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Stratabound copper-lead-zinc mineralisation in the Permo-Triassic of central East Greenland

by

B. Thomassen, L. B. Clemmensen and H. K. Schønwandt

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Abstract

Stratabound and stratiform copper-lead-zinc-mineralised horizons confined to specific sedimentary facies in the Permo-Triassic Jameson Land Basin of East Greenland were revealed during recent exploration and sedimentological studies. The occurrences are divided into fault-bounded–stratabound and stratabound-stratiform mineralisation. The first group comprises lead-zinc-copper mineralisation in Upper Permian limestone; the remaining mineralisation falls in the second group which is subdivided into mineralisation hosted in mudstones, in sandstones with mudflasers and in sandstones and conglomerates.

A lithogeochemical programme helped to define the mineralised horizons in the Triassic. During the interpretation of the geochemical data an empiric statistical function was introduced which is an estimate of how anomalous the 95 per cent fractile is for individual elements compared with the frequency distribution around the median.

The Upper Permian sediments host copper in basal shoreline conglomerates, zinc-lead-copper in lagoonal mudstones and lead-zinc-copper in carbonate buildup and shelf facies. The Lower Triassic contains copper-lead mineralisation in alluvial fan sediments, the Middle Triassic hosts lead-zinc-copper in sandy shoreline limestones and lagoonal mudstones and copper-lead-zinc in gypsiferous lacustrine sandstones and mudstones while the Upper Triassic contains copper in both dolomitic lacustrine sandstones and mudstones and in overlying carbonate-rich fluvial channel sandstones.

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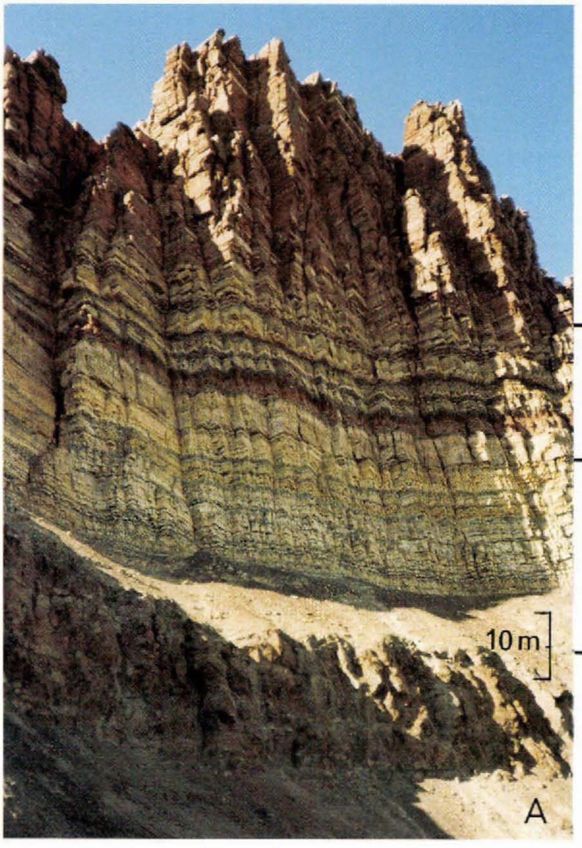


Malmros Klint Member

Pingel Dal Beds

Spor-fjeld Beds

Kap Seaforth Member

INTRODUCTION

The undeformed shallow marine and continental Permo-Triassic sedimentary rocks in Jameson Land and Scoresby Land, East Greenland (fig. 2) contain several hitherto little known stratiform and stratabound mineral occurrences.

The earliest account of mineralisation in the area was given by Nordenskjöld (1907), and since then notes on ore minerals occurring in the Permo-Triassic sediments have appeared in several papers (Noe-Nygaard, 1934; Eklund, 1944; Koch, 1955; Kempter, 1961; Grasmück & Trümpy, 1969; Perch-Nielsen *et al.*, 1972; Paar, 1974) as well as in internal reports of the mining company Nordisk Mineselskab A/S, which holds the concession over the area. However, not until recently was the relationship between stratigraphy, sedimentology, host-rocks and mineralisation determined in some detail in the course of field work carried out in mainly the Triassic strata by the present authors. The work by B. Thomassen and H. K. Schønwandt was carried out during a geochemical exploration programme in the eastern part of the basin for the Nordisk Mineselskab A/S. The sedimentological studies by L. Clemmensen were a joint Geological Survey of Greenland and University of Copenhagen project.

The aims of this paper are to describe the stratigraphical and depositional framework of the mineralised facies and to give a brief description of the ore mineralogy and the geochemistry of the mineralised strata. The nature and role of lithological facies controlling the mineralisation is described. The mineral occurrences are viewed in the light of tectonic events, basin configuration and palaeoclimate.

Fig. 1. Appearance of mineralised sediments in the Jameson Land Basin.

A. The Edderfugledal Member in a 60 m high cliff on the west side of Carlsberg Fjord. The member consists of a lower, thinly bedded, yellowish dolostone-mudstone unit (Sporfjeld Beds) and an upper, more composite unit with thick, grey sandstones and red mudstones (Pingel Dal Beds). The uppermost sandstone in the Pingel Dal Beds is copper-bearing.

B. Copper-lead mineralised, braided river sediments of the Klitdal Member (1) on the south side of Devondal. The 1 m thick, coarse arkosic beds (pink) are interbedded with thin, more fine-clastic, red layers. In the background near Nathorst Fjord a lead-zinc-copper mineralised bioherm (2) of the Limestone-Dolomite Member.

GEOLOGICAL SETTING

The mineralisation in question occurs in the 13 000 km^2 Jameson Land Basin, which forms the southern part of a more extensive N–S trending depositional basin in central East Greenland. The present investigation is mainly concerned with the eastern portion of the Jameson Land Basin, i.e. the fjord area between Klitdal in the south and Kap Biot in the north (fig. 2).

During the Upper Palaeozoic and Mesozoic, the Jameson Land Basin was the site of considerable deposition of continental and shallow marine sediments. The basin was demarcated to the west and also to some degree to the east by tectonically uplifted borderlands of Precambrian basement and Late Precambrian to Palaeozoic sedimentary rocks and granites (Haller, 1971; Surlyk, 1978; Clemmensen, 1980). Continental coarse-grained clastic molasse-type deposits of Devonian, Carboniferous and early Permian age (see e.g. Perch-Nielsen *et al.*, 1972) are unconformably overlain by 1–2 km of shallow marine and continental Upper Permian–Triassic rocks with a considerable amount of carbonates, evaporites and red-beds (Birkelund & Perch-Nielsen, 1976). A continuous marine, mainly clastic sedimentation through the Jurassic and Cretaceous was terminated in the Lower Tertiary by widespread magmatic activity along with uplifting and block faulting of the basin (Haller, 1971).

From a tectonic point of view, the Permo-Triassic represents a rift phase subsequent to the Caledonian orogenesis (Ziegler, 1978). The subsidence of the basin was slow and gradual in the late Permian, but accelerated in the early Triassic (early Scythian) and ended up with faulting along N–S trending lines in the late Scythian (Clemmensen, 1980). While deposition in the late Permian and in the overlying early Scythian was shallow marine, the faulting episode in the late Scythian changed the palaeogeographical picture to one of dominating continental deposition (Clemmensen, 1980). This situation, punctuated only by a brief Middle Triassic transgression, lasted until the Rhaetian-Liassic, when the basin was transgressed from the northeast (Clemmensen, 1976, 1980).

The maximum 300 m thick Upper Permian Foldvik Creek Formation in the Jameson Land Basin is subdivided into six members according to Maync (1942, 1961) and Birkelund & Perch-Nielsen (1976): Conglomerate Member, Gypsum Member, Limestone-Dolomite Member, Posidonia Shale Member, Productus Limestone Member and Martinia Limestone Member (table 1). The Gypsum Member does not, however, occur in the eastern part of the basin, and the Pro-

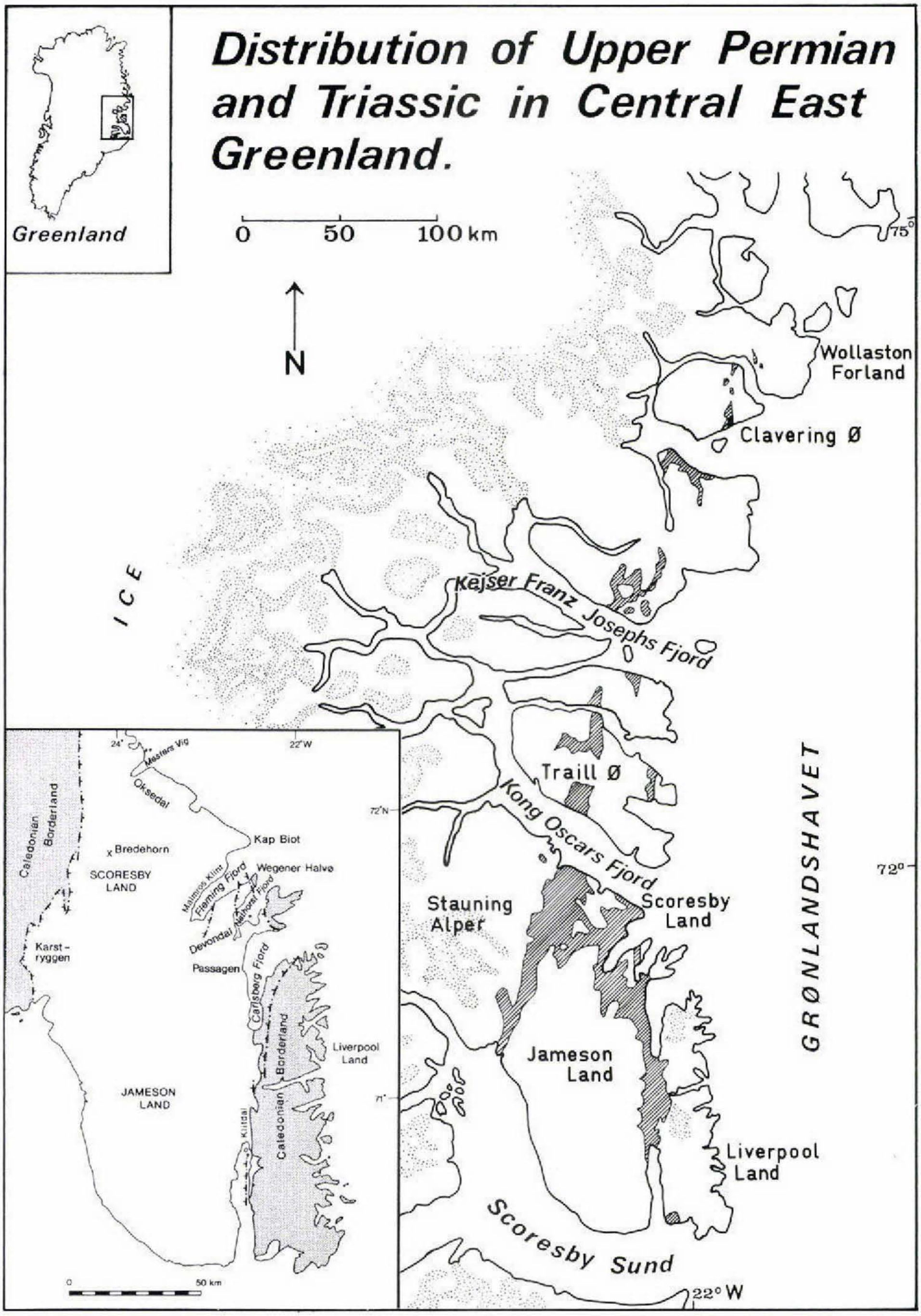


Fig. 2. Locality map of central East Greenland showing the distribution of outcropping Upper Permian and Triassic strata. Modified from Callomon *et al.*, 1972 and Escher (1970).

Table 1. Permo-Triassic lithostratigraphy in the Jameson Land Basin

SERIES	FORMATION	MEMBER	BEDS	MAX. THICK.	DOMINANT LITHOLOGY	MINERALISATION
(Rhaetian-Hettangian)	Kap Stewart			350 m	Grey, coal-bearing sandstones and black mudstones	
Upper Triassic	Fleming Fjord	Ørsted Dal	Tait Bjerg	70 m	Light-coloured carbonate rocks and variegated mudstones	
				150 m	Red mudstones and light grey sandstones	Cu
		Malmros Klint		200 m	Red mudstones and fine sandstones	(Cu)
		Edderfugledal	Pingel Dal	35 m	Variegated cyclic bedded sandstones and mudstones	*Cu*
			Sporfjeld	35 m	Yellowish cyclic bedded dolomitic sediments	
Middle Triassic	Gipsdalen	Kap Seaforth		160 m	Variegated cyclic bedded gypsiferous sediments	Cu, Pb, Zn
		Solfaldsdal		150 m	Red gypsiferous sandstones	
			Gråklint	30 m	Dark grey limestones and mudstones	Pb, Zn, Cu
		Kolledalen		180 m	Yellowish gypsiferous sandstones	
Lower Triassic	Pingo Dal	Klitdal and Paradigmabjerg		>450 m	Pink arkoses and conglomerates	*Cu, Pb,* (Zn)
		Rødstaken		330 m	Dark red sandstones	
	Wordie Creek			500 m	Greenish silty shales and sandstones	(Cu), (Pb), (Zn)
Upper Permian	Foldvik Creek	Martinia and Productus Limestone		130 m	Greyish silty and sandy fossiliferous limestones	
		Posidonia Shale		60 m	Black, often bituminous shales and limestones	Zn, Pb, (Cu)
		Limestone-Dolomite		200 m	Limestones and dolomites, often biohermal	*Pb,* Zn, Cu
		Gypsum		50 m	Gypsum and gypsiferous shales	
		Conglomerate		50 m	Conglomerates and breccias	(Cu)

Cu = major mineralisation; Cu = minor mineralisation; (Cu) = trace of sulphides

Stratigraphy based on Perch-Nielsen *et al.* (1972, 1974) and Clemmensen (1980).

UPPER PERMIAN MINERALISATION

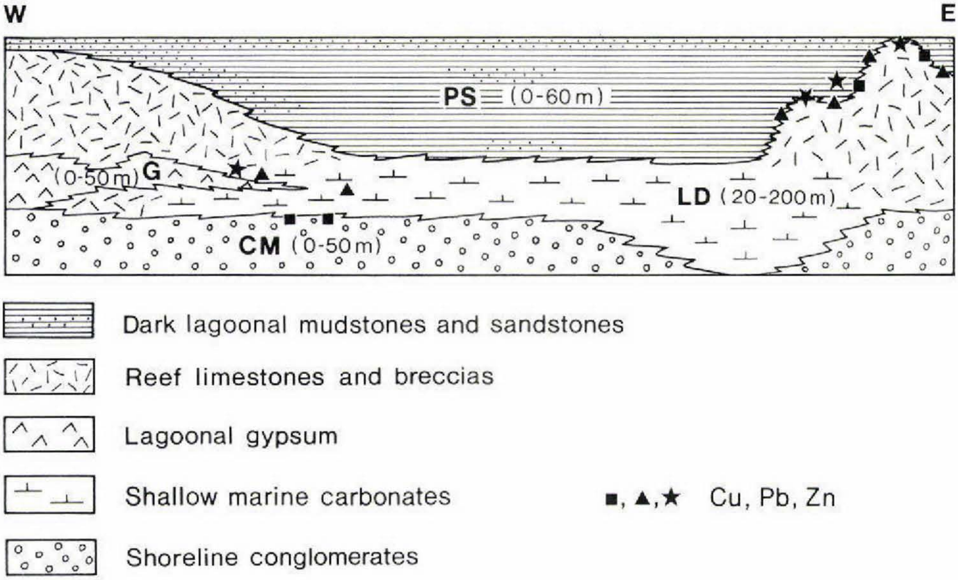


Fig. 3. Schematic facies pattern and mineralisation in the basal part of the Foldvik Creek Formation, Jameson Land Basin. CM = Conglomerate Member, LD = Limestone-Dolomite Member, G = Gypsum Member, PS = Posidonia Shale Member. The section runs from Karstryggen to Nathorst Fjord.

ductus Limestone and Martinia Limestone Members are not typically developed. The members display pronounced interfingering (fig. 3) and have been interpreted as various shallow-marine and lagoonal deposits (Maync, 1942, 1961; Perch-Nielsen *et al.*, 1972). Large reef-like bodies (up to 200 m thick) are common at the eastern margin of the basin in the Limestone-Dolomite Member, whereas limestone breccias are conspicuous at the western margin (Stemmerik, 1980).

The maximum 1800 m thick Triassic sediments in the Jameson Land Basin (fig. 4) have been divided into four formations (Wordie Creek, Pingo Dal, Gipsdalen and Fleming Fjord Formations) by Perch-Nielsen *et al.* (1974) and Clemmensen (1977, 1980). These formations can in turn be subdivided into nine members and four beds (table 1).

The fine sandstones and siltstones of the Lower Scythian Wordie Creek Formation were deposited in various sub-intertidal marine environments (Perch-Nielsen *et al.*, 1974); in time the basin was supplied with an increasing amount of coarse clastic material signifying initial upheavals of the borderlands, and coastal plain sediments (Rødstaken Member) were deposited. The major tectonic uplift in late Scythian changed the palaeogeographical picture dramatically and a N–S trending rift valley formed. As a direct response to the tectonic upheavals of the borderlands

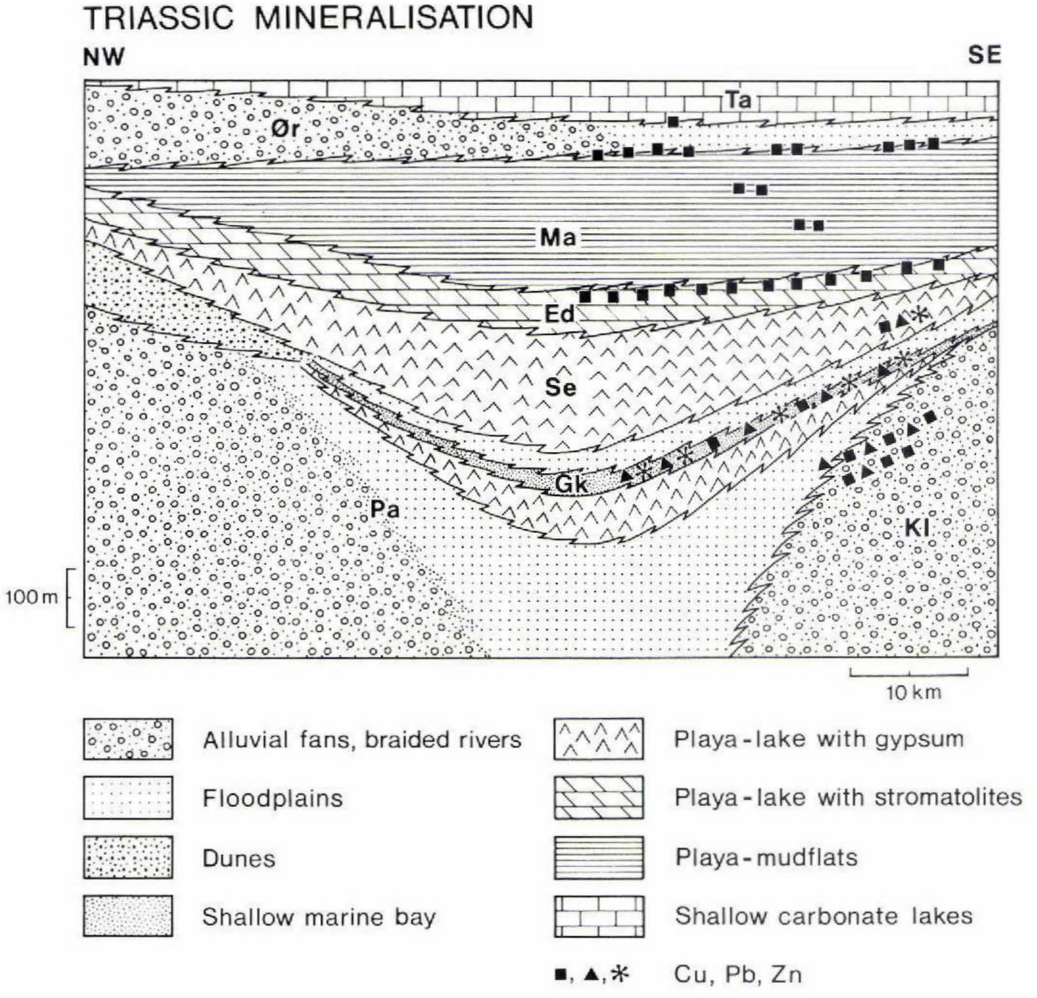


Fig. 4. Generalised facies pattern and mineralisation of the Pingo Dal, Gipsdalen and Fleming Fjord Formations. Kl = Klitdal Member, Pa = Paradigmabjerg Member, Gk = Gråklint Beds, Se = Kap Seaforth Member, Ed = Edderfugledal Member, Ma = Malmros Klint Member, Ør = Ørsted Dal Member, Ta = Tait Bjerg Beds. The section runs from east of Bredehorn to the head of Carlsberg Fjord.

a thick pile of alluvial fan deposits (Klitdal and Paradigmabjerg Members) from both eastern and western highlands built out into the basin, the central part of which was occupied by floodplain deposits. In early Middle Triassic times the palaeogeographical picture gradually changed to one of drifting dunes (Kolledal Member) and isolated playa-lakes (Solfaldsdal Member). A marine transgression depositing limestones and black mudstones (Gråklint Beds) affected the basin briefly in Middle Triassic, but after the withdrawal of the sea, floodplains (Solfaldsdal Member) and large gypsiferous playa-lakes (Kap Seaforth Member) were again established. In late Middle Triassic times shallow-lake sediments and stromatolites (Edderfugledal Member) were deposited over wide areas. Finally, in the late Triassic the basin saw the deposition of red mudstones of playa-mudflat origin (Malmros Klint Member). These mudstones were gradually replaced by conglomeratic fluviatile sandstones, mudstones and shallow lake carbonates (Ørsted Dal Member). The fluvial sediments formed in response to renewed tectonic upheaval of the western borderland.

In Permo-Triassic times, East Greenland was part of a large northern continent (Laurasia). In the Late Permian, East Greenland was situated at *c.* 15° N (Birkelund & Perch-Nielsen, 1976) and lay within the year-round dry zone of Robinson (1973). East Greenland was reached by a boreal sea arm, but experienced an arid climate as evidenced by the occurrence of red-beds, gypsum and reef limestones.

In the Triassic, East Greenland was still within the year-round dry zone of Robinson (1973) and the existence of continental red-beds, caliche, desert dunes, gypsum, rock salt pseudomorphs, dolostones and stromatolites indicate an arid to semiarid climate. A northwards drift to *c.* 40° N in the Rhaetian gradually changed the climate towards a more humid one (Clemmensen, 1980). The overall Triassic climate was probably punctuated by a semihumid period in the Middle Triassic in connection with a brief marine transgression.

LITHOGEOCHEMISTRY

The lithogeochemical data result from detailed field investigations including measuring of sections and systematic sampling. Several geological features were noted at each sampling site. These features and the lithogeochemical data were recorded in the field on data sheets to facilitate subsequent automatic data processing. The approximately 500 g samples were analysed for copper, lead and zinc by atomic absorption.

Each lithostratigraphic unit is treated as a geochemical unit. Due to the lithostratigraphic subdivision of the Triassic these units span from formation to beds. The sampling procedure was accordingly harmonised to the variation in lithology and thickness of the units. Depending upon the thickness of the unit the spacing between samples in a homogeneous lithology varies between 12.5 m and 50 m. At least three samples were collected from each unit (from the top, middle and bottom), independent of visible mineralisation. With increasing thickness of the unit additional samples were collected with constant spacing. In the statistical treatment it was not appropriate to further subdivide the unit, e.g. according to rock type, due to the restricted number of samples.

As the Permian was covered by no more than two sections, only the Triassic and the Jurassic Kap Stewart Formation (for comparison purposes) have been dealt with lithogeochemically. A total of 727 samples have been used in the geochemical survey. The area covered is approximately 2500 km^2, and therefore the trace element distribution patterns of the Triassic sediments (628 samples) are only known in broad outline.

The lithogeochemical programme was based on the supposition that each stratabound mineralisation is surrounded by an aureole containing the mineralising elements (copper, lead, zinc) in trace amounts. Provided the right sampling intervals are used, the aureoles should appear as anomalous areas and thereby distinguish lithological units with economic potential from barren units.

When establishing threshold values different definitions of anomalous values had to be used within the same geochemical unit for different elements as well as for the same element in different units. This problem will be discussed further in the following.

Determination of geochemical anomalies

When for each stratigraphical unit the concentrations of an element are plotted on logarithmic probability paper, two types of curves can be distinguished: (1) an approximately straight line (A-A', D-D', fig. 5a) equivalent to a nearly lognormal distributed population, (2) two intersecting nearly straight lines with different slopes (A-B-C, fig. 5b). Lepeltier (1969) interprets these lines as a lognormal distribution with an excess of high values.

According to Lepeltier (1969) the break point (point B, fig. 5b) can be used as threshold value for anomalous concentrations of that element. Where the plot gives a straight line (A-A', fig. 5a), Lepeltier (1969) uses the median plus two standard deviations as threshold level. Because both types of curves occur in this study, two definitions of threshold values must be used.

In order to avoid different definitions of threshold values, the 95% fractile value was chosen as threshold value. This definition, as well as Lepeltier's (1969) definitions of threshold value, will introduce anomalous values in all stratigraphic units regardless of trace element content. In an attempt to avoid this, a rough estimate was used of the 95% fractile value compared to the frequency distribution around the median. The following quantity was calculated

$$M + 3(Q3\text{-}Q1)\tfrac{1}{2} \qquad (1)$$

where M is the median and Q3 and Q1 the 75% and 25% fractile values respectively. The quantity (1) represents a linear estimate of a high fractile value of the population based on the frequency distribution around the median.

Because the frequency curves are poorly known the statistical parameters, mean and standard deviation, have been replaced by median and $(Q3\text{-}Q1)\tfrac{1}{2}$ respectively.

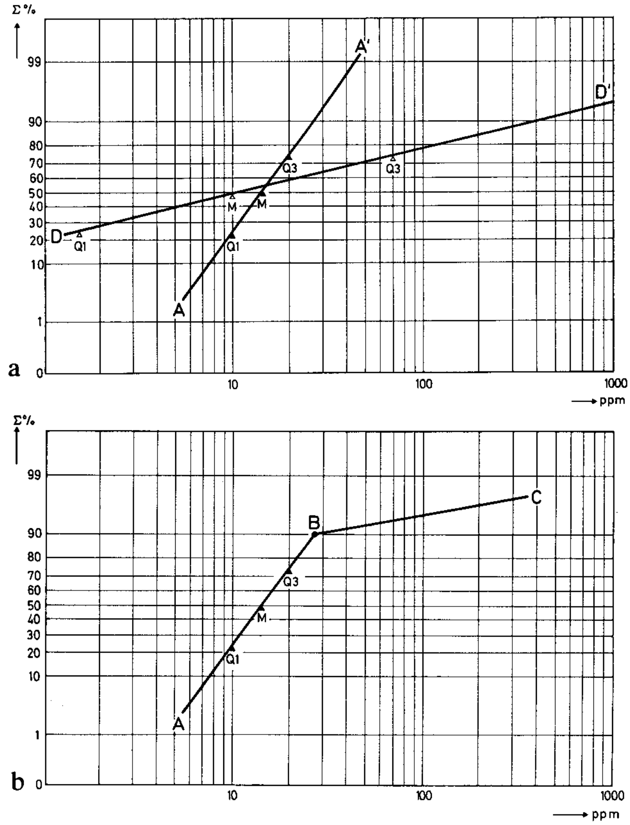


Fig. 5a & b. Cumulative frequency curves of trace element concentration in parts per million on a logarithmic scale to illustrate the parameters used in the definition of the empirical ratio (λ). Q1 and Q3 are the fractile values at 25% and 75% respectively, and M is the median. The curves have the following parameters and values:

curve	Q1	M	Q3	95% fractile	λ
A-A'	10 ppm	15 ppm	20 ppm	31 ppm	1.0
D-D'	1.5 ppm	10 ppm	70 ppm	1000 ppm	8.9
A-B-C	10 ppm	15 ppm	20ppm	100 ppm	3.3

For a normal distribution, the calculated quantity is equivalent to the 98% fractile value. Although the frequency curves are poorly known, they are more lognormal than normal distribution. For a lognormal distribution the calculated quantity will vary depending on the shape of the frequency curve and/or the figures involved. In this study quantity (1) varies between 68% and 99% fractile value.

The ratio (λ) between the 95% fractile value and quantity (1) gives a rough estimate of how anomalous the 95% fractile value is compared to the frequency distribution around the median

$$\lambda = \frac{95\%\ \text{fractile value}}{M + 3(Q3\text{-}Q1)\ \frac{1}{2}}$$

Because quantity (1) varies for frequency curves other than normal distributions, λ will also vary. Therefore in each investigation a critical λ value separating anomalous values from background values must be chosen.

To illustrate the significance of the λ value compared with the general treatment of geochemical data in prospecting work, three hypothetical populations have been plotted on logarithmic probability paper (fig. 5). For the populations plotted as curve A-A' and D-D' (fig. 5a) γ values of 1.0 and 8.9 respectively can be calculated. Broadly speaking the steeper the curves, the smaller the values of λ.

For the curve A-B-C (fig. 5b) which has a break point at B, the calculated λ value is 3.3. In this investigation this type of curve gives λ values above 1.8, provided that the break point occurs below the 95% fractile value. If the break point occurs above the 95% fractile value, then λ will depend on the steepness of the curve below the break point, as was the case for the curves A-A' and D-D'.

In table 2 are shown the calculated λ values for copper, lead and zinc in each stratigraphic unit.

According to field investigations no mineralisation has been found in the following stratigraphic units: Rødstaken, Solfaldsdal, Kap Seaforth (north) Members, Sporfjeld Beds and Kap Stewart Formation. The λ values for all elements within these units are lower than 1.8 except for copper in the Kap Seaforth Member (north), whereas stratigraphic units in which mineralisation occurs have λ values higher than 1.8 except for zinc in Wordie Creek Formation, lead in Klit-

Table 2. Summary of lithogeochemical values from the sedimentary units in the Permo-Triassic in the Jameson Land Basin

Stratigraphical unit	Number of samples	Median in ppm Cu	Pb	Zn	95% fractile in ppm Cu	Pb	Zn	Break point in ppm Cu	Pb	Zn	λ Cu	Pb	Zn
Kap Stewart Fm	37	21	17	29	65	45	122	–	–	–	0.9	1.0	1.0
Ørsted Dal Mb	67	22	20	28	122	42	67	70	–	–	2.0	1.2	1.0
Malmros Klint Mb	69	25	22	47	75	71	70	–	28	–	1.4	2.2	0.8
Pingel Dal Beds	67	24	25	49	6320	55	132	–	–	–	50.2	1.2	1.0
Sporfjeld Beds	43	13	22	37	48	37	132	–	–	–	1.6	1.1	1.7
Kap Seaforth Mb (south)	73	47	26	84	1806	1523	1407	–	27	80	7.3	5.1	4.9
Kap Seaforth Mb (north)	53	11	18	37	89	34	69	–	–	–	2.6	1.0	0.9
Gråklint Beds	110	16	39	69	119	1172	5280	–	29	200	2.5	4.9	14.6
Solfaldsdal Mb	46	10	16	32	33	43	72	–	–	–	1.4	1.7	1.2
Klitdal and Paradigmabjerg Mbs	63	6	12	12	28	26	64	17	26	27	1.9	1.1	2.4
Rødstaken Mb	13	3	12	35	6	22	98	–	–	–	1.3	1.0	1.5
Wordie Creek Fm	24	22	17	82	582	102	258	–	45	–	3.9	2.5	1.3

Table 3. Summary of lithogeochemical anomalies in the Permo-Triassic of the Jameson Land Basin

Stratigraphical unit	Anomalous elements Cu	Pb	Zn	Known mineralisation
Kap Stewart Fm	–	–	–	–
Ørsted Dal Mb	B,L	–	–	Cu
Malmros Klint Mb	–	B,L	–	(Cu)
Pingel Dal Beds	L	–	–	*Cu*
Sporfjeld Beds	–	–	–	–
Kap Seaforth Mb (south)	L	B,L	B,L	Cu, Pb, Zn
Kap Seaforth Mb (north)	(L)	–	–	–
Gråklint Beds	L	B,L	B,L	Pb, Zn, Cu
Solfaldsdal Mb	–	–	–	–
Klitdal and Paradigmabjerg Mbs	B,L	B	B,L	*Cu, Pb,* (Zn)
Rødstaken Mb	–	–	–	–
Wordie Creek Fm	L	B,L	–	(Cu, Pb, Zn)

Anomaly established by B = break point; L = $\lambda > 1.8$.

dal-Paradigmabjerg Members and copper in Malmros Klint Member. The high λ value for copper in the Kap Seaforth Member (north) is due to the fact that samples were taken close to basic sills. The copper mineralisation in the Malmros Klint Member occurs as small and scattered mineralisation in a local area which is represented in only two sections. Too few samples (24) of the Wordie Creek Formation are involved in the investigation to give a reasonable picture of the trace element distribution. For lead in the Klitdal-Paradigmabjerg Members the break point on the cumulative curve occurs at the 95% fractile value. It is therefore the steepness of the frequency curve below the break point that is reflected in the λ value.

A critical λ value of 1.8 successfully differentiates between the two lognormally distributed curves A-A' and D-D' (fig. 5a), as only the latter remains of interest because of its high trace element content. The ratio λ can thus be used to distinguish between lognormal distributions (curve A-A' and D-D') and at the same time classify break point curves having an excess of high values (curve A-B-C, fig. 5b) together with lognormal distributions which have a high trace element content.

In table 3 are shown the elements which have anomalous values established by break points on the frequency curve and which have λ values higher than 1.8. The mineralisation found in the different stratigraphic units is also shown. It appears that all frequency curves (fig. 6) which have break points also have λ values higher than 1.8 except lead in the Klitdal-Paradigmabjerg Members. Among the frequency curves without obvious break points a λ value higher than 1.8 indi-

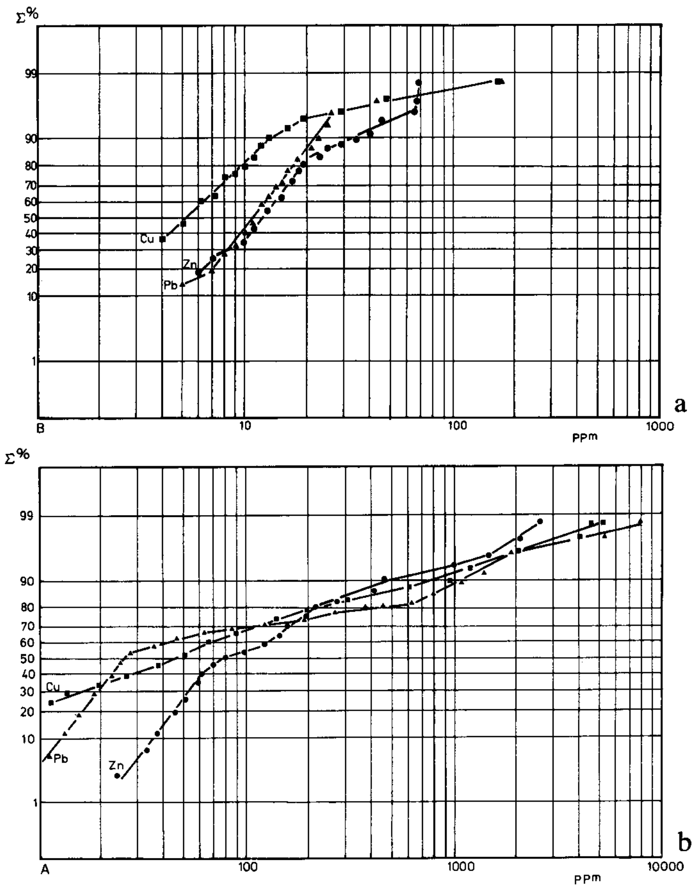


Fig. 6. Cumulative frequency distribution of lithogeochemical copper, lead and zinc. Fig. 6a. Klitdal-Paradigmabjerg Members. Fig. 6b. Kap Seaforth Member (south). All curves show break points, except copper in fig. 6b.

cates stratigraphic units in which copper mineralisation in particular occurs, e.g. Pingel Dal Beds, Kap Seaforth Member (south) and Gråklint Beds.

In the Malmros Klint Member lead is indicated by the break point in the cumulative curve and by a λ value greater than 1.8, although no lead mineralisation has been found in the member. No explanation for this fictitious mineralisation can be given at present.

In this investigation the empirical ratio (λ) has primarily been used to confirm the impression from the field work that some of the stratigraphic units seem to be of no interest in terms of mineralisation (i.e. $\lambda < 1.8$). It has also been used to select the elements which were of interest in the mineralised stratigraphic units. Since λ does not define a threshold value which can be presented on a map, various fractile values have to be selected. In this investigation the 95% fractile value is represented on lithogeochemical maps because (1) the fractile value is anomalous compared with the deviation around the median; and (2) to facilitate comparison between elements and stratigraphic units. Other appropriate fractile values have also been used to illustrate the geochemical conditions in the different stratigraphic units.

Lithogeochemical maps have only been produced where the 95% fractile value occurred at approximately the same stratigraphic level in the sections. In drawing the maps the stratigraphic sections have acted as centres, and supplementary evidence has been taken from the field investigations for drawing the contours and for illustrating the geochemical relations prior to later tectonic and erosional events. The individual maps will be discussed in the succeeding chapters.

MINERALISATION IN THE UPPER PERMIAN

Conglomerate Member

This unit, which mainly consists of bedded conglomerates, breccias and pebbly sandstones, was interpreted by Maync (1942) as fluviatile or shallow marine beach deposits. Scattered copper mineralised localities exist in the Mesters Vig area, at Bredehorn, on Traill Ø and in Giesecke Bjerge (north of Kejser Franz Josephs Fjord). The mineralisation is irregular and characterised by limited lateral continuity (700 m in north Giesecke Bjerge, 50 m in Mesters Vig). Disseminated sulphides may occur over the whole thickness of the conglomerate (9 m in Giesecke Bjerge) or be confined to the uppermost 0.5 m (Mesters Vig).

The sulphides are fine grained (d~0.2 mm) and occur mainly as cement, to a lesser extent also as replacement in the pebbles. The main ore mineral chalcopyrite replaces minor associated pyrite and may contain inclusions of sphalerite and bornite. Some silver is associated with the chalcopyrite (table 4). Estimated copper contents of mineralised localities are always well below 1%.

Limestone-Dolomite Member

Depositional environment

The Limestone-Dolomite Member consists of a number of subfacies ranging from limestone and dolostone breccias to bedded or massive reef limestones, and contains an abundant marine fauna. Deposition of the member apparently took place in a shallow marine bay with several large bioherms (up to 150–200 m thick) along the eastern shoreline (fig. 1B).

Mineralisation

Mineralisation occurs in both the eastern and western part of the Jameson Land Basin, with significant differences in patterns of mineralisation between the various areas.

Towards the east, on Wegener Halvø, sulphides occur scattered over the whole peninsula with major concentrations to the south in the Devondal area (fig. 1B). Lead and copper minerals are typically found near the top of the bioherms as millimetre to decimetre thick veinlets and breccia-fillings together with baryte, calcite and fluorite. Silicification and appreciable amounts of zinc are confined to the Devondal area.

In Devondal, the most intensely mineralised portions occur in the uppermost part of the reefy limestones near N–S striking faults belonging to the eastern fault-zone of the rift. Analyses of 20 chip samples from an area of 100×500 m^2 show mean values of 0.5% Cu, 0.17% Pb and 0.09% Zn. The major part of the mineralisation is open space fillings and is associated with silicification and dolomitisation of the limestones. The silicified zones are enveloped by zones of dolomitisation.

Typically the copper minerals are located within the silicified zones, whereas sphalerite and especially galena are found also in the enveloping dolomitic zones. The copper minerals are tennantite, chalcopyrite and minor enargite. Tennantite replaces chalcopyrite (fig. 7A) and both minerals contain small inclusions of pyrite, galena and sphalerite. The tennantite is relatively zinc-rich (3.8%) and silver-poor (0.14%). The galena is low in silver (table 4).

In the western part of the basin mineralisation is known from Oksedal, Bredehorn (Paar, 1974) and Karstryggen (Kempter, 1961), i.e. over a 70 km long NNE-trending belt. The mineralisation, dominated by baryte and galena, is

Table 4. Cu/Ag and Pb/Ag ratios in copper and lead mineralised samples

Mineralised unit	main Cu minerals	average Cu/Ag	no. of analyses	average Pb/Ag	no. of analyses
Ørsted Dal Mb	Chalcocite	3600	6	–	–
Malmros Klint and Ørsted Dal Mbs	native copper	1900	18	–	–
Pingel Dal Beds	chalcocite	1800	33	–	–
Kap Seaforth Mb	chalcocite	500	11	–	–
Gråklint Beds	–	–	–	5000	10
Klitdal and Paradigmabjerg Mbs	chalcocite	200	28	12000	15
Limestone-Dolomite Mb (Wegener Halvø)	tennantite, chalcopyrite	400	18	6000	6
Limestone-Dolomite Mb (Bredehorn)	–	–	–	2300	21
Conglomerate Mb	chalcopyrite	800	9	–	–

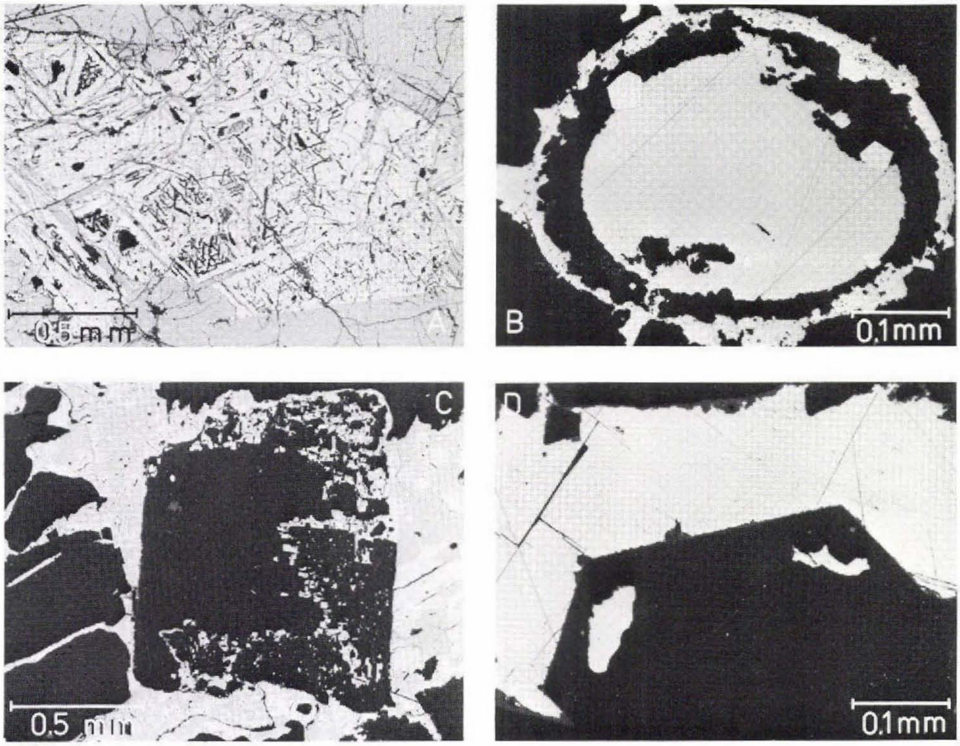


Fig. 7. Microphotographs (reflected light) of Upper Permian – Lower Triassic mineralisation. A. Tennantite (dark grey) replacing chalcopyrite (light grey) along (111) in chalcopyrite, Limestone-Dolomite Member. B. Galena replacement (grey) of unknown fossil and a few euhedral pyrite crystals (whitish-grey) in Posidonia Shale Member. C. Bornite (grey) and chalcocite (light grey) replacing clastic feldspar (black) in arkose from Klitdal Member. D. Galena (white) and autigene quartz in arkose from Klitdal Member. During autigene overgrowth of quartz on clastic grains, galena has been trapped in two areas. A and C in air, B and D in oil immersion.

situated in the lower part of the Limestone-Dolomite Member. Sphalerite, chalcopyrite, tetrahedrite, pyrite and marcasite are found only in trace amount.

At Bredehorn, an up to 10 m thick horizon of rhythmic-bedded (millimetre to centimetre) baryte-dolomite sequences, 'zebra-ore', containing galena outcrops over 300–400 m. The galena occurs in the rhythmic sequences as scattered grains and as several up to 15 cm thick and 30 m long massive lenses. It is rather coarse grained, relatively silver-rich (table 4) and contains abundant small inclusions of antimonite, tetrahedrite and other sulphosalts. Silicification of the host rock and remobilisation of the galena and baryte are common. Nine chip samples from a 300 m outcrop contain 1.5% Pb, 0.5% Zn and 57% baryte over an average thickness of 5.3 m. Adjacent to the 'zebra-ore' is a vein-type baryte-quartz-galena mineralisation related to a NNW–SSE fault.

The distribution of large scree-boulders of galena, 'zebra-baryte' and silicified limestone on the gentle slopes southeast of the described outcrop indicates a total mineralised area of approximately 1 km^2.

In the Oksedal area, similar geological situations exist at two localities where stratabound horizons of baryte-dolomite exhibiting 'zebra-structures' and containing some galena are adjacent to NNW–SSE trending, galena-bearing quartz-baryte veins.

At Karstryggen, celestite and baryte occur as breccia-fillings in a several metres thick transition zone from algal-laminated limestone to limestone breccias. Veinlets with minor galena, sphalerite and pyrite also exist (O. Harpøth, personal communication, 1980).

Posidonia Shale Member

Depositional environment

The member is characterised by dark, bituminous mudstones and limestones. The pelecypod *Posidonia* is the only common fossil. The sediments were deposited in low energy stagnant bays. On Wegener Halvø deposition took place in small inter-reef basins. The Posidonia Shale resembles the European Kupferschiefer and belongs to the same larger depositional basin (Maync, 1961).

Mineralisation

At Wegener Halvø the black mudstones contain zinc-lead-(copper) mineralisation, whereas only zinc has been seen in the Mesters Vig – Traill Ø area. In one cursorily examined inter-reef basin on Wegener Halvø, with a diameter of perhaps 800 m, high metal contents ($\sim$10% Pb+Zn) are restricted to a few 1–3 cm thick 'ore beds' of cherty, bioclastic limestone. These 'ore beds' are separated by 1 m of macroscopically unmineralised black shales. Their lateral continuity is unknown. A general vertical trend from zinc at the bottom, through lead, to copper at the top of the member exists at another investigated locality on Wegener Halvø (Thomassen, 1973). On Traill Ø, pyrite locally forms millimetre thick lenses and layers in the shales.

The mineralisation is stratiform and consists of fine-grained ($d<1$ mm), disseminated sphalerite and galena with minor chalcopyrite, pyrite and marcasite. The sulphides show colloform textures and replacement of fossils is widespread (fig. 7B). It appears that the Posidonia Shales are relatively rich in lead and possibly zinc, copper, cobalt and molybdenum (table 5). In spite of a substantial difference in thickness the Posidonia Shales are more comparable to the Kupferschiefer with regard to heavy metal contents than to average black shales.

Table 5. Average metal contents in Posidonia Shale

Locality	Thickness	Pb	Zn	Cu	V	Ni	Co	Mo	Th	U	Fe
Wegener Halvø	15 m	1300	350	200	79	72	30	<30	11	7	–
Mesters Vig east	5 m	130	<500	70	140	100	50	74	–	–	35000
Traill Ø south	11 m	87	<500	60	185	118	47	65	–	–	45000
Average in Kupferschiefer*	0.25 m	7500	17600	200	1640	328	95	240	–	–	31000
Average in black shales†		20	<300	70	150	50	10	10	–	–	20000

* Carbonate-bearing claystone (Rentzsch, 1974).
† According to Vine & Turtelot (1970).

Analyses by emission spectrography (U-Th by neutron activation) on chip samples.
All values in parts per million.

MINERALISATION IN THE TRIASSIC

Wordie Creek Formation

The lower part of the formation is in most places characterised by grey mudstones with ammonite and fish-bearing calcareous concretions and subordinate green siltstones or arkoses (Perch-Nielsen *et al.*, 1974). These sediments were deposited in marine sub-intertidal environments. Towards the top of the formation relatively thick units of shallow marine or fluviatile pink arkoses and conglomerates are common.

Scattered galena, sphalerite and pyrite (often replacing fossils) occur in calcareous concretions in the lower part of the formation; chalcocite, bornite, chalcopyrite and pyrite sometimes rim clay galls in the arkoses of the upper part of the formation. Lithogeochemically the occurrence of the sulphides has probably caused the break point on the cumulative frequency curve for lead and the high λ values for copper and lead (table 2). Because of the insignificance of these sulphides and the small number of lithogeochemical samples (24), the formation will not be discussed further in this account.

Klitdal and Paradigmabjerg Members

Depositional environment

This unit consists in the eastern part of the basin of up to 450 m thick sequences of cross-bedded conglomerates and pebbly arkoses with subordinate fine

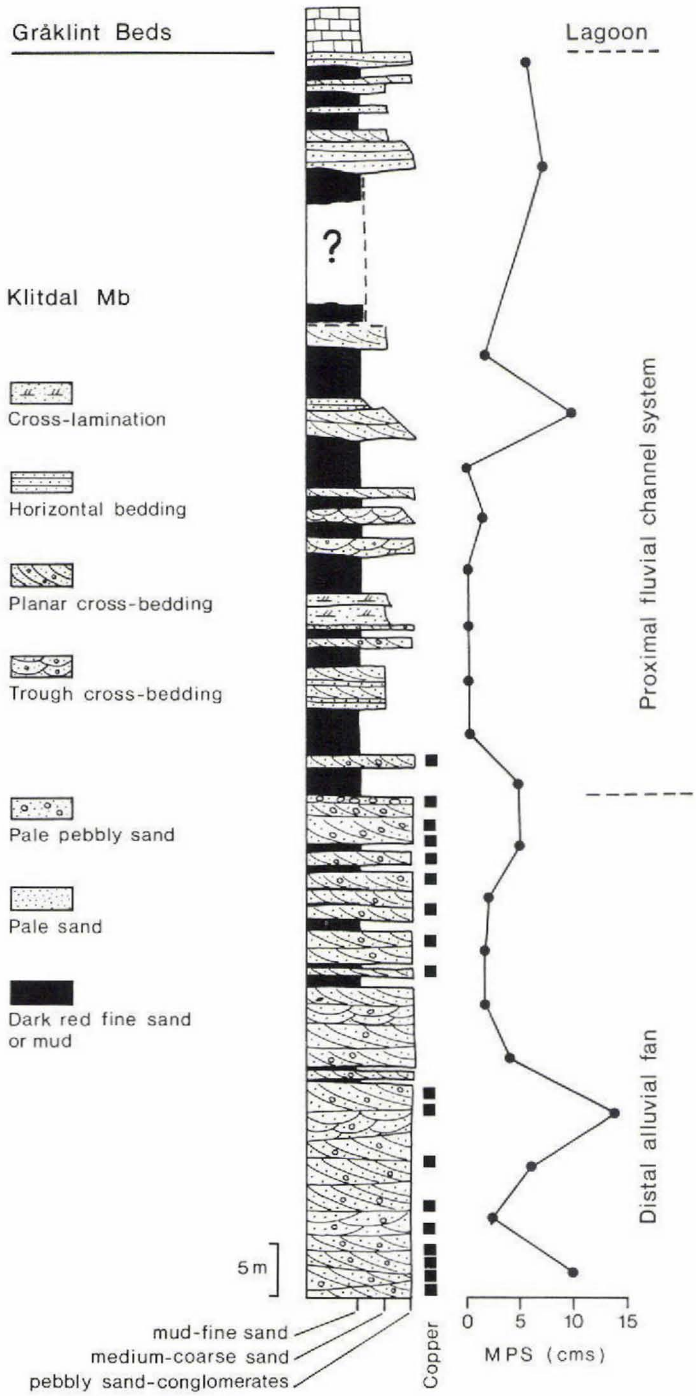


Fig. 8. Graphic log of the upper part of Klitdal Member in Devondal. MPS=maximal pebble size.

sandstones and mudstones. In the upper part of the members nodular limestone beds (incipient caliche) and jasper-horizons occasionally occur. The palaeocurrent data in this area indicate an easterly source and the sediments were probably deposited in alluvial fan and braided river environments along the margin of newly uplifted eastern highlands (Liverpool Land High and its northwards continuation). The coarse-grained proximal sediments grade westwards into more fine grained floodplain deposits with a northerly palaeo-slope.

Mineralisation

Copper-lead mineralisation is confined to a belt of distal alluvial fan sediments along the southern and eastern borders of the western, fault-bounded block of Wegener Halvø (figs 1B, 2, 8). In the Devondal area a lateral metal zoning seems to exist over an east–west distance of 6 km, with copper dominating to the east and lead to the west (Thomassen, 1977; Harpøth, 1979).

Ore minerals are contained in one or two up to 30 m thick levels of pink and whitish, cross-bedded arkoses and conglomerates with scattered pebbles and cobbles (figs 1B, 8). Within these levels, sulphides occur as irregular blebs, as millimetre thick stratiform layers in the most coarse-grained foresets or disseminated in metre thick beds. Subordinately sulphides may form millimetre thick, cross-cutting, massive veinlets. In east Devondal, 41 chip samples from the mineralised levels and from boulders show average contents of 0.22% Cu, 0.46% Pb, 0.04% Zn and 13 ppm Ag over a thickness of 1.41 m.

The ore minerals form the cement of the arkoses together with quartz, calcite and traces of albite and baryte. Clusters of small, subhedral anatase crystals are common in the cement. Replacement of clastic feldspar, especially by the copper-minerals, is widespread (fig. 7C). The interstitial ore grains have an average diameter of 0.4 mm. The relative age of the cement is: quartz (oldest) – lead-copper minerals – calcite (youngest) (fig. 7D). Chalcocite, bornite and galena are the main ore minerals, accompanied by minor sphalerite, chalcopyrite, tennantite and pyrite. Normal and 'blaubleibender' covellite is widespread, the normal type being of clearly secondary origin. Scanty amounts of galena occur as inclusions in the copper minerals, but otherwise copper and lead minerals are found separately. Characteristically, bornite always hosts small, orientated needles of chalcopyrite.

This mineralisation has the highest relative silver content of all the Permo-Triassic mineralisation. The silver is associated with the copper minerals (table 4). As no specific silver minerals have been identified, the silver must be contained in the lattices of the copper minerals. This is conceivable as chalcocite can contain up to 1.87 mol% Ag_2S in solid solution at 63° C, corresponding to a Cu/Ag ratio of 31 (Skinner, 1966).

Lithogeochemistry

This stratigraphic unit is the only one which has break points on the frequency curve for both copper, lead and zinc (fig. 6a). If, in this case, the break point values had been used instead of the 95% fractile as threshold values on the geochemical maps (fig. 9), the anomaly picture would have been roughly the same. Two anomalous areas exist, a major one on Wegener Halvø and a minor one in Klitdal. Only the one on Wegener Halvø corresponds to known mineralisation. It should be noted that the median values for the mineralised stratigraphic level are situated on a N–S line parallel to the eastern border of the depositional basin. The mineralisation is recorded only as high λ values for copper and zinc. Lead is not registered as a high λ value, because the break point value on the frequency curve and the 95% fractile value are coincident.

Gråklint Beds

Depositional environment

The unit is composed of grey calcarenites and calcareous sandstones associated with black mudstones and limestones and contains a restricted marine fauna (Grasmück & Trümpy, 1969). The marine sequence is between a few decimetres and 30 m thick and displays considerable facies variations throughout the basin. Barrier bar limestones and associated shoreline sandstones were deposited in the northeasternmost part of the basin at the same time as black lagoonal mudstones were laid down south and west of the barrier bar limestones (Clemmensen, 1980).

Mineralisation

Continuous lead-zinc-(copper) mineralisation is known from the head of Carlsberg Fjord to the head of Fleming Fjord, i.e. over an area of more than 500 km^2. The sulphides occur disseminated as fine grains (d~0.5 mm) in one or two 5–50 cm thick horizons in grey barrier bar calcarenites or shoreline calcareous sandstones immediately below layers of black lagoonal mudstones or limestones. The sulphide contents are always modest, but laterally continuous. A typical mineralised grey, calcareous sandstone contains 0.6% Zn, 0.5% Pb, 0.2% Cu and 4 ppm Ag. The black sediments also contain minor quantities of ore minerals, and bleached arkoses immediately below the Gråklint Beds are sporadically mineralised.

Galena and pale sphalerite are the dominant ore minerals, accompanied by minor pyrite, chalcopyrite and marcasite. These minerals often exhibit spongy

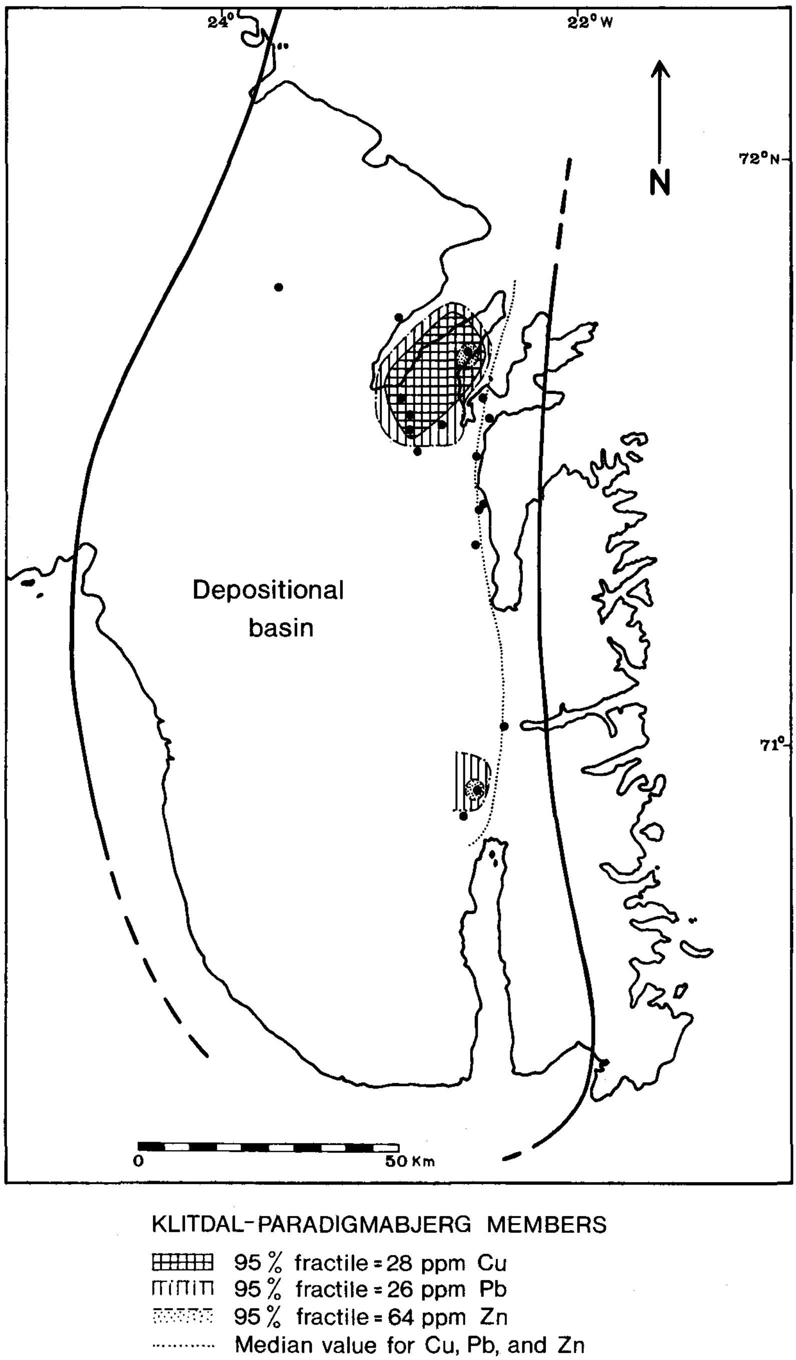


Fig. 9. Lithogeochemical map of copper, lead and zinc in the Klitdal-Paradigmabjerg Members for the level 100 m below the Gråklint Beds. Sections are designated by dots.

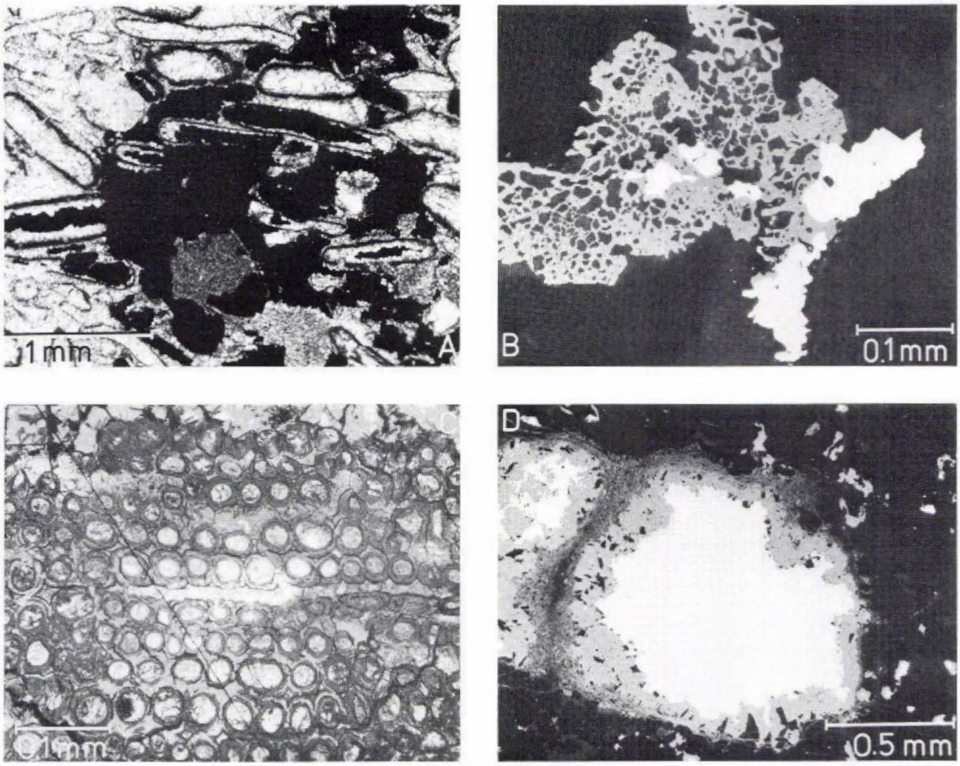


Fig. 10. Microphotographs of Middle – Upper Triassic mineralisation. A. Galena and sphalerite (black) replacing intraclasts and cement in intrasparite from Gråklint Beds. B. Typical textures in galena (white) and sphalerite (grey, spongy) in the grey limestones of the Gråklint Beds. C. Chalcocite (grey) and galena (white) forming pseudomorphoses of wood-cells in a scree boulder probably belonging to the Kap Seaforth Member. D. Native copper (white) rimmed by replacing cuprite (grey) in carbonate-rich sandstone from Ørsted Dal Member. A in transmitted light, B and C in reflected light and oil immersion and D in reflected light in air.

textures and irregular intergrowths (fig. 10A,B). Locally a chalcocite-bornite-covellite paragenesis occurs.

A lateral metal zonation is indicated, with relatively high copper and lead values in the Devondal area and high zinc values in Passagen further to the south.

Lithogeochemistry

The geochemical maps show a NNW-trending belt of anomalous lead and zinc in northeast Jameson Land. In a palaeogeographic context this belt is situated where thick barrier bar complexes interfinger with lagoonal limestones.

Lead and zinc generally have the highest values in the same bed (fig. 11). This is reflected in the large area overlap of anomalous lead and zinc values on the

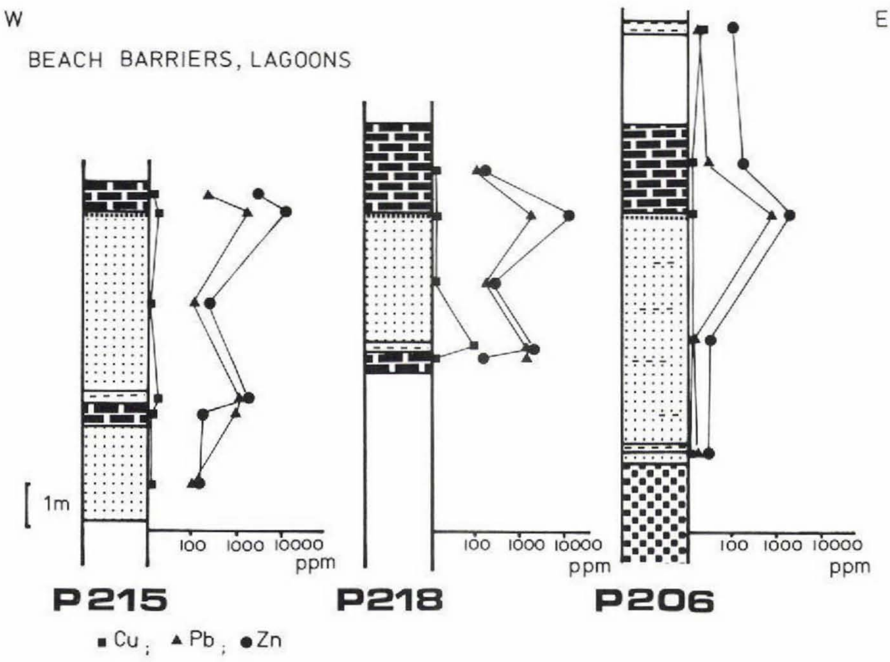


Fig. 11. Lithogeochemical logs of the Gråklint Beds – for location see fig. 13. Lead and zinc are concentrated in a horizon of pebble conglomerate below bituminous limestone. The distance between the logs is 1 km. Legend on fig. 16.

geochemical maps (figs 12,13). However, this overlap is not perfect, largely owing to separation of the elements, with high lead in the black calcareous mudstones and high zinc in the more clastic part of the black sediments.

Kap Seaforth Member

Depositional environment

The member is composed of cyclically bedded mudstones, fine-medium grained, cross-bedded sandstones and gypsum beds of shallow lake, sabkha and aeolian origin (Clemmensen & Andreasen, 1976; Clemmensen, 1978a). It appears that the Jameson Land Basin was occupied by two major lacustrine depositional centres in this time interval, the two lakes differing somewhat in sedimentary features (Clemmensen, 1980). It is the southeastern lake along the Liverpool Land High that contains the mineral occurrences.

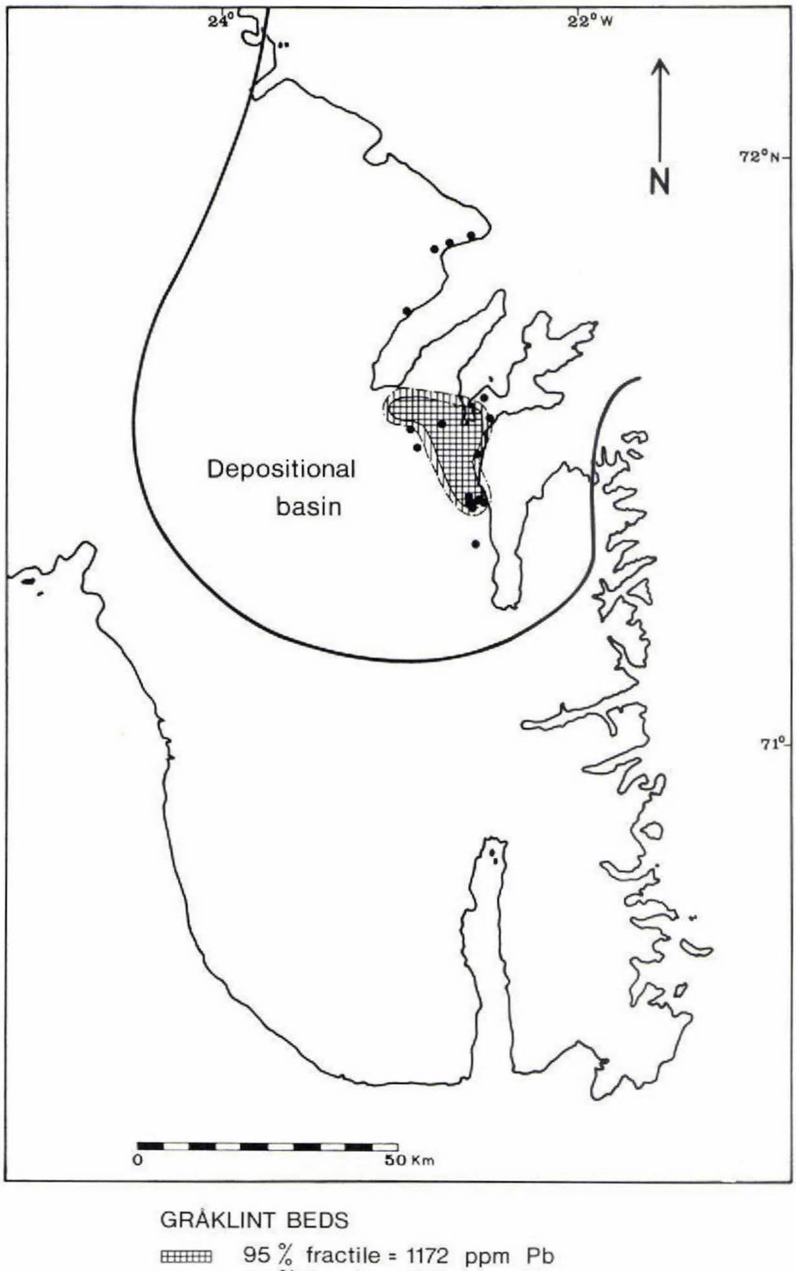
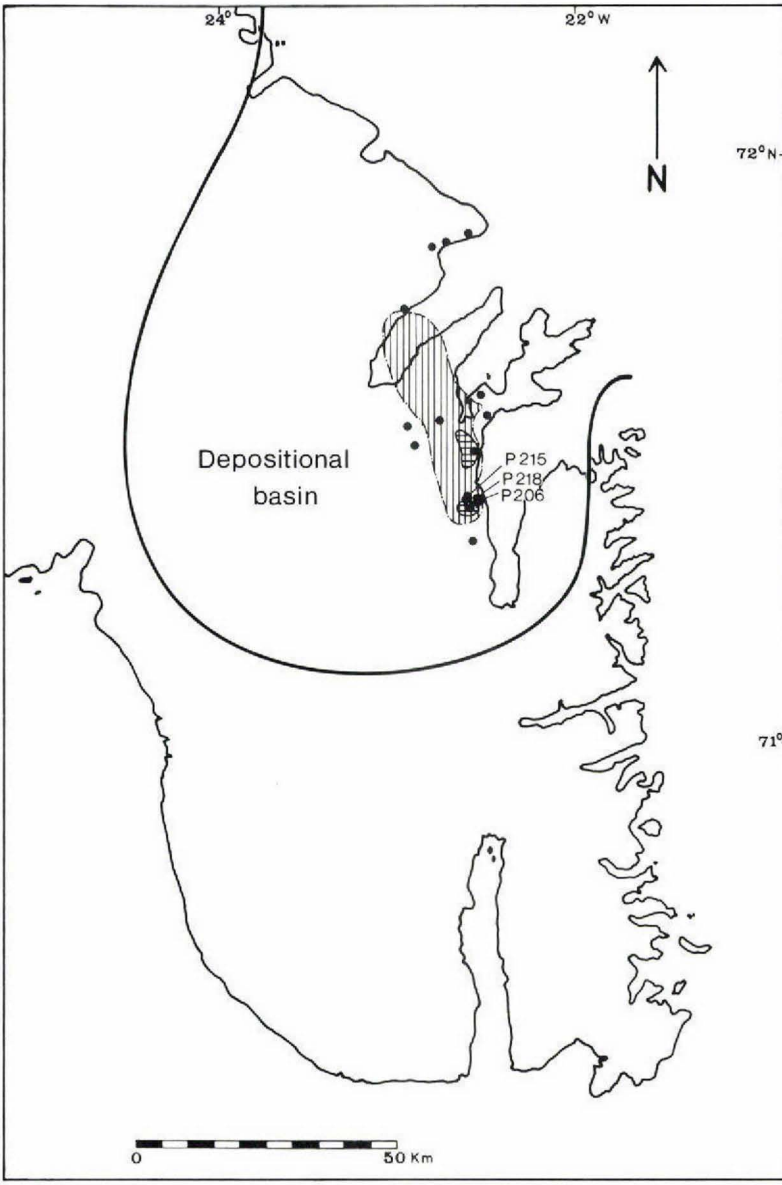


Fig. 12. Lithogeochemical map of lead, Gråklint Beds.



GRÅKLINT BEDS

95 % fractile = 5280 ppm Zn

90 % fractile = 2180 ppm Zn

Fig. 13. Lithogeochemical map of zinc, Gråklint Beds.

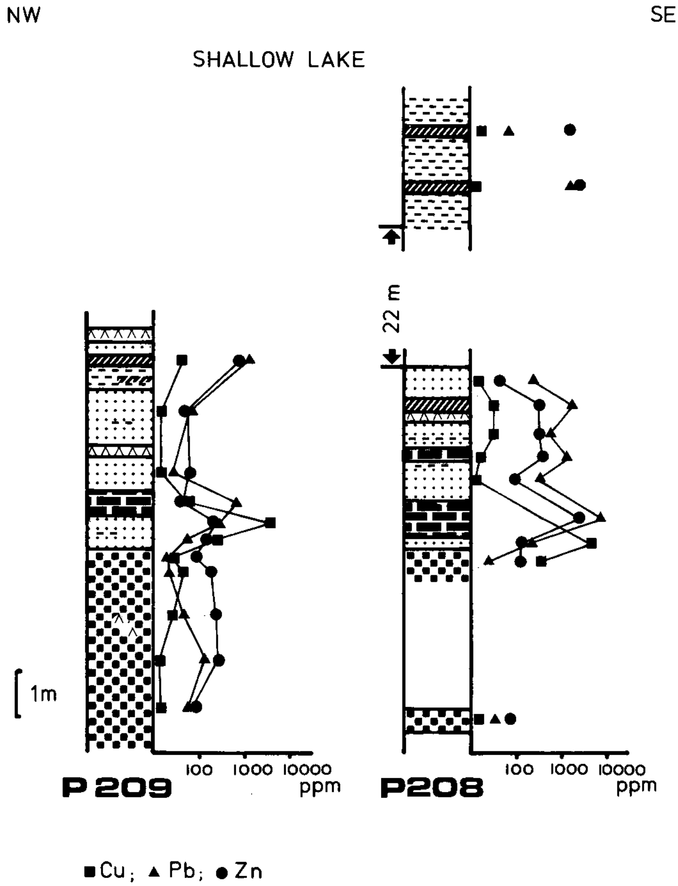
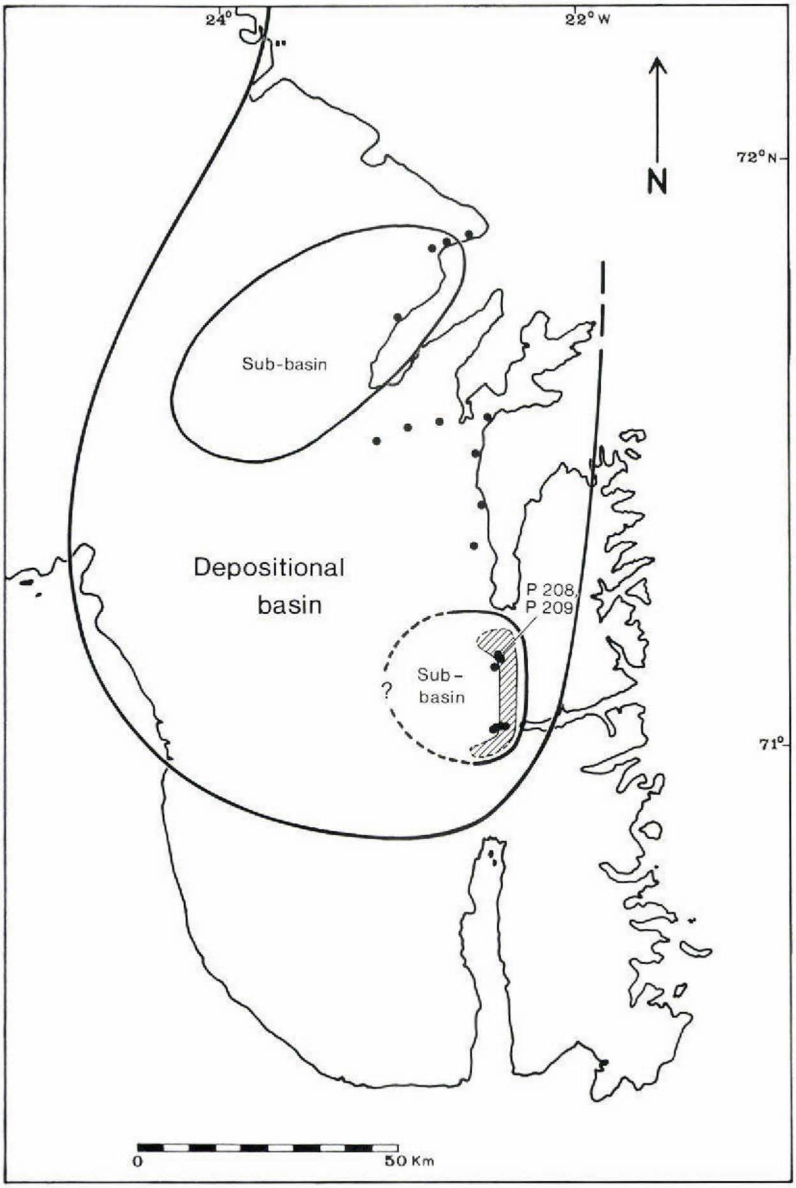


Fig. 14. Lithogeochemical logs of the Kap Seaforth Member – for location see fig. 15. The distance between the logs is 750 m. Legend on fig. 16.

Mineralisation

Copper-lead-zinc mineralisation in the Kap Seaforth Member is restricted to a well defined, approximately 100 km^2 lacustrine sub-basin south of Carlsberg Fjord. The basal part of the member in this area shows a vertical zonation: copper (bottom) – lead – zinc (top) (fig. 14). The copper minerals occur in an up to 0.5 m thick bed of grey, calcareous marginal lacustrine sandstones below open lacustrine black mudstones mineralised with lead and occasionally also with zinc. Black mudstones and dolostones at higher stratigraphic levels are also mineralised with lead or zinc, but here the underlying clastic rocks show no signs of copper mineralisation.

The mineralised sediments contain relatively abundant carbonaceous matter in the form of microscopic plant fragments, and plant cells may be replaced by sulphides (fig. 10C). The black mudstones and dolostones contain disseminated,



KAP SEAFORTH MEMBER

Area with Cu, Pb, and Zn > 95 % fractile
(Cu > 1806 ppm, Pb > 1523 ppm, Zn > 1407 ppm)

Fig. 15. Lithogeochemical map of copper-lead-zinc, Kap Seaforth Member. The two sub-basins both contain thick gypsum-bearing sequences, but only the southern sub-basin is mineralised.

fine-grained galena, sphalerite and a little pyrite. Especially the latter shows colloform textures, whereas galena may form euhedral crystals. Chalcocite, covellite and subordinate bornite, galena and sphalerite form part of the cement in the grey sandstones together with calcite and quartz. The copper sulphides are often associated with mud flasers containing organic matter and occasionally rock salt pseudomorphs.

The average mineralised grey sandstone contains 0.3% Cu, 0.05% Zn, 0.04% Pb and 7 ppm Ag. The relative silver content is generally rather high (table 4) and in a sulphide-rich sample with preserved plant structures it is extremely high (0.7% Ag).

Lithogeochemistry

The geochemistry clearly shows that the southern sub-basin is anomalous with respect to the copper, lead and zinc content (fig. 15), registered as break points on the frequency curve for lead and zinc (fig. 6b) and as high λ values for all three elements (table 3). In the northern sub-basin only copper shows a high λ value. The differences in content between the two sub-basins are also illustrated by the 95% fractile and median values (table 2). This difference is in accordance with the observed mineralisation pattern outlined above.

Pingel Dal Beds

Depositional environment

The Edderfugledal Member is characterised by stromatolites and can be divided into a lower, open lacustrine unit dominated by dolostones (Sporfjeld Beds) and an overlying shallow lacustrine unit with more clastic terrigenous material (Pingel Dal Beds), (fig. 1A). The upper shallow lacustrine unit shows well-developed cyclic bedding and consists of (cf. Clemmensen, 1978b): (1) open lacustrine mudstone, (2) near-shore lacustrine stromatolite facies, (3) near-shore or beach flat pebble conglomerate, (4) marginal lacustrine carbonate mudflat facies, (5) shoreline sandflat facies and (6) alluvial mudflat facies. The lake in question covered large parts of Jameson Land, Scoresby Land and Traill Ø, and may intermittently have been flooded by marine water from the northeast.

Mineralisation

Copper mineralisation is known over an approximately 1000 km² area from Kap Biot to the head of Carlsberg Fjord. This mineralisation is not confined to the eastern border of the basin, but has also been met with in the central part of the basin.

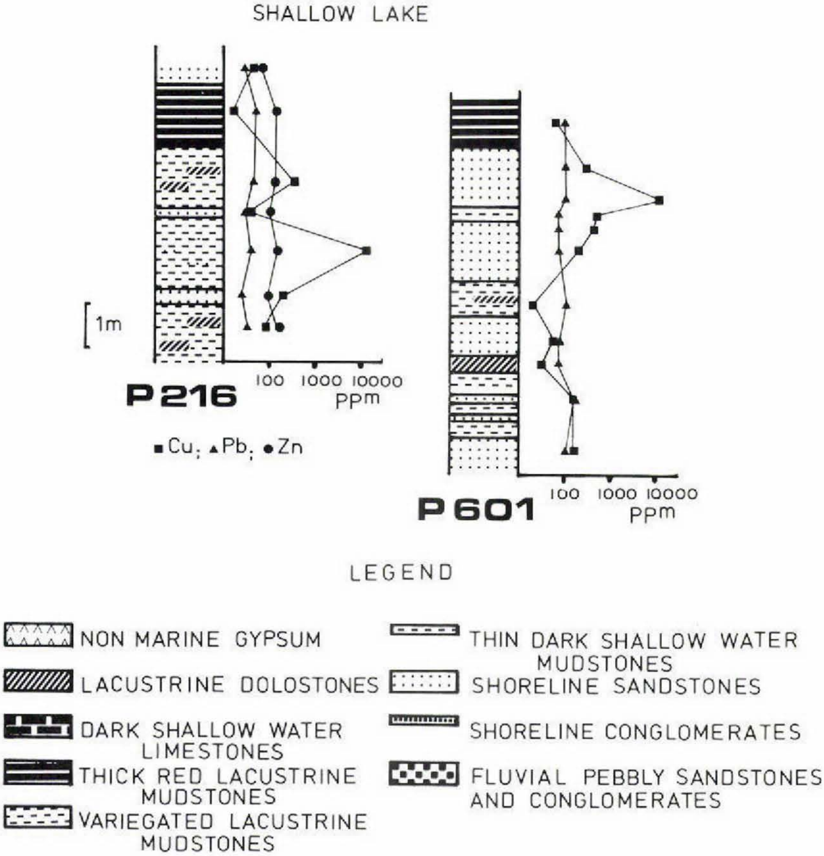


Fig. 16. Lithogeochemical logs of the Pingel Dal Beds, location on fig. 17. P601 is measured by O. Harpøth.

Three types of mineralised sediments can be distinguished: (1) a 0.5–1 m thick black, silty mudstone with sand lenses (open lacustrine environment, fig. 16) which laterally interfingers with (2) 1–2 m thick beds of alternating light greyish, flaser-bedded sandstones and black, silty shales (shoreline flat environments). Type (1) and (2) occur in the upper part of the unit and are overlain by red mudstones, whereas type (3) is situated 15 m higher in the sequence where it forms two 0.2–1.3 m thick, yellowish weathering dolomitic mudstone horizons interbedded in the red mudstones. At present type (1) is mainly known to the south of Passagen, type (2) in the area between Passagen and Fleming Fjord and type (3) to the northwest of Fleming Fjord.

The copper minerals form stratiform, fine-grained (d~0.035 mm) disseminations over the whole thickness of types (1)–(3) and the mineralised horizons are extremely consistent laterally. The clay-silt laminae in the mineralised sediments are characterised by relatively abundant microscopic plant fragments. The ore minerals are mainly located in coarse-grained laminae, and especially concentrated along the contact to the fine-grained laminae and in mud-cracks and burrows. The main ore mineral is chalcocite, accompanied by minor bornite, 'blaubleibender' covellite, chalcopyrite and pyrite. Bornite, with orientated chalcopyrite needles, is sometimes the main sulphide. Fifty-three chip samples from seven sections through the mineralised horizon in the Fleming Fjord area show average contents of 1591 ppm Cu, 88 ppm Zn, 15 ppm Pb and 1.9 ppm Ag over a thickness of 2.45 m.

A lateral mineral zonation can be distinguished with a chalcocite-bornite paragenesis in the central part of the palaeo-basin surrounded by a chalcocite paragenesis (fig. 17). The Cu/Ag ratio indicates a similar lateral zoning with the lowest values (highest silver contents) along the basinal axis.

Lithogeochemistry

As the mineralised horizon forms the top of the Pingel Dal Beds, the sampling procedure meant that this horizon was sampled directly, resulting in extraordinarily high copper values. In view of this it is remarkable that no break point occurs on the frequency curve.

The lithogeochemical map (fig. 17) illustrates the extensive area of the mineralisation, with the major copper-anomalous areas situated northwest of Fleming Fjord and south of Passagen. At some localities it was not possible to sample the uppermost horizon, due to the cliff-forming nature of the beds, so that the copper isoline is partly based on local scree-boulders (fig. 17).

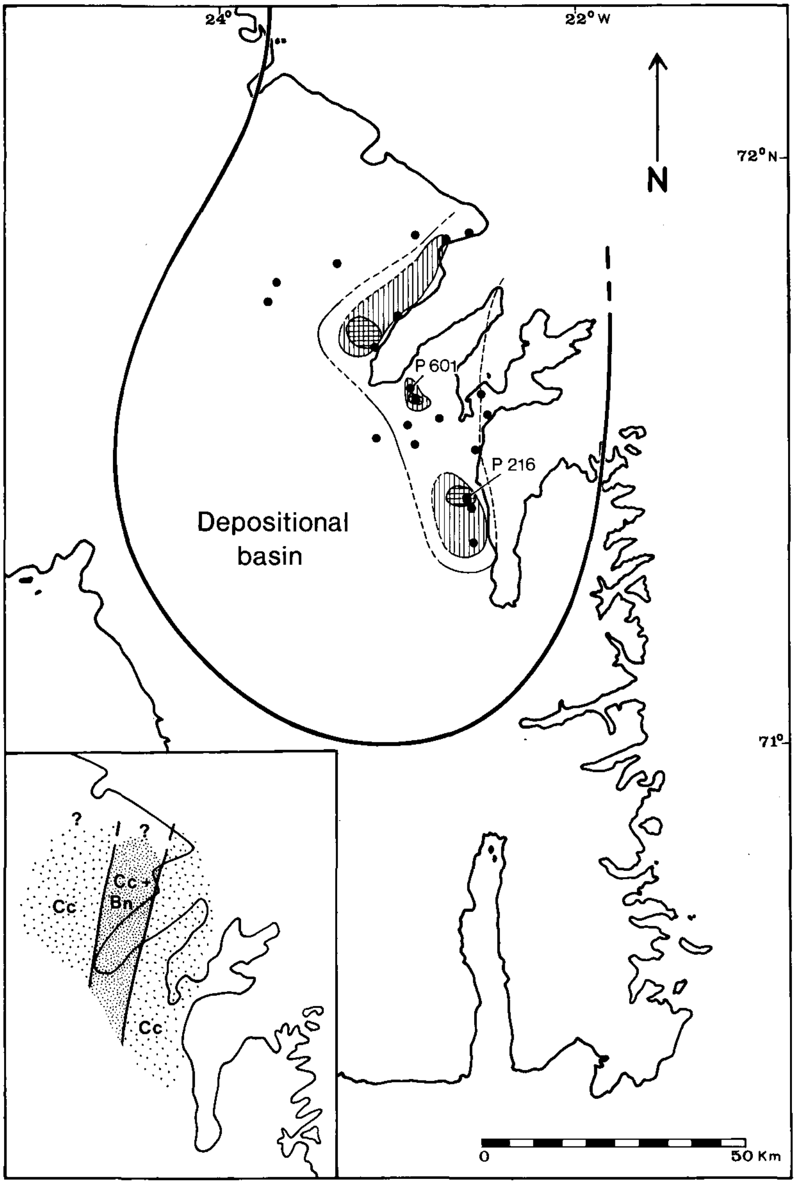
Malmros Klint and Ørsted Dal Members

Depositional environment

The red mudstones of playa-mudflat origin in the Malmros Klint Member show a gradual upwards transition to the more sandy distal floodplain deposits of the Ørsted Dal Member (Clemmensen, 1980). The channel sandstones of the latter member were mainly deposited by eastward or northward migrating rivers, and the playa-mudflats are most extensively developed along the northeast margin of the continental basin.

Mineralisation

Copper mineralisation located at the transitional zone of the two members has approximately the same area distribution as in the Pingel Dal Beds. The mineralisation is hosted in a few approximately 0.5 m thick, grey, pale-yellowish weather-



PINGEL DAL BEDS

—— -- 2000 ppm Cu. The eastern boundary based on blocks found in talus

Area with Cu > 6320 ppm = 95% fractile

Area with Cu > 10.000 ppm

Fig. 17. Lithogeochemical map of copper, Pingel Dal Beds. The inset is a generalised map of mineral zoning in the Pingel Dal Beds. Cc = chalcocite dominant sulphide, Cu/Ag > 1000. Cc + Bn = chalcocite and bornite dominant sulphides, Cu/Ag < 1000.

ing beds intercalated in red mudstones. The beds consist of fine-grained, muscovite-bearing, carbonate-rich sandstones with conspicuous cross-lamination. Thin intraformational breccias and septarians occur locally. Carbonaceous plant fragments up to 30 cm long have been met with northwest of Fleming Fjord.

The ore minerals appear partly as up to several cubic centimetre large blebs and plates of native copper, partly as more fine-grained disseminations in a few centimetre thick zones. Native copper, often rimmed by replacing cuprite, is the main ore mineral (fig. 10D).

Varying amounts of chalcocite (accompanied by a little bornite and covellite), native silver and minerals of the domeykite – algodonite group (Cu_3As – Cu_7As) also occur.

The copper content of the grey sandstone beds vary considerably, with a typical range of between 0.01% and 0.1%. A lateral mineral zoning seems to exist, with chalcocite dominant west of Fleming Fjord, native copper and copper arsenides between this fjord and Passagen and copper arsenides dominant south of Passagen.

DISCUSSION

The Permo-Triassic represents a rift phase subsequent to the Caledonian orogenesis and is characterised by an overall dry climate. Within this geotectonic-palaeoclimatic framework a number of mineralisation types occur. They can be divided into fault-bounded – stratabound mineralisation, and stratabound-stratiform mineralisation.

The fault-bounded – stratabound mineralisation

This type of mineralisation occurs in the Upper Permian Limestone-Dolomite Member. It is located near N–S and NW–SE trending faults and is mainly hosted in carbonate rocks. The fault systems are supposed to have acted as channels for mineralising solutions which have replaced, silicified and barytised the limestones. At least some of the sulphides have been precipitated in open space.

The stratabound-stratiform mineralisation

This type of mineralisation occurs in mainly clastic sediments of Upper Permian and Triassic age. The mineralisation is hosted in the following type of rocks: (1) black mudstones, (2) sandstones with mud flasers and (3) sandstones and conglomerates (table 6).

The mudstones represent a low energy reducing environment, the sandstones and conglomerates represent a high to medium energy oxygenated environment,

Table 6. Summary of the Permo-Triassic stratabound-stratiform mineralisation in the Jameson Land Basin.

Host rocks	Stratigraphical unit	Environment
black mudstones	Pingel Dal Beds (north)	marginal lacustrine, low energy
	Pingel Dal Beds (south)	off-shore lacustrine, low energy
	Gråklint Beds	lagoonal, low energy
	Posidonia Shale Mb	off-shore marine, low energy
sandstones with mud flasers	Pingel Dal Beds (central)	shoreline sandflat, medium energy
	Kap Seaforth Mb	off-shore lacustrine, low energy
sandstones and conglomerates	Ørsted Dal Mb	meandering river, medium energy
	Klitdal and Paradigmabjerg Mbs	proximal braidplain – distal alluvial fan, high energy
	Conglomerate Mb	fluviatile – beach, high energy

whereas sandstones with mud flasers were deposited during alternating medium to low energy conditions. The mineralisation hosted in mudstones (1) and in sandstones with mud flasers (2), is fine grained and generally associated with organic matter. The ore minerals and the mineralised horizons form part of the stratification and appear as an original part of the sediment. These mineralised horizons have great lateral consistency and are of true stratiform character. They are comparable to the Kupferschiefer type deposits (Wedepohl, 1971).

It should be stressed that in the Kupferschiefer type the element distribution is highly variable even within the same environmental context. Thus in the case of the Kap Seaforth Member (south), shoreline sandstones are initially copper anomalous, whereas higher lying sandstones of the same facies are poor in copper (fig. 14). In the same sections off-shore limestones are constantly high in lead and/or zinc. In contrast in the Gråklint Beds no copper anomaly occurs in the shoreline sandstones, whereas lead and zinc anomalies exist in lagoonal limestones as well as in beach conglomerates.

In the Pingel Dal Beds, copper anomalies occur in black mudstones, in sandstones with mud flasers and in dolomitic mudstones belonging to different depositional environments. Although the same rock types occur at lower levels, the copper anomalies are restricted to a zone of 2–3 m thickness below the red mudstone sequence (fig. 16). It should also be stressed that the mineralised facies are different in various areas (table 6). Thus in the area northwest of Fleming Fjord the copper is concentrated in marginal lacustrine dolostones only, in the area between Fleming Fjord and Passagen the copper is located in shoreline sandflat facies, and finally south of Passagen only off-shore black mudstones are mineralised.

The mineralisation hosted in sandstones and conglomerates (3) is relatively coarse grained and the ore minerals form part of the cement together with quartz, calcite and occasional baryte. The ore minerals are concentrated in the more coarse grained and originally most permeable parts of the sediments. The mineralisation occurs within the reduced part of the sediments, but not all reduced parts are mineralised. Both mineralisation and the reduced parts of the clastic sediments have an irregular geometry which often cuts the stratification. Due to these characteristics, the mineralisation does not appear as an original part of the sediment, but must be related to diagenetic processes in the sediment. This type of mineralisation belongs to the sandstone type deposits (Samama, 1976).

Lithogeochemically there is a significant difference between the Kupferschiefer and the sandstone type. In the Kupferschiefer type, the copper-plot on probability paper shows a nearly straight line indicating a single approximately lognormal population (fig. 6b) whereas in the sandstone type the copper-plot shows two nearly straight lines indicating two lognormal populations (fig. 6a). This suggests that the copper in the Kupferschiefer type forms an integral part of the reducing environment, whereas the two copper populations in the sandstone type indicate that two sets of processes were involved here. The statistical copper distributions are thus in agreement with the known relationship between host rock and mineralisation in the two environments. In both environments plots of lead and zinc indicate two populations (fig. 6a,b). Following the distribution of copper this is not surprising in the case of the sandstone type mineralisation, but for the Kupferschiefer type the distribution of lead and zinc seems to involve at least one additional factor compared to those controlling the copper distribution. That factor could be copper, which has the lowest solubility product of the involved sulphides, and therefore would influence the sulphide ion capacity of the environment and consequently the precipitation of lead and zinc sulphides.

According to the characteristics given above the mineralisation hosted in sandstones and conglomerates was formed during diagenesis by circulating water probably representing a mixture of surface water and intrabasinal formed brines (fig. 18). The surface water could have been enriched in elements from weathered Precambrian copper mineralisation and Devonian copper-lead-zinc mineralisation known to exist in the borderlands (Caby, 1972). The intrabasinal formed brines were probably enriched in specific elements by leaching sediments during their circulation in the basin (Samama, 1976). Sulphur, necessary for the formation of the mineralisation, could have originated from the evaporites. However, no indication of what caused the reduction of the sulphate has been found.

The mineralisation hosted in mudstones and in sandstones with mud flasers are thought to have been supplied by elements synchronous with sedimentation. Two major sources possibly contributed to the formation: elements from organic-rich sediments and elements from sea or lake water (fig. 18). This combination is a potential for stratiform sulphide formation (cf. Rickard, 1973). Bacterial reduction of sulphate probably produced the major part of the neccessary sulphide, organic sulphur playing a minor role. Later redistribution of elements by compaction fluids

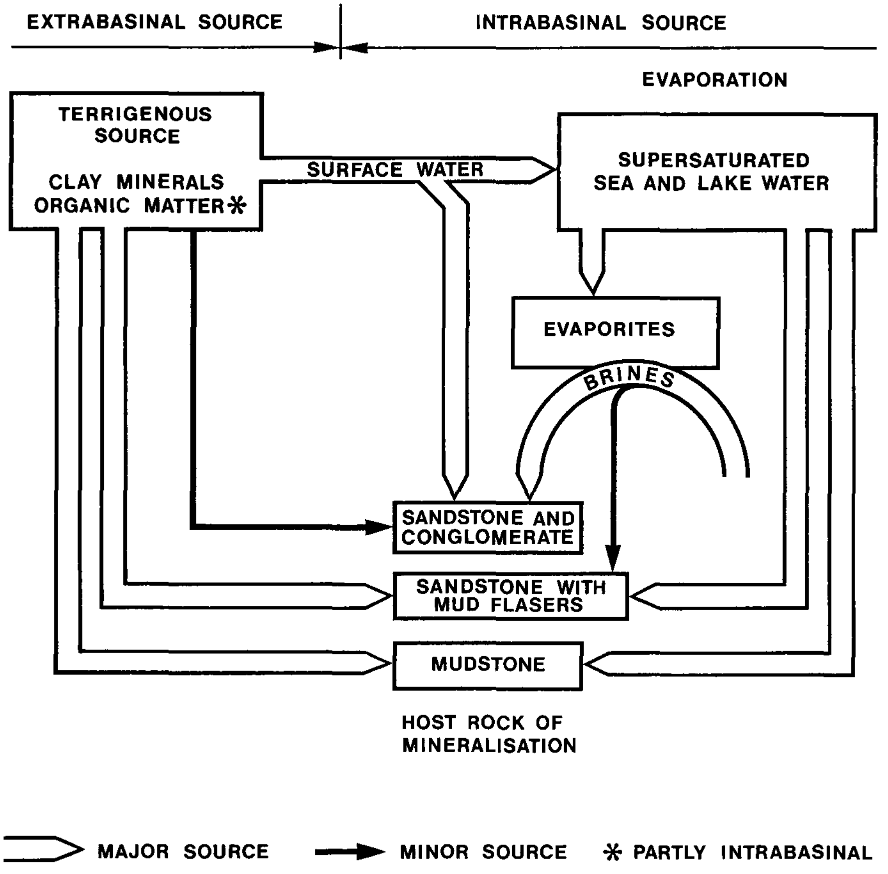


Fig. 18. Possible sources of elements in the stratabound-stratiform mineralisation.

is probable, especially in the mudstones with mud flasers. This is indicated by the concentration of sulphides at the sand-mud flaser contacts.

The suggested genesis involving weathering of uplifted borderlands gains support from the general trend in the mineral occurrences from Lower to Upper Triassic: from mixed copper-lead-zinc contents (Klitdal Member, Gråklint Beds and Kap Seaforth Member) to pure copper contents (Pingel Dal Beds and Ørsted Dal Member). This trend is paralleled by a gradual climatic shift towards a more humid climate. A similar, climatically controlled development has been reported from the Triassic of France by Bernard & Samama (1976). They interpret this trend of changing element content as caused by weathering of the borderlands during changing weather conditions.

There is no direct evidence of contributions from hydrothermal solutions in the formation of the Triassic stratabound-stratiform mineralisation. However, faint Upper Permian volcanic activity in the form of lamprophyre dykes is known from the southwest margin of the basin (Stemmerik & Sørensen, 1980). It is an open question whether this activity has any connection with the solutions which formed the mineralisation hosted in the Upper Permian sediments.

CONCLUSIONS

1. The Permo-Triassic rift environments of central East Greenland with minor or no volcanic activity and a dry palaeoclimate represent favourable conditions for the formation of metal concentrations.

2. The ore mineralogy of nine mineralised units in the Permo-Triassic sequence is described in some detail for the first time.

3. The mineralised horizons are found in a variety of sedimentary facies representing Upper Permian shoreline, euxinic lagoonal and carbonate buildup and shelf environments and Triassic alluvial fan, shoreline, lagoonal, lacustrine and fluvial channel environments.

4. A new statistical function, λ, is introduced. A λ value of 1.8 successfully differentiates between mineralised and barren stratigraphic units.

5. Five lithogeochemical maps illustrate the geochemical situation in various Triassic lithostratigraphical units. There is commonly good agreement between palaeogeographical setting and geochemical pattern.

6. Two main types of mineralisation occur: fault-bounded – stratabound mineralisation (Upper Permian Limestone–Dolomite Member) and stratabound-stratiform mineralisation. The latter group is divided into mineralisation hosted in (1) black mudstones, (2) sandstones with mud flasers and (3) sandstones and conglomerates.

7. There is a clear upwards trend in the Triassic sequence from mixed copper-lead-zinc mineralisation to pure copper mineralisation. It is suggested that this trend is climatically controlled and reflects weathering of the borderlands during increasingly humid weather conditions.

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