DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2010/54

Hyperøst 2008-09: Ground check of hyperspectral anomalies in the Werner Bjerge – Wollaston Forland region, North-East Greenland

Part 1: analytical results

Bjørn Thomassen & Tapani Tukiainen

(1 DVD included)

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MINISTRY OF CLIMATE AND ENERGY

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***Frontispiece**. Geologist trying to solve the riddle of the west face of Parkinson Bjerg, Hudson Land. The Post-Devonian Main Fault with its hallo of light grey alteration products runs N-S across the mountain slope. A reddish Devonian granite is seen at the top of the slope. Relief is c.1000 m.*

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1. Abstract

Hyperøst 2008–09 is a follow-up to an airborne hyperspectral survey flown in North-East Greenland in 2000. The aim is to test the suitability of hyperspectral techniques to detect mineral occurrences and specific rock types in Arctic regions. The purpose of this report is to summarise the field activities and present geochemical data on the collected samples. Hyperspectral results will be presented in a later report.

Field work was carried out in six areas underlain by Caledonian and post-Caledonian rocks of Proterozoic to Palaeogene age (Map 1). The work comprised measurements of rocks, minerals and their weathering products with a field spectroradiometer in order to determine their spectral character and to compare these with the airborne data. In both 2008 and 2009, field work was conducted in three weeks from four field camps. Main activities and results follow.

Immediately south of the Palaeogene *Werner Bjerge* alkaline complex which hosts the Malmbjerg porphyry molybdenum deposit, the airborne hyperspectral mapping had defined a locality with many spectral similarities to Malmbjerg. This anomaly hosts a significant number of pyrite-fluorite-bearing trachytic dykes and sheets in Permo-Carboniferous sandstone. These intrusions may represent the top of a porphyry system with a blind granite stock at a lower level.

The *Mesters Vig area* hosts an as yet unexplained 500 m wide zone of pervasive kaolinisation of Permo-Carboniferous arkosic sandstone located 3 km north-east of the mined out Blyklippen lead-zinc deposit. This could be related to mineralisation of the Blyklippen type.

Ymer Ø hosts a number of E–W-striking W-Sb-Au and Pb-Cu-Zn-bearing quartz veins in Neoproterozoic sediments. Linear jarosite-anomalies detected in the airborne data turned out to originate from E–W-striking rhyolitic veins, probably forming a part of the mineralising system in this area.

In *Hudson Land,* Sn-bearing greisen veins probably related to Devonian magmatism were investigated at two localities in an attempt to explain distinct geochemical Sn-W-Mo-Nb-anomalies in the area. Gold and base metal mineralisation was also inspected.

At *Clavering Ø,* extensive fault-controlled rust zones in Proterozoic supracrustals caused by hydrothermal alteration and base-metal mineralisation were investigated but no significant mineralisation was encountered.

On *Wollaston Forland,* a scree block of pyritiferous Proterozoic paragneiss returned high concentrations of Platinum Group Elements: 19.0 ppm Pt, 7.2 ppm Ir, 1.5 ppm Os and 0.5 ppm Rh. The source is unknown but it could be related to a local mafic sheet.

Recommendations for future work are based on the field observations and geochemical data presented in this report. The work up of the hyperspectral investigations might add further suggestions.

2. Introduction

The project *Hyperøst 2008–09: Ground check of airborne hyperspectral anomalies in the Werner Bjerge – Wollaston Forland region* aims at testing the suitability of hyperspectral techniques to detect mineral occurrences and specific rock types in Arctic regions. The project is a follow up on the *HyperGreen project* (see next section) and includes field work in 2008 and 2009. It has been financed by the Geological Survey of Denmark and Greenland (GEUS) and has benefitted through logistical co-operation with International Molybdenum Ltd. (InterMoly) in 2008. This company conducted a major exploration campaign at the Malmbjerg molybdenum deposit south of Mesters Vig in 2008.

The field work covered six out of eight areas in North-East Greenland (Map 1) originally selected for the *HyperGreen* airborne survey (see next section) because they host a number of known mineral occurrences in Caledonian and post-Caledonian rocks. Areas 1–4 were investigated in 2005 (Thomassen & Tukiainen 2008a); investigations 2008–09 comprised areas 2–3 and 5–8, all situated inside the National Park of North and North-East Greenland. The logistic framework was supplied by GEUS' North-East Greenland Expeditions (Bojsen-Koefoed *et al*. 2009). Logistics and preliminary results have been reported by Thomassen & Tukiainen (2008b, 2009). During both summers the weather and snow conditions were conductive to field work.

This report has the main purpose of summarising the field activities and present data on the collected samples: sample locations with coordinates, sample descriptions and analytical results with brief comments. Results of the hyperspectral investigations will be published later. For place names not shown on Maps 1–3, the reader is referred to the Survey's two geological maps at 1:500 000 covering the investigated region: Sheet 11 (Escher 2001) and Sheet 12 (Bengaard & Henriksen 1984).

3. Previous hyperspectral projects

Airborne hyperspectral measurements were carried out in North-East Greenland in 2000 with HyVista Corp. as contractor (Tukiainen 2001). A Dornier 228 from Deutsches Zentrum für Luft und Raumfart served as platform for the HyMap^{TM} hyperspectral spectrometer and a Zeiss aerial camera. The measurements had a resolution of 4 x 4 m nominal pixel size. The survey consisted of two parts.

- MINEO: *Assessing and monitoring the environmental impact of mining activities in Europe using advanced Earth observation techniques.* This EU-supported project was directed towards mining-related pollution which included the abandoned lead-zinc mine Blyklippen at Mesters Vig. The project was completed in 2003 (Aastrup *et al.* 2001a, b; Tamsdorf *et al.* 2003).

- HyperGreen: *Assessing the applicability of high resolution image spectroscopy as a mineral exploration tool.* This project tested the method's suitability in mineral exploration. This project, supported by the Bureau of Minerals and Petroleum (BMP), Government of Greenland, assessed airborne data from eight areas with known mineral occurrences.

4. Regional geology and mineralisation

North-East Greenland is dominated by the north–south-trending Caledonian fold belt and coast-parallel rift basins with Late Palaeozoic and Mesozoic sediments and Palaeogene igneous rocks. The *Hyperøst 2008–09* region, comprising areas 2–3 and 5–8 as defined on Map 1, is underlain by Caledonian rocks of Proterozoic–Ordovician age, and post-Caledonian rocks of Devonian–Palaeogene age. The latter comprise Devonian to Lower Permian clastic sediments with minor intercalations of Devonian volcanics, Upper Permian to Cretaceous, mainly marine clastic and carbonate sediments, and Palaeogene intrusive and extrusive igneous rocks (Henriksen & Higgins 2008, Henriksen *et al.* 2009).

Mineral occurrences of the region include 1) sedimentary deposits in Upper Permian carbonates, especially strata-bound lead-zinc sulphides together with baryte and quartz, 2) magmatic deposits associated with the Palaeogene intrusions in the Werner Bjerge – especially sub-volcanic porphyry molybdenum deposits – and with Devonian granites, and 3) vein-type mineralisation of uncertain age: a large number of quartz veins with variable concentrations of baryte, calcite, fluorite and lead-zinc-copper minerals, and more rarely tin-greisen veins, occur in both magmatic and sedimentary rocks (Harpøth *et al.* 1986).

5. Follow-up work in 2008

5.1 Work carried out

In 2008, field work was carried out in the areas 2, 5 and 6 (Map 1). As preparation for the work, a number of maps of significant primary minerals and alteration minerals were prepared on the basis of the airborne hyperspectral data: iron sulphate (jarosite), greisen (tourmaline and topaze), alunite, kaolinite, illite and fengite. The hyperspectral interpretation from Ymer Ø was accomplished on contract with the exploration company NunaMinerals A/S. These maps, as well as all airborne raw data, were accessed in the field on CD-ROM. For field measurements, a spectroradiometer borrowed from BRGM, Orleans, France, was used: model PIMA II Infrared Spectroradiometer produced by Integrated Spectronics Pty. Ltd.

Field work was conducted between 1 and 22 August from four camps, of which one was Intermoly's base camp south of Malmbjerg (Map 2). Each camp was located near known mineralisation and hyperspectral anomalies. These were localised and investigated during daily traverses, four days supported by helicopter lifts. Investigations comprised the collection of minerals and rocks for measurements with the field spectroradiometer in order to determine the spectral character of the rocks and their weathering products. At the same time, the airborne data were further processed in an iterative process of visualising of, and comparing with, the geological field observations.

The investigated mineral occurrences are of three types. (1) Magmatic occurrences associated with granite. In Werner Bjerge sub-volcanic molybdenum deposits of the porphyry type (Malmbjerg). In Hudson Land a Devonian granite at Parkinson Bjerg which is surrounded by distinct geochemical anomalies of especially Sn, W and Mo. (2) High-temperature greisens (quartz-muscovite) veins with W-Mo-Sn, found at Malmbjerg and indicated at Parkinson Bjerg. (3) Epithermal quartz veins with barite, fluorite and Pb-Zn-Cu-minerals associated with the Post-Devonian Main Fault in Hudson Land, and Sb-W-Au-(Cu-Pb-Zn)-bearing quartz veins on Ymer Ø. The veins are hosted by Neoproterozoic (Eleonore Bay Supergroup) and Devonian–Carboniferous sediments (Harpøth *et al.* 1986).

A hundred and one reference samples were registered with GGU numbers: 469501–54 (BTh) and 496901–47 (TT). Furthermore, 12 soil samples/scree fines were collected (530701–08, 26–29). They are briefly described in Table 1 with GPS geographical coordinates. The samples have been analysed for 49 elements by a combination of instrumental neutron activation (INNA) and inductively coupled plasma emission spectrometry (ICP) at Activation Laboratories Ltd. (Actlabs), Ontario, Canada. Samples with high metal concentrations were subsequently assayed for the relevant elements, and ten samples were submitted to major element analysis by fusion XRF. The analytical results are presented in Table 2 and CIPW-norm calculations carried out by L. Melchior Larsen are presented in Table 5. Twenty-three polished thin sections were prepared (Table 1).

5.2 Main results

Area 2. Werner Bjerge

Malmbjerg. Field work in 2005 showed that alteration zones surrounding the Malmbjerg porphyry molybdenum deposit in the Palaeogene Werner Bjerge alkaline complex are especially enriched in topaz (Bearth 1959, Thomassen & Tukiainen 2008a). In 2008, altered Permo-Carboniferous sediments were systematically sampled along the Arcturus Gletscher with a view to a closer investigation of the alteration minerals.

Comments: The altered sediments collected along the Arcturus Gletscher are especially enriched in tungsten (max. 203 ppm, Table 2).

Malmbjerg South. The airborne hyperspectral mapping defined a locality just south of Werner Bjerge which displays many spectral similarities to Malmbjerg (Thomassen & Tukiainen 2008a). In 2008, the southern part of this anomaly was traversed in 1300 m's altitude during a one-day helicopter-supported visit. It was found to host a significant number of few metres thick felsic dykes and sheets in Permo-Carboniferous sandstone. The intrusive rocks may contain abundant wall-rock fragments and are often enriched in pyrite and fluorite. A Pb-Cu-bearing quartz vein and scree blocks of similar material were located at lower levels.

Comments: The felsic dykes and sheets are of trachytic composition and strongly enriched in potassium and depleted (leached) in calcium and sodium (Table 5). Furthermore, the samples show relatively high concentrations of tungsten (max. 35 ppm), molybdenum (max. 21 ppm) and thorium (max. 226 ppm). These intrusions may represent the top of a porphyry system with a blind granite stock at a lower level. Samples of mineralised vein quartz show high Pb-Zn-Cu-Ag-Sb-Ba concentrations.

Area 5. Ymer Ø

Noa Dal. On the south side of this valley, mostly E–W-striking Sb-Au and Pb-Cu-Zn-bearing quartz veins are hosted by sediments of the Neoproterozoic Eleonore Bay Supergroup (Harpøth 1986, Pedersen 1993). These were localised, sampled and measured.

Comments: The stibnite-bearing veins returned up to 23.4% Sb, 2.15% As and 4.67 ppm Au. The gold seems to be concentrated along hanging and foot walls. Samples from the base-metal-bearing veins returned up to 1.4% Cu, 12.9% Pb, 2.3% Zn, 83 ppm Ag and 10.2 ppm Hg.

Area 6. Hudson Land

Ankerbjergdal. The north side of this valley exhibits extensive hydrothermal alteration with associated base metal, gold and tin mineralisation occurring along the Post-Devonian Main Fault (Geyti 1982, Harpøth 1984, Stendal 1999). The alteration zone and malachite-stained greisen veins up to 1 m thick were sampled. Furthermore, scree blocks of Pb-Zn-bearing vein quartz and stream boulders of pyrite-cemented breccias were collected.

Comments: Samples from the greisen veins returned up to 1.44% Sn, 0.51% Cu, 151 ppm Ag, 799 ppm Bi and 434 ppm Sb. Scree blocks of vein quartz gave up to 1.37% Zn, >0.5% Pb, 1.34% As, 0.56 ppm Au, 84 ppm Ag and 294 ppm Sb.

Parkinson Bjerg. The mountain hosts a Devonian granite intrusion with geochemical Sn, W, Mo, Nb etc. anomalies in the surrounding drainage systems (Thomassen 1979, Lind 1981, Harpøth 1984). The granite was traversed along the north side of Blokade Gletscher and its contacts were investigated. Abundant fluorite-tourmaline-quartz veining and scree blocks of magnetite skarn were noted.

Comments: The fluorite-tourmaline-bearing quartz veins and the magnetite skarn may be enriched in tin (max. 0.39%), beryllium (max. 1680 ppm) and yttrium (max. >1000 ppm). Two samples of scree-fines are enhanced in a number of elements with up to 50 ppm Be, 376 ppm Y, 103 ppm U, 92 ppm Th and 14 ppm W.

6. Follow-up work in 2009

6.1 Work carried out

In 2009, field work was accomplished in areas 3, 5, 6, 7 and 8 (Map 1). The work was carried out 28 July–18 August from four fly camps (Map 3). Like the previous year, each camp was located near known mineralisation and hyperspectral anomalies. These were localised and investigated during daily traverses, three days supported by helicopter lifts. Investigations comprised the collection of minerals and rocks for measurements with a field spectroradiometer in order to determine the spectral character of the rocks and their weathering products, and to compare these with the airborne data. At the same time, the airborne data were further processed in an iterative process of visualising of, and comparing with, the geological field observations. In 2009, GEUS purchased an advanced spectroradiometer, model FieldSpec 3 HiRes, produced by ASD Inc., USA.

Investigated mineral occurrences included mineral concentrations associated with the Devonian granite at Parkinson Bjerg (Hudson Land) which is surrounded by distinct geochemical Sn-W-Mo-Nb-anomalies. Further, epithermal quartz veins with variable concentrations of barite, fluorite and base metals associated with the Post-Devonian Main Fault in Hudson Land and on Clavering Ø (Harpøth *et al.* 1986).

Sixty-three rock samples were registered with GGU numbers 476601–33 (BTh) and 496701–30 (TT). Furthermore, four stream sediment samples/scree fines (530000–02, 04) and one heavy mineral concentrate (503274) were collected. They are briefly described in Table 3 with GPS geographical coordinates. The samples have been analysed for 49 elements by a combination of instrumental neutron activation (INNA) and inductively coupled plasma emission spectrometry (ICP) at Actlabs, Ontario, Canada. Samples with high metal concentrations were subsequently assayed for the relevant elements and nine samples were submitted to major element analysis by fusion XRF. The analytical results are presented in Table 4 and calculated CIPW norms in Table 5. Nine polished thin sections were also prepared (Table 3).

6.2 Main results

Area 3. Mesters Vig

Blyklippen. The Mesters Vig area hosts fault-controlled epithermal lead-zinc veins, including the mined-out Blyklippen deposit (Bondam & Brown 1955, Thomassen 2005a, Thomassen & Tukiainen 2008a). The veins are accompanied by silicification and kaolinisation of the arkosic wall rocks. An airborne hyperspectral anomaly located some 3 km north-east of the mine was investigated during a brief helicopter stop. It comprises a *c.* 500 m-wide zone of pervasively kaolinised Permo-Carboniferous arkosic sandstone and conglomerate.

Comments: The alteration zone could be related to unknown base-metal mineralisation of the Blyklippen type.

Area 5. Ymer Ø

Nord Margerie Dal. Linear jarosite-anomalies in Neoproterozoic Eleonore Bay Supergroup sediments have been detected in the airborne hyperspectral data west of Margerie Dal. During a helicopter reconnaissance, these anomalies were checked and it turned out that they origin from two 3–5 m thick, E–W-striking near vertical felsic dykes. The dykes are fine-grained with kaolinite alteration but they show no signs of mineralisation.

Comments: The dyke rocks are of rhyolitic composition, occur in approximate strike continuation of the North Margerie Dal Sb-W-mineralised vein and probably form a part of the mineralising system in this area.

Area 6. Hudson Land

Parkinson Bjerg. The northern part of the Devonian granite at Parkinson Bjerg was investigated (Frontispiece). It was found to have a fine-grained, foliated margin and a coarse-grained, pegmatic core rich in quartz, fluorite and tourmaline, corresponding to a distinct tourmaline response in the airborne data, and indicating a potential source for the surrounding geochemical Sn, W, Mo, Nb anomalies.

Comments: Samples of granite with fluorite veins returned up to 0.42% Sn, 89.3 ppm Th, 31.8 ppm U, 174 ppm Y and 63 ppm Bi. Three stream sediment/scree fine samples are enhanced in a number of elements, with up to 34 ppm Be, 108 ppm Th, 48 ppm U, 173 ppm Y and 13 ppm W.

Area 7. Clavering Ø

Rustplateau. Extensive rust zones in Proterozoic supracrustals overlain by Carboniferous sandstones are associated with two set of faults. The faults are affected by hydrothermal alteration and host pyrite mineralisation with a minor component of base metals (Koch 1955, Thomassen 1982). The alteration and mineralisation causing the rust zones were investigated.

Comments: A sample of vein quartz returned 1.0% Pb and a sample of brecciated pyrite gave <2 ppb Au, 13.3% Fe and 15.8% S.

Auspicia ("Lauge Koch's Gold Mine"). At this fault-controlled rust zone in Proterozoic supracrustals, a test adit excavated in 1933 intersected a 1.3 m wide zone of massive pyrite with negligible gold (Eklund 1944). A helicopter-supported visit was made to this historical locality where samples of the pyritic "ore" mined in 1933 were collected.

Comments: The pyritic "ore" returned up to <2 ppb Au, 24.6% Fe and >20% S.

Area 8. Wollaston Forland

Dombjerg. This area was included in the airborne survey with a view to biological studies around the research station Zackenberg and no mineralisation has been previously reported. The investigated part of the area is underlain by Palaeoproterozoic gneiss and Neoproterozoic metasediments with quartz veining. A prominent structure – Kildedalen shear zone – occurs in the northern part of the area and hyperspectral jarosite-anomalies seem to be associated with it. The scree slopes of north-western Dombjerg were traversed and sampled. They consist mainly of blocks of paragneiss and mica schist but also mafic–ultramafic blocks were observed. An up to 100 m thick mafic "sill" has been described from similar rocks further to the north-west by Leedal (1952).

Comments: A scree block of chlorite-calcite-cemented breccia assayed 0.5 ppm Au. Another scree block of pyritiferous paragneiss revealed an extraordinary high iridium concentration of 4,070 ppb but no other remarkable metal concentrations (90 ppb Au, 324 ppm Cu, 12.5% Fe, 4.97% S and 0.358% P). After this, a full nickel sulphide fire assay for Platinum Group Elements (PGE) was undertaken by Actlabs that gave the following results: 19,000 ppb Pt, 7,230 ppb Ir, 1,470 ppb Os, 486 ppb Rh, 85 ppb Pd, 70 ppb Ru, <5 ppb Re and 49 ppb Au. These high PGE values definitely warrant further investigation. Although the sample represents metamorphosed sediment, it could originate from the contact towards a mafic sheet like the one described by Leedal (1952), thus representing an attractive source rock for PGE mineralisation.

7. Recommendations

Based on the data presented in this report, the following recommendations for future work are suggested. When the results of the hyperspectral investigations are incorporated, these recommendations will undoubtedly be expanded.

Area 2. Werner Bjerge

A petrologic study of the trachytic rocks from Malmbjerg South should be carried out. Furthermore, the remaining parts of the hyperspectral anomaly should be investigated and litho-geochemical sampling carried out in order to establish possible alteration patterns associated with a blind granitic stock.

Area 3. Mesters Vig

A more detailed investigation of the pervasive alteration zone north-east of Blyklippen is necessary before its significance can be evaluated.

Area 5. Ymer Ø

A petrologic study of the rhyolitic rocks should be carried out with a view to establishing their relationship to the mineralising system of the area.

Area 6. Hudson Land

In Ankerbjergdal, detail sampling of the main base metal vein should be carried out and the source area for the gold-bearing floats localised. The greisen veins here and at Parkinson Bjerg should be mapped out.

Area 7. Clavering Ø

No further investigations are recommended.

Area 8. Wollaston Forland

It is recommended to confirm the PGE find by the determination of the minerals in the mineralised sample. If the existence of PGE-bearing minerals is confirmed, field work aiming at the localisation of outcropping PGE mineralisation should be conducted. The local mafic–ultramafic unit in the metasediments constitutes an obvious candidate.

8. References

Aastrup, P., Tamsdorf, M. & Tukiainen, T. 2001a: Blyklippen lead-zinc mine, Mestersvig. Existing knowledge. Mineo site Report. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2001/115**, 39 pp.

Aastrup, P., Tamsdorf, M. & Tukiainen, T. 2001b: MINEO. Use of hyperspectral data for monitoring pollution from the lead-zinc mine, Mestersvig, in Northeast Greenland. In: Olsen, H.K., Lorentzen, L. & Rendal, O. (eds): Mining in the Arctic, 25–28. Lisse, The Netherlands: A.A. Balkema Publishers.

Bearth, P. 1959: On the alkali massif of the Werner Bjerge in East Greenland. Meddelelser om Grønland **153**(4), 62 pp.

Bengaard, H.-J. & Henriksen, N. 1984: Geological map of Greenland, 1:500 000, Scoresby Sund, sheet 12, Copenhagen: Geological Survey of Greenland.

Bojsen-Koefoed, J.A., Bjergager, M. & Piasecki, S. 2009: Shallow core drilling and petroleum geology related field work in East and North-East Greenland 2008. Geological Survey of Denmark and Greenland Bulletin **17**, 53–56.

Bondam, J. & Brown, H. 1955: The geology and mineralisation of the Mesters Vig area, East Greenland. Meddelelser om Grønland **135**(7), 40 pp.

Eklund, O. 1944: Malmgeologisk forskning på Nordostgrönland. Teknisk Tidsskrift, Stockholm **14**, 393–401.

Escher, J.C. 2001: Geological map of Greenland, 1:500 000, Kong Oscar Fjord, sheet 11, Copenhagen: Geological Survey of Denmark and Greenland.

Geyti, A. 1982: Geological reconnaissance for porphyry-type mineralization 1981. Hudson Land, Hold With Hope, Bontekoe Ø, Scoresby Land, and Traill Ø, NM 4/81. Internal report, Nordisk Mineselskab A/S, 57 pp. (in archives of Geological Survey of Denmark and Greenland, GEUS Report File 20724).

Harpøth, O. 1984: Precious metal and tin exploration in Hudson Land and Andrées Land, central East Greenland, NM 14/83. Internal report, Nordisk Mineselskab A/S, 50 pp. (in archives of Geological Survey of Denmark and Greenland, GEUS Report File 20782).

Harpøth, O. 1986: The Noa Dal antimony-gold vein on Ymer Ø, central East Greenland, NM 1/86. Internal report, Nordisk Mineselskab A/S, 45 pp. (in archives of Geological Survey of Denmark and Greenland, GEUS Report File 20862).

Harpøth, O., Pedersen, J.L., Schønwandt, H.K. & Thomassen, B. 1986: The mineral occurrences of central East Greenland. Meddelelser om Grønland, Geoscience **17**, 139 pp.

Henriksen, N., Higgins, A.K., Kalsbeek, F. & Pulvertaft, T.C.R. 2009: Greenland from Archaean to Quaternary. Descriptive text to the 1995 Geological map of Greenland, 1:2 500 000. 2nd edition. Geological Survey of Denmark and Greenland Bulletin **18**, 126 pp. + map.

Henriksen, N. & Higgins, A.K. 2008: Caledonian orogen of East Greenland 70º N–82º N: Geological map at 1:1,000,000 – Concepts and principles of compilation. *In* Higgins, A.K., Gilotti, J.A. and Smith, M.P. *eds*.: The Greenland Caledonides: Evolution of the Northeast Margin of Laurentia. Geological Society of America Memoir **202**, 345–368.

Leedal, G.P. 1952: The crystalline rocks of East Greenland between latitudes 74º30' and 75º N. Meddelelser om Grønland **142**(6), 80 pp.

Lind, M. 1981: Scheelitprospektering i Polhems Dal, Fuchs Bjerg, Lucia Dal, Geologfjord, Eleonores Bugt–Kap Weber, Murgangsdalen, Rosinante, Kalkdal, NM 6/81. Internal

report, Nordisk Mineselskab A/S, 38 pp. (in archives of Geological Survey of Denmark and Greenland, GEUS Report File 20726).

Pedersen, J. 1993: Gold-antimony exploration at Noa Dal on Ymer Ø, East Greenland, in 1992. Internal report, Nunaoil A/S, 22 pp. (in archives of Geological Survey of Denmark and Greenland, GEUS Report File 21299).

Stendal, H. 1999: Mineralisation follow-up in fault zones, Hudson Land, Gauss Halvø and Steno Land, North-East Greenland. In: Higgins, A.K. & Frederiksen, K. (eds): Geology of East Greenland 72º–75ºN, mainly Caledonian: preliminary reports from the 1998 expedition. Danmarks og Grønlands Geologiske Undersøgelse Rapport **1999/19**, 201–205.

Tamsdorf, M., Tukiainen, T. & Aastrup, P. 2003: MINEO arctic environment test site. Contamination/impact mapping and modelling. Final report. www.brgm.fr/mineo, 87 pp.

Thomassen, B. 1979: Note on tin content in GGU stream sediment samples from E. Hudson Land. Internal report, Nordisk Mineselskab A/S, 3 pp.

Thomassen, B. 1982: Prospecting for Cu-Pb-Zn-Ag-Au in the Upper Permian sediments and Devonian volcanics of East Greenland, NM 1–2. Internal report, Nordisk Mineselskab A/S, 100 pp. (in archives of Geological Survey of Denmark and Greenland, GEUS Report File 20702).

Thomassen, B. 2005a: The Blyklippen lead-zinc mine at Mesters Vig, East Greenland. Geology & Ore **5**, 12 pp. Copenhagen: Geological Survey of Denmark and Greenland.

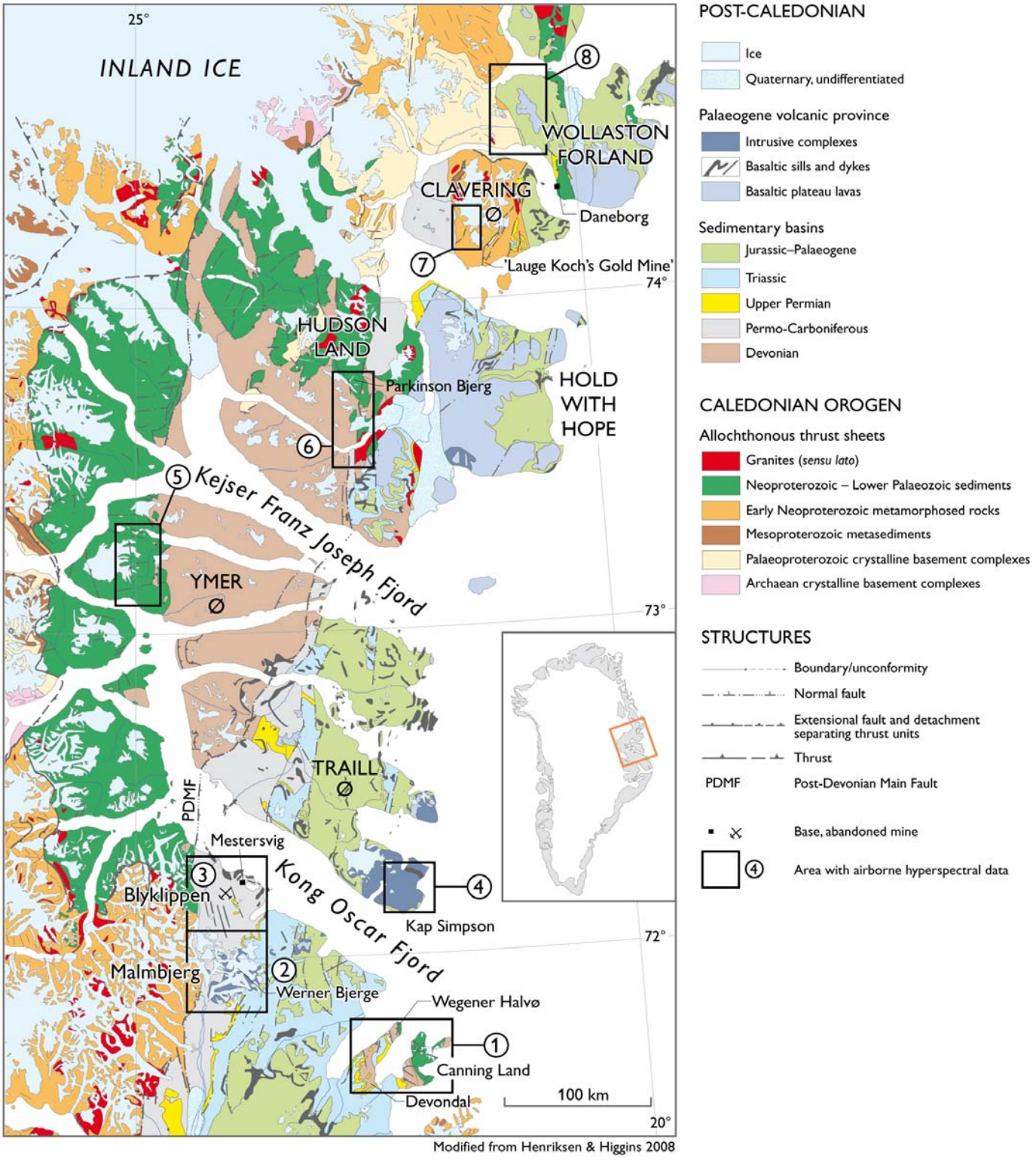
Thomassen, B. & Tukiainen, T 2008a: Ground check of airborne hyperspectral anomalies in the greater Mesters Vig area, central East Greenland. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2008/14**, 85 pp., 1 DVD.

Thomassen, B. & Tukiainen, T. 2008b: Feltrapport for Hyperøst 2008 projektet. GEUS Notat 14-MI-08-10, 5 pp.

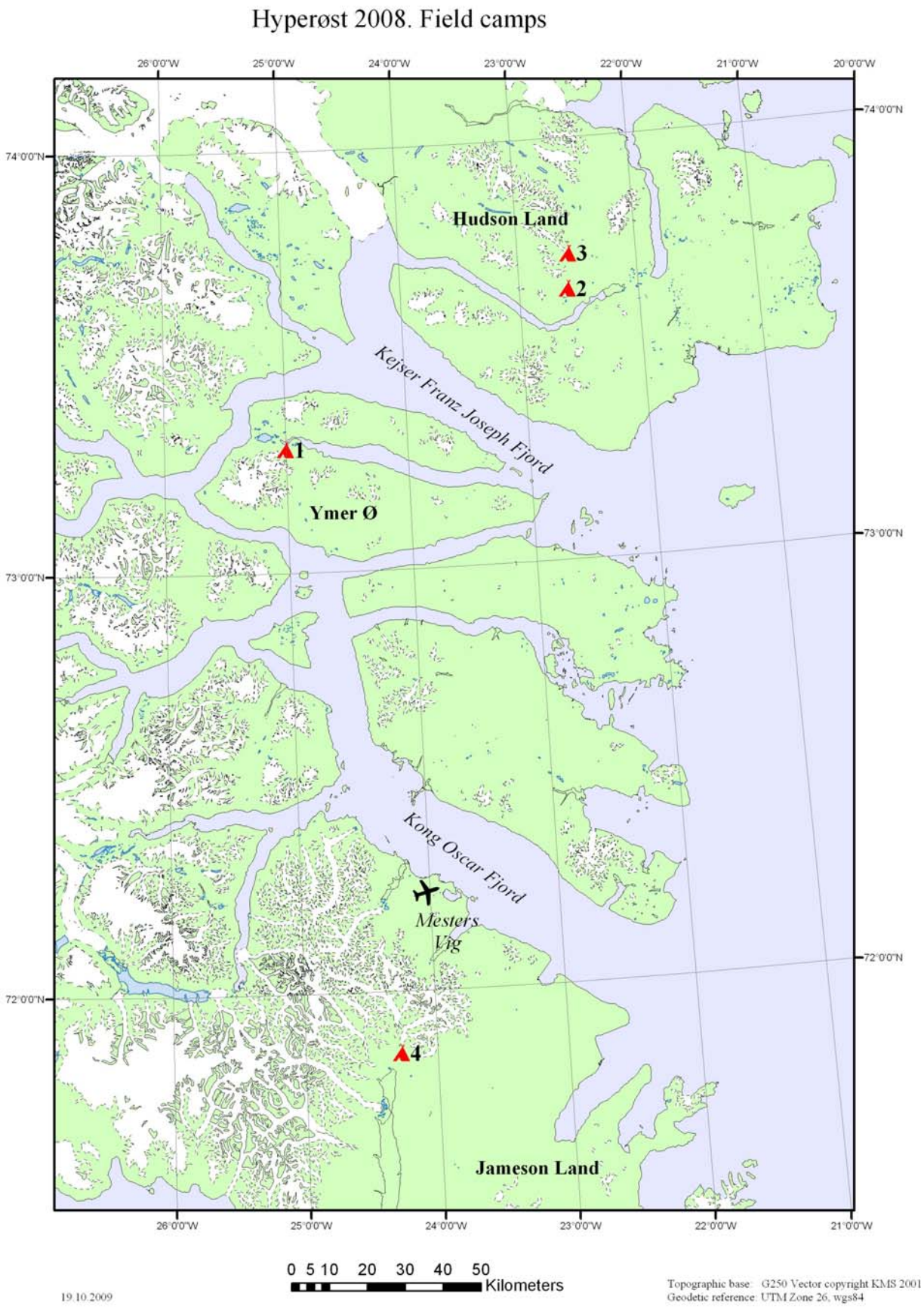
Thomassen, B. & Tukiainen, T. 2009: Feltrapport for Hyperøst 2009 projektet. GEUS Notat 14-MI-09-08, 5 pp.

Tukiainen, T. 2001: Projects MINEO and HyperGreen: airborne hyperspectral data acquisition in East Greenland for environmental monitoring and mineral exploration. Geology of Greenland Survey Bulletin **189**,122–126.

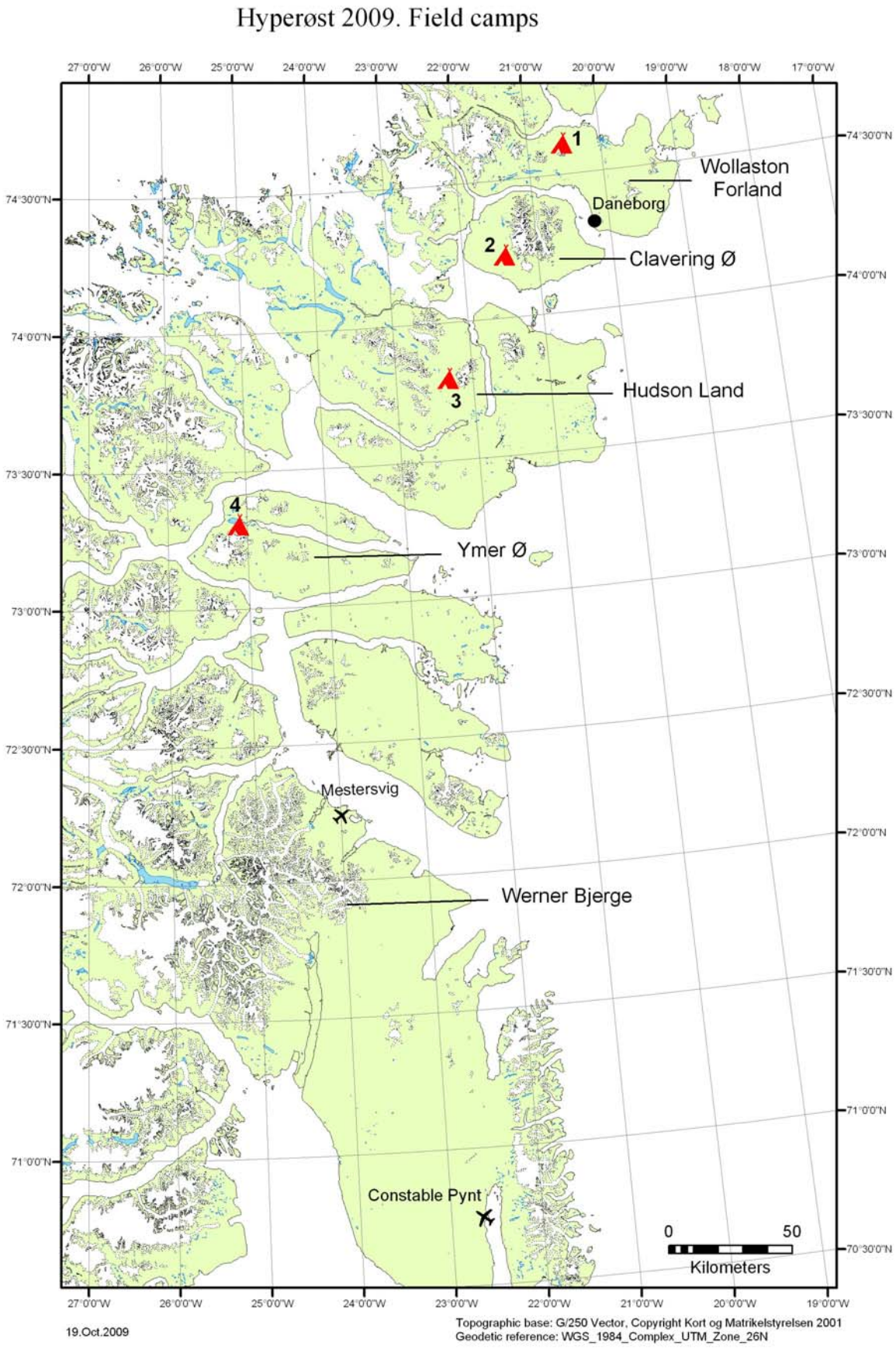
9. Maps



Map 1. *Geological map of North-East Greenland showing areas covered by airborne hyperspectral data. Areas 2, 3, 5, 6, 7 and 8 are discussed in this report. Modified from Henriksen & Higgins (2008).*



Map 2. *Toponymic map showing the four field camps from season 2008.*



Map 3. *Toponymic map showing the four field camps from season 2009.*