DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2014/6

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

Results of the 2013 Season

Diogo Rosa, Jan Audun Rasmussen,
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GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
DANISH MINISTRY OF CLIMATE, ENERGY AND BUILDING

G E U S

Contents

Abstract

Exploration reconnaissance carried out by the Geological Survey of Denmark and Greenland (GEUS) in southern Peary Land, during the summer of 2013, allowed for the identification of two new multi-locality Mississippi-Valley Type showings, and to further expand one showing identified in 2012. In contrast, SEDEX mineralisation was unsuccessfully searched for in Amundsen Land.

The Mississippi-Valley Type (MVT) mineralisation consists of sphalerite and/or galena, occasionally fluorite or barite, in white calcite veinlets and breccias hosted in the Turesø Formation dolostones (Upper Ordovician to Lower Silurian - Morris Bugt Group), of the Franklinian Basin carbonate platform. The highest grades recorded in *in situ* grab samples are 6.79 % Zn and 36.1 % Pb. Mineralisation is present in three distinct horizons:

- within the lowermost pale-weathering Lower Turesø Formation, ~10 m above the contact with the Børglum River Formation;
- within the lowermost dark-weathering Upper Turesø Formation,~80 m below the contact with the Ymers Gletcher Formation;
- within the dark-weathering Upper Turesø Formation, ~50 m below the contact with the Ymers Gletcher Formation.

Of these three horizons, the intermediate one is the best represented and is therefore interpreted as being the most continuous.

Introduction

A zinc resource assessment, performed following the procedures of the Global Mineral Assessment Project, as defined by the United States Geological Survey (USGS), considered the Franklinian Basin of North Greenland (inset of Figure 1) as highly prospective, both for Sedimentary Exhalative (SEDEX) deposits and for Mississippi Valley-Type (MVT) deposits (Sørensen *et al.* 2013). This, coupled with the previous identification of several significant showings and prospects of these deposit types (Jensen & Schønwandt 1998; Cope & Beswick 1999; Jakobsen & Steenfelt 1985; von Guttenberg & van der Stijl 1993) and of the Citronen Fjord SEDEX deposit (van der Stijl and Mosher 1998), has encouraged the Geological Survey of Denmark and Greenland (GEUS) to propose to the Bureau of Minerals and Petroleum of Greenland (BMP) an expedition to the eastern part of the basin during the summer of 2012.

The 2012 expedition revealed two new MVT showings, with sphalerite veinlets and pockets 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 (Rosa & Kalvig 2013). The fact that one of these showings in Western Melville Land (Peary Land) and the other in Kronprins Christian Land, more than 200 km from each other (Figure 1), demonstrated that a large-scale hydrothermal system, transporting zinc, operated in the eastern part of the Franklinian carbonate platform. Therefore, while the showings identified in 2012 are of no economic interest *per se*, it was considered that they confirmed the potential for economic deposits and another expedition was undertaken during the summer of 2013.

This expedition of 2013 had a twofold purpose. On one hand, it was aimed at following up on the discoveries of 2012 and further study the Turesø Formation, to try to identify areas and stratigraphical levels of increased permeability within it, in which hydrothermal fluids may have focused to form significant MVT orebodies. On the other hand, reaching into Amundsen Land, which had not been possible in the previous year due to logistical constraints, was an opportunity to investigate the trough sequence, favourable to SEDEX deposits. Accessorily, stream sediment samples were collected in the field, to broaden the coverage of the regional stream sediment program and possibly highlight new anomalous areas for future prospecting follow-up.

With basecamp established in Station Nord, two two-man teams were deployed to the field during four weeks, working out of a total of ten field camps, the location of which is included in Figure 1. Additionally, some helicopter reconnaissance and stream sediment sampling was carried out, during some of the camp moves.

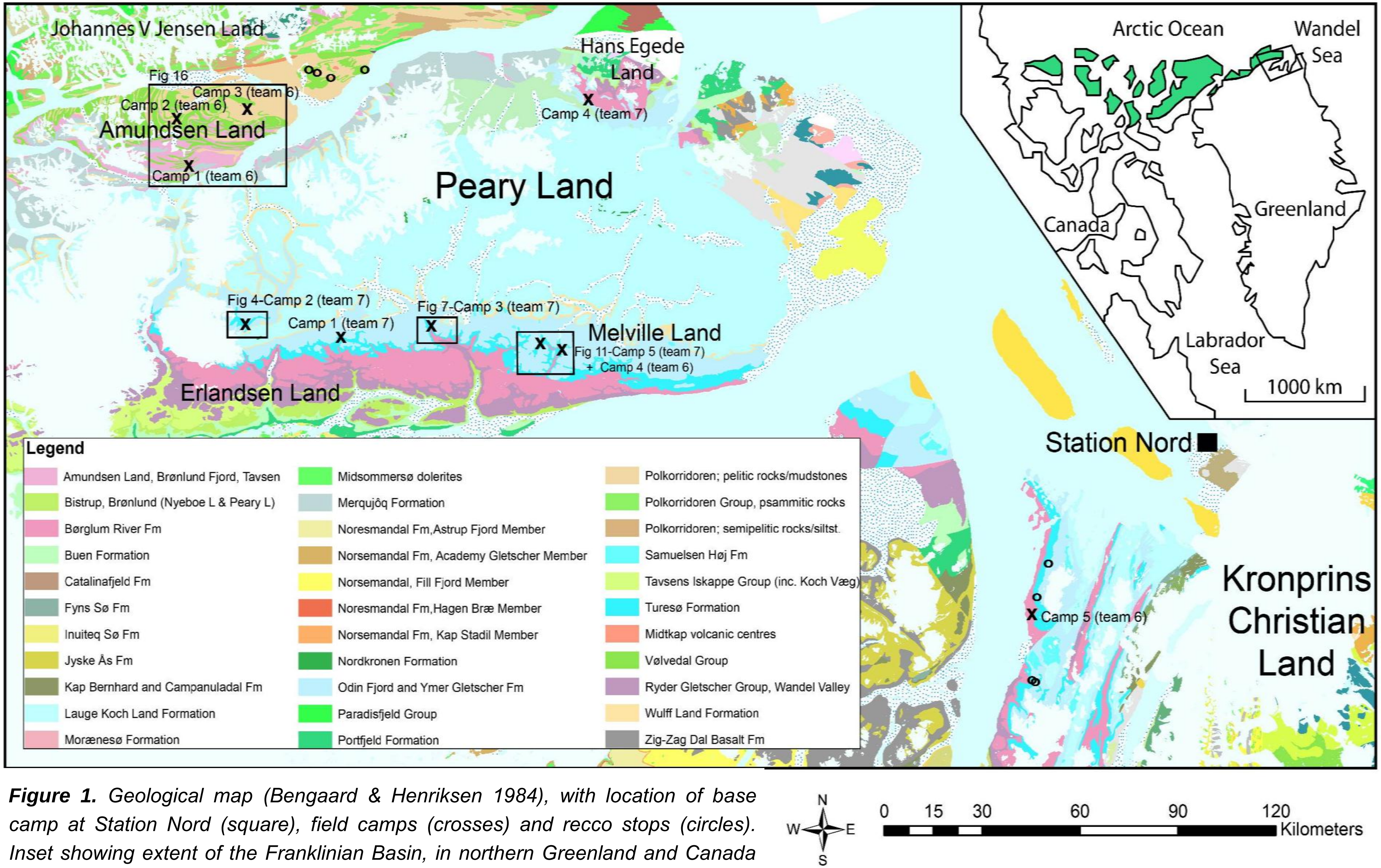

Figure 1. *Geological map (Bengaard & Henriksen 1984), with location of base camp at Station Nord (square), field camps (crosses) and recco stops (circles). Inset showing extent of the Franklinian Basin, in northern Greenland and Canada (green) and location of study area.*

Geological Setting

The lower Palaeozoic strata of Peary Land form the eastern part of the Cambrian to Devonian Franklinian Basin (Figure 1), extending 2500 km from the Canadian Arctic Islands to eastern North Greenland (Troelsen 1950; Peel & Christie 1982; Higgins *et al*. 1991; Dawes 2009). In Peary Land, these outcrop in an east-west oriented belt with a maximum preserved north-south width of about 200 km.

The Franklinian Basin was characterised by a distinct facies transition from shallow-water platform carbonates in the south (Figure 2), to deep-water, mainly fine siliciclastic trough sediments to the north including northern Peary Land and parts of Amundsen Land throughout the Lower Palaeozoic (Higgins *et al*. 1991). While the platform carbonates can host MVT deposits, the trough can host SEDEX deposits, so the whole basin can be considered of interest for zinc-lead mineralisation. The location of the northern margin to the Franklinian Basin in North Greenland is not established with certainty. Deformed strata of the same platform sequence comprise the Lower Palaeozoic succession in the northern part of the East Greenland Caledonides (Peel 1985, Smith & Rasmussen 2008).

Deposition in the trough was brought to an end by the mid-Palaeozoic Ellesmerian Orogeny, which formed the North Greenland fold belt and caused compression from north to south during the late Devonian to early Carboniferous (Soper & Higgins 1987, 1990; Higgins *et al.*1991). Deformation is largely confined to the trough succession in Amundsen Land and other parts of Johannes V. Jensen Land, where metamorphism reached low amphibolite facies towards the north (Henriksen *et al*. 2000). The resulting Ellesmerian fold belts of both North Greenland and northern Ellesmere Island are characterised by E–W- to NE–SW-trending chains of folds, broadly parallel to the main facies boundaries within the Franklinian Basin.

In the light of the 2012 field investigations, the 2013 field season was concentrated mainly on shelf sediments of the upper part of the Morris Bugt Group, which includes the Børglum River and Turesø formations, as well as on the Ymers Gletcher Formation.

The Upper Ordovician (Sandbian–Katian) Børglum River Formation comprises lithologically monotonous, dark, burrow-mottled lime mudstones and wackestones, and – less abundant – packstones. The formation is generally highly fossiliferous in the upper part with abundant stromatoporoids, corals, cephalopods and gastropods together with rarer brachiopods and trilobites. Only the uppermost part of the formation was studied.

The overlying Turesø Formation is commonly about 150 m thick in Peary Land (Christie & Peel 1977; Hurst 1984) but the present study reveals that it in places in southern Peary Land may be approaching 180 m in thickness. The lower part of the formation, commonly up to about 80 m thick, is characterised by pale-weathering dolostones, often distinctly burrow-mottled. Fossils are rare, but stromatoporoids, tabulate corals, macluritid gastropods, nautiloid cephalopods and ostracods were occasionally observed in the lower part of the formation. The upper part of the Turesø Formation is 80–100 m thick and characterised by dark, subtidal, burrow-mottled intervals of dolomitic or limy mud- and wackestone alternating with pale-weathering, laminated or fenestral dolostone beds. The overall appearance is generally darker than the lower part of the formation. Macroscopic fossils are also rare here, but brachiopods are more common than in the lower part of the formation.

The Ymers Gletscher Formation (25-45 m) comprises grey, thinly laminated and well bedded fenestral lime mudstones. Coquinas dominated by pentamerid brachiopods are present as well as desiccation cracks (Armstrong & Lane 1981; Hurst, 1984). The sediments reflect deposition in peritidal environments, possibly with raised salinities (Fürsich & Hurst 1980). Finally, within the Franklinian deep-water trough, sediments of the Vølvedal Group and the Amundsen Land Group were investigated in Amundsen Land. Upper lower Cambrian to Lower Ordovician slope and trough-floor sediments of the Vølvedal Group include mudstones, cherts, thickly developed turbiditic sandstones and conglomerates (Friderichsen *et al.* 1982, Surlyk & Hurst 1984). The biostratigraphical control of its age is generally poor (Higgins *et al.* 1991), but Early Ordovician graptolites occur in mudstones in the upper part of the group. The succeeding Amundsen Land Group consists of Lower Ordovician to lower Silurian radiolarian cherts and mudstones, distal turbidites and carbonate conglomerates (Friderichsen *et al.* 1982; Higgins *et al.* 1991).

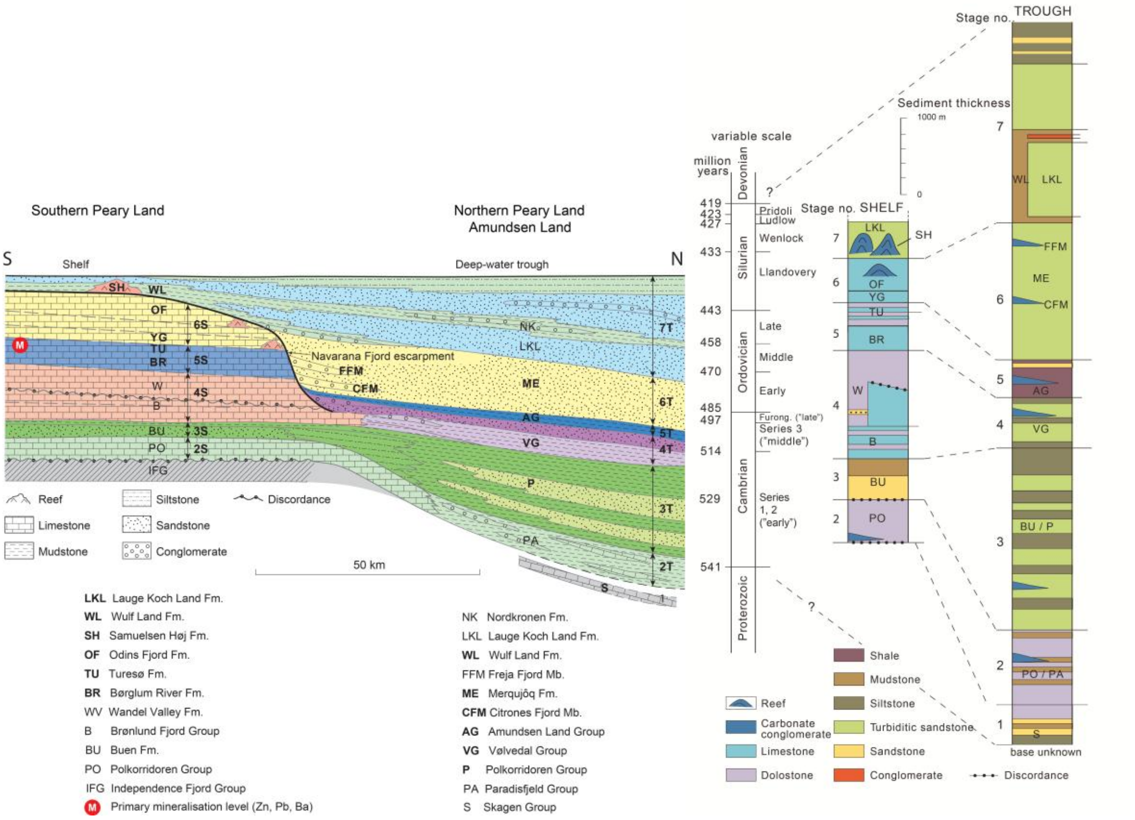

Figure 2. A) Shelf-slope transition (left); B) Stratigraphic column (right). Modified from Henriksen (2008). Absolute ages are from Cooper & Saddler (2012).

Reconnaissance of MVT targets

Target development and rationale

The MVT mineralisation found in the field, during the 2012 season, is not linked to rust zones and therefore the usefulness of the processing of ASTER images was considered limited (Rosa & Kalvig 2013). An alternative hyperspectral survey, which could have assisted in identifying effective mineralisation footprints, was not carried out. Furthermore, the area is not covered by detailed geophysical surveys, such as a detailed aeromagnetic survey that could aid in identifying basement structures that could have channelled mineralising fluids. As a result, MVT target selection was largely based on stream sediment data and analysis of the stratigraphic and structural context around the Turesø Formation, previously identified as being a key aquifer for mineralising fluids (Rosa & Kalvig 2013).

The stream sediment dataset of Thrane *et al.* (2011) was supplemented by the results of the sampling carried out during 2012 (Rosa & Kalvig 2013). In most cases, it appears that anomalous Zn concentrations in stream sediments can be related to the Turesø Formation (Figure 3). Because it was documented that this formation hosts the mineralised horizon at the two showings identified in 2012, it was considered that areas where this formation appears to be related to the stream sediment anomalies should be prioritized for follow up.

Since intermittent mineralisation, as identified in 2012, is an important guideline but is not, by itself, of economic interest, it was considered that criteria for the presence of increased permeability of the Turesø Formation (whether primary or secondary) should be identified. Therefore, among the prioritized areas, camps were planned for locations where important structures could have created extensional domains, through which mineralising fluids could have ascended and precipitated metals. This approach is limited by the fact that it is unknown when and how different structures were active and it is therefore uncertain if they could have collected mineralising fluids, which presumably circulated while the Ellesmerian Orogeny was active, during the late Devonian to early Carboniferous (Soper & Higgins 1987, 1990; Higgins *et al.* 1991). Nevertheless, important lineaments, likely reflecting the presence of important and long lasting structures, were identified and camps set up to investigate them. These important lineaments include the Central Peary Land Fault Zone, striking N70, and other parallel structures. In Erlandsen Land (Figure 1), synclines appear to be bound by this type of structures, which can therefore be interpreted as belonging to a negative flower structure (Guarnieri, *pers. comm, 2013.*). If this is the case, these structures are likely related to strike slip movements and extensional domains can be expected to exist within bends. Other important structures strike N110.

In addition to structures that could have promoted secondary permeability, the possible influence of the dolomitization on the primary permeability of carbonates and mineralisation was studied by establishing a camp in a Hans Egede Land, in a more basinward setting. While the Turesø Formation *sensu stricto* has not been mapped in this area (Christie & Ineson 1979), it was thought that its stratigraphic equivalent was worth investigating.

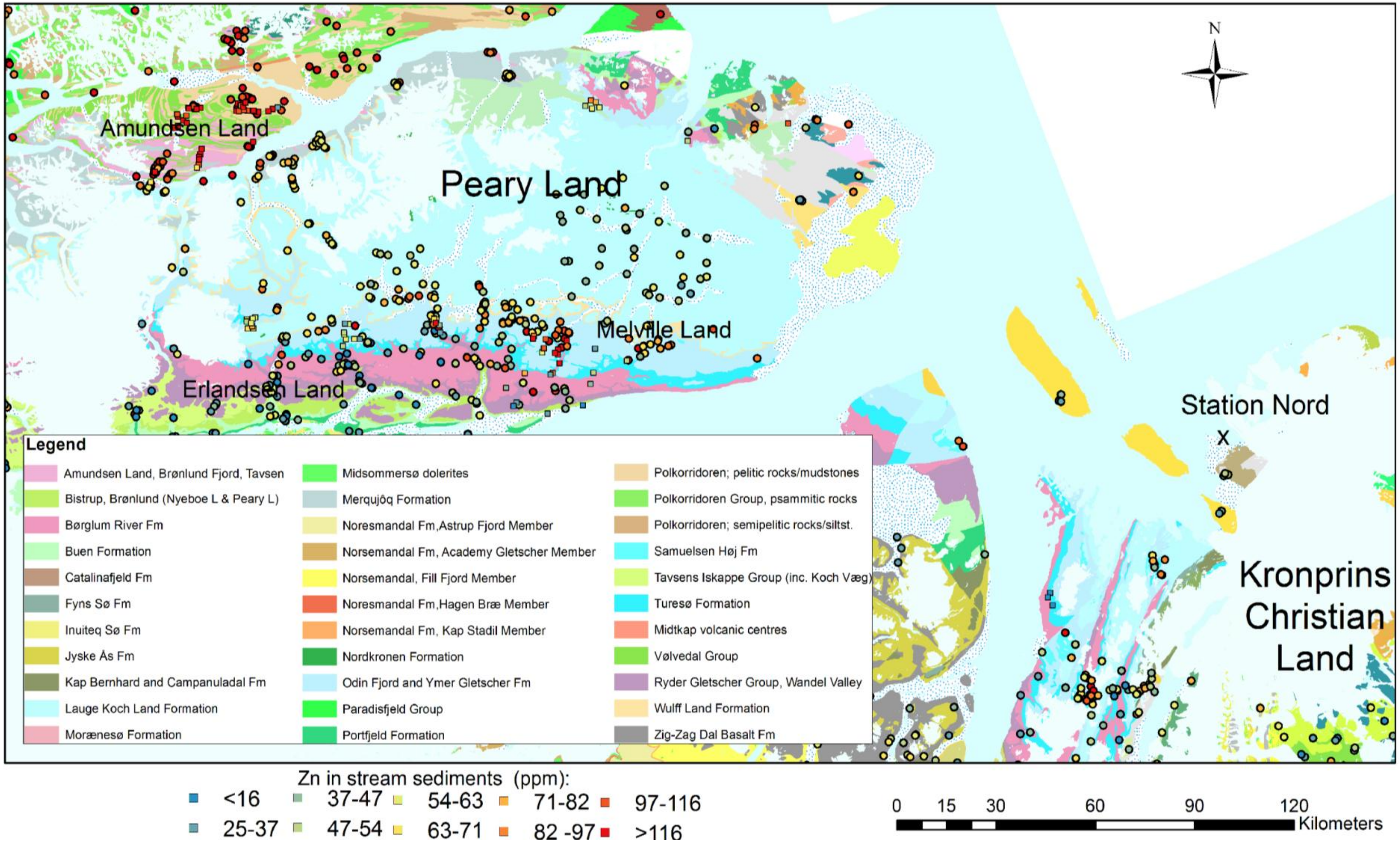

Figure 3. Zn values (ppm), in stream sediment samples. Circles correspond to samples collected prior to the summer of 2013, squares to samples collected during the present study.

Results

Camp 1 (Team 7) – Erlandsen Land / SW Peary Land.

This camp was set up to study a pronounced N110 lineament, which straddles a valley mapped as being within the Turesø Formation (Figure 1). This formation has also been mapped south of camp. The camp was also established to investigate possible sources for a stream sediment anomaly present to the north.

Fieldwork demonstrated that the N110-trending valley, from camp to 5 km to the east, is actually within the Odins Fjord Formation, rather than within the favourable Turesø Formation, as it had been previously mapped (Bengaard & Henriksen 1994). Likely because of this, no evidence for MVT mineralisation was identified. Furthermore, it appears that this lineament corresponds to an intensively karstified domain, which is more easily eroded, originating the N110-trending valley. It therefore likely corresponds to a feature postdating the MVT mineralisation event.

Karstic features, such as breccias and speleothems, were also identified towards the South of camp, within the Turesø and Odins Fjord formations. Again, however, no signs of zinc mineralisation were identified.

Finally, a hill located ~5 km northwest of camp was also assessed in detail, as it could have sourced the stream sediment anomaly present in the valley to the north of it. In addition to Odins Fjord Formation limestones, some bioherms reminiscent of the Samuelsen Høj Formation were identified towards its top, but no signs of zinc mineralisation were recognized. It therefore appears that the stream sediment anomaly may be derived from the opposite side of the valley or from further upstream.

Camp 2 (Team 7) – Erlandsen Land / SW Peary Land.

This camp was established by the Upper Tvilum Elv valley, close to the Bure Icecap (Figures 1 and 4). In addition to being located near an extensive area which had been mapped as Turesø Formation (Bengaard & Henriksen 1994), it is located just north of a possible negative flower structure, with a syncline enclosed by N70-trending structures of the Central Peary Land Fault system (Guarnieri, *pers. comm.*). Furthermore, structures striking in other directions had also been mapped. Any of these structures could have created extensional domains which could have promoted ascension and accumulation of mineralising fluids.

The deep and fast flowing Tvilum Elv was impossible to cross or to follow along some of its margins, so that no work was carried out on its left bank or on its most upstream section. Furthermore, a significant extent of Børglum River Formation outcrops on the river bottom, in what has been mapped as Turesø Formation, so that the extent of the latter is more limited than expected. Nevertheless, a locality with *in situ* Zn mineralisation (samples 542913-15,17-19), as well as a rather extensive area with abundant zinc mineralised float (samples 542923-24), were identified. The *in situ* mineralisation was identified on the main Tvilum Elv valley (Figure 4), and consists of caramel sphalerite, with some pyrite, within brecciated pale dolostones of the lowermost part of the Turesø Formation (Figure 5). Representative assays are included in Table 1, confirming consistent Zn grades between 2 and 7%, with only one sample containing significant Pb (0.5%). Extensions to this locality were searched, but the abundance of scree covering the favourable horizon made this attempt unsuccessful. Abundant float, with weathered sphalerite and white calcite in veined and brecciated dark Upper Turesø Formation dolostone, was found along two tributaries of the Tvilum Elv;

the one where camp was set and the one immediately to the west of it (Figure 4). Representative assays of samples of this float are also included in Table 1. Other tributaries were not evaluated. The extensive development of scree surfaces made it impossible to identify the source for this float. However, the abundance of float, its sizes, and its lithological type suggests that it is likely near its source.

Figure 6 illustrates the stratigraphic setting for the mineralised localities, with the *in situ* mineralisation being hosted approximately 10 m above the base of the Turesø Formation, and the float deriving from an uncertain horizon within the upper part of the Turesø Formation.

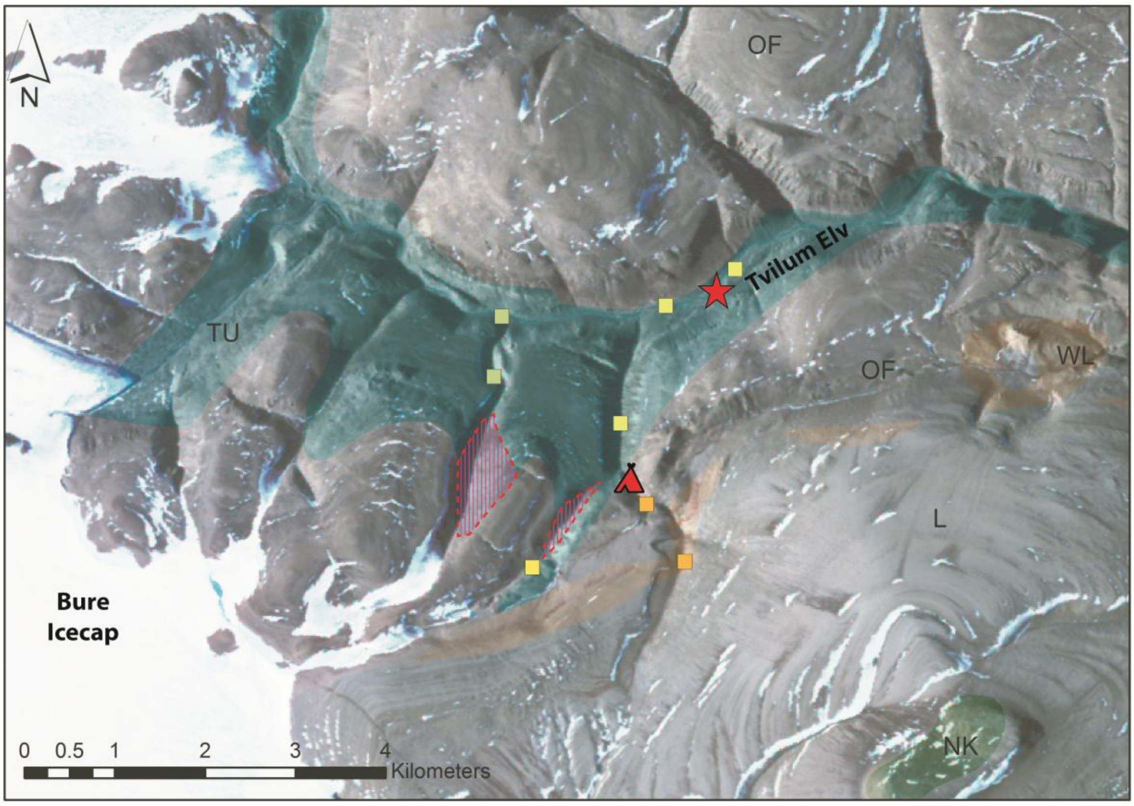

Figure 4. *Geological setting in the vicinity of Camp 2 (Team 7). TU-Turesø Fm; OF-Ymers Gletcher + Odins Fj formations; WL-Wulff Land Fm; L-Lauge Koch Land Fm; NK-Nordkronen Fm (Bengaard & Henriksen 1984), overlaid on a false colour composite ASTER image. Tent symbol denotes camp site. Star marks location of in situ mineralisation, striped area indicates area with abundant mineralised float. Squares mark locations of stream sediment samples, colour coded according to their Zn content, as in Figure 3.*

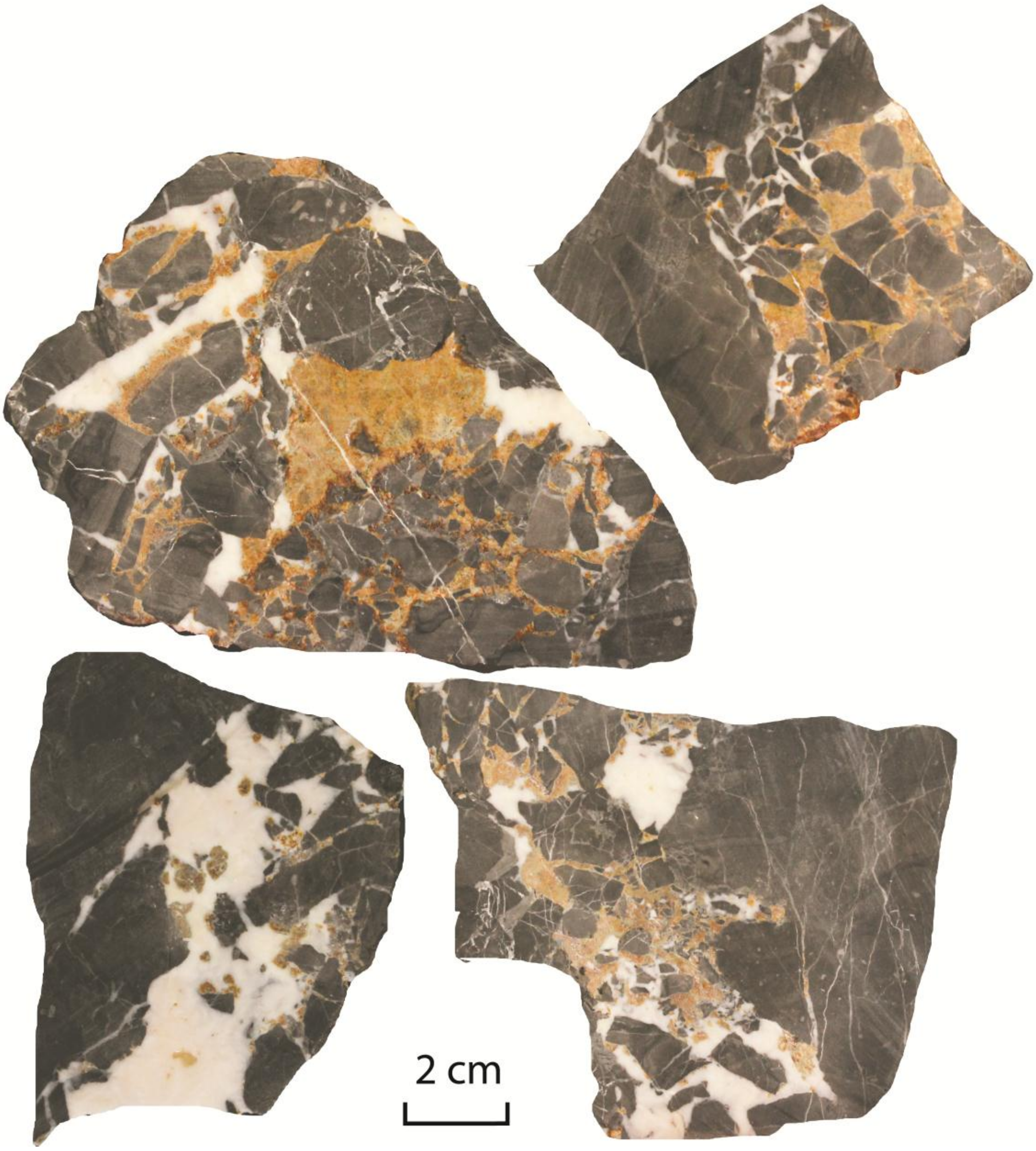

Figure 5. *Textural aspects of the mineralisation found at Camp 2 (Team 7). Slabs of samples 542915 (top left and right, and bottom right) and 542919 (bottom left), with caramel sphalerite and white calcite as matrix to brecciated dolostone.*

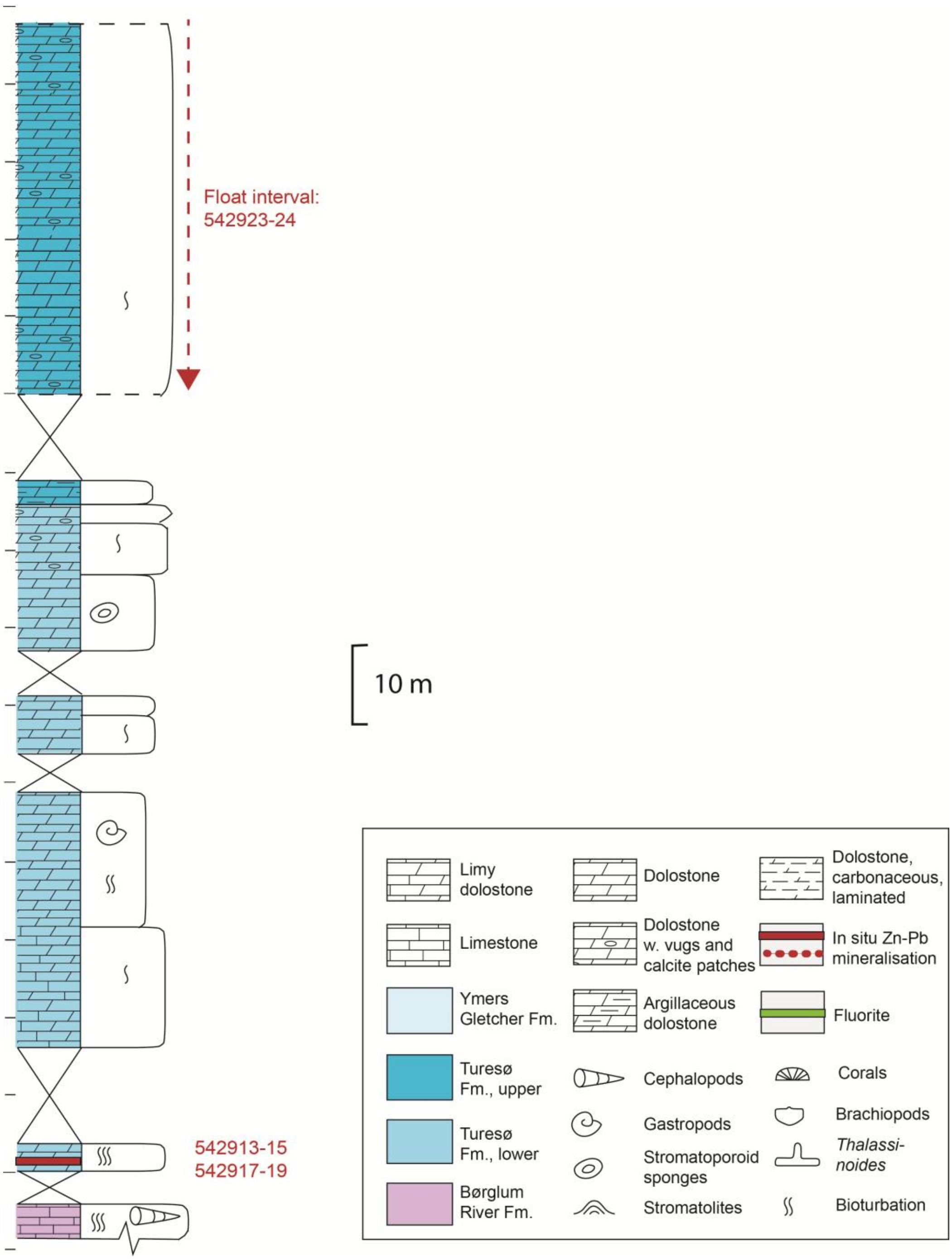

Figure 6. *Composite stratigraphic column at Camp 2 (Team 7), illustrating setting of mineralisation.*

Table 1. *Summary of Zn, Pb and Ag analyses of mineralised samples, determined through assay or fusion ICP-MS, at Actlabs (Ontario, Canada). Area abbreviations used: PL – Peary Land, HEL – Hans Egede Land, KPCL – Kroprins Christian Land.*

Sample	Longitude W	Latitude E	Area / Camp	Locality	Sample type	Zn		Pb		Ag	Sample weight (g)
						Assay %	FUS-MS ppm	Assay %	FUS-MS ppm	FUS-MS ppm	
542913	34°25,308´	82°31,998´	PL-Tvilum Elv-Camp 2 (Team 7)		In situ	6.73			11	7.7	576
542914	34°25,308´	82°31,998´	PL-Tvilum Elv-Camp 2 (Team 7)		In situ	6.24			4990	0.9	384
542915	34°25,308´	82°31,998´	PL-Tvilum Elv-Camp 2 (Team 7)		In situ	3.26			8	14.4	835
542917	34°25,308´	82°31,998´	PL-Tvilum Elv-Camp 2 (Team 7)		In situ	5.88			< 5	7.2	521
542918	34°25,308´	82°31,998´	PL-Tvilum Elv-Camp 2 (Team 7)		In situ	6.61			13	13.4	489
542919	34°25,308´	82°31,998´	PL-Tvilum Elv-Camp 2 (Team 7)		In situ	2.33			< 5	15.8	321
542923	34°37,164´	82°30,906´	PL-Tvilum Elv-Camp 2 (Team 7)		Float	1.66			6	< 0.5	706
542924	34°33,708´	82°30,630´	PL-Tvilum Elv-Camp 2 (Team 7)		Float	1.74			14	< 0.5	226
542926	30°40,566´	82°27,966´	PL-Børglum Elv-Camp 3 (Team 7)	Southern Locality	In situ	5.16			5	< 0.5	931
542935	30°42,546´	82°28,368´	PL-Børglum Elv-Camp 3 (Team 7)	Northern Locality	In situ	6.79		24.0		8.4	1679
543856	30°41,556´	82°28,122´	PL-Børglum Elv-Camp 3 (Team 7)	Central Locality	In situ	0.98			33	16.5	243
542938	26°20,478´	82°56,826´	HEL-Camp 4(Team 7)		Float		950		184	< 0.5	656
543865	28°44,526´	82°23,406´	PL-"Løgum" Elv-Camp 5 (Team 7)	Locality A	In situ	5.45			185	< 0.5	259
543862	28°35,478´	82°21,420´	PL-"Løgum" Elv-Camp 5 (Team 7)	Locality B	Float	9.76			98	< 0.5	175
543863	28°36,426´	82°21,306´	PL-"Løgum" Elv-Camp 5 (Team 7)	Locality B	In situ	2.35			65	< 0.5	219
542946	28°35,946´	82°21,150´	PL-"Løgum" Elv-Camp 5 (Team 7)	Locality B	Float		990		3840	< 0.5	169
542950	28°19,668´	82°19,548´	PL-"Løgum" Elv-Camp 5 (Team 7)	Locality C	Float		1200	36.1		5.3	271
542951	28°19,986´	82°19,470´	PL-"Løgum" Elv-Camp 5 (Team 7)	Locality C	In situ		230		977	0.5	262
545128	28°06,012´	82°21,930´	PL-"Løgum" Elv-Camp 4 (Team 6)	Locality D	Float		1400		14	0.7	290
545129	28°06,012´	82°21,930´	PL-"Løgum" Elv-Camp 4 (Team 6)	Locality D	Float	1.40			< 5	17.8	203
545130	28°06,012´	82°21,930´	PL-"Løgum" Elv-Camp 4 (Team 6)	Locality D	Float		5290		7	< 0.5	252
545131	28°08,850´	82°20,112´	PL-"Løgum" Elv-Camp 4 (Team 6)	Locality E	Float		3080		256	< 0.5	214
545132	28°08,394´	82°19,776´	PL-"Løgum" Elv-Camp 4 (Team 6)	Locality E	In situ		70		< 5	< 0.5	211
545133	28°08,394´	82°19,776´	PL-"Løgum" Elv-Camp 4 (Team 6)	Locality E	In situ	4.89			< 5	< 0.5	211
545134	28°08,394´	82°19,776´	PL-"Løgum" Elv-Camp 4 (Team 6)	Locality E	In situ	2.69			9	< 0.5	182
545135	28°08,364´	82°19,776´	PL-"Løgum" Elv-Camp 4 (Team 6)	Locality E	Float	3.37			31	0.5	237
545136	28°08,364´	82°19,776´	PL-"Løgum" Elv-Camp 4 (Team 6)	Locality E	Float		1850		< 5	< 0.5	204
545137	28°10,098´	82°18,420´	PL-"Løgum" Elv-Camp 4 (Team 6)	Locality F	Float		790		4320	15.3	190
545139	27°58,662´	82°16,938´	PL-"Løgum" Elv-Camp 4 (Team 6)	Locality G	In situ		3410		59	< 0.5	189
545140	27°58,662´	82°16,938´	PL-"Løgum" Elv-Camp 4 (Team 6)	Locality G	In situ		910		10	< 0.5	254
545141	27°58,662´	82°16,938´	PL-"Løgum" Elv-Camp 4 (Team 6)	Locality G	In situ		1780		46	< 0.5	212
545145	20°50,838´	81°10,332´	KPCL	Recco flight	Float		2210		115	< 0.5	168
545146	20°50,244´	81°10,421´	KPCL	Recco flight	Float		880		< 5	< 0.5	113

Camp 3 (Team 7) – Melville Land / SE Peary Land.

This camp was set just east of the Børglum Elv, across the river from the showing locality identified in the 2012 season (Figures 1, 7, and 8).

Mineralisation was identified in three different localities, significantly expanding the extent of the previously known showing, which had been a single locality showing (Rosa & Kalvig 2013). Sample 542926 was collected at the southern locality, samples 542929-30 and 543856 were collected at the central locality, and sample 542935 was collected at the northern locality. The southernmost and central localities are located in steep and partially inaccessible canyons and were therefore not as extensively sampled as the northernmost locality. Nevertheless, it appears that at the former localities Zn is clearly predominant in the form of sphalerite, while at the latter locality significant amounts of Pb are also present, in the form of galena (Figure 9). The observed textures suggest that this galena follows sphalerite in the paragenetic sequence. The assays, included in Table 1, show Zn grades ranging between 1 and 7% and Pb reaching 24%. Despite the high galena contents of one of the samples, Ag content is not significant.

While the three mineralised localities are hosted in Upper Turesø Formation dark dolostone, they represent two distinct horizons (Figure 10). The northernmost and central localities are within a horizon running approximately 80 m below the Ymers Gletcher / Turesø formation contact, while the southernmost locality is within an horizon located approximately 50 m below that contact. It appears that the locality across the Børglum Elv, identified in 2012, is located 80 m below the contact, suggesting this is the most continuous mineralised horizon at this camp. This horizon, 80 m below the contact with the Ymers Gletcher Formation, yielded the Silurian brachiopod *Viridita* (Christian Mac Ørum Rasmussen, *pers. comm.*, 2013), showing that the Ordovician-Silurian boundary most likely is present just above the base of the dark-weathering part of the Turesø Formation.

In addition to these three new localities, traces of zinc were found on siliceous stromatoporoid sponge fragments, within pale dolostones characterising the lower part of the Turesø Formation (Figure 10).

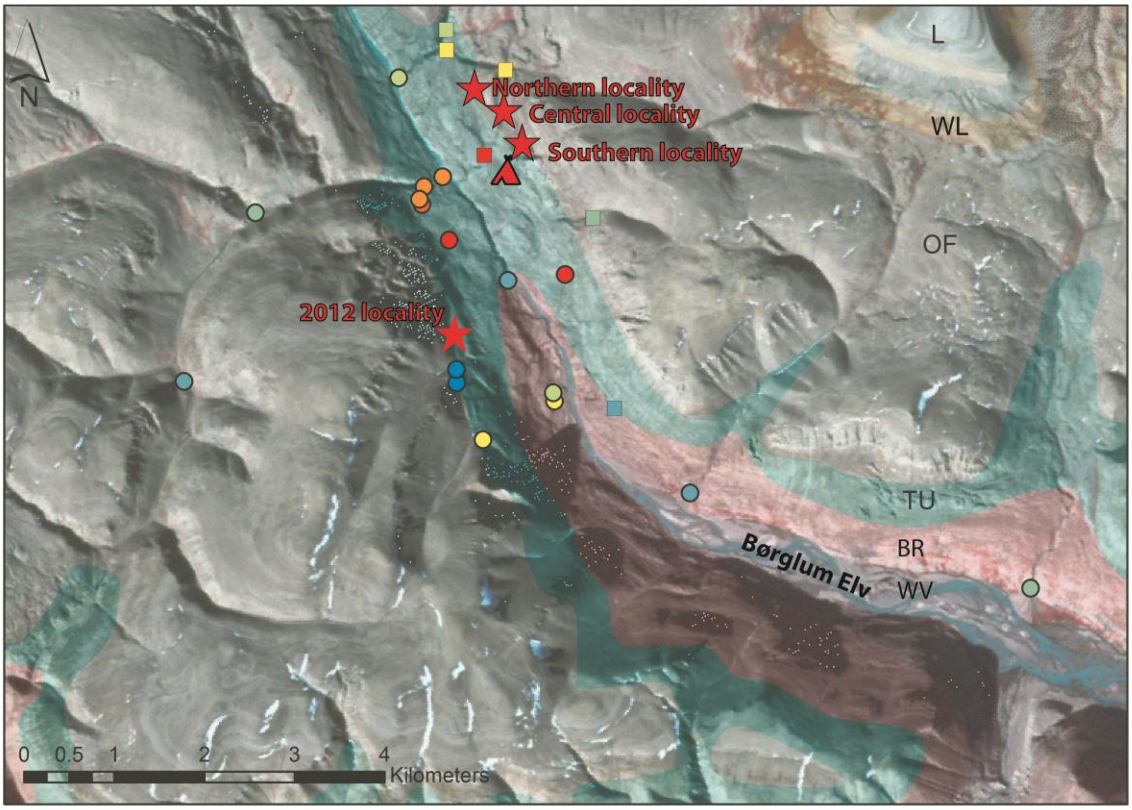

Figure 7. *Geological setting in the vicinity of Camp 3 (Team 7). WV-Wandel Valley Fm; BR-Børglum River Fm; TU-Turesø Fm; OF-Ymers Gletcher + Odins Fj formations; WL-Wulff Land Fm; L-Lauge Koch Land Fm (Bengaard & Henriksen 1984), overlaid on a false colour composite ASTER image. Tent symbol denotes camp site. Star marks location of in situ mineralisation. Locations of stream sediment samples, colour coded according to their Zn content as in Figure 3, indicated by squares (collected in 2013) and circles (collected prior to 2013).*

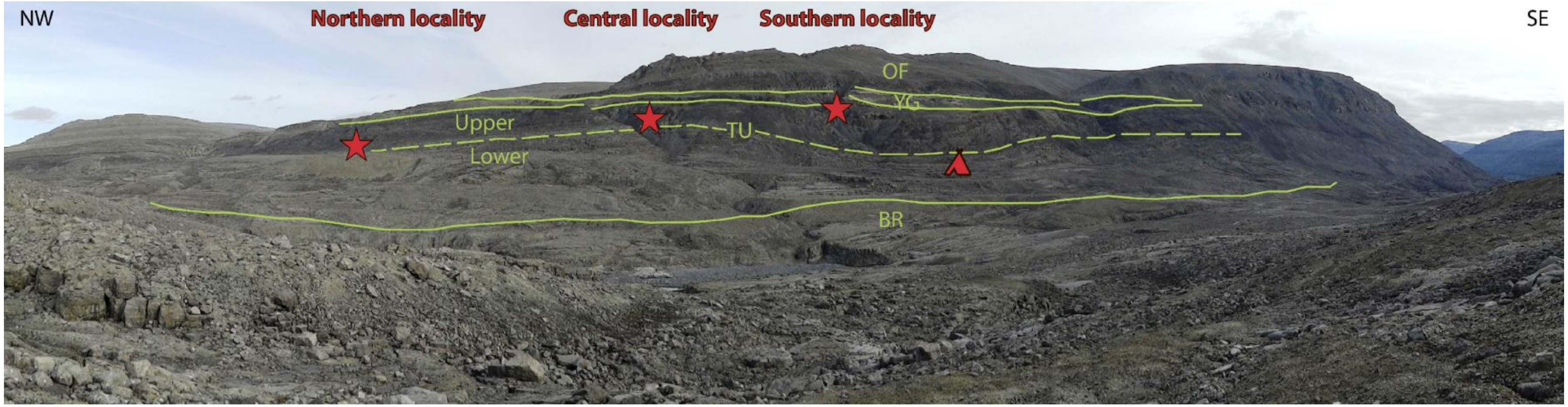

Figure 8. *Panorama of the western (left) side of the Børglum Elv, as seen from its eastern (right) side, taken during the 2012 expedition. Field of view is approximately 5 km across. Highlight of the stratigraphy: BR-Børglum River Fm; TU-Turesø Fm (further subdivided in upper and lower part); YG-Ymers Gletcher Fm; OF-Odins Fjord Fm. Tent symbol denotes Camp 3 (Team 7) location. Stars mark localities with in situ mineralisation identified during the 2013 expedition.*

Figure 9. *Textural aspects of the mineralisation found at the northern locality at Camp 3 (Team 7), as documented in a slab of sample 542935, a dolostone with pockets of caramel sphalerite, galena and white calcite.*

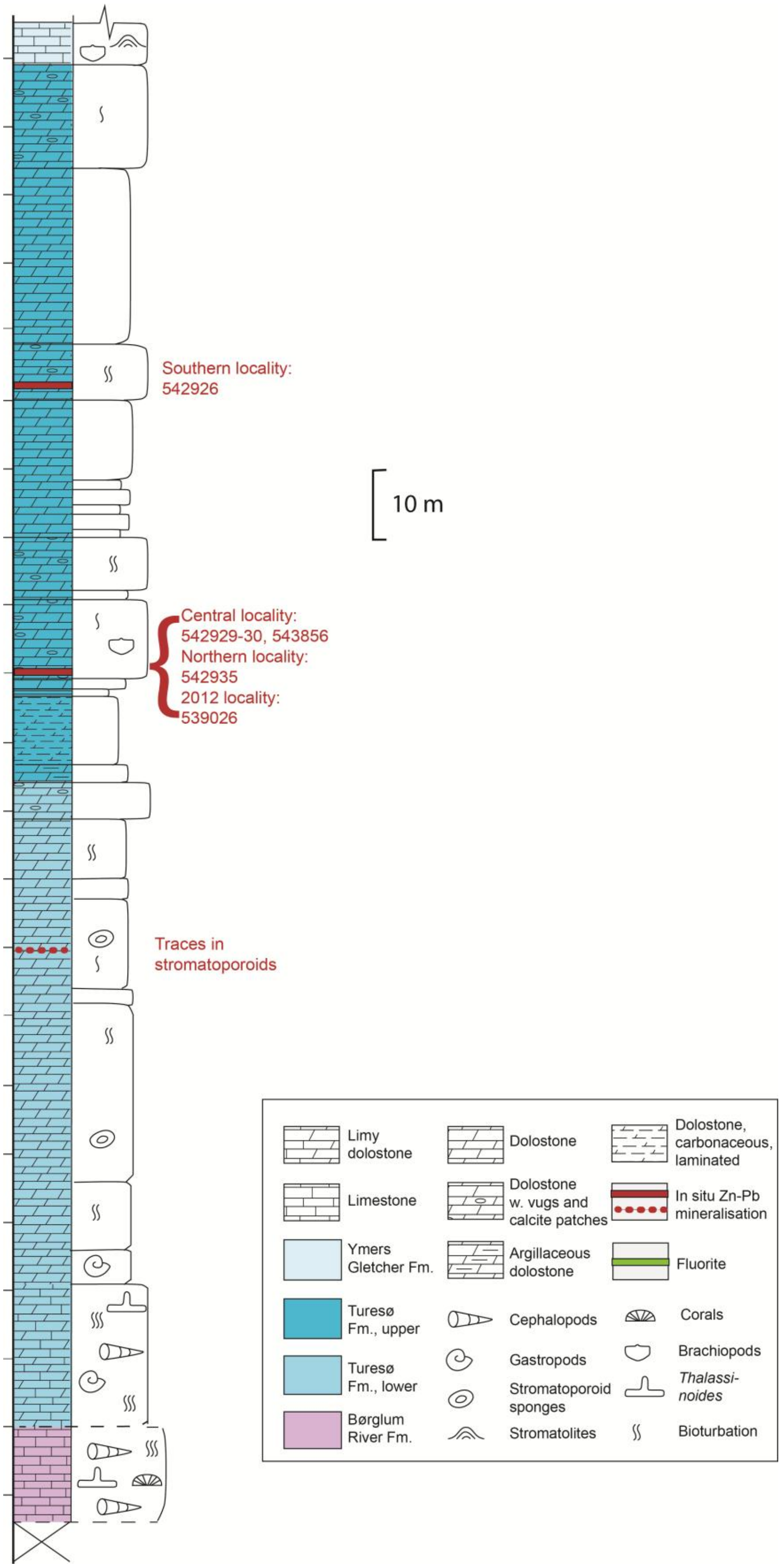

Figure 10. *Composite stratigraphic column at Camp 3 (Team 7), illustrating setting of mineralisation.*

Camp 4 (Team 7) – Hans Egede Land / NE Peary Land.

This camp was set in Hans Egede Land, roughly halfway between G.B. Schley Fjord and Citronen Fjord (Figure 1). The Turesø Formation *sensu stricto* has not been mapped in this area (Bengaard & Henriksen, 1994), because no true dolostones were identified between the Børglum River Formation and the Odins Fjord Formation (Christie & Ineson 1979; Hurst 1984). This absence of dolostones is likely caused by sedimentation in a more subtidal, basinward setting than the very shallow water, peritidal conditions that characterised the proximal platform further south in Peary Land. However, since dolomitisation can play an important role in controlling the porosity and permeability, it was thought worthwhile verifying its relevance for the mineralisation process.

The fieldwork confirmed the absence of dolomitic formations, as previously reported. Probably because of this, and despite the very tectonized nature of the limestones, containing many white calcite veinlets resulting of the proximity to the Herluf Trolle Land fault system, field work did not reveal any clear signs of mineralisation. While some limonite float collected from frost boils (sample 542938) proved to be anomalous in Zn and Pb (see Table 1), it appears that dolomitisation may indeed be necessary to establish the permeability needed for the flow of mineralising fluids.

Other than that, fieldwork allowed the identification of several rust zones which correspond to the accumulation of *terra rossa* clay from karstification processes.

Camp 5 (Team 7) + Camp 4 (Team 6) – Melville Land / SE Peary Land.

These camps were established along the informally called “Løgum Elv”, draining Melville Land into Independence Fjord (Figures 1 and 11). This is an area with extensive Turesø Formation outcrops and significant stream sediment anomalies that can be sourced to it. Team 7 studied the western part, while Team 6 studied the eastern part, as the river constituted an uncrossable barrier.

The E-W fault that crosses the river, ~3km south of a lake, was investigated by both teams. This fault downthrows the southern block, but does not appear to control any mineralisation.

However, zinc-lead mineralisation, consisting of galena and/or weathered sphalerite, locally with accessory purple fluorite or barite, in white calcite vugs and/or breccias (Figures 12 and 13), was found elsewhere throughout the area, both as float and as *in situ* (Figure 11). Representative assays of samples are included in Table 1. *In situ* zinc-lead mineralised samples were collected from localities A (sample 543865), B (sample 543863), E (samples 545132-34) and G (samples 545139-41), as illustrated in Figure 11. Mineralisation in localities A and B, and possibly also in E and G, is present in a horizon in the lowermost dark-weathering Turesø formation (Figure 14). While no *in situ* zinc mineralisation was identified at locality C, abundant float rich in galena (sample 542950, Figure 13) can be confidently sourced from the same stratigraphic horizon mentioned above. Although with a lower degree of certainty, the float identified in localities D and F appears to also be derived from this same stratigraphic horizon. Therefore, at this camp, the lowermost dark-weathering dolostone unit of the Turesø Formation, appears to host mineralisation in a quite continuous manner. In addition to this zinc-lead mineralised horizon, another horizon with black fluorite (figure 15), but only traces of Zn and Pb mineralisation (sample 542951), was identified further up in the stratigraphy at locality C (Figure 14).

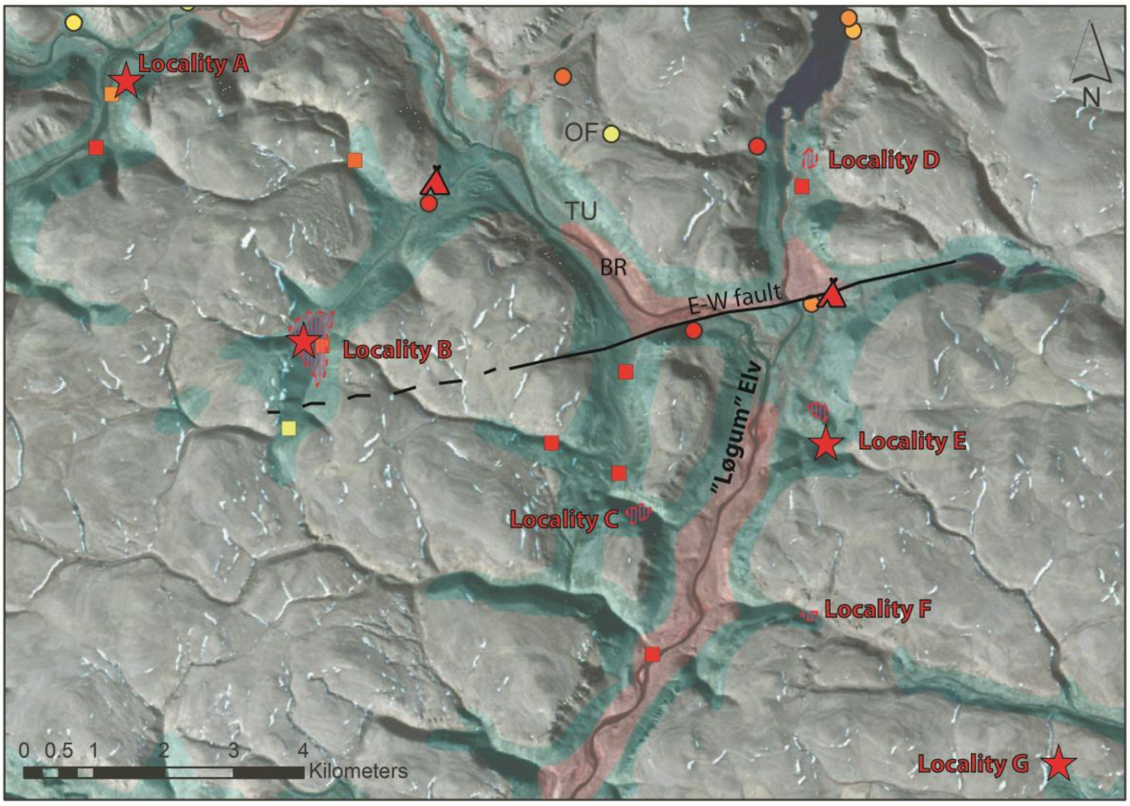

Figure 11. *Geological setting in the vicinity of Camp 5 (Team 7) + Camp 4 (Team 6). BR-Børglum River Fm; TU-Turesø Fm; OF-Ymers Gletcher + Odins Fj formations (Bengaard & Henriksen 1984), overlaid on a false colour composite ASTER image. Tent symbols denote camp sites. Star marks location of in situ mineralisation, striped area indicates area with abundant mineralised float. Locations of stream sediment samples, colour coded according to their Zn content as in Figure 3, indicated by squares (collected in 2013) and circles (collected prior to 2013).*

Figure 12. *Dolostone with sphalerite and white calcite vugs at locality A, Camp 5 (Team 7): view of outcrop, looking north (above), detail of outcrop (bottom left), and detail of locally derived mineralised float (bottom right).*

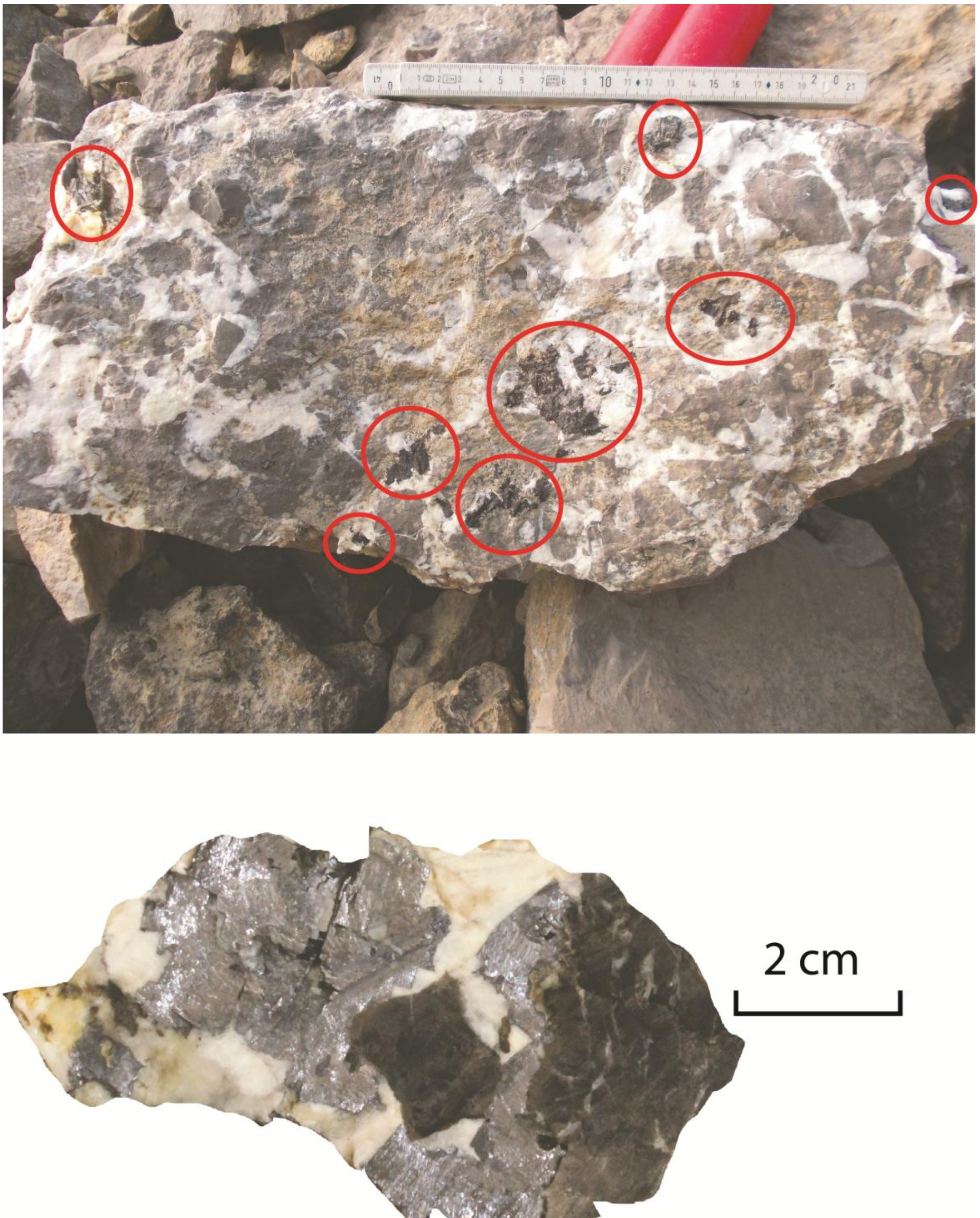

Figure 13. *Galena, barite and white calcite breccia at locality C, Camp 5 (Team 7): view of large float blocks, with galena pockets marked in red (above), and slab of sample 542950 (below).*

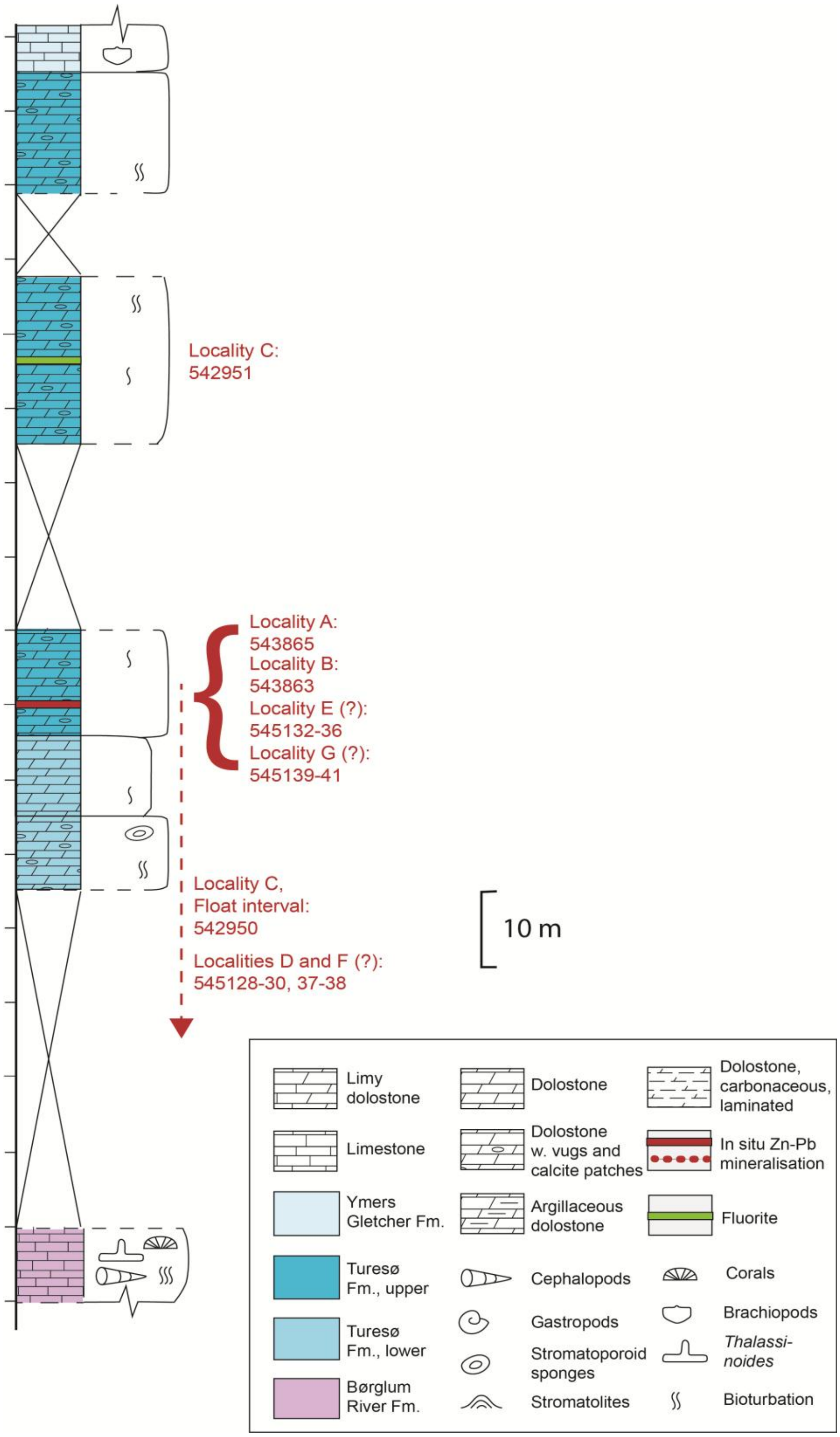

Figure 14. *Composite stratigraphic column at Camp 5 (Team 7) and Camp 4 (Team 6), illustrating setting of mineralisation.*

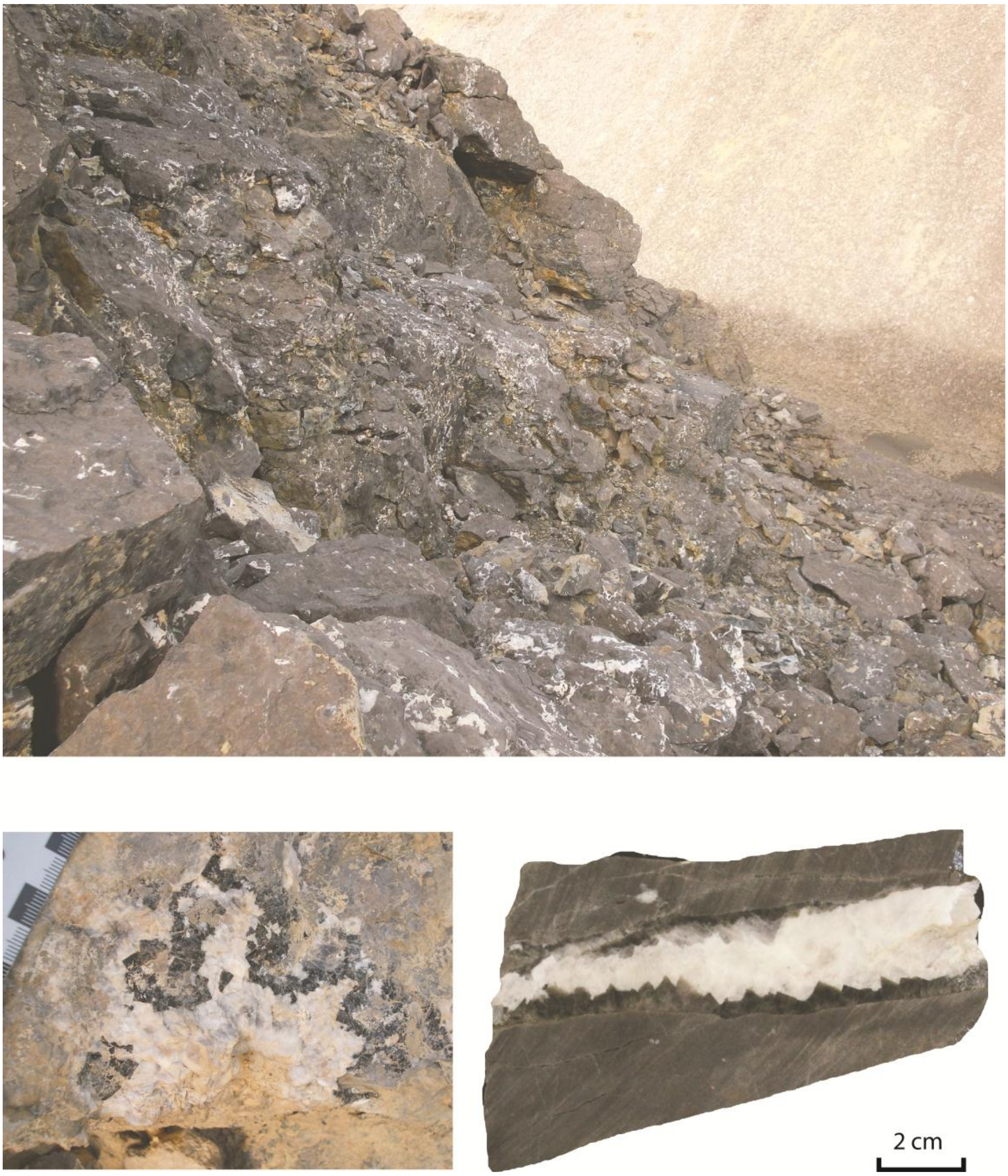

Figure 15. *White calcite and black fluorite veining in Upper Turesø dolostone at locality C, Camp 5 (Team 7): outcrop aspect, field of view ~2m across (above), detail of one pocket (below left), and slab of sample 542 51, with black fluorite selvage on white calcite vein (below right).*

Camp 5 (Team 6) – Kronprins Christian Land.

A brief camp (1 day) was set up in Kronprins Christian Land (Figure 1) to follow up on Zn showings discovered during the summer 2012 (Rosa & Kalvig 2013). The camp was setup in between two larger gullies from where the otherwise poorly exposed geology could be inspected. The main focus was on the Turesø Formation that was investigated where exposed. Locally, the bioturbation in this formation appears to have a more rusty appearance than at Peary Land. Furthermore, the Turesø Formation appears to be more compact and less porous, and noticeable lacks the brecciation and white calcite that hosts the mineralisation in Peary Land. The conducted field work did not reveal any signs of zinc mineralisation.

Reconnaissance flight (Team 6 + Team 7).

Leaving from Station Nord at the end of the season, one afternoon was spent on four stops in Kronprins Christian Land (see Figure 1 for recco stop locations). The primary target was the Turesø Formation but, in many places along the eastern shores of Danmarks Fjord, the unit was partially or completely covered by Quaternary sediments. Only at the two southernmost stops was the Turesø Formation well exposed. Two weakly mineralised float pieces (samples 545145-46, see Table 1 for analytical results) were found approximately 50 m below the upper boundary of the Turesø Formation, but the time limitations did not allow for a more complete understanding of their setting.

Reconnaissance of SEDEX targets

Target development and rationale

The geology of Amundsen Land (Figures 1 and 16) reflects a more basinward part of the Franklinian Basin, compared to the carbonate platform of Southern Peary Land and Kronprins Christian Land, investigated for MVT targets during the 2012 expedition (Rosa & Kalvig 2013) and again in 2013 (this report). This more basinward setting is favourable for SEDEX targets, as illustrated by the presence of the Citronen Fjord SEDEX deposit (van der Stijl & Mosher 1998), located in the eastern part of Frederik Hyde fjord. This deposit was formed in the deeper through part of the Franklinian Basin during Ordovician time, synchronously with deposition of the Amundsen Land Group. Special attention was therefore given to areas located within Ordovician strata of the Amundsen Land Group.

Within Amundsen Land, targets were generated considering exploration criteria derived from the SEDEX deposit model of Emsbo (2009). In contrast to MVT targets on the carbonate platform, which were shown to be very poor in pyrite and therefore not generating rust zones (Rosa & Kalvig 2013), it is believed that SEDEX mineralisation is pyrite rich and yields rust upon weathering, so that the identification of rust zones through the processing of ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) images can be an effective tool to generate targets.

Therefore, processing of multispectral satellite imagery from Amundsen Land was done at GEUS, in order to highlight zones enriched in ferric iron. Satellite data of reasonable or good quality from the ASTER imaging instrument, onboard NASA's Earth Observing System, was used. Processing lead to the identification of a number of areas anomalous in ferric iron (Tukianen, pers comm. 2013), referred to as ASTER anomalies; AA1 to AA8 (Figure16).

The areas identified through remote sensing were considered priority targets while stream sediment anomalies from data compilations (Thrane *et al*. 2011) were regarded as secondary targets. In mudstone-rich areas, stream sediments samples can reflect a high background of metal values, which can mask the existence of mineralised areas, and metal mobility in such acid environments can generate geochemical anomalies at significant distances from their source. However, known stream sediment anomalies were still investigated whenever encountered in the field.

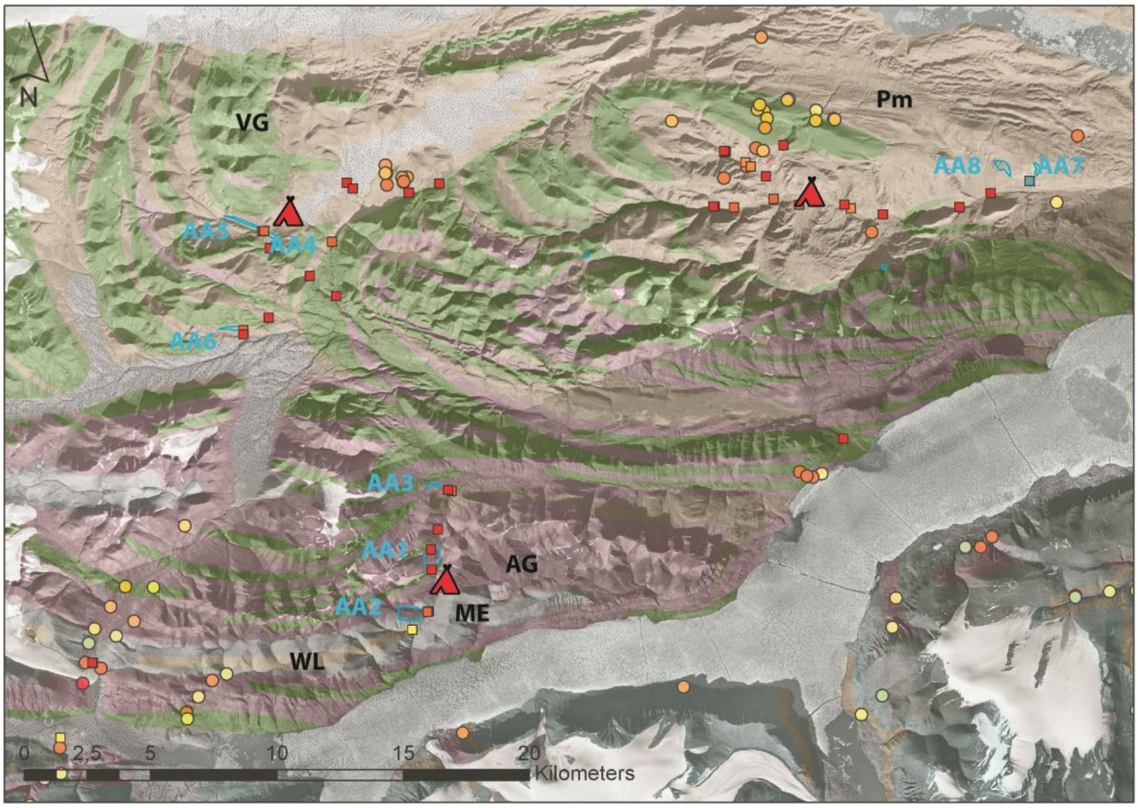

Figure 16. *Geological map of Amundsen Land overlaid on an orthophotograph mosaic. Pm – Polkorridoren Gp; VG – Vølvedal Gp; AG – Amundsen Land Gp; ME –Merqujôq Fm; WL – Wulff Land Fm (Bengaard & Henriksen 1984). Areas anomalous in ferric iron, as established through remote sensing, indicated by blue polygons, labelled AA -8. Tent symbols denote camp sites. Locations of stream sediment samples, colour coded according to their Zn content as in Figure 3, indicated by squares (collected in 2013) and circles (collected prior to 2013).*

Results

Camp 1 (Team 6) – Amundsen Land.

This camp was set up to study the Amundsen Land group within the southern part of Amundsen Land (Figure 16). Camp 1 was located within a narrow, approximately N-S trending, gully that allowed access to target areas AA1, AA2 and AA3. The gully cuts through Cambrian rocks of the Vølvedal Group at sea level to Silurian rocks of the Wulff Land Formation (Peary Land Group) within the core of marked syncline approximately four kilometers inland, close to target area AA2. Further inland, between target areas AA1 and AA3, rocks of the Ordovician Amundsen Land Group are outcropping together with older Cambrian rocks of the Vølvedal Formation which are exposed in anticline structures. This allows assessing for mineralisation over a broad depositional time-span. The area is structurally complex with numerous fold-and-thrust sheets (Pedersen 1980), that formed in response to intense deformation during the Ellesmerian orogeny in Devonian-Carboniferous times (Higgins *et al*., 1991).

AA 1, 2 and 3 were investigated from Camp 1 and none of them could be related to mineralisation. The AA1 target area is located within the Ordovician part of the Amundsen Land

Group inside a small valley flanked by Cambrian rocks. Exposures are scarce within the target area and mainly confined to the valley flanks. It is difficult, therefore, to assess what causes the remote sensing anomaly. In this respect, it is noted that a bedded chert sequence in the northwestern part of the target area has bands with rusty surface colours, which potentially could lead to an enhanced ferric iron signal. However, the bands are relatively small and whether they could be responsible for the iron-enrichment is unclear and highly speculative. The AA2 target area is also located within strata of the Amundsen Land Group but also straddles younger Silurian rocks of the Merqujôq Formation (Peary Land Group). Based on the investigations, it is unclear what causes the anomalous character of this target area. A suite of rocks from the draining system around the anomaly was collected for further analysis. The AA3 target area is situated within strata of the Amundsen Land Group in an approximately east-west trending valley (Figure 17). The anomalous area corresponds to a slightly-elongated hilly area within the valley. This area is crosscut by a few east-west trending mafic dykes. No mineralisation was revealed and it is considered likely that the remote sensing anomaly within the target area may be caused by the presence of mafic dykes.

Figure 17. *Panorama showing the hilly elevated area around AA 3. Viewing direction is north and the field of view is approximately 1.5 km. The area is cross-cut by a few east-west trending mafic dykes as indicated by the arrows. It is considered likely that the dykes cause to the Fe-anomaly observed from the Aster satellite data***.**

Camp 2 (Team 6) – Amundsen Land.

This camp was setup to investigate target areas AA4 – AA6 and a cluster of stream sediment anomalies (Figure 16). The area covers mainly Cambrian rocks of the Polkorridoren Group and Vølvedal Group. Similarl to Camp 1, no evidence of Zn mineralisation was identified.
The studied target areas are all located within rocks from the Polkorridoren Group, mainly consisting of variegated mudstone or siltstone. Only minute and rare occurrences of pyrite were found at one location within the AA4 target area, where dolostone with iron staining was also observed in a couple of places. These findings are insignificant and no clear evidence for SEDEX mineralisation was identified. The three areas show the same conspicuous reddish/greenish colour variations (Figure 18), which are likely related to differences in the Fe^{3+}/Fe^{2+} ratio of the mudstones. Areas with reddish colours are likely to be richer in ferric iron and poorer in ferrous iron, compared to the greenish parts as well as the surroundings. The target areas roughly coincide with areas where the reddish colour predominates, suggesting that the remote sensing anomalies could be caused by higher ferric iron content, than in the surrounding mudstones.

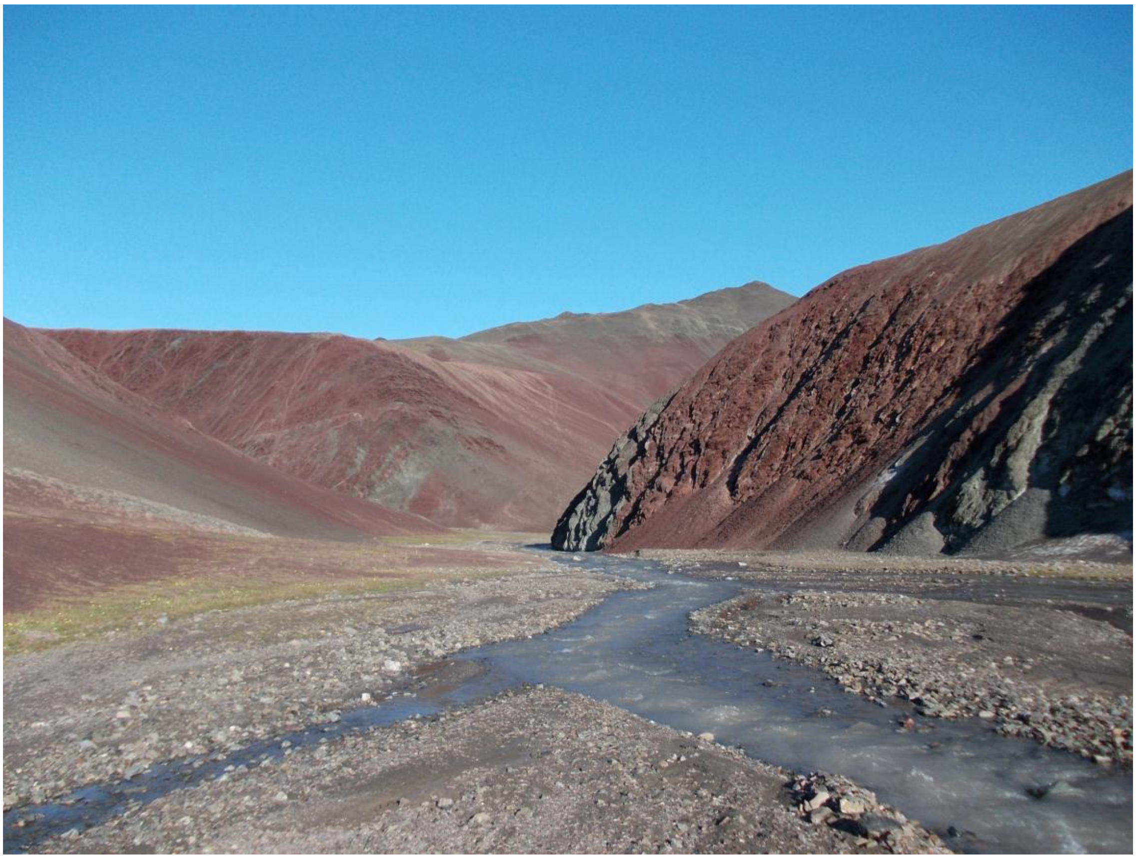

Figure 18. *View of the variegated nature of the Polkorridoren mudstones around target areas AA4 and AA5. Looking east and the field of view is approximately 75 m.*

In addition to the discussed remote sensing target areas, an area around a cluster of stream sediment samples with high Zn content (Figure 16), to the northeast of camp, was investigated. These stream sediments were collected within Cambrian mudstones of the Polkorridoren Group and the outcome of the investigation was negative with respect to mineralisation. Although none of the stream sediment samples could be sourced to a mineralised area, it was noted that reddish mudstones were partly outcropping in the area. While speculative, it cannot be ruled out that the Cambrian mudstones could be rather rich in Zn and have given rise to the anomalies. As a further note, a number of dikes crosscut the valley floor. One east-west trending dike is rather rich in pyrite.

Camp 3 (Team 6) – Amundsen Land.

This camp was set up to visit target area AA7 and AA8, and investigate the stream sediment sample Zn anomalies (Figure 16). Target areas and stream sediment samples are all located within Cambrian mudstones of the Polkorridoren Group. In comparison to Camp 2, the area around Camp 3 has a relatively high abundance of clay material (Figure 19) which is outcropping within the Tyrs Elv valley. The AA7 and AA8 target areas (Figure 16 and 19) are located in the outer part of valley and correspond to an area with variegated mudstones with predominantly reddish colours. No mineralisation was observed and the anomalous character of the area is attributed to a higher Fe^{3+}/Fe^{2+} ratio within the reddish coloured mudstone, similarly to what was previously discussed. Stream sediment sample anomalies were located in the inner part of Tyrs Elv (Figure 16). It was not possible to trace the anomalies to mineralisation in outcrop, so the cause to the elevated Zn content remains unknown. It is noted though that the reddish variety of the variegated mudstone frequently outcrops in the vicinity of the stream sediment samples. In order to better understand the area, a more systematic collection of stream sediment samples was undertaken within the Tyrs Elv area.

Figure 19. *Panorama showing the variegated mudstone of the Polkorridoren around target areas AA7 and AA8. The Polkorridoren mudstones are here found above a marked bed of hardened clay, which is frequently found outcropping in the Camp 3 (Team 6) area. Looking north and the field of view is approximately 5 km.*

Reconnaissance flight (team 6)

A set of intrusions has been reported between Frigg Fjord and Midtkap, the so-called Midtkap Igneous Complex (Soper *et al.* 1980; Parsons 1981; Pedersen 1980; Pedersen & Holm 1983). One of these intrusions has been dated at 380+/-5 Ma using the K/Ar dating method (Pedersen & Holm 1983). However, it is most likely that the age represents the time of metamorphism and not the age (closure temperature) of the original rock. In case of the Midtkap area, the area was affected by the Ellesmerian orogeny and the K/Ar age could represent the timing of deformation related to the orogeny. If this is the case, it is possible that the igneous complex is older than reported which would have significant geodynamic and, potentially, metallogenic implications. Therefore, a reconnaissance flight visiting four of the intrusions was undertaken. Adopting the naming convention of Soper *et al.* (1980), intrusions A, D, E and F were visited on short ground stops where samples were collected with the aim of age determination (see Figure 1 for stop locations).

Stream sediment sampling program

Approach

A total of 100 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). Most of the 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. Only some of the undertaken sampling has a regional character, aimed at filling in areas that were not sampled in previous campaigns, namely near the southeastern coast of Peary Land.

Results

The geochemical results have been added to the GEUS database. Figure 3 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). Note that due to recent corrections made to the locality database, prompted by improved cartographic information, the location of some stream sediment samples is different than that included in Figure 5 of Rosa & Kalvig 2013.

As expected, samples collected within the trough part of the basin, in Amundsen Land, have higher zinc concentration than those collected within the carbonate platform, in southern Peary Land and Kronprins Christian Land. However, as stated above, this is most likely the result of higher background values in local mudstones, coupled with enhanced metal mobility in a more acid environment, rather than the presence of widespread mineralisation.

In Amundsen Land, the highest zinc concentrations are found in stream sediment samples collected within or draining areas of the Ordovician Amundsen Group. Lower values are found in samples collected within the Silurian Merqujôq Formation. However, field work in Camp 1 (Team 6) failed to identify any evidence for SEDEX mineralisation within the former group, which hosts the Citronen Fjord deposit, approximately 100 km to the east. High zinc concentrations also occur in samples collected within or draining areas of the Cambrian Vølvedal or Polkorridoren groups, some of which were investigated in camps 2 and 3 of Team 6, without yielding any evidence for mineralisation.

Within the carbonate platform of Peary Land, the newly acquired data set complements the pre-existing data set but does not significantly add to the observations reported by Rosa & Kalvig (2012). Significantly anomalous zinc values in stream sediments appear in areas where MVT mineralisation has been identified within the Turesø formation. However, as for example in Tvilum Elv, mineralised localities exist which do not translate as outstanding stream sediment zinc anomalies. This may be due to the limited mobility of metals in the prevailing alkaline environment. Therefore, while stream sediment zinc anomalies appear to be an important tool in recognising mineralised MVT localities, they are not necessarily always effective, at least when sampling density is rather low.

Conclusions

The Turesø Formation was confirmed as a favourable stratigraphic horizon for MVT zinc-lead mineralisation. Two new multi-locality showings were identified, at Tvilum Elv and at “Løgum Elv”, and one of the showings identified in 2012, in Børglum Elv, was re-visited and significantly expanded, also to multi-locality status. In addition to the identification of more showings and mineralised localities, the newly discovered mineralisation is also mineralogically more complex, as indicated by the presence of significant amounts of galena, in addition to the previously documented sphalerite. This suggests a longer lasting hydrothermal event, favourable to the deposition of larger amounts of metals.
The mineralisation in the three identified showings can be present within three specific stratigraphic horizons; one within the pale-weathering Lower Turesø Formation, the other two within the dark-weathering Upper Turesø Formation. While the former horizon was only identified in one locality (Tvilum Elv), the latter two can be correlated across the southern part of Peary Land (Figure 20). Mineralised horizons within the dark-weathering Upper Turesø Formation include one horizon located ~50 m and another ~80 m below the contact of this formation with the Ymers Gletcher Formation. Mineralisation in the lowermost of these two horizons, located immediately above the transition from pale-weathering Lower Turesø Formation to the dark-weathering Upper Turesø Formation, was particularly well documented, which suggests this mineralised horizon is quite continuous. It is likely that the mineralisation identified by Rosa & Kalvig (2013), in Kronprins Christian Land, is also hosted by this more continuous horizon. Tis study therefore constitutes a significant refinement of what has been initially reported by Rosa & Kalvig, 2013.
In contrast to the search for MVT mineralisation, the search for SEDEX mineralisation failed to yield any possible showings. The reasons for this may be attributed to a variety of factors which generated inadequate targets. It is possible that part of the reconnaissance was focused too low in the stratigraphy, below the favorable Citronen Fjord horizon. Furthermore, it is possible that the remote sensing of ASTER images is hampered by the low level of radiance, due to low sun illumination angle, and might be too sensitive to Fe^{3+}/Fe^{2+} variations in mudstones, to allow the identification of rust zones from weathering sulphide bodies. Furthermore, the elevated zinc concentration background in mudstones may be masking mineralisation anomalies, effectively excluding the use of stream sediment values for target generation. This is further exacerbated by the fact that some of the stream sediment sample locations are misplaced.

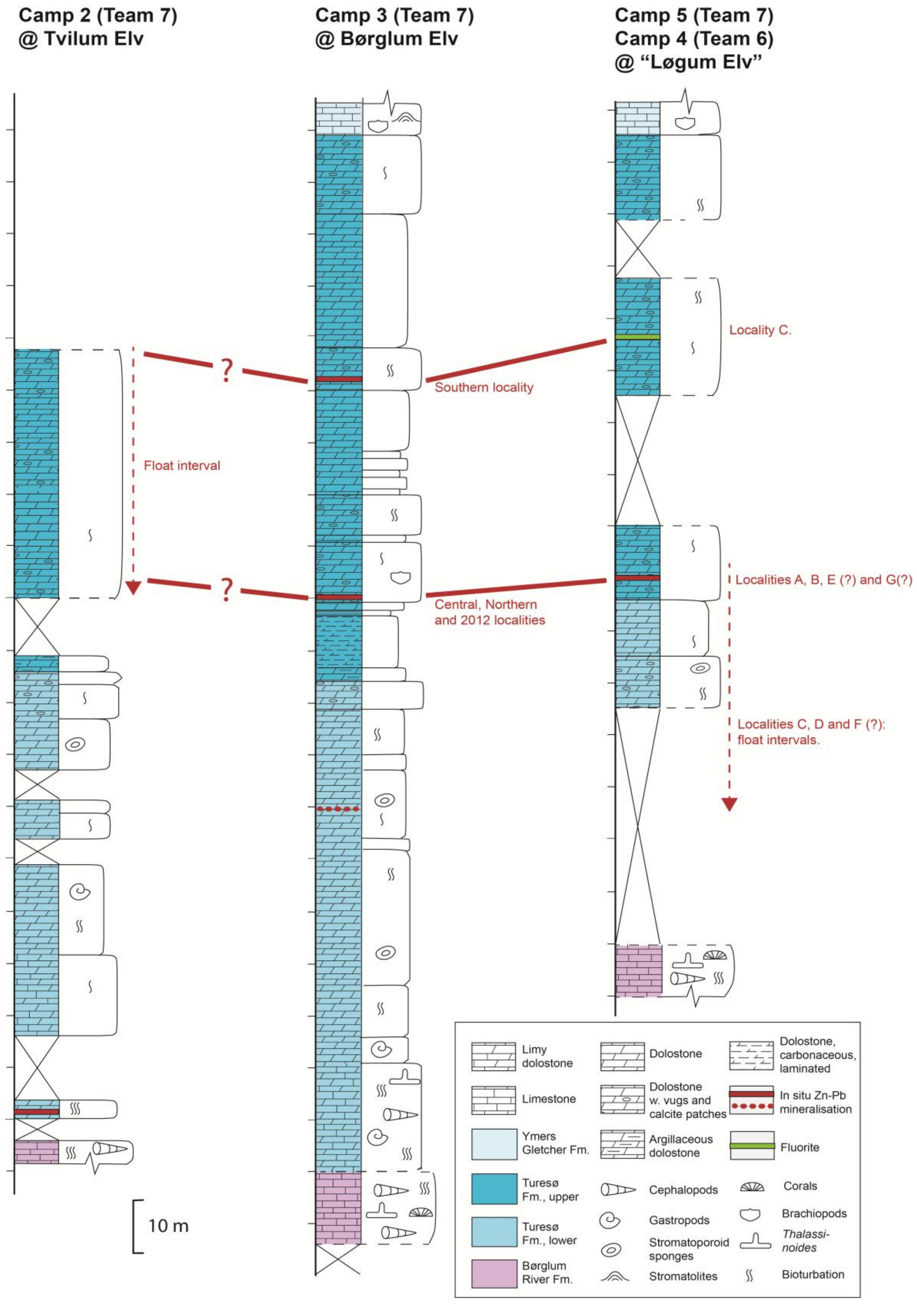

Figure 20. *Correlation across the composite stratigraphic columns at each of the mineralised showings.*

Recommendations

It is suggested that future work focuses on the lowermost part of the dark-weathering Upper Turesø Formation, as this is the stratigraphic level where the most continuous and extensive mineralised horizon was identified. The equivalent horizon towards the west, in Central Northern Greenland, within the Aleqatsiaq Fjord Formation, should also be studied in more detail. To further constrain the presence of mineralisation, and as recommended by Rosa & Kalvig (2013), a regional aeromagnetic survey should be flown, as it would assist in identifying basement structures that could channel mineralising fluids.

The overall stream sediment zinc content in Amundsen Land is elevated and additional follow up work is therefore still warranted. For this, it is recommended that the use of alternative satellite sensors (i.e. Worldview, Geoeye-1, Ikonos, Quickbird), which have a more extended coverage than ASTER, is exploited as a tool for effective target selection.

Acknowledgements

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References

Armstrong, H. A. & Lane, P. D. 1981: The un-named Silurian (?) dolomite formation, Børglum Elv, central Peary Land. Rapport Grønlands geologiske Undersøgelse 106, 29–34.

Bengaard, H.J., & Henriksen, N. 1984: Geology 1: 500 000 Peary Land. Copenhagen, Geological Survey of Greenland.

Christie, R.L. & Ineson, J.R., 1979: Preecambrian-Siluarina geology of the G.B. Schley Fjord region, eastern Peary Land, North Greenland. Rapport Grønlands Geologiske Undersøgelse, 88, 63–71.

Christie, R. L. & Peel, J. S. 1977: Cambrian-Silurian stratigraphy of Børglum Elv, Peary Land, eastern North Greenland. Rapport Grønlands geologiske Undersøgelse 82, 48 pp.

Cooper, R. A. & Sadler, P. M. 2012. Chapter 20. The Ordovician Period. In Gradstein, F. M., Ogg, J. G., Schmitz, M. D. & Ogg, G. M. (eds): The Geological Time Scale 2012, 489–523. Elsevier, Amsterdam.

Cope, I. & Beswick, J., 1999; Wahsingtion Land Report, 30 pp. + enclosures. Unpublished report Rio Tinto Mining and Exploration Ltd, Bristol, UK (in archives of Geological Survey of Denmark and Greenland, GEUS Report File 21718).

Dawes, P.R., 2009: Precambrian–Palaeozoic geology of Smith Sound, Canada and Greenland: key constraint to palaeogeographic reconstructions of northern Laurentia and the North Atlantic region. Terra Nova 21, 1–21.

Friderichsen, J.D., Higgins, A.K., Hurst, J.M., Pedersen, S.A.S., Soper, N.J. & Surlyk, F. 1982: Lithostratigraphic framework of the Upper Proterozoic and Lower Palaeozoic deep water clastic deposits of North Greenland. Rapport Grønlands Geologiske Undersøgelse 107, 20 pp.

Fürsich, F.T, & Hurst, J.M. 1980: Euryhalinity of Paleozoic articulate brachiopods. Lethaia 13, 303–312.

Henriksen, N., Higgins, A.K., Kalsbeek, F. and Pulvertaft, T.C. 2000: Greenland from Archaean to Quaternary. Descriptive text to the Geological map of Greenland 1:2 500 000. Geology of Greenland Survey Bulletin 185, 93 pp.

Henriksen, N. 2008. Geological History of Greenland: Four Billion Years of Earth Evolution. Geological Survey of Denmark and Greenland, Ministry of Environment. 270 pp.

Higgins, A.K., Ineson, J.R., Peel, J.S., Surlyk, F., & Sønderholm, M. 1991: Lower Palaeozoic Franklinian Basin of North Greenland, Bull. Grønlands Geologiske Undersøgelse, 160, p. 71–139.

Hurst, J.M., 1984: Upper Ordovician and Silurian carbonate shelf stratigraphy, facies and avolution, eastern North Greenland, Bull. Grønlands Geologiske Undersøgelse, 148, 73 pp.

Jakobsen, U.H. & Steenfelt, A., 1985: Zinc mineralization at Navrana Fjord, central North Greenland, Rapport Grønlands Geologiske Undersøgelse, 126, 105-109.

Jensen, S.M. & Schønwandt, H-K, 1998: A new carbonate-hosted Zn-Pb-Ag occurrence in Washington Land, western North Greenland. Danmarks og Grønlands Geologiske Undersøgelse Rapport 1998/3, 31 p

Parsons, I. 1981: Volcanic centres between Frigg Fjord and Midtkap, eastern North Greenland. Rapport Grønlands Geologiske Undersøgelse, 106, 69-75.

Pedersen, S. A. S. 1980: Regional geology and thrust fault tectonics in the southern part of the North Greenland Fold Belt, North Peary Land. Rapport Grønlands Geologiske Undersøgelse, 99, 79-87.

Pedersen, S. A. S &, Holm, P. M. 1983: The significance of a Middle Devonian K/Ar age of an intrusive rock in the southern part of the North Greenland Fold Belt. Bull. Geol. Soc. Denmark, vol. 31, p. 121-127.

Peel, J. S. 1985: Cambrian - Silurian platform stratigraphy of eastern North Greenland. In Gee, D. G. & Sturt, B. A. (ed.) The Caledonide Orogen - Scandinavia and related areas, 1077–1094. London: John Wiley & Sons.

Peel, J . S. & Christie, R. L. 1982: Cambrian-Ordovician platform stratigraphy: correlations around Kane Basin. In Dawes, P. R . & Kerr, J . W. (ed.) Nares Strait and the drift of Greenland: a conflict in plate tectonics. Meddelelser om Grønland, Geoscience 8, 117–135.

Rosa, D. & Kalvig, P., 2013: Reconnaissance for Mississippi Valley-type Zn-Pb deposits in the Franklinian Basin, Eastern North Greenland – Results of the 2012 Season. Danmarks og Grønlands Geologiske Undersøgelse Rapport 2013/19, 33pp.

Smith, M.P. & Rasmussen, J.A., 2008: Cambrian–Silurian development of the Laurentian margin of the Iapetus Ocean in Greenland and related areas. In Higgins, A.K., Gilotti, J.A. & Smith, M.P. (eds): The Greenland Caledonides – evolution of the Northeast margin of Laurentia. Geological Society of America, Memoir 202, 137–169.

Soper, N.J. & Higgins, A.K. 1987: A shallow detachment beneath the North Greenland fold belt: implications for sedimentation and tectonics. Geological Magazine 124, 441–450.

Soper, N.J. & Higgins, A.K. 1990: Models for the Ellesmerian mountain front in North Greenland: a basin margin inverted by basement uplift. Journal of Structural Geology 12, 83–97.

Soper, N. J., Higgins, A. K., Friderichsen, J. D. 1980: The North Greenland Fold Belt in eastern Johannes V. Jensen Land. Rapport Grønlands Geologiske Undersøgelse, 99, 89-98.

Surlyk, F. & Hurst, J. M. 1984: The evolution of the early Palaeozoic deep-water basin of North Greenland. Bulletin of the Geological Society of America 95, 131–154.

Sørensen, L., Stensgaard, B.M., Thrane, K., Rosa, D. & Kalvig, P. 2013: Sediment-hosted zinc in Greenland - Reporting the mineral resource assessment workshop 29 November - 1 December 2011, Danmarks og Grønlands Geologiske Undersøgelse Rapport 2013/56, 184 pp.

Thrane, K., Steenfelt, A. & Kalvig, P. 2011: Zinc potential in North Greenland, Danmarks og Grønlands Geologiske Undersøgelse Rapport 2011/143, 64pp.

Troelsen, J.C., 1950: Contributions to the geology of northwest Greenland, Ellesmere Island and Axel Heiberg Island. Meddelelser om Grønland 149, 86 pp.

van der Stijl, F.W., & Mosher, G.Z. 1998: The Citronen Fjord massive sulphide deposit, Peary Land, North Greenland: discovery, stratigraphy, mineralization and structural setting. Geology of Greenland Survey Bulletin 179, 44 pp.

von Guttenberg, R. & van der Stijl, F. 1993: Nanisivik Mines Ltd., Platinova A/S. North Greenland project 1992, report of work. January 1993. Internal report, Strathcona Mineral Services Ltd., 65 pp.