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West Greenland coal deposits: distribution and petrography

by

E. J. Schiener

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West Greenland coal deposits: distribution and petrography

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Abstract

Surface investigations in the coal-bearing sediments of Disko and Nûgssuaq are used for an outline of the geological framework and for reserve estimates of 20–30 million tons. Some of the technical properties of West Greenland coals are evaluated on the basis of laboratory investigations of selected seams. Dominating maceral is vitrinite. Rank is in the high volatile bituminous A range with minimum ash percentages around 5 per cent. Coking properties are poor. Ashes have fusion temperatures from 1450°C upwards.

Contents

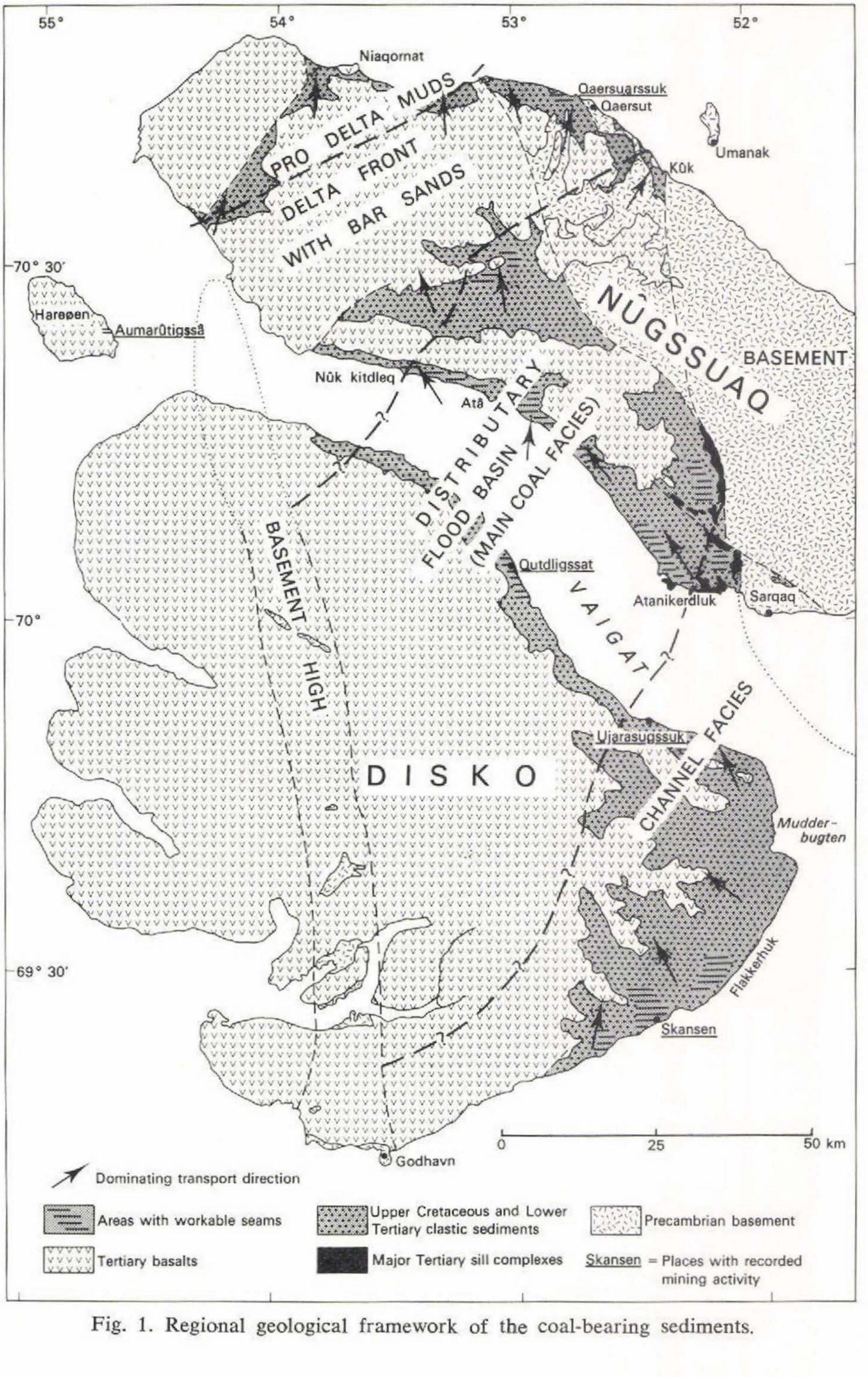


Fig. 1. Regional geological framework of the coal-bearing sediments.

Introduction

The 'energy crisis' late in 1973, almost exactly one year after the closure of the mine at Qutdligssat, resulted in a revival of interest in the coal deposits of central West Greenland.

Advances in mining technology (Skipsey, 1970) as well as in coal processing have brought the marginal deposits into the limelight. Although apparently not of immediate interest, economic exploitation of poor quality coal even under less favourable mining conditions will be possible, provided sufficient reserves can be proved. The small mine at Qutdligssat had final recoverable reserve estimates in the region of two million tons; annual production averaged 20 000 tons from a 1.5 m seam. One of the main problems of the mine was the lack of a harbour, resulting in rather unwieldy shipping procedures of the product, which had difficulties in competing with imported, higher quality coals.

Field investigations

As part of a basin study programme initiated in 1972, the Cretaceous–Tertiary sediments of Disko and Nûgssuaq were sampled and sections were measured especially in the coal-bearing facies on southern Nûgssuaq. Channel samples of coal seams thicker than 25 cm were taken and a selection of these samples were submitted for coal petrographic analyses to Bergbau Forschung G.m.b.H., Essen, Germany. Material from earlier collections (Pedersen, 1956) was also utilized for this purpose even though very small quantities were available.

From previous surveys it is known that seams exceeding 1.0 metre in thickness are concentrated in the slopes between Atanikerdluk and Atâ on the south coast of Nûgssuaq. (figs. 1 & 2). In the central valley of Nûgssuaq (Auvfarssuaq) some seams of similar thickness were encountered while measuring the sedimentary column (figs. 2 & 3).

Stratigraphy

A detailed review of the existing literature containing stratigraphical information has been given by Henderson *et al.* (1976). A short resumé will therefore suffice here.

The oldest coal-bearing sediments occur on northern Nûgssuaq in the ? non-marine Kome Formation (Barremian–Aptian). These Lower Cretaceous strata are restricted to the coast and to the mountainous hinterland between Ikorfat and Kûk. This area

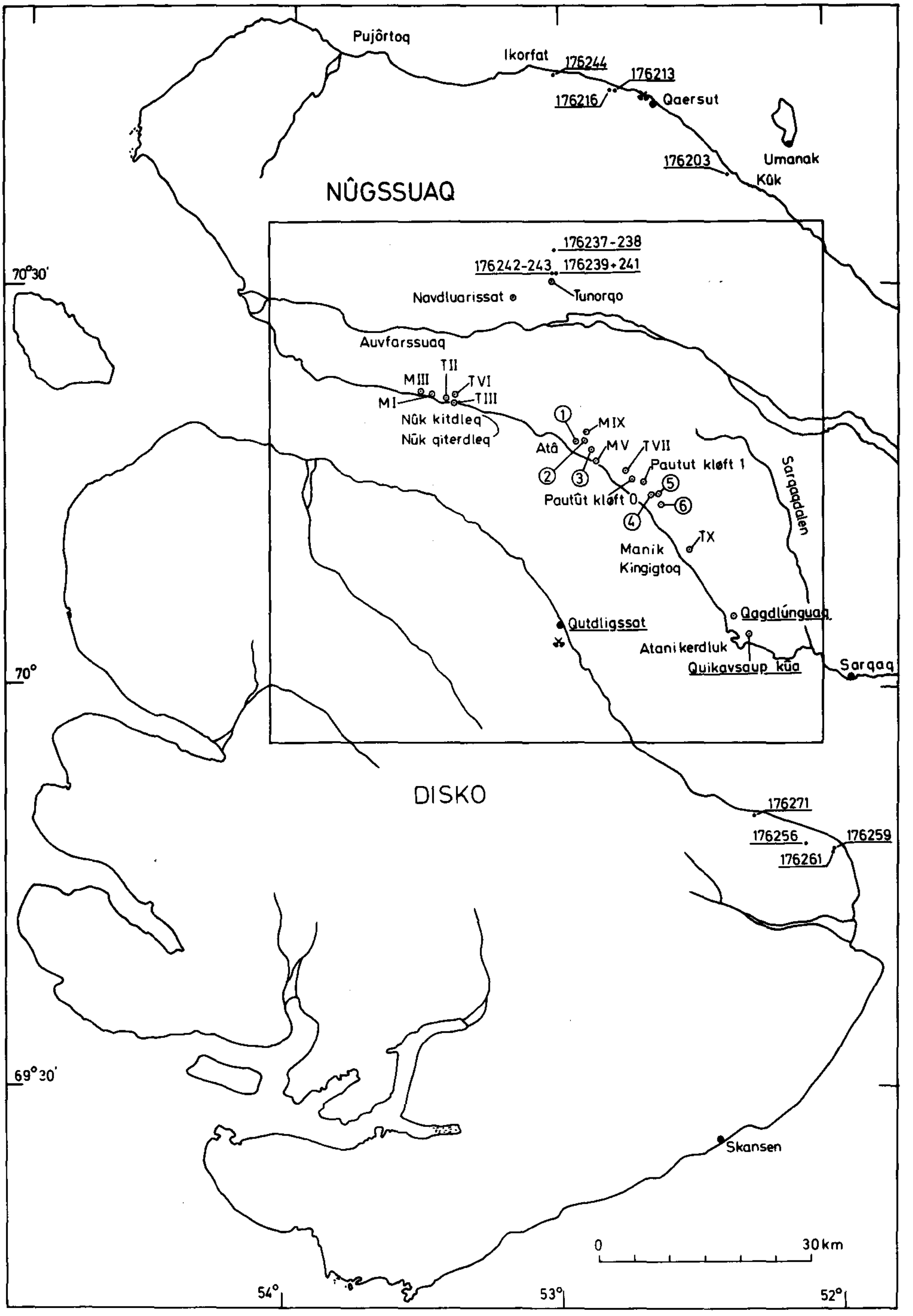


Fig. 2. Distribution of sample localities and measured sections.

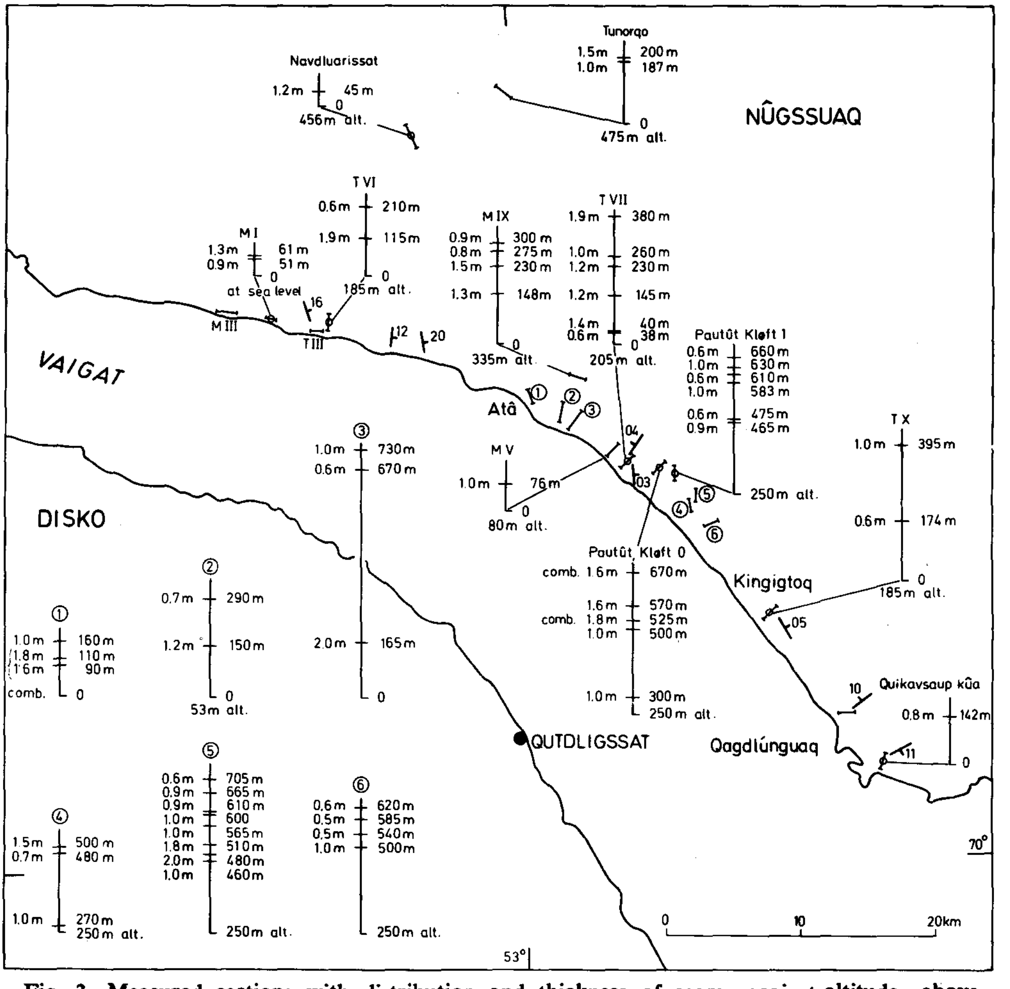


Fig. 3. Measured sections with distribution and thickness of seams against altitudes above sea level.

is bounded by major faults to the west against Upper Cretaceous marine sediments and to the east against Precambrian basement. Seams in this area are thin (< 50 cm) and impersistent. A small mine was operative at Qaersuarssuk near Qaersut, between 1908 and 1920 in a 1.2 m seam with intercalated stone bands. Output was around 1200 t/a.

The majority of seams occur on the south coast of Nûgssuaq in the non-marine to deltaic Atane Formation (? Albian–Campanian–?Lower Tertiary). The optimal development is found between Sarqaqdalen in the south-east and the river delta of Kugssinerssuaq emerging at Atâ in the north-west where about 600 m of Cretaceous–Tertiary sediments are exposed from sea level upwards. Tertiary pillow breccias and lavas form the rugged and precipitous mountain tops exceeding 1500 m above sea level. It has not yet proved possible to subdivide and thus correlate units within this formation. However, preliminary results of recently initiated palynological investigations are encouraging.

Lithologies

In line with the recognized upper delta-top environment with braided and meandering stream deposits the sediments consist almost exclusively of clastic rocks. Light coloured feldspar–quartz arenites and dark micaceous-carbonaceous lutites constitute the end members. Mixing, resulting in extensive flaser-bedded units is common. Sand/shale ratios vary between 5.0 and 0.5, depending on position relative to the basin margin. In the area with most and thickest coal seam development the ratio lies around 1.0.

Sandstones bear the characteristics of channel deposits, frequently with wash-outs at their bases. Grain sizes range from pebbly to medium sand, with modes in the coarse sand fractions.

Cementation varies considerably, even within a single bed. Exposures frequently give the impression of very weak cementation, but surficial leaching of the common carbonate cement is considered to play a major role.

Below shale or coal horizons iron oxide-hydrates are the common cementing agent, resulting in variously thick developed hardpans.

Thicknesses of sandstone units with channel character vary considerably, but statistically have a maximum at the 1–2 metre range (fig. 4).

Fine grained overbank sands are recognized by their low-energy sedimentary structures and better horizontal persistence.

Lutites are characterized by their content of dispersed carbonaceous matter and their common contamination by silt sized quartz and feldspar. Kaolinite and mixed-layer clays predominate, occasionally illite and montmorillonite are found. The weathered appearance varies between blocky and fissile in outcrop; in fresh exposures, however, a relatively high degree of induration is recognizable. Carbonates appear to be one of the main cements, which in extreme cases can lead to the development of concretionary horizons. Gypsum is present locally in varying amounts. Pyrite is a common constituent, finely dispersed or as concretions of varying dimensions.

Some units, up to several tens of metres thick, consist of rapidly alternating, cross-laminated clean sandstones and parallel laminated siltstone/shale (flaser units). Clean clayey shales are relatively rare, where they occur it normally is in connection with coal.

Coal seams and seamlets are more commonly associated (by a factor of three) with lutites than with arenites, although rootlet horizons and seat earths are rarely developed. For practical mining considerations it may be of significance that seams are frequently developed a short distance above sandstone units. Between 15 to 50 cm of mostly laminated shale can be intercalated between the sandstone top and the floor of the coal.

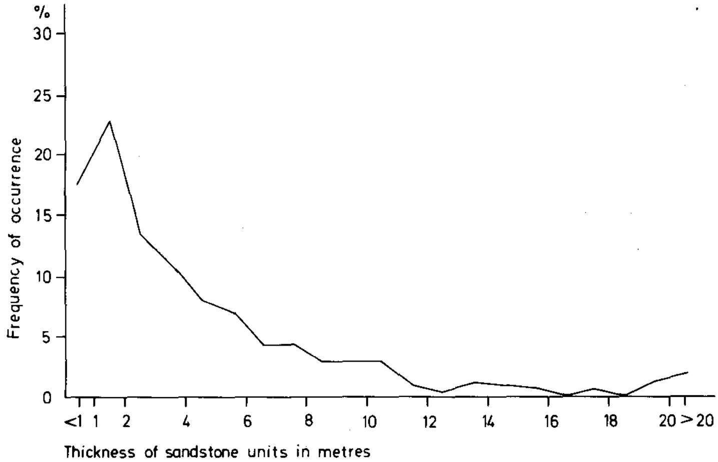


Fig. 4. Frequency distribution of thickness of sandstone units (single and multiple beds).

Structure

Superficially structure appears to be simple with gentle dips prevailing and faults concentrated in major fault zones. Outside these fault zones, faulting is very difficult to detect owing to the rapidly changing facies. It has been stated by Koch (1960) that coast parallel, slope controlled, slip movements are very prominent along the south coast of Nûgssuaq. It was not possible to find major planes of movement, although smaller displacements with up to several metres throw are not uncommon. Minor displacements were also observed in the vicinity of dykes and sills. Larger throws cannot be ruled out, especially near major sill or dyke complexes.

Folding on a regional scale is recognizable. On southern Nûgssuaq a very gentle coast parallel anticline is traceable through several gullies at Kingigtoq. From shallow penetration seismic work in the Vaigat similar gentle folds have been found (Denham, 1974) to exist throughout below fjord bottom.

The steepest dips are around 18–20° NE and are found in the north-western parts of the south coast around Nûk kitleq; in the remaining area dips hardly exceed 8°, either NE or SW.

Coal petrography and rank

A total of 64 samples of coal from Nûgssuaq and Disko were submitted for analyses. The majority of samples came from the south coast of Nûgssuaq between Atanikerdluk and Nûk kitdleq; six samples were from a core drilled in the now abandoned mine at Qutdligssat (fig. 2).

Sample preparation

Aliquots of channel samples, where available, were mechanically broken down to < 1 mm diameter. Gravity separation by flotation was carried out, utilizing liquid of specific gravity 1.9. The float fraction was embedded in resin and polished sections were prepared of these grain-mounts. Standard statistical reflectance measurements were carried out with oil immersion at 546 nm. The same grain-mounts served for standard statistical determination of the distribution of macerals. Additional control was achieved by optical inspection of polished sections prepared on resin embedded pieces from floor, central and roof parts of individual seams.

For smaller samples of cobbles with less contamination by mineral matter the procedure was modified in the separation phase and liquid of specific gravity 1.5 was used.

Composition

Terminology, unless otherwise indicated, according to *International handbook of coal petrography* 2nd ed.

All West Greenland coal seams investigated so far are of the banded coal type and microscopic studies reveal their humic origin. Of the macroscopically recognizable lithotypes vitrain and clarain are dominant; the relatively high proportion of carbargillites, simulating greater proportions of clarite, is first recognized as such under the microscope. Fusain occurs only in impersistent millimetre-thick bands and is frequently more readily recognizable by the accompanying mineralization of predominantly pyrite or of ferro-oxidhydrates after pyrite.

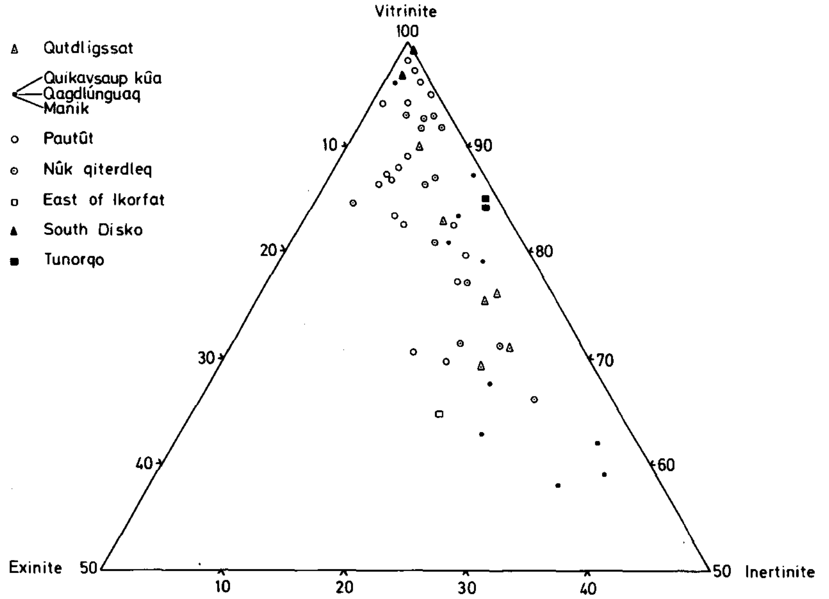


Fig. 5. Plot of vitrinite–inertinite–exinite ratios (mineral free) on coal samples from Nûgssuaq and Disko.

Table 1. Analyses of maceral groups

		Vitrinite	Exinite	Inertinite	Minerals	Wt % of mineral matter	% volatiles (reflectance)	R_m oil % (546 nm)
South Disko	176259	87	2	1	10	0.4	-	0.45
	176261	99	-	0.5	0.5	0.4	-	0.42
	176271	67	4	17	12	0.4	-	0.58
Quikavsaup kûa	9628	35	35	26	4	8.6	-	0.48
	9629	44	6	26	24	96.0	-	0.51
	9630	-	-	-	-	80.0	-	-
	9631	83	1	11	5	90.0	-	0.48
Qagdlúnguaq	9644	65	9	22	4	6.2	39.0	0.66
	9645	58	4	36	2	1.6	34.4	0.74
	9648	76	4	11	9	20.0	-	0.63
	9649	95	3	1	1	17.7	41.5	0.67
	9650	76	4	16	4	12.3	-	0.63
	9651	59	3	33	5	12.7	34.6	0.65
	9652	80	6	13	1	1.0	-	0.57
	9653	59	12	23	6	6.0	-	0.54
Qutdligssat	1754-7(1-B-1)	88	4	6	2	28.5	-	0.55
	1754-7(1-B-2a)	73	6	18	3	40.6	-	0.57
	1754-7(1-B-2b)	81	6	10	3	13.9	-	0.52
	1754-7(2-B-2a)	68	9	21	2	8.9	-	0.51
	1754-7(2-B-2b)	69	6	22	3	72.6	-	0.55
	Q 3116	79	5	11	5	4.4	-	0.57
Pautût kløft 1	9766	65	4	11	20	97.5	-	0.52
	9767	73	5	14	8	94.8	-	0.45
	9768	85	8	5	2	45.9	-	0.48
	9769	94	1	2	3	84.0	-	0.50
	9770	91	3	3	3	67.9	-	0.45
	9771	92	1.5	1.5	5	57.4	-	0.48
Pautût kløft O	9681	89	4	1	6	91.5	-	0.58
	9682	95	1	1	3	52.2	-	0.57
	9683	95	-	1	4	20.6	-	0.53
	9684	95	3	1	1	2.6	-	0.54
	9685	81	9	8	2	3.0	-	0.50
	9686	89	5	1	5	91.0	-	0.52
	9687	76	7	4	13	39.0	-	0.45
	9688	82	5	5	8	89.1	-	0.46
Pautût N	173376 T VII	66	5	4	25	5.7	-	0.54
	173379 T VII	74	7	15	4	1.6	-	0.54
	173404 + 408 T VII	71	8	7	14	14.4	-	0.51
	173419 + 423 T VII	76	8	4	12	4.1	-	0.51
	173426 T VII	64	11	17	8	5.5	-	0.51
	173451 T VII	55	11	12	22	8.4	-	0.55
Nûk kitdleq	173308 T I	52	5	16	27	7.7	39.0	0.67
	173338 T II	88	3	5	4	93.2	36.6	0.91
	173339 T II	61	6	25	8	10.6	36.2	0.82
	173351 T VI	70	6	15	9	17.6	40.4	0.65
	173354 T VI	76	7	11	6	0.8	41.2	0.65
	173360 T VI	65	9	17	9	10.0	40.8	0.64
Nûk kitdleq W	170401 M I	76	2	4	18	4.1	40.0	0.72
	170402 M I	82	5	8	5	16.0	40.7	0.68
	179403 M I	76	3	3	18	3.6	40.9	0.71
	170406 M I	66	1	4	29	22.9	38.9	0.74
	170424 M I	77	11	3	9	4.0	43.2	0.72
	170441 M III	80	4	8	8	3.6	39.4	0.75
	170449 M III	67	1	5	27	36.1	38.7	0.75
Central and N Nûgssuaq	176238 Tunorqo	13	1	76	10	4.0	22.2	0.64
	176239 Tunorqo	59	1	10	30	2.7	-	0.60
	176243 Tunorqo	72	1	12	15	4.4	-	0.58
	176203	20	55	19	6	4.1	-	0.61
	176213	17	8	70	5	0.4	29.2	0.74
	176216	43	4	47	6	1.2	32.4	0.70
	176244	57	13	18	12	38.8	40.2	0.74

For R_m values below 0.65 determination of volatile (reflectance) per cent impossible, values > 45-50% vol.

Under the microscope textural detail of individual macerals is generally well preserved, owing to the prevailing low rank. Only few samples that demonstrably were exposed to igneous heating are so strongly altered that textural detail is lost.

According to fig. 5 and table 1 the relation of group macerals is: vitrinite $>>$ exinite $>$ fusinite.

Vitrinite is in many instances developed as collinite (observation of polished surfaces with oil immersion). This is frequently the case where thicker monomaceral bands ($>$ 5–10 mm) are developed. Telinite with widely varying cell patterns that rarely show strong compactional distortion is more characteristic for monomaceral layers, but it is also found in bi- and trimaceral microlithotypes together with corpocollinite (fig. 6a).

Exinite is best studied under ultra-violet radiation. It is commonest in the bi- and trimacerites (clarite V and duroclarite). In vitrite bands occasionally single tenuispores are recognizable by their bright yellow fluorescence whereas orange yellow fluorescing cutinite is frequently associated, though hardly exceeding 5 per cent within a 50 μ band. The cutinite is normally developed as folded crassi-cutinite with well preserved cuticular ledges (fig. 6b).

Resinite occurs almost exclusively in discrete oval to flattened bodies, predominantly in the bi- and trimacerites. Under ultra-violet radiation a fawn-coloured fluorescence is observable, as well as a granular texture (fig. 6c). It has not been found associated with telinite, filling cell lumina, but in some corpocollinite bands orange-brown fluorescing matter infilled interstitial spaces around individual bodies (fig. 6a). Since other fluorescing macerals of the types described by Teichmüller (1974) have only been observed in doubtful positions (contacts between embedding resin and coal), proper identification is not attempted here.

Inertinite occurs in a variety of fusinite submacerals as well as sclerotinites, but rarely makes up more continuous monomaceral layers. In contrast many clarite bands approach the 5 per cent limit to duroclarite, owing to the common occurrence of inertodetrinitic particles. Some of these inertodetrinites with no recognizable cell structures and high reflectance are impossible to separate from reworked, equally highly reflecting vitrinite particles.

Fusinite has well preserved cell structures, frequently filled by pyrite or ferric carbonates, especially when closely associated with vitrinitic bands. Some of this fusinite may be of pyrofusinite origin, in particular where vitrinite is seen to accomodate around a hard fusinite fragment. The same applies to layers displaying 'bogenstructures'.

The transition between fusinite and semifusinite to vitrinite is a common feature. The gradual plastic deformation of the cell structures until almost complete obliteration is well displayed (fig. 6e). Semifusinite on its own is also quite frequently observed.

Sclerotinite is an important contributor to the bi- and trimacerites. Apart from a variety of multicellular irregular bodies, *Sclerotites brandonianus* and numerous fungal spores with single, dual or triple chambered bodies (fig. 6f) have been observed in samples of Late Cretaceous age.

Mineral matter is normally closely associated with trimacerites, in higher concentrations giving rise to carbargillite bands of variable thickness. Dispersed clay minerals,

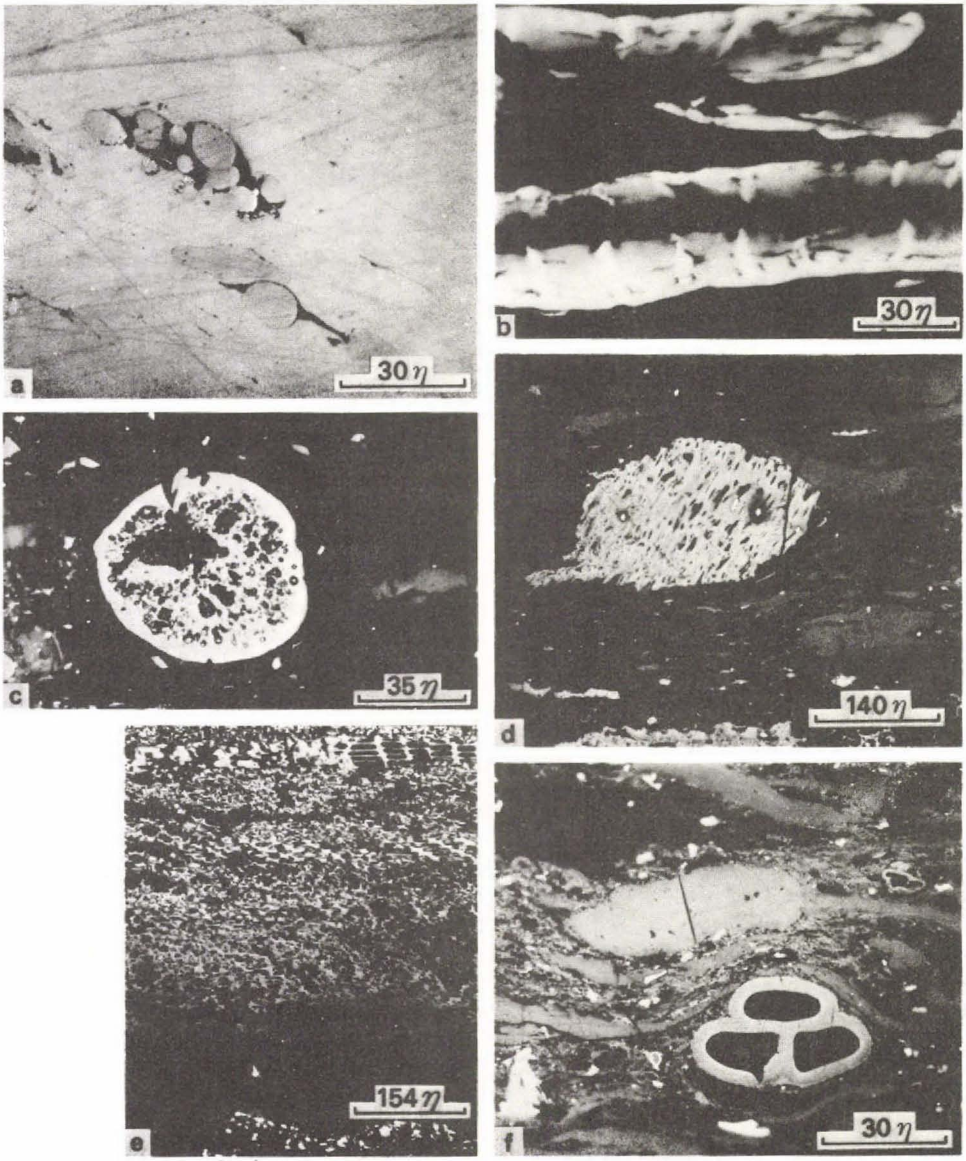


Fig. 6. a. Carpocollinite associated with 'bituminite' in vitrinite. Polished surface, oil immersion, white light. b. Crassicutinite. Polished surface, oil immersion, ultra-violet light. c. Sclerotinite with marginal notch. Polished surface, oil immersion, white light. d. Isolated pyrofusinite in clarite. Polished surface, oil immersion, white light. e. Transition fusinite–semifusinite. Pyrite infilling of cell lumen. Polished surface, oil immersion, white light. f. Teleutospore. Polished surface, oil immersion, white light.

Table 2. Relations between specific gravity and ash content in grain size < 0.5 mm (average of 5 samples)

Specific gravity	Weight %	Ash %	Grain size mm	Weight %	Ash %
1.4	46.20	5.7	20	0.9	4.5
1.4 - 1.5	17.6	14.0	20 - 10	1.9	19.5
1.5 - 1.6	8.8	25.3	10 - 6	13.0	20.9
1.6 - 1.8	7.7	41.0	6 - 3	24.5	23.3
1.8 - 2.0	5.5	56.9	3 - 1	35.8	25.9
2.0 - 2.2	5.6	68.1	1 - 0.5	12.9	32.1
2.2	8.9	78.1	0.5	11.8	77.9

predominantly kaolinite and mixed-layer clays are of detrital origin. The same applies to most of the irregularly shaped quartz, whereas the rare idiomorphic quartz grains are presumably of authigenic origin.

Carbonates occur frequently; a distinction between early and late introduction is only possible, where pseudomorphs after pyrite are formed. Some of the ankeritic infillings of cell-lumen in semifusinites may, however, be of early diagenetic origin. Pyrite is commonly associated with fusinite lenses (fig. 6e) in the vitrinite rich clarite, but occurs also as euhedral or framboidal aggregates in the other microlithotypes, preferentially in vitrites. Ferro-oxidhydrates are clearly formed after pyrite and are most commonly found in weathered coal, where the numerous small cracks and fissures may also be infilled, often with wall parallel layering. Hematite occurs as a late diagenetic introduction since it commonly fills wider fissures that opened after solidification of the coal.

Percentages of mineral matter, that will be the ultimate contributor to the ash content, are extremely variable; they range from less than 1 per cent to more than 40 per cent of the fraction lighter than 1.9 in specific gravity. The average for this fraction lies around 12 per cent, the average for the fraction lighter than 1.5 in specific gravity lies at 10 per cent (Table 2).

Rank

West Greenland coals in general hardly exceed high volatile bituminous A in rank (Flammkohle–Gasflammkohle in German terminology). However, the early Tertiary igneous activity in the form of sills and dykes locally produced anthracite rank coals to natural coke by contact alteration.

In some of the analysed samples anthracite rank fragments occurred together with the low rank bulk. The occurrences may indicate 'cannibalism', i.e. erosion of older, already coalified deposits. Since the Lower Cretaceous Kome Formation is coal-bearing such an origin is conceivable. It has, however, been mentioned by the investigators that where contact coking was recognizable the petrographic characteristics indicated coking in very early diagenetic stages (lignite–coke). This might point to syngenetic

Table 3. Analyses of coal samples from southern Nûgssuaq

Moisture %		Ash %	V.M. %	Calorific value kcal/kg		S %	H %	C %	N %	O %	Locality (see fig. 2)
Air dried	Inherent			Water and ash free	Effective						
10.5	3.1	5.1	45.4	6.070	5.060	0.3	6.2	61.0	1.3	16.6	Quikavsaup kua
12.7	1.7	6.6	48.0	6.000	4.760	0.4	4.5	61.9	1.2	15.1	
16.9	3.9	17.7	51.7	6.210	3.960	0.4	3.3	47.0	0.72	13.7	T X
18.0	3.7	7.5	48.7	6.350	4.630	0.34	3.8	55.0	0.95	14.4	
29.5	4.2	8.9	55.5	5.760	3.390	0.4	3.0	45.4	0.86	12.6	Pautût
28.3	3.3	8.4	50.6	5.900	3.570	0.3	3.0	47.0	1.48	12.8	
19.6	2.9	17.7	50.8	6.300	3.840	0.6	3.2	45.0	0.46	13.0	
14.3	2.7	16.6	48.0	5.720	3.880	0.5	3.6	50.3	0.67	13.3	
17.1	1.7	13.3	45.7	6.380	4.340	0.8	5.0	50.5	0.76	14.5	M X
15.4	2.3	10.4	48.9	6.430	4.680	0.6	3.7	57.1	0.76	14.3	
17.6	2.6	13.0	47.6	6.360	4.310	1.1	3.6	52.1	1.13	13.0	

erosion of thermally altered lignites and subsequent incorporation of the transported material in almost contemporaneously deposited plant accumulations.

Rank determinations carried out by optical means (reflectance, composition of macerals) on the West Greenland coals are in accordance with rank determined from chemical analyses, owing to the dominance of vitrinite and weak representation of exinites. This means in essence that for the given amount of fixed carbon (on average 52 per cent water free) the oxygen/hydrogen ratio is around 4.5 (Table 3).

Technical properties

Information on properties of West Greenland coal that may affect its use for either combustion processes or possible further processing is scarce and applies mostly to coals from the Qutdligssat mine. However, some additional investigations have been commissioned at Bergbau Forschung G.m.b.H., Essen. A number of observations on physical properties were previously reported to the Danish mining authorities by Steinkohlenbergbauverein (1960).

The coal as mined is friable, pieces consisting on average of 59 % > 25 mm, 19 % > 20 mm and 22 % < 20 mm. During handling and transport the fine fraction increases considerably.

Moisture content is high: in freshly mined coal average values are around 13–14 %, in stockpiled coal moisture can reach up to 20 %. Drying at elevated temperatures, carried out in laboratory tests, reduced moisture values down to 1.5 %. After relatively short time of exposure to normal atmospheric conditions hygroscopic adsorption of water raises moisture contents to around 10 %, close to the original values.

Experience at the mine has shown that when stockpiled, the coal is prone to self-ignition. A similar phenomenon is observable under natural conditions in the highly carbonaceus shales of the region. There in several places subrecently, and in one place (Pujôrtoq on north-west Nûgssuaq) in recent times, self-ignition led to smouldering combustion of the organic content (Henderson, 1969). Oxidation processes in the coaly matter and in pyrite presumably initiate the reaction, which later is replaced by self accelerating strongly exothermic reactions between pyrite, sulphuric acid and organic matter. The presence of water seems to be of importance (Münzner, 1972) since combustion is most active after rainfall or, in misty weather.

Coking

The method of collecting the coal samples and subsequent handling prevented physical testing of the coal's suitability for coking. The parameters of Table 4 were therefore determined by calculations utilizing empirical values derived from coal petrographical data (Mackowski & Simonis, 1969; Brown *et al.*, 1964).

Despite the dominance of vitrinite amongst the macerals, the derived values for agglomeration (swelling index) and coke stability (shatter index and hardness factors) are rather unfavourable for its use as coking coal. Since the analysed samples were selected to represent bulk composition and rank of the majority of West Greenland coals that have been investigated, it seems reasonable to assume that unblended coals from West Greenland are unsuitable for coking processes.

Table 4. Physical properties of coal from Nûgssuaq

GGU sample No.	G_{RM} value*	Swelling index	ASTM stability	1 1/2 inch shatter index	1/4 inch hardness factor†
173379	0.1931	< 1	< 10	< 75	≲ 50
173431	0.3059	< 1	< 10	< 75	≲ 50
176239	0.1877	< 1	< 10	< 75	≲ 50
176243	0.1556	< 1	< 10	< 75	≲ 50
176404-408	0.0478	< 1	< 10	< 75	≲ 50

* Mackowski,M.-Th. & Simonis,W., 1969

† Brown et al., 1964

Dry distillation

No extensive tests have been carried out in this field but a number of coal samples have been subjected to simple test-tube distillation (Day, 1922). Although, compared with black shale samples, greater quantities of mainly tarry distillate were observed, the yield was generally small. Condensation droplets were only observed occasionally, the normal feature was a thin tarry coating on the cooler parts of the test tube.

Ash

Ash content is directly related to the amounts of mineral matter present in the raw coal. From the chemical analyses and several other investigations the varying but generally above average ash content has been determined. It ranges from a minimum of around 5 % to maxima around 18 % in hand-picked raw coal with average values lying at around 12–14 %.

The mineral matter and hence the ash producing components are closely associated with the coal macerals as already mentioned under that section. This explains the specific gravity/ash relations (Table 2), where firstly only in the very fine range (< 0.5 mm diameter) ash contents of the < 1.4 specific gravity fraction are near the minimum of 5 %, and secondly only the weakly represented fraction > 20 mm diameter reveals similar values.

The immediate consequence of these conditions is the requirement of more effective and thus more complicated washing procedures if it should be attempted to obtain coals with lower ash percentages.

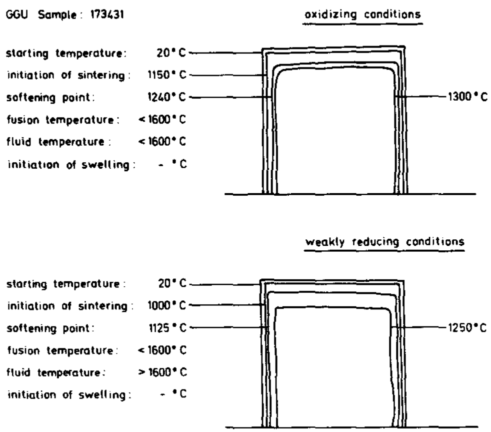
Physical and chemical parameters

In order to obtain some indications of possible uses of West Greenland coal other than for domestic fuel, five samples were selected for relevant analyses. Three of the samples were collected from seams on the south coast of Nûgssuaq, two came from seams outcropping in the central valley Auvfarssuaq (GGU 173379, 173404–408, 173431, 176239, 176243).

The limited number of samples demands great caution in drawing generalized conclusions, especially since marked and important variations were encountered in the small batch of samples. Three samples representing the extremes in composition and behaviour during heating are shown in fig. 7. Further investigations are required to lend broader applicability to the present results.

Fusion characteristics of the inorganic components of coals are dependent on the chemical components present. Of the syngenetic minerals the clays together with silicates (quartz and feldspars) play a major role. The spectrum of epigenetically introduced minerals in coals is very broad, with carbonates, sulphates and sulphides in order of importance. The interplay of the various components during combustion is difficult to assess in detail, but for the behaviour of the melts only three main components have to be considered, $Al_2O_3 + SiO_2$ (in clays and clastic components), iron oxides (from iron carbonates) and alkalis (mainly CaO from carbonates). In the absence of possible fluxes, clay and quartz-rich ashes have high fusion points (with kaolinite in excess of 1600° C). Presence of appropriate amounts of alkalis and iron oxides will, under appropriate weakly reducing conditions during combustion, result in lower fusion temperatures.

For the actual examples, high kaolinite percentages in the mineral matter, together with clastic quartz are the explanation for the fusion temperature observed. The one

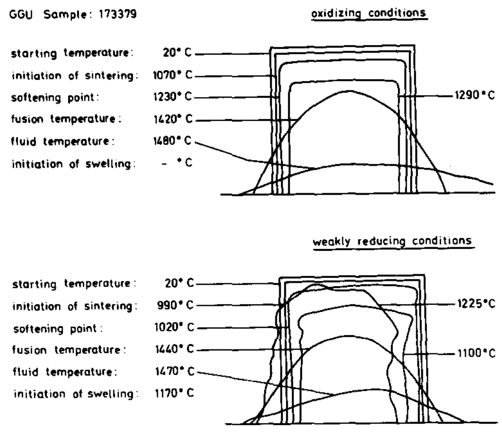


weight percent of ash in sample (wf): 5,4

chemical analysis (weight percent)

SiO_2	43,9	CaO	2,0
Al_2O_3	42,4	K_2O	0,8
Fe_2O_3	4,3	TiO_2	1,5
		S	< 0,5

a. High silica and alumina content, low iron and alkali content; very inert during heating.

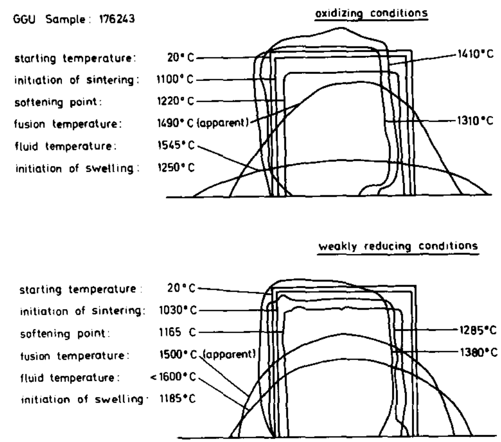


weight percent of ash in sample (wf): 5.4

chemical analysis (weight percent)

SiO_2	11.7	CaO	10.1
Al_2O_3	15.0	K_2O	0.4
Fe_2O_3	35.9	TiO_2	0.5
		S	5

b. Low silica and alumina content, high iron and calcium content; relatively low fusion temperatures, no swelling.



weight percent of ash in sample (wf): 21.0

chemical analysis (weight percent)

SiO_2	46,6	CaO	3,9
Al_2O_3	31,4	K_2O	1,4
Fe_2O_3	3,5	TiO_2	1,0
		S	1

c. High silica and alumina content, low iron and alkali content; high fusion temperatures, swelling.

Fig. 7. Chemical composition and melting behaviour of ash.

sample with strongly differing chemical composition did, however, not differ markedly in fusion behaviour. Presumably the ratios of available flux components were insufficient to allow low-fusing fayalite melts to form.

Prospects

Judging by the number of seams thicker than 80 cm that have been observed along the south coast of Nûgssuaq (fig. 8) the minable reserves are estimated to lie in the range of 20–30 million tons (Schiener, 1976). Included in this calculation is a 50 per cent reduction from the basic calculation of seam thickness, number of seams and two-dimensional extent of seams considered. The reason for this reduction lies in the geologically controlled conditions, where pinching, feathering and wash-outs are frequently observable features in surface outcrops. Additional reductions may have to be considered, owing to difficulties raised by the terrain. If, however, reserve calculations are extended to include the area south of the river of the Auvfarssuaq valley, the reserve figures could be raised considerably. Although no detailed geological investigations have been conducted in that area, geological reasoning and structural conditions would almost demand the presence of at least an equal number of sufficiently thick seams in that area. The presence of good quality seams further north (Tunorqo) in itself would justify such reasoning.

The morphology of the terrain, environmental factors and the distribution of relatively thin seams preclude the possibility of opencast mining in West Greenland. Application of a variety of advanced mining techniques nevertheless would allow extraction even under the conditions encountered in these latitudes. The presence of permafrost has to be considered as a beneficial factor in the extraction phase. As experienced in the

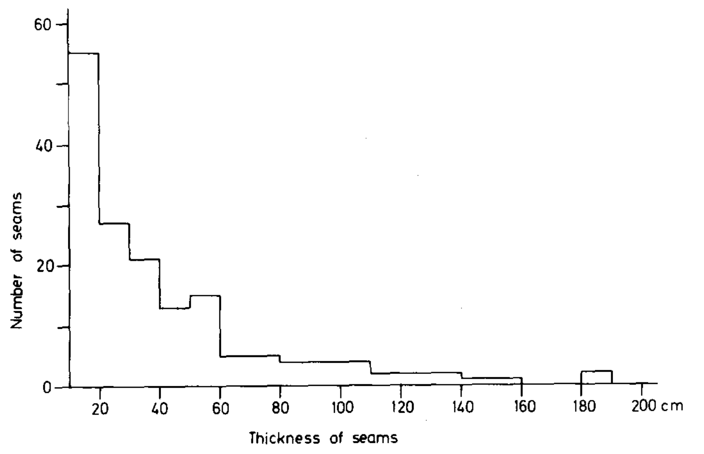


Fig. 8. Distribution of seam thicknesses encountered in measured profiles in the Disko–Nûgssuaq area.

lead-zinc mine at Mârmorilik, permafrost conditions provide uniform rock-mechanical properties. For operations in mechanically widely differing sediment types (shales–sandstones with differing cementation) the presence of permafrost might facilitate mining activities.

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