Carbonate-hosted Zn-Pb-Ag mineralisation in Washington Land, western North Greenland

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The multidisciplinary research project 'Resources of the sedimentary basins of North and East Greenland' was initiated in 1995 with financial support from the Danish Research Councils (Stemmerik *et al.* 1996). In 1997, North Greenland field studies under this project were carried out by the Geological Survey of Denmark and Greenland (GEUS) in Washington Land. A two-week field season included sedimentological and petroleum geology-related studies, and reconnaissance exploration for economic mineral occurrences.

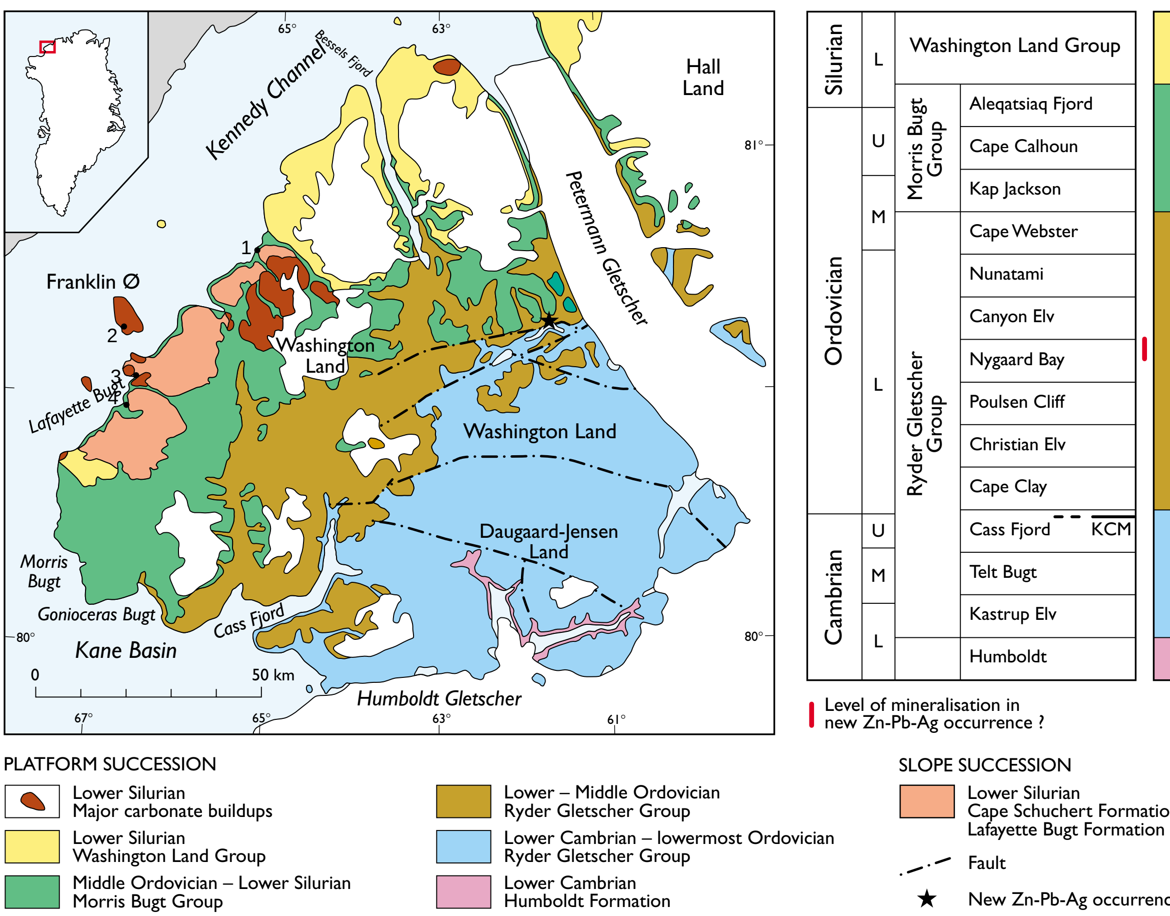


Fig. 1. Geological map of Washington Land, modified after Jepsen *et al.* (1983) and Bengaard & Henriksen (1991). A star shows the location of the new Zn-Pb-Ag occurrence. The only previously known sulphide occurrence (Norford 1972) is located at Kap Schuchert (locality 1). Finds of boulders with sphalerite (or hydrozincite) or galena are numbered 2–4. **Right**: Cambrian – Lower Silurian platform stratigraphy of Washington Land, after Higgins *et al.* (1991). Red bar indicates speculative stratigraphic level of mineralisation in the new Zn-Pb-Ag occurrence. KCM: Kap Coppinger Member.

Fig. 2. New Zn-Pb-Ag occurrence, eastern Washington Land: aerial photograph looking north-north-west over the central part of the train of rusty weathering patches (indicated by dashed line). Width of view is *c.* 500 m.

Washington Land is made up of Cambrian – Lower Silurian carbonate platform and Lower Silurian reef belt successions of the Franklinian Basin. In northern Canada, platform carbonates of the Franklinian Basin host a major producing Zn-Pb deposit (Polaris) and several other sulphide occurrences (Kerr 1977; Gibbins 1991). The platform succession in North Greenland has received less attention from an exploration point of view, and to date only a few, scattered carbonate-hosted sulphide occurrences have been discovered (Jakobsen & Steenfelt 1985; von Guttenberg & van der Stijl 1993; Lind *et al.* 1994). One sulphide occurrence was known in Washington Land prior to the 1997 field work (Norford 1972; Lind *et al.* 1994).

Cambrian – Lower Silurian carbonate platform

Discovery of a new Zn-Pb-Ag occurrence

One of the prospecting targets in Washington Land was fault-related Zn-Pb mineralisation in the carbonate platform succession. A number of roughly E–W trending regional-scale faults transect east-central and southern Washington Land, as marked on the 1:250 000 geological map (Jepsen *et al.* 1983) which forms the basis of Figure 1. An approximately 15 km wide, WSW–ENE trending corridor between central Washington Land and Petermann Gletscher was thought to be a promising area in which to look for signs of fault-related mineralisation.

A new Zn-Pb-Ag occurrence was discovered in eastern Washington Land during helicopter reconnaissance, *c.* 8 km west of Petermann Gletscher (Fig. 1). The surface expression of the mineralisation is a train of rusty weathering patches on a gently sloping plain covered by soliflucted mud and frost-heaved blocks (Fig. 2). The plain lies on the north shore of a 9–10 km long, narrow lake in the foothills of the ice-capped mountains of northern Washington Land. To the south of the lake lies a large plateau of poorly exposed Cambrian carbonate rocks.

The train of rusty weathering patches was followed over a 2.4 km long and approximately 100 m wide NE–SW trending zone. A dozen patches with diameters of 3–30 m were distinguished. The greatest density of patches is just east of the N–S flowing stream that cuts a shallow gorge into bedrock (Fig. 2).

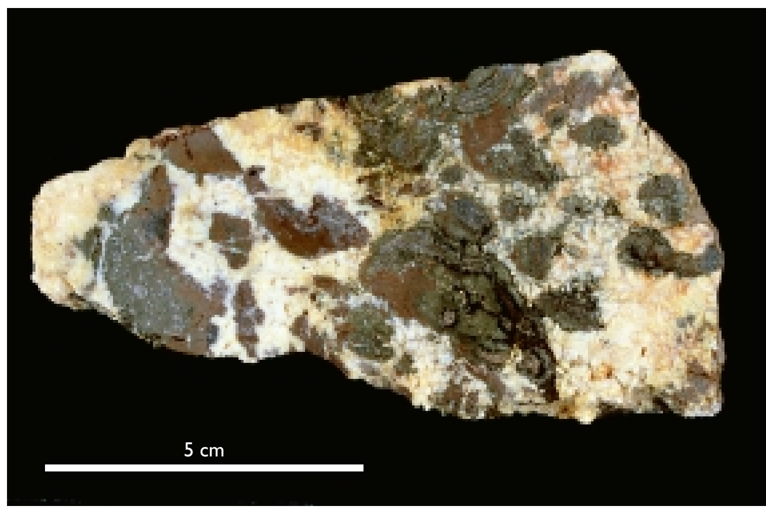
Mineralisation

Dolomitic boulders variably mineralised with sphalerite, galena and pyrite were found within the rusty weathering patches (Fig. 3). The mineralised samples collected are strongly dolomitised and show very variable sulphide parageneses. Both pyrite-dominated, sphalerite-galena-dominated and pyrite-sphalerite-galena-rich mineralised rocks were found within most patches. Due to prolonged subaerial exposure the mineralised samples are rarely fresh.

Zinc mineralisation was revealed in the field either by visible sphalerite or a strong Zn spot test reaction. The sphalerite occurs most commonly as large (0.5–5

Fig. 3. New Zn-Pb-Ag occurrence, eastern Washington Land: rusty weathering outcrop of sulphide-rich, dolomitised limestone. Note seated person at left for scale.

Fig. 4. New Zn-Pb-Ag occurrence, eastern Washington Land: cut slab of boulder sample. Coarse-grained dolomite with large sphalerite aggregates – note colloform-banded pyrite and sphalerite in central part of slab (sample GGU 447027: 15% Zn, 0.4% Pb).



cm) aggregates, but can also be found fine-grained and disseminated. The colour varies from dark brown to honey coloured. Galena is often present as large (5–10 mm), relatively fresh euhedral grains. Pyrite occurs with a range of textures, from very fine-grained and massive to colloform-banded (Fig. 4) or coarse-grained aggregates. Bitumen with vitreous lustre was found in a few mineralised samples near the stream, occupying vugs in coarse-grained, sparry dolomite.

Judging from outcrops along the stream, the sulphide mineralisation is associated with a pervasively dolomitised horizon of 6–8 m thickness. Sulphide-rich pods occur very irregularly, and appear to be concentrated in the upper parts of the dolomitised horizon. The *in situ* mineralisation observed is generally pyrite-dominated.

Sampling and analyses

Samples from the rusty weathering patches are all strictly speaking loose blocks, but are believed to have lain directly above, or within a few metres distance of their original bedrock position (Fig. 3). Only the samples collected along the stream are true bedrock samples. One or two composite samples of *c.* 3 kg size were collected from each of the rusty weathering patches.

Visually estimated Zn and Pb grades vary from close to nil to over 20% Zn and 10% Pb. Multi-element neutron activation (INAA) and inductively coupled plasma emission (ICP) analyses of 23 samples have indicated several anomalous Ag values, with a maximum of *c.* 170 ppm. Subsequent assays of eight samples have confirmed the highest Zn, Pb and Ag values. The mineral-

Table 1. Summary of zinc, lead, silver and iron analyses of boulder samples from the new Zn-Pb-Ag occurrence, eastern Washington Land

Sample GGU no.	Zn* %	Pb* %	Ag* ppm	Fe† %
447018	2.85	2.94	31	2.40
447021	1.25	0.18	1.6	12.1
447022	0.22	0.03	1.4	22.6
447023	8.21	0.01	20	24.8
447024	0.04	0.01	0.4	34.7
447025	0.03	0.001	0.5	2.09
447026	0.06	0.64	0.4	4.44
447027	15.3	0.41	–	6.89
447028	0.34	0.06	4.4	6.71
447029	0.66	7.67	2.5	9.80
447030	0.20	0.02	3.7	1.76
447033	24.5	12.70	170	4.96
447034	0.08	0.03	1.3	18.2
447035	3.27	0.01	1.6	1.35
447036	0.53	0.02	2.3	15.2
447037	0.38	0.004	0.9	5.29
447038	0.20	0.01	0.7	33.6
447040	0.12	0.18	1.4	25.4
447043	0.72	0.01	–	32.7
447044	0.09	0.01	–	42.9
447045	0.01	0.005	–	37.2
447046	0.01	0.01	–	27.1
447047	0.03	0.01	–	30.0
mean	2.57	1.09	14	17.5
median	0.22	0.02	1.6	15.2
standard deviation	5.92	3.03	41	13.5

– below detection limit of 0.4 ppm;
* estimated from INAA, ICP and assay values;
† Fe is total iron determined by INAA.
Analyses by Activation Laboratories Ltd., Ancaster, Ontario, Canada.

isation is further characterised by high Cd and Hg contents (Cd up to 841 ppm, median 10 ppm, 19 analyses; Hg up to 47 ppm, median 11 ppm, 7 analyses). Analyses for Zn, Pb, Ag and Fe are summarised in Table 1; the full analytical data set is given in Jensen & Schønwandt (1998).

Although the higher grades are generally found near the intersection of the stream and the train of rusty weathering patches, the best mineralised sample (447033) was collected at the far south-western end of the mineralised zone, about 2 km south-west of the main cluster of patches.

Geological setting

The sedimentary succession in the area around the new Zn-Pb-Ag occurrence has a shallow dip to the north-west, with measured orientations of bedding planes of 025–035°/5–15°NW. On the published 1:250 000 geological map (Jepsen *et al.* 1983), the sulphide occurrence is seen to lie within the upper part of a mapped unit comprising the Poulsen Cliff and Nygaard Bay Formations (Ryder Gletscher Group). The exact stratigraphic position of the dolomitisation and sulphide mineralisation remains to be established, but seems likely to be within the evaporitic upper part of the Nygaard Bay Formation (Fig. 1).

The main cluster of rusty weathering patches lies about 1 km north of the projected trace of a regional E–W striking fault (Fig. 1). The trace of the regional fault was not observed directly in the field, but is shown on the 1:250 000 geological map (Jepsen *et al.* 1983). At the far south-western end of the mineralised trend, a 6–8 m wide faulted zone (048°/58°N) is exposed for *c.* 10 m along strike. This faulted zone is oblique to the regional fault, but aligned roughly with the mineralised trend.

Tentative model

The new Zn-Pb-Ag occurrence is hosted by the partly evaporitic, Lower Ordovician part of the carbonate platform succession. One can speculate that hydrothermal fluids carrying metals in solution migrated up along fault planes and that sulphides precipitated where dolomitisation created open space and sulphur was available. The sulphur was perhaps derived from the evaporite beds. For this sulphur to have been incorporated into sulphides, a mechanism to reduce SO_4^{2-} to S^{2-} must have been available. The presence of bitumen in some of the sulphide-mineralised samples suggests that thermochemical sulphate reduction may have taken place, at least very locally. The source of metals is suggested to have been the underlying Lower Cambrian siliciclastic sequence (Humboldt Formation) or perhaps the crystalline basement.

Lower Silurian reef and slope succession

Kap Schuchert

Mineralisation at Kap Schuchert (locality 1 in Fig. 1) was discovered in 1966 during joint Geological Survey of Canada and Geological Survey of Greenland field work in North Greenland and Ellesmere Island, Canada (Norford 1972). The results of a brief visit to the locality in 1971 by Cominco geologists did not warrant follow-up (Cominco Ltd. 1971).

Analyses of three mineralised vein samples collected at the locality in 1997 are listed in Table 2. All three samples show anomalous silver contents. Sample 447013 is from a 5 cm wide and 10 m long sulphide-bitumen-rich quartz-calcite vein that was also described by Norford (1972). The mineralised rocks are brownish, nodular weathering limestones with a distinct petroliferous odour. Sulphide-filled vugs (Norford 1972) and sulphide-bitumen-rich, small veins occur in the brownish limestone unit. Overlying light grey crinoidal limestones and calcarenites appear to have formed a 'lid' over the hydrocarbon-impregnated unit, and are only mineralised where breached by vertical joints or small veins.

Scattered mineralised boulders

A few boulders with minor amounts of sphalerite or galena were collected along rivers draining Lower Silurian reef and slope complexes exposed on the coast of Kennedy Channel (localities 2–4 in Fig. 1). None of the boulders were traced back to bedrock mineralisation. Sample 447008, collected on Franklin Ø, is anomalous with respect to silver (Table 2). The boulder samples probably represent mineralisation similar to that found at Kap Schuchert.

Table 2. Summary of zinc, lead, silver and iron analyses of boulder samples from the Lower Silurian reef and slope succession

Sample GGU no.	Locality, Fig. 1	Zn† %	Pb† %	Ag† ppm	Fe‡ %
100825*	1	1.5	2.0	36	0.14
447013*	1	4.6	1.3	37	24.0
447016	1	0.02	0.07	6.6	12.1
447017	1	0.01	0.04	5.0	9.05
447008	2	0.12	0.03	6.5	0.11
447005	3	0.20	0.003	–	0.19
447004	4	0.73	0.20	–	0.11

– below detection limit of 0.4 ppm;
* sample 447013 is from the same vein as Norford's (1972) sample 100825;
† estimated from INAA, ICP and assay values;
‡ Fe is total iron determined by INAA.
Analyses by Activation Laboratories Ltd., Ancaster, Ontario, Canada.

Regional perspective

The decision to look for fault-related, carbonate-hosted mineralisation in east-central Washington Land arose from consideration of the geological setting of the Polaris Zn-Pb deposit in Canada (located *c.* 900 km south-west of Washington Land). Without wishing to suggest the new Zn-Pb-Ag occurrence to even remotely approach Polaris-class mineralisation, the two areas share several characteristics that may relate to their ore genesis (based on Polaris descriptions from Randell & Anderson 1990; Gibbins 1991; Sharp *et al.* 1995): (1) overall stratigraphic setting, (2) faults may have provided channels for metal-bearing fluids from a source in the basement or underlying siliciclastic units, (3) evaporitic units may have been the source of sulphate ions, (4) hydrocarbons may have caused thermochemical reduction of sulphate to sulphide, (5) extensive dolomitisation of host rocks.

The overall stratigraphy of the Cambrian–Ordovician platform of Washington Land has been correlated with that of eastern Ellesmere Island (Peel & Christie 1982), and areas farther south-west (Trettin *et al.* 1991; de Freitas *et al.* 1997). The Washington Land occurrence is, however, not hosted by the western North Greenland correlative to the Thumb Mountain Formation, Polaris' host rock. The Thumb Mountain Formation correlates in Washington Land with the Kap Jackson Formation (Morris Bugt Group, Fig. 1; Peel & Christie 1982; Smith *et al.* 1989). Although mineralisation at occurrence or deposit scale seems to be restricted to certain stratigraphic levels, this is not necessarily the case at regional scale, as illustrated by recent discoveries in the vicinity of the Polaris deposit (Harrison & de Freitas 1996).

Of a total of 37 analysed samples from Washington Land, 26 have shown detectable Ag (0.4 ppm or more), 16 over 1 ppm, 9 over 5 ppm, and 3 over 30 ppm, with a maximum of *c.* 170 ppm. Mineralisations in both the carbonate platform and the reef and slope successions, at localities up to 100 km apart, are thus characterised by somewhat anomalous silver contents. Mineralisations in the reef and slope succession differ geochemically from that of the new Zn-Pb-Ag occurrence in the carbonate platform in having anomalous As, Mo, Ba, Sr, V and REE contents, but no Hg enrichment.

Follow-up

The airborne geophysical survey 'AEM Greenland 1998', financed by the Government of Greenland and managed by GEUS, will include an about 9500 line kilometre GEOTEM/magnetic survey over east-central Washington Land, encompassing the new Zn-Pb-Ag occurrence and several prospective regional fault zones (Thorning & Stemp 1998, this volume).

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