Upernavik 98: reconnaissance mineral exploration in North-West Greenland

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The Upernavik 98 project is a one-year project aimed at the acquisition of information on mineral occurrences and potential in North-West Greenland between Upernavik and Kap Seddon, i.e. from 72°30′ to 75°30′N (Fig. 1A). A similar project, Karrat 97, was carried out in 1997 in the Uummannaq region 70°30′–72°30′N (Steenfelt *et al.* 1998a). Both are joint projects 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 main purpose of the projects is to attract the interest of the mining industry. The field work comprised systematic drainage sampling, reconnaissance mineral exploration and spectroradiometric measurements of rock surfaces.

The region of the 4500 km^2 project, which covers most of Upernavik kommune and the southernmost part of Qaanaap (Thule) kommune, consists of islands, peninsulas and nunataks with relatively gentle topographic relief. Operating in the region by boat is not without problems. The main obstacle is the sea ice, especially calf ice in the so-called 'isfjorde' which drain directly from the Inland Ice. Starting the work in the southern part of the region and progressing towards the north for 330 km to reach Kap Seddon in mid-August, ensured that reasonable ice conditions were encountered in all areas.

The field work was carried out by a team of three geologists (B.T., J.K., T.T.) and two local assistants during eight weeks in July–August 1998. A chartered 36 foot vessel served as a mobile base working from 18 anchorages – M/S *Sila* (see Frontispiece of this volume, p. 3). Two rubber dinghies were used for local transport to all coastal localities while an AS 350 helicopter was chartered for six days to cover inland areas. The weather was relatively stable with only five days lost due to bad weather.

Geological outline

The project region is underlain by the Precambrian shield capped by Tertiary sediments and flood basalts in the southernmost part (Fig. 1A). The shield is composed of an Archaean gneissic basement with a cover of Palaeoproterozoic sediments (Fig. 2). These were folded and metamorphosed at granulite facies, and north of 73°15′N at amphibolite facies, during the Rinkian (Hudsonian) orogenesis around 1.85 Ga. Fold styles are dominantly overturned to nearly recumbent sheath folds involving both gneiss and metasediments (Grocott & Pulvertaft 1990). In the south a major syn-tectonic granitic complex exists, and the whole area is transected by a swarm of 1.65 Ga, NNW–SSE striking dolerite dykes (Nielsen 1990). The main part of the region was mapped in the period 1977–79 by the Geological Survey of Greenland at a scale of 1:100 000 (Escher & Stecher 1978, 1980); the northernmost part was mapped at 1:200 000 in 1980 (Dawes 1991).

The Archaean basement consists of intensely folded tonalitic to granodioritic gneisses with lenses and layers of metasediments, and mafic to ultramafic rocks. To the north, in the Kap Seddon area, the basement also contains thin horizons of banded iron formation (Dawes & Frisch 1981).

The Palaeoproterozoic metasediments belong to the Karrat Group (Henderson & Pulvertaft 1967, 1987), which continues southwards to *c.* 70°N where it hosts the abandoned 'Black Angel' lead-zinc mine (Pedersen 1980, 1981; Thomassen 1991). The Karrat Group has been correlated with coeval sediments of the Foxe Fold Belt in Canada (Grocott & Pulvertaft 1990). Based on U–Pb isotope data on detrital zircons from the Uummannaq region, it is estimated that deposition took place about 2 Ga ago (Kalsbeek *et al.* 1998). In the project region the Karrat Group comprises two formations. The lower, Qeqertarssuaq Formation, is developed as an intensely sheared unit, less than 50 m thick, of vari-

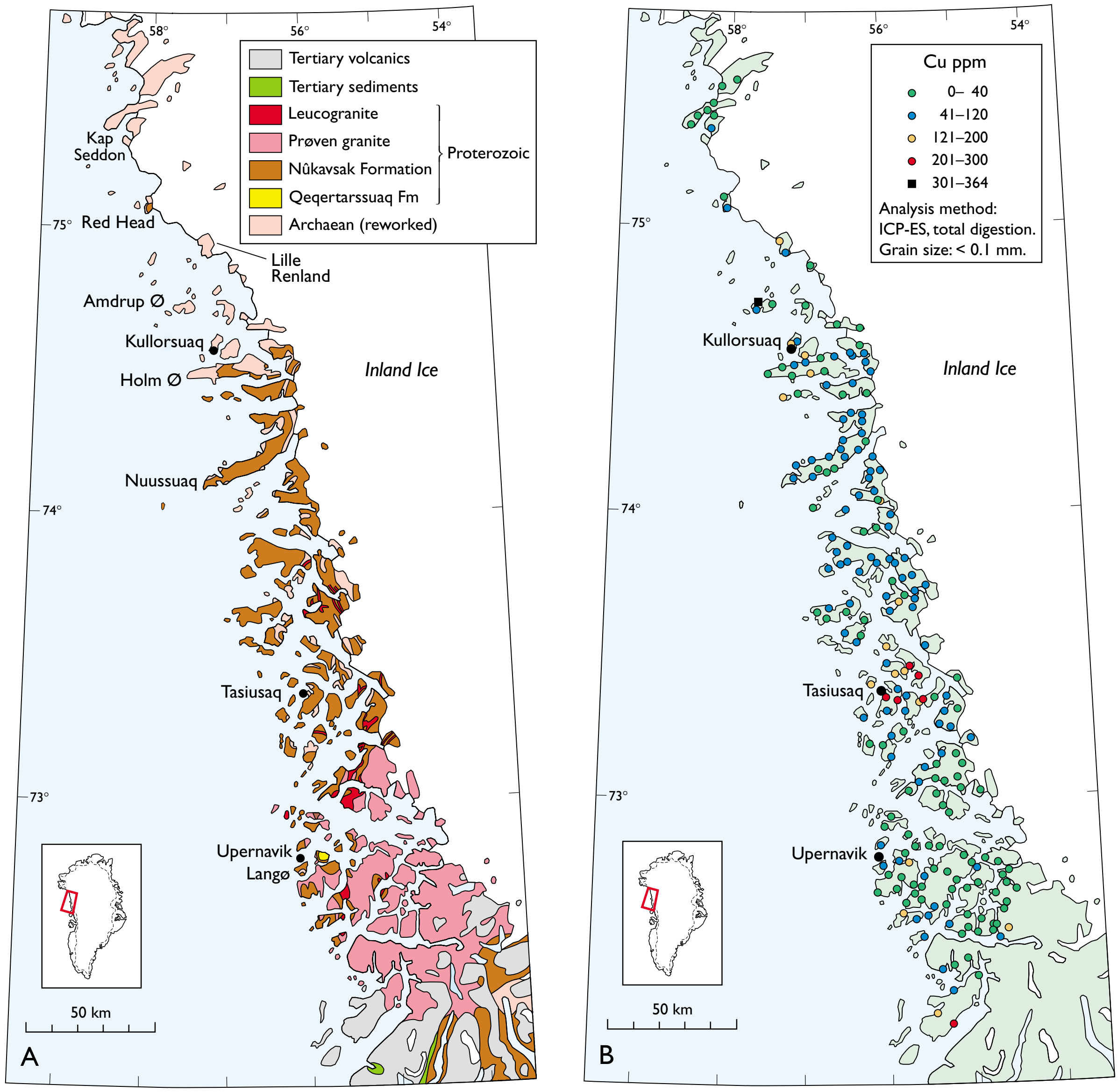

Fig. 1. Maps of the project region. **A**: Geological map based on Grocott & Pulvertaft (1990) and Dawes (1991). **B**: Geochemical map of Cu concentrations in the < 0.1 mm fraction of stream sediment samples.

able proportions of pelitic and graphitic schists, marble, skarns and quartzite of marine to open shelf origin. Minor layers of amphibolite are believed to represent metavolcanic rocks. The upper Nûkavsak Formation is a 1.5 km or more thick succession of monotonous, often rusty-weathering metagreywackes interpreted as flysch sediments deposited during a later transgression (Escher & Stecher 1980). The metagreywackes of the Upernavik – Kap Seddon region (Fig. 1A) are commonly migmatised with a gneissic character, unlike their less metamorphosed counterparts in the Uummannaq region to the south (70°30′–72°30′N).

The Prøven granite is a hypersthene-bearing igneous complex of various granitic units with an age of *c.*1.86 Ga (Kalsbeek 1981). The two main types are coarse-grained granites commonly with porphyritic feldspar forming massive sheets, and more fine-grained leucogranites occurring as irregular sheets and veins.

During the field work it was noticed that erratic boulders of undeformed, reddish brown sandstone and mud-

Fig. 2. Typical basement–cover section in an 800 m high, south-west-facing cliff east of Holm Ø. Rusty Karrat Group metasediments rest on grey Archaean gneiss.

stone with cross-bedding and mud cracks are widespread in the Tasiusaq area, indicating the existence of such post-orogenic sediments towards the east beneath the Inland Ice. These rocks form a redbed assemblage not unlike some lithologies of the Proterozoic Thule Supergroup (Dawes 1997).

The Tertiary rocks present in the southernmost part of the region were not studied during the 1998 field work.

Geochemical survey

The geochemical survey was a northerly continuation of the 1997 geochemical mapping of the Uummannaq region (Steenfelt *et al.* 1998a, b) and comprised collection of stream sediment and water samples at a nominal density of one sample per 15 to 20 km^2 of the land surface. Prior to the field work preferred sample sites were selected and marked on aerial photographs. An attempt was made to obtain an even distribution of sample localities in first or second order streams with drainage basins not larger than 10 km^2. In total, 238 sites were sampled. The fine fractions (< 0.1 mm) of the stream-sediment samples were used for analyses. Major elements were determined at the Survey by X-ray fluorescence spectrometry using fused samples, while trace elements were determined at Activation Laboratories Ltd., Canada by a combination of instrumental neutron activation analysis and inductively coupled plasma emission spectrometry. The analytical results are summarised in Table 1.

Many element distributions show geochemical patterns related to lithology. Thus the area south of 73°N, dominated by the Prøven granite, is characterised by elevated Ba, Sr, Ti, V and Y, while the area north of Holm Ø, dominated by basement gneisses, has elevated Sr and Ti and low levels of U, Th, K and Pb. The Karrat Group rocks, in the central area, have higher As, U, Th, Cu and Zn than the basement to the north. The most interesting geochemical feature, interpreted to indicate mineralisation, is a cluster of samples at Tasiusaq with high values of Cu (Fig. 1B). In the same area there are also anomalies of Au, Co, Cr, La, Mo, Ni, Th, U, V and Zn. In the vicinity of Kullorsuaq there are some high zinc and copper values and one gold anomaly.

Mineral exploration

From a mineral exploration point of view, the Upernavik – Kap Seddon region is one of the least explored parts of Greenland. Minor amounts of graphite were quarried on Langø near Upernavik in 1845 (Ball 1923) and samples of sphalerite were collected on Red Head at the beginning of the century (Bøggild 1953). Four short reconnaissance visits have been carried out by mining companies in the period 1969–81 (viz. Stuart Smith & Campbell 1971; Neale & Stuart Smith 1973; Brunet 1980; King 1981). During mapping by the former Geological Survey of Greenland some malachite staining and iron sulphides were reported from the basal part of the Karrat Group (Escher & Stecher 1980), while the scattered

Table 1. Statistical parameters for major and trace elements of stream sediment samples between Upernavik and Kap Seddon, North-West Greenland

	Min.	Max.	Med.	98 pc.	An. meth.
SiO_2	30.35	73.59	64.67		XRF
TiO_2	0.29	5.21	0.78		XRF
Al_2O_3	7.0	25.13	15.37		XRF
Fe_2O_3	2.26	28.83	7.07		XRF
MnO	0.03	0.29	0.08		XRF
MgO	0.67	18.65	1.93		XRF
CaO	0.86	15.57	2.18		XRF
Na_2O	0.37	4.54	2.63		AAS
K_2O	0.25	4.98	3.27		XRF
P_2O_5	0.11	3.47	0.27		XRF
As	<0.5	110	2.7	20	INAA
Au (ppb)	<2	32	<2	12	INAA
Ba	<100	2000	650	1478	INAA
Co	3	150	14	48	INAA
Cr	14	3000	73	203	INAA
Cu	6	364	41	219	ICP-ES
Hf	1	140	15	50	INAA
Mo	<2	87	<2	30	ICP-ES
Ni	7	1193	31	100	ICP-ES
Pb	<5	81	32	50	ICP-ES
Rb	<5	200	110	180	INAA
Sb	<0.1	0.6	<0.1	0.4	INAA
Sc	4.7	45	15	29	INAA
Sr	49	1022	175	392	ICP-ES
Th	0.9	170	33	98	INAA
U	<0.5	31	5.4	21	INAA
V	22	549	86	280	ICP-ES
Y	14	80	36	72	ICP-ES
Zn	24	223	83	182	ICP-ES
La	7.9	489	100	268	INAA
Ce	19	600	193	520	NAA
Nd	10	270	74	195	INAA
Sm	1.5	40	13	32	INAA
Eu	<0.2	7.2	1.4	4.1	INAA
Yb	<0.2	7	2.7	5.9	INAA
Lu	<0.05	1.2	0.5	1.0	INAA

Analytical methods (An. meth.) for the < 0.1 mm grain size fraction of 240 stream sediment samples.
XRF: x-ray fluorescence spectrometry by the Survey, Copenhagen.
INAA: instrumental neutron activation analysis by Activation Laboratories Ltd., Canada.
ICP-ES: inductively coupled plasma emission spectrometry by Activation Laboratories Ltd., Canada.
AAS: atomic absorption spectrometry by the Survey, Copenhagen.
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.

occurrences of banded iron formation mapped at Kap Seddon represent the southern exposures of the regional magnetite province that stretches north-westwards for 350 km along the Lauge Koch Kyst of Melville Bugt as far north as 76°30′N (Dawes & Frisch 1981).

The 1998 exploration work was mainly carried out as shoreline exploration, i.e. visual inspection of the coastal exposures for signs of mineralisation while passing slowly in a rubber dinghy. Prospective localities were investigated by sampling of mineralised boulders, scree, and *in situ* rock, and by the panning of stream sediments. A few localities were visited on helicopter stops. Before the field season, a remote sensing study of rust zones based on Landsat TM imagery was carried out and maps showing the zones of more intense ferric iron staining were produced for use in the planning of field visits. The samples have been analysed at Activation Laboratories Ltd., Canada for a suite of elements including precious and base metals. The main results are summarised below.

Archaean basement

Malachite staining caused by weathering of disseminated chalcopyrite was observed in some of the mafic–ultramafic lenses and layers in the basement gneisses north of Kullorsuaq (Fig. 1A). The most extensive mineralisation was found on Amdrup Ø where malachite patches are scattered over a 50–100 m high cliff of mafic gneisses. Sulphide-bearing grab samples from this locality contain up to 0.59% Cu and 57 ppb Au. On Lille Renland 25 km further north, a grab sample from a *c.* 5 m thick lens of hornblendite of magmatic origin shows surprisingly high precious-metal values: 0.25% Cu, 554 ppb Au, 477 ppb Pt and 1073 ppb Pd.

Scattered malachite staining was also observed over a more than one kilometre strike length in leucogneiss not far below the base of the Karrat Group on north-eastern Nuussuaq. A grab sample of biotite-rich gneiss from this locality with traces of chalcopyrite returned 0.06% Cu, 145 ppb Au and 79 ppm Bi. Local blocks of reddish, brecciated granite with pyrite and fluorite were sampled on Amdrup Ø and Holm Ø, but analyses show nothing noteworthy in these rocks.

The banded iron formation at Kap Seddon was sampled at two localities 9 km apart that probably represent the same 0.5–1.0 m thick horizon. In addition to magnetite and iron silicates, minor disseminated pyrrhotite and chalcopyrite were observed. Samples returned up to 32% Fe, 0.24% Mn, 0.1% Cu and 5 ppb Au. Banded iron formation was not encountered south of this area, but it was noted that the gneisses of the Kullorsuaq area are rich in disseminated magnetite.

Karrat Group

The basal, thin unit of the Karrat Group (Qeqertarssuaq Formation) was regarded as a prime exploration target because of its diversified lithologies. Strongly deformed layers and lenses of graphite schist with variable iron sulphide content were mainly encountered north of Tasiusaq. The graphite grades were not inspected more closely but it was noted that the old pits on Langø (mentioned above, see Fig. 1A) are only a few metres in each dimension corresponding to the size of the graphite lenses mined. Semi-massive pyrrhotite-pyrite lenses sampled in the Nuussuaq – Holm Ø area show similarities with the iron sulphide horizons in the Nûkavsak Formation in the Uummannaq region to the south (Thomassen 1992; Thomassen & Lind 1998). The sulphide-rich graphite schist is especially conspicuous on the south coast of Holm Ø, where it forms a spectacular folded 5–10 m thick horizon. The highest base-metal values were encountered on north-eastern Nuussuaq, where the 5 m thick horizon crops out *c.* 20 m above the contact with the basement gneiss. Grab samples of semi-massive pyrrhotite-pyrite with sphalerite and chalcopyrite contain up to 2.43% Zn, 0.21% Cu, 21 ppb Au, 96 ppb Pt and 100 ppb Pd.

Carbonate rocks range from pure, white calcite marble to green diopside marble, grey scapolite marble and other rocks rich in calc-silicate minerals. They may contain sporadic disseminated sulphides. The highest

Fig. 3. Typical, *c.* 1 km wide rust zone in Karrat Group metasediments on Red Head. View towards the north.

base-metal values (0.57% Zn and 0.03% Pb) stem from a grab sample of diopside marble with minor sphalerite, pyrrhotite and graphite from eastern Holm Ø. A scheelite-bearing block of calc-silicate rock from southern Holm Ø returned 744 ppm W.

The upper, thick unit of the Karrat Group (Nûkavsak Formation) hosts conspicuous red and yellow rust zones of regional extent which are especially well developed in the Tasiusaq region and on Red Head (Fig. 3). The extent of these zones is well displayed on Landsat rust anomaly maps which show that they are almost exclusively confined to the western parts of the area. The absence of rust zones or rust-stained rocks close to the ice margin is probably due to recent glacial erosion. In the field it was observed that the rust zones consist of conformable, tens of metres thick units, which only differ from the neighbouring grey metagreywackes by a somewhat higher content of biotite, graphite and minor pyrrhotite and magnetite. No signs of semi-massive sulphide concentrations were observed, but the stream sediment anomalies suggest that mineralisation has occurred. The analysed rock samples show no significant metal concentrations apart from 125 ppb Au in a chip sample of a 10 cm thick pyrite-bearing chert from Red Head.

Malachite staining was observed in metasediments near the contact to the Prøven granite 30 km east of Upernavik, where minor blebs of chalcopyrite (up to 0.18% Cu) occur in pelite intruded by granitic veins. In the same area, a number of arsenopyrite-bearing, quartzitic boulders returned up to 0.34% As and 111 ppb Au.

Spectroradiometric measurements

A programme of spectroradiometric measurements was carried out during August by using a GER Mark V Infrared Intelligent Spectroradiometer, which provides accurate spectral measurements from 350 to 2500 nm in 704 channels. The objective was to determine spectral characteristics of representative lithologies and various types of hydrothermal alteration. The effect of partial lichen cover on the spectral characteristics of rocks was measured in selected localities. The measurement programme was combined with collection of representative rock samples from each investigated locality. The results of the spectroradiometric survey will provide an accurate reference data set for a more sophisticated processing and interpretation of available multispectral satellite data and future hyperspectral data sets from air- and satellite-borne sensors.

Concluding comments

Archaean basement

The copper mineralisation associated with mafic and ultramafic rocks in the northern part of the region holds a potential for magmatic gold and platinum group elements. However, further investigations are required to clarify the extent, characteristics and economic significance of this mineralisation.

Although no economic metal values were detected in the banded iron formation in the northernmost part of the project region, its regional extent northwards for 350 km into Qaanaap kommune invites further exploration (Dawes & Frisch 1981).

Karrat Group

The rust zones of the Upernavik – Kap Seddon region apparently do not host semi-massive sulphide concentrations, as found in the Uummannaq region, and the coloration seems merely to stem from breakdown of biotite and oxidation of minor sulphides in the metasediments. However, the one horizon in the Upernavik – Kap Seddon region with semi-massive sulphides, in the Qeqertarssuaq Formation at the very base of the Karrat Group, has yielded a promisingly high zinc value of 2.4%. This target certainly deserves follow-up investigations for shale-hosted base metal deposits. Furthermore, the source of the multi-element stream-sediment anomalies in the Karrat Group metasediments should be determined.

The marbles in the Upernavik – Kap Seddon region are normally only a few metres thick (max. 30 m according to Escher & Stecher 1980) in contrast to those of the Uummannaq region, where they may be several hundreds of metres thick and host Pb-Zn ores of the Black Angel type (Pedersen 1980, 1981; Thomassen 1991). Lead-zinc mineralisation in interfingering thin marbles and pelites is, however, also known from the Uummannaq region (Thomassen & Lind 1998), and this lithology is widespread in the Qeqertarssuaq Formation of the Upernavik – Kap Seddon region. It is therefore believed that the carbonate components of the Qeqertarssuaq Formation add to the prospectivity of this unit.

Arsenopyrite mineralisation with enhanced gold, common in the northern part of the Uummannaq region (Thomassen 1992; Thomassen & Lind 1998), has only been recognised in the southernmost part of the Upernavik – Kap Seddon region, corresponding to relatively low arsenic concentrations in the stream sediment samples from this region (Table 1).

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