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Continued environmental studies in the Qaumarujuk and Agfardlikavsâ fjords, Mârmorilik, Umanak district, central West Greenland

Gert Asmund, Haldis J. Bollingberg and Jan Bondam

The results of studies of the heavy metal background level in the natural environment of the Qaumarujuk and Agfardlikavsâ fjords, adjacent to the lead-zinc mine Sorte Engel (= Black Angel) near Mârmorilik (71°07'N, 51°16'W), have been briefly communicated by Bondam & Asmund (1974), Asmund (1975), Bohn (1975) and Bollingberg (1975). Full details of the analytical results of these surveys have been reported in Danish elsewhere (Vandkvalitetsinstituttet 1972; Grønlands Fiskeriundersøgelser *et al.*, 1974; GGU *et al.*, 1975).

Since then, renewed sampling has been carried out, both in February and August 1974, and in April and September 1975, in order to follow closely the environmental dissemination of some heavy metals in the fjord region, due to disposal of tailings from the flotation plant adjacent to Agfardlikavsâ fjord (fig. 18).

This short communication deals with the content of certain heavy metals of bottom sediments, biological tissues and samples of sea water in the fjord regime after full production started in October 1973.

The tailings of the flotation plant at Mârmorilik are currently being dumped in the outer part of Agfardlikavsâ, which is separated from Qaumarujuk by a sill at a depth of 21 m. From the start of operations in October 1973, until the 1st of January 1975, approximately 450 000 metric tons of tailings have been dumped. The average heavy metal content of the solids in the tailings is currently 1.3 % Zn, 0.37 % Pb, 0.037 % Cu and 0.006 % Cd. The liquid of the tailings contains 1.6 ppm Zn, 0.9 ppm Pb, 0.5 ppm Cu and 0.7 ppm Cd; approximately 6 m^3 of sea water is used for each metric ton of solid waste. The effects of solid waste disposal of this magnitude on the fjord regime has shown to be detectable at an appreciable distance from the source after only two years of operation.

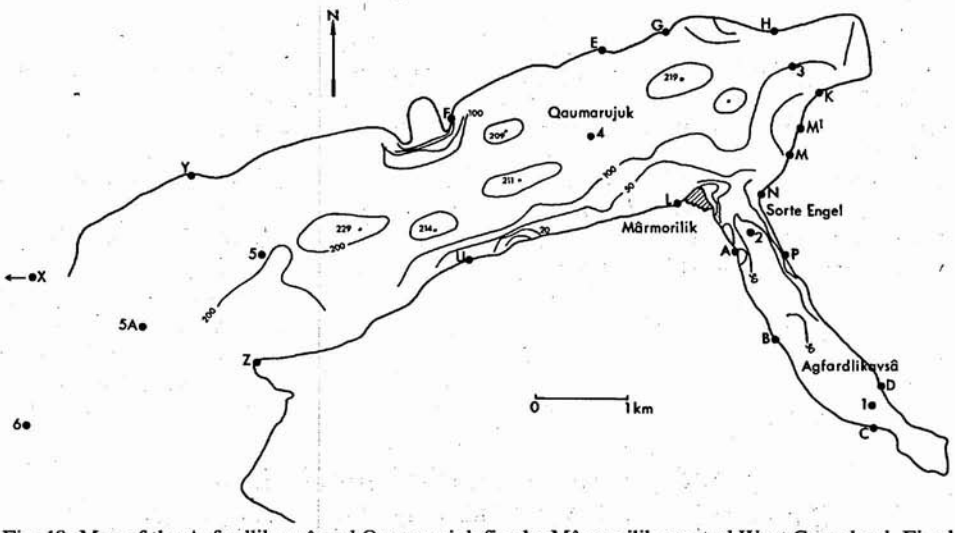

Fig. 18. Map of the Agfardlikavsâ and Qaumarujuk fjords, Mârmorilik, central West Greenland. Fjord depths are in metres. Numbers refer to sample stations referred to in the text; letters are sample localities illustrated in fig. 22.

A short review is given below of the dissemination of solids and dissolved heavy metal ionic species in the fjord system.

Bottom samples

Bottom sediments have been sampled at localities 1–5 (fig. 18). The core from station 2, near to the outlet of the tailings conduit has been treated separately. In 1973, before mining

Table 2. Heavy metal content (in ppm) of the bottom sediments of Agfardlikavsâ and Qaumarujuk fjords, Mârmorilik

	range	average $\bar{x}$	stand. dev. s
Cu ppm	10-60	32	5.3
Ni ppm	14-78	53	7.3
Pb ppm	17-40	27	2.8
Zn ppm		c. 40	
Ag ppm	< 1.0-2.0	1.2	0.2
Fe%	1.4-3.9	2.65	0.45

Table 3. Heavy metal content in the upper 2 cm of bottom sediments in Agfardlikavsâ and Qaumarujuk fjords, Mârmorilik, in August 1974. Detection limit of Zn is normally 200 ppm. At station 3 the Zn content has been determined with an accuracy of ± 30 ppm

Locality	ppm					%
	Cu	Ni	Pb	Zn	Ag	Fe
Agfardlikavsâ						
Station 1	32	46	23	< 200	n.d.	3.0
Qaumarujuk						
Station 3	33	53	66	230	n.d.	2.0
Station 4	30	53	22	< 200	n.d.	2.6
Station 5	29	53	39	< 200	n.d.	2.4

began, bottom sediments were cored at the localities to a depth of 50 cm below the bottom surface. Samples were taken at 10 cm intervals and analysed spectrographically for Cu, Ni, Pb, Zn, Ag, Fe. Table 2 summarises the results on an average basis. The Zn content was determined with less accuracy, for which reason only the approximate average has been given.

In August 1974 bottom sediments were again sampled at the same localities. The upper 2 cm of the cores taken at station 1 in Agfardlikavsâ and stations 3, 4 and 5 in Qaumarujuk, were analysed in the same way as previously. The results are given in Table 3. From this table it is apparent that solid dissemination has reached station 3. The Pb content is outside the given range, with an enrichment of approximately 2.4 times average background, while Zn contamination reaches over 5 times average background.

The core taken at station 2, to a depth of 56 cm below bottom surface, shows a tailings column of 18 cm. The core was sectioned and analysed spectrographically, the results are

Table 4. Heavy metal content of bottom sediment core at station 2, Agfardlikavsâ fjord, Mârmorilik

Depth in cm	ppm					%
	Cu	Ni	Pb	Zn	Ag	Fe
0-9	540	tr.	5300	30500	12	22
9-18	560	tr.	6900	26000	11	17
19-28	35	53	25	< 200	n.d.	3.1
28-37	39	61	20	< 200	n.d.	3.6
38-47	36	61	25	< 200	n.d.	3.1
47-56	27	51	20	< 200	n.d.	2.3

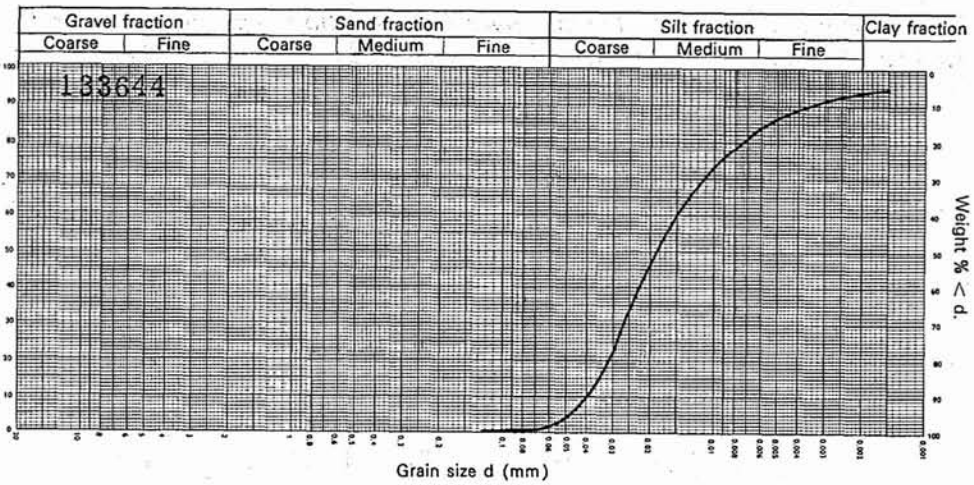

Fig. 19. Grain size distribution of deposited tailings in Agfardlikavsâ fjord. Station 2: GGU sample no. 133644. Mârmorilik, central West Greenland.

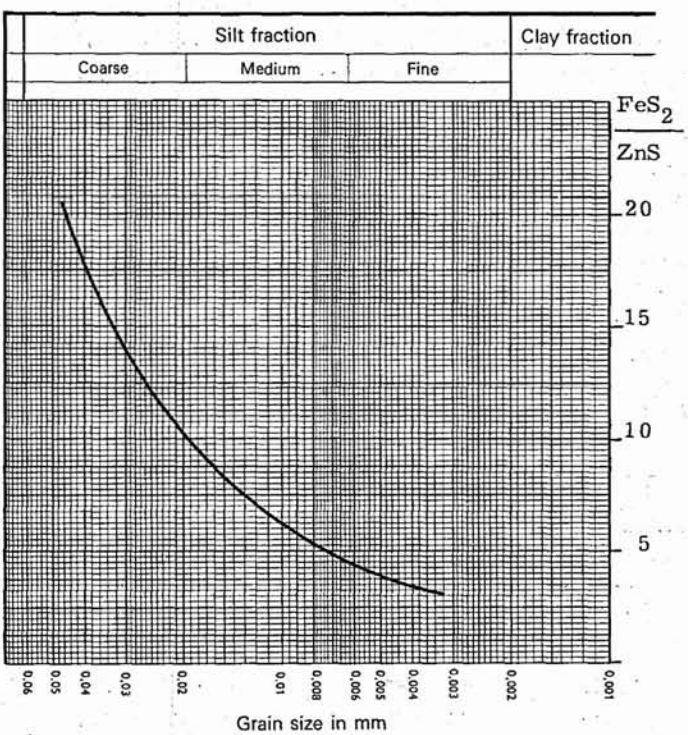

Fig. 20. The ratio pyrite/sphalerite of the tailings of a sample taken at the outflow in October 1973. Mârmorilik, central West Greenland.

given in Table 4. From this it appears that fractionation of the sulphides takes place at some distance from the outflow, presumably due to to differences in grain size (fig. 19). The average Pb and Zn content of the solid deposited waste is increased by a factor of two compared to that of the disposed solid tailings. The rate of accumulation indicates that the influence of the tide on its deposition is negligible.

In order to account for the transportation of solids in suspension, the grain size of the solid waste has been determined, as shown in fig. 19. The ratio FeS_2/ZnS of the tailings against its grain size, as shown in fig. 20, illustrates the accumulation of sphalerite in the fines, with the main constituent of the sulphides in the tailings, being pyrite. With the lowest density of the sulphides in question, sphalerite will be the main indicator for the gradual dissemination of particulate heavy metals in the fjord system.

Biological tissue

Earlier reports show the amounts of various heavy metals in organic samples before mining commenced (Vandkvalitetsinstituttet, 1972; Grønlands Fiskeriundersøgelser *et al.*, 1974).

The geochemical anomaly constituting the outcrop of the Sorte Engel sulphide ore body was found to be mirrored both by sulphide mineral inclusions in seaweed, and by absorbed heavy metals in the tissue of blue mussels (Bondam & Asmund, 1974). New samples of seaweed, mussels and fish were collected in September 1974 (GGU *et al.*, 1975). About 30 samples of wolf-fish and halibut from the inner and outer parts of the adjoining Qaumarujuk fjord were analysed spectrographically for lead, zinc, silver, cadmium and copper, and compared with 80 analyses from fish caught in 1973 (Tables 5 & 6). The 1974 post-mining samples show no heavy metal accumulations in wolf-fish muscles and in wolf-fish liver, and even a slight decrease with age of the content of some heavy metals has been observed.

Statistical data are still insufficient to warrant any conclusion on the effect of mine waste disposal on migrant fish species in the fjord system. However, the content of lead and zinc in

Table 5. Content of some heavy metals (in ppm) in muscles of wolf-fish (Anarrhichas lupus) *from catches made in 1973 and 1974, Mârmorilik*

Wolf-fish muscle	Ag	Cu	Pb	Cd	Zn
Average 1973	< 0.02	0.38	0.15	< 0.2	1.9
Average 1974	0.02	0.19	0.17	0.1	1.9
Median 1973	-	0.24	0.14	-	1.8
Median 1974	0.02	0.18	0.06	-	1.8
Maximum 1973	0.02	1.21	0.71	< 0.2	6.4
Maximum 1974	0.05	0.34	0.16	< 0.2	2.8
Minimum 1973	< 0.01	0.07	0.01	< 0.2	0.1
Minimum 1974	0.01	0.12	0.03	< 0.2	1.2

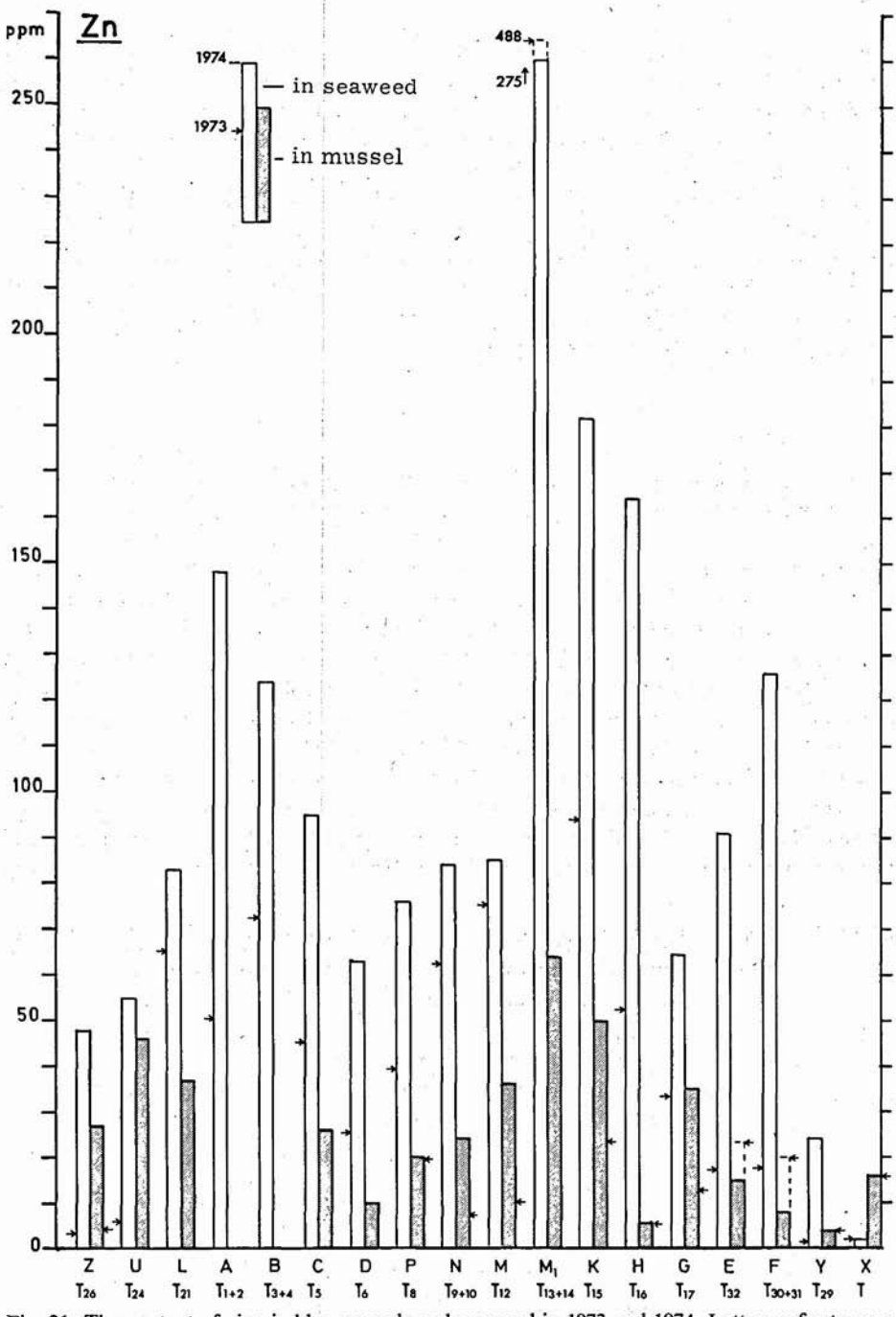

Fig. 21. The content of zinc in blue mussels and seaweed in 1973 and 1974. Letters refer to sample localities 1973 (fig. 18), T designates samples taken in 1974. Mârmorilik, central West Greenland.

*Table 6. Content of some heavy metals (in ppm) in halibut (*Platysomatichtys hippoglossoides*) from catches made in 1973 and 1974, Mârmorilik*

Halibut	weight/length	Ag	Cu	Pb	Zn
Average 1973	1.2 kg	0.011	0.18	0.08	0.9
Average 1974	52 cm	0.01	0.20	0.09	0.9
Median 1973	1.0 kg	0.01	0.16	0.08	0.9
Median 1974	50.5 cm	0.01	0.18	0.09	1.0
Maximum 1973	4.5 kg	0.04	0.72	0.20	1.4
Maximum 1974	74 cm	0.04	0.54	2.10	1.5
Minimum 1973	0.3 kg	tr.	0.07	0.1	0.1
Minimum 1974	42 cm	tr.	0.11	0.1	0.2

blue mussels and seaweed from nearly all localities sampled shows an increase over their natural, already anomalously high pre-mining levels. This increase is apparently due to the tailings dumped in Agfardlikavsâ fjord.

Fig. 21 shows the analytical results for zinc only, as an indication of the progressive dissemination of waste products.

Sea water

Sea water is sampled every half year at various depths at fixed stations in the fjord system and subsequently analysed by anodic stripping voltammetry.

The results of the chemical analyses of the sample batch taken in September 1975 is given in Table 7. The conclusion drawn is the same as that mentioned in Bondam & Asmund (1974), that the threshold sill separates heavily contaminated water in Agfardlikavsâ from sea water in the Qaumarujuk fjord.

The large number of samples taken in 1975 as a whole, shows that the sea water in the fjord region is very inhomogeneous with respect to lead, zinc and cadmium contents. Therefore exact calculations of the dispersion rates of the dissolved heavy metals in question is impossible.

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Station	Depth	ppb			
No.	Metres	Zn	Cd	Pb	Cu
1	0	4.6	0.08	2.3	0.6
	10	3.1	0.07	3.0	1.0
	20	22.6	0.26	10	1.2
	30	300	2.00	226	
	50	3.1	0.13	4.0	1.5
2	0	4.6	0.10	4.6	1.0
	10	9.0	0.14	25.5	1.0
	20	15.0	0.28	12.2	0.9
	30	71	0.82	86	2.5
	50	560	4.97	448	
	65	900	5.26	488	
3	0	1.5	0.08	4.6	0.9
	10	1.1	0.22	2.3	0.7
	20	3.0	0.10	3.1	1.3
	30	10.7	0.09	7.6	1.0
	50	8.2	0.10	5.4	0.5
	75	7.1	0.13	6.2	0.9
	100	5.8	0.10	5.4	0.7
	120	3.7	0.10	3.9	0.7
4	0	2.8	0.05	2.0	1.4
	10	1.3	0.03	1.1	0.5
	20	3.3	0.17	2.9	0.7
	30	3.8	0.14	3.0	0.4
	50	5.1	0.18	3.9	0.4
	75	8.8	0.20	7.5	0.4
	100	5.7	0.08	6.6	0.6
	150	1.7	0.11	1.9	0.4
	170	6.3	0.13	6.2	0.8
5	0	3.5	0.18	1.8	0.8
	10	1.2	0.09	1.4	0.3
	20	2.3	0.15	2.5	0.5
	30	4.1	0.19	2.7	0.5
	50	1.5	0.16	2.2	0.2
	75	4.6	0.15	3.5	0.3
	100	5.6	0.28	4.2	0.8
	150	1.8	0.13	1.4	0.5
	200	1.9	0.11	1.1	0.8
5A	0	0.6	0.03	1.4	0.4
	10	0.4	0.03	1.1	0.4
	20	5.8	0.15	2.6	0.4
	30	1.1	0.15	3.0	0.4
	50	7.6	0.44	27	0.6
	75	2.9	0.16	3.8	0.3
	100	6.3	0.20	4.3	0.6
	150	2.4	0.15	2.4	0.9
	170	6.7	0.19	2.4	0.3
6	0	0.5	0.04	0.9	0.4
	10	0.2	0.06	1.8	0.4
	20	0.4	0.03	0.9	0.4
	30	0.6	0.07	1.5	0.6
	50	0.9	0.03	2.7	0.4
	75	<0.2	0.03	1.4	0.3
	100	1.3	0.06	1.8	0.6
	150	0.3	0.10	1.6	0.3
	200	0.4	0.08	2.2	0.3

Table 7. Content of dissolved metals in sea water at Mârmorilik during September 1975

GGU *et al.* 1975: Recipientundersøgelse 1974, Agfardlikavsâ, Qaumarujuk. 108 pp. Copenhagen.

Grønlands Fiskeriundersøgelser *et al.* 1974: Recipientundersøgelse af Qaumarujuk Fjord og Agfardlikavsâ. July – August 1973. 169 pp. Copenhagen.

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Aeromagnetic surveys in southern and central West Greenland between 63° and 71°N

Leif Thorning

A two-year programme of aeromagnetic investigations has been planned for certain areas of West Greenland. The work was started in 1975 from a base camp at Søndre Strømfjord with the majority of the operations taking place in the region south of 67°N. The airborne measurements of the total intensity of the earth's magnetic field were carried out in co-operation with the party doing radiometric work in the same part of Greenland (Secher, this report). The same aircraft and in part the same instruments were used. Next year, the work will be continued with the main emphasis on the regions north of 67°N. On completion of the airborne programme follow-up geophysical groundwork will be initiated.

In 1975 more than 30 000 km of magnetic profile were measured (fig. 22). Most of this (25 000 km) was located in grids covering approximately 40 000 km². At the time of writing most of the digital data is in the process of computer compilation, and only comments based on inflight observations and on inspections of the analogue records can be presented here. This note therefore, deals with the extent of the field work, and points to some of the more obviously interesting features seen in the data.

Instrumentation

The equipment for the geophysical work was installed in a Britten-Norman Islander aircraft which has an endurance of 6–8 hours. The equipment consisted of a proton-free precision magnetometer with a stinger mounted sensor, a compensation unit, a radar altimeter, equipment for analogue and digital in-flight registration of total intensity and radar altitude, and a scintillometer. All instruments used the same time base supplied by a quartz clock. The sensitivity of the magnetometer is 1 gamma with a sampling interval of 1 sec. Another proton magnetometer of the same sensitivity situated at Søndre Strømfjord served as a base magnetometer. This also supplied analogue and digital registration of the total intensity of the ambient magnetic field and thus provided the necessary record of the diurnal