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The Black Angel lead-zinc mine 1973–90

Bjørn Thomassen

On 25th July 1990 the last ore was processed in the ore dressing plant at Mârmorilik thereby terminating seventeen years exploitation of the Black Angel (Sorte Engel) lead-zinc deposit (Fig. 1). During that period some 1.4 million tons zinc, 0.4 million tons lead and 250 tons silver have been extracted from the deposit which originally comprised 13.6 million tons ore grading 12.3% Zn, 4.0% Pb, 29 ppm Ag and 13.7% Fe (Table 1). The mining operations ceased because the extractable ore reserves were exhausted.

Samples of lead-zinc sulphides that led to the discovery of the Black Angel deposit were found in connection with marble quarrying in the 1930s (Eklund, 1940) and investigated by Danish geologists in the 1930s and 1940s (Sølver, 1943; Pauly, 1952). Commercial investigations including diamond drilling (21 holes totalling 7.3 km) were carried out in the 1960s by a syndicate dominated by Cominco Ltd. of Canada. In 1971 the Danish mining company Greenex A/S (incorporated in 1964 and 62.5% owned by Cominco Ltd. through the subsidiary Vestgron Mines Ltd.) obtained an exploitation concession. Underground exploration in 1971–72 indicated a probable ore reserve of 4.1 million tons grading 15.0% Zn, 5.0% Pb and 28 ppm Ag. Based on this reserve and after a hectic construction period, production started in October 1973. In July 1986 Greenex A/S was sold to the Swedish company Boliden Mineral AB.

Geology

The ores are hosted in the Mârmorilik Formation of the Lower Proterozoic Karrat Group (Garde, 1978; Henderson & Pulvertaft, 1987). The formation rests unconformably on an Archaean gneiss complex and is overlain by semipelites of the upper Karrat Group. It consists of calcitic and dolomitic marbles with a basal quartzitic unit and intercalations of anhydrite-bearing marbles and semipelitic schists. The formation is be-

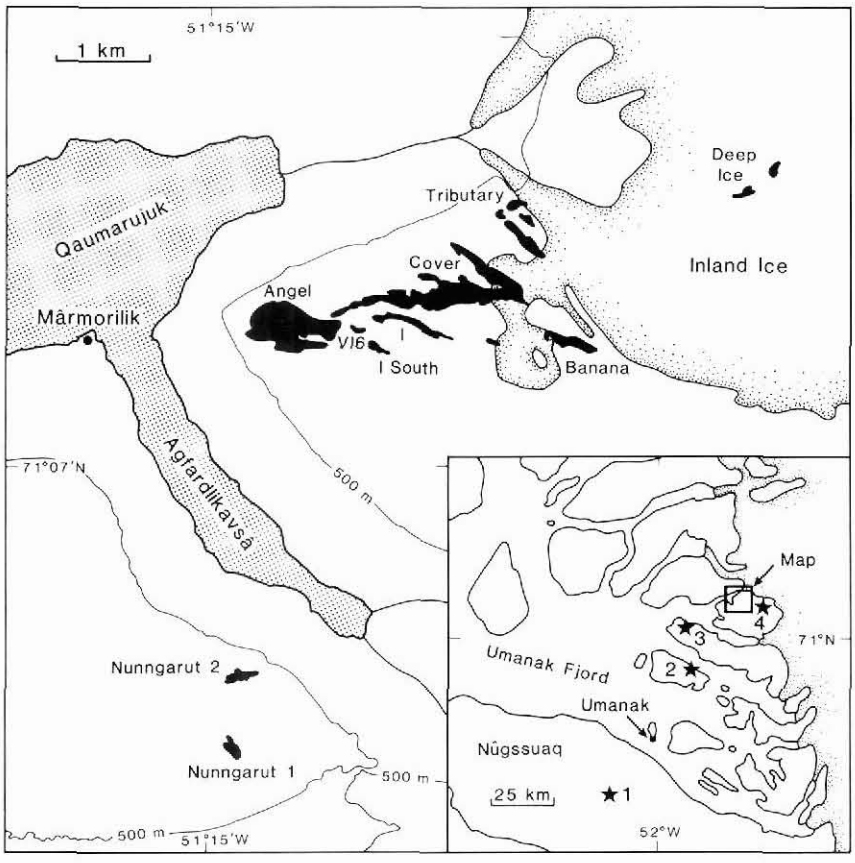

Fig. 1. Map of the Mârmorilik area with ore bodies shown in black. Stars in inset map show main prospects of Black Angel type: 1. Central Nûgssuaq, 2. Agpat, 3. Uvkusigssat, 4. South Lakes.

lieved to have been deposited on a carbonate shelf in a back-arc basin between 1900 and 2500 million years ago (Grocott & Pulvertaft, in press).

The Mârmorilik Formation was deformed during the mid-Proterozoic Rinkian orogeny. Metamorphism reached upper greenschist facies. In the mine area, where the formation has been tectonically thickened to *c.* 1000 m, three main phases of folding and thrusting have been distinguished (Pedersen, 1980).

Table 1. Production and ore reserves at the Black Angel mine

	Ore in 1000 t	Grades Pb%	Zn%	Metal in 1000 t Pb	Zn
Production 1973–1990	11 196	4.1	12.6	456	1 411
Non-extractable reserve 1990	2 355	3.5	10.6	81	249
Total reserve	13 557	4.0	12.3	537	1 661
Recovery	83%			85%	85%

Source: van der Stijl (1990).

Stratabound sulphide mineralisation occurs at various levels in the carbonate sequence. The main ore bodies are located 600–700 m a.s.l. in the upper part of the sequence which is dominated by calcitic marble, whereas the satellite ores of Nunngarut to the south are hosted in the lower, dolomite marble dominated part of the sequence. The ore forms flat-lying, highly deformed, massive sulphide lenses, of which ten reach economic size (Fig. 1, Table 2). The massive ore consists of pyrite, sphalerite and galena, with abundant rotated marble fragments and quartz inclusions (Fig. 2). The main accessory ore minerals are pyrrhotite, chalcopyrite, tennantite and arsenopyrite. Cherty horizons and disseminated graphite are quite common in the wall rocks, whereas minor fluorite and baryte are restricted to a few of the ore bodies. Various ore tectonites (massive ore, banded ore, porphyroclastic ore, remobilised ore) have been distinguished (Pedersen, 1980).

Opinion on the genesis of the ores has varied. Pedersen (1981) proposed a sabkha model whereas a Mis-

Fig. 2. Typical ore left in pillar in the Cover zone of the Black Angel mine. Fractures indicate that the maximum load-bearing capacity of the pillar has been exceeded. The ore consists of sphalerite, galena and pyrite. White marble rafts and inclusions are conspicuous in the upper part af the pillar.

sissippi Valley type has been suggested by Carmichael (1988) and a sedex type by Sangster (1990).

Mining

For the ore reserve calculations, computerised from the early 1980s, a diluted cut-off grade of 8% combined lead and zinc was used. The development in ore reserves is illustrated in Table 3. It can be seen that it was possible to more than triple the original minable reserves during the lifespan of the mine. New ore bodies were located by extensive surface drilling programs (total of 160 km in 400 holes) and further investigated by underground exploration. At mine closure 2.4 million tons of ore were tied up in pillars and other inaccessible areas (Table 1).

Table 2. Tonnage and production (block tonnage) of individual ore bodies of the Black Angel mine

Ore zone	Tonnage in 1000 t	Pb%	Zn%	Production in 1000 t	Pb%	Zn%	Recovery % Ore	Recovery % Metal
Angel	6 645	4.8	14.2	5 283	5.0	14.6	83	85
Cover	3 992	2.8	10.5	3 343	3.0	11.0	84	88
Tributary	767	2.0	9.1	683	2.0	9.2	89	90
I	684	4.6	12.3	622	4.7	12.7	91	94
Banana	450	2.9	8.3	335	3.2	9.1	73	82
Nunngarut 1	347	3.8	8.7	327	3.8	8.8	94	95
Deep Ice	316	5.5	14.8	312	5.5	14.9	99	99
Nunngarut 2	197	3.1	7.2	150	3.2	7.5	76	79
I South	119	4.3	11.1	112	4.4	11.2	95	95
V 16	36	1.9	5.3	28	2.0	5.4	79	81
Total	13 557	4.0	12.3	11 196	4.1	12.6	83	85

Source: van der Stijl (1990).

The ore was mainly mined by the room-and-pillar method; only smaller steep ore bodies were mined by cut-and-fill methods. In thin parts of the ore, selective mining was conducted. Remnant mining, guided by a careful registration of metal contents in the pillars aiming at maximal metal recovery, and supervised by an extensive rock mechanics programme (Krauland & Söder, 1987), led to a very high metal extraction rate (Table 2). Pillar mining in the Angel zone required extensive backfilling of waste.

All the ore zones, except the Deep Ice zone, are in permafrost. On the whole, the permafost proved to be an asset for mine stability, and contributed to the high extraction rate.

After drilling by hydraulic jumbos and blasting, the broken ore was hauled by truck to ore passes and from there by locomotive haulage to the primary crusher. The crushed ore was skipped across the fjord to the ore dressing plant in Mârmorilik by an aerial tramway with free span of 1500 m and a capacity of 120 tons an hour. From Nunngarut the ore was trucked directly to a crusher in Mârmorilik. The concentrating process was a conventional selective flotation of galena and sphalerite. In recent years the recovery was *c.* 96% for zinc, 90% for lead and 75% for silver. Annual production averaged 135 000 t of 57.6% zinc concentrate and 35 000 t of 69.7% lead, 420 ppm silver concentrate. Tailings were discarded through a pipeline to the bottom of Agfardlikavsâ fjord (Alm *et al.*, 1987; Wyllie, 1988).

Table 3. Annual ore production (mill feed) and ore reserves at the Black Angel mine

	PRODUCTION			EXTRACTABLE RESERVES		
Year	Ore in 1000 t	Pb%	Zn%	Ore in 1000 t	Pb%	Zn%
1973	159	4.3	18.6	3 409	5.0	16.1
1974	575	5.1	18.3	2 793	5.1	15.6
1975	590	4.8	15.4	3 995	4.9	14.1
1976	590	5.2	14.7	3 572	4.9	13.9
1977	556	6.1	15.1	3 575	4.6	12.4
1978	619	5.8	14.5	3 067	4.8	13.9
1979	636	5.5	14.6	3 022	4.6	13.4
1980	642	5.3	13.4	3 177	4.4	13.4
1981	662	5.0	12.7	2 756	4.2	13.5
1982	675	4.7	12.2	1 958	4.0	13.4
1983	675	3.6	12.3	2 115	3.4	10.7
1984	675	3.0	11.0	1 774	3.3	10.1
1985	728	2.8	10.0	1 462	3.0	9.7
1986	735	2.5	9.0	1 207	3.0	9.4
1987	740	3.2	9.9	976	3.4	9.4
1988	735	3.7	11.1	612	3.3	9.1
1989	785	3.5	9.7	238	3.1	8.6
1990	469	4.1	10.8	0	-	-
Total	11 265	4.2	12.4			

Source: van der Stijl (1990).

The future

In connection with the closure of the mine, Greenex A/S deposited a variety of geological records at the

Geological Survey of Greenland (GGU): data files comprising the ore reserves data base, all geological sections and mine maps, a collection of typical ore specimens and 23 km of drill cores. A complete set of surface exploration reports was already housed at GGU. Based on this collection of geological material it will be possible to continue studies of the Black Angel ores and possibly gain new understanding of the distribution of ore deposits in the area.

Outside the old mine area, lead-zinc prospects of Black Angel type mineralisation occur in four areas (Fig. 1). Three of these were drill tested, but all have been rejected as viable prospects by Greenex A/S. It is to be hoped that further research in the Black Angel records and continued exploration of the Mârmorilik Formation will ultimately result in renewed mining in the region.

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Ornamental stones in West and South Greenland

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In the spring of 1990 the Greenland Home Rule administration initiated a project to evaluate the potential for ornamental stones in West and South Greenland, with support from the Geological Survey of Greenland (GGU). The project was established in view of an interesting new development of the international ornamental stone market which might be exploited to diversify the economy and provide new job opportunities