Reconnaissance for noble metals in Precambrian and Palaeogene rocks, Amdrup Fjord, southern East Greenland

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A zone of hydrothermal veins in the Kangerlussuaq region, southern East Greenland, is the focus of a one-year project by the Geological Survey of Denmark and Greenland (GEUS). The project aims to localise, map, sample and analyse silver-gold-bearing veins in a selected area of Precambrian and Palaeogene rocks north of Amdrup Fjord (Figs 1, 2). This report describes the field work and presents some preliminary results.

The study area comprises a *c.* 3 km wide and 10 km long ridge between Amdrup Fjord and Søndre Syenitgletscher, centred on the 938 m high mountain Flammefjeld (Figs 2, 3). The area is of alpine character with small glaciers and with extensive snow cover most of the year. The field programme was chosen to coincide with the time of minimum snow cover, from 25 July – 23 August. During this period, the major part of the area was investigated on daily foot traverses from four fly camps, helped by helicopter lifts on two occasions. Logistically, the work was part of a larger expedition to East Greenland – *EG 2000* – organised by the Danish Lithosphere Centre and GEUS, which is reported on elsewhere (Nielsen *et al.* 2001, this volume). A temporary field base in Sødalen, some 50 km east of Amdrup Fjord, supported the expedition's Ecureuil AS 350 helicopter and provided services for the field teams of the various activities attached to *EG 2000*. Air connections with Iceland were maintained by Twin Otter aircraft operating from a gravel landing strip in Sødalen (Fig. 1).

Geological setting

The Kangerlussuaq region of southern East Greenland is underlain by a Precambrian crystalline basement

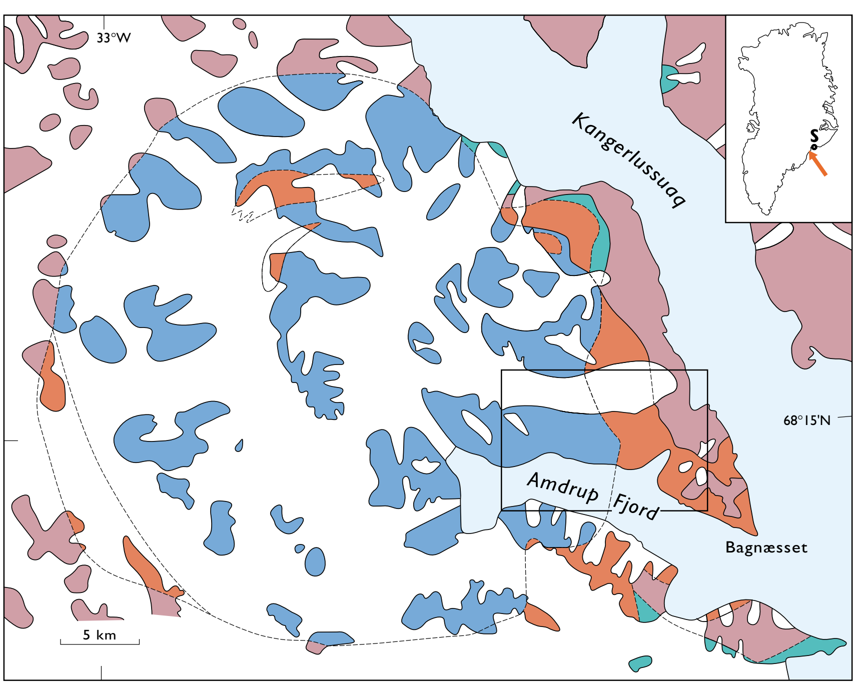

Fig. 1. Simplified geological map of the Kangerdlugssuaq complex with the investigated area framed and shown in Fig. 2. On inset map arrow shows location of the study area and **S**: Sødalen. Modified from Nielsen (1987).

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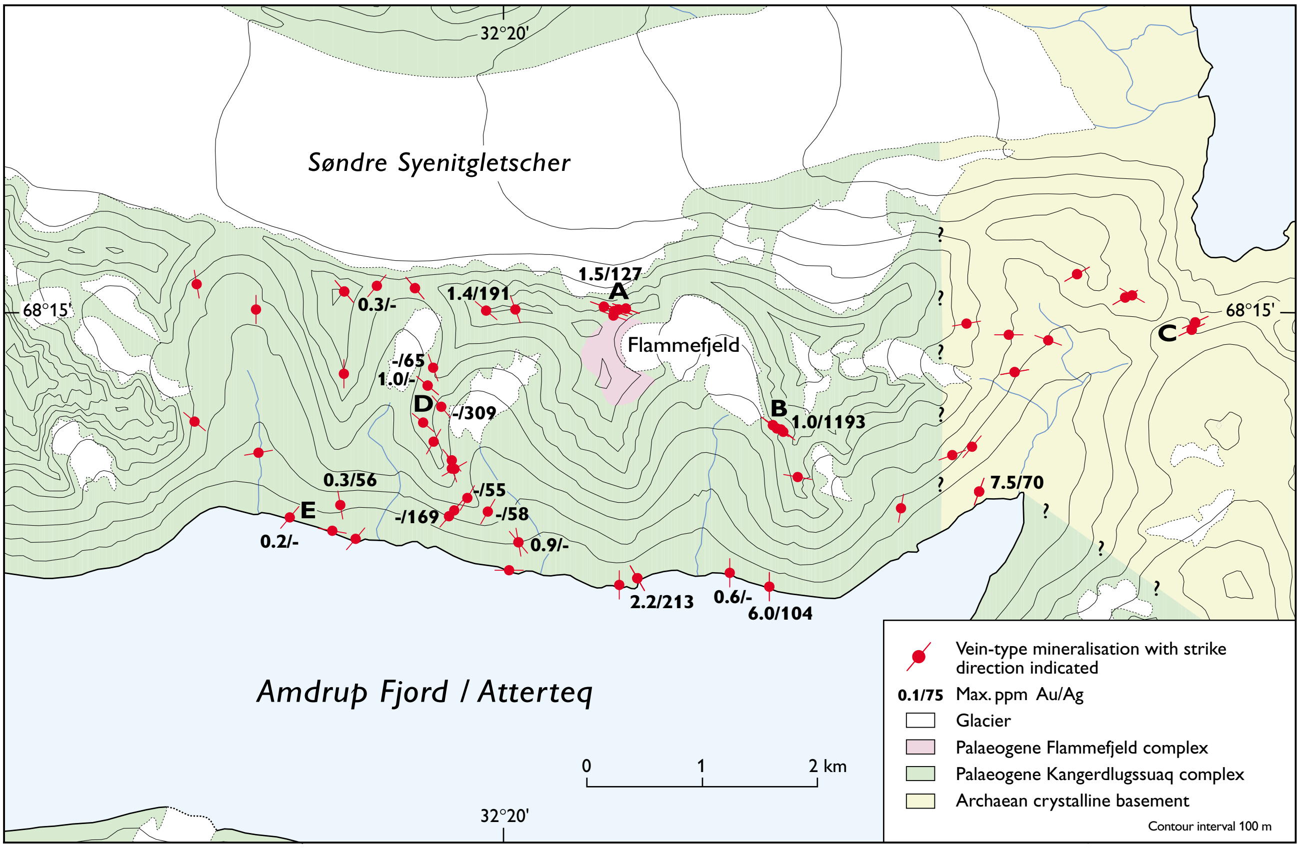

Fig. 2. Simplified geological map of the Amdrup Fjord area, showing occurrences of *in situ* vein-type mineralisation and localities **A–E**. Maximum gold and silver values are shown where Au > 0.1 ppm and Ag > 50 ppm. Bedrock geology based on Kempe *et al.* (1970), Geyti & Thomassen (1983) and Myers (1988).

intruded by magmatic rocks generated during the continental break-up of the North Atlantic in the Early Palaeogene (Wager 1934; Brooks & Nielsen 1982). The crystalline basement consists predominantly of quartzo-feldspathic gneisses formed during a major late Archaean episode of sialic crust formation between 3.0 and 2.8 Ga ago (Taylor *et al.* 1992).

The Palaeogene magmatic rocks include extensive plateau basalts, several felsic and mafic alkaline intrusions and a major coast-parallel dyke swarm. The largest of the intrusions is the Kangerdlugssuaq complex located on the west side of the fjord Kangerlussuaq (formerly 'Kangerdlugssuaq'). This consists of the *c.* 50 Ma Kangerdlugssuaq alkaline intrusion and a number of both older and younger satellite intrusions (Fig. 1; Kempe *et al.* 1970; Brooks & Gill 1982; Nielsen 1987). The *c.* 700 km^2 Kangerdlugssuaq alkaline intrusion consists of concentric zones with gradational contacts of quartz syenite at the outside through syenite to nepheline syenite at the centre. The satellite intrusions include a variety of syenites and granites. The presumed youngest intrusive rocks comprise the 500 × 800 m sub-volcanic Flammefjeld complex which is intruded into quartz syenites at the contact between the Kangerdlugssuaq alkaline intrusion and younger satellite intrusions (Fig. 3). The Flammefjeld complex comprises a breccia pipe intruded by quartz porphyries and surrounded by a halo of hydrothermal alteration displaying vivid yellow and red oxidation colours; the name Flammefjeld translates as 'flame mountain' (Geyti & Thomassen 1984).

Mineral exploration by Nordisk Mineselskab A/S in 1970 and 1982 east and north of Flammefjeld revealed a number of base metal-bearing hydrothermal veins with enhanced silver and gold concentrations as well as stockwork-type molybdenum mineralisation in granitic breccia fragments of the Flammefjeld breccia pipe (Brooks 1971; Thomassen 1971; Geyti & Thomassen 1983, 1984; Brooks *et al.* 1987). The existence of a blind 'Climax-type' porphyry molybdenum deposit at 300–500 m a.s.l. below Flammefjeld, and 1–2 km below the palaeosurface, has been suggested (Geyti & Thomassen 1983; Stenstrop 1987). Hydrothermal veins of quartz-

Fig. 3. View to the west of 'Tågegang' (locality B) with Flammefjeld in the background to the left. For scale, note person clad in red (**arrowed**) collecting chip samples (GGU 456522, 23) over part of the *c.* 30 m wide vein structure.

carbonate cemented breccia are widespread in the Kangerlussuaq region, but tend to be barren outside the Amdrup Fjord area (Brooks 1972; Geyti & Thomassen 1983; Brooks *et al.* 1987).

Subsequently, the 'Ujarassiorit' annual minerals hunt programme managed by the Bureau of Minerals and Petroleum, Nuuk, Greenland, has received a number of gold-bearing rock samples from the area (Dunnells 1995). These samples are described as pyrite-bearing vein quartz with up to 24 ppm Au, often hosted by a basaltic wall rock; unfortunately, the precise sample localities are not known.

Preliminary results

During the field work all outcrops with visible *in situ* mineralisation were investigated and sampled. Where possible, 2–4 kg chip samples were collected across a mineralised structure; otherwise composite or selected grab samples were taken. Loose blocks with sulphides from either scree cones or local moraines were also sampled, and stream sediment samples and panned heavy mineral concentrates were collected from water courses. All samples were analysed for 49 elements by a combination of instrumental neutron activation and induc-

Table 1. Summary of selected elements for mineralised rock samples, Amdrup Fjord area

Type	Vein / *in situ* 82 samples / 40 localities			Vein / float 49 samples / 36 localities			Disseminated / *in situ* & float 22 samples / 18 localities		
	Range	Average	Median	Range	Average	Median	Range	Average	Median
Au ppb	< 2–7540	390	35	< 2–38400	1842	35	< 2–3430	186	15
Ag ppm	< 1–1193	59	6	< 1–687	55	10	< 1–47	4	< 1
Cu ppm	2–46670	1901	70	< 1–35150	1160	74	6–145	43	28
Pb ppm	< 3–431400	18786	1331	63–447200	32538	1773	< 3–10010	1082	125
Zn ppm	7–65510	6249	914	16–34220	4711	1506	11–5043	750	173
Bi ppm	< 2–628	47	5	< 2–91	7	< 2	< 2–121	10	3
Mo ppm	< 1–410	21	4	< 1–1430	69	4	< 1–31	7	5
As ppm	1–26700	1200	95	2–27500	979	149	2–1030	104	49
Sb ppm	< 1–4350	246	6	< 1–722	70	11	< 1–17	2	1
Mn ppm	55–> 100000	18877	4716	14–> 100000	24110	13430	26–11260	2949	1703
S %	0.01–25.73	4.00	1.39	0.02–16.93	3.32	1.74	0.29–12.09	2.98	2.01

Analyses by Activation Laboratories Ltd., Ontario, Canada.
Analytical methods:
Inductively coupled plasma emission spectrometry: Ag, Cu, Pb, Zn, Mo, Bi, S.
Instrumental neutron activation: Au, As, Sb, Mn (Fe).
Fire assay: Au > 100 ppb, Ag > 100 ppm and Pb > 2 pct.

tively coupled plasma emission spectrometry. Samples with > 0.1 ppm Au, > 100 ppm Ag, or > 2% Pb were subsequently assayed for these elements. The description below is based on field observations and analytical results.

Two types of mineralisation were observed and examined: (1) disseminated mineralisation, and (2) vein mineralisation. The known porphyry molybdenum mineralisation at Flammefjeld was not re-investigated during the 2000 field work.

1. Disseminated mineralisation

This type of mineralisation consists of pyrite disseminated in syenites; it is spatially and genetically related to the Flammefjeld intrusive complex which owes its conspicuous coloration to the oxidation of pyrite. The intensity of pyritisation diminishes away from the complex, and at about 1 km distance only isolated patches of pyrite-bearing syenite occur. Minor amounts of galena were noted in a few samples. Analytical results, summarised in Table 1, indicate that base metals and silver are low in this mineralisation type and only four samples returned more than 0.1 ppm Au. Of these, two samples with 3.4 ppm and 0.1 ppm Au respectively, stem from a > 10 m rusty outcrop west of Flammefjeld, near locality D (Fig. 2).

2. Vein mineralisation

Hydrothermal vein zones are widespread in both the syenitic and gneissic parts of the area within a distance of 5 km from Flammefjeld; some 40 *in situ* localities with this type of mineralisation were observed and sampled. Red-brown weathering colours of carbonates, black staining of manganese oxide and the intersection of brittle structures are useful guides to mineralisation. In the syenite area, mineralisation is nearly always located in cross-cutting dolerite dykes. These dykes are fine-grained, typically 1–3 m wide and steeply dipping with mainly NNW to NW trends.

The mineralised veins generally have widths in the cm–dm range. However, a few vein systems have widths in the metre range, and can be followed over distances of several hundreds of metres. The veins are typically developed as breccia fillings and crustifications of epithermal character, often displaying vuggy and colloform structures (cockade structures) (Fig. 4). Gangue minerals are quartz, calcite, Fe-Mn-Mg-carbonates and occasionally fluorite and barite. Galena is the most common ore mineral, followed by pyrite and sphalerite. Copper minerals (chalcopyrite and tetrahedrite-tennantite) are less common and arsenopyrite occurs sporadically. The sulphides occur as massive lenses and irregular seams of cm-thickness, and disseminated. Total sulphide concentrations rarely exceed 1% over the full width of the veins. The wall rocks exhibit silicification, carbonatisation, kaolinisation and phyllic alteration, with propylitic alteration of the mafic dykes.

The processes of brecciation, alteration and invasion of quartz, carbonates and sulphides affect the doleritic, syenitic or gneissic wall rocks to various degrees. The dolerites are typically asymmetrically mineralised, i.e. they are only mineralised on one side along the contact with unaltered syenite, and the ratios between fissure veins, cemented dyke rock breccias and unaffected dolerite wall rock are very variable. At some localities the entire width of a dyke is altered and mineralised; this is typically the case at the intersection of two or more dykes.

Vein mineralisation types and their metal concentrations

The vein mineralisation can be grouped into three types according to their dominant sulphides (Fig. 4):

1. Pyrite-bearing veins with typical widths in the cm–dm range. These predominate along the coast. The gold-bearing 'Ujarassiorit' samples (mentioned above) seem to be of this type.
2. Galena-sphalerite-pyrite veins. This is the most common type, and the largest outcrop encountered is the 30 × 200+ m 'Tågegang' of Geyti & Thomassen (1983; locality B, Figs 2, 3). The metal contents of two chip samples from locality B are given in Table 2, which also shows values from two other localities of this type (localities C, D).
3. Chalcopyrite-tetrahedrite-tennantite-pyrite ± galena ± sphalerite veins. These are only known from three outcrops and two boulder finds. The most prominent example is the 'Yellow Zone' of Geyti & Thomassen (1983), located at the northern margin of the Flammefjeld breccia pipe (locality A). This comprises a 50 × 200+ m vein swarm with individual vein thickness in the metre range (see Frontispiece of this volume, p. 3). Examples of chip sample values from this locality are given in Table 2.

Metal contents for 130 samples of vein-type mineralisation are summarised in Table 1. Gold concentrations above 0.1 ppm were recorded in 28% of these samples,

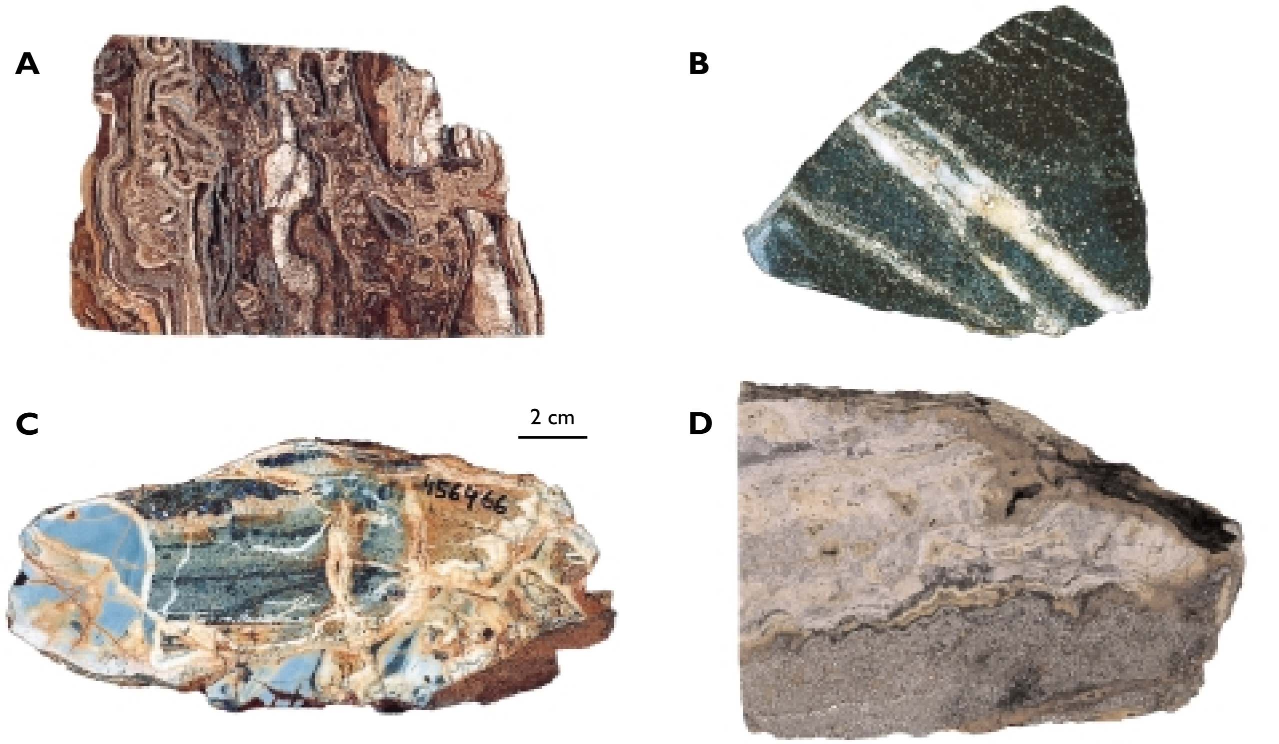

Fig. 4. Four hand-specimens showing typical vein mineralisation. **A**: Weathered surface of quartz-carbonate gangue displaying colloform structures. **B**: Cut surface of type (1) vein showing dolerite invaded by vein quartz and pyrite with 0.6 ppm Au and 37 ppm Ag. **C**: Cut surface of type (2) vein with brecciated structures (bluish chalcedony fragment to the left, bands of sulphides in the centre) and containing 14.4% Pb, 4.9% Zn and 309 ppm Ag. **D**: Cut surface of type (3) vein with seam of pyrite-chalcopyrite-tetrahedrite in quartz-carbonate gangue displaying colloform and vuggy structures, and with 1.5 ppm Au, 104 ppm Ag, 0.6% Cu, 0.5% Pb and 0.6% Zn. The scale bar is 2 cm. Photo: Jakob Lautrup.

while concentrations above 1 ppm were recorded in 12% with two maximum values of 38 ppm Au. Enhanced gold values are most common in vein types (1) and (3), and are often associated with copper, arsenic and bismuth, but rarely with silver. The Ag/Au ratio has a median of 200 for samples with > 0.1 ppm Au and/or > 50 ppm Ag. The overall distribution of gold and silver concentrations indicates that elevated values occur within a distance of 3–4 km from Flammefjeld, whereas low values characterise the gneisses to the east and the nepheline syenites to the west (Fig. 2).

The highest *in situ* gold values (up to 7.5 ppm) stem from vein types (1) and (3) along the coast south and south-east of Flammefjeld. The one maximum gold value of 38 ppm stems from a pyrite-arsenopyrite-bearing float collected near the coast 3 km south-west of Flammefjeld (locality E, Fig. 2). Together with other nearby auriferous type (1) floats and veinlets, the gentle slopes of this area constitute a worthwhile gold exploration target. The other maximum gold value stems from a strongly oxidised type (3) float collected on the glacier east of Flammefjeld just north-west of locality B. Two other nearby float samples returned 28 ppm and 2 ppm Au, respectively. Distinct vein structures occur in a steep cliff above the collection sites.

Silver concentrations above 50 ppm occur in 25% of the samples, values above 100 ppm in 15% and above 200 ppm in 8%; the maximum value recorded is 1193 ppm Ag. Silver correlates well with lead and is most common in vein types (2) and (3). The sample with 1193 ppm Ag stems from locality B ('Tågegang'). Locality B and floats just north-west of locality B account for seven of the eight samples which yielded silver values above 250 ppm. The eighth sample comes from locality D. Outcrop samples and float from a vein system 1 km east of locality E yielded 222 ppm, 169 ppm and 55 ppm Ag, whereas the previously reported high silver concentrations at locality C ('Wild Willys Vein', Brooks 1971) could not be confirmed (Table 2).

Average and median values in Table 1 indicate that Pb > Zn > Cu and thereby confirm the field observations. Lead values above 1% were returned from 25%

Table 2. Analytical values of selected chip samples, Amdrup Fjord area

Locality	A	A	B	C	D
GGU sample no.	456531	456538	456522–23	456401	456463
Length in m	5	4	10	5	1
Au ppm	1.03	0.34	0.21	0.05	0.05
Ag ppm	96	127	157	36	256
Ag/Au	93	374	748	720	5120
Cu%	1.51	0.78	0.03	0.02	0.03
Pb%	0.51	1.36	10.23	1.73	7.45
Zn%	0.57	3.23	0.98	0.08	1.66
Bi ppm	121	30	22	14	< 2
Mo ppm	245	108	2	7	5
Fe%	14.37	4.36	9.20	6.58	6.85
As%	0.26	0.19	0.01	0.01	0.02
Sb%	0.21	0.32	0.02	< 0.01	0.02
S%	13.79	5.73	2.44	0.29	2.39
Mn%	3.73	0.47	6.85	1.64	0.85

Analyses: details as for Table 1. Localities are shown on Fig. 2.

of the samples, zinc values above 1% were returned from 17%, and copper values above 1% were returned from 5%. The vein-type mineralisation is also characterised by relative high manganese concentrations, and occasionally elevated arsenic, antimony, molybdenum and bismuth (see Table 1).

Concluding remarks

Prior to the field work in 2000, five hydrothermal vein systems were known from the Amdrup Fjord area; during the summer an additional 35 veins, albeit mostly of modest size, were found. We assume that several more could have been found given more time, and we conclude that mineralisation is surprisingly widespread around Flammefjeld.

The vein-type mineralisation centred on Flammefjeld is confined to brittle structures and shows similarities with epithermal gold-silver veins of low-sulphidation type generated at shallow depths, i.e. within *c.* 1.5 km of the Earth's surface (see e.g. Sillitoe 1993). Porphyry-type deposits, like that proposed below Flammefjeld (see above), are often accompanied by distal base metal veins enriched in precious metals, as is the case in the investigated area, and a genetic relationship between the two is likely. No distinct hydrothermal zoning centred on Flammefjeld was observed for the vein-type mineralisation, but proximal copper – distal lead is indicated, and the predominance of pyrite over galena along the shore of Amdrup Fjord also suggests a vertical pyrite-galena zonation. No obvious preferred orientation of the mineralised veins could be identified, but an ongoing structural study based on LANDSAT images and aerial photographs aims to investigate this issue further. The vein-type mineralisation which was encountered is unlikely to yield economic base metal deposits, but does have a potential for gold and silver. Among the proposed targets for further exploration are the coast south-east of Flammefjeld and the sub-areas designed as A, B, D and E on Fig. 2.

The reconnaissance project centred on the Amdrup Fjord region and Flammefjeld will be concluded with a report including sample descriptions, locality maps and chemical analyses. The results from this project will be incorporated in the Survey's assessment of the regional ore potential in the Palaeogene igneous province of East Greenland.

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