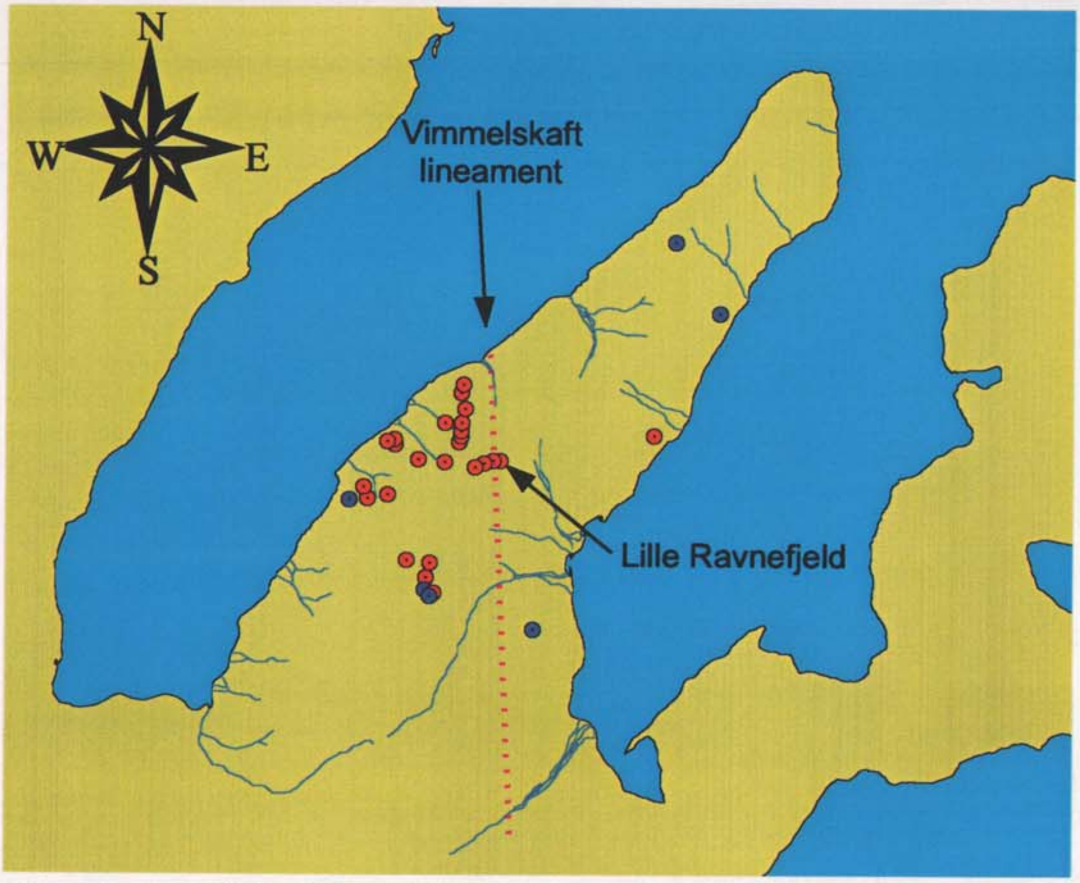

Figure 7. *Sample localities on Wegener Halvø. Red symbols are position of base metal-enriched samples., blue are samples with normal base metal levels. Red stippled line is the Vimmelskaft lineament.*

mined due to difficulties getting down below the cliff-forming carbonates. Judged from the geological map, however, the Devonian-Upper Permian boundary is off-set. The observations suggest that any fault-movements along the zone have been pre-Upper Permian.
The N-S orientated lineament seen in shale basin on top of Lille Ravnefjeld lies in the exact extension of the Vimmelskaft Valley and will be shown later in this report to belong to a hitherto undescribed, extensive N-S lineament, which according to Pedersen (1997) will be termed the ***Vimmelskaft lineament*** *(see Fig. 7)*.

In one case on Lille Ravnefjeld, a normal fault, which is orientated 55N56E, is found to radiate out from the main N-S lineament towards the west in the Ravnefjeld Formation (Fig. 8b). Ca. 5 m of normal movement can be observed along this fault. Spatial considerations suggest that this movement may likely have been accompanied by movements (possibly of local character) along the Vimmelskaft lineament. This could have been of a strike-slip movement, which would explain why no displacement is immediately observed.

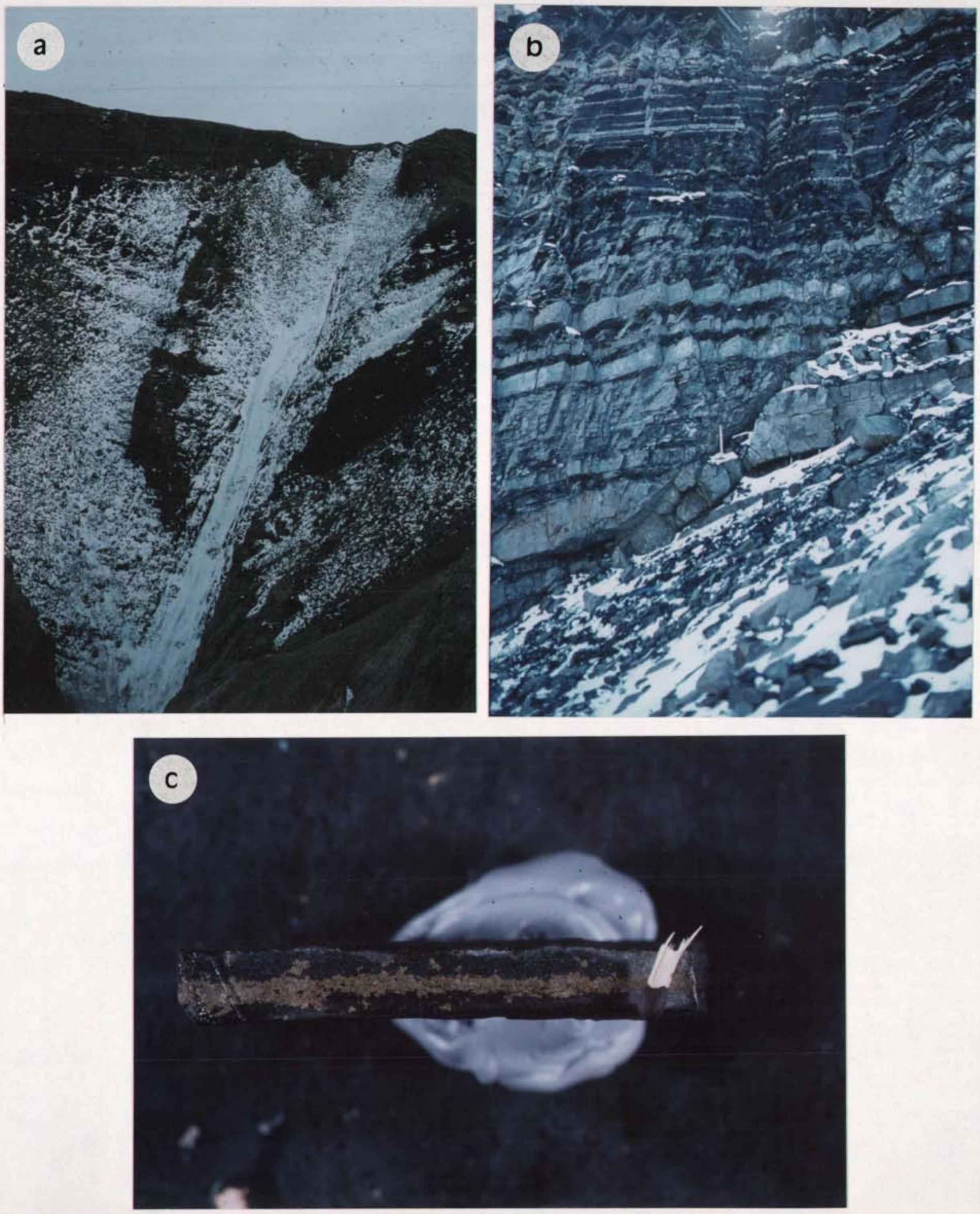

Figure 8. ***a)*** *The Vimmelskaft lineament in the southern extension of the Vimmelskaft Valley on Wegener Halvø. The axis of the lineament coincides with a steep trough in the carbonates suggesting that the lineament acted as a zone of weakness already during one of the karstic events in the Upper Permian. No faulting is observed in the Upper Permian levels, but the zone is penetrated by a Tertiary sill and intense base metal mineralisation occur in the Ravnefjeld Formation shales around the zone.* ***b)*** *Close-up of an area to the right in picture a. Around 10 meters of faulting is seen in this zone and mineralisation around it is widespread. Ore-bearing fluids have obviously been redistributed from the main lineament (picture a) into small faults and fractures like this.* ***c)*** *Sphalerite-rich layer in the Ravnefjeld Formation on Wegener Halvø.*

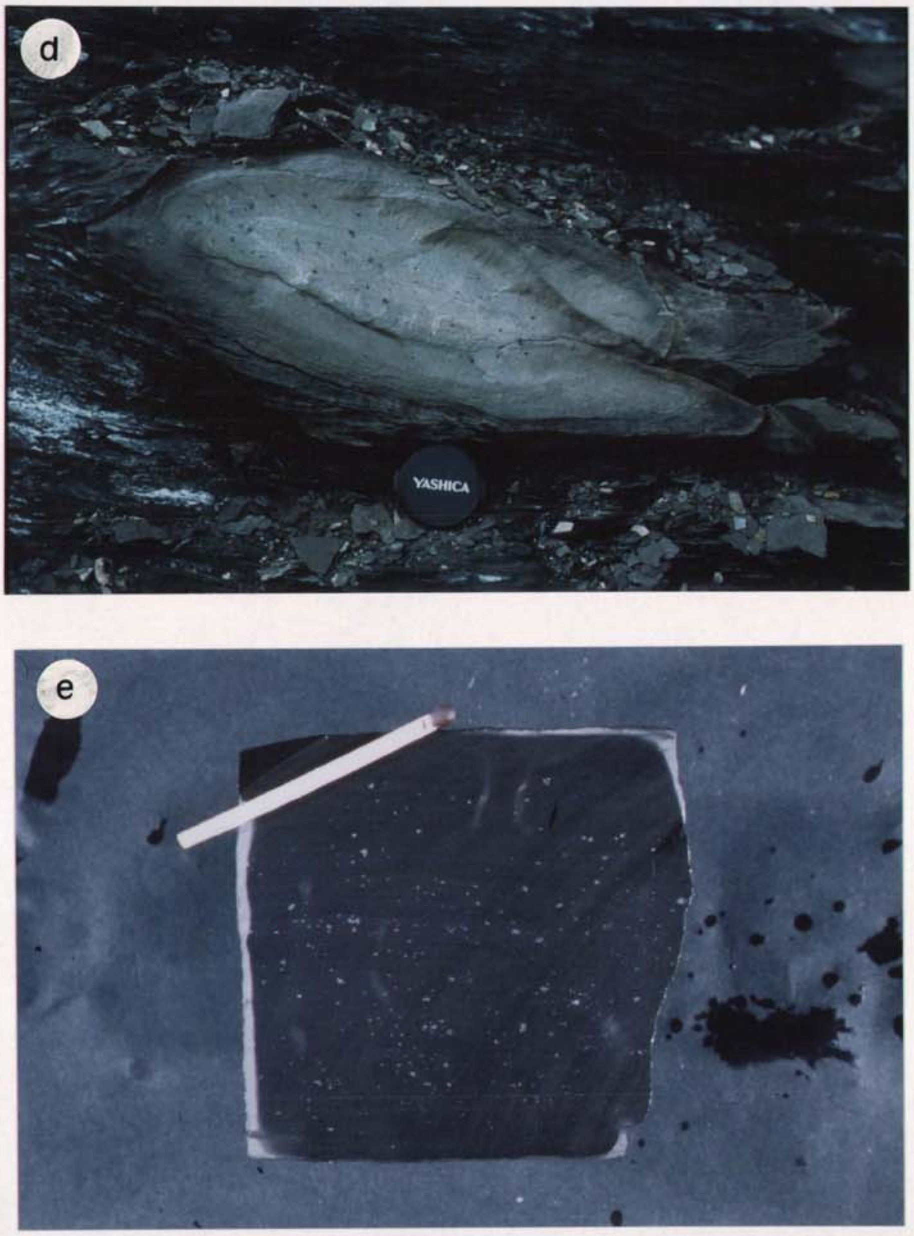

Figure 8 cont. ***d)*** *Ore mineralised concretion in the lower part of the Ravnejfeld Formation on the SW side of the Vimmelskaft Valley.* ***e)*** *Close-up of a Pb- and Cu-mineralised concretion. The disseminated nature of the ore minerals (bright spots) strongly suggests that metals were introduced before lithification took place.*

The coincidence of the main N-S Vimmelskaft lineament with the axial plane of the Lille Ravnefjeld shale basin and the presence of a dyke in the same zone (dykes are not very common in the area), suggest that the Vimmelskaft lineament has acted as a (probably deep-seated) zone of weakness till at least the Tertiary.

Mineralisation in the shale basin on the north-slope of Lille Ravnefjeld is remarkably being present nearly throughout the shale sequence and not only in the lowermost part. Furthermore many highly metal enriched samples can be found in the zone. Field observations strongly suggest that the mineralising fluids were channelled up along the N-S orientated weakness zone and were distributed laterally out from this along permeable layers and radiating faults and fractures.

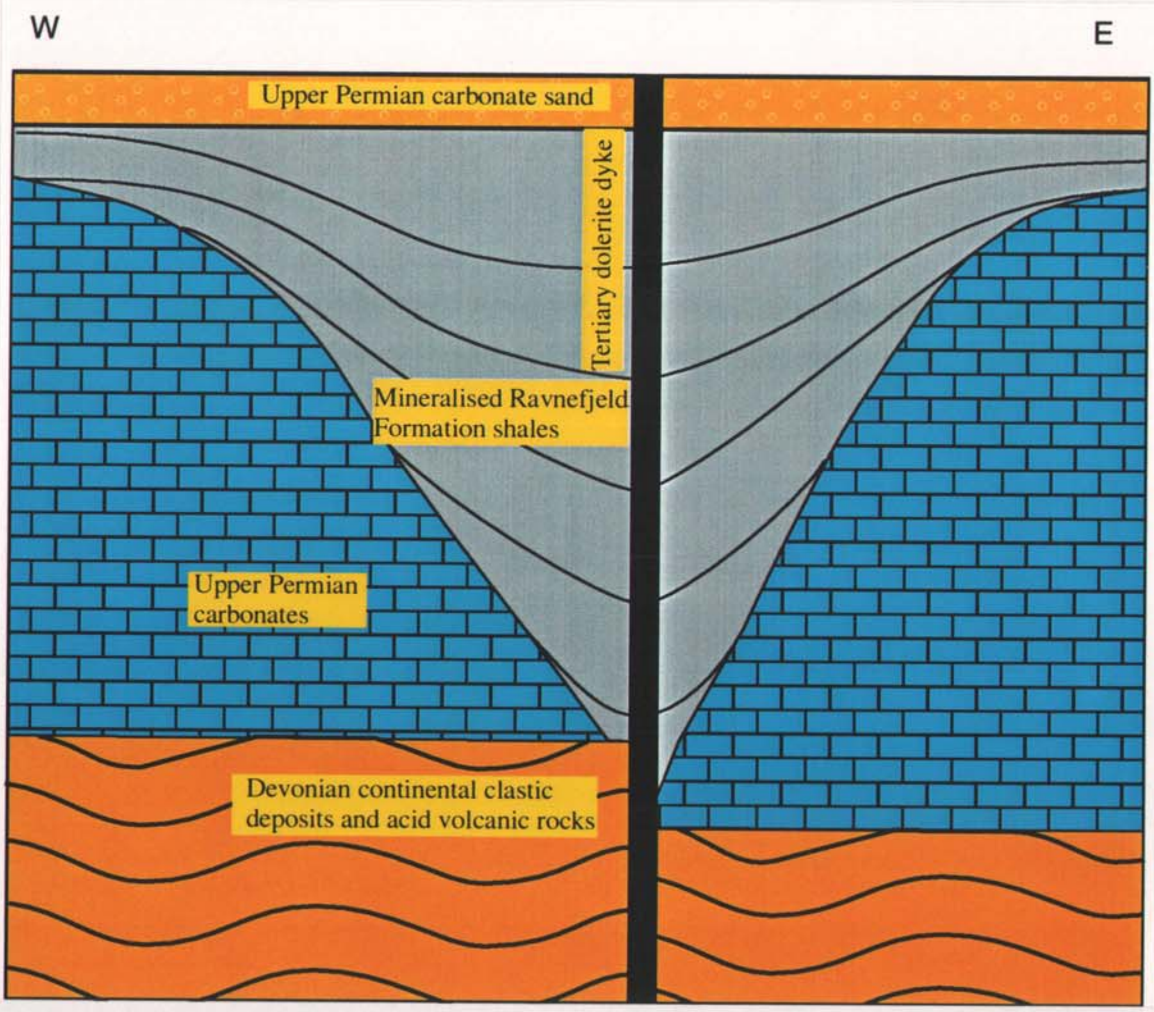

Figure 9. *Scematic section through the heavily mineralised shale basin on Lille Ravnefjeld. Not to scale.*

Looking at the ore mineral distribution map (Fig. 7), it can be seen that the Vimmelskaft lineament is located close to the centre of the mineralised area. In the field it was furthermore clear that the localities closest to the lineament are the heaviest mineralised and that mineralisation decreases away from it. This suggests that the Vimmelskaft lineament has been the controlling structure for the mineralising fluids. The distribution of fluids as far as 1 km away from the Vimmelskaft lineament has probably taken place along fractures in the underlying carbonates. These do normally not cut up through the shales, which well explain the confinement of sulphides to the lowermost part of the shales.

It is most probable that the Vimmelskaft lineament is a deep and laterally extensive structure, although it has not been described previously. First of all, the coincidence of the zone with the southern extension of the Vimmelskaft Valley, suggests that this valley is part of the lineament. Furthermore, the helicopter reco. revealed that zone similar to the one in Fig. 8a is located on Quensel Bjerg in the exact southerly extension of the mineralised zone on Lille Ravnefjeld. The zone on Quensel Bjerg, is a deep carbonate trough filled with the Ravnefjeld Formation like the shale basin described from Lille Ravnefjeld and cut by a N-S running dyke. The Ravnefjeld Formation on Quensel Bjerg is more coarse grained and less suitable as host for mineralisation - and none are found. The carbonates surrounding the zone, however, are thoroughly mineralised with barite and copper and even drusy quartz. Looking at a mineralisation map (Fig.10), it can be seen that carbonates on this part of Quensel Bjerg in general are heavily mineralised, supporting the statement that the Vimmelskaft lineament has been an important channelway for hydrothermal fluids the area.

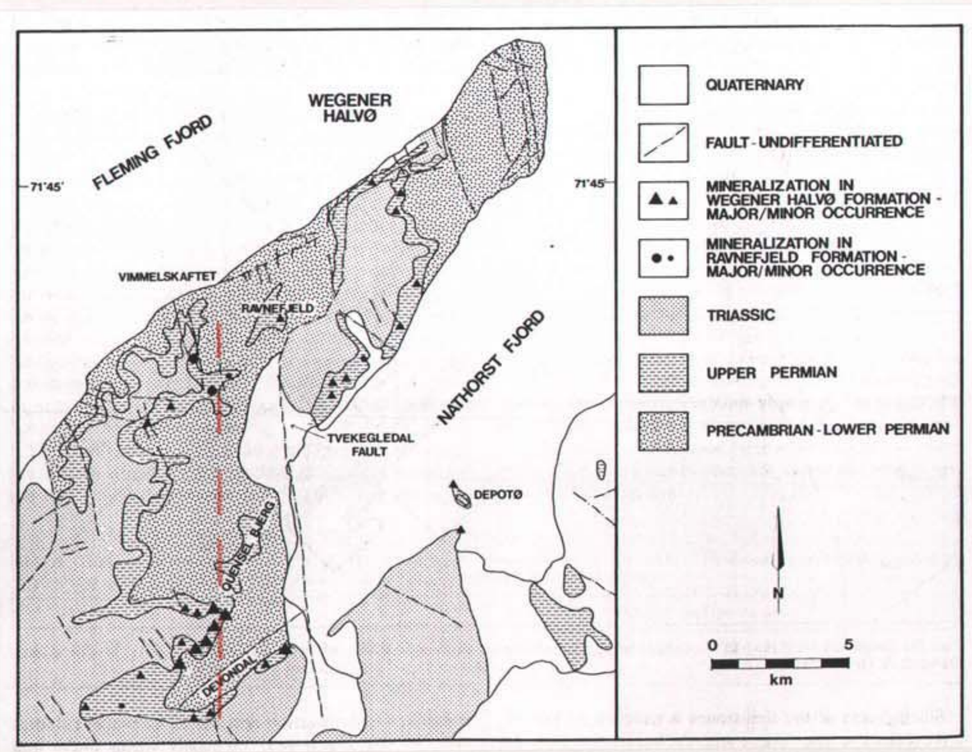

Figure 10. *Simplified geological map of Wegener Halvø with indicated Upper Permian mineralisation. Note the concentration of carbonate-hosted mineralisation on the tip of Quensel Bjerg, which is in the exact southern extension of the main Ravnefjeld Formation mineralisation on Lille Ravnefjeld, just south of Vimmelskaftet (from Harpøth et al., 1986).*

A last point of interest with regard to the Vimmelskaft lineament is, that a N-S running dyke was found to cut the carbonates on the east side of the 'lake bioherms' in south Devondal during fieldwork in '94. Looking at a map, this can be seen to be in the exact prolongation of the Vimmelskaft lineament. If this dyke is hosted by a fracture which is connected to the rest of the lineament (which is believed to be likely), it can be concluded that the Vimmelskaft lineament is an *at least 16 km long, well defined lineament, along which important hydrothermal activity has taken place.*

The Mesters Vig area

Three one-day trips were made in the Mesters Vig area in order to evaluate the potential of mineralisation in the Ravnefjeld Formation here. The main effort was put along the faults which outlines the 'Mesters Vig graben' and which have been controlling for mineralisation in the underlying Permo-Carboniferous red beds in the area.

In general the Ravnefjeld Formation in the Mesters Vig area is more sandy and less bituminous than on Wegener Halvø and the unit is considered unsuitable for Kupferschiefter type of mineralisation. No signs of ore minerals were found in the formation, but some samples were taken for further studies.

Concluding remarks and suggestions for further investigations

The conclusions that can be made from the fieldwork alone is that the Wegener Halvø area is the single most important area with regard to base metal mineralisation within the Ravnefjeld Formation. No signs of mineralisation was found in the unit either on Traill Ø or in the Mesters Vig area. It must, however, be said that mineralisation on Traill Ø could have been overlooked, because the mineralisation is very difficult to detect. (Considerable effort in the known mineralised area on Wegener Halvø was needed in order to spot the first mineralised block). Chemical analyses of the samples from Traill Ø will, however, reveal if any metal enrichment is present.

The Ravnefjeld Formation mineralisation on Wegener Halvø is due to observations in the field believed to be controlled by the Vimmelskaft lineament and to be of pre- to syndiagenetic, possibly exhalative, origin. This statement is mainly based on the presence of disseminated sulphides inside concretionary lenses (Fig. 8c-e). This point should, however, be investigated more carefully through microscopic and other work, because dating of the mineralising event is considered essential for the understanding of the thermal history of the area.

The presently accepted thermal model for the area envisages maturation of the Ravnefjeld shales and consequent hydrocarbon migration during maximal burial in the late Cretaceous. Hydrocarbons were trapped in the carbonate buildups, but were later flushed out by hydrothermal fluids, which may then have been introduced during the regional heating event in the Tertiary.

If, however, hydrothermal activity took place during or shortly after deposition of the shales, the maturation of the sediments could have happened already in the Upper Permian and all mineralisation could then in theory be pre-Tertiary (most likely Upper Permian to Triassic). The timing of the mineralising event is essential to the understanding of the mineralisation processes and thereby to the prediction of what types of occurrences to expect in the area.
In order to gain knowledge of all the mentioned factor, the following investigation methods are suggested for further study on the collected samples:

- Geochemistry
- Microscopy
- Lead isotope investigations (an extensive reference database already exists from the area)
- Fluid inclusion work on sphalerite from the Ravnefjeld Formation
- Ro-measurements on mineralised samples
- Regional S-isotope investigations (in order to see if pyrite and other sulphides in shales from mineralised areas deviate from those from unmineralised areas).

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