The gold and base metal potential of the Lower Proterozoic Karrat Group, West Greenland

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The mineral potential of the Karrat Group in West Greenland became important after exhaustion in 1990 of the Black Angel lead-zinc mine situated within this supracrustal unit. It consists of shelf and turbidite type metasediments and subordinate metavolcanics deposited in an epicontinental marginal basin. Known mineralisation comprises the Black Angel deposit and a number of other marble-hosted lead-zinc occurrences, as well as extensive sulphide facies iron formations and vein type base and precious metals mineralisation in quartzites and metagreywackes. Further areas with anomalously high contents of both base metals and gold-arsenic-tungsten are indicated by drainage geochemistry. The mineral potential of the Karrat Group is for massive base metal sulphide deposits hosted in marbles or clastic metasediments, and turbidite hosted gold-bearing veins and shear zones.

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The Lower Proterozoic Karrat Group (Fig. 1) is the most extensive supracrustal unit in the Precambrian shield of West Greenland. It also hosted the largest commercial ore deposit of Greenland, the Black Angel (Sorte Engel) lead-zinc deposit at Mârmorilik, which was mined during the period 1973–90.

Geological reconnaissance of the supracrustal rocks in the area commenced in the nineteenth century, and systematic mapping at scale 1:100 000 was carried out between 1962–1983 by the Geological Survey of Greenland (GGU) (Escher & Stecher, 1980; Grocott & Vissers, 1984; Henderson & Pulvertaft, 1987). Mineral exploration has been concentrated on the Black Angel style lead-zinc ores which were first discovered in 1938. In the 1960s, 1970s and early 1980s, extensive exploration of the marble outcrops south of Mârmorilik was carried out by Greenex A/S and Cominco Ltd. (Gill, 1975; King, 1982), whereas the area north of Mârmorilik was only investigated in one major reconnaissance programme (Allen & Harris, 1980). North of Svartenhuk Halvø, the Karrat Group remains virtually unexplored from an economic point of view.

The approaching closure of the Black Angel mine induced GGU to initiate an assessment of the mineral potential of this part of Greenland. In this context selected mineralised localities in the Umanak district were reconnoitred in 1989 (Thomassen, 1989), and an orientation survey was carried out 1989–90 in the Íngia area in the northern part of the district (Thomassen, 1990; 1991a) (Fig. 1).

This paper summarises the geology, mineralisation and drainage geochemistry of the Karrat Group and presents an assessment of mineral potential.

Geological framework

The Karrat Group belongs to the Foxe–Rinkian mobile belt of NE Canada and central West Greenland (Henderson & Pulvertaft, 1987). The belt constitutes a component of the major Early Proterozoic Trans-Hudson Orogen of North America (Lewry & Collerson, 1990). Exposures of Karrat Group supracrustal rocks are known from Red Head in the north to Nûgssuaq in the south, a distance of *c.* 550 km covering an area of some 10 000 km^2 (Fig. 1). About two thirds of the exposures occur in the Umanak district south of 72° 30′N, the remaining third in the Upernavik district north of this latitude. The supracrustal rocks unconformably overlie an Archaean basement (Umanak gneiss) and are, north of Svartenhuk Halvø, intruded by a major syn-tectonic granite/charnockite body, the 1860 ± 25 Ma Prøven igneous complex (Kalsbeek, 1981). The Rinkian mobile belt is transected by a major NNW–SSE dolerite dyke swarm dated at 1645 ± 30 Ma (Kalsbeek & Taylor, 1986) and to the south-west the

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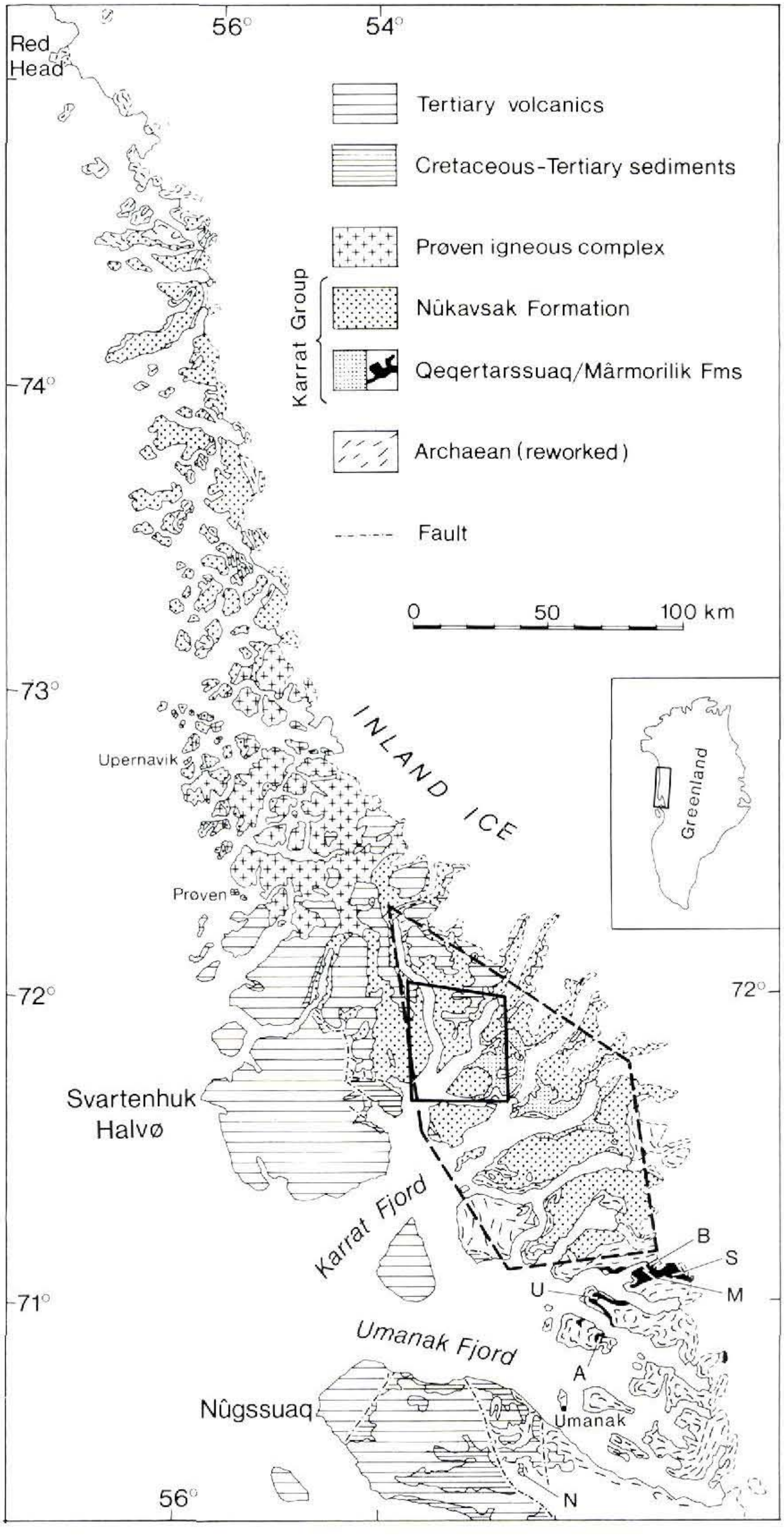

Fig. 1. Map showing the extent of the Karrat Group in West Greenland (modified from Grocott & Pulvertaft, 1990), and the areas covered by the 1979 Cominco geochemical survey (*dashed line*) and the 1989–90 GGU geochemical survey in the Íngia area (solid line). M = Mârmorilik, B = Black Angel mine, S = South Lakes prospect, U = Uvkusigssat prospect, A = Agpat prospect, N = Nûgssuaq showing.

Precambrian rocks are covered by Cretaceous–Tertiary sediments and volcanics.

The Karrat Group is divided into three formations (Henderson & Pulvertaft, 1967, 1987). The carbonate-dominated Mârmorilik Formation occurs in the southern part of the Umanak district, whereas the mainly siliciclastic Qeqertarssuaq Formation occurs further to the north. The two formations are believed to have been deposited simultaneously in separate sub-basins. The Mârmorilik Formation, which reaches a thickness of 1600 m, consists of calcitic and dolomitic marbles with a thin basal clastic unit, intercalations of pelitic and cherty schists, and locally evaporites (Garde, 1978). The Qeqertarssuaq Formation is dominated by impure quartzites with variable amounts of pelitic schists and rare marbles and is up to 3000 m thick. It hosts pods of ultramafic rocks and, at the very top there is a mafic unit of hornblende schist and amphibolite of volcanic origin. The latter is restricted to a sub-basin in the northern Umanak district, where it reaches a maximum thickness of *c.* 600 m. The Mârmorilik and Qeqertarssuaq Formations are overlain by a blanket of flysch-type metasediments, the Nûkavsak Formation, that has a minimum structural thickness of 5 km. Graphitic pelites occur near the base of this formation, but otherwise the sequence is wholly dominated by interbedded pelitic and semipelitic rocks, often displaying graded bedding. These rocks are metamorphosed shales and greywackes.

The depositional environment was first a stable shelf setting with rifted sub-basins (Mârmorilik and Qeqertarssuaq Formations); this was terminated by a volcanic episode. After this, the depositional environment changed to a larger, deeper turbidite basin (Nûkavsak Formation). It has been suggested that the Karrat Group was deposited in an epicontinental marginal (back-arc) basin developed in the upper plate above a subduction zone further to the south (Grocott & Pulvertaft, 1990).

The Precambrian rocks underwent deformation during the Middle Proterozoic Rinkian (Hudsonian) orogenesis. The tectonic style is characterised by mantled gneiss domes and gneiss-cored fold nappes north of Mârmorilik, whereas tectonic interleaving of cover and basement rocks is common to the south. However, a number of major low-angle ductile shear zones involving both basement and cover have also been identified in the northern part of the Umanak district. The Rinkian metamorphism occurred under high temperature – low pressure conditions related to lithospheric extension, in an orogenic setting in which several phases of extension and shortening are evident (Grocott & Pulvertaft, 1990). The regional metamorphic grade ranges from greenschist to granulite facies, but amphibolite facies rocks are the most widespread.

Mineralisation

Mârmorilik Formation

The *Black Angel mine* worked ten ore bodies of commercial size (0.1–6.6 million tonnes) with a total of 13.6 million tonnes grading 12.3% Zn, 4.0% Pb, 29 ppm Ag and 13.7% Fe (Pedersen, 1980, 1981; Carmichael, 1988; Thomassen, 1991b). Mining ceased in 1990. The main ore bodies are hosted in the upper part of the Mârmorilik Formation, which is dominated by calcite marble. This host rock contains variable amounts of dolomite, phlogopite, graphite, chert, anhydrite, fluorite and barite as well as lenses of pelitic schist. The distribution of ore bodies is controlled by a major *z*-fold with a 070° striking near-horizontal axis. The individual bodies form mainly flat-laying, tectonised sheets of massive sulphides with abundant marble and quartz inclusions. The main ore minerals are pyrite, sphalerite and galena. Two satellite ore bodies are hosted in the dolomite marble that dominates the lower part of the Mârmorilik Formation. The existence of an additional ore potential in the old mine area is indicated by ore grade intersections known from surface drillings in two areas east of the known ore bodies (Harris, 1986).

The *South Lakes prospect* is situated some 10 km south-east of Mârmorilik and hosted in lower Mârmorilik Formation marbles (Fig. 1). Massive pyrite-sphalerite-galena lenses and sheets are concentrated in a number of fold closures. Surface investigations and diamond drilling have indicated a maximum potential tonnage of 50 000 tonnes with 20% combined lead and zinc for the most promising lens (Harris, 1985).

At the *Uvkusigssat prospect*, located 20 km south-west of Mârmorilik, folded sheets and stringers of massive pyrite-sphalerite-galena outcrops on a steep marble cliff (Fig. 1). The structural pattern is little understood. The prospect has been investigated by mountaineers and by a 1.7 km drilling programme. The best intersection shows 1.4% Pb and 6.0% Zn over an indicated true thickness of 7 m, but no minable tonnage has been proved (Della Valle, 1980).

The *Agpat prospect* occurs in a tectonically thickened marble unit some 30 km south-west of Mârmorilik (Fig. 1). Folded sheets of massive pyrite-sphalerite-galena outcrop at the top of a steep cliff. The structural control of the mineralisation is enigmatic. A 2.1 km diamond drilling programme with a best intersection of 0.1% Pb and 33.6% Zn over 1.4 m failed to demonstrate a continuous ore body of commercial size (Gannicott, 1977).

On Nûgssuaq peninsula, sheets of marble probably belonging to the Mârmorilik Formation are folded in the local gneiss. The largest marble outcrop, situated 85 km south-west of Mârmorilik, hosts the *Nûgssuaq showing* with lead-zinc mineralisation of the Black Angel type (Fig. 1). The sulphide outcrops occur in steep cliffs. They are little known but chip sampling at one locality indicates 0.7% Pb and 42.5% Zn over 0.7 m (Garde & Thomassen, 1990; Della Valle & Dentan, 1991).

Qeqertarssuaq Formation

The pelitic schists of the Qeqertarssuaq Formation host beds of sulphide and rare oxide facies iron formation. This mineralisation has only been summarily investigated (Allen & Harris, 1980; Thomassen, 1991a). The quartzites of the formation host epigenetic copper mineralisation. An up to 15 m thick mineralised zone, possibly a low-angle thrust or shear zone, is exposed laterally over more than 200 m in the Íngia area (Fig. 1). Chalcopyrite and pyrrhotite occur disseminated and as blebs both in centimetre-thick quartz veins and in the wall rocks. A 13 m chip sample across the mineralised zone averages 910 ppm Cu and 3 ppb Au; a grab sample from the same zone contains 1.9% Cu and 323 ppb Au (Thomassen, 1991a).

In the metavolcanic hornblende schists of the uppermost part of the Qeqertarssuaq Formation, minor disseminations of pyrrhotite and subordinate chalcopyrite are quite common, but malachite staining is rare (Grocott & Vissers, 1984; Thomassen, 1991a). In the Íngia area and to the south-east, a pyrrhotite-rich horizon of supposed exhalative origin is often present at the contact between the metavolcanics and the overlying flyschoid Nûkavsak Formation (Allen & Harris, 1980; Thomassen, 1991a). This horizon is 0.5–5.0 m thick, rusty weathering and generally cherty and graphitic. The pyrrhotite may occur disseminated in pelitic schists or in cherty bands a few centimetres thick alternating with schistose bands. The horizon typically contains one or two, 0.5–1.0 m thick layer(s) of semi-massive to massive pyrrhotite breccia which pinch and swell along strike and are obviously strongly deformed. The pyrrhotite breccia consists of fragments of pyrrhotite, graphite and chert in a matrix of pyrrhotite and quartz. Pyrite, chalcopyrite and arsenopyrite are minor components. These rocks strongly resemble the sulphide horizons which occur at higher levels in the Nûkavsak Formation. At one investigated locality, the pyrrhotite horizon exhibits somewhat elevated copper (max. 0.3%) and zinc (max. 0.1%) contents, but is low in lead (max. 45 ppm) and gold (max. 9 ppb) (Table 1).

Nûkavsak Formation

Rusty-weathering horizons containing a few per cent disseminated pyrrhotite are very common in the turbidite sequence of the Nûkavsak Formation, and cherty layers rich in pyrrhotite and graphite, often containing semi-massive pyrrhotite-graphite breccias, are widespread at one or more levels in the formation (Allen & Harris, 1980; Escher & Stecher, 1980; Henderson & Pulvertaft, 1987). Allen & Harris (1980) distinguished between cherty and graphitic sulphide horizons in the Umanak district. The former are best developed south-east of the Íngia area in the lower 500–600 m of the formation. They are multiple bands with prominent thicknesses (5–10 m) and strike extent (5–10 km). The graphitic sulphide horizons are pyrrhotite-rich black shales typically quite thick (2–5 m) and fairly extensive. They show no preference to a particular stratigraphic level or geographical part of the formation. The sulphide minerals are invariably dominated by pyrrhotite with minor pyrite and trace amounts of chalcopyrite and occasionally arsenopyrite. The metal contents of rock samples from this mineralisation are summarised in Table 1. It appears that noble and base metals as well as arsenic and molybdenum are higher here than in the similar mineralisation associated with the metavolcanic rocks of the Qeqertarssuaq Formation.

The existence of other types of stratiform mineralisation in the Nûkavsak Formation is indicated by boulders with fine-grained, disseminated arsenopyrite and boulders of tourmalinite in the northern Umanak district (Thomassen, 1991a; Nunaoil A/S, 1992). Such mineralisation, easily overlooked, might be quite common in the turbidite sequence. Chip samples with up to 10.8% Zn from the basal part of the formation have been reported from an area *c.* 25 km NW of Mârmorilik, but no detailed information is available about this mineralisation (Thomassen & Lind, 1987).

Quartz veins are common in the Nûkavsak Formation. Most veins are of segregational character and both concordant and discordant to the host rock bedding. They are typically 1–10 cm thick lenses a few metres long, but can be up to 2 m thick and several hundred metres long. Various sets of structurally controlled vein systems exist. In addition to white quartz, the veins often contain carbonate and mica along with minor amounts of chlorite, feldspar, red garnet, tourmaline and sulphides. The predominant sulphide is pyrrhotite, accompanied by minor pyrite and traces of chalcopyrite and rarely galena, sphalerite, scheelite, molybdenite

Table 1. Trace element contents in pyrrhotite-rich rocks of the Karrat Group

Element	1 min.	1 max.	1 average	1 median	2 min.	2 max.	2 average	2 median	3 min.	3 max.	3 average
Samples	6 chips				9 boulders				113 rocks		
Au ppb	2	9	5	4	6	113	50	38			
As ppm	1	49	11	3	<2	433	83	20			
W ppm	<2	7	4	4	<2	10	3	<2			
Ni ppm	110	370	197	155	300	960	643	640	307	2800	994
Co ppm	33	170	62	44	40	120	69	71	5	410	59
Pt ppb	<5	10	6	5	<5	18	12	12			
Pd ppb	<1	26	18	17	7	73	23	14			
Cr ppm	140	370	250	275	77	300	186	180			
Fe %	10	17	16	15	15	29	21	20			
Cu ppm	129	2648	698	358	156	2845	749	475	36	5050	467
Zn ppm	369	958	611	532	956	5250	2895	2750	19	5700	975
Pb ppm	11	45	23	18	8	89	34	31	5	283	39
Ag ppm	<5	<5	<5	<5	<5	8	<5	<5			
Sb ppm	<1	6	2	1	<1	10	4	3			
Mo ppm	12	190	57	26	63	228	157	170	2	490	65
Ba ppm	<100	230	152	200	<100	850	248	220			
U ppm	4	20	9	8	9	31	21	20			
Th ppm	4	6	5	5	1	13	4	3			

1. The top of the Qeqertarssuaq Formation, 2. Nûkavsak Formation, 3. Nûkavsak Formation. 1 and 2 are from the Íngia area; analysis by neutron activation, aqua regia/atomic obsorption (Cu, Zn, Pb) and fire assay (Au) (Thomassen, 1991a). 3 is from the area covered by the Cominco survey (Allen & Harris, 1980).

and arsenopyrite. Higher-than-normal gold values have been obtained from boulders of this type. The highest value, 1.4 ppm Au, stems from a boulder of meta-greywacke cut by a 5–10 cm thick quartz vein with 1–2% irregularly distributed pyrrhotite and pyrite, and traces of chalcopyrite, native bismuth and bismuthinite (Thomassen, 1991a).

The pegmatite veins and granitic sheets which cut the metasediments in some areas may contain traces of molybdenite (Allen & Harris, 1980).

Drainage geochemistry

The Umanak district has a rugged, alpine topography and an arctic climate with permafrost. Vegetation is virtually absent in the streams, and the secondary geochemical dispersion is, as in most parts of Greenland, predominantly mechanical (Steenfelt, 1987). Two geochemical surveys of reconnaissance character using stream sediment samples and heavy mineral concentrates have been carried out (Fig. 1).

A survey carried out by Cominco Ltd. in 1979 was mainly confined to streams draining the Karrat Group (Allen & Harris, 1980). About 2500 km^2 of the 7000 km^2 project area was sampled with an average density of *c.* 1 sample pair per 12 km^2. The survey carried out by GGU in 1989–90 in the Íngia area concentrated on streams draining the Nûkavsak Formation (Thomassen, 1991a). About a third of the samples were collected relatively close to each other in two anomalous areas, whereas the remaining samples stem from a semi-regional survey. In total, the samples represent a drainage area of *c.* 1000 km^2 corresponding to an average sample density of *c.* 1 sample pair per 10 km^2.

The analytical results show that relatively high values might occur for elements such as gold, arsenic, tungsten, copper and zinc, whereas the values for lead are relatively low (Tables 2, 3). For the stream sediment samples, the analytical values are of the same order of magnitude in the two surveys. For the heavy mineral concentrates, GGU values for gold, arsenic, tungsten and cobalt are of a higher magnitude than the values obtained by Cominco, although the highest Cominco values for these elements are concentrated in the GGU survey area. Furthermore, gold correlates well with arsenic, cobalt and tungsten in the GGU data, but not in

Table 2. Summary statistics for stream sediment samples from the Karrat Group

Element		Cominco (231 samples) min.	max.	av.	med.	95%	GGU (100 samples) min.	max.	av.	med.	95%
Au	ppb	-	-	-	-	-	<5	33	<5	<5	10
As	ppm	<2	189	22	13	68	<1	239	22	10	93
W	ppm	-	-	-	-	-	<2	22	4	3	10
Ni	ppm	7	249	60	50	123	26	180	69	66	110
Co	ppm	3	47	16	14	29	10	56	25	24	39
Cr	ppm	-	-	-	-	-	57	490	164	150	310
Fe	%	0.5	11.0	3.3	3.0	5.6	2.4	8.8	4.4	4.3	6.1
Cu	ppm	13	265	72	64	142	34	169	83	75	135
Zn	ppm	8	620	105	88	207	18	330	116	98	240
Pb	ppm	1	60	7	4	17	4	26	9	9	17
Sb	ppm	<5	<5	<5	<5	<5	<0.2	1.3	<0.2	<0.2	0.7
Ba	ppm	-	-	-	-	-	184	740	483	500	640
U	ppm	0.1	20.0	3.0	2.4	6.4	1.6	26.0	4.6	4.2	7.8
Ce	ppm	-	-	-	-	-	31	230	67	63	110

Minimum, maximum, average, median and 95% percentile values from the Cominco and GGU surveys. Analysis of the −80 mesh fraction by 20% HNO_3/atomic absorption, colorimetric (As) and fluorimetric (U) (Cominco: Allen & Harris, 1980); and of the −150 mesh (0.1 mm) fraction by neutron activation and aqua regia/atomic absorption (Cu, Zn, Pb) (GGU: Thomassen, 1991a).

the Cominco data. Both surveys show that zinc is correlated with copper and lead, and that cobalt and nickel are correlated. The correlation between values from stream sediment/heavy mineral concentrate pairs is poor for most elements, i.e. the two sample types can be expected to supplement one another.

Preliminary mineralogical investigations of the GGU heavy mineral concentrates revealed ubiquitous iron

Table 3. Summary statistics for heavy mineral concentrates from the Karrat Group

Element		Cominco (176 samples) min.	max.	av.	med.	95%	GGU (102 samples) min.	max.	av.	med.	95%	R
Au	ppb	<10	160	<10	<10	22	<5	18800	<5	<5	1004	0.19
As	ppm	<2	994	91	23	320	<2	58000	1964	290	8400	0.28
W	ppm	<2	40	7	5	20	<4	6300	291	49	1200	0.35
Ni	ppm	12	513	141	116	316	<200	2800	570	350	1800	−0.43
Co	ppm	3	150	37	32	85	42	1200	191	120	540	−0.24
Cr	ppm	-	-	-	-	-	49	1800	473	440	910	0.41
Fe	%	3	36	12	10	28	14	51	28	25	44	−0.28
Cu	ppm	41	1020	248	188	690	35	2110	359	245	958	0.06
Zn	ppm	28	1140	282	212	800	90	920	358	280	655	0.50
Pb	ppm	<4	112	17	10	58	<20	260	56	40	120	0.39
Sb	ppm	-	-	-	-	-	<0.2	15.0	<0.2	<0.2	3.9	0.48
Ba	ppm	82	1403	466	399	-	<200	1000	<200	<200	695	0.30
U	ppm	<0.1	45	7	5	17	<0.5	47	10	8	29	0.47
Ce	ppm	-	-	-	-	-	19	684	111	95	254	0.27

Minimum, maximum, average, median and 95% percentile values. R is the std. regression coefficient for GGU stream sediment samples and heavy mineral concentrates. Analysis of the -1 mm fractions by aqua regia/atomic absorption and colorimetric (As,W) (Cominco: Allen & Harris, 1980); and by neutron activation and aqua regia/atomic absorption (Cu, Zn, Pb) (GGU: Thomassen, 1991a).

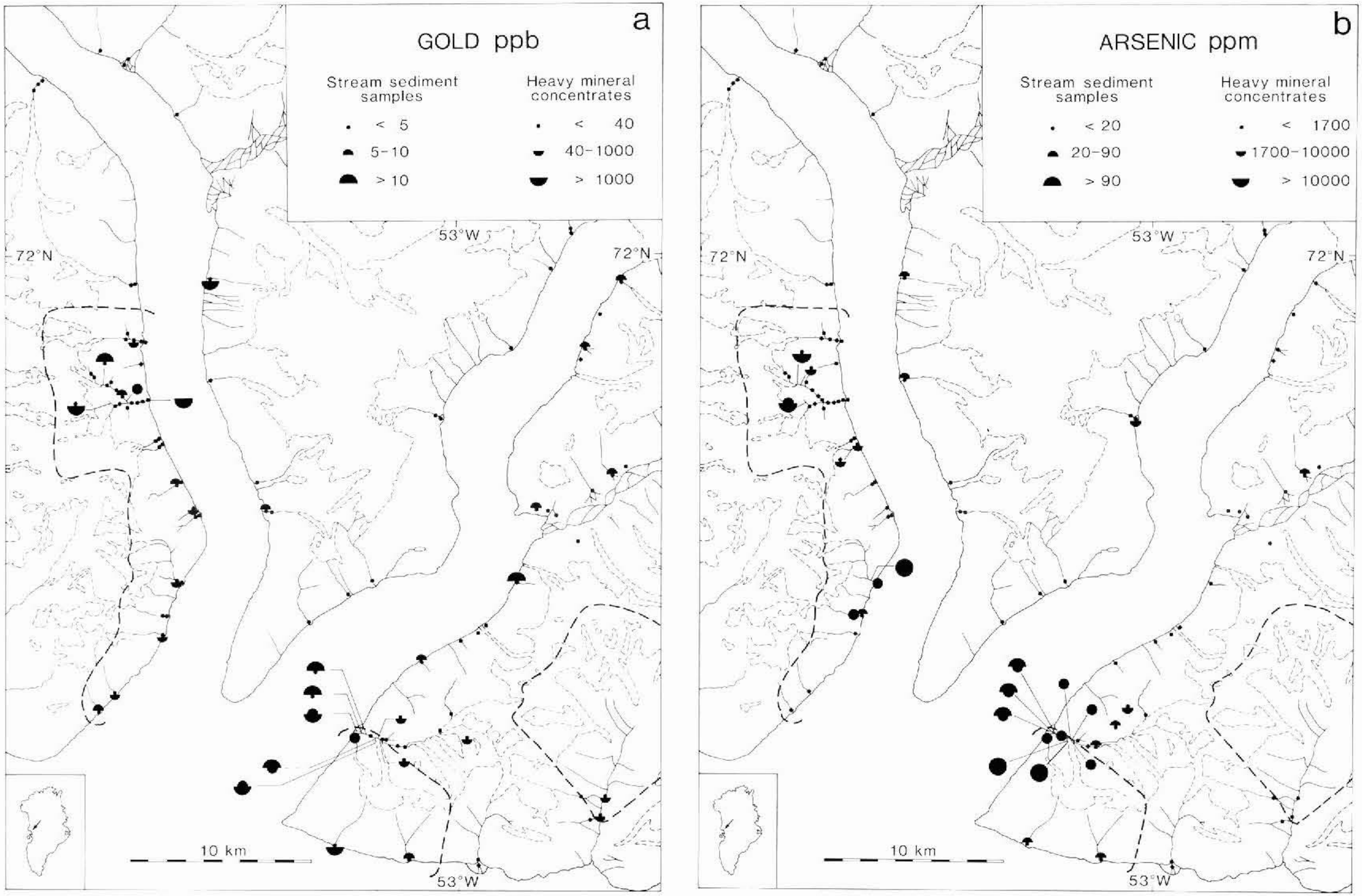

Fig. 2. Geochemical maps from the Ingia area, a: gold, b: arsenic. Catchment basins with anomalous gold are indicated by broken lines. For location see Fig. 1. Modified from Thomassen (1991a).

sulphides and common chalcopyrite, arsenopyrite and scheelite in the heavy fractions, but no free gold. It is believed that the gold is hosted in sulphide minerals, first and foremost in arsenopyrite.

The most interesting result from the Cominco survey is the delineation of an area anomalous in copper-zinc-barium at the transition zone between carbonates and clastic rocks situated some 25 km north-west of Mârmorilik. This area is believed to hold a potential for shale or carbonate-hosted base metal mineralisation. Furthermore, the survey shows modest gold-tungsten anomalies in the Íngia area. The GGU geochemical results indicate the existence in the Íngia area of three gold-anomalous catchment basins between 40 and 100 km^2, two of which are also anomalous in arsenic, tungsten and cobalt (Fig. 2 a,b). These basins are thought to hold a potential for vein-type gold mineralisation. Both the GGU study and a geochemical study based on lake sediments carried out in equivalents of the Karrat Group in Canada (Cameron, 1986) indicate that the metaturbiditic part of the sequences has a high background in arsenic (cf. Tables 2, 3 and Fig. 2 b), a feature thought to be favourable for gold mineralisation (Thorpe, 1984).

Mineral potential

Indications of three main types of mineralisation occur in the Karrat Group: (1) carbonate-hosted lead-zinc deposits, (2) shale-hosted massive base metal sulphide deposits, and (3) gold-bearing quartz veins. These types of base and precious metals mineralisation constitute the most obvious mineral potential of the region.

Carbonate-hosted lead-zinc deposits of the Black Angel type have been the main target of previous exploration, and a number of occurrences of this type are now documented. They are all within marble horizons that have been tectonically thickened, and control by major structures such as folds or thrusts is suggested. The Black Angel deposit shows many similarities to the Balmat zinc deposits of New York State, for which a sedimentary exhalative (sedex) type origin has been proposed (deLorraine & Dill, 1982). The genesis of the Black Angel ores remains unsettled, although sabkha type (Pedersen, 1981), Mississippi Valley type (Carmichael, 1988) and sedex type (Sangster, 1990) origins have been advocated. However, all Greenland occurrences are strongly tectonised and metamorphic mobilisation has played an important role in their formation.

Unexplained ore grade drill core intersections or exposures remain both in the old mine area and at the four showings mentioned above, and such indications constitute obvious targets for further exploration. Since marble outcrops in the Umanak district are of modest extent (*c.* 150 km^2), new major sulphide exposures are not to be expected. However, the search for blind deposits has been confined to the ground east of the old mine, and such exploration merits intensification in the future.

Shale-hosted massive base metal sulphide deposits associated with the iron sulphide horizons have been the main target for exploration in the clastic units of the Karrat Group. In view of the restricted character of this work, the possibility that economic metal concentrations of this type do exist has been by no means eliminated. The Nûkavsak Formation in particular represents a suitable depositional environment for sedex type mineralisation. The widespread pyrrhotite-rich horizons, which are often tectonically milled out, might be of exhalatic or sedimentary black shale origin. It has been demonstrated that elevated contents of gold, copper, zinc, arsenic and molybdenum occur in some of these rocks, indicating a potential for stratiform base metal deposits as for example at Sullivan, British Columbia (Hamilton *et al.*, 1982). This possibility is supported by the drainage geochemistry and by the occurrence of tourmalinite boulders in the area. The search for this type of mineralisation is best accomplished within the framework of a regional programme aimed at the study of zonation patterns in potentially ore-bearing stratigraphic levels, such as the horizons rich in pyrrhotite and arsenopyrite.

The existence of *gold-bearing quartz veins* is mainly supported by boulder finds and by gold values in the ppm range in heavy mineral concentrates. The likely economic occurrences are turbidite-hosted vein and shear-zone gold deposits, similar to those of the Meguma Group of Nova Scotia and in Victoria State, Australia (Keppie *et al.*, 1986). The conceptual model for this type of mineralisation involves source rocks from which trace metals migrated to be concentrated in epigenetic structures elsewhere in the rock pile.

The iron sulphide horizons in the clastic units of the Karrat Group are regarded as excellent source rocks for epigenetic mineralisation. The occurrence of stratiform, disseminated arsenopyrite, as indicated by boulder finds and drainage geochemistry, suggests other possible source rocks. The most likely cause of mobilisation of metals was the Rinkian metamorphism, and the low-angle thrusts which cut the basement and supracrustal pile are the obvious channelways for mineralising solutions. Thrust-controlled shear zones could also be the location for precipitation. Thus the copper showing in the Íngia area might be a shear-zone mineralisation hosted in a thrust plane. Other possible epigenetic traps for migrating solutions are zig-zag folds and other fold noses with saddle-reef-like structures.

It is concluded that the Karrat Group has a considerable potential for gold and base metal deposits. Further exploration of the clastic units should include a systematic geochemical survey with target elements such as gold, copper and zinc, and pathfinder elements such as arsenic, antimony and tungsten. Stratiform mineralisation often displays vertical and lateral metal zonation, and the exploration should therefore include extensive lithogeochemical sampling. A structural study might help pin-point favourable sites for vein-type mineralisation. Continued exploration of the marble units of the Karrat Group should concentrate on detailed structural, geochemical and geophysical studies of the known mineralised localities with a view to drilling for blind ore bodies.

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References

Allen, C. R. & Harris, C. J. 1980: Karrat Group reconnaissance programme, Marmorilik area, West Greenland. Year end report 1979. Internal report, Cominco A/S, 33 pp.

Cameron, E. M. 1986: An introduction to the interpretation of data from central Baffin Island, District of Franklin. *Pap. geol. Surv. Can.* **86–10,** 22 pp.

Carmichael, A. J. 1988: The tectonics and mineralisation of the Black Angel Pb-Zn deposits, central West Greenland. Unpublished thesis, Goldsmith's College, Univ. London, 371 pp.

Della Valle, G. 1980: Uvkusigssat Drilling 1979. Greenex A/S Prospecting Concession, West Greenland. Internal report, Cominco Ltd., 8 pp.

Della Valle, G. & Dentan, P. 1991: Geological report on the 1990 zinc and lead exploration program in central Nugssuaq peninsula, Maarmorilik Formation, West Greenland. Internal report, Intergeo Exploration, 17 pp.

deLorraine, W. F. & Dill, D. B. 1982: Structure, stratigraphic controls, and genesis of the Balmat zinc deposits, Northwest Adirondacks, New York. *In* Hutchinson, R. W., Spence, C. D. & Franklin, J. M. (ed.) Precambrian sulphide deposits. *Spec. Pap. geol. Ass. Can.* **25,** 571–596.

Escher, J. C. & Stecher, O. 1980: Field work on Precambrian granites and metasediments in the Søndre Upernavik – Kuvdlorssuaq region (72° 00′–74° 40′N), northern West Greenland. *Rapp. Grønlands geol. Unders.* **100,** 38–41.

Gannicott, R. A. 1977: Report on the 1976 Agpat island drilling project. Greenex A/S exploration concession, North-West Greenland. Internal report, Greenex A/S, 6 pp.

Garde, A. A. 1978: The Lower Proterozoic Marmorilik Formation, east of Mârmorilik, West Greenland. *Meddr Grønland* **200**(3), 71 pp.

Garde, A. A. & Thomassen, B. 1990: Structural and economic aspects of the Proterozoic marble on Nûgssuaq, West Greenland. *Open File Ser. Grønlands geol. Unders.* **90/6,** 14 pp.

Gill, F. D. 1975: Report on the 1975 reconnaissance program, Greenex A/S exploration concession, North West Greenland. Internal report, Cominco Ltd., 12 pp.

Grocott, J. & Pulvertaft, T. C. R. 1990: The Early Proterozoic Rinkian Belt of central West Greenland. *In* Lewry, J. F. & Stauffer, M. R. (ed.) The Early Proterozoic Trans-Hudson Orogen of North America. *Spec. Pap. geol. Ass. Can.* **37,** 443–463.

Grocott, J. & Vissers, R. L. M. 1984: Field mapping of the early Proterozoic Karrat Group on Svartenhuk Halvø, central West Greenland. *Rapp. Grønlands geol. Unders.* **120,** 25–31.

Hamilton, J. M., Bishop, D. T., Morris, H. C. & Owens, O. E. 1982: Geology of the Sullivan orebody, Kimberly, B.C., Canada. *In* Hutchinson, R. W., Spence, C. D. & Franklin, J. M. (ed.) Precambrian sulphide deposits. *Spec. Pap. geol. Ass. Can.* **25,** 597–665.

Harris, C. J. 1985: South Lakes – Plateau drilling, Maarmorilik, West Greenland. 1984 year end report. Internal report, Greenex A/S, 23 pp.

Harris, C. J. 1986: Black Angel surface drilling, 1985 year end report. Internal report, Greenex A/S, 19 pp.

Henderson, G. & Pulvertaft, T. C. R. 1967: The stratigraphy and structure of the Precambrian rocks of the Umanak area, West Greenland. *Meddr dansk geol. Foren.* **17,** 1–20.

Henderson, G. & Pulvertaft, T. C. R. 1987: The lithostratigraphy and structure of a Lower Proterozoic dome and nappe complex. Descriptive text to 1:100 000 sheets Mârmorilik 71 V.2 Syd, Nûgâtsiaq 71 V.2 Nord and Pangnertôq 72 V.2 Syd. Copenhagen: Grønlands Geologiske Undersøgelse, 72 pp.

Kalsbeek, F. 1981: The northward extent of the Archaean basement of Greenland – a review of Rb-Sr whole-rock ages. *Precambrian Res.* **14,** 203–219.

Kalsbeek, F. & Taylor, P. N. 1986: Chemical and isotopic homogeneity of a 400 km long basic dyke in central West Greenland. *Contr. Miner. Petrol.* **93,** 439–448.

Keppie, D., Boyle, R. W. & Haynes, S. J. (ed.) 1986: Turbidite-hosted gold deposits. *Spec. Pap. geol. Ass. Can.* **32,** 186 pp.

King, A. R. 1982: Report on prospecting and correlation programme in the Marmorilik Formation, West Greenland 1982. Internal report, Greenex A/S, 20 pp.

Lewry, J. F. & Collerson, K. D. 1990: The Trans-Hudson Orogen: Extent, Subdivision, and Problems. *In* Lewry, J. F. & Stauffer, M. R. (ed.) The Early Proterozoic Trans-Hudson Orogen of North America. *Spec. Pap. geol. Ass. Can.* **37,** 1–14.

Nunaoil A/S 1992: Ujarassiorit 1991, (opfølgning 1991 på mineralfund fra Ujarassiorit, 7–8).

Pedersen, F. D. 1980: Remobilization of the massive sulphide ore of the Black Angel Mine, central West Greenland. *Econ. Geol.* **75,** 1022–1041.

Pedersen, F. D. 1981: Polyphase deformation of the massive sulphide ore of the Black Angel mine, central West Greenland. *Mineral. Dep.* **16,** 157–176.

Sangster, D. F. 1990: Mississippi Valley-type and sedex lead-zinc deposits: a comparative examination. *Trans. Instn Min. Metall.* Sect. B, **99,** B21–B42.

Steenfelt, A. 1987: Geochemical mapping and prospecting in Greenland – a review of results and experience. *J. Geochem. Explor.* **29,** 183–205.

Thomassen, B. 1989: Reconnaissance of mineral occurrences in the Umanak district. Field report 1989. Unpubl. intern. GGU rep., 43 pp.

Thomassen, B. 1990: Prospecting for base and noble metals in the Íngia area, West Greenland: analytical results. *Open File Ser. Grønlands geol. Unders.* **90/2,** 61 pp.

Thomassen, B. 1991a: Gold and base metal potential of the Íngia area, central West Greenland. *Open File Ser. Grønlands geol. Unders.* **91/5,** 115 pp.

Thomassen, B. 1991b: The Black Angel lead-zinc mine 1973–90. *Rapp. Grønlands geol. Unders.* **152,** 46–50.

Thomassen, B. & Lind, M. 1987: Report on reconnaissance prospecting in the Karrat Group and at West Gossan, summer 1986. Internal report, Greenex A/S, 17 pp.

Thorpe, R. I. 1984: Turbidite-hosted vein and shear zone gold. *In* Eckstrand, O. R. (ed.) Canadian mineral deposit types: a geological synopsis. *Geol. Surv. Can., Economic geology report* **36,** 31 only.

Note. Cited company reports can be inspected at GGU, or copies can be purchased from GGU.