DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2011/129

Economic geological reconnaissance between Lambert Land and J.C. Christensen Land (North and North-East Greenland 79°N to 82°N)

Tapani Tukiainen & Mogens Lind

(1 CD-Rom included)

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
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GEUS

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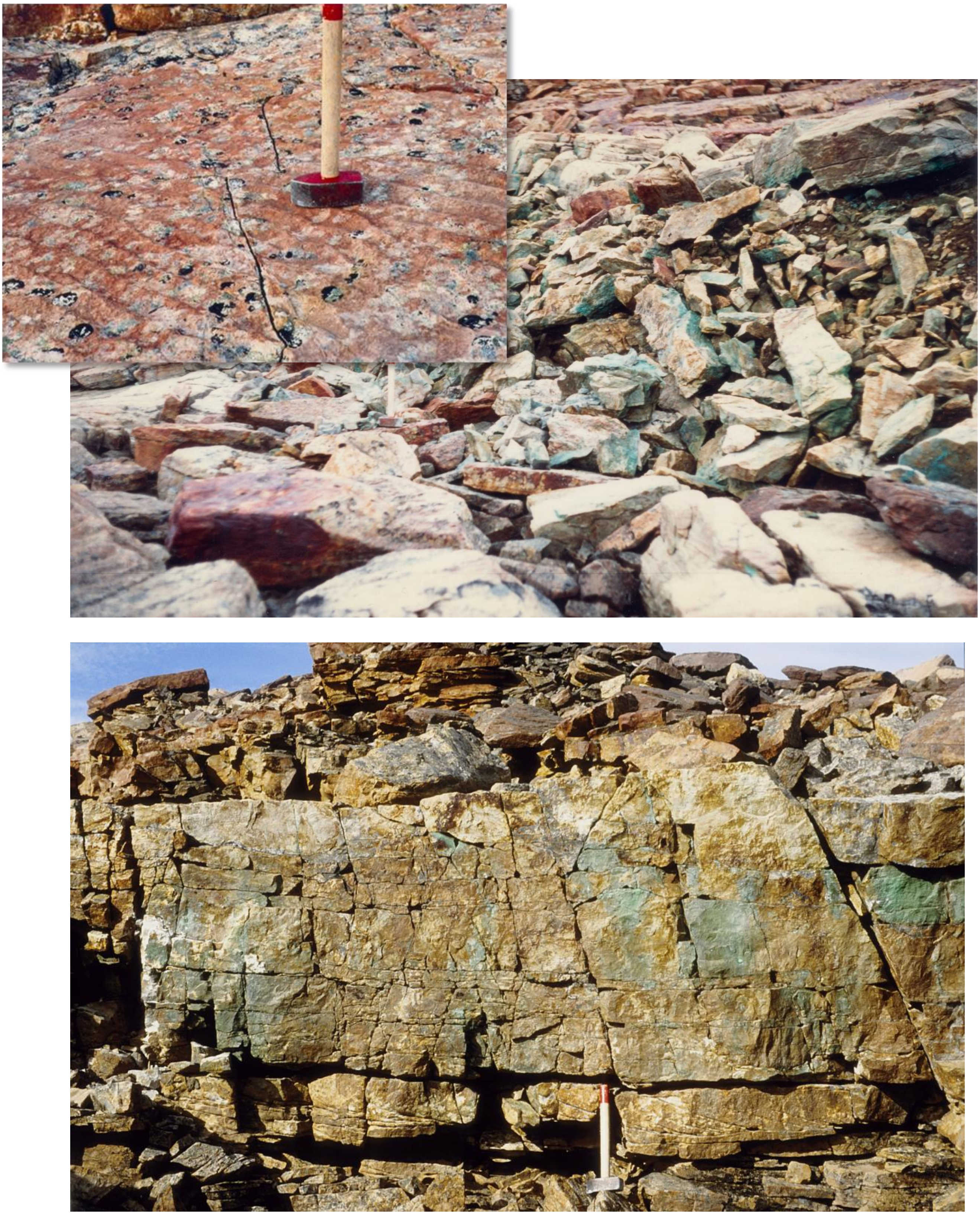
G E U S



Frontispiece. Jyske Ås Formation sandstone (Hagen Fjord Group). Malachite coatings disclosing the copper sulphides in sandstone. Neergaard Dal, J.C. Christensen Land

Contents

1. Abstract

The geological history of eastern North Greenland spans from Palaeoproterozoic to Neogene with major depositional basins extensively reworked during the Caledonian orogeny. The Geological Survey of Greenland‟s (GGU) mapping project in eastern North Greenland (1993-1995) aimed at producing a general overview of the onshore geology between Jøkelbugten and Kronprins Christian Land area (78 – 81ºN). The mapping project included an economic geological reconnaissance in selected areas to evaluate the economic potential of the area with respect to minerals.

Palaeo - Mesoproterozoic volcanic rocks

Cu mineralisation in volcanic rocks:

The succession of white quartzitic sandstones and thinner silt-dominated units of the Independence Fjord Group is everywhere cut by mafic dykes and sills considered to be related to the overlying 1350 m succession of Mesoproterozoic continental tholeitic flood basalts known as the Zig-Zag Dal Basalt Formation in the west. Strongly folded representatives of the Independence Fjord Group in a broad zone of central Kronprins Christian Land within the Caledonian orogeny contain older units of basaltic lavas: the Hekla Sund Formation (1740 Ma) and the Åge Berthelsen Gletscher Formation, which in contrast to the Zig-Zag Dal Basalt Formation were deposited in marine rift basins. The basaltic lavas contain a widespread Cu mineralisation (Cu-sulphides, native Cu) in the vesicles of the lava flows or in the volcanic breccias of pillow lavas. The occurrences are typically small and of no economic interest.

Fe-Ti-Cr mineralisation in dolerite dykes and sills:

There is evidence that chromite and titanomagnetite mineralisation along with minor Cu and Ni sulphides took place in the Midsommer Sø Formation Dolerite sills and dykes during the crystallization of the basaltic magma. The investigated occurrences are of uneconomic size and grade. The large extent and volume of the dolerite dykes and sills in mind the occurrence of economically significant concentrations of chromite and titanomagnetite cannot be excluded.

Magnetite Ironstone in siliciclastic sediments

Heavy mineral accumulations as seams of predominantly magnetite occur in the siliciclastic sediments of the Independence Fjord Group. In Lambert Land the magnetite accumulations have been metamorphosed to magnetite ironstones which, with respect to the high Fe-content, volume and spatial extent, deserve further investigations.

Structurally controlled Au mineralisation:

The sheared rock units adjacent to the Storstrømmen shear zone from Lambert land to Ingolf Fjord frequently display a slightly enhanced content of Au in the stream sediment samples. Follow up on the selected localities in Lambert land showed only insignificant Au-content in the sheared and altered rocks.

Neoproterozoic sediments

Sedimentary-hosted Cu mineralisation:

The western group of the Neoproterozoic sediments – the Hagen Fjord Group was visited at two localities (Campanula Dal and Neergaard Dal, J.C. Christensen land), 160 km apart. The occurrences of sedimentary hosted Cu-mineralisation were located at both localities, although at different stratigraphic levels. Despite not being of economic size and grade, the occurrences, particularly the Neergaard Dal showing, demonstrates that a Cu-mineralising process of significance did take place.

The Eastern group of the Neoproterozoic sediments – the Riveradal Group was traversed in two localities. Apart from slightly elevated levels of Cu, Pb Zn and sporadically Au in the drainage geochemical samples, no evidence of mineralisation was discovered.

Ordovician-Silurian shelf sequence

Carbonate hosted Pb-Zn:

The Silurian platform carbonates in Kronprins Christian Land, including the carbonate buildups in this area were investigated in 7 localities to check the potential for carbonate-hosted Zn-Pb mineralisation, where more detailed drainage geochemical sampling was carried out. The results from these areas were entirely negative, no evidence of this type of mineralisation was found.

Au mineralisation:

The drainage geochemical samples from the selected localities of the platform carbonates showed conspicuously high Au-values. The high Au values cluster particularly in the Vestfjeldet-Grottedal area with a maximum of 13 ppm Au in heavy mineral concentrate and 1 ppm Au in stream sediment respectively. The source of anomalous Au-values is not known. The pyritic black shale units in the inter-mound sediments of the Silurian Samuelsen Høj Formation demonstrate enhanced values of Au, A, Sb and base metals making these rock a candidate as a source for the stream sediment anomalies. The anomalous Au values of the drainage geochemistry may indicate the presence of Carlin type gold mineralisation in the Ordovician-Silurian shelf sequence.

2. Introduction

The Geological Survey of Greenland‟s (GGU) mapping project in eastern North Greenland (1993-1995) aimed at producing a general overview of the onshore geology between Jøkelbugten and Kronprins Christian Land area (78 – 81ºN). In addition to establishing a general overview of the regional geology, the project aimed at obtaining an evaluation of the economic potential of the region, with respect to both minerals and hydrocarbons (Stemmerik et al., 1995)

The field investigations were initiated in 1993 with limited reconnaissance work (Henriksen 1944), and continued with a major field campaign in 1994 (Henriksen 1995). The planning of the field work 1995 was carried out as in 1993 and 1944 by the Geological Survey of Greenland (GGU), but following the merger of GGU with the Geological survey of Denmark (DGU) on 1 June 1995, the field work itself was completed under the auspices of the new organization – the Geological Survey of Denmark and Greenland (GEUS).

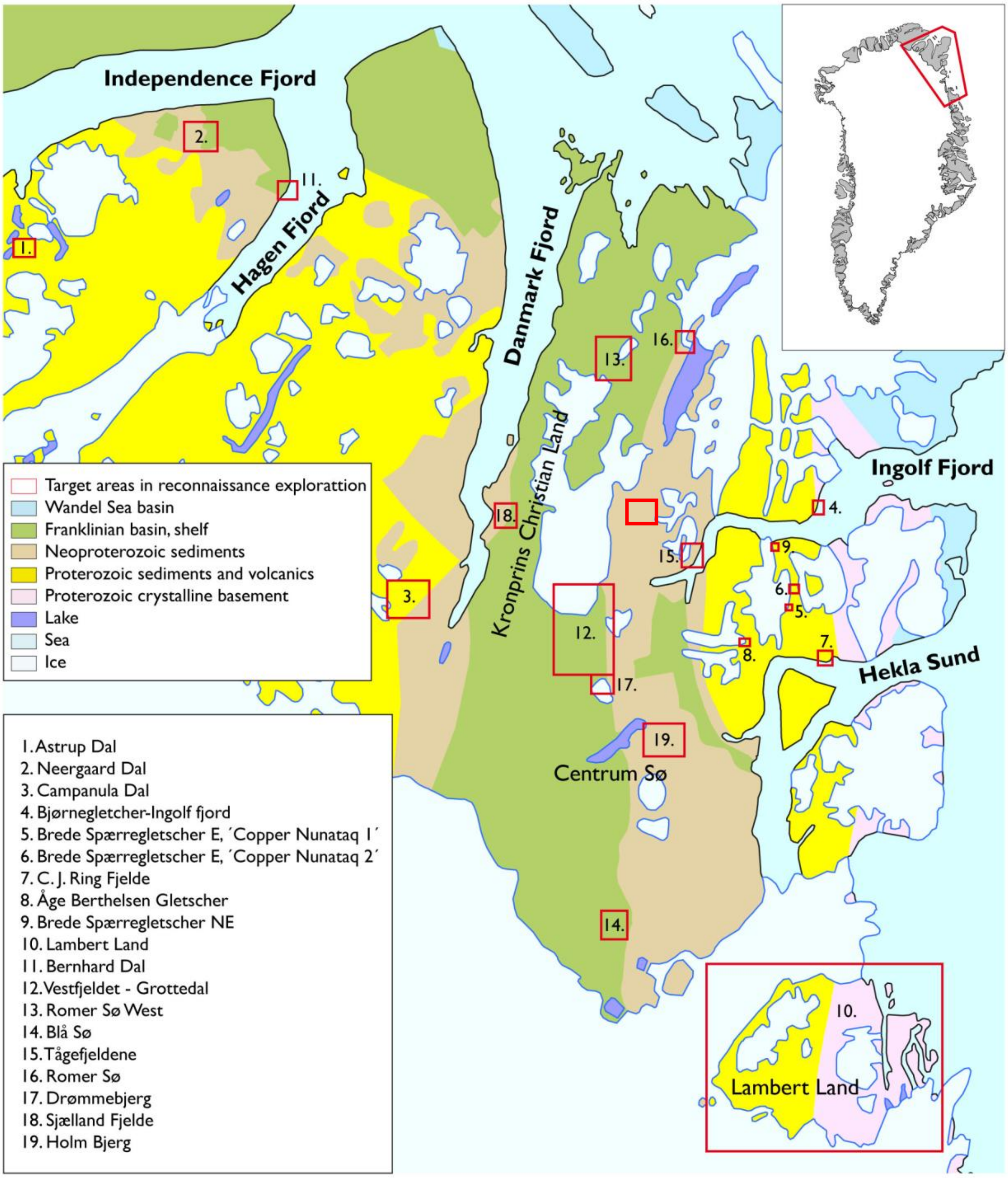
The persons responsible for the studies related to the mineralization in the GGU/GEUS mapping project were as follows:

1993 S. M. Jensen (GGU), A. Steenfelt (GGU) & E. Dam (GGU) Drainage geochemical mapping of Lambert Land and southern Kronprins Christian Land (79º to 80º55‟N, 18º50‟ to 25ºW).

1994 M. Lind (GGU), T. Tukiainen(GGU) & K. Kragh (GGU): Geochemical sampling of water and stream sediments in central Kronprins Christian Land and west of Danmark Fjord, Studies of mineralization.

1995 M. Lind (GGU) & T. Tukiainen (GGU): Mineralization and geochemical sampling of stream sediments and heavy mineral concentrates. Area from Independence Fjord to Kronprins Christian Land.

This report compiles and summarizes the results related to the mineralization in eastern North Greenland. Valuable contributions to the assessment of the economic potential came from the other persons involved in other aspects/topics of the regional geology (J. C. Friderichsen, J. Escher, J. Hull, H. F. Jepsen, K. Jones, S. A. S. Pedersen and M. Sønderholm).



Map 1. *Overview of the geology of eastern North Greenland (Jepsen et al., 2003). The localities cited in the text are shown on the map.*

3. Geological setting

The geological history of eastern North Greenland spans from Palaeoproterozoic to Neogene with major depositional basins extensively reworked during the Caledonian orogeny (Map 1). Jepsen et al. (2003) summarise the geology as briefly described in the following sections.

3.1 Palaeoproterozoic crystalline basement

Palaeoproterozoic orthogneisses are widespread in East Greenland north of c. 73°N, and dominate the exposure north of 76°N. They represent segments of the Greenland Precambrian shield that have been extensively reworked during the Caledonian orogeny and, like the Achaean orthogneisses further south in East Greenland, they have been incorporated into major Caledonian thrust sheets displaced westwards across the foreland to the west.

The Proterozoic orthogneisses of northern East Greenland are considered to represent a major juvenile crust forming episode (2000-1750 Ma old). Deep burial and subsequent uplift of the Proterozoic basement terrains during the Caledonian orogeny led to the formation of widespread eclogites north of 76°N, a region known as the North-East Greenland eclogite province.

3.2 Palaeo-Mesoproterozoic sediments and volcanics

The earliest major depositional basin developed on the Greenland shield is represented by the Independence Fjord Group, a more than 2 km thick succession of white quartzitic sandstones and thinner silt-dominated units. The Independence Fjord Group is everywhere cut by mafic dykes and sills considered to be related to the overlying 1350 m succession of tholeitic flood basalts known as the Zig-Zag Dal Basalt Formation. The lavas are too chemically altered for age determination, but, as the basalts are considered to have the same igneous source as the Midsommersø dolerites (intruded into the underlying Independence Fjord Group sediments), an age of the c. 1380 Ma for the dolerites is assumed for the basalts as well (Upton et. al., 2005).

The most widespread exposures of these units occur in the Caledonian foreland between Independence Fjord and Danmark Fjord, with further outcrops in a block-faulted area of eastern Peary Land. Strongly folded representatives are found in a broad zone of central Kronprins Christian Land within the Caledonian orogeny and can be traced southwards through Lambert Land into the westernmost nunatak region with sporadic exposures recorded as far south as western Dronning Louise Land. In Kronprins Christian Land a zircon age of 1740 Ma for rhyolitic rocks of the Hekla Sund Formation interbedded with the Independence Fjord Group suggests a late Palaeoproterozoic age.

No age determinations exist for the Åge Berthelsen Gletscher Formation volcanics. Correlations has been suggested with both the Hekla Sund Formation (1740 Ma) and the Zig-Zag Dal Basalt Formation (1380 Ma). Collinson et al., 2008, favour a correlation with the Hekla Sund Formation as both formations are deposited in marine rift basins (in contrast to the continental setting of the Zig-Zag Dal Basalt Formation).

3.3 Neoproterozoic sediments

The Hagen Fjord Group comprises a c. 1000 m thick succession of Neoproterozoic shallow marine sediments that overlie the Palaeoproterozoic Independence Fjord Group and Mesoproterozoic Zig-Zag Dal Basalt Formation. The upper part is characterized by red and yellow weathering limestones and dolomites. The group outcrops extensively between Independence Fjord and Danmark Fjord in eastern North Greenland. In central Kronprins Christian Land, an 8-10 km thick succession of siliciclastic rocks known as the Rivieradal Group represents the fill of a half-graben basin, and is conformably overlain by the Hagen Fjord Group. The Morænesø Formation is an up to 200 m thick succession of diamictites and sandstones of probable Varangian age, preserved in isolated outcrops in southern Peary Land.

3.4 Franklinian Basin - shelf sequence

The Palaeozoic Franklinian Basin extends from the Canadian Arctic Islands across North Greenland to Kronprins Christian Land in eastern North Greenland, an E-W distance of about 2000 km. Sedimentation in the North Greenland segment of the basin began in the earliest Cambrian and continued until the earliest Devonian, and was brought to an end by the mid- to late Palaeozoic Ellesmerian orogeny. Throughout the Early Palaeozoic the basin was divided into a southern carbonate shelf and slope area (about 3 km thick) and a northern deep-water trough (siliciclastic sediments up to 8 km thick). The shelf-trough boundary was probably essentially fault-controlled, and with time the trough expanded southwards with final foundering of the shelf areas in the Silurian. The shelf-trough boundary is the Navarana Fjord escarpment, a prominent scarp-like feature controlling deposition between the Middle Ordovician and Early Silurian. The southern boundary of the Franklinian Basin has a general E-W trend across North Greenland, that changes abruptly to a N-S trend in Kronprins Christian Land.

3.5 Wandel Sea Basin

Carboniferous-Palaeogene sediments and volcanic rocks that were laid down along the northern and north-eastern margin of the Greenland shield are collectively known as the Wandel Sea Basin. The earliest phase of deposition is a widespread Carboniferous-Triassic event of fluvial to shallow marine deposition associated with block faulting and regional subsidence. This was followed by more localised basin deposition in the Late Jurassic and Cretaceous, associated with strike-slip displacements along a zone formed at the plate boundary between Greenland and Svalbard. The main exposures of the Wandel Sea Basin are in northern Kronprins Christian Land (overlying the folded rocks of the northern extremity of the Caledonian orogeny), and eastern Peary Land (overlying sediments of the Franklinian Basin. At Kap Washington on the north coast of Greenland a c. 5 km thick succession of latest Cretaceous extrusive volcanic rocks of peralkaline affinity associated with volcanogenic sediments is preserved. They extrusion may be associated with mainly N-S trending dense swarms of alkali dolerite dykes. The volcanic rocks are preserved beneath a major southward dipping thrust, formed during the Eurekan phase of compressive deformation.

4. Mineral occurrences

The chemical analyses of the rock samples from discovered mineral occurrences and drainage-geochemical samples are in the appendix 1, The Mineral Occurrence ID no in the described localities refer to the Greenland mineral occurrence map (Thorning et al., 2004)

4.1 Palaeo - Mesoproterozoic siliciclastic sediments and volcanic rocks

4.1.1 Campanuladal, Cu- mineralisation in Zig-Zag Dal basalt

4.1.1.1 History

1969-1973: Greenarctic Consortium, photo geology, regional aeromagnetic survey, gossans check. Copper sulphides and native copper were located in a couple of showings within the Zig-Zag Dal Basalt Formation N and W of Campanuladal.

1978-80: The GGU regional mapping campaign included stream sediment sampling for geochemistry and ore microscopy of heavy minerals from the sediment samples (Ghisler et. al., 1979; Ghisler, 1994). Showings with copper sulphides and native copper within the Zig-Zag Dal Basalt Formation were reported by mapping teams (Bevins et al., 1991; H.F Jepsen personal communication)

1993: GGU regional stream sediment sampling and supplementary local sampling in Campanuladal (Jensen, et. al., 1994).

1994: GGU regional stream sediment sampling and ground follow up on geochemical anomalies resulted in a new mineralised locality on the NW side of Campanuladal (Lind and Tukiainen 1994).

Mineral Occurrence ID no. 918

4.1.1.2 Geological setting

The Zig-Zag Dal Basalt Formation is a continental tholeiitic flood basalt sequence that conformably overlies the Independence Fjord Group of siliciclastic sediments. The bulk of the lavas were extruded under subaerial conditions, with minor subaqueous episodes indicated by pillow lavas. The lavas are too chemically altered for age determination, but, as the basalts are considered to have the same igneous source as the Midsommersø dolerites (intruded into the underlying Independence Fjord Group sediments), an age of the c. 1380 Ma for the dolerites is assumed for the basalts as well (Upton et. al., 2005).

The copper mineralised localities associated with the Zig-Zag Dal Basalt Formation share a number of characteristics. In outcrops they appear to be stratabound as the ore minerals occur as vesicle fillings in the top slag of particular basalt flows (Bevins et. al., 1991). On a map scale the known localities are located at or close to steep regional faults. In Campanuladal a steep NE-SW trending fault follows the centreline of the valley. There is a down throw of c. 600 m to the SE which make the Zig-Zag Dal basalts crop out on the top of the NW valley side and on the valley floor SE of the fault.

4.1.1.3 Ore description

The Campanuladal copper showing is located on the North-West side of the valley at c. 700 m‟s elevation (Map 3). It is situated two metres above the contact between the Independence Fjord Group sandstones and the basal unit of the Zig-Zag Dal Basalt Formation. The contact is marked by a strong brick red coloration zone in the uppermost few metres of the sandstones. The host rock to the mineralisation is black, fine grained, vesicular basalt (Fig. 1). The presence of copper mineralisation is indicated by scattered spots of vague malachite stain around vesicles (up to ½ cm across) with a filling of chalcocite. A 1.5 m chip sample perpendicular to a vesicular zone gave 1.97% Cu while a grab sample returned 3.17% Cu. Both samples had slightly enhanced Zn values at c. 100 ppm. In the microscope the following ore mineral were observed (Fig. 2): orthorhombic chalcocite, digenite, covellite and cuprite. Chalcocite - digenite in combination with gangue minerals fill the vesicle. Cuprite represents a later replacement of the Cu sulphides under more oxidizing conditions. The initial stage of the cuprite replacement is seen as a lining on the wall of the vesicles, but the process may proceed along grain boundaries, fractures and cleavage planes to give a nearly complete replacement. Covellite is also a replacement mineral but subordinate to cuprite.

Bevins et al, 1991, studied the metamorphic conditions of the Zig-Zag Dal Basalts. They established that the basalts had been altered by low temperature hydrothermal metamorphism at zeolite facies to low prehnite-pumpellyite facies conditions (up to 200^{O}C). During this process epidote, chlorite, quartz, calcite and zeolite minerals were precipitated in the vesicles – on several occasions together with native copper. Collinson et al., 2008 p. 95, concluded that the hydrothermal metamorphism took place “shortly after or coeval with volcanism”. The copper sulphides on this locality are likely to have a similar origin as the gangue minerals in the vesicles.

4.1.2 Astrup Dal Cu-mineralisation in Midsommersø Dolerite , J.C. Christensen Land

4.1.2.1 History

1978-80: The GGU regional mapping campaign included stream sediment sampling for geochemistry and ore microscopy of heavy minerals concentrates (Ghisler et al. 1979;

Ghisler 1994). A malachite coated showing from a Midsommersø Dolerite sill was sampled during the geological mapping (H.F. Jepsen 1978).

1994: GGU ground check and sampling (Lind and Tukiainen 1994).

1995: GGU supplementary sampling and reconnaissance of adjacent areas (Lind and Tukiainen 1995).

Mineral Occurrence ID no. 925

4.1.2.2 Geological setting

„Astrup Dal" is trending in a SSW direction from the head of Astrup Fjord towards the Inland Ice. The topography is characterised by broad valleys between ice covered table Mountains reaching 1000 metres elevation. The geology of this region is reviewed by Collinson et al. 2008. The western J. C. Christensen Land is dominated by two unconformity separated, homoclinal successions: Paleo-Mesoproterozoic sandstones and a Mesoproterozoic basaltic lava sequence. The Paleo-Mesoproterozoic Independence Fjord Group siliciclastic sediments were deposited in an interior sag basin and are made up of alluvial sandstones with subordinate lacustrine siltstone members. This sedimentation was followed by a period of rifting during which large volumes of tholeiitic magma (the Midsommersø Dolerite Formation) intruded the sandstones forming dolerite dykes, sheets and sills, often displaying multiple intrusive relationships. Radiometric dating produced an age of c. 1230 Ma. The extrusive equivalent, the Zig-Zag Dal Basalt Formation, is overlying The Independence Fjord Group sandstones. Basaltic effusion was initiated at subaqueous conditions as indicated by pillow lavas in the basal section, but the bulk of the sequence was extruded in a sub aerial environment.

4.1.2.3 Ore description

The showing (Map 2) is hosted by a minimum 60 m thick dolerite sill on the east side of „Astrup Dal". Large landslides parallel to the valley side complicate the outcrop pattern considerably as illustrated by Jepsen 1978, pp. 13-14.

H. F. Jepsen"s 1978 sample (GGU 197285: 0.13% Cu, 113 ppb Au, 227 ppb Pt and 40 ppb Pd) is from the informally named „Sill D" in a position possibly not disturbed by landslides. Samples GGU 420525 (0.2% Cu, 46 ppb Au, 72 ppb Pt and 33 ppb Pd) and GGU 420529 (0.13% Cu, 19 ppb Au, 48 ppb Pt and 26 ppb Pd) are from „Sill D" exposed in a land slide block in front of Jepsen"s locality. All three samples represent the magnetite enriched lower part of „Sill D". The land slide block samples are from particular magnetite rich lenses, c. 1 m long and 0.2 m thick. The lenses are located at the foot wall contact between metre sized irregular shaped pockets of gabbroic pegmatite and the enclosing dolerite. Malachite-azurite coatings together with white crusts disclose these lenses. There is only a scarce appearance of malachite spots, when the land slide block is followed laterally.

„Sill D" was sampled on a vertical trace over 60 m (8 samples with an average spacing of 7.5 m) from the chilled margin at the bottom of the sill to the top of the exposure. The sample trace did not include malachite spots. The result is somewhat surprising as the content of Cu (38-304 ppm), Fe_2O_3 (10.6-19.7%), V (197-682 ppm) and TiO_2 (0.8-1.9%) increases upwards - that is away from the copper and magnetite showings. In contrast Cr (280-15 ppm) is decreasing upwards (Table 1).

In the microscope disseminated magnetite is seen to be titanomagnetite rather than pure magnetite (Fig. 3). The grains are subhedral to rounded with a well developed lattice of ilmenite lamellae. Magnetite inside the ilmenite lattice is in various degree of decomposing into fine grained hematite. Individual chalcopyrite grains range in size from a few microns up to 100 microns. Most chalcopyrite is present as intergrowths with magnetite. Exsolution lenses of pentlandite were noted in chalcopyrite. Pyrrhotite and pyrite occur in subordinate amounts. The magnetite rich lenses are characterized by heavy disseminations of magnetite grains, not by massive or semi massive magnetite bands.

Table 1. *Analysis results from 'Sill D' dolerite, Astrup Dal, J.C. Christensen Land*

GGU sample no	Sample	Au ppb	Pt ppb	Pd ppb	Cu ppm	Ni ppm	Co ppm	Cr ppm	V ppm	Fe203 tot%	Ti02%	Geology
197285	RO	116	227	40	1300	165	120	14	2296	39.17	4.72	Sill D outcrop
420525	RO	46	72	33	1963	119	87	8	2524	35.31	5.09	Sill D land slide
420529	RO	19	48	26	1345	94	73	9	1807	30.45	3.77	Sill D land slide
Mean		60	116	33	1536	126	93	10	2209	34.98	4.53	
420472	RO	0			324	40	45	0	507	17.30	1.73	Sill D bottom
420473	RC	0			415	39	46	0	648	17.87	2.20	Sill D bottom
420516	RO	0			38	72	40	280	197	10.57	0.80	Sill D profile, FW
420517	RO	10	0	15	83	55	44	260	168	9.88	0.77	Sill D profile
420519	RO	0			69	70	36	300	169	9.65	0.72	Sill D profile
420518	RO	2			178	92	53	87	323	14.44	1.12	Sill D profile
420520	RO	0			186	66	47	100	342	14.00	1.17	Sill D profile
420521	RO	9			185	72	48	65	319	13.63	1.08	Sill D profile
420522	RO	5			210	59	50	25	378	15.58	1.23	Sill D profile
420523	RO	10			175	52	46	45	307	14.87	1.07	Sill D profile
420524	RO	14			304	47	57	15	682	19.73	1.93	Sill D profile, Top
Analytical method		10	36	36	42	42	10	10	42	10.00	42	
10: INA												
42: ICP/4AC												

4.1.3 Bjørnegletcher-Ingolf fjord, Cu-mineralisation in Midsommersø Dolerite

4.1.3.1 History

1994: GGU regional stream sediment sampling and ground follow up on Landsat anomalies (Lind & Tukiainen 1994).

Mineral Occurrence ID no. 920

4.1.3.2 Geological setting:

The geological setting is the same as for Mineral Occurrence ID no. 919: Independence Fjord Group sandstones intruded by numerous Midsommer Sø dolerite dykes and sills and subsequently sheared within the East Greenland fault zone.

4.1.3.3 Ore description

Several Midsommer Sø dolerite dykes and sills with malachite coatings are present on the North coast of Ingolf Fjord between Bjørnegletscher and Kap Canis Major (Map 4). A 2.5 km traverse was made from Bjørnegletscher towards S–W following the top of the scree cones. On the individual showings most of the malachite coatings are located close to the sandstone-dolerite contact zones. The shearing has been particular intense here and transformed the sandstones into phyllonitic schist and the dolerites into mafic schist.

Grains of pyrite and pyrrhotite are often seen on joints or following discrete shear structures. They may be accompanied by tiny grains of chalcopyrite in connection with the malachite spots. In the microscope chalcopyrite occurs as c. 0.1 mm irregular aggregates and individual grains a few tens of microns across. Chalcocite seems to be a more common copper sulphide. Grains on the order of 1 mm are seen with pyrrhotite and chalcopyrite exsolution blebs. Cuprite is replacing chalcocite from the rim and following fractures. Several cuprite aggregates up to 0.5 mm may represent full replacement of chalcocite or chalcopyrite. Covellite is present in small amounts as replacement of both chalcopyrite and chalcocite.

The best sample, GGU 420417 with 0.2% Cu, is composed of chips from malachite spotted scree boulders below the foot wall contact between a c. 50 m wide dolerite and sandstones. The contact is positioned in a steep cliff face and could be followed for c. 50 m. The malachite and subordinate azurite spots were observed over 15–20 m.

4.1.4 Brede Spærregletscher E, 'Copper Nunataq 1'

4.1.4.1 History

1994: GGU regional stream sediment sampling, (Lind and Tukiainen 1994).

1995: GGU ground check of malachite staining reported by H.F. Jepsen (Lind and Tukiainen 1995).

Mineral Occurrence ID no. 921

4.1.4.2 Geological setting

Two copper showings were checked in the central part of Prinsesse Caroline Mathilde Alper on the east side of Brede Spærregletscher (Map 4). The terrain is alpine with glaciers separating steep mountain ridges and peaks reaching levels of 1200-1500 m. The geology of this region is reviewed by Collinson et al., 2008; Higgins and Leslie, 2008 and Leslie and Higgins, 2008.

The area is mainly composed of Paleo-Mesoproterozoic Independence Fjord Group siliciclastic sediments including a basaltic volcanic formation, the Hekla Sund Fm, with an age of c.1740 Ma. Supposed Midsommer Sø Dolerite dykes and sills are common through the area and may in places approach half of the rock volume.

Caledonian westward thrusting has created complex structural relations. West of the prominent Spærregletscher thrust - following the NNE-SSW trace of Brede Spærregletscher - the Independence Fjord Group is part of the Thin-skinned fold-and-thrust belt. East of the Spærregletscher thrust the Independence Fjord Group (incl. Hekla Sund Fm) is part of the Western thrust belt. Internal thrust imbrication is common within both thrust belts. To the East the Western thrust belt is bordered by another prominent structure, the East Greenland fault zone.

4.1.4.3 Ore description

Copper mineralisation was observed during helicopter reconnaissance of the Independence Fjord Group by H.F. Jepsen (personal communication 1995), where malachite staining on a shallow-dipping rusty quartz lens is recognisable from a distance. The quartz lens has an estimated length of 100 m and may be up to 15 m thick. The enclosing rock is a Midsommer Sø Dolerite sill conformal with the layering in the basalts and intercalations of slates and sandstones. Both the quartz lens and the dolerite are strongly sheared and brecciated with rafts and irregular fragments of the dolerite floating in the quartz lens (Fig. 5).

There is a spotty distribution of the malachite coatings with some preference for the dolerite rafts. A 10 m chip sample (GGU 420450) across the lens returned 2446 ppm Cu and 52 ppb Au. Tiny pyrite specs were noted in the field. In the microscope c. 1 mm pyrite grains are strongly fragmentised by cataclastic deformation. The fractures have subsequently been filled with goethite. Chalcopyrite is present as scattered cataclastic grains c. 100 microns forming the cores in larger limonite grains with a botryoidal texture.

4.1.5 Brede Spærregletscher E, 'Copper Nunataq 2'

4.1.5.1 History

1995: GGU ground check of malachite staining observed from the helicopter (Lind and Tukiainen 1995).

Mineral Occurrence ID no. 922

4.1.5.2 Geological setting

Same as the occurrence „Copper Nunataq 1".

4.1.5.3 Ore description

The malachite coatings are exposed on both sides of a small gully at the southern tip of an elongate nunataq 4.5 kilometres north-east of Mineral Occurrence ID no. 921. The copper mineralisation is associated with a system of dm-m quartz veins in a dolerite sill in the Hekla Sund Formation. The exposed strike length is c. 50 metres. The veins are dipping steeply to the East with a general North-South strike direction. In detail a more complex deformation pattern with tight fold closures is seen. The vein system itself is on the order of 5 metres wide with the quartz making up c. 30% of the rock volume. The exposed strike length is c. 50 metres. The system is enclosed by a 10-30 metres wide rusty coloured zone. A 5 metres chip sample (GGU 420448) returned 234 ppm Cu and 6 ppb Au. No copper sulphides were observed.

4.1.6 C.J. Ring Fjelde, Cu-mineralisation in Midsommersø Dolerite

4.1.6.1 History

1994: GGU regional stream sediment sampling. Malachite stained sheared sandstone floats were sampled in the river bed (Lind & Tukiainen 1994; Jensen et al., 1995).

1995: Ground follow-up on geochemical and Landsat anomalies. (Lind & Tukiainen 1995).

Mineral Occurrence ID no. 919

4.1.6.2 Geological setting:

A couple of copper showings occur in the Caledonian Orogen in eastern Kronprins Christian Land from Hekla Sund to north of Ingolf Fjord. The geology of this region is reviewed by Collinson et al., 2008; Higgins and Leslie, 2008 and Leslie and Higgins, 2008.

The area is mainly composed of Paleo-Mesoproterozoic Independence Fjord Group siliciclastic sediments including two basaltic volcanic formations (Åge Berthelsen Gletscher Fm. and Hekla Sund Fm, the latter with an age of c.1740 Ma). Supposed Midsommer Sø Dolerite dykes and sills are common through the area and may in places constitute up to half of the rock volume.

Caledonian westward thrusting has created complex structural relations. West of the prominent Spærregletscher thrust - following the NNE-SSW trace of Brede Spærregletscher - the Independence Fjord Group (incl. Åge Berthelsen Gletscher Fm) is part of the Thin-skinned fold-and-thrust belt. East of the Spærregletscher thrust the Independence Fjord Group (incl. Hekla Sund Fm) is part of the Western thrust belt. Internal thrust imbrication is common within both thrust belts. To the East the Western thrust belt is bordered by another prominent structure, the East Greenland fault zone. Fault movement is steep with east-side-up. East dipping mylonitic Independence Fjord Group sandstones are seen in a several kilometres wide zone together with the Midsommer Sø Dolerites transposed into close parallel orientation with the fault zone. The contacts between dolerites and sandstones are often the focus of local shearing.

4.1.6.3 Ore description:

Geologically the showing (Map 4) is situated just west of the East Greenland fault zone within the area strongly influenced by Caledonian shearing and mylonite formation. The Copper mineralisation is located in a N-S trending local shear/breccia zone dipping E at 38 degree. The host rock is a Midsommersø dolerite sheared and metamorphosed into mafic schist. The shear zone is 0.5-0.8 m wide and characterised by epidote-chlorite-quartz-calcite alteration veins and patches. Small malachite spots in conformal sheared dm quartz lenses indicate the presence of copper minerals. A 0.5 m chip sample (422217) across the shear zone returned 954 ppm Cu and 8 ppb Au. A grab sample (420453) from a similar setting 1.4 km to the SE returned 889 ppm Cu and 20 ppb Au. Pyrite and pyrrhotite were noted in the field. In the microscope chalcopyrite and bornite were observed as the main copper minerals, both occurring as tiny grains up to c. 100 microns. They can be partly replaced by chalcocite/digenite and covellite. Precipitation of the ore minerals is related to the shearing either as trains of minerals following thin discrete shears in the rock. Or they can be precipitated together with the alteration minerals and flakes of specular hematite in shear parallel veinlets. In addition, observations were made of discordant possible dilation veinlets containing chalcopyrite.

Considering the close connection between the ore minerals and the regional East Greenland fault zone, the mineralisation age is best set as Caledonian.

4.1.7 Åge Berthelsen Gletscher, Cu-mineralisation in basalt

4.1.7.1 History

1995: A copper showing was found during geological mapping in the Prinsesse Caroline Mathilde Alper (Pedersen et al. 1995).

Mineral Occurrence ID no. 923

4.1.7.2 Geological setting

The copper showing is located on the cliff section on the North side of Åge Berthelsen Gletscher in the western part of Prinsesse Caroline Mathilde Alper. The terrain is alpine with glaciers separating steep mountain ridges and peaks reaching levels of 900–1600 m. The geology of this region is reviewed by Collinson et al., 2008; Higgins and Leslie, 2008 and Leslie and Higgins, 2008.

The Prinsesse Caroline Mathilde Alper is mainly composed of Paleo-Mesoproterozoic Independence Fjord Group siliciclastic sediments including two basaltic volcanic formations (Åge Berthelsen Gletscher Formation and Hekla Sund Formation, the latter with an age of c.1740 Ma). Supposed Midsommer Sø Dolerite dykes and sills are common through the area and may in places constitute a substantial part of the rock volume.

Caledonian westward thrusting has created complex structural relations. West of the prominent Spærregletscher thrust - following the NNE-SSW trace of Brede Spærregletscher - the Independence Fjord Group (incl. Åge Berthelsen Gletscher Formation) is part of the Thin-skinned fold-and-thrust belt. East of the Spærregletscher thrust the Independence Fjord Group (incl. Hekla Sund Fm) is part of the Western thrust belt. Internal thrust imbrication is common within both thrust belts.

No age determinations exist for the Åge Berthelsen Gletscher Formation volcanics. Correlations has been suggested with both the Hekla Sund Formation (1740 Ma) and the Zig-Zag Dal Basalt Formation (1380 Ma). Collinson et al., 2008, favour a correlation with the Hekla Sund Formation as both formations are deposited in marine rift basins (in contrast to the continental setting of the Zig-Zag Dal Basalt Formation).

4.1.7.3 Ore description

The copper showing (Map 4, Fig. 6) is hosted by basalts of the Åge Berthelsen Gletscher Formation. The following description is quoted from Pedersen et al. 1995, p. 78, who made the discovery and investigated the showing:"The lowermost part of the member consists of 15 m of black ash sand interbedded with a few hyaloclastic breccias. The ash beds are mainly planar laminated indicating deposition from ash falls. The ash is overlain by 150 m dark grey to greenish pillow basalts with vesicular structures and pyroxene phenocrysts. The lower part of this series is intercalated with a few 0.5–3 m thick beds of pale sandstone. On top of the pillow basalts a 5 m thick Cu-mineralized volcanic breccia occurs. The primary minerals are bornite and a minor content of chalcopyrite; the secondary minerals malachite and hematite make the mineralized horizon easy to identify in the field. Above the Cu-mineralized volcanic breccia follows a c. 40 m thick massive, grey, vesicular basalt rich in disseminated sulphides".

Analysis of a grab sample, 433711, gave 0.5% copper, none of the other metals showed enhanced value.

Bevins et al, 1991, studied the metamorphic conditions of the Zig-Zag Dal Basalts. They established that the basalts had been altered by low temperature hydrothermal metamorphism at zeolite facies to low prehnite-pumpellyite facies conditions (up to 200^{O}C). During this process, epidote, chlorite, quartz, calcite and zeolite minerals were precipitated in the vesicles – on several occasions together with native copper. Collinson et al., 2008 p. 95, concluded that the hydrothermal metamorphism took place "shortly after or coeval with volcanism". The copper sulphides in Åge Berthelsen Gletscher Formation may have a similar origin.

4.1.8 Brede Spærregletscher NE, Fe - Cr mineralisation in Midsommersø Dolerite

4.1.8.1 History

1994: GGU regional stream sediment sampling, (Lind and Tukiainen 1994; Jensen et al.1995).

1995: GGU ground follow-up on a stream sediment sample with 3400 ppm Cr (Lind and Tukiainen 1995). Mineral Occurrence ID no. 924

4.1.8.2 Geological setting

The chromium anomalous stream sediment sample was collected in Prinsesse Caroline Mathilde Alper on the east side of Brede Spærregletscher near the corner to Ingolf Fjord (Map 4). The terrain is alpine with glaciers separating steep mountain ridges and peaks reaching levels of 1000-1500 m. The geology of this region is reviewed by Collinson et al., 2008; Higgins and Leslie, 2008 and Leslie and Higgins, 2008.

The area is mainly composed of Paleo-Mesoproterozoic Independence Fjord Group siliciclastic sediments including a basaltic volcanic formation, the Hekla Sund Fm with an age of c.1740 Ma. Supposed Midsommer Sø Dolerite dykes and sills (c.1380 Ma) are common through the area and may in places approach half of the rock volume.

Caledonian westward thrusting has created complex structural relations. West of the prominent Spærregletscher thrust - following the NNE-SSW trace of Brede Spærregletscher - the Independence Fjord Group is part of the thin-skinned fold-and-thrust belt. East of the Spærregletscher thrust the Independence Fjord Group (incl. Hekla Sund Fmt) is part of the Western thrust belt. Internal thrust imbrication is common within the belts.

4.1.8.3 Ore description

The anomalous stream sediment sample (382703 with 3400 ppm Cr and 1200 ppm Ni) was sampled from a river draining a lithology dominated by Midsommer Sø Dolerite sills intruded into Independence Fjord Group sandstones. Thin dolerite sills occur on the lower part of the mountain side, while a sequence of sills constitute the upper part of the mountain.

The foot wall contact of this dolerite sequence with the sandstones is not exposed. Based on altimeter readings from the two parallel sampled sections 0.6 km apart, the contact is slightly below 700 m at this position. The lowermost estimated 50 m thick unit is a strongly sheared light coloured serpentine-tremolite-schist with talc and magnetite. Magnetite is seen in the lower half of this unit as spots and mm-cm discontinuous schlieren and also as coatings on joint surfaces. A weighted average of 4 chip samples (total length 19 m) representing the lower part containing visible magnetite returned 3647 ppm Cr (range 3100-4100 ppm) and 1637 ppm Ni (range 1400-1800 ppm). Three grab samples representing further 75 m of dolerite sills above the magnetite showing contained comparable amounts of Cr

(4100–5400 ppm) and Ni (1500-1700 ppm). Total iron content - expressed as percent Fe2O3 - is within a narrow range of 13-16% for the combined chip and grab samples. There is no correlation between the presence of magnetite and the analytical results for Cr, Ni and total iron content. Copper is present in trace amounts only despite some small malachite spots, best value is 80 ppm.

In the microscope chromite is seen as disseminated euhedral grains up to c. 100 microns (Fig. 4). Cataclastic features are common and a thin bleached rim is present on the grain boundaries and along the fractures. The chromite grains are in various stages of being overgrown by or totally enclosed in magnetite aggregates. Magnetite forms a very directional texture where growth is initiated as tails in pressure shadows on both sides of the chromite grains. These tails may join to produce a magnetite foliation and eventually a very planar cm magnetite banding. In zones with strong shearing, the magnetite bands develop a durchbewegung texture.

The following copper minerals were identified: native copper, chalcopyrite, chalcocite/digenite and covellite, all in the 10-20 micron size range. They occur as rare inclusions in magnetite. Pyrrhotite, pyrite and marcasite have the same mode of occurrence.

4.1.8.4 Age of host rocks

If the dolerite sill correlates with the Midsommersø Dolerites from the foreland, then the age is c.1380 Ma. If the sill is an intrusive equivalent to the Hekla Sund Formation basalts, then the age is c. 1740 Ma.

4.1.8.5 Age of mineralisation

Chromite is among the early formed minerals when a basaltic magma crystallises and will thus have the same age as the host rock.

Magnetite is later than chromite as can be seen from the preferred growth of magnetite in pressure shadows surrounding the chromite grains in a period with high strain conditions. Very high strain is demonstrated by the mylonitic development in some of the magnetite bands. The showing is positioned a few hundred metres above the regional Spærregletscher thrust separating the Vandredalen Thrust Sheet from the overlying Western Thrust Belt (Leslie and Higgins 2008). It is tempting to relate the formation of magnetite to the time of Caledonian metamorphism and thrusting.

The sampling has provided an explanation for the stream sediment chromium anomaly by demonstrating c. 100 metres of exposed dolerite with 0.3-0.5% Cr. Nickel minerals were not observed to explain the nickel anomaly. The best explanation is that nickel has is incorporated by the silicate minerals.

4.1.9 Quartzite hosted magnetite ironstone, northern Lambert Land

4.1.9.1 History

1993-1995: geological mapping of Lambert Land.

1993: regional sampling of stream sediments for geochemistry.

1994: Magnetite ironstone identified and sampled during regional mapping.

Mineral occurrence ID no. 927

4.1.9.2 Geological setting

Lambert Land is built up of west to north-west directed Caledonian thrust sheets (Higgins & Leslie 2008; Jepsen 2000). The oldest and structurally uppermost, the Nørreland thrust sheet, is found east of Jomfru Tidsfordriv Fjord. It is dominated by high grade Palaeoproterozoic orthogneisses with eclogite facies enclaves. The Western thrust belt is structurally positioned beneath the Nørreland Thrust Sheet and occupies Lambert Land west of Jomfru Tidsfordriv Fjord. It is *composed* of imbricate thrust sheets of Palaeoproterozoic gneisses alternating with Palaeoproterozoic to Mesoproterozoic Independence Fjord Group siliciclastic sediments intruded by dolerites.

4.1.9.3 Ore description

The field relations of the magnetite ironstone were described by Escher & Jones (1994) who mapped and sampled this unit. The ironstone is hosted by sandstones of the Independence Fjord Group and is exposed at a number of localities within the Western thrust belt (Map 5).

The locality in northern Lambert Land (GMOM locality no. 927) was selected because it is part of the longest mapped strike length of discontinuous magnetite enriched layers (4.7 km), in addition grab samples (418529-532) were available for analyses and microscopy. In detail four 2-3 m thick layers containing bands of massive ironstone are exposed over several hundred metres near the top of a monotonous quartzite sequence. Average total content of selected elements from the four samples is Fe_2O_3: 55.9 % (total iron), MnO: 0.14 %, P_2O_5: 1.4 %, As: 3 ppm, 418532 was the only sample containing detectable gold at 12 ppb.

In the microscope magnetite is seen to be about the only ore mineral present (Fig.14). The individual grains are up to 0.5 mm with a sub- to euhedral form. Inclusions of gangue minerals are common. Elongate aggregates may together with the host rock minerals define a vague planar texture. Rare presences of sulphide minerals are indicated by pyrite relicts (c. 10 microns) together with magnetite being replaced by goethite.

The genetic relations have not been established and the present ore textures are most likely a result of metamorphic recrystallisation at up to amphibolite facies conditions. For this reason GMOM locality no. 927 has been listed as “Stratiform iron” and “Metamorphic” in the Genetic model fields of GMOM. One option could be that the magnetite bands represent heavy mineral seams. This kind of deposits have been described from less metamorphosed parts of the Independence Fjord Group elsewhere e.g. in Ingolf Fjord. Here abundant heavy mineral laminae (magnetite in particular) have been pointed out as characteristic of several sandstone levels (Pedersen et al. 1995).

4.1.9.4 Comment

The iron grade of 56 % Fe_2O_3 is high, but as this number is based on four grab samples only, further systematic sampling and detailed mapping is needed to obtain a more reliable grade estimate.

4.1.10 Geochemical investigations in Lambert Land - Au

4.1.10.1 History

The first geological section through Lambert Land based on ground observations was drafted from a helicopter reconnaissance (Jepsen 1980 pp. 27-30). Systematic geological mapping of Lambert Land was carried out during 1993-1995. Prior to that, the overview picture was obtained mainly from aerial observations and photo interpretations. The regional stream sediment sampling in 1993 (Jensen et al. 1994) produced two gold anomalous areas, one along Jomfru Tidsfordriv Fjord and the other in the central western Lambert Land. Ground follow up was done in both areas during the 1994 field season.

4.1.10.2 Geological setting

Lambert Land is built up of west to north-west directed Caledonian thrust sheets (Higgins & Leslie 2008; Jepsen 2000). The oldest and structurally uppermost, the Nørreland thrust sheet, is found east of Jomfru Tidsfordriv Fjord. It is dominated by high grade Palaeoproterozoic orthogneisses with eclogite facies enclaves. The Western thrust belt is structurally positioned beneath the Nørreland Thrust Sheet and occupies Lambert Land west of Jomfru Tidsfordriv Fjord. It is composed of imbricate thrust sheets of Palaeoproterozoic gneisses alternating with Palaeoproterozoic to Mesoproterozoic Independence Fjord Group siliciclastic sediments intruded by dolerites. The gneisses will often include interleaved metavolcanic and metasedimentary units. Furthest to the west an outlier of Ordovician Wandel Valley Formation carbonates is exposed (Smith & Rasmussen 2008). Rivieradal Group clastic sediments belonging to the Vandredalen thrust sheet make up the small nunataks due west of Lambert Land.

The area of large nunataks in the north-western part of Jøkelbugten is geologically very similar to Lambert Land. The Nørreland thrust sheet occupy the eastern part while the Western thrust belt is present west of and structurally below the Nørreland thrust sheet. The Nørreland window provides an exposure of orthogneisses and Independence Fjord Group sediments including Midsommersø Dolerites below the Nørreland thrust.

The Storstrømmen shear zone is a major NNE-SSW trending regional structure. It is found in the coastal exposures in the NW part of Jøkelbugten and continues up to Lambert Land where the shear zone is following Jomfru Tidsfordriv Fjord. The several kilometres wide shear zone is dipping steeply to the east with a sinistral horizontal movement and an east-side-up vertical component. Several subordinate shear zones with the same general orientation are seen on both sides of the main zone.

4.1.10.3 Jomfru Tidsfordriv Fjord area

The ground follow up included fill-in sampling of 12 stream sediments supplemented by 8 heavy mineral concentrates and ground traverses to check for signs of mineralisation Map 5).

The 1993 stream sediment anomaly is related to streams draining through areas deformed by the Storstrømmen shear zone. Three out of four neighbouring samples contained detectable gold (6-8 ppb Au). Out of the total of 16 1993-94 stream sediments from the Jomfru Tidsfordriv Fjord area 7 samples contain gold above 5 ppb (6-10 ppb). They define an elongate cluster with the trend of the shear zone. Slight enhancement of copper (153 ppm) is present in one sample and arsenic in two samples (8-9 ppm).

Of the 8 heavy mineral concentrates 2 contained gold above detection limit (29 and 227 ppb). Five sampled locations with pairs of stream sediment and pan samples had gold in the stream sediment samples only. This could indicate that gold I present as inclusions in the rock forming minerals or that free gold is very fine grained. Fine grained gold tends to be lost with the tailing during the panning process.

A ground traverse from the head of Jomfru Tidsfordriv Fjord towards the south coast of Lambert Land was held entirely within the shear zone. Three rock samples of outcropping sheared garnet amphibolites with pyrite lamination (GGU 420350-351, 420353) contained trace amounts of gold (3-8 ppb). Due to their rusty weathering the pyrite bearing amphibolites are easily distinguished as folded and boudinaged 0.1-1 m bands within the general amphibolite exposure. Two samples (GGU 420355-356) were obtained from coarse grained granite/pegmatite dykes associated with widespread brick red coloration. They did not contain gold and were low in arsenic and copper. These dykes have only suffered brittle deformation and may postdate the shearing.

In conclusion: the fill-in sampling of stream sediments has confirmed the presence of low but persistent amounts of gold over a distance of c. 22 km along the Storstrømmen shear zone. The only candidate for a gold source identified so far, is the pyrite laminated amphibolite bands with gold contents just above the analytical detection limit.

4.1.10.4 Central western Lambert Land

The target for ground investigations was a single 1993 stream sediment sample (GGU 381355) with 110 ppb gold. 1994 sampling comprised stream sediments (382927-937), heavy mineral concentrates (390090-091) and rock samples (420357-380, 420501-505).

The area is situated within the Western thrust belt at a position where a thrust slice of Palaeoproterozoic gneisses is sandwiched between Independence Fjord Group sediments and associated Midsommer Sø dolerites. The anomaly river is draining a glacier. The gradient is low and the riverbed is almost entirely in surficial deposits of a more than 1 km wide floodplain. Sheared gneisses are exposed W and NW of the river while sandstones form the low hills to the E and S.

Eleven stream sediments encompassing the 110 ppb anomaly were obtained from the anomaly river itself and from small surrounding first order streams. Six samples with enhanced gold (6-23 ppb) define an elongated N-S trending anomaly immediately east of the 110 ppb sample. GGU 382927 sampled 500 m downstream from the 110 ppb sample contained 7 ppb gold. In GGU 382931, taken where the anomaly river emerged from the glacier, gold was below detection limit. Pan samples from these two localities had gold below detection limit.

The best 1994 stream sediment sample (GGU 382928, 23 ppb Au) is from a small stream 1.4 km north-east of GGU 381355. This stream is draining a strongly sheared metadolerite lens hosted by phyllonitic sericite schist. Both the metadolerite and its hanging wall phyllonites are cut by discontinuous quartz-calcite veinlets showing both concordant and discordant relationships with the host rock schistosity. Detectable gold was present in two continuous chip samples (GGU 420359: 6 ppb/4.2 m and 420360: 6 ppb/0.8 m). The metadolerite is characterized by strong green epidote-quartz-calcite veining. According to J. Escher (personal communication 1994) this is a regional feature caused by retrogressive metamorphism. A chip sample of the metadolerite did not contain detectable gold.

A composite chip sample (GGU 420404) from rusty weathering, pyrite bearing boulders of quartz 1.8 km south of GGU 381355 returned 50 ppb gold. This type of boulder was common at the sample site, but being located within a larger boulder field, information about the source will require further investigations.

The stream sediment anomaly was confirmed, although with less spectacular assay results. A convincing in situ gold source was not located. Six of the epidote-calcite-quartz vein structures have gold slightly above detection limit (max 6 ppb), but the other 8 samples fell below detection limit. Best candidate for a source rock is provided by the accumulation of possible vein quartz at the GGU420504 location. This might be part of a boulder train that could be back tracked or it could be regolith of local material.

4.2 Neoproterozoic sediments

4.2.1 Neergaard Dal, Cu mineralisation in sandstone, J.C. Christensen Land

4.2.1.1 History

1978-80: The GGU regional mapping campaign included stream sediment sampling for geochemistry and ore microscopy of heavy minerals concentrates (Ghisler et. al., 1979; Ghisler, 1994). A malachite stained showing from a fault zone in basal Hagen Fjord Group sandstones was sampled during geological mapping (H.F. Jepsen 1980, p. 38).

1995: GGU ground stop, reconnaissance sampling (Lind & Tukiainen 1995).

1998: AEM Greenland, a combined airborne magnetic and electromagnetic survey covering the eastern part of J.C. Christensen Land (Rasmussen, T.M. & Thorning, L. 1999).

2010: Avannaa Resources Limited, 2 week field programme centred on this locality.

Mineral Occurrence ID no. 536

4.2.1.2 Geological setting

The Jyske Ås Formation, hosting the copper showing, belongs to the Neoproterozoic Hagen Fjord Group (Clemmensen & Jepsen, 1992; Sønderholm et. al., 2008). This group is deposited in an east-facing half-graben structure following the western margin of the Hekla Sund Basin. The Hecla Sund Basin was formed during the very early extension phases leading towards the opening of the Iapetus Ocean. The lowermost formation of the Hagen Fjord Group, the Jyske Ås Formation, is resting with an unconformity upon the Mesoproterozoic Zig-Zag Dal Basalt Formation and is composed of sandstones deposited in a beach and shallow tidal environment. The overlying Campanuladal Formation consists of variegated fine- to medium-grained sandstones and shaly siltstones representing a transition from tidal to offshore conditions. The Campanuladal Fm is succeeded by the carbonate-platform deposits of the Kap Bernhard and Fyns Sø Formations. The total thickness of the Hagen Fjord Group in the Neergaard Dal area can be estimated to c. 400 m. In places the Neoproterozoic sequence is unconformably overlain by the Cambrian (Portfjeld and Buen Formations) and Ordovician (Wandel Hav Formation) sediments. The area is dissected by two sets of vertical faults, one striking N20°E and another N25°W. The spacing of the faults varies from a few hundred meters to 3 km. The faulted segments display a variable vertical component up to a few hundred meters.

4.2.1.3 Ore description

The occurrence is exposed on a flat-lying area in the northern part of Neergaard Dal (Map 2), approximately 6 km from the shore of Independence Fjord. In places the presence of the mineralisation is shown by malachite staining but the amount of malachite staining is conspicuously weakly developed. The mineralisation has been traversed over an area of 50 m by 300 m plan. The extent of the mineralisation has not been defined. The exposed vertical thickness can be estimated to a minimum 2 m. The mineralisation is hosted by bleached, relatively homogeneous grey sandstone of the Jyske Ås Formation (Fig 7). Minor, open fractures and vugs partially filled with euhedral tiny quartz crystals (and carbonate?) are common. Fracturing of the sandstone at the time of mineralisation is manifested by the centimetre scale dislocations cutting masses of Cu-minerals (Lind & Tukiainen 1995).

Two grab samples (272927 and 420475) were analysed showing 3.8 % and 0.4 % Cu respectively and with slightly elevated content of Ag (124 and 28 ppm Ag). A composite chip sample (420469) returned 3.1% Cu and 106 ppm Ag.

The most important ore mineral is bornite. Chalcocite (including digenite), covellite and native copper are less common. Chalcopyrite has only been identified with the microscope as small exsolution lenses in bornite and as rare grains up to 50 microns (Fig. 8).

The main mode of occurrence for bornite is as tiny disseminated grains and trains of grains sitting in an interstitial position relative to the sand grains. Thin bornite fracture fillings and joint coatings in the sandstone are common. In places massive rounded bornite nodules up to 5 cm in diameter are present. The typical size of the disseminated grains is 1 mm or less, while grains up to several mm are common in the massive bodies. Chalcocite is a replacement mineral of bornite – often in combination with covellite. The textures range from thin fracture replacement over ragged patches of chalcocite distributed in the bornite grains to nearly full replacement with only scattered remains of bornite. In the massive bornite bodies a particular complex zoned structure is locally outlined where chalcocite and covellite define spherical and botryoidal textural domains inside the bornite aggregates.

Native copper may occur as conspicuous irregular masses; one lump of native copper weighting ca. 1 kg (420471) was discovered among the malachite stained rubble lying on the top of the mineralised bed illustrated in the frontispiece. It is not clear whether this sample is of local origin or represents glacially transported material from nearby exposures of the Zig-Zag Dal Basalt Formation.

The 1998 AEM Greenland geophysical survey was not able to establish clear correlations with any of the known Cu-showings (Rasmussen & Thorning 1999 p. 15). From the sample microscopy it was noted that overall the sulphide grains are not interconnected to such a degree, that they will make the showing a good conductor for an electromagnetic geophysical survey.

From preliminary information released by Avannaa Resources Limited, it has now been established, that the mineralisation is hosted by a structurally controlled breccia (Avannaa Resources 2010). The company still considers the field indications positive.

4.2.1.4 Comment

Bearing in mind that the available information is obtained during two short field checks, then this is the most promising of the Hagen Fjord Group showings so far. The few available samples have encouraging grades and the areal extent of the mineralisation has still to be determined. If a connection between the regional faults and the mineralisation can be established, then there will be tens of kilometres of strike length to check.

4.2.2 Bernhard Dal, J.C. Christensen Land, Cu in sandstone

4.2.2.1 History

1978-80: The GGU regional mapping campaign included stream sediment sampling for geochemistry and ore microscopy of heavy minerals concentrates (Ghisler et. al., 1979; Ghisler, 1994). A malachite stained showing in sandstones from the Campanuladal Formation was sampled during geological mapping (L.B. Clemmensen 1978).

1998: AEM Greenland, a combined airborne magnetic and electromagnetic survey covering the eastern part of J.C. Christensen Land (Rasmussen, T.M. & Thorning, L. 1999)

Mineral Occurrence ID no. 926

4.2.2.2 Geological setting

The Campanuladal Formation, hosting the copper showing, belongs to the Neoproterozoic Hagen Fjord Group (Clemmensen & Jepsen, 1992; Sønderholm et. al., 2008). This group is deposited in an east-facing half-graben structure following the western margin of the Hekla Sund Basin. The Hecla Sund Basin was formed during the very early extension phases leading towards the opening of the Iapetus Ocean. The lowermost formation of the Hagen Fjord Group, the Jyske Ås Formation, is resting with an unconformity upon the Mesoproterozoic Zig-Zag Dal Basalt Formation and is composed of sandstones deposited in a beach and shallow tidal environment. The overlying Campanuladal Formation consists of variegated fine- to medium-grained sandstones and shaly siltstones representing a transition from tidal to offshore conditions. The Campanuladal Fm is succeeded by the carbonate-platform deposits of the Kap Bernhard and Fyns Sø Formations. In places the Neoproterozoic sequence is unconformably overlain by the Cambrian (Portfjeld and Buen Formations) and Ordovician (Wandel Hav Formation) sediments. The area is dissected by two sets of vertical faults, one striking N20°E and another N25°W. The spacing of the faults is between 2 and 3 km. The faulted segments display a variable vertical component up to a few hundred meters.

4.2.2.3 Ore description

The showing is located at an elevation of c. 400 m on the north east side of Bernhard Dal right at the corner to Hagen Fjord (Map 2). The copper mineralisation is hosted by yellow to grey cross-bedded sandstones deposited in a tidal facies. Clemmensen 1978 estimated the position to be c. 300 m above the contact to Zig-Zag Dal basalts. The only copper mineral noted in the field was the cm thick malachite crusts. In the microscope pyrite grains up to about 100 microns were seen interstitial to the sand grains. In one positions in the polished section a very fine dust of possible chalcopyrite grains less than 10 microns were distributed in a small grain of strained feldspar. The sample analyse returned 646 ppm Cu, 5 ppm Pb and 2 ppm Zn (GGU 198434).

This is most likely an epigenetic mineralisation in line with the (Campanuladal East, Cu), where disseminated chalcopyrite was found in Campanuladal Formation sandstones. Geochemically both showings are enhanced in copper but low in lead and zinc. The chalcopyrite dust is hardly sufficient to explain the analytical copper value, the malachite may have contributed as well. Future prospecting should not only trace the showing along strike, but also look further up in the sequence for another copper source for the malachite crusts.

The airborne magnetic and electromagnetic survey did not pick up the locality.

4.2.3 Campanuladal East, Cu & Pb-mineralisation in sandstone

4.2.3.1 History

1969-1973**:** Greenarctic Consortium, photo geology, regional aeromagnetic survey, gossan check.

1978-80: The GGU regional mapping campaign included stream sediment sampling for geochemistry and ore microscopy of heavy minerals from the sediment samples. One sample from a stream draining through the Campanuladal Fm in Campanuladal identified a significant chalcopyrite anomaly (Ghisler et. al., 1979; Ghisler, 1994).

1993: GGU regional stream sediment sampling and supplementary local sampling in Campanuladal (Jensen, et. al., 1994.)

1994: GGU regional stream sediment sampling and ground follow up on geochemical anomalies. The Cu and Pb showings were located in Campanuladal Formation by back tracking the chalcopyrite anomaly up the stream gully (Lind & Tukiainen 1994).

Mineral Occurrence ID no. 916

Mineral Occurrence ID no. 917

4.2.3.2 Geological setting

The Campanuladal Formation belongs to the Neoproterozoic Hagen Fjord Group (Clemmensen & Jepsen, 1992; Sønderholm et. al., 2008). This group is deposited in an east-facing half-graben structure following the western margin of the Hekla Sund Basin. Hecla Sund Basin is part of the very early extension phases leading towards the opening of the Iapetus Ocean. The lowermost formation of the Hagen Fjord Group, the Jyske Ås Formation, is resting with an unconformity upon the Mesoproterozoic Zig-Zag Dal Basalt Formation and is composed of sandstones deposited in a beach and shallow tidal environment. The overlying Campanuladal Formation consists of variegated fine- to medium-grained sandstones and shaly siltstones representing a transition from tidal to offshore conditions. The Campanuladal Fm is succeeded by the carbonate-platform deposits of the Kap Bernhard and Fyn Sø Formations.

4.2.3.3 Cu in sandstone: ore description

Strata bound epigenetic/diagenetic copper mineralisation is present in the middle of the Campanuladal Formation at a position c 50 m below the strata bound lead mineralization (Map 3, Fig. 9). The ore minerals are hosted within a rusty weathering 2-3 m thick band composed of mixed sandstones and silty shales with sandstones dominating in the lower part. Visible ore is confined to a light grey 2-3 dm thick sandstone bed with tiny specs of chalcopyrite and pyrite just above the foot wall contact of the rusty band. A chip sampled section (3 samples) through the rusty band from foot wall to hanging wall gave the following Cu values: 1010 ppm/0.23 m, 17 ppm/0.45 m, 79 ppm/1.62 m. There are only slightly elevated values for Pb, Zn and other metals. In microscope both chalcopyrite and pyrite are seen to be interstitial to the sand grains (Fig. 11). Chalcopyrite is partly replacing pyrite grains and may corrode sand grains. The characteristic weathering appearance with strong bleaching of the lower sandstone beds and widespread yellow coatings of jarosite and white sulphate crusts makes the mineralised band traceable in outcrops and in sub crops between proper exposures. The structure could be followed in gully outcrops towards W for 2.3 km along the valley S side. At 2 km a chip sample through the structure gave 151 ppm Cu/ 2.2 m and a 2 dm sample of bleached shale with malachite spots from the upper part of the section gave 1438 ppm Cu. The structure disappeared below overburden at 2.3 km. Towards the E the structure is covered by talus cones.

4.2.3.4 Pb in sandstone: ore description

Strata bound epigenetic lead mineralisation is present in the upper part of the Campanuladal Formation at a position c 50 m above the strata bound copper mineralization. The ore minerals are hosted within a rusty weathering c. 4 m thick zone composed of mixed sandstones and thin silty shales. Wave rippled sandstone dm beds dominate the zone. Visible ore is confined to a light grey 2-3 dm thick sandstone bed positioned centrally in the rusty zone. Tiny specs of disseminated pyrite can be seen on fresh surfaces. Rusty spots 2-3 cm across are common on joints and sedimentary surfaces. They owe their colour to weathering accumulations of tiny pyrite grains. On the same surfaces galena is present as scattered 1 sq cm ragged coatings. In the microscope Pyrite is seen as small euhedral grains interstitial to the sand grains (Fig. 10). Galena was not observed in the examined polished section. A composite chip sample from the mineralized sandstone bed (2 dm) contained 107 ppm Pb and 170 ppm Zn. A chip sample section through the rusty band (representing a total of 4.2 m, (0.9 m not exposed) returned 7 ppm Pb and 30 ppm Zn. Both samples had only trace values for Cu. Within the river gully outcrop the lead is red to this particular sandstone bed, but unlike the strata bound Cu mineralization lower in the sequence, the lead bearing structure could not be identified along strike. This may well be a function of not having malachite to act as a pathfinder.

4.3 Ordovician-Silurian shelf sequence

The Silurian platform carbonates in Kronprins Christian Land, including the carbonate buildups in this area were investigated during the 1994 and 1995 seasons by GGU in 7 localities (Fig. Map 1), where more detailed drainage geochemical sampling was carried out. The primary aim of these investigations was to check the potential for carbonate-hosted Zn-Pb mineralisation. The Samuelsen Høj Formation carbonate mounds were the prime 1994 target. They are part of a discontinuous belt of mound complexes trending W-E through North Greenland from Washington Land to Peary Land where they bend southward to Valdemar Glückstadt Land and Kronprins Christian Land. Small galena showings were previously reported from similar mound complexes in Washington Land (Norford 1972). Despite frequent rust stainings the results from these areas were entirely negative, no evidence of this type of mineralisation was found. Apart from the negative results, the heavy mineral concentrates collected by GGU showed conspicuously high Au-values. One of the samples collected from a stream draining the Vestfjeldet area (Fig. Map1), returned 13 ppm Au. Distinctly elevated Au-content in the stream sediments and heavy mineral concentrates were obtained also in the area around the lovality „Romersø West" .

4.3.1 Vestfjeldet - Grottedal Au-mineralisation?

4.3.1.1 History

1993: GGU regional stream sediment sampling (Jensen, et. al., 1994).

1994: GGU ground check and geochemical sampling (Lind and Tukiainen 1994).

1994: Platinova A/S prospecting for base metals in possible Mississippi Valley and sedimentary exhalative settings (Della Valle 1995).

1995: GGU supplementary sampling and reconnaissance of adjacent areas (Lind and Tukiainen 1995).

4.3.1.2 Geological setting

The area is underlain by Silurian-late Ordovician limestone and dolomite (Turesø Formation (Hurst 1984), Odins Fjord Formation (Hurst 1984), Samuelsen Høj Formation (Smith et al. 1989) and Børglum River Formation (Smith et al. 1989). The stratigraphical relationships of the limestone and dolomite are complicated by the "thin skinned" westward Caledonian thrusting. Thrust zones are well exposed in the area around Vestfjeldet and Palisaderne (Fig. 12)

The limestone lithologies are characterized by a varying degree of iron-oxide staining. This makes them readily distinguishable from a lighter colored dolomite. The area is striking for the abundance of karstic holes and cavities varying in size from small holes to spectacular caves and galleries up to tens of meters in diameter. The holes and cavities are variably filled with poorly consolidated limonite rich carbonate material and aragonite, often as botryoidally layered masses or in places as spectacular crystal aggregates with aragonite crystals up to c. 70 cm in length. The karstic phenomena are clearly related to the thrust zones.

During the 1995 season the Vestfjeld-Palisaderne-Grottedalen area was covered by a more detailed drainage geochemical sampling, whereby 37 paired stream sediment and heavy mineral concentrate samples were collected (Map 6). The thrust zones and the associated karstic phenomena, including the precipitation of low temperature minerals, are thus the most likely candidates to host a gold mineralization, which could be similar to the sediment-hosted gold deposits in Nevada, USA, also known as Carlin-type gold deposits.

In attempt to localize *in situ* mineralisation in the thrust zones and associated karstic features, these were extensively chip sampled.

The drainage geochemical survey totaling 43 stream sediment samples and 39 heavy mineral concentrates outline an approximately 25 km long and 6 km wide NNE – SSW striking trend, where the stream sediment samples contain detectable gold in 15 samples with a maximum of 1200 ppb Au in one sample on the south side of Grottedalen. Seven heavy mineral concentrates contain detectable Au varying from 3 ppb to a maximum of 13.7 ppm in a sample from a river draining the south side of Vestfjeldet. Thirty five sampled locations with pairs of stream sediment and pan samples had gold in the stream sediment only. This may imply that gold is present as inclusions in the rock forming minerals and/or that free gold is very fine grained. The anomalous Au-values are accompanied by enhanced levels of As and Sb.

The altered thrust zones and karstic features with low temperature minerals and limonite were chip sampled in 14 locations The content of gold in all samples is low, close to the detection limit with a highest value of 13 ppb Au. The source of gold remains unknown.

4.3.2 Romer Sø West: geochemical investigations for Au

4.3.2.1 History

1978-80: The GGU regional mapping campaign included stream sediment sampling for geochemistry.

1994: GGU ground traverses and geochemical sampling (Lind and Tukiainen 1994, Jensen, et. al., 1995).

1994: Platinova A/S prospecting for base metals in possible Mississippi Valley and sedimentary exhalative settings (Della Valle 1995).

4.3.2.2 Geological setting and exploration

The geological setting is a northwards extrapolated continuation of the conditions in the Vestfjeldet – Grottedal area. The prime target was an epigenetic carbonate hosted Pb-Zn mineralisation in a Samuelsen Høj Formation mound complex.

The rust stained mounds themselves showed no signs of base metal mineralisation. Intercalations of pyritic black shale units within the inter-mound sediments were also investigated. Their strong rusty weathering, often combined with yellow jarosite and white sulphate crusts, catches the eye from a distance. They are possibly a part of the Profilfjeldet Member (Lauge Koch Land Formation of latest Llandovery to Wenlock times, Smith & Rasmussen 2008, fig. 5).

Two localities 2.5 km apart were sampled and selected analytical results are summarised in table 2. Sample 420536 is a grab sample from the northern locality representing a 25 m wide exposure of yellow weathering shale. Samples 420393-398 are from the southern exposure representing a horizontal 26 m long chip sample line from a river gully exposure. Sample line orientation is 72° for samples 420393-96 and 128° for samples 420397-98. Orientation of the shales is 17°/46°E. By comparing the analytical results for both localities with the world average data for shales (Krauskopf & Bird 1995, appendix IV), the most interesting result is the repeated presence of low but detectable amounts of Au (max. 14 ppb). Zn (max. 269 ppm) and less so Cu (max. 87 ppm) are slightly enhanced. Pb and Ba are both close to the shale average. As (max. 92 ppm) and Sb (max. 7.8 ppm) both show enhanced values.

Table 2. *Selected analytical results from inter-mound black shales. See text for explanation.*

GGU nr.	Type	Lengt	Au	Au ppb	As ppm	Sb ppm	Ba ppm	Cu ppm	Zn ppm	Pb ppm	Field description
420536	Grab		7	7	92	4,3	600	87	155	34	Yellow weathering 25 m wide black shale unit in silty flysch
420393	Chip	9,0	6	6	27	6,9	400	65	228	25	Black fractured shale
420394	Chip	5,0	11	11	26	7,8	500	64	216	23	Black shale, white crusts, cm rusty bands
420395	Chip	1,3	14	14	20	7,6	560	75	212	23	Rusty black shale, fine lamination, white crusts
420396	Chip	0,6	0	0	15	4,7	790	51	67	20	Jarosite coated laminated black shale, 5 % antraconite lenses
420397	Chip	2,1	0	0	15	4,3	480	58	149	24	Black shale, white crusts, cm rusty bands
420398	Chip	8,0	8	8	16	3,7	720	58	269	19	Black shale, white crusts, cm rusty bands, some antraconite lenses
Weighted average chip spls				7	22	5,9	541	62	227	23	
World average shales 1)				<0.1	13	1,5	580	45	95	20	
Analytical package			10	10	10	10	10	42	42	42	
10: INA/ICP, 42: ICP + 4AC											
1) Krauskopf & Bird 1995, Appendix IV											

Ore microscopy of samples 420532-33 representing the chip sample 420396 demonstrated that pyrite is by far the dominant ore mineral (Fig. 13). Pyrite is both scattered through the shale and accumulated in mm wide bands as heavy disseminations following the fine shale lamination. Framboidal texture is very common with a typical particle size of 10 microns. Euhedral to subhedral pyrite grains and aggregates may be up to 100 microns. The aggregates are often rich in inclusions and may have domains resembling relict framboids. Sparse sphalerite is present as grains up to 30 microns disseminated in the shale while a 200 micron grain was noted in a pyrite rich band. The sphalerite grains are often corroded and enclosing pyrite grains along the rim. Chalcopyrite is only observed as rare inclusions a few microns across in sphalerite. Pyrite is possibly a diagenetic product formed under reducing conditions as the framboids. Subsequent authigenic enlargement has then resulted in the euhedral pyrite grains and aggregates. A similar course is likely for sphalerite only slightly later, as indicated by the overgrowth textural relations with pyrite.

4.3.2.3 Summary of stream sediment geochemistry

A dataset was selected to contain stream sediments from rivers between Romer Sø and Danmark Fjord draining the Ordovician-Silurian lithologies only. Of the 46 samples 12 came from the 1978-80 campaign. As recommended in Jensen 1995, they were re-analysed using the same method as for the 1993-95 campaign, to obtain a consistent dataset. A set of symbol plots were prepared for selected elements: Au (≤2-9 ppb), As (≤2-48 ppm), Sb (0.2-5.1 ppm), Cu (6-64 ppm), Pb (6-31 ppm), Zn (19-147) and Ba (100-730 ppm). A three-fold classification was used based on natural breaks in the datasets.

For Au the highest values (7-9 ppb) were found in the mound complex checked in the framed area and in another, larger complex near Danmark Fjord. One high value is located in an Odins Fjord Formation thrust slice at the west side of the framed target area and one in a Turesø Formation thrust slice near Romer Sø. Medium values (4-6 ppb) followed the same pattern with a wider distribution and also included the Lauge Koch Land Formation. High Zn values (110-147 ppm) are present in the two mound complexes; the Odins Fjord Formation thrust slice and a Turesø Formation locality near Danmark Fjord. High and medium Pb values (28-31, 21-27 ppm) characterise the two mound complexes, the Odins Fjord Formation thrust slice and the Turesø Formation thrust slice near Romer Sø. High Cu values (40-64 ppm) are present in the mound complexes and the Odins Fjord Formation thrust slice, while medium Cu values (26-39 ppm) are more widespread. As and Sb have a good correlation where samples with high values for both are confined to the framed mound complex and the Odins Fjord Formation thrust slice. High Ba values are present in both mound complexes. There is a close spatial correlation between the sampled pyritic black shales and the base metals and the high As-Sb pairs, but of a more general nature for Au.

4.3.2.4 Comments

The stream sediment geochemistry outlined the Samuelsen Høj Formation as anomalous with respect to gold, base metals and other trace elements. Following ground traverses in the Vestfjeld-Grottedal area and between Romer Sø and Danmark Fjord, both the Platinova

A/S and the GGU team concluded, that the mounds themselves had a low potential for carbonate hosted base metal occurrences. The pyritic black shale units in the inter-mound sediments demonstrated enhanced values of gold and base metals. This lithology may be source for the stream sediment anomalies. As this is a first-pass exploration only, conclusions are tentative.

5. Summary & concluding remarks

5.1 Lower Palaeozoic Ordovician-Silurian passive margin shelf sequence

The Silurian platform carbonates, including the carbonate build-ups in Kronprins Christian Land fold and thrust belt were checked for the potential of carbonate hosted Pb-Zn mineralisation in seven selected traverses where also a more detailed drainage geochemistry was carried out. The results for outlining evidence for carbonate hosted Pb-Zn mineralisation were entirely negative but the drainage geochemistry returned conspicuously high contents of Au. The high values of Au in stream sediments (max 1.2 ppm Au) and heavy mineral concentrates (max. 13 ppm Au) cluster particularly in the area around Vestfjeldet – Grottedal and Romer Sø West The samples of low temperature alteration zones of the carbonate rocks (limonite, aragonite) in Vestfjeldet-Grottedal showed insignificant Au content. The results from the area around Romer Sø West delineate the Samuelsen Høj Formation as anomalous with respect to gold, base metals and other trace elements, particularly As and Sb. The carbonate mounds of the Samuelsen Høj Formation themselves have a low potential for carbonate hosted base metal occurrences. The pyritic black shale units of the inter-mound sediments are enriched in Au and base metals and As & Sb. This lithology may be source for the stream sediment anomalies. It cannot be excluded, that the anomalous Au values of the drainage geochemical samples manifest the presence of Carlin type gold mineralisation in the platform carbonates.

Carlin-type deposits are characterized by relatively high Au/Ag, enrichment in As, Sb, Hg, and Tl, and by the dominance of "invisible gold" as ions or submicron-sized particles in iron sulphide, typically in the dolomitic – limy mudstones and shaly rock portions of the carbonate rock sequences (Kuehn & Rose, 1995, Thompson et al., 2002)

The Carlin type deposits are typically hosted by Palaeozoic carbonate rocks and it has been proposed that they are largely controlled by deep-seated, ancient structures. The recent research indicates the formation of the Carlin type Au-deposits from relatively low temperature (150-250 Cº), low pH, and low- to moderately-saline fluids of mixed meteoric and magmatic or metamorphic origin.

The source and the economic significance of the anomalously high gold values remain to be solved.

5.2 Neoproterozoic sediments of eastern North Greenland

The western group of the Neoproterozoic sediments – the Hagen Fjord Group was visited at two localities (Campanula Dal and Neergaard Dal, J.C. Christensen land), 160 km apart. The occurrences of sedimentary hosted Cu-mineralisation were located at both localities, although at different stratigraphic levels. Despite not being of economic size and grade, the occurrences, particularly the Neergaard Dal showing, demonstrates that a Cu-mineralising process of significance did take place.

The Eastern group of the Neoproterozoic sediments – the Riveradal Group was traversed in three localities. Apart from slightly elevated levels of Cu, Pb Zn and sporadically Au in the drainage geochemical samples, no evidence of mineralisation was discovered.

5.3 Palaeo – Mesoproterozoic sediments and volcanics of eastern North Greenland

The mafic dykes and sills of the Midsommer Sø Dolerite Formation and the related tholeitic flood basalts of the Zig-Zag Dal Formation and the basalts of Hekla Sund and Åge Berthelsen Gletscher formations in the Independence Fjord Group sandstone contain a widespread Cu-mineralisation both in the undeformed Caledonian Foreland between Independence Fjord and Danmark Fjord and in the strongly folded sediments and volcanics of central Kronprins Christian Land within the Caledonian orogeny.

The Cu-content related to the presence of Cu-sulphides and native Cu is moderate and the investigated occurrences are of limited size and of no economic interest

There is evidence that chromite and titanomagnetite mineralisation took place in the Midsommer Sø Formation Dolerite sills and dykes during the crystallisation of the basaltic agma. The investigated occurrences are of uneconomic size and grade. The large extent and volume of the dolerite dykes and sills in mind the occurrence of economically significant concentrations of chromite and titanomagnetite cannot be excluded.

The Independence Fjord Group siliciclastic sediments host abundant heavy mineral (mainly magnetite) accumulations as heavy mineral seams, The heavy mineral accumulations are remarkably extensive both in terms of spatial extent and Fe- grade in Lambert land where the accumulations of magnetite have been metamorphosed to up to 5 m thick bands of magnetite ironstone in quartzite.

The sheared rock units adjacent to the Storstrømmen shear zone from Lambert land to Ingolf Fjord frequently display a slightly enhanced content of Au in the stream sediment samples. Follow up on a shear zone locality in Lambert land showed only insignificant Au-content in the sheared and altered amphibolite rocks. At C. J. Ring Fjelde and Bjørnegletscher Cu-minerals has a clear association with discrete shear bands and related dilation veinlets. The host rocks at both localities are the Midsommer Sø Dolerite with a record of small Cu-showings through the region. These two localities are seen as examples of shear induced redistribution of Cu already present in the rocks, rather than deposition of Cu from a outside source.

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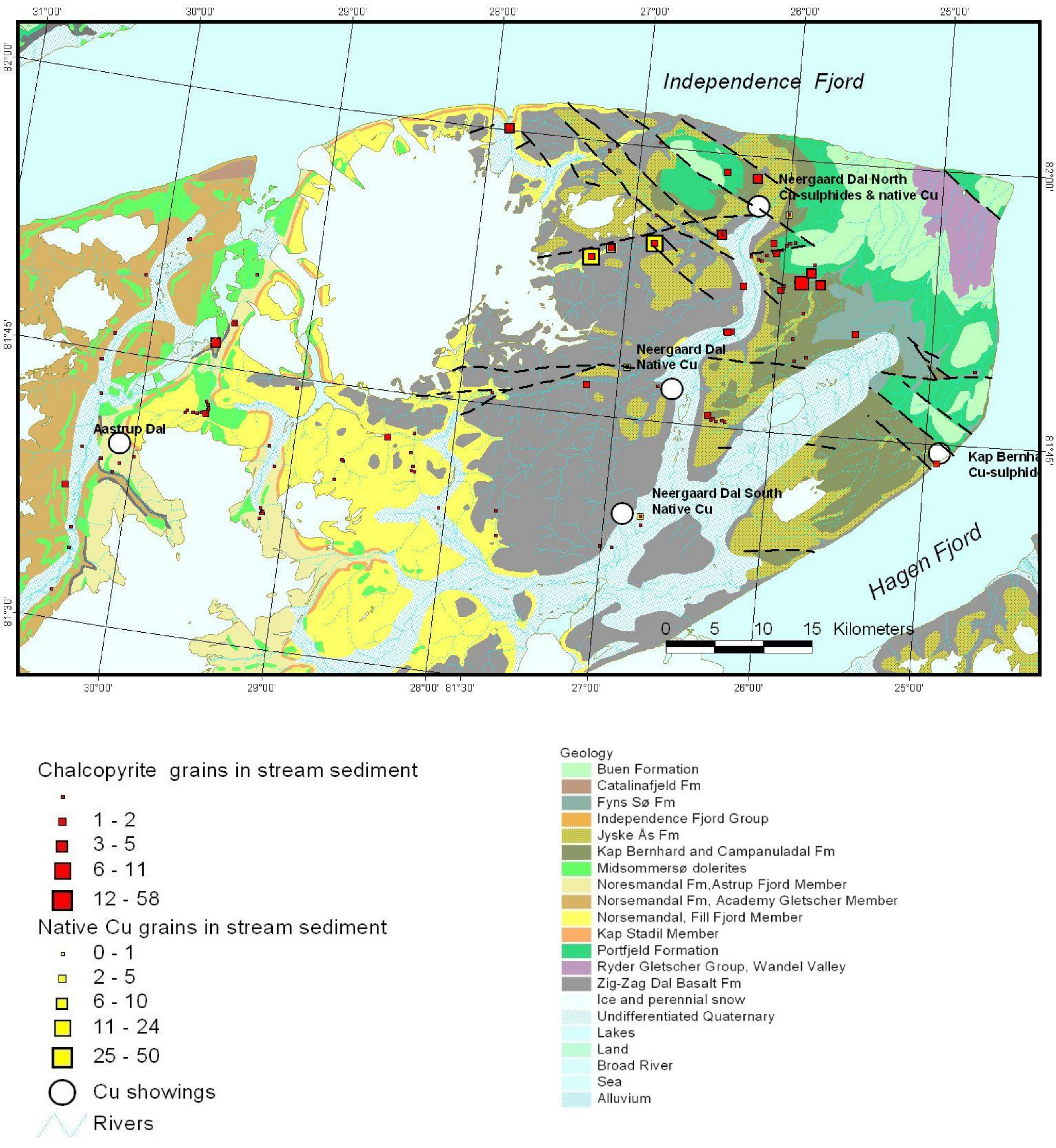
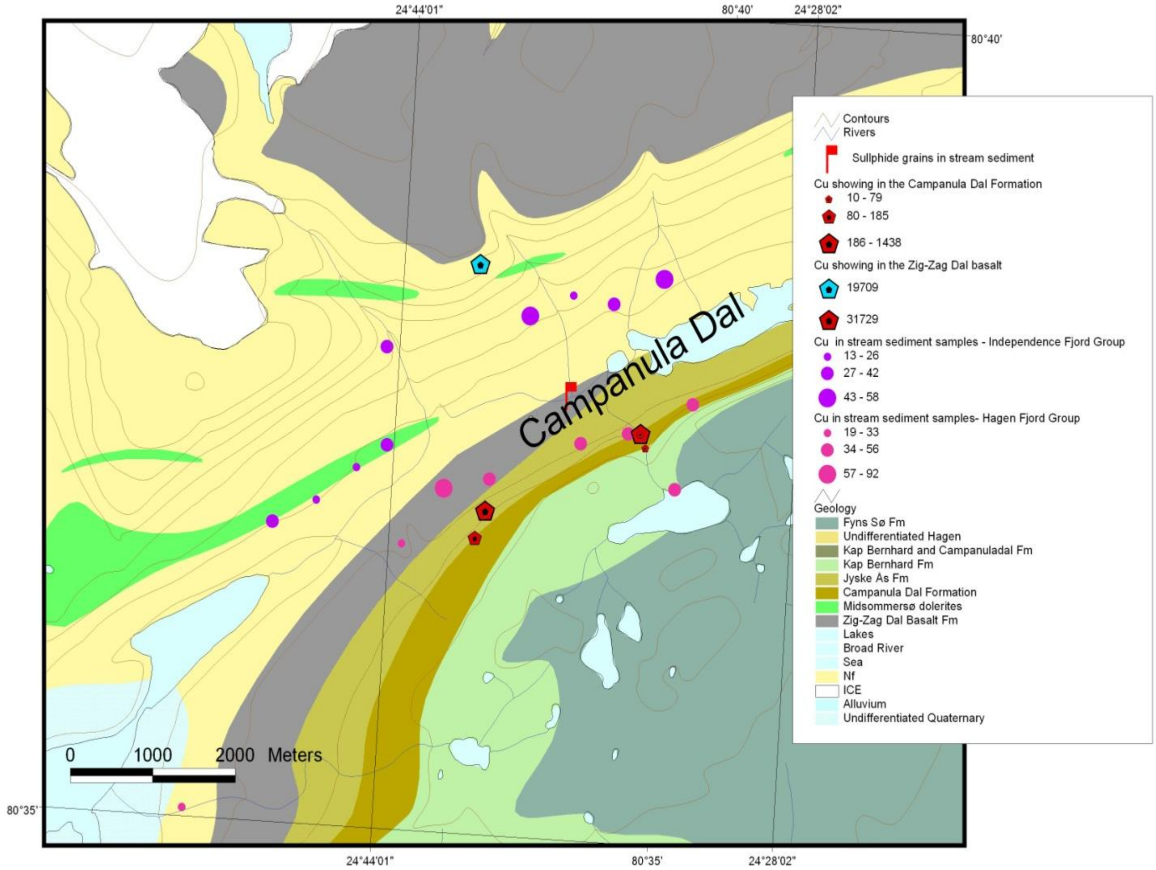
7. Appendix: DVD containing chemical analyses

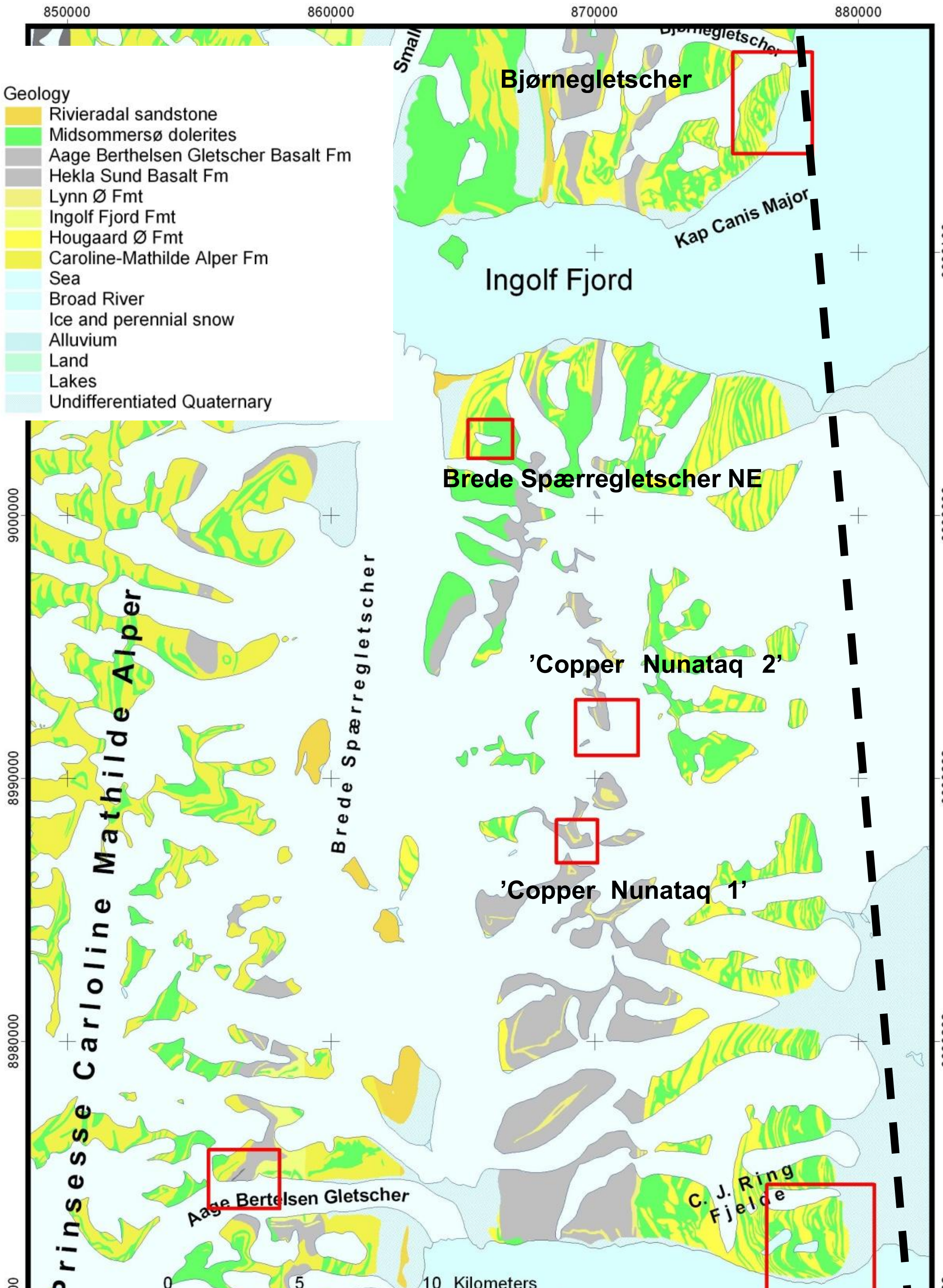
Geochemical analyses: Rock Samples, chip samples stream sediment samples and heavy mineral concentrate samples, sample geolocation data, analysis methods and laboratory information.



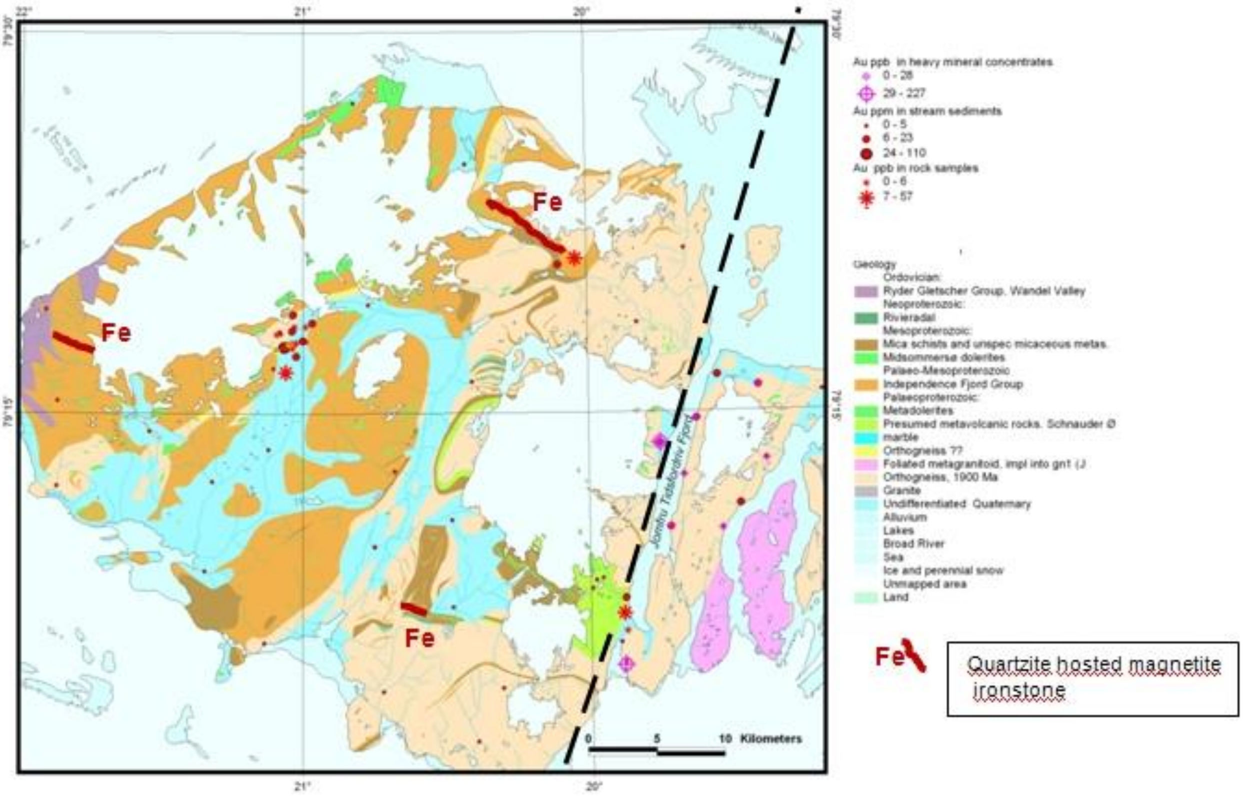
Map 2. *Geological map of J.C. Christensen Land (Jepsen et al., 2003). The localities cited in the text are shown on the map.*



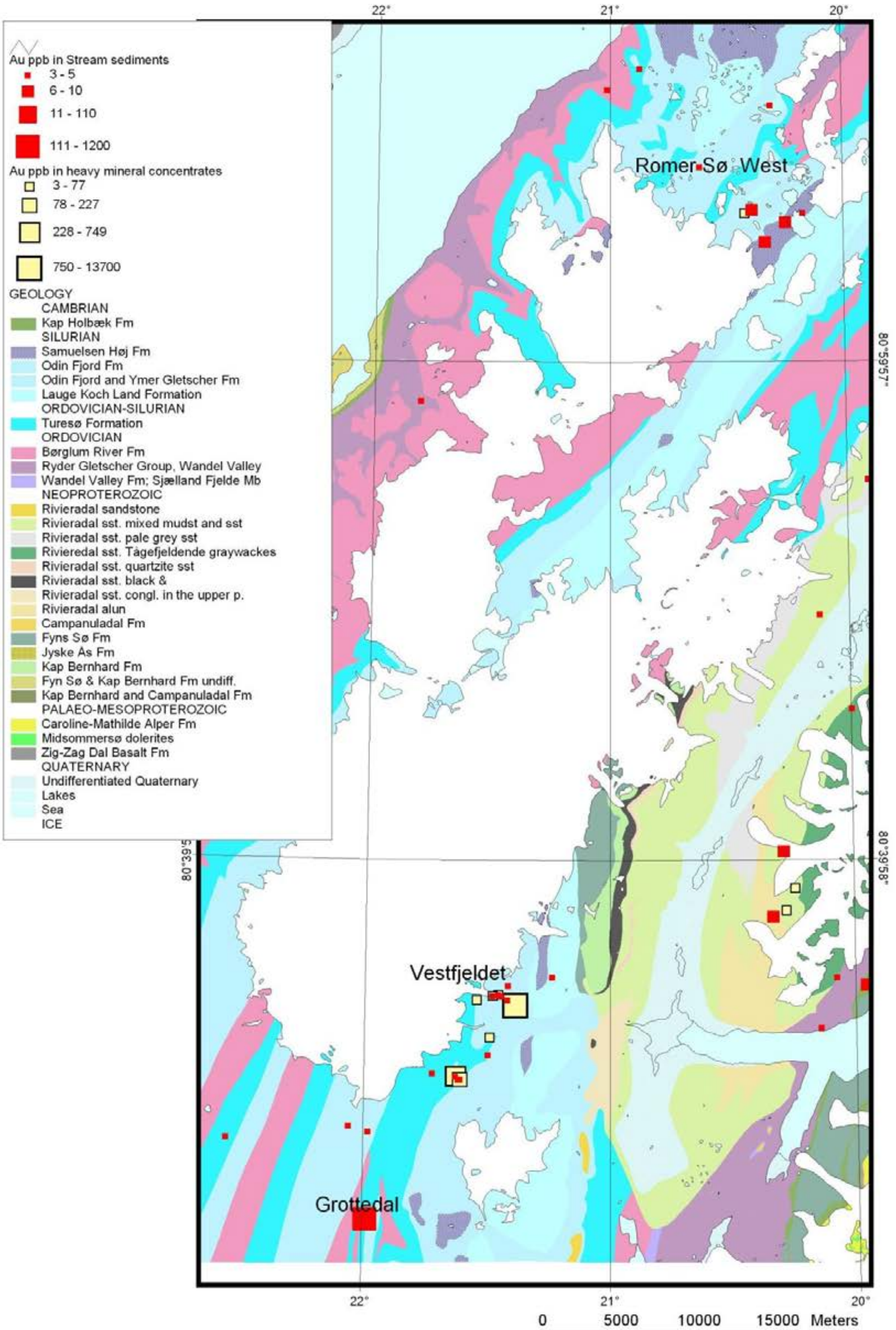
Map 3. *Geological map of Campanula Dal area (Jepsen et al., 2003). The localities cited in the text are shown on the map.*



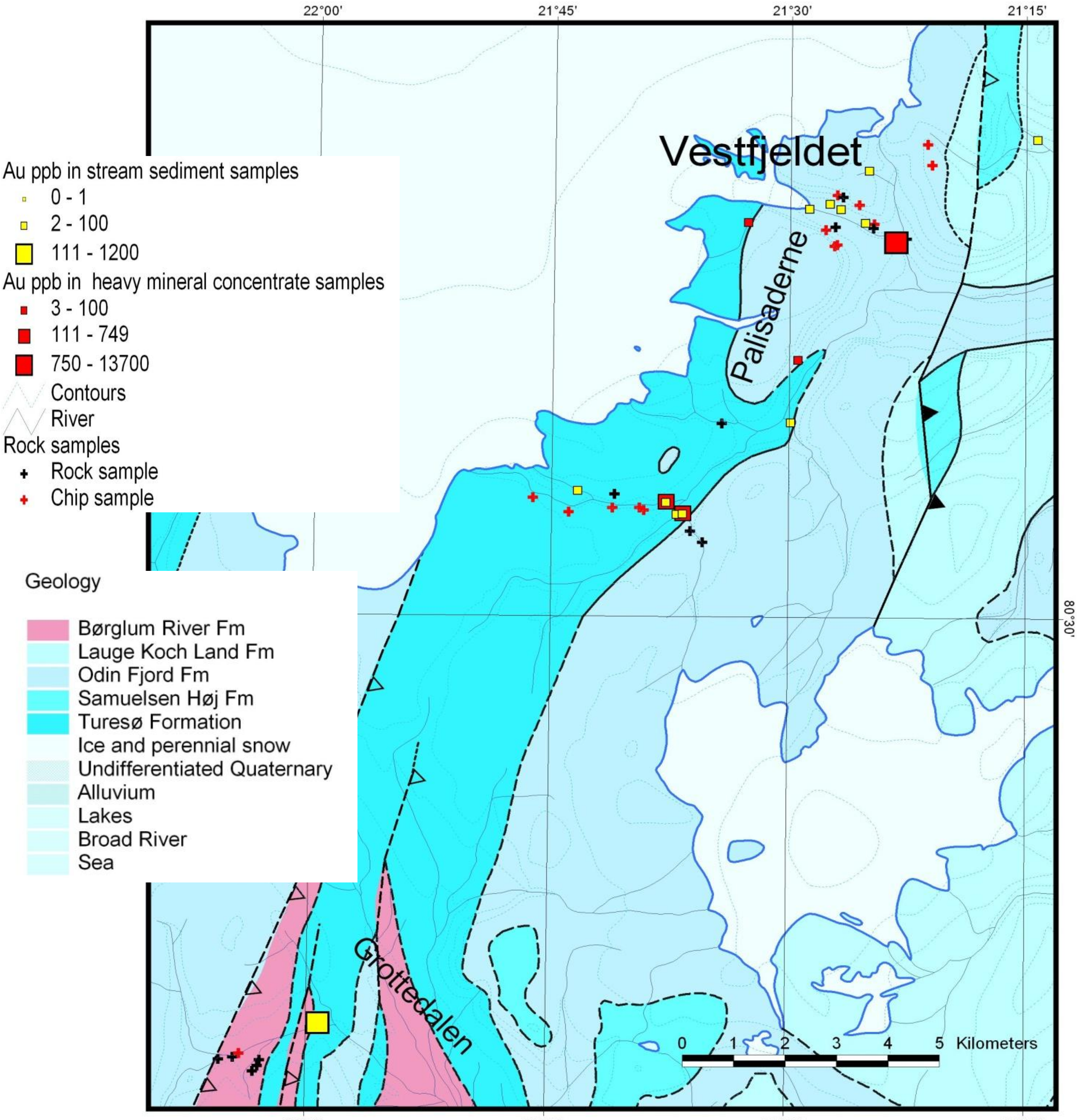
Map 4. *Geological map of eastern Kronprins Christian Land (Jepsen et al., 2003). The localities cited in the text are shown on the map. Black stippled line represents the Storstrømmen Shear Zone.*



Map 5. *Geological map of Lambert Land (Jepsen et al., 2003). The localities cited in the text are shown on the map. Black stippled line represents the Storstrømmen Shear Zone.*



Map 6. *Geological map of central Kronprins Christian Land Greenland (Jepsen et al., 2003) The anomalous Au values in the drainage geochemical samples cluster in Grottedal – Vestfjeldet and Romer Sø West.*



Map 7. *Geological map of Vestfjeldet – Grottedal area (Jepsen et al., 2003).*

Figure 1. *Zig-Zag Dal Basalt Formation, West side of Campanula Dal.* ***A:*** *Copper minerals in a fine-grained malachite stained vesicular basalt together with zeolite group minerals (420402). Width of sample 6 cm* ***B:*** *Saw-cut face with chalcocite mineralised vesicles. Light grey colour is due to metallic reflections. Width of sample 4 cm (420402).*

Photos: P. Warna-Moors.

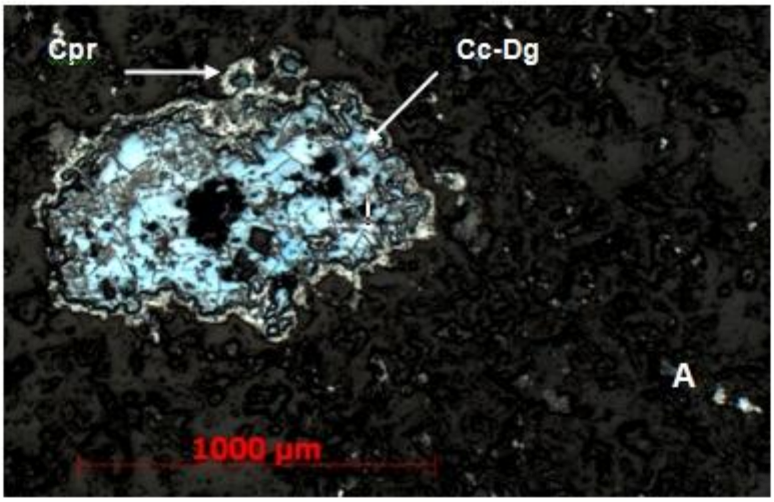
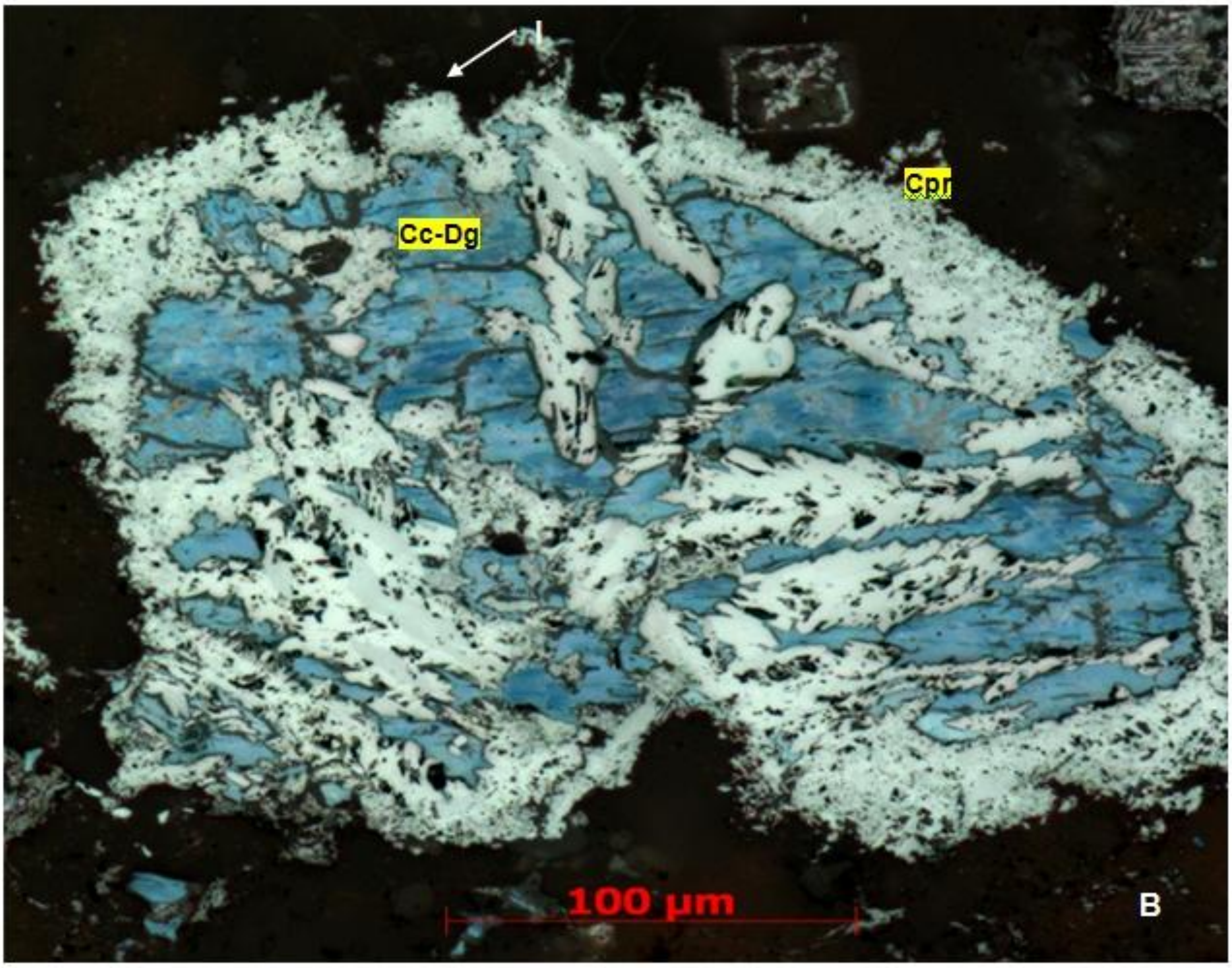


Figure 2. **A:** Vesicle in basalt with chalcosite-diegenite (**Cc-Dg**) filling. Alteration to cuprite (**Cpr**) is developing along the rim. Also, note disseminated specs of cuprite in the basalt. **B:** Vesicle originally filled with chalcosite-diegenite now in an advanced stage of cuprite alteration progressing from the rim into the grain.



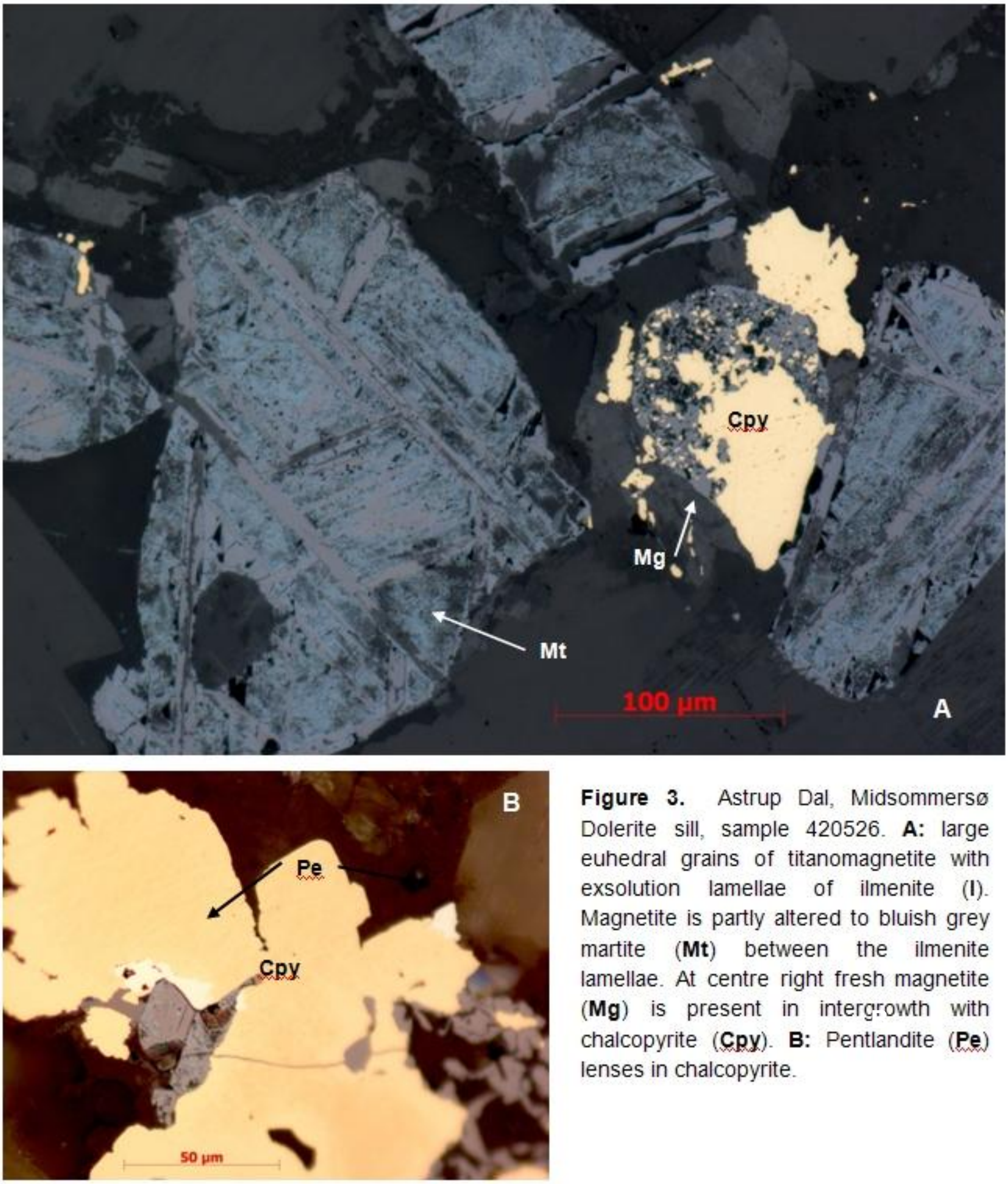


Figure 3. Astrup Dal, Midsommersø Dolerite sill, sample 420526. **A:** large euhedral grains of titanomagnetite with exsolution lamellae of ilmenite (**I**). Magnetite is partly altered to bluish grey martite (**Mt**) between the ilmenite lamellae. At centre right fresh magnetite (**Mg**) is present in intergrowth with chalcopyrite (**Cpy**). **B:** Pentlandite (**Pe**) lenses in chalcopyrite.

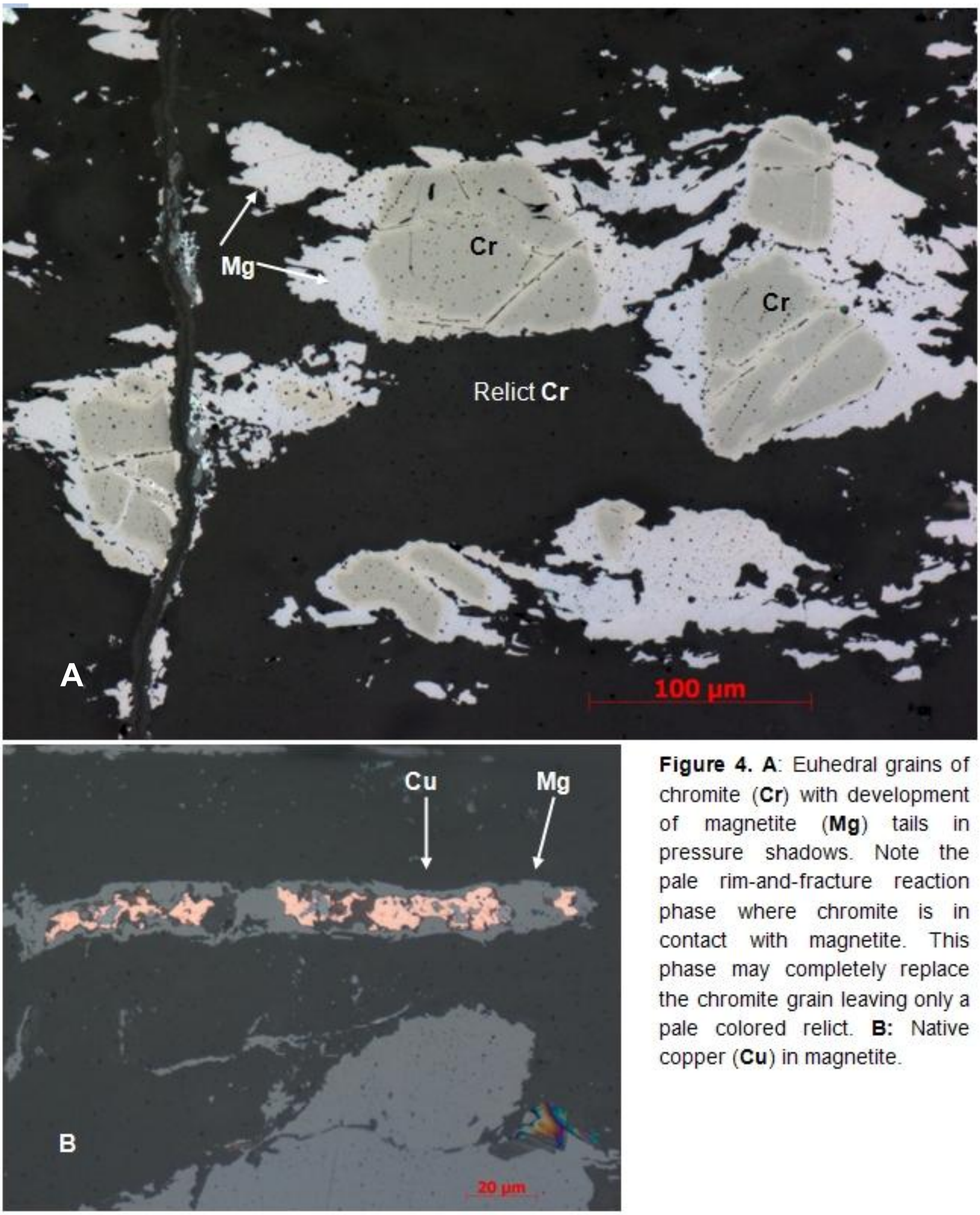
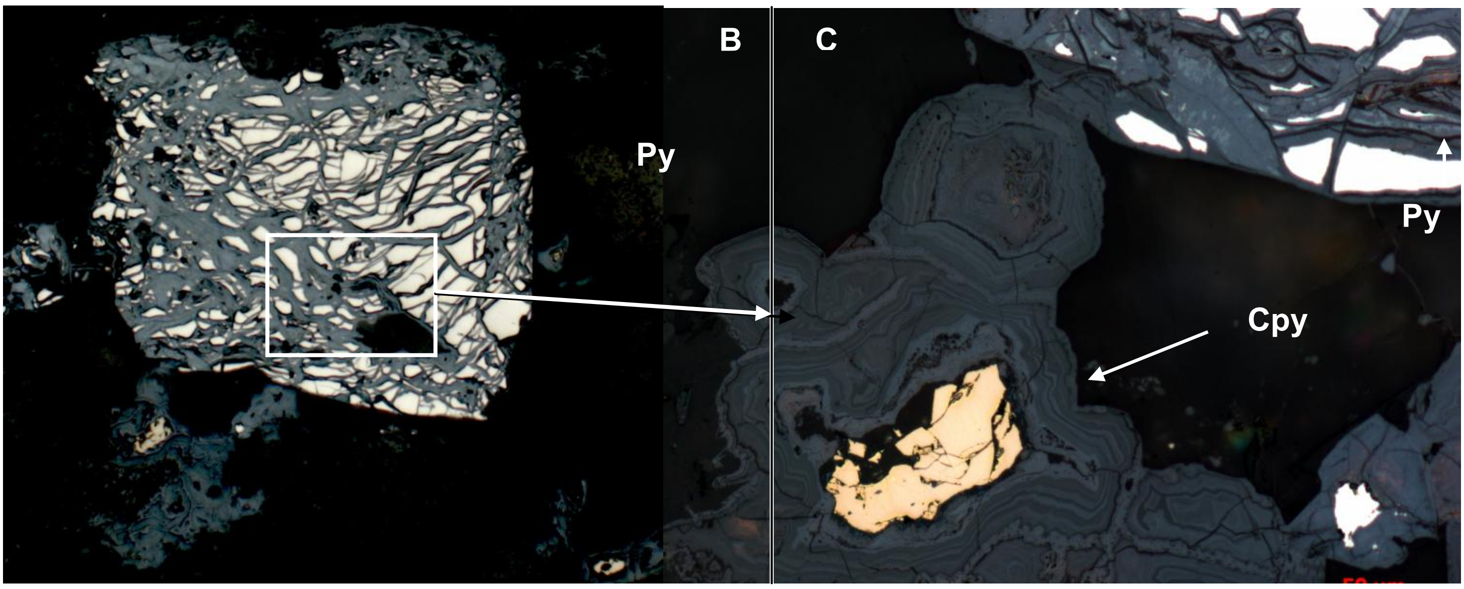


Figure 4. A: Euhedral grains of chromite (**Cr**) with development of magnetite (**Mg**) tails in pressure shadows. Note the pale rim-and-fracture reaction phase where chromite is in contact with magnetite. This phase may completely replace the chromite grain leaving only a pale colored relict. **B:** Native copper (**Cu**) in magnetite.

Figure 5. A*:* *Chip sampling of 'Cu-Nunatak' mineralisation (veinlets and disseminated chalcopyrite) in strongly cataclastic rafts of metadolerite floating in a c. 100 m long and up to 15 m wide lens of sheared quarts.* ***B & C*** *are photomicrographs from sample 420451 representing the sample line above.*

B: *Sheared pyrite (**Py**) with extensive goethite alteration following several shear directions.*

C: *Detail of **B**, fractured chalcopyrite (**Cpy**) at the centre of concentric goethite shells.*



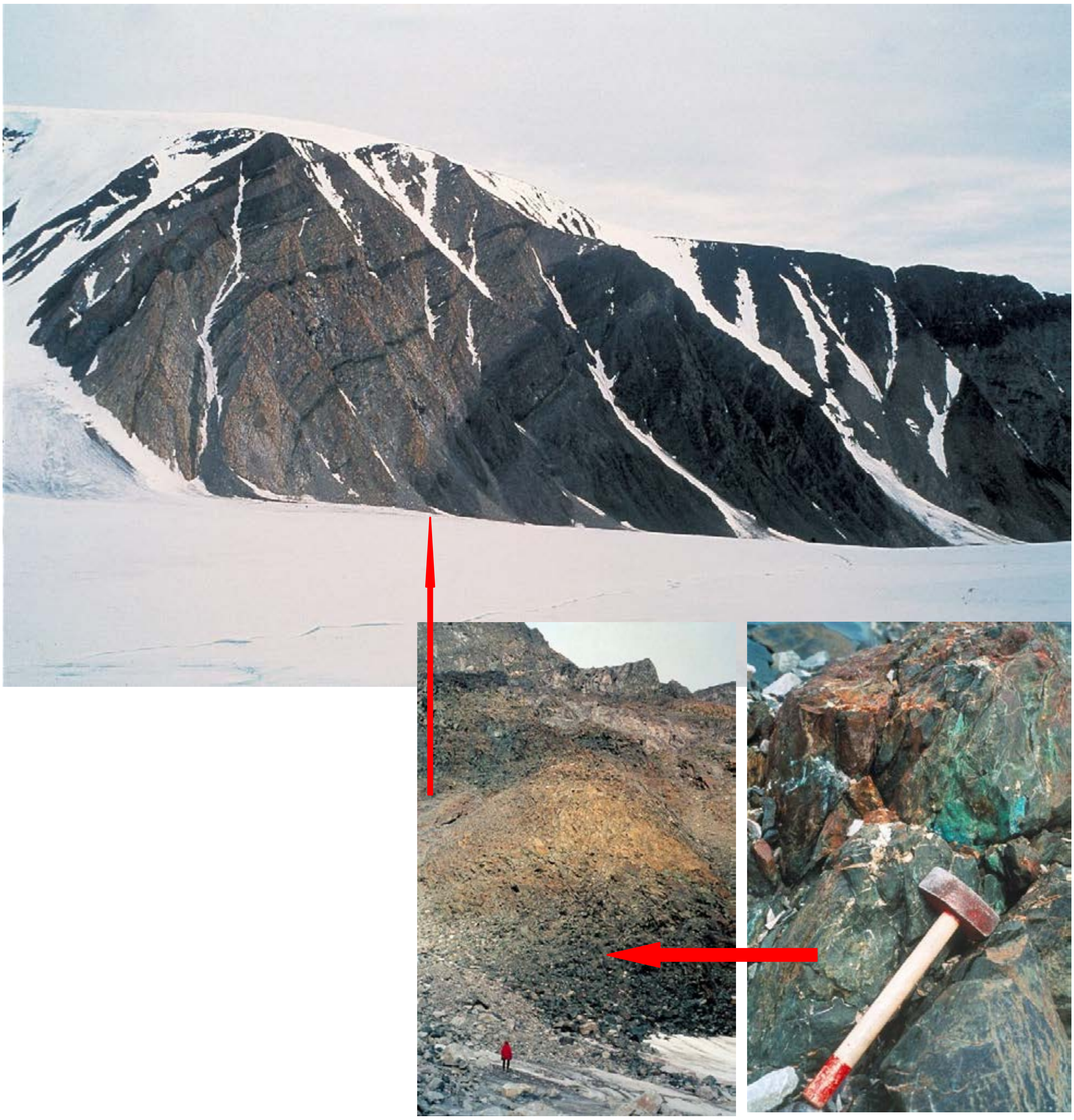


Figure 6. *Cu-mineralised volcanic breccias on top of the pillow lavas of Åge Berthelsen Gletscher Formation. North side of Åge Berthelsen Gletscher, the height of the cliff is c. 700 metres.*

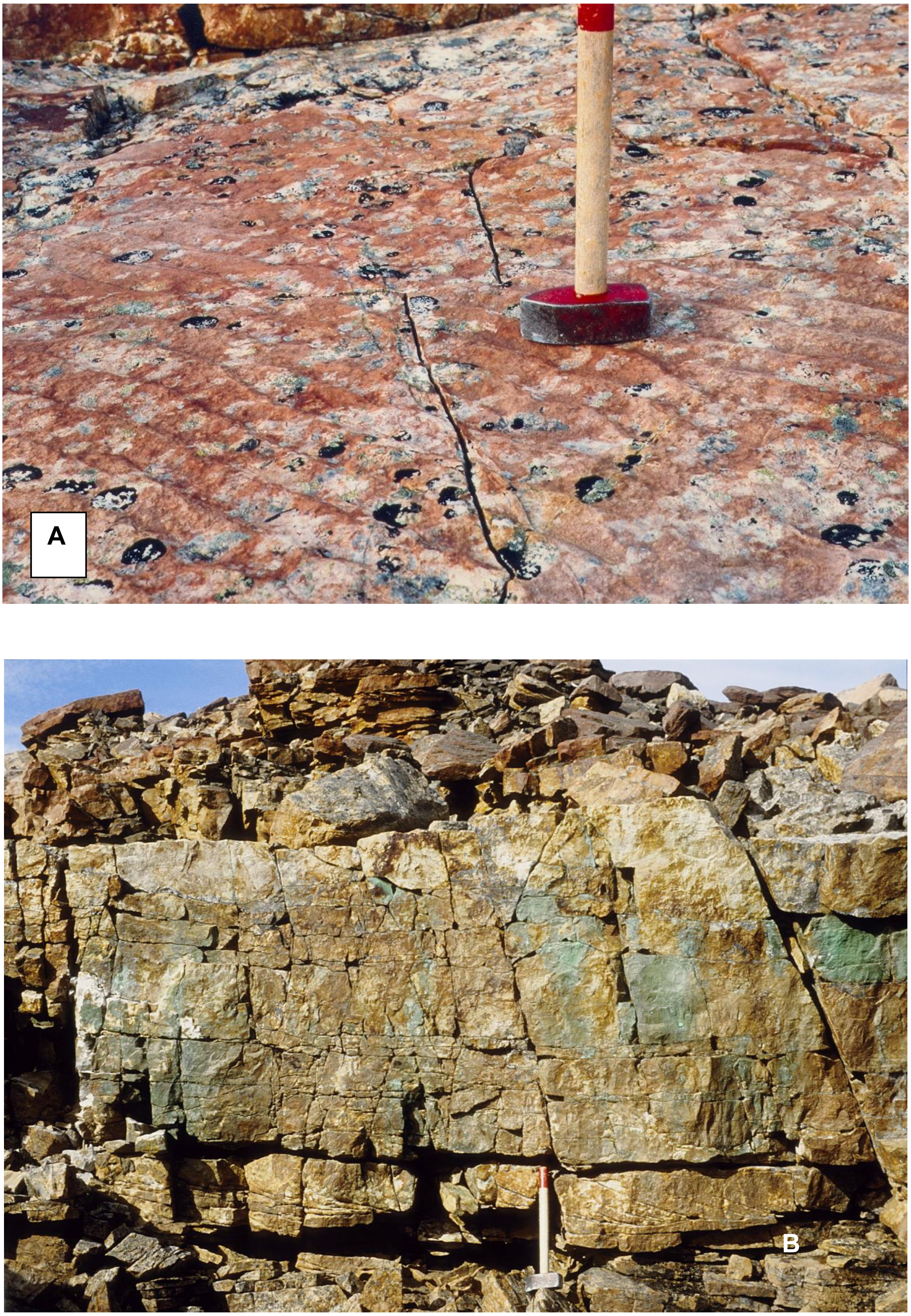


Figure 7. ***A:*** *bedding plane with wave ripples in Jyske Ås Formation sandstone.* ***B:*** *malachite coatings disclosing the copper sulphides in sandstone. Note cross bedding at the hammer*

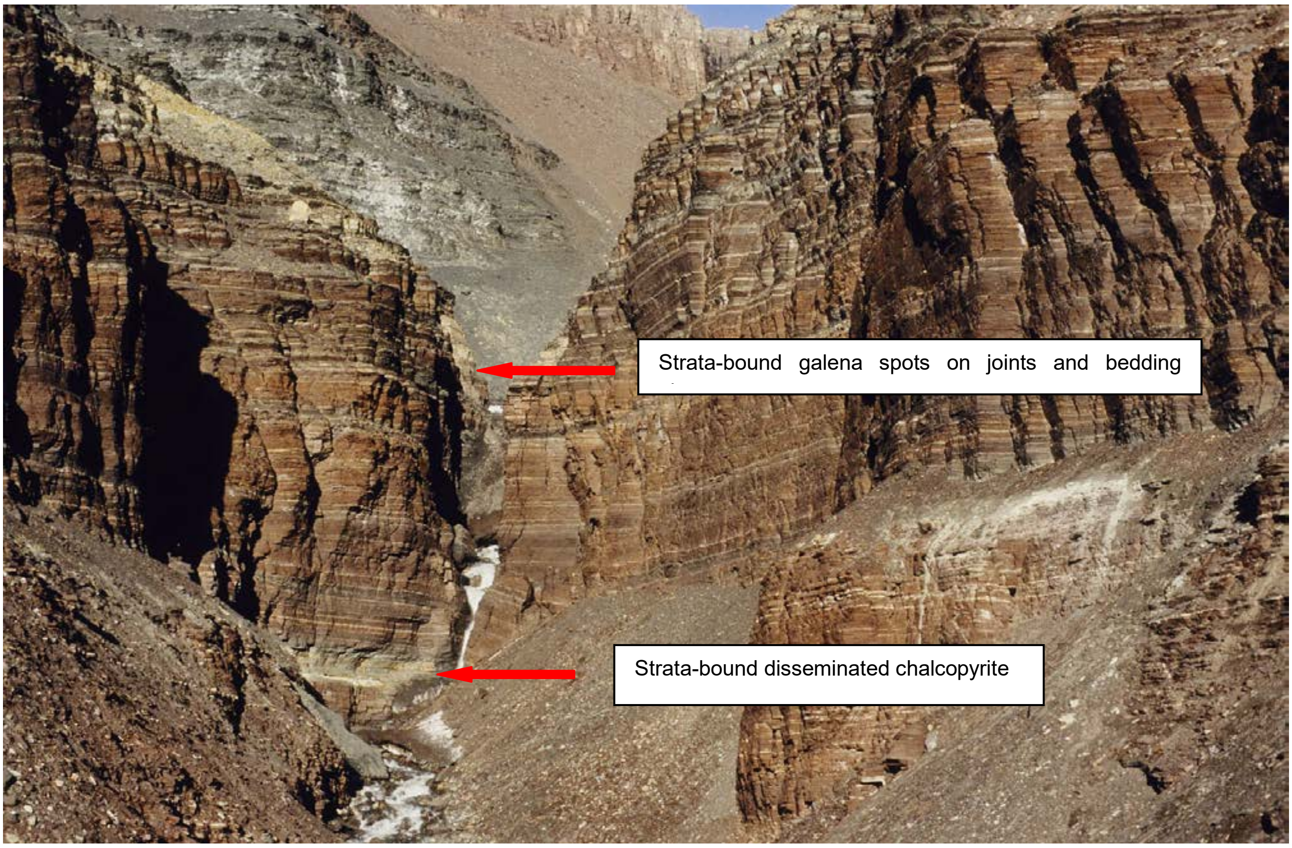


Figure 9. ***A:*** *Strata-bound Cu- and Pb – mineralisation in sandstones and silty shales of the Campanuladal Formation, east side of Campanuladal.* ***B:*** *Sandstone with spotty galena and marcasite on bedding planes and joints. Encircled spot is c. 1.5 cm wide. Sample 420309. Photo: P.Warna-Moors.*

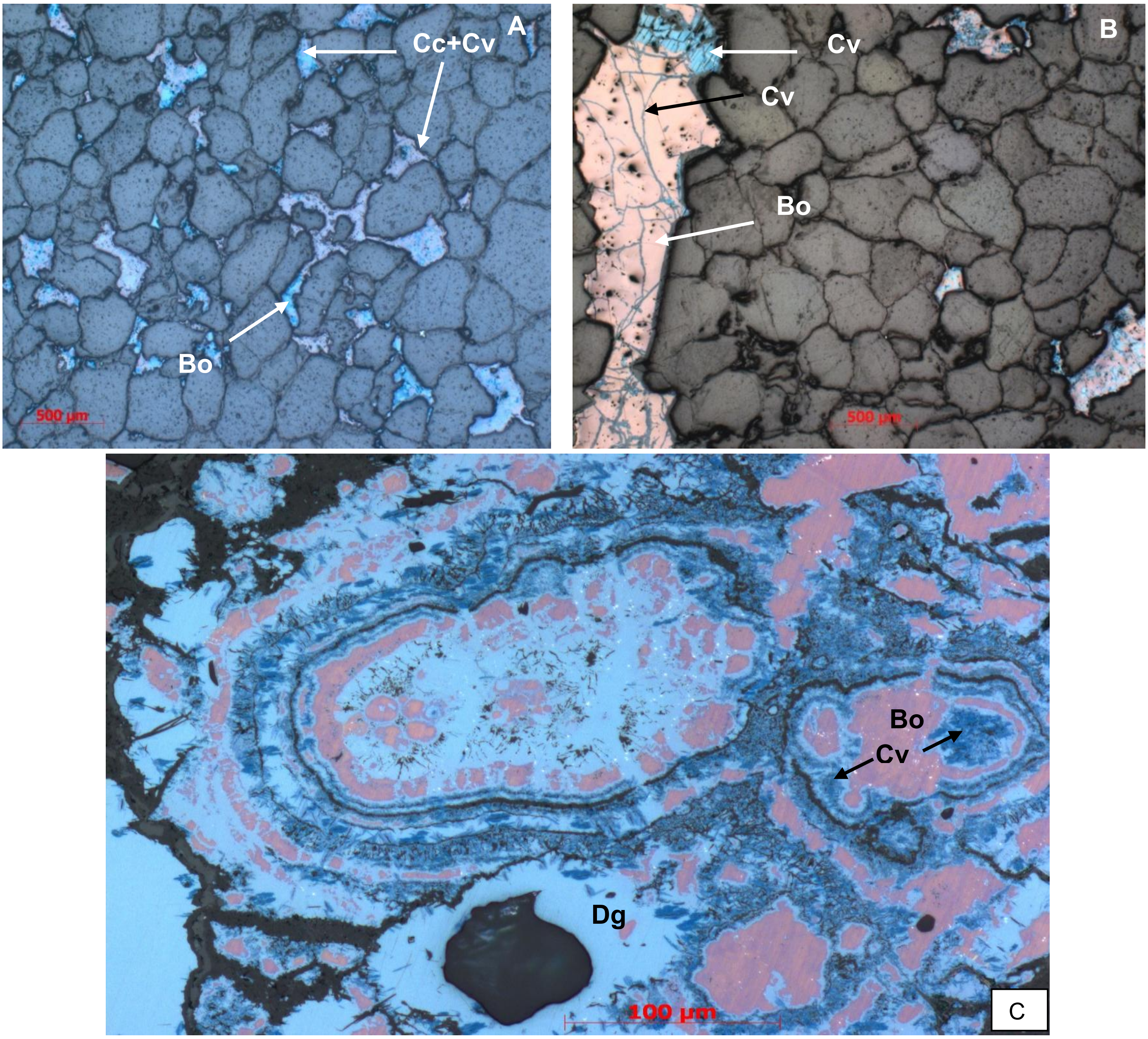
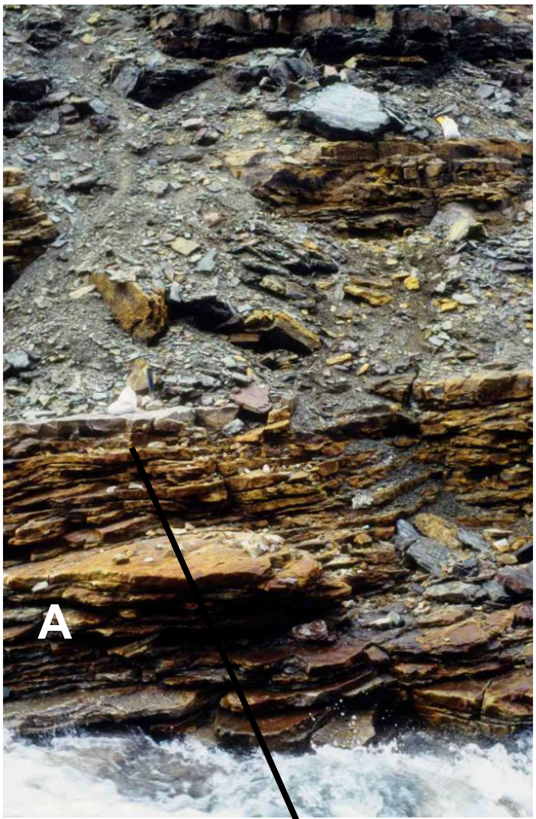


Figure 8. *Neergaard Dal, Jyske Ås Formation sandstone.* ***A:*** *interstitial bornite (**Bo**) grains in sandstone, partly altered to bluish chalcocite (**Cc**) and covellite (**Cv**) (272927).* ***B:*** *discordant bornite fracture filling (left) with development of covellite domains (top left) and hairline fillings (272927).* ***C:*** *Bornite nodule partially altered to digenite and covellite. The latter is in particular outlining concentric shells indicating an indigenous botryoidal growth texture in bornite (420474).*



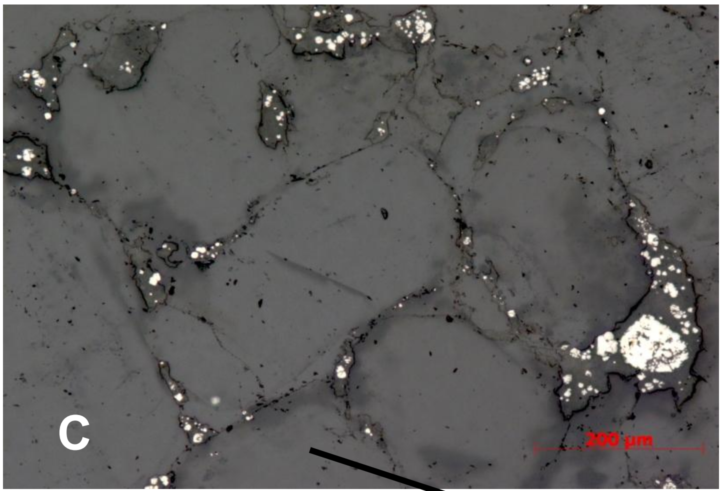
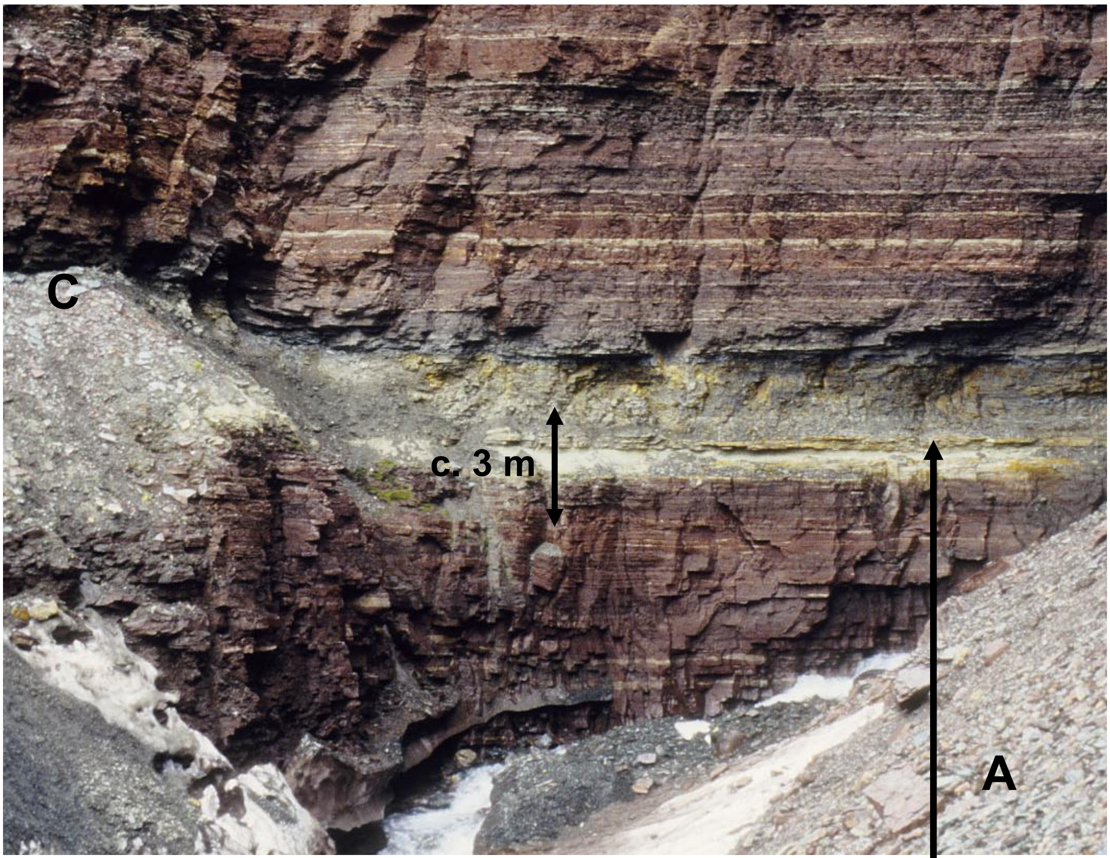
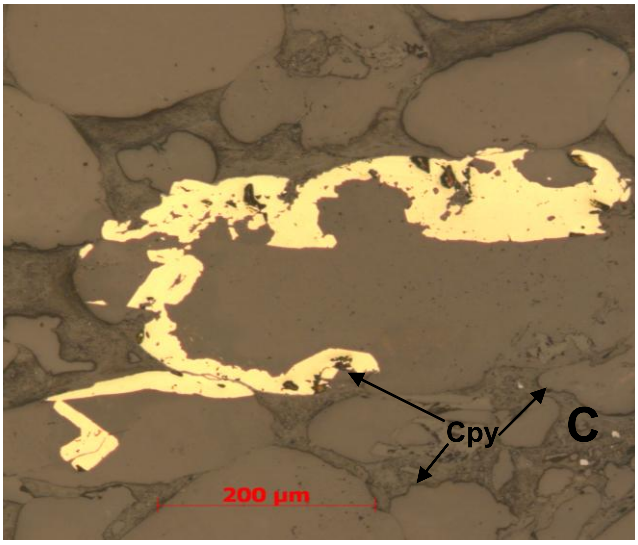


Figure 10. A: *Campanula Dal Formation sandstone beds with shale intercalations. Yellow colour is due to weathering of disseminated pyrite.* ***B:*** *Bleached sandstone bed with spotty galena coatings on joint surfaces. Note wave ripples and cross bedding. Length of hammer is 27 cm.* ***C:*** *Sandstone with interstitial pyrite grains and aggregates.*





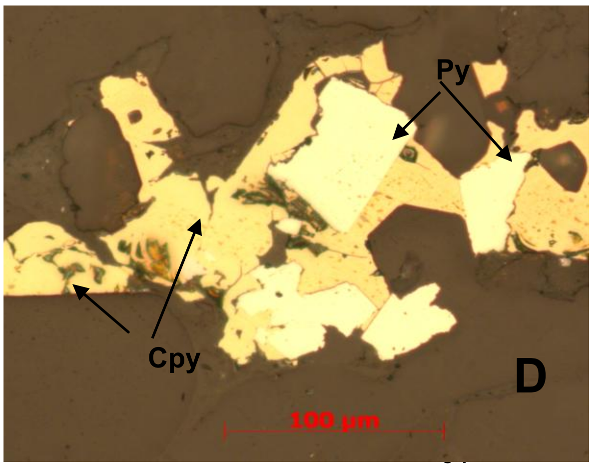
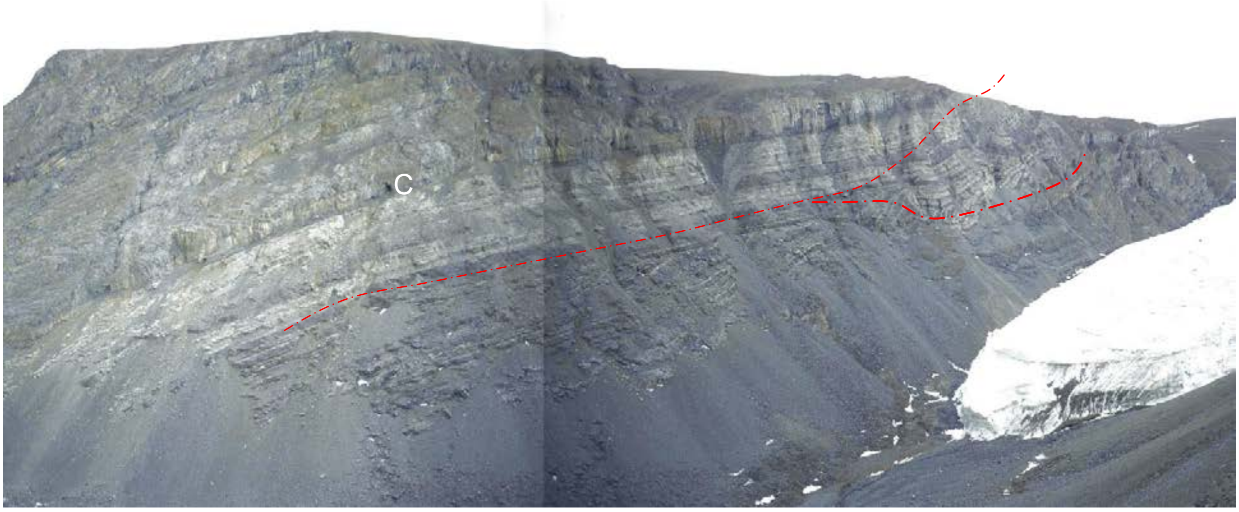


Figure 11. *A: Campanuladal Formation siltstones with yellow mineralised bed. B: Disseminated chalcopyrite is present in the 1-2 dm sandstone bed at the hammer head. Length of hammer is 27 cm. C: Sandstone with interstitial chalcopyrite, the sand grains are partly corroded by the chalcopyrite. D: Sandstone with interstitial euhedral pyrite. Chalcopyrite is enclosing and partly replacing pyrite.*

A

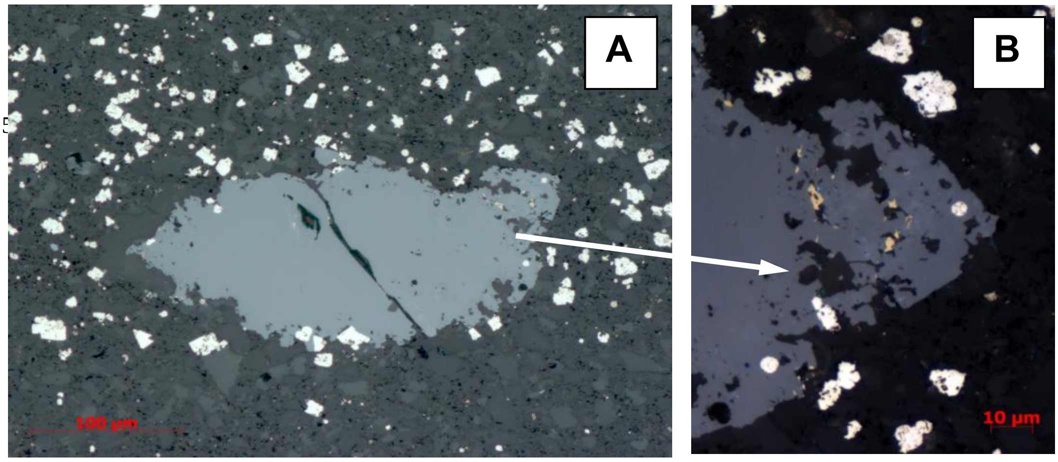


B

Figure 12. A: *Major thrust zones (red stippled line) displacing the lithologies of the Odins Fjord Formation (OF, Silurian)) and Turesø Formation (TF, Late Ordovician-Early Silurian)The E-W directed northern Ccliff face of Palisaderne is c. 2.6 km long and c. 300 m high. C: cave*

Figure 12 B: *Southern cliff face north of Vestfjeldet. The limestone has abundant karstic developments as caves and linear subvertical features. The reddish-yellowish coloration is due to the limonite rich carbonate material. Height of the cliff is c. 350 m.*

Figure 12 C: *Late hydrothermal limonite rich carbonate material in thrust zone, Vestfjeldet.*



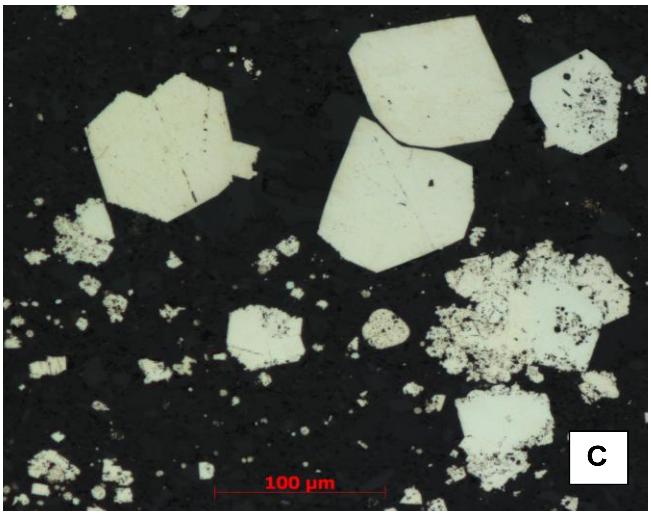
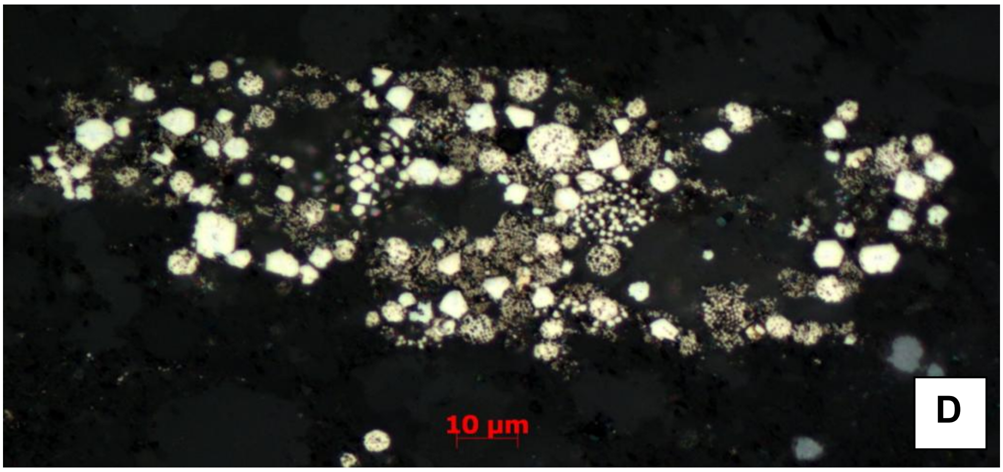


Figure 13. Black pyritic shales. Microphotographs from sample 420532 (A,B,C) and 420533 (D). **A:** Pyrite-rich band with large sphalerite grain (medium grey). Note sphalerite overgrowth of pyrite at the rim. **B:** Detail of **A** showing tiny yellow chalcopyrite inclusions in sphalerite. Light yellow grains are pyrite, mostly as framboids. **C:** Stages in progressive diagenetic enlargement of framboidal pyrite into euhedral pyrite, e.g. grain at upper right corner. **D:** Accumulation of pyrite framboids and discrete grains of euhedral pyrite outside of the pyrite rich bands. Bluish grey grains at lower right corner are possibly sphalerite.



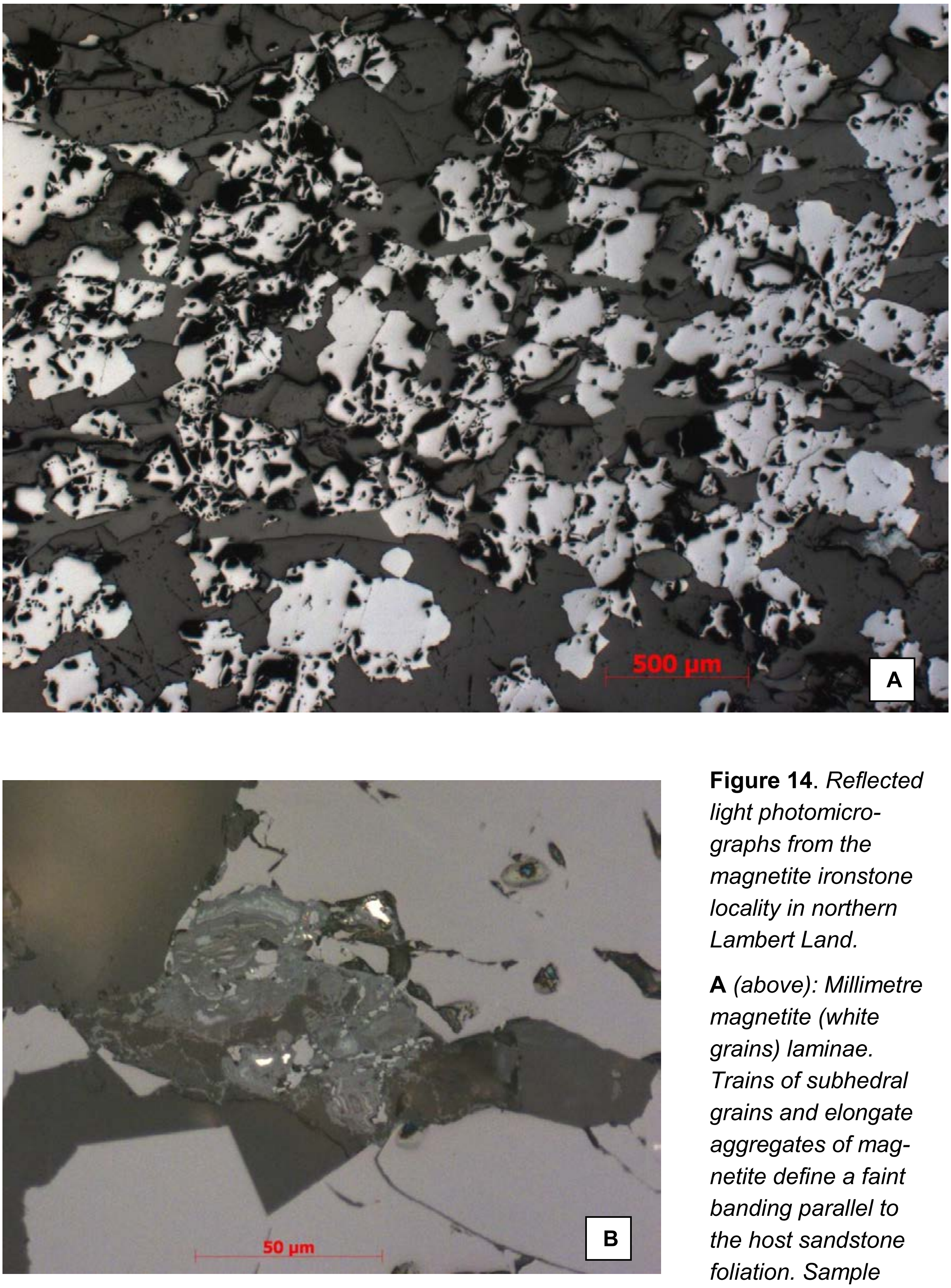


Figure 14. *Reflected light photomicrographs from the magnetite ironstone locality in northern Lambert Land.*

A *(above): Millimetre magnetite (white grains) laminae. Trains of subhedral grains and elongate aggregates of magnetite define a faint banding parallel to the host sandstone foliation. Sample 418531.*

B *(left): Magnetite aggregate (light grey) with partly enclosed goethite replacing both magnetite and pyrite (light yellow). Sample 418532.*