

Karrat 97: reconnaissance mineral exploration in central West Greenland

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The Karrat 97 project aims at the acquisition of geochemical data from drainage samples and information on mineralisation within a 10 000 km² area, which stretches from Uummanaq northwards to Prøven (i.e. from 70°30' to 72°30' N; Fig. 1). The project area comprises a major Palaeoproterozoic supracrustal unit, the Karrat Group, from which the project takes its name, and which hosts the abandoned Black Angel lead-zinc mine. It is a joint project between the Geological Survey of Denmark and Greenland (GEUS) and the Bureau of Minerals and Petroleum (BMP), Government of Greenland, and wholly funded by the latter. The goal of the project is to win back the interest of the mining industry to the area.

The eastern part of the project area is difficult of access due to alpine topography with peaks up to 2300 m, abundant glaciers, and steep-sided, often ice-filled fjords. A somewhat more gentle topography prevails in the western parts of the area. The whole area is underlain by permafrost.

Field work was carried out during seven weeks in July–August 1997 by a team of four geologists and four local prospectors. Job-training of the prospectors was an integral purpose of the project, and the manning of the teams was periodically changed so that all four prospectors were introduced to the different topographical and geological terrains in the area as well as to the methods of operation. A chartered 68 foot, 77 tons vessel – *M/S Nukik* – served as mobile base with accommodation and meals on board; a MD 500 E helicopter with crew chartered through Grønlandsfly A/S participated for one month. The work was carried out from five anchorages, with the helicopter stationed on the adjacent coast. The weather was relatively unstable in the field period, but only five days of work were lost due to bad weather.

The field work comprised regional-scale systematic drainage sampling, and detailed mineral exploration at selected sites. The sampling of stream sediment and

stream water supplements the geochemical mapping programme of Greenland undertaken jointly by GEUS and BMP (Steenfelt 1993, 1994), the aim of which is to provide systematic, quality controlled geochemical data. The data are used together with geological and geophysical information in the evaluation of the potential for economic mineral resources. Samples were collected by two teams, transported by helicopter or small boats. All ice-free, near-coastal localities were sampled by the boat team, whereas all other localities were sampled by the helicopter team. The results of this work have been reported on by Steenfelt *et al.* (1998).

The detailed mineral exploration was follow-up work on previously outlined indications and anomalies. It was carried out by two teams on daily trips by rubber dinghy or helicopter, or by foot traverses from field camps. This part of the project has been reported on by Thomassen & Lind (1998).

Geological setting

The area between Uummanaq and Prøven comprises four main litho-stratigraphic units: Archaean basement dominated by tonalitic gneisses, a several kilometres thick succession of Palaeoproterozoic metasediments, a Palaeoproterozoic granite intruding the metasediments, and Tertiary plateau basalts (Fig. 1). In addition, there are minor units of down-faulted Cretaceous sediments. The first three units are transected by 1.65 Ga old dolerite dykes. The area is covered by two geological maps at scale 1:500 000, published by the Survey, and most of the area, except the north-western corner, are covered by 6 geological map sheets at scale 1:100 000.

The Archaean rocks comprise a complex of tonalitic to granodioritic grey gneisses with occasional intercalated supracrustal units and mafic to ultramafic bodies.

The Palaeoproterozoic sediments, the Karrat Group (Henderson & Pulvertaft 1967, 1987), overlie the Archaean

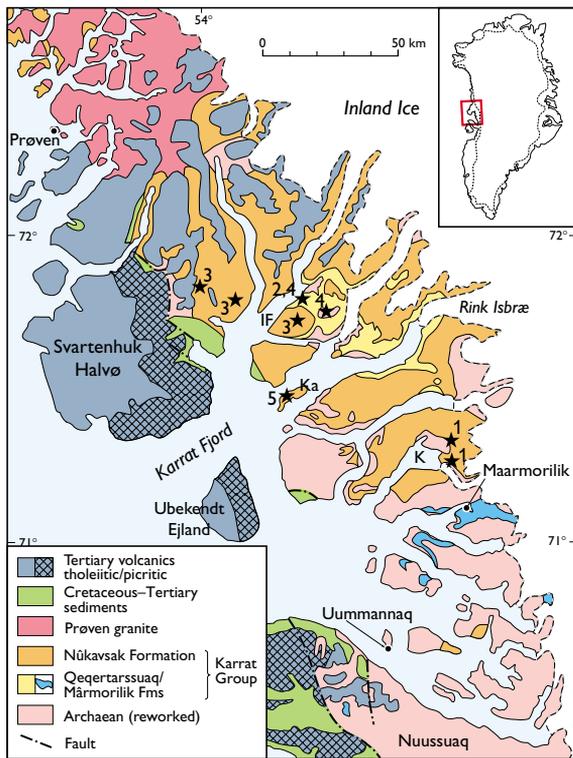


Fig. 1. Geological map of the Uummannaq-Prøven area, based on Grocott & Pulvertaft (1990). IF: Inngia Fjord; K: Kangerluarsuk, Qarsukassak; Ka: Karrat island. Stars 1 to 5 indicate mineral localities discussed in the text.

basement over a 500 km long stretch of coast from 70°30' to 75°00' N. The sequence was laid down in an epicontinental environment, and comprises minor platformal units and a major basinal turbidite flysch succession with a minimum structural thickness of 5 km (Grocott & Pulvertaft 1990). Based on U-Pb isotope data on detrital zircons it is estimated that the deposition, of at least the basinal facies, took place around 2 Ga ago (Kalsbeek *et al.* 1998). The carbonate-dominated Marmorilik Formation occurs in the southern part of the area, whereas the mainly siliciclastic Qeqertarsuaq Formation occurs further to the north. The uppermost part of the latter comprises hornblende schist and amphibolite, interpreted as flows and tuffs, and commonly minor carbonate. The two formations are overlain by the Nûkavsak Formation, which is dominated by dark coloured (grey, brown, black), alternating pelitic and semipelitic schists (greywackes) with occasional graphite-pyrrhotite-rich horizons.

During the Rinkian (Hudsonian) orogenesis around 1.85 Ga the basement and cover sequence were sub-

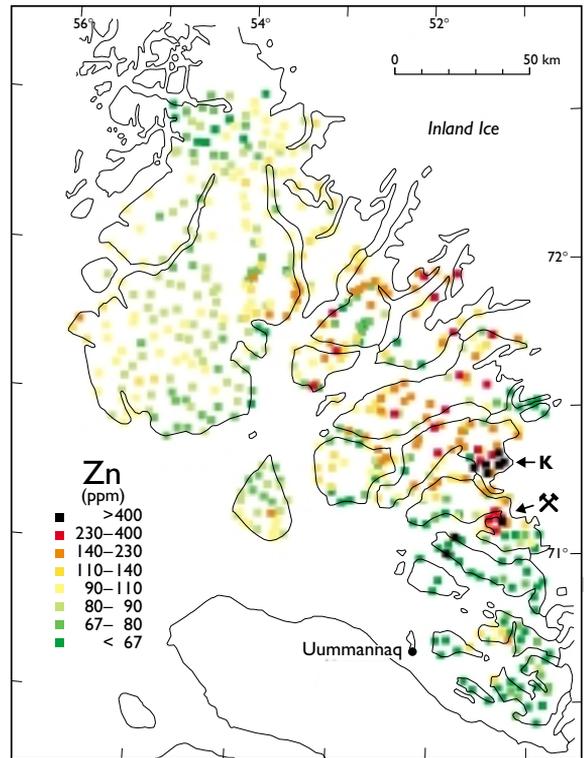


Fig. 2. Geochemical map of Zn concentrations in the < 0.1 mm fraction of stream sediment samples. K: Kangerluarsuk. Position of the abandoned lead-zinc mine at Maarmorilik is indicated by the mine symbol.

jected to strong folding and thrusting, and the rocks were variably affected by high temperature-low pressure metamorphism (Grocott & Pulvertaft 1990). The resulting structural pattern is characterised by mantled gneiss antiforms and displacements on low-angle detachment zones. A syn-tectonic, hypersthene-bearing granite body, the Prøven granite, was intruded north of Svartenhuk Halvø, and has given a Rb-Sr age of 1.86 ± 0.25 Ga (Kalsbeek 1981).

The mafic lavas and subordinate sedimentary rocks in the western and northern part of the project area form part of the Tertiary volcanic province of West Greenland (Clarke & Pedersen 1976). The genesis of the province of plateau basalts has been related to the same hot mantle plume which was responsible for the creation of the North Atlantic Tertiary igneous province (Upton 1988). The lava series occurring at Svartenhuk Halvø and Ubekendt Ejland comprises basal picritic breccias and olivine-rich lavas followed by a thick sequence of feldspar-phyric basalts (Clarke & Pedersen 1976). The Tertiary igneous rocks also comprise a granite at

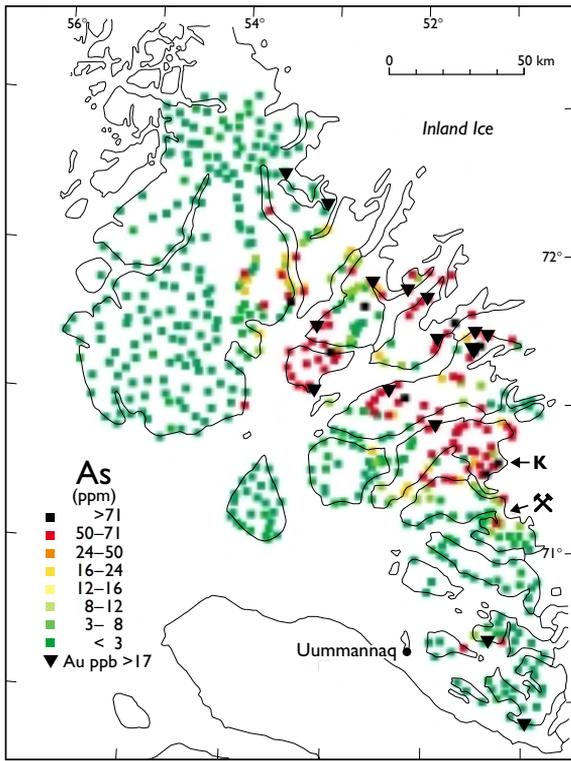


Fig. 3. Geochemical map of As concentrations in the < 0.1 mm fraction of stream sediment samples. The black triangles show sites with Au concentrations equal to or above the 98th percentile of the Au values. Letter and mine symbol as in Fig. 2.

Ubekendt Ejland and a number of thin lamprophyric dykes throughout most of the survey region.

Geochemical reconnaissance exploration and mapping

The stream sediment samples were collected with an average density of 1 sample per 15 to 20 km². Prior to the field work preferred sample sites were selected and marked on aerial photographs. It was attempted to obtain an even distribution of sample localities located in first or second order streams with drainage basins not larger than 10 km².

The fine fractions (< 0.1 mm) of the stream sediment samples have been used for analysis. Major elements were determined by X-ray fluorescence spectrometry using fused samples, trace elements were determined by a combination of instrumental neutron activation analysis and inductively coupled plasma emission spectrometry.

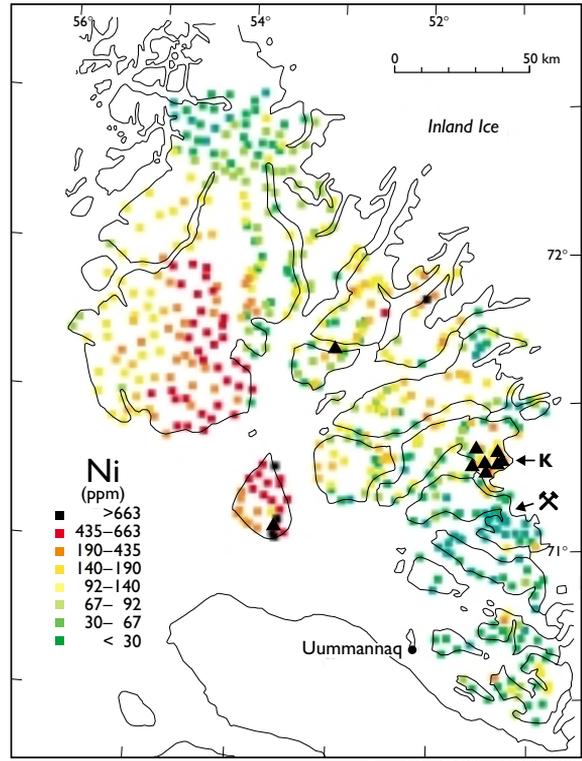


Fig. 4. Geochemical map of Ni concentrations in the < 0.1 mm fraction of stream sediment samples. The black triangles indicate sites where Ni is enriched relative to MgO, the sample points marked as triangles in Fig. 5. Letter and mine symbol as in Fig. 2.

The total number of localities sampled for the geochemical mapping was 528. Samples from 44 previously sampled localities are also included in the survey. The distribution of the sites are seen in the geochemical maps (Figs 2–4), and Table 1 contains simple statistical parameters for the analytical data.

Preliminary results

Element distribution maps have been produced for forty elements (Steenfelt *et al.* 1998), three of which are presented here as examples (Figs 2–4). Figure 2 demonstrates how the distribution pattern of Zn reflects major lithological provinces: low Zn in the Archaean gneisses and the Prøven granite, medium Zn in the Tertiary lavas. Within the Karrat Group the Zn is unevenly distributed with high Zn in the Marmorilik Formation, low in the Qeqertarsuaq Formation and scattered high concentrations in streams derived from the south-central parts of the Nûkavsak Formation. The highest Zn concentrations outside the Black Angel mining area are located

Table I. Statistical parameters for major and trace elements of stream sediment samples between Ummannaq and Prøven, West Greenland

	Min.	Max.	Med.	98 pc.	An. meth.
SiO ₂	8.89	76.02	62.14		XRF
TiO ₂	0.05	4.92	0.88		XRF
Al ₂ O ₃	1.29	19.52	13.64		XRF
Fe ₂ O ₃	1.48	26.05	8.92		XRF
MnO	0.03	0.39	0.11		XRF
MgO	0.73	28.65	3.75		XRF
CaO	0.47	78.4	3.9		XRF
Na ₂ O	0.31	4.41	2.09		XRF
K ₂ O	0.07	4.64	1.99		XRF
P ₂ O ₅	0.05	0.88	0.17		XRF
As	0	190	2.9	71	INAA
Au (ppb)	<2	61	0	18	INAA
Ba	<100	5500	450	1000	INAA
Co	1	130	27	74	INAA
Cr	<5	5400	170	2600	INAA
Cu	5	776	107	285	ICP-ES
Hf	<1	110	6	24	INAA
Mo	<2	35	0	11	ICP-ES
Ni	5	804	91	620	ICP-ES
Pb	<5	327	19	62	ICP-ES
Rb	<5	240	61	150	INAA
Sb	<0.1	7.5	0	1.8	INAA
Sc	0.5	61	18	50	INAA
Sr	68	423	164	296	ICP-ES
Th	<0.2	90	11	50	INAA
U	<0.5	230	3.4	39	INAA
V	7	611	142	483	ICP-ES
Y	5	202	24	51	ICP-ES
Zn	21	1483	91	344	ICP-ES
La	2.2	610	42	216	INAA
Ce	4	970	77	312	INAA
Nd	<5	550	28	140	INAA
Sm	0.3	95	5.8	23	INAA
Eu	<0.2	15.1	1.3	3.3	INAA
Yb	<0.2	18	2.7	5.6	INAA
Lu	<0.05	2.8	0.4	0.9	INAA

Analytical methods (An. meth.) for the < 0.1 mm grain size fraction of 572 stream sediment samples. XRF: X-ray fluorescence spectrometry, INAA: instrumental neutron activation analysis, ICP-ES: inductively coupled plasma emission spectrometry.

Statistical parameters: minimum (Min.), maximum (Max.), median (Med.) and the 98th percentile (98 pc.).

Major elements in percent, trace elements in ppm, except Au, ppb.

in the area east of Kangerluarsuk (K in Fig. 1) in the lowermost part of the Nûkavsak Formation. The highest Zn value obtained in this district is 1483 ppm.

The south-central part of the Nûkavsak Formation is also characterised by high concentrations of As (Fig. 3), whereas all other units are low in As. Twelve of the sixteen samples with elevated gold concentrations are located within the high As province. The two parallel

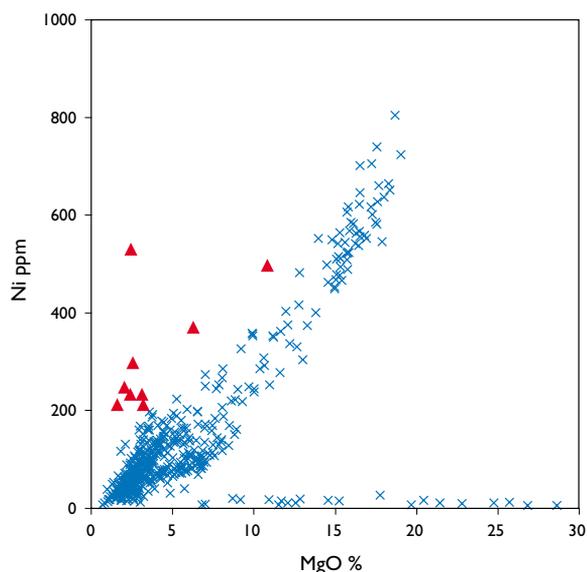


Fig. 5. Ni concentrations versus MgO concentrations in stream sediment samples. The strong correlation illustrates that most of the Ni occurs in Mg-bearing silicate minerals. The high MgO-low Ni samples are derived from dolomites of the Marmorilik Formation. Samples with excessive Ni, red/filled triangles, are likely to contain Ni-sulphides.

north-western trends of the gold anomalies are parallel with the dominating structural trends, and a possible gold mineralisation is tentatively considered to be structurally controlled. There is a small cluster of samples with high As values and one Au anomaly in the south, associated with an infolded remnant of the Nûkavsak Formation in the otherwise gneiss dominated terrain.

The map of Ni (Fig. 4) shows high concentrations in a belt across Svartenhuk Halvø and Ubekendt Ejland, which reflect the olivine-rich breccias and lavas of the Vaigat Formation (Pedersen 1985) in the lower part of the Tertiary plateau basalt sequence on Svartenhuk Halvø. The strong correlation between MgO and Ni in most of the samples, illustrated by the scatter diagram (Fig. 5), demonstrates that the Ni is, indeed, associated with olivine. From an economic point of view the high concentrations of olivine-bound Ni are not immediately interesting. However, samples showing Ni enrichment relative to MgO, marked by red triangles in the diagram, are likely to contain Ni in sulphide phases. The locations of these samples are shown by the black triangles in Figure 4 that are seen to form a cluster east of Kangerluarsuk (K in Fig. 1), where also Zn values are high. This area therefore constitutes an interesting target for further prospecting.

Mineral occurrences and exploration activities

The field work comprised examination of known showings, follow-up of gold anomalies, and visits to selected localities of the Greenlandic minerals hunting project, Ujarassiorit (Dunnells 1995; Erfurt & Tukiainen 1997). The follow-up work included visual prospecting for mineralised float and outcrops on foot traverses, supplemented with local stream sediment sampling and panning. The collected samples were submitted for multi-element analysis including gold and base metals. Results are reported by Thomassen & Lind (1998).

Carbonate-hosted lead-zinc mineralisation is common in the Marmorilik Formation. The Black Angel deposit, at Maarmorilik (Fig. 1), comprised ten ore bodies of commercial size, totalling 13.6 million tonnes grading 12.3% Zn, 4.0% Pb and 29 ppm Ag, of which 11.2 million tonnes were extracted in the period 1973–90 by Greenex A/S, a Danish company controlled by Cominco Ltd., and from 1986 by Boliden Mineral AB (Pedersen 1980, 1981; Thomassen 1991a). The massive sphalerite-galena-pyrite ores are hosted by calcitic and dolomitic marbles with intercalations of anhydrite-bearing marbles and pelitic schists. The origin of the ores is uncertain (Thomassen 1991a) as the sulphides are strongly tectonised and metamorphosed at greenschist facies conditions. The present ore distribution is structurally controlled. A number of similar galena-sphalerite-pyrite occurrences are known from the marble outcrops between Maarmorilik and Nuussuaq.

The Qeqertarsuaq Formation hosts scattered epigenetic copper mineralisation in quartzites and in the metavolcanic hornblende schists at the top of the formation. The copper showing at the east coast of Inngia Fjord (loc. 2 on Fig. 1, Fig. 6) was found by the Survey in 1989 (Thomassen 1991b). It consists of disseminated or blebby slightly auriferous chalcopyrite and pyrrhotite in a few centimetres thick quartz veins which have been followed laterally over 300 m and appear to be controlled by a thrust or flat-lying shear zone. The host rocks are quartzites with ultramafic lenses. The overall metal contents are low, but the style represents an interesting epigenetic exploration target, as thrusts and shear zones are abundant in the area. During the field visit, copper-bearing scree samples were found above the mineralised zone, which indicates that the mineralisation is more widespread than previously assumed.

Two mineralised samples collected in the neighbouring area (locs 4 on Fig. 1) stem from lateral moraines to glaciers transecting mainly Qeqertarsuaq Formation

rocks. One is a 0.5 m sized boulder of tourmaline-bearing vein quartz with semi-massive, intergrown pyrite and pyrrhotite containing 649 ppb Au, 2100 ppm Co and 415 ppm Cu. The other is a mica schist with veinlets and blebs of pyrrhotite, pyrite, chalcopyrite and magnetite which returned 325 ppb Au, 510 ppm Co, 1212 ppm Cu, 630 ppm Th and 300 ppm U. These samples are indicative of epigenetic mineralisation with potential for gold in the Qeqertarsuaq Formation.

The hornblende schists of the Qeqertarsuaq Formation are often overlain by a 0.5–5.0 m thick, rusty-weathering horizon of graphite-pyrrhotite schist with conformable lenses and layers of semi-massive iron sulphides (Allen & Harris 1980; Thomassen 1991b). Similar horizons of sulphidic, graphitic and often cherty schists with lenses and layers of semi-massive, brecciated pyrrhotite, minor pyrite and traces of chalcopyrite are widespread in the Nûkavsak Formation. Such horizons may be 5–10 m thick and continue for 5–10 km along strike, and they seem to be most common in the lower part of the formation (Allen & Harris 1980).

The semi-massive, pyrrhotite-graphite mineralisation was sampled in outcrop and boulders at several localities. The values are comparable with previously reported values for this type of mineralisation (Thomassen 1992) although a zinc value of 0.9% is the highest recorded to date outside the Kangerluarsuk area. It stems from an outcropping rust zone on Karrat island (loc. 5 on Fig. 1).

Zinc showings were found by RTZ Mining and Exploration Ltd. in 1991, east of Kangerluarsuk (locs 1 on Fig. 1; Fig. 7; Coppard *et al.* 1992). The mineralisation is stratabound and consists of sphalerite, pyrrhotite and minor galena hosted by marbles, pelites and cherts near the base of the Nûkavsak Formation. The sulphides occur as recrystallised massive layers or lenses, as chert-pelite-sulphide lamina, and as disseminated grains in various host rocks (Fig. 8). The mineralisation occurs intermittently over a strike-length of some 9 km, and the best outcrop so far located is a 15–35 cm thick horizon of massive, dark brown sphalerite assaying 41% Zn which seems to be of limited lateral extent (Coppard *et al.* 1992).

Quartz veins with minor sulphides and occasionally elevated gold contents are common in the turbidite sequence of the Nûkavsak Formation, and a potential for epigenetic 'turbidite-hosted gold deposits' (Keppie *et al.* 1986) has been proposed by Thomassen (1992). Three gold-anomalous areas were delineated by the Survey on eastern Svartenhuk Halvø and south-east of Inngia Fjord (Thomassen 1993). The anomalies are



Fig. 6. Part of the east coast of Inngia Fjord displaying grey quartzites of the Qeqertarsuaq Formation conformably overlain by brown greywackes of the Nûkavsak Formation two thirds up the 1800 m high mountain ridge. The copper showing (2) and the location of the boulder of vein quartz (4), mentioned in the text, are indicated.



Fig. 7. Zinc showing at Qaarsukassak, east of Kangerluarsuk. The zinc mineralisation is hosted by the rusty metasediments in the foreground. In the background, light grey Archaean gneiss is overlain by typical dark brown Nûkavsak Formation greywackes. The contact is tectonic. View from the south-east. The relief shown is about 1000 m.

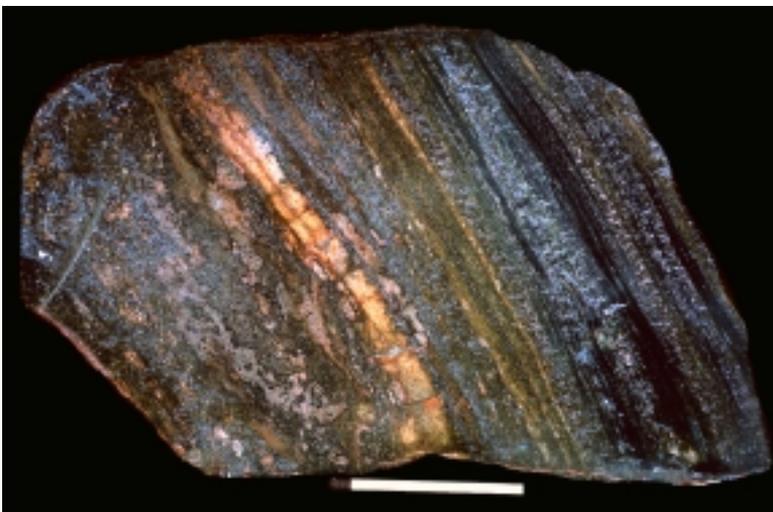


Fig. 8. Polished slab from the zinc showing at Qaarsukassak, east of Kangerluarsuk, displaying interbedded pelite, chert and sulphides (sphalerite, galena and pyrrhotite). The analysis gave 6.5% Zn, 0.2% Pb, 200 ppm Ag and 8.4% Fe. Matchstick, 4.5 cm. Photo: Jakob Lautrup.

mainly defined by heavy mineral concentrates which yielded gold values in the parts per million range, whereas the gold response in stream sediment samples was modest. Two of the gold anomalies coincide with arsenic anomalies and are located within the Nûkavsak Formation. Parts of these anomalies were checked in the field on the assumption that gold is associated with arsenopyrite, the latter being the prospecting target. Boulders of vein quartz or metasediment with disseminated arsenopyrite were encountered in three areas (locs 3 on Fig. 1), and the highest element concentrations of 11 samples were 1083 ppb Au and 2.5% As. Native gold was observed microscopically in some of the samples forming up to 40 micrometre inclusions and vein-fillings in arsenopyrite.

Concluding comments

The stream sediment data from the Uummanaq to Prøven region represent the first systematic exploration at a regional scale over the entire district, and in the preliminary evaluation of the data two targets have appeared with potential for mineral deposits: (1) Qaarsukassak, east of Kangerluarsuk, with indications of base metal sulphides (Zn, Ni, Cu), and (2) the gold anomalous trends.

Zinc mineralisation had already been noted at Qaarsukassak (Coppard *et al.* 1992). However, the geochemical anomaly for Zn and sulphide-bound Ni is much larger than the known mineralisation, and therefore there is good reason to re-examine the area with detailed soil sampling and electromagnetic surveys.

The anomalous gold trend is a new feature which warrants field work and detailed rock and scree sampling to obtain more information of the geological setting and possible types of mineralisation. During the sampling at Rink Isbræ it was noticed that the uppermost part of the Qeqertarsuaq Formation consists of red coloured, well preserved, finely laminated beds which are overlain by tens of metres of black pelitic schist; the latter presumably belong to the Nûkavsak Formation although the 'diagnostic' amphibolite was not seen.

The mineral exploration part of the project has confirmed the existence of arsenopyrite-bearing rocks with elevated gold contents in parts of the Nûkavsak Formation. Until this mineralisation is found in outcrop, its economic significance cannot be determined. The locality of the sample with elevated zinc content on Karrat island invites closer inspection, and in gen-

eral it is felt that the stratabound, pyrrhotite-dominated mineralisation in the Nûkavsak Formation deserves a systematic regional investigation.

Finds of boulders from the Qeqertarsuaq Formation with elevated concentrations of gold and other metals indicate an additional exploration target.

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