sion, viz. Unit 12. The estimated thickness of Unit 10 is between 200 and 450 m.

Unit 11: Upper debris flow

This unit is a clast-supported limestone conglomerate in which clast size varies from centimetre to a couple of metres (see Fig. 26). In general, the rock is poorly sorted; vague preferred orientation of clasts is locally seen. The clasts are fossiliferous with crinoids and reef corals the most common forms. The matrix is argillaceous but it becomes increasingly sandy in northern exposures where the unit thins out and gradually changes into a matrix-supported conglomerate. The Upper debris flow, which is characterized by sharp upper and lower boundaries (Fig. 11), has an average thickness of about 20 m.

The Upper debris flow corresponds with the thin limestone conglomerate beds that occur in the uppermost part of the type section of the Citronens Fjord Member of Hurst & Surlyk (1982, section 33; location in Fig. 3).

Unit 12: Sandstone turbidites

This, the uppermost unit of the exposed succession the map area, is a reddish brown weathering, fine-grained turbiditic sandstone with common intercalations of carbonate and quartz-chert debris flows, and abundant calcareous siltstone. Sedimentary features such as graded bedding, cross-bedding, load casts, and flute marks are common (Fig. 12).

The sandstone turbidites interfinger with the calcareous siltstones of Unit 10 and they are limited upwards by the present erosion surface and surficial deposits. Our estimate of the preserved thickness of Unit 12 in the Citronen Fjord area is about 700 m but a greater thickness may occur to the south.

Lithostratigraphic correlation

In the section above, the twelve informal lithostratigraphic units recognized in the Citronen Fjord area, are described under three formally-named rock units, viz. the Cambrian Buen Formation, the Ordovician Amundsen Land Group and the Silurian Peary Land Group. In addition, the early Silurian part of the succession is correlated at formation level (Merqujôq Formation) while one member – the Citronens Fjord Member – that has its type section at Citronen Fjord (see Fig. 3), is readily applicable to this study (Fig. 7).

However, formal lithostratigraphic subdivision of the Cambro-Ordovician trough sediments in North Greenland has not been made and the formations mentioned in the literature and included on published maps of the Frederick E. Hyde Fjord area have not been formally described (Bengaard & Henriksen 1986a, b; Pedersen & Henriksen 1986; Higgins *et al.* 1991a; Henriksen 1992).

A summary of the lithostratigraphy of the Frederick E. Hyde Fjord area, taken from published sources, is given in Figure 13 but the stratal limits of the seven formations of the Vølvedal and Amundsen Land Groups, and their spatial distribution, remain unpublished. The correlation of the lower eight units mapped by us at Citronen Fjord to named units in the literature is not obviously apparent and therefore in this paper no formal correlation is attempted. However, some comments on the correlation of the informal units with the regional lithostratigraphy are given below as an aid to further mapping and research.

Cambrian

Are the Cambrian strata recognized herein at Citronen Fjord representative of the Buen Formation or the Polkorridoren Group?

The Polkorridoren Group is a monotonous sequence at least 2 km thick of turbiditic sandstones, siltstones and mudstones with a type area to the north-west of Citronen Fjord in Johannes V. Jensen Land (see Fig. 22; Dawes & Soper 1973; Friderichsen *et al.* 1982). The nearest exposures of this group have been mapped by Soper *et al.* (1980) immediately north of Citronen Fjord on the opposite side of Frederick E. Hyde Fjord, some 5 km distant. During our field work, Units 1, 2 and 3 were referred to the Buen Formation of Jepsen (1971) that is exposed to the east of Citronen Fjord in the Depotbugt – G. B. Schley Fjord area on the north-east side of the Trolle Land Fault Zone (Christie & Ineson 1979; see Fig. 22). The formation has a wide distribution farther south in Peary Land, everywhere overlying the platform carbonates of the Portfjeld Formation (Henriksen 1992).

The Buen Formation (Jepsen 1971) is defined as a typical siliciclastic shelf facies that grades over the outer shelf and margin into the slope and trough sediments of the Polkorridoren Group (Higgins *et al.* 1991a). Although the Cambrian strata at Citronen Fjord are situated north of the early Cambrian shelf and therefore might invite direct correlation with the deep water sediments of the Polkorridoren Group in Johannes V. Jensen Land, we favour placing the oldest strata of the Citronen Fjord area (Units 1, 2 and 3) in the Buen Formation. This disposition is based on the following observations and considerations.

1. The Cigar debris flow (Unit 2), which intermittently occurs within the Lower Cambrian sequence, probably represents an early base-of-slope debris flow derived from, and closely associated with, the nearby platform.

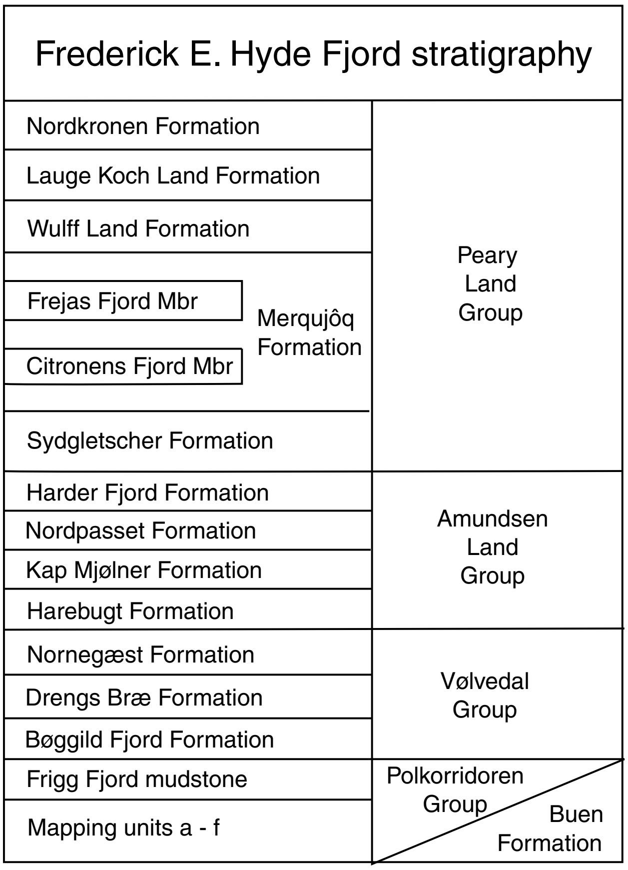

Fig. 13. General stratigraphic chart of the Lower Palaeozoic succession of the Frederick E. Hyde Fjord region compiled mainly from Higgins *et al.* (1991a), with some reference to Soper *et al.* (1980) and Henriksen (1992).

2. Our reconnaissance mapping along the southern coast of Frederick E. Hyde Fjord towards Depotbugt has proved the regional extent of the early Cambrian strata, with the correlation to the tripartite sequence at Citronen Fjord being confirmed by lithology and occasional finds of olenellid trilobites in black shales. As previously described (see section 'Cambrian–Silurian contact', p. 17), at the contact with the overlying sandstone turbidites of the Merqujôq Formation, a highly tectonized limestone debris flow with strongly elongated pebbles confirms the tectonic relationship between the Cambrian and Silurian parts of the succession.

3. In the Depotbugt area, the Merqujôq Formation and underlying Cambrian strata are in direct contact with early Silurian laminated and banded shelf carbonates of the Odins Fjord and Ymers Gletscher Formations (Hurst 1984). A few kilometres farther east, carbonates belonging to the Cambrian Portfjeld Formation are overlain by dark clastic sediments of the Buen Formation (Christie & Ineson 1979; Bengaard & Henriksen 1986a, b; Henriksen 1992).

4. The Polkorridoren Group of Johannes V. Jensen Land is structurally separated from the Lower Palaeozoic sediments south of Frederick E. Hyde Fjord by a major and regional dislocation – the Harder Fjord Fault Zone. This fault zone may well have been active during the Lower Palaeozoic sedimentation (Soper & Higgins 1987, 1991; see section 'Harder Fjord Fault Zone', p. 32).

We conclude that the Cambrian sediments exposed at Citronen Fjord and along the south side of Frederick E. Hyde Fjord to Depotbugt (Fig. 22), and referred herein to the Buen Formation, form a structural wedge tectonically separated from the Silurian succession by a low-angle thrust fault. To the north, this wedge is separated from the Cambrian deep-water sediments of the Polkorridoren Group by the Harder Fjord Fault Zone. This group is exposed over large areas of Johannes V. Jensen Land (Bengaard & Henriksen 1986b; Henriksen 1992). The nearest exposures to Citronen Fjord have been mapped by Soper *et al.* (1980) immediately to the north on the opposite side of Frederick E. Hyde Fjord, some 5 km distant.

Ordovician

Two groups of deep-water trough sediments containing Ordovician strata have been formalized in Peary Land: a lower, Vølvedal Group that overlies the Polkorridoren Group, and the Amundsen Land Group that passes up into the Peary Land Group (Friderichsen *et al.* 1982). At Citronen Fjord, the Ordovician strata are in stratigraphic contact with overlying Silurian strata and, based on lithology and regional thickness considerations, we refer all the Ordovician strata at Citronen Fjord to the Amundsen Land Group.

The definition of the Amundsen Land Group by Friderichsen *et al.* (1982) was unfortunately not accompanied by the formal subdivision into formations. However, three (originally 'un-named') formations were identified, viz. "two mainly fine-grained formations" and "a southern resedimented conglomeratic formation" (Friderichsen *et al.* 1982, p. 15). These were named on the 1:500 000 Peary Land map sheet (Bengaard & Henriksen 1986a) as a unit of resedimented carbonate conglomerate – the Kap Mjølner Formation – and two units of bedded chert, mudstone and siltstone – the Harebugt and Nordpasset Formations. Pedersen (1982; adopted in Lind 1993) referred all strata at Citronen Fjord identified at that time as Ordovician, to a single formation – the Nordpasset Formation.

However, a fourth formation is now recognized in Peary Land – the Harder Fjord Formation – representing the youngest strata of the group being overlain by the Peary Land Group (Higgins *et al.* 1991a). This formation, of black chert, mudstone, siltstone and thin-bedded silty turbidite, heralds the end of starved basin deposition in latest Ordovician to early Silurian times.

Published descriptions imply that the Harder Fjord Formation is present throughout southern Johannes V. Jensen Land; it has certainly been recognized to the south of Frederick E. Hyde Fjord in eastern Hans Egede Land (see Higgins *et al.* 1991a, fig. 2). The uppermost part of the Citronen Fjord succession composed of mudstone, siltstone and intercalations of turbidites and carbonate debris flows (Unit 8) that passes up into the Peary Land Group is thus provisionally referred to the Harder Fjord Formation.

However, the precise correlation of the remaining part of the Ordovician to Silurian strata at Citronen Fjord to the tripartite division of Harebugt, Kap Mjølner and Nordpasset Formations is more debatable, although clearly the two major carbonate conglomerate units (Units 5 and 7) are candidates for correlation with the debris flow units that make up the Kap Mjølner Formation and that form prominent outcrops to the west in Amundsen Land (Pedersen & Henriksen 1986).

We conclude that the Vølvedal Group does not occur in the Citronen Fjord area. The lower limit of the younger Amundsen Land Group (Fig. 13) at Citronen Fjord is unknown and the absence of the Vølvedal Group could be due to tectonism. However, in any attempts at regional correlation, it should be kept in mind that the apparent, rather *restricted occurrence* of massive sulphides in the Citronen Fjord area implies the existence of a sedimentary sub-basin, the boundaries of which probably were defined by syngenetic fault systems. Therefore, the Citronen Fjord stratigraphy could be of local development with the extension of specific lithological sequences limited to the size of the original sub-basin and without obvious correlational characteristics with time-equivalent rock units elsewhere in the region.

Silurian

The Silurian calcareous siltstones, sandstone turbidites and carbonate debris flows that form the major part of the exposed bedrock in the Citronen Fjord area, are correlated with the Merqujôq Formation of Hurst & Surlyk (1982). As discussed in the lithostratigraphic descriptions, Units 9, 10 and 11 belong to the Citronens Fjord Member of Hurst & Surlyk (1982), the type section of the member being in our study area (location on Fig. 3). This debris flow member marks the end of the massive sulphide deposition in the Citronen Fjord sub-basin.

It needs to be stressed that these Silurian strata (Units 9 to 11) are part of the 'hangingwall' sequence that overlies the late Ordovician 'ore-bearing' mudstones and siltstones with the intermediate carbonate debris flows (Units 6 to 8; Fig. 7). This interpretation and stratigraphic correlation differ from the published interpretation of Stemmerik *et al.* (1996) according to which all ore-bearing sediments are concentrated in the Silurian Citronens Fjord Member.

Citronen Fjord mineralization

Mineral assemblages and grades

The stratabound sulphide mineralization at Citronen Fjord is comprised of massive and bedded pyrite that contains variable amounts of sphalerite and minor amounts of galena. Silver, barium and copper are present in very minor quantities. A preliminary estimate of the total tonnage of sulphides encompassed by the two ore-bearing argillaceous units – the Footwall shale (Unit 8) and the Middle mudstone units (Unit 6) – exceeds 350 million tons. This figure is calculated on the basis of the mean value for the cumulative thickness of sulphides intersected by each drill hole and on the apparent lateral continuity of the sulphides between the holes.

The sulphides are generally fine- to medium-grained; some are weakly-bedded and laminated, others lack sedimentary features. There is a variation in the textures from massive and semi-massive to the intermittent presence of dendritic-textured pyrite (Figs 14, 15); the net-like texture of Kragh *et al.* (1997). When best developed, this dendritic texture is a fern-like pattern of open spaces lined with pyrite framboids that locally are overgrown by euhedral pyrite crystals. The open spaces, representing up to 50 per cent of the rock volume, are filled by calcite or dolomite spar. This pattern can be seen to overprint or replace sedimentary textures within sulphides but in most instances no suggestions of primary textures remain.

Zinc and lead grades are characteristically less than 3 per cent zinc and less than 1 per cent lead within the massive and dendritic-textured pyrite. Sphalerite and minor galena appear to have been remobilized into open spaces and fractures as irregular, medium- to coarse-grained concentrations.

The bedded and laminated sulphides contain the greatest concentrations of lead and zinc. Bedded sulphides are characteristically fine grained, planar-laminated and thin-bedded (Fig. 16). Individual layers range in thickness from 1 mm to 1 m, although decimetre thicknesses are most common and beds in excess of 30 cm are rare. Sedimentary structures such as graded bedding, cross-lamination and dewatering features have been observed (Kragh 1997; Kragh *et al.* 1997). With few exceptions, contacts with interbedded mudstone are sharp (Fig. 16) but they can often have an irregular form (Fig. 17).

Relationships suggesting that the sulphides grew within the mudstone sediment or at the water/sediment transition zone before consolidation confirm the syn-sedimentary character of sulphide genesis (Fig. 17).

Sulphides contain clay and silt as impurities and mudstone commonly contains up to 20 per cent disseminated pyrite.

Sphalerite has clearly been deposited contemporaneously with the enclosing pyrite and it commonly forms laminae but rarely beds. Normally it occurs interstitially to the pyrite framboids (Kragh 1997). Sphalerite is difficult to detect visually in pyrite when in

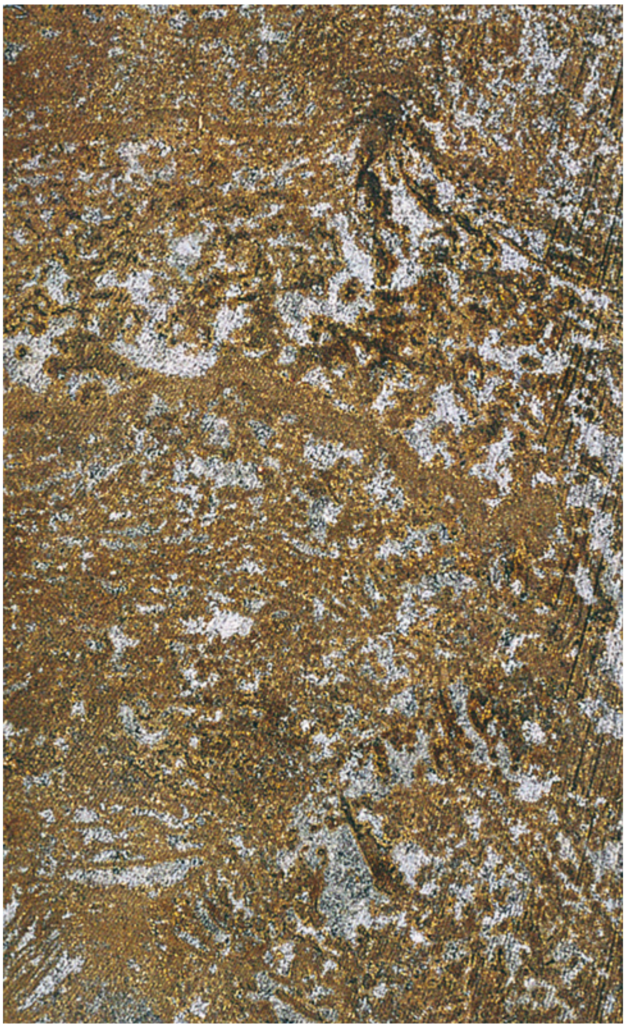

Fig. 14. Detail of typical dendritic-textured pyrite with calcite infilling. Platinova drill-core CF94-15 from Level 2 mineralization. The core is 3.6 cm across. Photo: Jakob Lautrup.

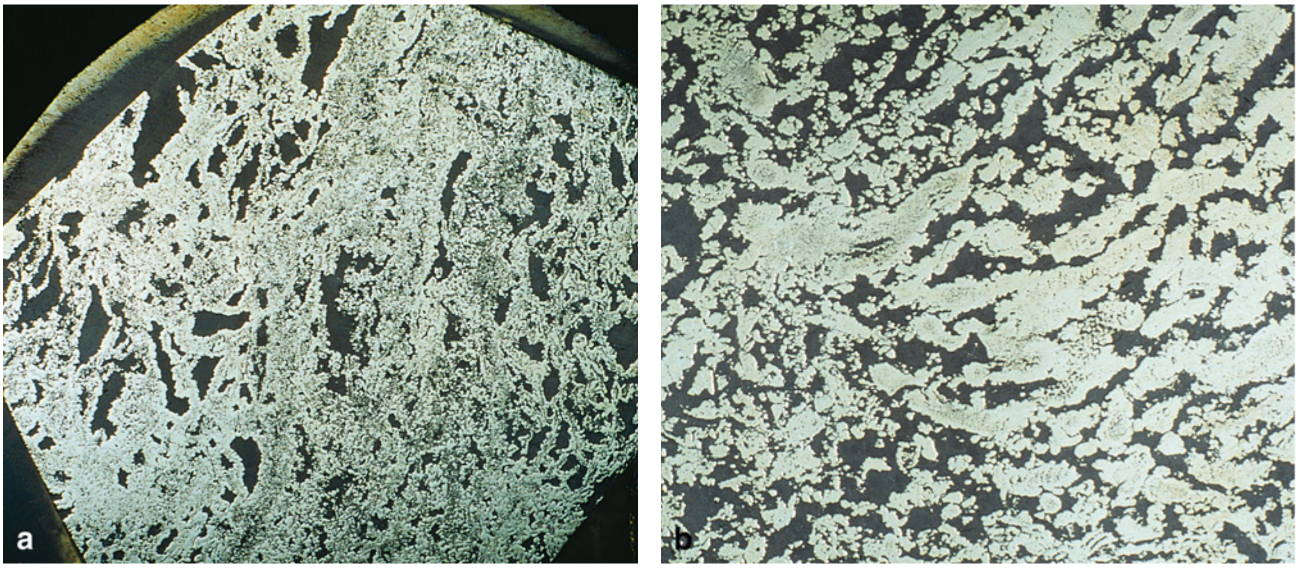

Fig. 15. Semi-massive dendritic sulphides (light) with sparry carbonate (dark). Reflected light, both samples about 2 cm across. **a**, GGU sample 410005 from Level 1 mineralization; also figured in Kragh (1996); **b**, Platinova drill-core CF94-15 in Level 2 mineralization. Photos: Jakob Lautrup.

quantities less than 10 per cent volume. The colour of the pyrite varies in proportion with the amount of zinc present. Thus where zinc content is in the range of 15–20 per cent, the pyrite has a brownish cast, and where zinc is in excess of 20 per cent, the pyrite is pinkish to reddish. The highest zinc content of a pyrite bed noted to date is 35 per cent.

No examples have been found of sedimentary sphalerite that has been deposited without accompanying pyrite but sedimentary pyrite without sphalerite is common. Many beds of pyrite have zinc contents of less than 1 per cent.

Pyrite, as microscopic spheres, occurs in all textures – massive, dendritic and bedded/laminated (Kragh 1997). Sphalerite and galena occur both as inclusions and, more commonly, as overgrowths on the pyrite spheres.

Main levels of massive sulphide mineralization

In the Discovery, Beach and Esrum areas, three main sulphide levels occur within a 200 m thick stratigraphic interval (Figs 3, 7). In the fourth mineralized area shown in Figure 3 – the West gossan area – one level of mineralization is delimited although disseminated suphides with slightly enhanced Zn values occur at various overlying stratigraphic levels.

Discovery, Beach and Esrum areas

The tripartite sulphide system that characterizes the Citronen Fjord area has been traced uninterruptedly by geophysics and drilling over a strike length of more than 5 km and a width of up to 500 m. The gross strike of this trend is about 145° azimuth. The individual sulphide sheets, hosted in argillaceous strata, are from uppermost to lowermost, termed Levels 1, 2 and 3, and they are spatially associated with three extensive limestone conglomerate units (Fig. 7).

Sulphide Levels 1 and 2

Levels 1 and 2 occur both within the Footwall shale (Unit 8) at slightly variable positions in relation to the Hangingwall debris flow (Unit 9) and underlying Middle debris flow (Unit 7, Fig. 7). In part of the Discovery area, the Hangingwall debris flow immediately overlies Level 1 sulphides, but elsewhere the upper sulphide sheet is separated from this debris flow by a siltstone of variable thickness. The division into two main upper sulphide levels is not always applicable in the Discovery area, since most of the Footwall shale is taken up by massive sulphides.

Level 2 sulphides in the Beach area are defined as occurring immediately above, or separated by a thin mudstone unit from the Middle debris flow (Unit 7) while Level 3 sulphides always occur immediately be-

Fig. 16. Fine-grained laminated sulphides in black mudstone. The sulphide laminae consist of framboidal pyrite in a matrix of sphalerite and carbonate. Zn-content in the upper sulphide layer is 25–30% and in the lower layer 1–3%. Platinova drill-core CF-15 in Level 2 mineralization; figured in Kragh (1996). The core is 3.6 cm across. Photo: Jakob Lautrup.

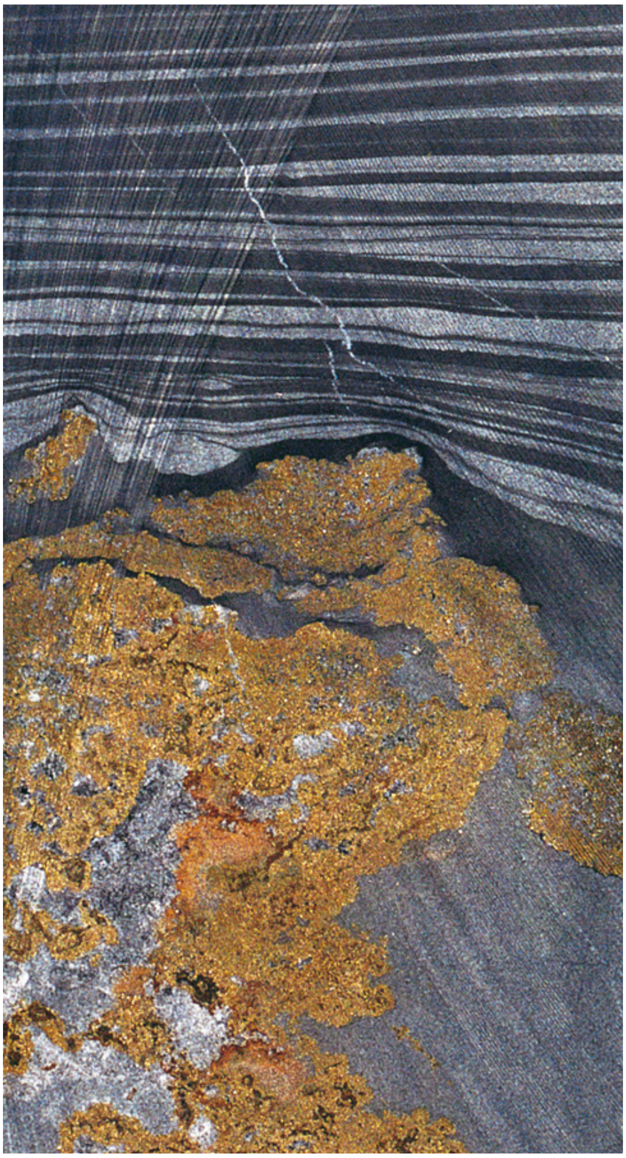

Fig. 17. Semi-massive sulphides draped by laminae of turbiditic calc-arenite and mudstone; evidence of syn-sedimentary genesis. Platinova drill-core CF94-15 in Level 3 mineralization; also figured in Kragh (1996). The core is 3.6 cm across. Photo: Jakob Lautrup.

low this debris flow in the Middle mudstone (Unit 6). There is evidence that the Middle debris flow has, in part, eroded the underlying Level 3 sulphides during deposition (Fig. 18).

Level 1 is the most southerly of the sulphide sheets and forms the massive sulphides exposed at surface (Discovery area shown in Fig. 19), as well as minor accumulations of pyrite laminae further to the north-west. This level of sulphides is exposed over a strike length of about 1200 m and a width of 300 m.

Apart from local occurrences in the Discovery area, Level 2 mineralization is mainly restricted to two separate areas: it occurs sub-surface as a 2 km long and up to 500 m wide north–south striking belt in the Beach area (dipping 5–8° towards the north) and as a 1 km long and 250 m wide, sub-parallel belt in the Esrum area (Fig. 3). In the intervening area, massive sulphides are absent in the Footwall shale.

In the Beach area, Level 2 is characterized as a series of massive to dendritic-textured sulphide mounds,

Fig. 18. Drill cores showing the transition from the Middle debris flow (Unit 7, left core) to the underlying Level 3 sulphides within the Middle mudstone unit (Unit 6; middle and right cores). Numerous fragments of finely laminated sulphides contained in carbonate debris indicates depositional erosion of the underlying sulphides by the debris flow. The middle core shows dendritic texture, while dense to vaguely slumped textures are seen in the more massive sulphides core on the right. Each core is 3.6 cm across.

up to 20 m thick surrounded by thin aprons of bedded sulphides 1–5 m thick. The highest combined zinc/lead grades occur in a ‘channel’ of mainly fine-grained, bedded sulphides 1 km long and some hundreds of metres wide that runs along the eastern rim of this Level 2 belt. The sulphide sheet characteristically consists of two prime layers which in most cases are separated by a less mineralized siltstone up to 10 m wide. In the southern and western part of this channel, the highest zinc/lead values occur in the upper layer while in the north-eastern part the best combined grades come from the lower layer. Detailed exploration drilling at 100 m intervals within this Level 2 sulphide corridor has indicated a resource of 7 million tons, averaging 9 per cent zinc and 1 per cent lead by using a cut-off grade of 6 per cent zinc over 2 m.

Sulphide Level 3

Level 3 comprises all sulphides within the Middle mudstone (Unit 6), between the overlying Middle Debris Flow and underlying Lower Debris Flow (Fig. 7). This level contains the greatest volume of sulphides with intercepts in excess of 10 m cumulative thickness encountered continuously for almost 3 km (strike 140–180°) in the Beach and Discovery areas and for at least 1.5 km (strike 160–180°) in the Esrum area (Fig. 3). There exists a series of mounds of massive and dendritic sulphide within these trends, the thickest of which reaches 57 m. However, these sulphide accumulations have very low contents of base metals. Away from the mound centres, the dendritic texture becomes less conspicuous with the increase of fine-grained and laminated, more zinc-rich sulphide bands with intercalated mudstone and calcarenite.

In contrast to the Footwall shale (Unit 8), the Middle mudstone (Unit 6) is also mineralized in the area between the two main Level 3 sulphide corridors and consequently, this lower sulphide sheet can be traced continuously from south-east of the Discovery area to the north-western end of the Esrum area.

West gossan area

The sulphide mineralization in the West gossan area (see Fig. 3) occurs in both the carbonate breccio-conglomerates and the intervening argillaceous and siliciclastic strata (Fig. 20). Reconnaissance drilling in the area has delimitated an extensive occurrence of extremely dense, massive pyrite at a stratigraphic level that is comparable to Level 3 of the Beach and Esrum areas. Slightly enhanced lead values, but only with zero

→

Fig. 19. Views of the Discovery area. **Upper**: view from the north showing two of the main gossans with exposures of massive sulphides at the base of the mountain slope immediately east of ‘Citronen Elv’. The mountains in the background are also seen in the regional view of Fig. 1. **Lower**: outcrops of massive sulphides up-slope of the gossans shown in upper view. For map location of the Discovery area, see Fig. 3.

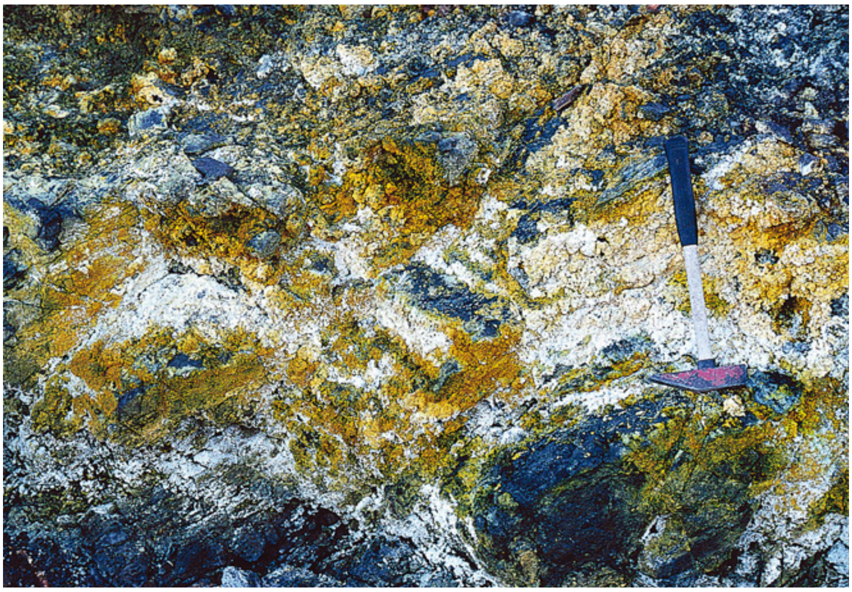

Fig. 20. Strongly pyritized and gossanous carbonate debris flow in exposures immediately west of the mouth of Citronen Fjord in the West gossan area. The hammer is 40 cm long. For location, see Fig. 3.

or very low zinc values, occur within the massive pyrite although more zinc-rich disseminated sulphides are present in overlying arenites and siltstones. The tonnage potential of this massive pyrite sheet, as indicated by three drill holes and on the basis of the outline of a pronounced gravity anomaly, is probably in the order of 30 million tons.

The textures and composition of the massive sulphides, viz. dense, no dendrites, low zinc and weakly enhanced lead values, and the hosting lithologies, viz. slumping, tectonic brecciation, high amount of quartz-arenites and polymict, matrix-supported debris flows with generally rounded, lenticular clasts, are strikingly different from those in the Beach, Esrum and Discovery areas. It is assumed that the nearby Harder Fjord Fault Zone has played an active role during syn- and post-sedimentary processes and might have facilitated sulphide genesis in the West gossan area.

Post-sedimentary mineralization

Evidence of post-sedimentary, epigenetic mineralization is commonly seen in drill cores and rock exposures of especially the Middle and Hangingwall debris flows (Units 7 and 9). This later stage mineralization also left its traces on the stratiform massive sulphides, giving rise to a both laterally and vertically irregular pattern of zinc/lead enrichment.

An important area of post-sedimentary mineralization was found in 1996 in the Discovery area during 'fill-in' drilling and field-named 'Zone XX' (Figs 3, 21). The zone is formed by a 20–30 m wide and up to 30 m thick corridor of strongly mineralized carbonate conglomerate that forms part of the Middle and/or Hangingwall debris flow (Units 7 and 9). It occurs along the northern side of a tectonic lineament which probably acted as a channel-way for metal-bearing fluids. This linear feature is partly exposed at surface and further traceable on the basis of drill core data. It can be followed over a strike length of about 1 km (see section 'Regional geology') and in a direction which is subparallel to the strike of the Trolle Land Fault Zone.

Zone XX clearly shows the irregular and discontinuous character of this mineralizing event which genetically was closely related to a process of penetrative dolomitization and minor silicification of the debris flow. This resulted in typical replacement textures with associated fading and locally bleaching of the clast-supported fabric with the subsequent accentuation of the original carbonate clasts by colloform linings of pyrite. This initial stage of replacement continues gradually into an increasingly massive pyritic sulphide with dendritic textures and floating 'clasts' of recrystallized carbonate. Solution vugs with or without secondary fillings of sparry dolomite and/or bitumen are commonly developed. Veins and veinlets of quartz/carbonate are numerous and they occasionally result in a stockwork-like pattern.

The occurrences of abundant secondary, light brown to green-grey sphalerite and minor galena are restricted to certain well-defined intervals in the highly pyritic carbonate rocks of the Middle and Hangingwall debris flows.

Type of ore genesis

The Citronen Fjord massive sulphides form a stratiform deposit displaying clear evidence of deposition on the sea floor contemporaneously with the enclosing sediments. It is interpreted to have formed at relatively low temperatures by the precipitation of sulphides from metal-bearing fluids introduced onto the sea floor from underlying fractures. It is thus placed in the sedimentary-exhalative class or SEDEX class of sulphide deposits (Large 1981; Carne & Cathro 1982; Goodfellow *et al.* 1993). Sulphur isotope compositions of the sulphides suggest that the sulphur in the more distal parts of the mounds is mainly derived from sea water while in recrystallized parts, the sulphides have a component of hydrothermally transported sulphur (Kragh *et al.* 1997).

The Selwyn Basin sulphide deposits in the Canadian Cordillera show close similarity in geological setting and morphology to the Citronen Fjord zinc-lead occurrence. SEDEX mineralization in the Selwyn Basin has been identified within three separate ages of shale, ranging from Early Cambrian (Faro) through Early Silurian (Howards Pass) to Upper Devonian (Tom). Like the Citronen Fjord deposit, the Howards Pass deposits (XY and Anniv) are characterized by a high degree of sedimentary intercalation, a preponderance of zinc sulphides with respect to lead, low silver, copper and barium values, a weakly zoned nature of the mineralization, and the apparent absence of an identifiable feeder zone (Carne & Cathro 1982). These deposits are thought to have formed in Early Silurian time at relatively low temperatures (< 220°C) from metalliferous chlorite-bicarbonate brines discharged at the surface of an epicratonic sub-basin along local extensional faults (Carne & Cathro 1982; Goodfellow & Jonasson 1986).

Significant components of the SEDEX depositional model include the existence of a tensional tectonic regime, deep-seated fractures, and a restricted basin morphology. The tensional tectonic regime provides not only the mechanism for basin subsidence, but also an enhanced heat flow, which is presumed to be the 'engine' that drove the fluid migration necessary to transport metals to the sea floor. Deep-seated fractures act as conduits for fluid migration, and the restricted sub-basin morphology provides the physical trap to contain the precipitated sulphides.

The mound-like accumulations of massive to dendritic-textured pyrite at Citronen Fjord are interpreted to represent vent-facies deposition with the bedded sulphides representing the corresponding distal facies. In this model the position of mounds of massive sulphides should therefore indicate the locus of sea-floor vents.

Fig. 21. Post-sedimentary sulphide mineralization in carbonate breccia. Brecciated massive pyrite with preserved mudstone clasts and vugs of sparry dolomite from Zone XX. Platinova drill-core CF96-96. The cores are 3.6 cm across. For location of Zone XX, see Fig. 3. Photo: Karsten Kragh.

The clear spatial association of sedimentary exhalative sulphides and carbonate debris flows at Citronen Fjord is noteworthy. The debris flows are a reflection of a particular tectonic regime – the break-up of the carbonate platform to the south along the inferred Navarana Fjord Escarpment – while the occurrence of several intervals of such rocks indicates repetition of tectonic events. Although the debris flows themselves are not considered to have a direct genetic role in the formation of the sulphides, it is probable that the tectonic events that initiated the debris flows were also responsible for localizing the metal-bearing fluids on the sea floor.