DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2013/19

Reconnaissance for Mississippi Valley-type Zn-Pb deposits in the Franklinian Basin, Eastern North Greenland

Results of the 2012 Season

Diogo Rosa & Per Kalvig

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DANISH MINISTRY OF CLIMATE, ENERGY AND BUILDING

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Contents

Abstract

Two new Zn showings were discovered within the same general stratigraphic horizon, one in Western Melville Land (Peary Land) and the other in Kronprins Christian Land, Eastern North Greenland, during exploration reconnaissance carried out by the Geological Survey of Denmark and Greenland (GEUS) in the summer of 2012.

Mineralisation consists of lime-green sphalerite and minute traces of galena and sulfosalts, in calcite, dolomite, and, occasionally, fluorite veinlets and pockets. These veinlets and pockets are intermittently distributed within dolostones of the upper part of the Turesø Formation (Upper Ordovician to Lower Silurian – Morris Bugt Group), of the Franklinian Basin carbonate platform. Recorded zinc grades, for these Mississippi Valley-Type (MVT) showings, are variable due to the irregular distribution of relatively coarse-grained sphalerite. The highest grade recorded is 5.81% Zn, with most mineralised samples having Ag and Pb concentrations below the detection limit.

It is suggested that metal precipitation, from basinal brines circulating within the upper part of the Turesø Formation, was promoted by reduced sulphur derived from the reduction of evaporite sulphate likely initially present in immediately underlying beds. These underlying beds were likely to have contained evaporites, since desiccation cracks, documenting their subaerial exposure were identified. The reduction of sulphate to sulphide could have been caused by the reaction with organic matter since the pale yellow colour of these underlying beds suggests the organic matter, presumably present originally, has been consumed in that process.

Furthermore, two float samples collected in Samuelsen Høj Formation carbonate mounds in Melville Land (Peary Land) were found to be mineralised or anomalous in zinc. The mineralised float contains fluorite and weathered sphalerite and yielded 3.58% Zn and 263 ppm Pb. The anomalous float yielded 140 ppm Zn. This suggests that some mineralising fluids moved up the stratigraphy and could have been collected in this formation, underneath the Lauge Koch Land Formation turbidites, which would have acted as an important aquitard.

Introduction

Since the Franklinian Basin of Northern Greenland is known to host several zinc prospects and showings, an assessment of its zinc potential was performed at a workshop organised by the Geological Survey of Denmark and Greenland (GEUS) and the Bureau of Minerals and Petroleum (BMP), held in Copenhagen between November 29th and December 1st 2011. Following the procedures of the Global Mineral Assessment Project, as defined by the United States Geological Survey (USGS), an assessment and ranking of different areas was performed (Sørensen et al, 2013). The Franklinian Basin (Figure 1) was considered highly prospective, both for Sedimentary Exhalative (SEDEX) deposits and for Mississippi Valley-Type (MVT) deposits, formed during basin fill or subsequently, during the Ellesmerian orogeny, respectively. The encouraging outcome of this assessment led GEUS to propose to the BMP an expedition to the eastern part of the basin during the summer of 2012.
The ensuing project was recognised as an opportunity to verify the zinc potential of some of the more underexplored areas of the Franklinian Basin in the field, as well as to extend the regional stream sediment program, while taking advantage of the logistical support that was made available by another ongoing GEUS project, operating out of Station Nord.

While initially the intention was to focus field work on Peary Land and Amundsen Land, the geographical and logistical constraints of operating out of Station Nord caused a refocusing of the field work towards Peary Land and Kronprins Christian Land instead. This caused the exclusion of study areas in the trough sequence, favourable to SEDEX deposits, but allowed the study of a wider area of the carbonate sequence, favourable to MVT deposits, including areas with more extensive Caledonian deformation, whose uncertain influence was thought to merit some further study.

Two two-man teams were deployed to the field during four weeks, working out of a total of six field camps, whose location is included in Figure 1. The two teams shared the first two field camps and later split into different field camps. Additionally, some helicopter reconnaissance and stream sediment sampling was carried out, during some of the camp shifts.

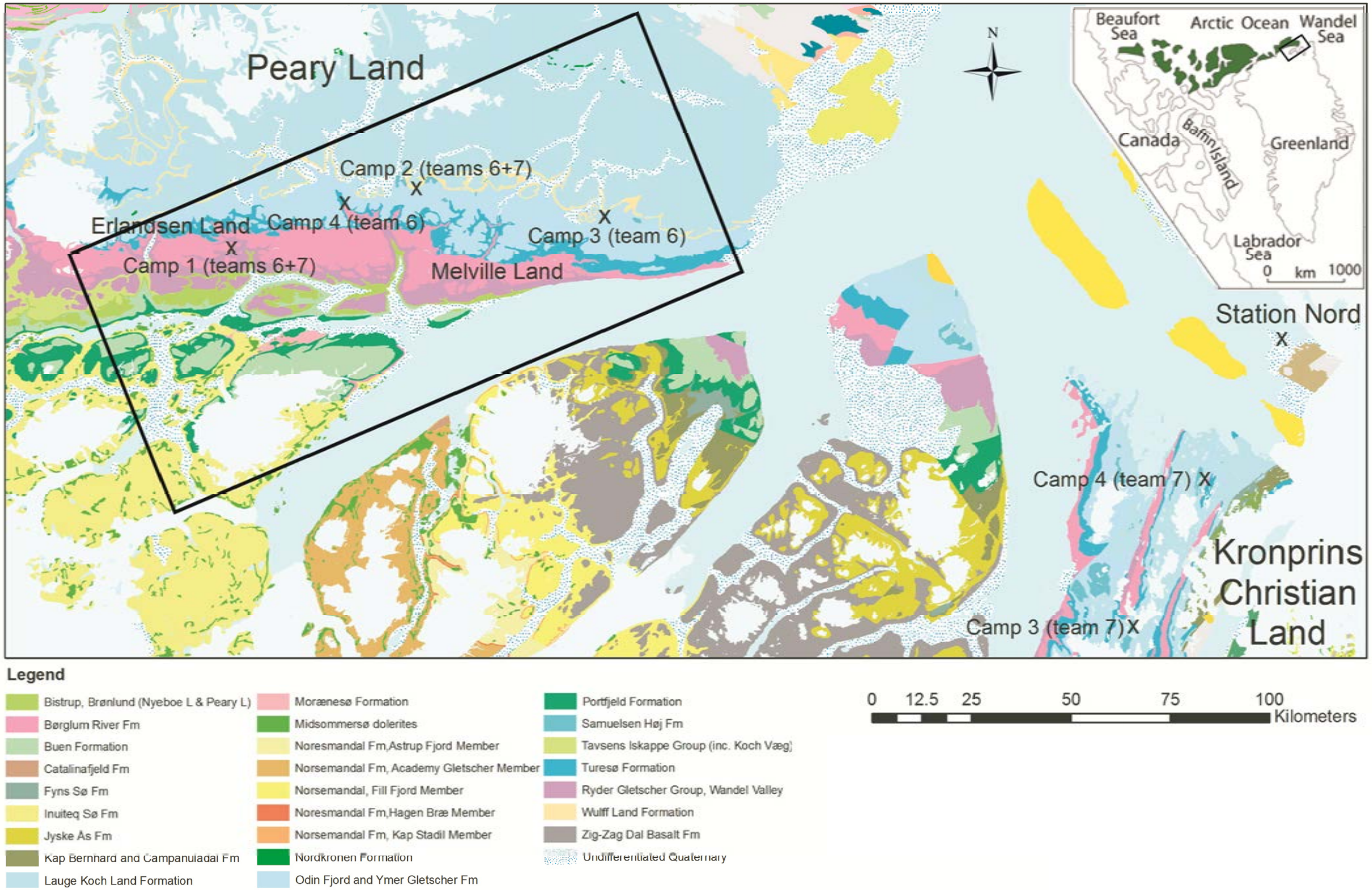

Figure 1. *Geological map (Bengaard and Henriksen 1984), with location of field camps and base camp (Station Nord). Polygon indicates areas of remote sensing coverage of figures 2, 3 and 4. Inset showing extent of the Franklinian Basin, in northern Greenland and Canada (green), and location of study area.*

Reconnaissance of MVT targets

Target development and rationale

Targets were generated considering exploration criteria derived from the MVT deposit model proposed by Leach et al (2010), and based on the in-house processing of ASTER satellite images and on the evaluation of existing stream sediment data (Thrane et al, 2011). This was complemented by results of previous mineral evaluation programs, carried out in Kronprins Christian Land, namely Tukianen & Lind (2011) and Della Valle (1995).

Processing of multispectral satellite imagery from the southern Peary Land carbonate platform (area indicated in Figure 1) was done at GEUS, in order to highlight dolomitisation, rust zones and the presence of hydrocarbons (Figures 2, 3 and 4, respectively). Satellite data of reasonable or good quality from the ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) imaging instrument, onboard NASA's Earth Observing System, was used. The satellite data coverage consists of 13 nominal ASTER scenes of reconstructed unprocessed instrument data, acquired within the summer periods from 2003 to 2005. Details on the satellite raw data, preprocessing and image analysis can be found in Appendix 1.

Areas with anomalous Zn concentrations (Figure 5), coupled with low Cu concentrations, in stream sediments, were considered of interest since these could likely reflect the presence of MVT mineralisation, rather than the presence of shale horizons with higher metal background values than normally present in carbonate rocks. Considering the alkaline environment prevailing in carbonate rocks, which limits metal mobility, values significantly lower than found within shale areas should still be considered significant anomalies. Of particular interest were areas where anomalous stream sediment values could hypothetically be sourced to major fault zones.

The location of the field camps (Figure 1) was determined by the proximity to significant remote sensing targets, stratigraphic horizons and structures deemed favourable and/or stream sediment anomalies, and in a way to cover as much as possible of the Ordovician to Lower Silurian stratigraphy. As is evident in Figure 5, despite a good sampling density, no significant stream sediment anomalies were identified below the Wandel Valley Unconformity, within the Cambrian sequence (Figure 6).

Results

Dolomitisation

The processing of ASTER images revealed that dolomite distribution appears to be stratigraphically-controlled (Figures 1 and 2) and is therefore possibly primary to diagenetic in origin, rather than discordant, and linked to mineralising processes. In any case, dolomitisation may have created porosity and enhanced permeability to mineralising fluids. Dolomite

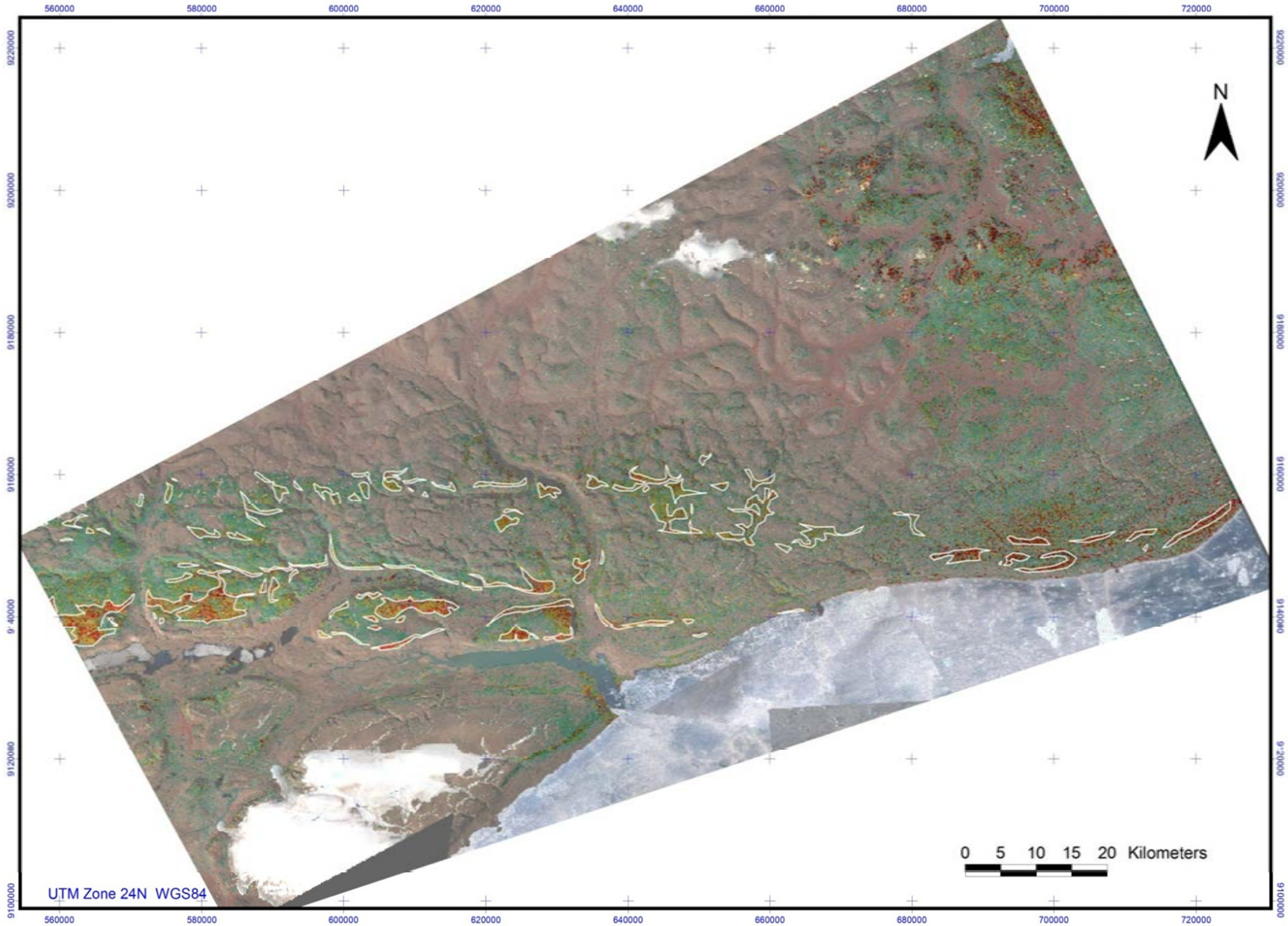

Figure 2. *False colour composite of the ASTER VNIR data, highlighting dolomitised areas.*

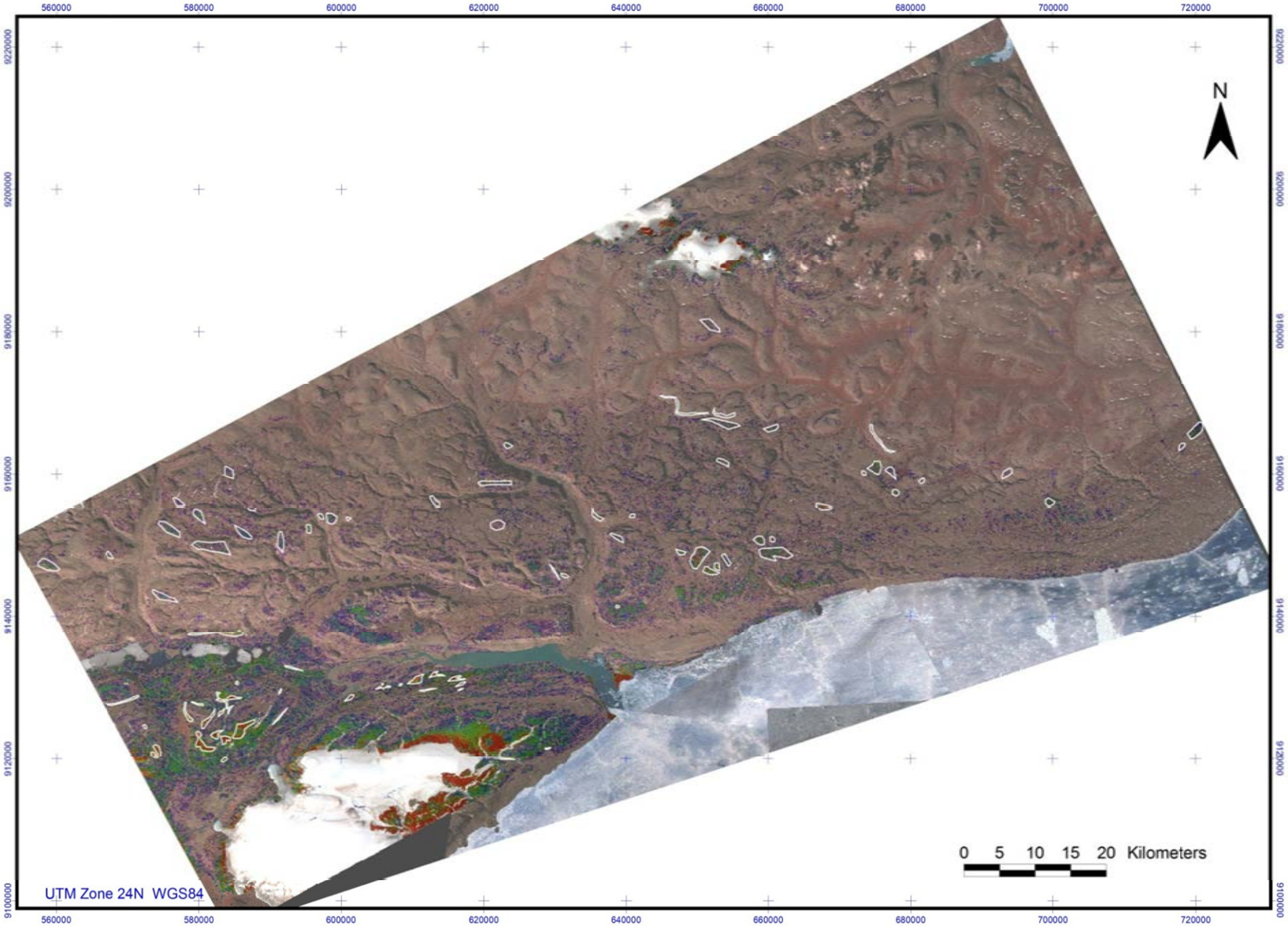

Figure 3. *False colour composite of the ASTER VNIR data, highlighting rust zones (iron sulphate + ferric oxides).*

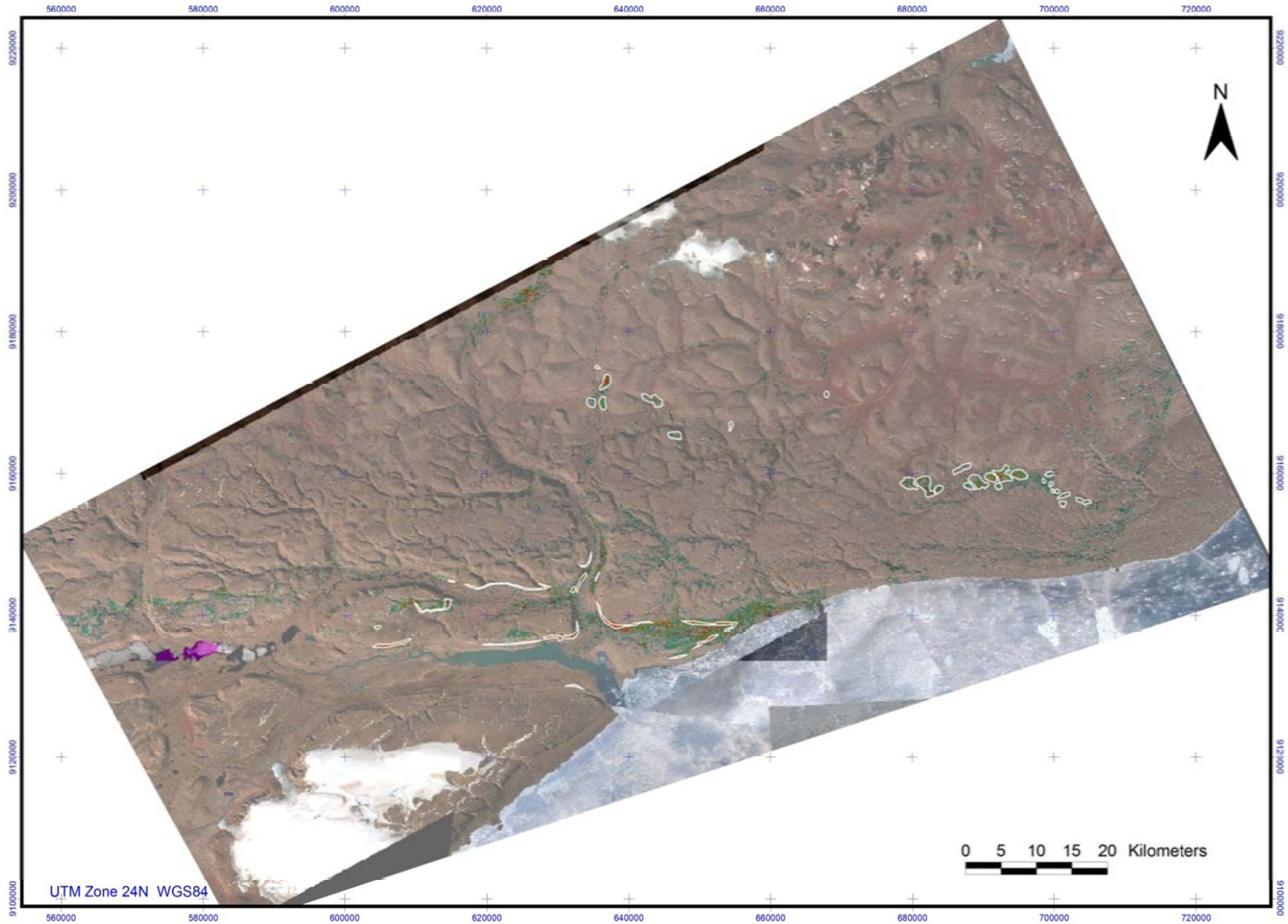

Figure 4. *False colour composite of the ASTER VNIR data, highlighting hydrocarbon-rich rocks.*

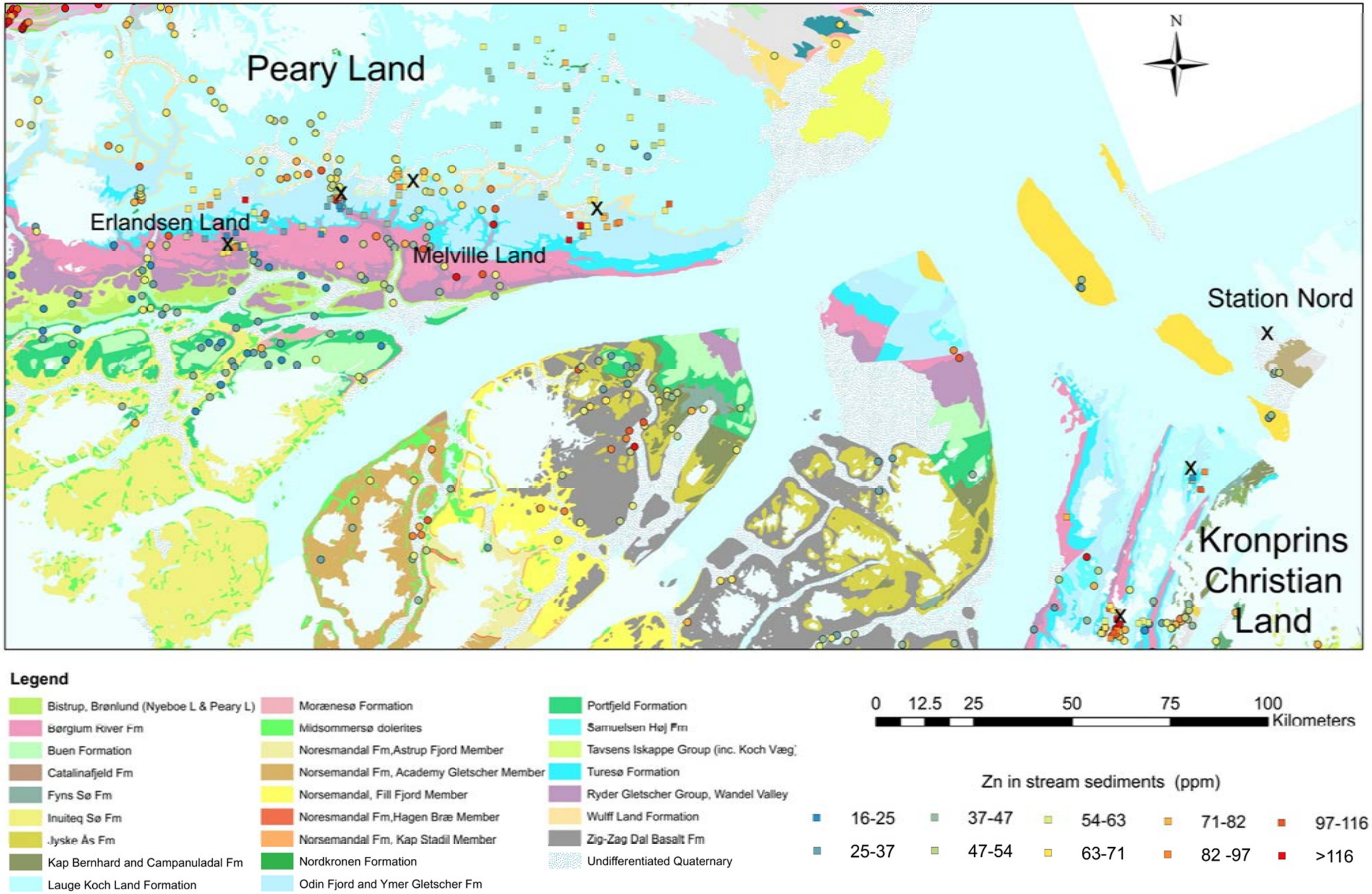

Figure 5. *Zn values (ppm) in stream sediments. Circles correspond to samples collected prior to the summer of 2012, squares are samples collected during the present study.*

is particularly abundant in the Turesø Formation, which corroborates the published descriptions of this unit (Higgins et al, 1991). Therefore, the Turesø Formation was considered of interest and it was studied in more detail were stream sediment anomalies could be related to it, with results reported in the Stream Sediment Anomalies Follow-up subsection below.

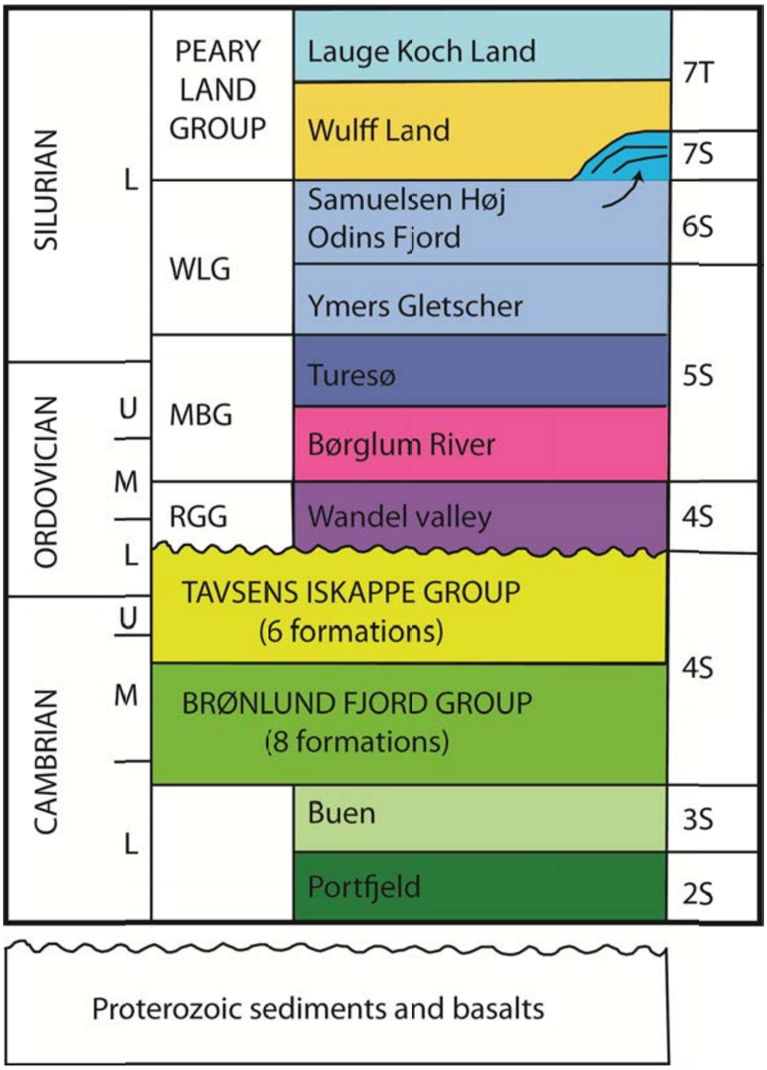

Figure 6. *Schematic stratigraphic division of the Franklinian Basin (modified after Higgins et al, 1991).*

Rust zones

Rust zones denoting elevated ferric iron contents were considered to be possibly related to the weathering of iron sulphides and therefore of interest as a target. Remote sensing revealed the presence of rust zones in multiple locations of the carbonate platform of Peary Land (Figure 3).

The intensity and extent of these rust zones are particularly large in Erlandsen Land, within the Børglum River Formation and Wandel Valley Formation limestones. Camp 1 was therefore set up in this area (Figure 1). These rust zones could clearly be identified in the field (Figure 7) and appear confined to some stratigraphic horizons. However, it was verified that these rust zones appear mostly to be related to karstification surfaces and weathering of terra rossa from out of caverns (Figure 8). Testing with zinc zap (Hitzman et al, 2003) on the observed veins and breccias revealed no positives. Nevertheless, stream sediments were collected around these zones to constrain any signs of mineralisation that may have been overlooked.

Figure 7. *Aspect of the rust zones in the field, near Camp 1, Erlandsen Land. Looking West.*

Despite documenting that the rust zones identified through remote sensing are not related to a mineralisation, the circulation of hydrothermal fluids within the Wandel Valley Formation was recognised. Just east of Camp 1, a calcite pocket with some pyrite and fluorite was identified within this formation.

Smaller rust zones, that are surrounded by rocks with traces of hydrocarbons, within the Samuelsen Høj Formation carbonate mounds, are present in Eastern Melville Land, as identified by remote sensing. Camp 3 (team 6) was established to look into this aspect (Figure 1). Work in the field was hindered by limited outcrops and remote sensing results could not be verified. Positive zinc zap results were obtained over a stretch of approximately 100 m but could not be sourced; one float sample (539118) only yielded an anomalous zinc value of 140 ppm (Table 1).

Figure 8. *Weathering of karstified limestone, releasing iron-rich clay residue (terra rossa). Near Camp 1, Erlandsen Land.*

Although no remote sensing processing was done for Kronprins Christian Land, parts of the Samuelsen Høj Formation carbonate mounds were found to be rusty. Near Camp 3 of team 7 (Figure 1), it was verified that this corresponds to rusty algal mat beds (Figure 9) that, in spite of the folding and thrusting, could be documented to be towards the stratigraphic top of the Samuelsen Høj Formation (Figure 10). In detail, this facies of the Samuelsen Høj Formation displays alternating dark grey, presumably detrital sand and clay bands, and rusty brown, presumably organic-rich bands. The geochemistry of samples of this rusty facies is in contrast with the underlying grey-white crinoid and stromatoporoid bioclastic limestone facies (Table 2). While the gray-white facies is essentially a pure limestone, the rusty facies is both enriched in lithophile elements such as SiO2, Al2O3, V, Cr, Y, Zr, Nb, La, Hf, Ta, Th and U, which can be accounted by quartz sand, clays and heavy minerals that were trapped in the dark grey bands, and enriched in chalcophile elements such as Cu and Zn, which may have been transported in an hydrothermal fluid that was trapped in this reservoir, possibly through the reaction with reducing organic matter, or even sour gas. Further chalcophile element enrichment can be achieved through weathering of the algal mats, which are a likely source for the limonite crust collected in this location and analysed (Table 2). Despite the fact that the resulting elevated Zn concentrations are far of being of economic significance, at least in this area, they provide an elevated background, which can possibly result in anomalous concentrations in stream sediment samples.

Table 1. *Summary of Zn, Ag, Pb analyses of anomalous and mineralised samples, determined through assay or fusion ICP-MS, at Actlabs (Ontario, Canada).*

Sample	Longitude W	Latitude N	Area	Host rock Fm	Zn (%) Assay	Zn (ppm) FUS-MS	Ag (ppm) FUS-MS	Pb (ppm) FUS-MS	Sample weight (g)
539026	30° 44.7143´	82° 27.0948´	Peary Land - Camp 4	Turesø	4.84		< 0.5	< 5	811
539034	20° 13.2706´	81° 08.3821´	Kronprins Christian Land	Turesø	3.11		< 0.5	16	275
539036	20° 14.6558´	81° 08.2573´	Kronprins Christian Land	Turesø		760	3.2	< 5	244
539037	20° 20.6298´	81° 07.4580´	Kronprins Christian Land	Turesø		380	2.7	< 5	255
539040	20° 13.7797´	81° 07.9143´	Kronprins Christian Land	Turesø		3370	< 0.5	< 5	185
539041	20° 12.2907´	81° 08.6600´	Kronprins Christian Land	Turesø		250	2.2	< 5	261
539109	29° 43.3793'	82° 29.3498'	Peary Land - Camp 2	Samuelsen Høj (float)	3.58		< 0.5	263	266
539118	26° 25.4437'	82° 19.0202'	Peary Land - Camp 3	Samuelsen Høj (float)		140	< 0.5	< 5	212
539126	26° 46.9668'	82° 16.4145'	Peary Land - Camp 3	Turesø		130	1.3	< 5	228
539132	26° 58.0239'	82° 16.6965'	Peary Land - Camp 3	Turesø	1.30		< 0.5	< 5	166
539172	30° 47.3410'	82°28.5330'	Peary Land - Camp 4	Turesø		4580	< 0.5	< 5	285
539173	30° 47.1870'	82° 28.5660'	Peary Land - Camp 4	Turesø	5.81		0.6	< 5	175
539175	30° 45.0830'	82° 27.2720'	Peary Land - Camp 4	Turesø	1.81		< 0.5	< 5	197
539176	30° 44.7143'	82° 27.0948'	Peary Land - Camp 4	Turesø		7080	< 0.5	< 5	139
539180	30° 46.6752'	82° 28.2594'	Peary Land - Camp 4	Turesø	3.89		< 0.5	6	185
539181	31° 46.6752'	83° 28.2594'	Peary Land - Camp 4	Turesø		4690	< 0.5	< 5	99

Table 2. *Summary of Samuelsen Høj formation analysed samples, collected in Kronprins Christian Land (Camp 3), to contrast grey-white limestone facies with overlying rusty algal mat facies, and limonite crusts resulting from the weathering of the latter. Major element oxides in % and trace elements in ppm, determined through Fusion ICP-MS, at Actlabs (Ontario, Canada).*

Sample	Longitude W	Latitude N	SiO_2	Al_2O_3	Fe_2O_3t	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	LOI	Total
Samuelsen Høj Fm, gray-white facies:														
539031	20° 19.6574´	81° 05.7561	0.72	0.16	0.13	0.036	0.34	53.4	0.02	0.04	0.01	< 0.01	43.14	98.03
539044	20° 10.0983´	81° 06.1084	0.55	0.11	0.09	0.019	0.46	53.9	0.02	0.04	0.01	0.01	43.35	98.57
Samuelsen Høj Fm, rusty algal mats facies:														
539030	20° 20.2834´	81° 05.7661	34.16	5.12	4.06	0.574	1.92	27.2	0.21	1.37	0.27	0.08	24.06	99.05
539043	20° 09.7281´	81° 06.0905	34.91	5.27	2.74	0.681	2.27	26.4	0.22	1.81	0.3	0.09	23.65	98.36
Limonite crust, weathering of rusty algal mat Samuelsen Høj Fm:														
539029	20° 10.9512´	81° 06.562´	30.60	4.8	48.42	0.744	0.57	0.6	0.03	0.91	0.3	0.24	12.28	99.48

Sample	V	Cr	Co	Ni	Cu	Zn	Pb	Y	Zr	Nb	La	Hf	Ta	Th	U
539031	6	< 20	< 1	< 20	< 10	< 30	< 5	1.0	3	< 0.2	1.08	< 0.1	0.01	0.09	0.09
539044	6	< 20	< 1	< 20	< 10	< 30	< 5	5.6	2	< 0.2	3.61	< 0.1	0.01	0.05	0.12
539030	35	30	29	70	30	100	< 5	17.2	63	4.6	20.6	1.5	0.29	4.80	0.87
539043	35	40	44	70	10	40	6	18.3	70	4.6	21.1	1.6	0.29	5.04	1.00
539029	114	70	123	250	20	330	12	50.4	115	6.3	33.6	2.8	0.41	4.07	8.66

Figure 9. *Outcrop aspect of the rusty algal mat facies of the Samuelsen Høj Formation. Looking North, near Camp 3, Kronprins Christian Land.*

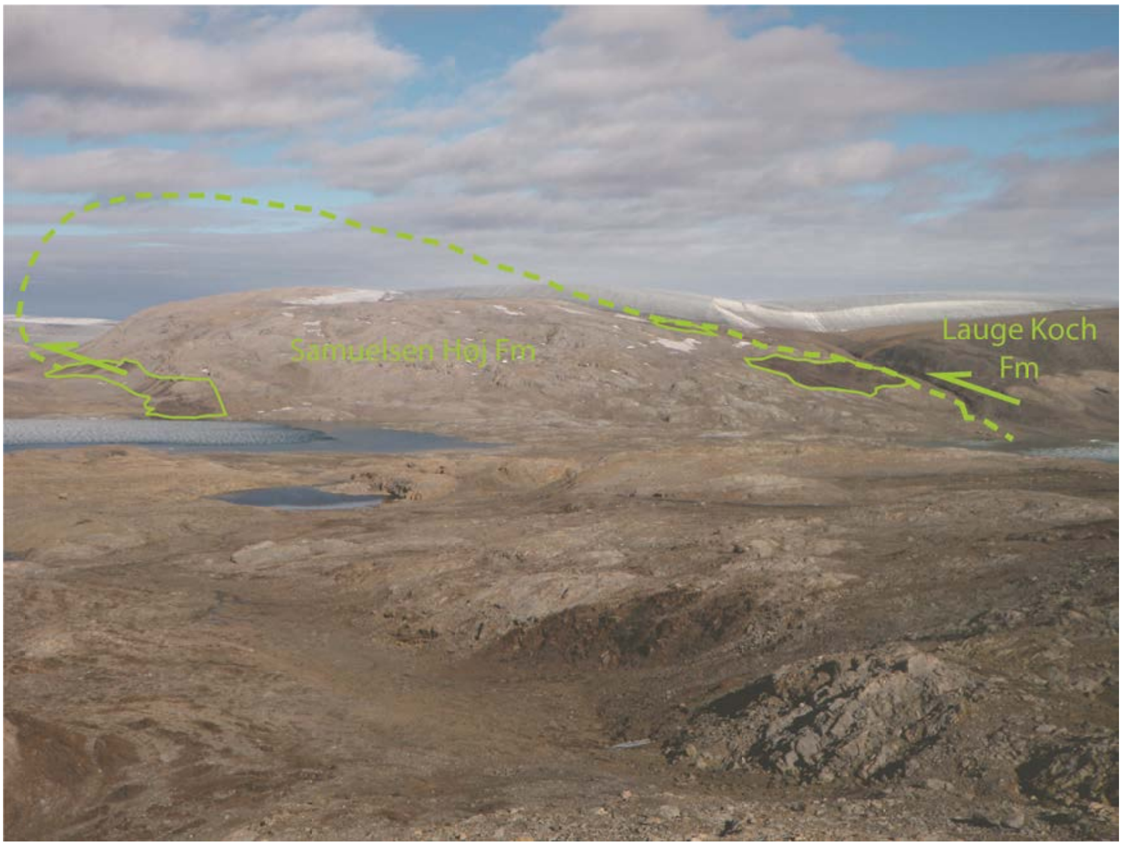

Figure 10. *Rusty algal mat facies of Samuelsen Høj Formation in the foreground and, in the background, on the long limb (right) and short limb (left, partially covered by scree) of folded mud mound, with gray-white facies of the Samuelsen Høj Formation in its core. Looking NE, near Camp 3, Kronprins Christian Land. Field of view is approximately 2 km across.*

Hydrocarbon-bearing rocks

Traces of hydrocarbons were identified, through remote sensing. The presence of hydrocarbons was interpreted as reflecting the existence of traps which could also have collected mineralising fluids, with the reducing nature of the hydrocarbons possibly also favouring redox reactions with mineralising fluids and therefore possibly contributing towards metal precipitation. Remote sensing revealed that, in some locations, rust zones were spatially associated with hydrocarbon presence, which was considered to be of particular interest as targets.

Traces of hydrocarbons were found below the Wandel Valley Unconformity (Figures 1 and 4), within the Buen Formation and the Tavsens Iskappe Formation, depending on which formation is cut by the unconformity. It is evident that hydrocarbons could have been sourced from the Buen Formation mudstones and stayed in these rocks, or migrated up towards the Buen Formation sandstones or the Tavsens Iskappe Formation limestones, depending on the relative position of the unconformity trapping them. Since the rather extensive stream sediment coverage in areas draining these formations failed to yield anomalous values, it was considered that these hydrocarbon reservoirs were unlikely to have trapped zinc mineralising fluids and no field work was carried out in these areas.

Instead, field work focused on the Samuelsen Høj Formation, which remote sensing documented as also having traces of hydrocarbons, but for which only limited stream sediment sampling was previously carried out in the eastern part of the Franklinian Basin, leaving open the possibility that zinc mineralisation may be related with the carbonate mounds of this formation. In fact, stream sediment sampling across the western part of the Franklinian Basin in Greenland reveals that several anomalies can be related to this formation. Furthermore, several showings in the western part of the Franklinian Basin of Greenland are hosted by an equivalent reef complex, namely the Kap Schuchert (Norford, 1972) and Kayser Bjerg (von Guttenberg & van der Stijl 1993) occurrences.

Field work was carried out around several Samuelsen Høj carbonate mounds, to cover them with stream sediment sampling and verify possible signs of zinc mineralisation. Camps 2, 3 (team 6), 3 (team 7) and 4 (team 7) were all located in the vicinity of carbonate mounds (Figure 1). Studied mounds include the localities in Western Melville Land described in Mabillard (1980) and localities further east, and two mounds in Kronprins Christian Land. These mounds consist of grey-white crinoid and stromatoporoid bioclastic limestone and its fossils and fractures are locally soaked in hydrocarbon residues (Figure 11), which are in turn cut by sets of white calcite veins and veinlets. Near Camp 2 of team 6 (Figure 1), a float sample (539109) containing fluorite and weathered sphalerite, was recovered. This sample is likely sourced from Samuelsen Høj Formation outcrops and was shown to have 3.58 % Zn (Table 1). However, the breccias or veins observed in Kronprins Christian Land failed to yield positive results to zinc zap testing, further extending the negative results documented by Tukiainen & Lind (2011).

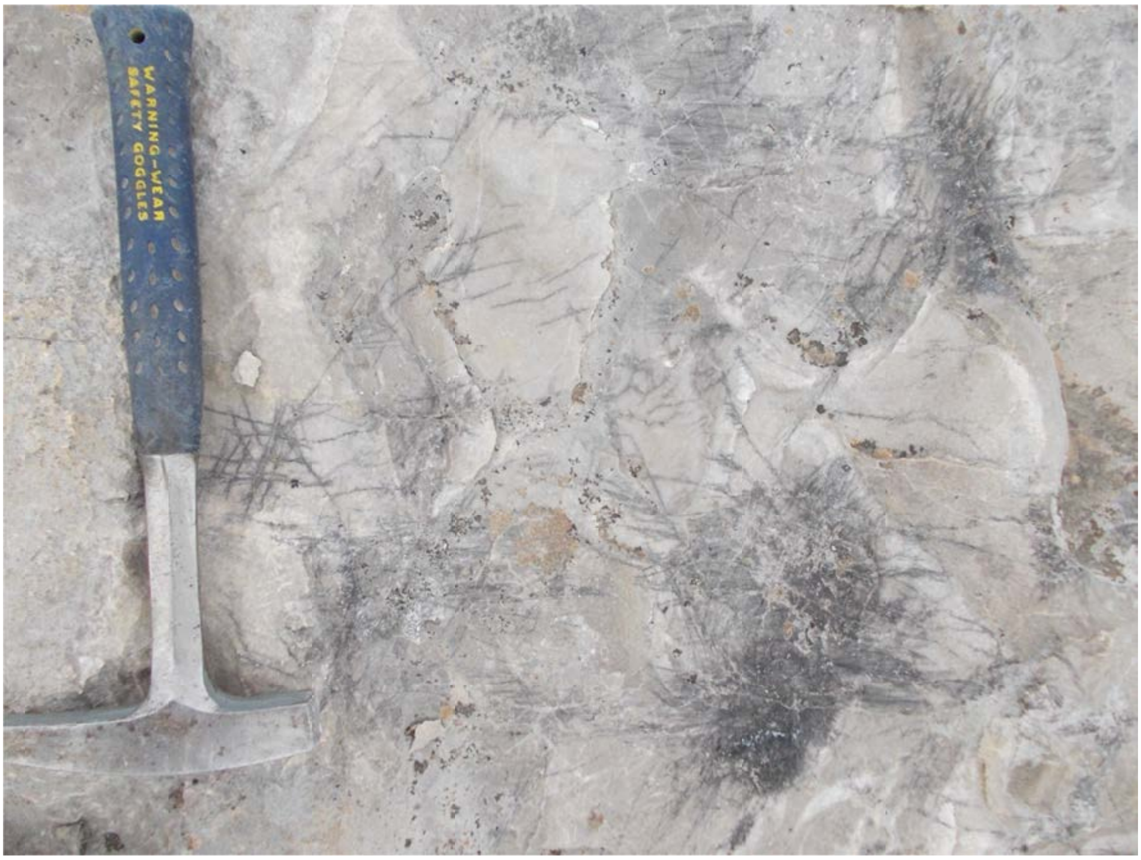

Figure 11. *Aspect of gray-white facies of the Samuelsen Høj Formation, with hydrocarbon filling fractures, near Camp 3, Kronprins Christian Land.*

Stream sediment anomalies follow-up

Two anomaly clusters were considered outstanding for them to be merit a detailed follow-up study, including denser stream sediment sampling and comprehensive field work. One set of anomalies that was studied is related to small streams draining directly into the Børglum River, in Western Melville Land, where Camp 4 (team 6) was set up (Figure 1). Another set of studied anomalies is located in Kronprins Christian Land, where Camp 3 (team 7) was established (Figure 1). In both cases, anomalies were sourced to sphalerite showings.

In Western Melville Land, several small pockets and veinlets of white sparry calcite and fine- to medium-grained lime-green sphalerite, as well as a few small purple to white fluorite pockets, were recognised within the upper, brown-weathering part of the Turesø Formation dolostone. This intermittent evidence extends along a length of 2.5 km, parallel to the right bank of the Børglum Elv. The left bank of the Børglum Elv was not visited but it is likely that it also shows evidence for mineralisation, as the Turesø Formation, which appears to control the mineralisation, straddles across the river. Figure 12 documents the general setting of the area, located along a stretch where the Børglum Elv runs WNW-ESE, while both upstream and downstream it follows a NNW-SSE direction. This bending of the river path

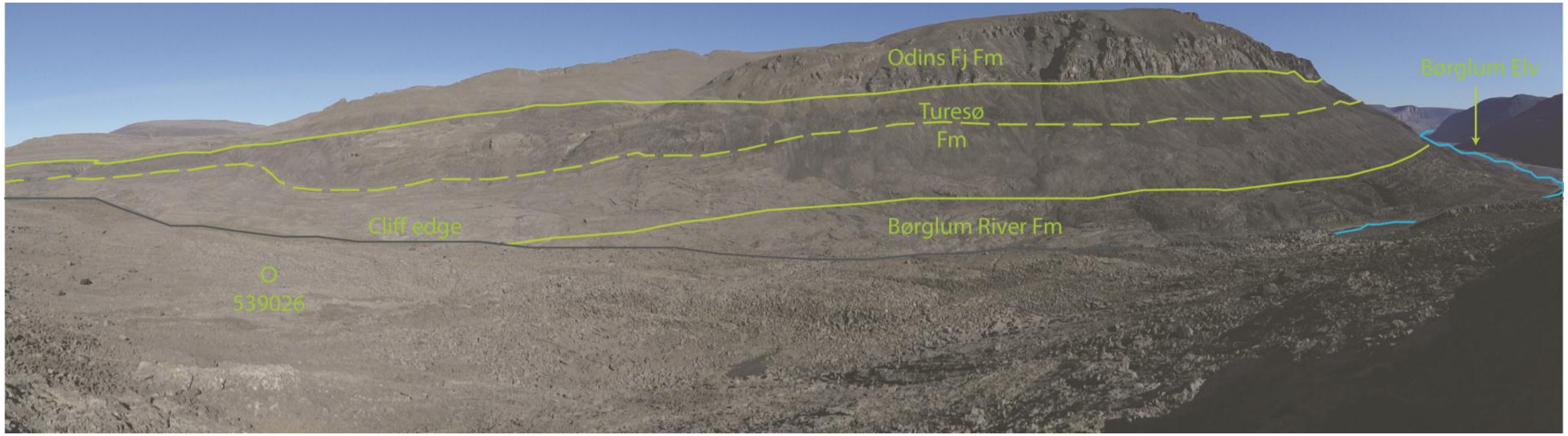

Figure 12. *Panorama photograph of the Børglum Elv valley, looking East-Northeast. The pronounced bend in the river, from an ESE-WNW towards SSE-NNW direction, is visible towards the right. The platform, where part of the mineralised showing (sample 539026) was identified, is seen in the foreground, before the edge of the cliff. The left bank of the Børglum river is seen in the background, exposing from bottom to top, the Børglum River Formation, the Turesø Formation (subdivided into pale yellow- and dark brown-weathering beds) and the Odins Fjord Formation (prominent cliffs). Cliff is approximately 600 m.*

probably reflects the structural framework. Figures 13 and 14 illustrate the textures of the mineralisation, evidently related to fracturing and brecciation events, and postdated by the white calcite. Due to the effects of weathering the more exposed sphalerite tends to acquire a caramel colour or even wash away. This, coupled with the absence of pyrite, which would easily turn into noticeable rust, makes this mineralisation rather inconspicuous.

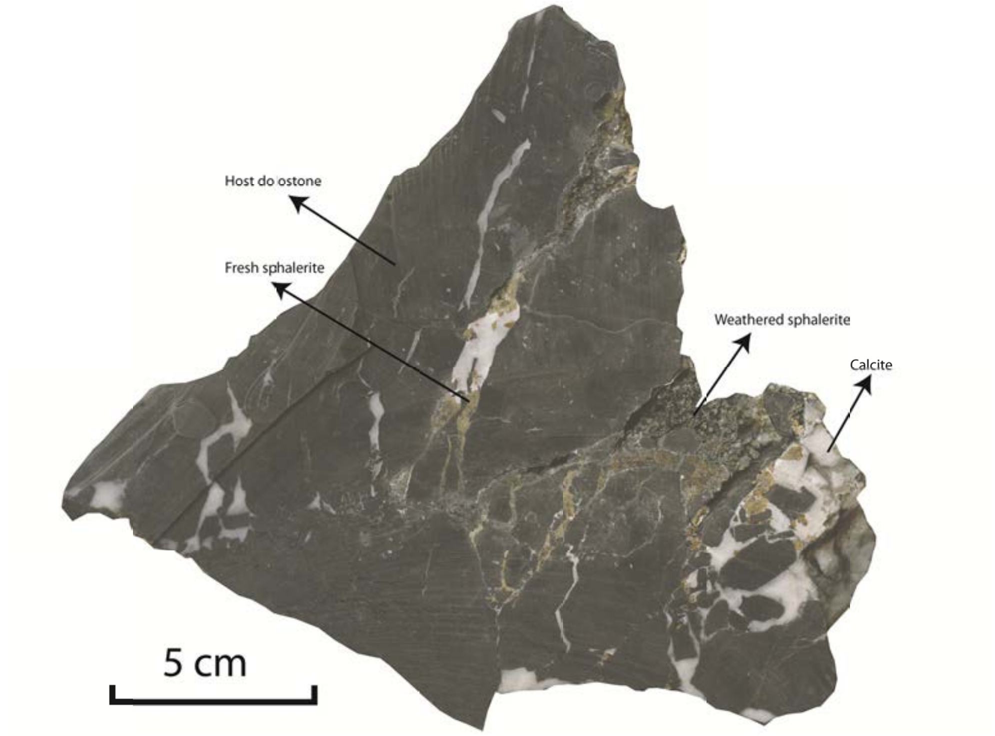

Figure 13. *Slab of sample 539026, collected near Camp 4 (Børglum Elv, Western Melville Land).*

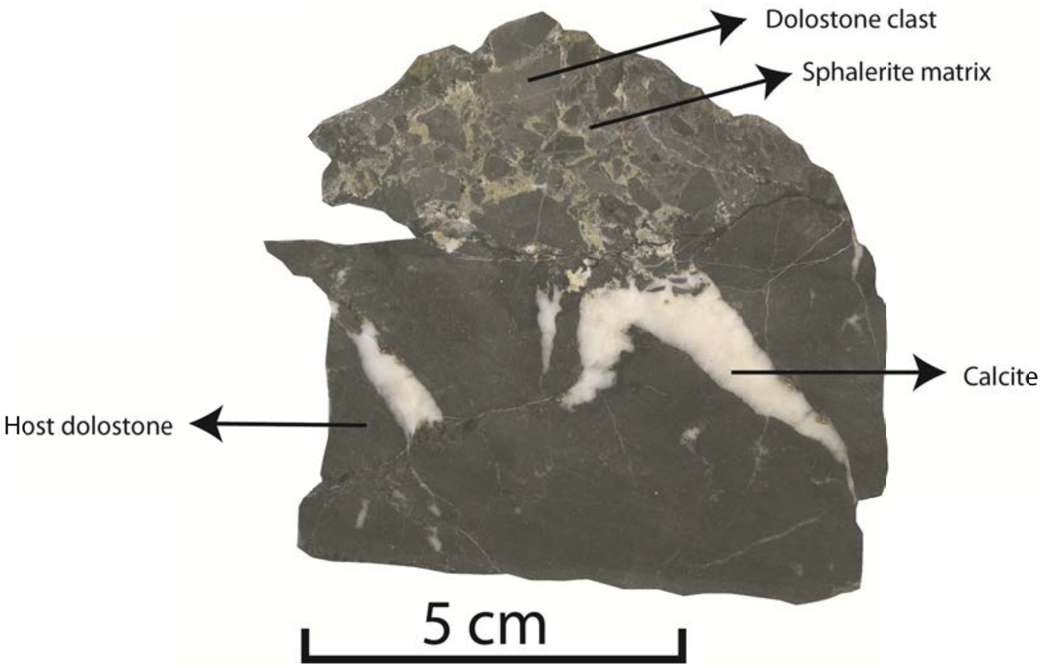

Figure 14. *Slab of sample 539180, collected near Camp 4 (Børglum Elv, Western Melville Land).*

In Kronprins Christian Land, the identified stream sediment anomalies can be related to framboidal pyrite with scarce sphalerite, present in Lauge Koch Formation shales, as documented by Tukiainen & Lind (2011), or to the rusty algal mat facies of the Samuelsen Høj Formation, described above as having elevated Zn backgrounds. However, due to the proximity to the Turesø Formation dolostones, which host the showing in Melville Land, the outcrops of the upper part this formation, were also studied in detail. This revealed the existence of one horizon, which can be followed for approximately 3 km, with part of it repeated due to thrusting (Figures 15 and 16), which intermittently contains veinlets and small pockets (<3 cm), often related to coral fragments, filled by white sparry calcite with coarse-grained lime-green sphalerite, locally salmon dolomite, and traces of galena, sulphosalts and purple fluorite. Similarly to what was described for the Western Melville Land showing, the way this mineral assemblage weathers contributes for its inconspicuous character. Figure 17 shows the outcrop aspect of these pockets and Figure 18 illustrates the textures of the mineralisation.

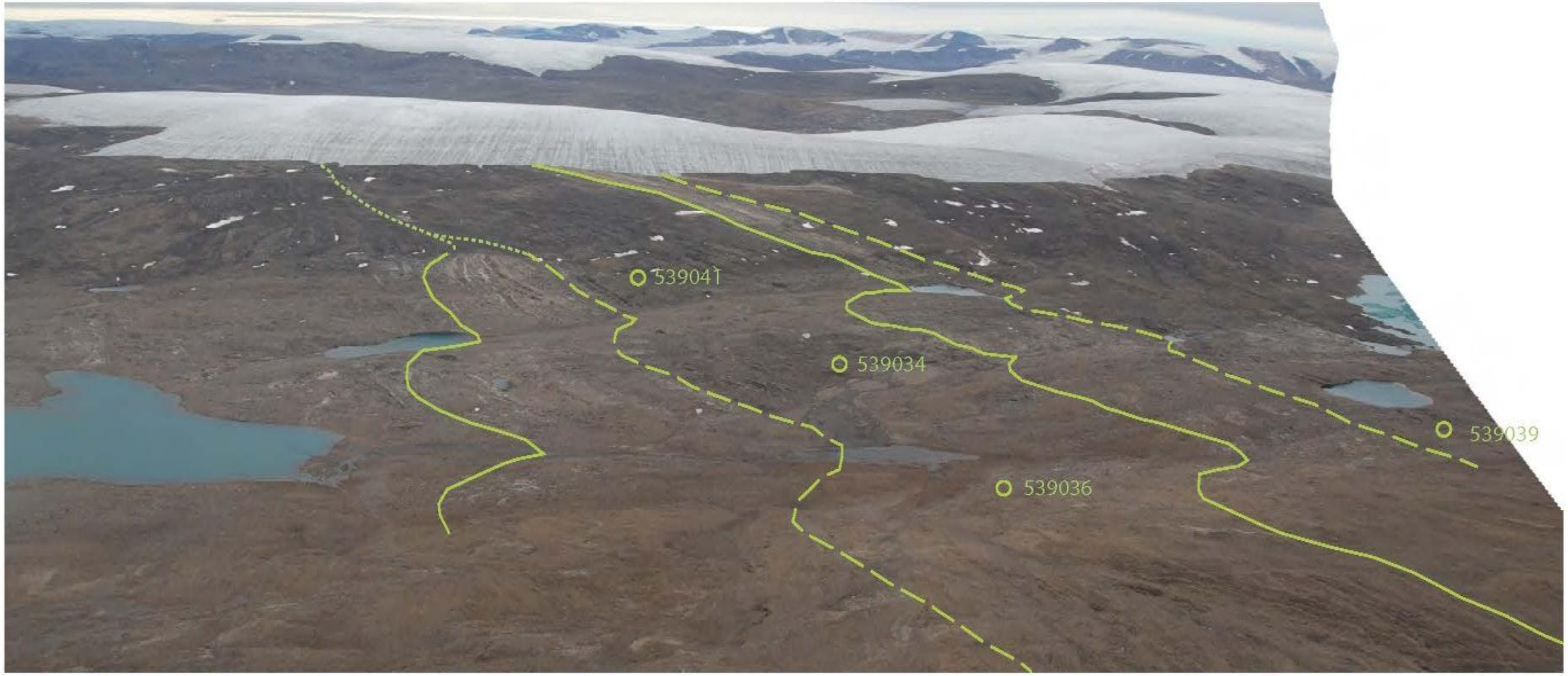

Figure 15. *Composite aerial photograph over the Kronprins Christian Land showing, near Camp 3. Looking NW. Continuous line highlights location of thrust plane, which doubles the sequence. Broken line indicates approximate contact between lower pale yellow- and upper brown-weathering Turesø Formation. Mineralised sample locations indicated by circles. Field of view is approximately 2.5 km across.*

Figure 16. *View of the brown dolostone horizon with intermittently-dispersed pockets and veinlets of white calcite with sphalerite, extending to the NE up to the glacier. Note that this horizon lies immediately above the pale-yellow dolostone horizon. Near Camp 3, Kronprins Christian Land.*

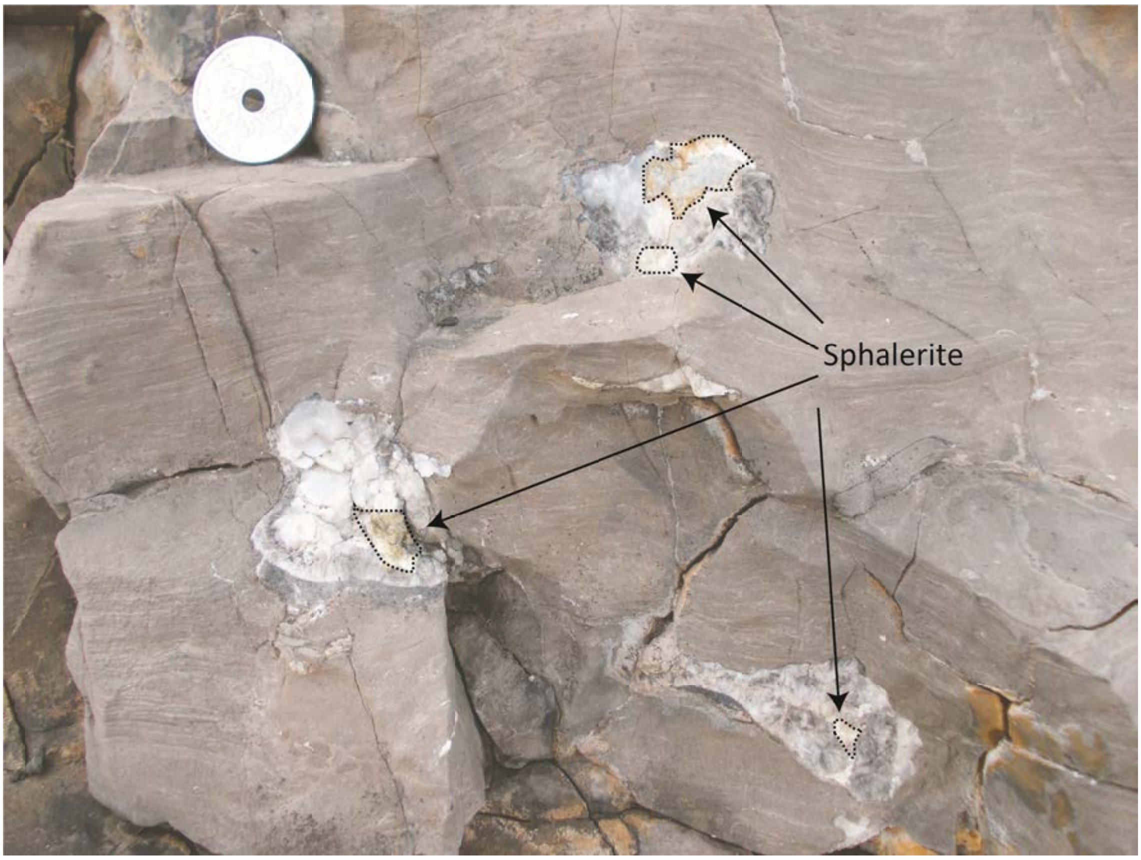

Figure 17. *Detailed view of the pockets of white calcite with sphalerite, in laminated dolostone. 5 DKK coin for scale. Sample 539039 locality, near Camp 3, Kronprins Christian Land.*

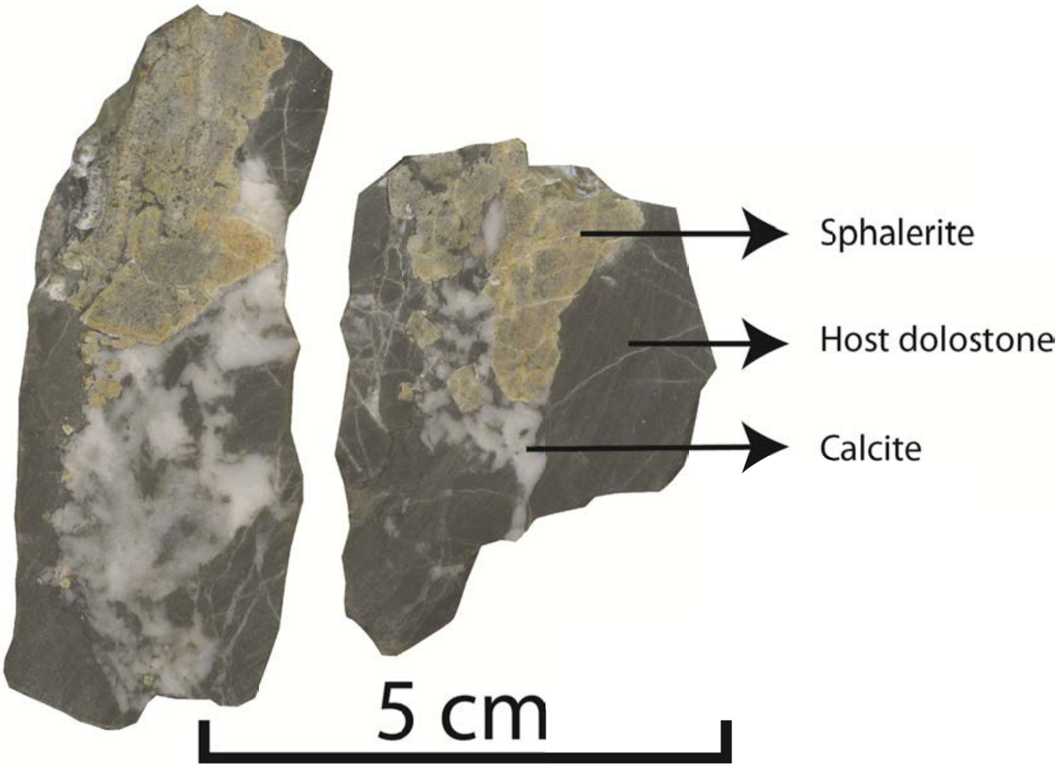

Figure 18. *Slabs of mineralised sample 539034. Collected near Camp 3, Kronprins Christian Land.*

Analyses of mineralised samples collected at these showings are included in Table 1. Sixteen samples were analysed with an analytical package combining lithium metaborate/tetraborate fusion ICP and a trace element ICP/MS, providing quantitative values for lithophile elements, at Activation Laboratories Ltd (Canada). In addition to confirming significant Zn contents, of up to 5.81 %, these analyses reveal very low Ag and Pb contents, confirming the sphalerite-dominated assemblages described.

In addition to these two showings, one sample that was collected in Eastern Melville Land, near Camp 3 of team 6 (Figure 1), revealed to be mineralised upon being analysed (sample 539132, Table 1). Another additional sample proved to be anomalous in zinc (sample 539126). While their more detailed context was not documented, these samples also belong to the Turesø Formation and therefore may be part of a potential third showing.

Stream sediment sampling program

Approach

A total of 133 stream sediment samples (including field duplicates) were collected and analysed for a suite of 62 elements, using a combination of INAA, Total Digestion (four acids) - ICP, Lithium Metaborate/Tetraborate Fusion - ICP and ICP/MS methods, at Activation Laboratories Ltd (Canada). Some of the undertaken sampling has a regional character, aimed at filling in areas that were not sampled in previous campaigns, namely, to the East of the 28^0W meridian in Peary Land. Included in this area are basins draining the Central Peary Land Fault, striking ENE-WSW, which could be a pathway for mineralising fluids. Other sampling has a reconnaissance character, with stream sediments sampled in order to further constrain a previously identified anomaly or to evaluate the possible extent and context of the recognised mineralised showings identified during this expedition.

Results

The acquired results have been added to the GEUS database. Figure 5 displays the values for zinc concentrations in stream sediments from the study area (pre-existing data set as circles, new data set as squares, both with the same colour coding). The newly acquired data set complements the pre-existing data set and, put together, these allow a more in-depth view on possible sources for anomalous zinc concentrations in stream sediments. It is immediately apparent that, as would be expected, zinc values are generally lower in the Silurian turbidites of the Lauge Koch Land Formation than in the underlying carbonate platform, even in locations close to where this formation is cut by the Central Peary Land fault. A few slightly anomalous zinc values within the Lauge Koch Formation are very near its contact with the carbonate platform, so it is possible that the latter may be locally subcropping or outcropping and has not been mapped as such. Alternatively, the drainage may locally have transported anomalies from the platform into the Lauge Koch Formation

Within the carbonate platform, in addition to the two showings identified during fieldwork, significantly anomalous zinc values in stream sediments appear in other areas draining the Turesø Formation suggesting that other showings may be present (Figure 5). This appears to be the case mostly in Melville Land, rather than in Erlandsen Land, while in Kronprins Christian Land this is less clear, due to the incomplete coverage of its stream sediment sampling. In other instances, zinc concentrations are only slightly anomalous or not anomalous at all downstream from the Turesø Formation. This is possibly because of the limited mobility of metals in the prevailing alkaline environment and/or because this formation is not mineralised throughout, as the intermittent nature of mineralisation in the identified showings suggests.

Furthermore, significantly to slightly anomalous zinc values are also present within or immediately downstream from Samuelsen Høj Formation carbonate mounds, namely in Eastern Melville Land (Figure 5). This fact, coupled with the mineralised or anomalous floats that were identified in the same area during fieldwork, suggests that this formation has the potential to host MVT mineralisation. Near Camp 3 (Kronprins Christian land), several anomalous stream sediment samples appear related to the Samuelsen Høj Formation carbonate mounds. However, no evidence of sulphide mineralisation was identified within this formation and it therefore appears that zinc may derive from the rusty facies of the Samuelsen Høj Formation, which may contribute with elevated zinc backgrounds over relatively extended areas, rather than economic concentrations as in a mineralised showing (see Table 2).

Finally, some anomalous stream sediment samples, from Erlandsen Land, were collected in basins draining parts of the ENE-WSW striking Central Peary Land Fault, where this fault constitutes the contact between the carbonate platform and the Lauge Koch Land Formation. So, while towards the East, where this fault cuts exclusively across Lauge Koch Land Formation turbidites, it appears to be barren, towards the West this fault may actually have channelled mineralising fluids into the carbonate platform.

Working model

At the two showings, the horizon with intermittently dispersed mineralisation, confined to a thickness of a few tens of meters, is present towards the top of the Turesø Formation. The upper part of this formation consists predominantly of brown-weathering burrowed to laminated dolostone, while in the lower part, pale yellow-weathering laminated dolostone, which at least in Kronprins Christian Land displays desiccation cracks, predominates. This suggests that the mineralisation occurs on the first beds that followed a pronounced shallowing event. On the basis of the brachiopod fauna, Fürsich & Hurst (1980) actually suggested that slightly elevated salinities may have occurred during deposition of the Turesø Formation.

It is therefore possible that the pale yellow colour of the lower beds, which record the shallowing, may be the result of bleaching, caused by consumption of organic matter as it reacted with evaporite sulphate to yield sulphide. Such reduced sulphur could have promoted the precipitation of zinc transported in hydrothermal solutions travelling along an overlying dolostone layer with favourable porosity and/or favourable structures to have acted as a conduit.

Hydrothermal solutions also appear to have travelled up the stratigraphy and ended up being collected in some of the Samuelsen Høj Formation carbonate mounds, underneath the impermeable Lauge Koch Land Formation. While this caused metal to precipitate, the context for this is poorly understood because it is, at this stage, based exclusively on the observation of float.

Conclusions

While stream sediment anomalies have shown to be effective as vectors towards the mineralised showings, the processing of ASTER images was proved to be of limited use in identifying showings of sphalerite that appear to be rather inconspicuous, and not necessarily related to hydrocarbon-rich and/or rust zones. Nevertheless, remote sensing using other signal parameters and better resolution images will likely allow for an improved analysis of possible mineralisation footprints.

The Turesø Formation was identified as a favourable stratigraphic horizon for zinc mineralisation. The fact that the two showings, identified within this horizon, are located at more than 200 km from each other demonstrates that a large-scale hydrothermal system, transporting zinc, operated in the eastern part of the Franklinian carbonate platform. This is considered favorable for the presence of economic MVT deposits, confirming the high prospectivity assessed by the expert panel at the workshop (Sørensen et al, 2013).

Additionally, the presence of mineralised float and significant stream sediment anomalies in the Samuelsen Høj Formation carbonate mounds suggests that some mineralised fluids may locally have reached this formation. Therefore it should be considered to hold some potential to host MVT deposits.

Recommendations

The significance of the identified showings and of the newly identified stream sediment anomalies warrants a return to the study area. This return should be aimed at more detailed studies of the identified showings, which should improve the understanding of the context to the mineralisation, as well as to verify its more exact extent. Particular care should be placed in documenting structural and stratigraphic aspects. This, coupled with a geochronology program that could constrain the timing for the mineralising fluids, could assist in evaluating the pathways for mineralising fluids and where and how they may have precipitated economic concentrations of metals. Furthermore, a follow-up on the stream sediment anomalies, namely those related to the Turesø or Samuelsen Høj formations and the Central Peary Land Fault, should be carried out as it can possibly disclose more showings.

Further fieldwork would greatly benefit from remote sensing techniques that would overcome the shortcomings revealed by the use of ASTER images. It is therefore recommended that an airborne hyperspectral survey using thermal bands is flown over the area. Additionally, a magnetic survey which would assist in identifying basement structures that could channel mineralising fluids, would also prove useful to direct work in the field.

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APPENDIX 1

The image data were georeferenced (UTM Zone 24, WGS84) and the VNIR (visible and near infra-red) and SWIR (short wave infra-red) datasets were co-registrered whereby the SWIR dataset was resampled to match the 15 m resolution of the VNIR dataset The co-registered VNIR_SWIR datasets were converted to the spectral reflectance by using the ENVI/FLAASH software.

The spectral masks for vegetation, snow/ice and water were calculated from the data to eliminate these from the image analysis. The selected mineral indexes were calculated for the unmasked data:

Jarosite/iron sulphate gossans
Mask of ratios 2/1, 3/2 within known ranges of jarosite; on VNIR MF (Matched filtering) result for jarosite 6.

Ferric oxides:
Mask of of ratios 2/1, 3/2 & 3/1 within known ranges for goethite and hematite

Dolomite:
Mask of ratios: 4/5 >1, 5/6>1, 7/6 <1, 7/5<1, 7/8<1, 9/8>1, 6/9>1 on SFF (Spectral Feature Fitting) result for dolomite 1.

Hydrocarbon –induced mineralogical alteration
2/1(R) 3(G) and 4/8 (B)

Satellite raw data
The ASTER nominal scenes used in this study:
Granule ID : ASTL1A 0307061823570307220208
Granule ID : ASTL1A 0307161722220307300714
Granule ID : ASTL1A 0307161722490307300717
Granule ID : ASTL1A 0506191722330506260513
Granule ID : ASTL1A 0506191900330506260528
Granule ID : ASTL1A 0506201805410506270361
Granule ID : ASTL1A 0506221931120506290130
Granule ID : ASTL1A 0506221931200506290133
Granule ID : ASTL1A 0507071710110507140127
Granule ID : ASTL1A 0507071710200507140128
Granule ID : ASTL1A 0507071710290507140129
Granule ID : ASTL1B 0507081753091203130024
Granule ID : ASTL1A 0506291937080507040275
Granule ID : ASTL1A 0506291937170507040276
Granule ID : ASTL1A 0506291759170507040246
Granule ID : ASTL1A 0506291759080507040245