DET KONGELIGE DEPARTEMENT
FOR HANDEL, SJØFART, INDUSTRI, HÅNDVERK OG FISKERI

NORGES SVALBARD- OG ISHAVS-UNDERSØKELSER
LEDER: ADOLF HOEL

SKRIFTER OM SVALBARD OG ISHAVET

Nr. 60

THOROLF VOGT

LATE-QUATERNARY OSCILLATIONS OF LEVEL IN SOUTHEAST-GREENLAND

WITH 14 FIGURES

OSLO
I KOMMISJON HOS JACOB DYBWAD
1933

Results of the Norwegian expeditions to Svalbard 1906—1926 published in other series. (See Nr. 1 of this series.)

The results of the Prince of Monaco's expeditions (Mission Isachsen) in 1906 and 1907 were published under the title of 'Exploration du Nord-Ouest du Spitsberg entreprise sous les auspices de S. A. S. le Prince de Monaco par la Mission Isachsen', in Résultats des Campagnes scientifiques, Albert Ier, Prince de Monaco, Fasc. XL—XLIV. Monaco.

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The following topographical maps and charts have been published separately:

Maps:

Bear Island. 1 : 25 000. 1925. Kr. 10,00.
Bear Island. 1 : 10 000. (In six sheets). 1925. Kr. 30,00.
East Greenland. Eirik Raudes Land from Sofiasund to Youngsund. 1 : 200 000. 1932. Kr. 5,00

Charts:

No. S. 1. Bear Island. 1 : 40 000. 1932. Kr. 4,00.
„ S. 2. Bear Island Waters. 1 : 350 000. 1931. Kr. 5,00.
„ S. 3. From Bellsound to Foreland Reef with the Icefjord. 1 : 200 000. 1932. Kr. 5,00.
„ S. 5. Norway—Svalbard, Northern Sheet. 1 : 750 000. 1933. Kr. 4,00.
„ S. 6. Norway—Svalbard, Southern Sheet. 1 : 750 000. 1933. Kr. 4,00.

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A. W. BRØGGERS BOKTRYKKERI A/S

Contents.

Introduction.

In the summer of 1931 the author had an opportunity of visiting Southeast-Greenland (Vogt 1933) as leader of a scientific expedition sent out to that country by *Norges Svalbard- og Ishavs-undersøkelser.* It was clear from the outset that the Quaternary geological work of the expedition would have to be kept within narrow limits, as the main object of the geological work was the investigation of the solid rocks of the area; and the excursions had also to be planned with due consideration to a geographical survey of the country. The area visited was quite large, including the east coast from $62^1/2^\circ$ to $64^1/2^\circ$ Lat. N., and the time spent there amounted to not more than about 30 days.

An interesting task of a more limited nature was to find out the inclination towards the sea of the levels of the raised shore-lines. The gradients of the raised shore-lines in Greenland was utterly unknown, despite the fact that a large number of shore-lines have been measured along the coasts of the continent. But is was, in the author's opinion, obvious that in Greenland, too, the shore-lines were lifted up to a higher level in the inner fjord tracts than in the outer coastal area, as is the case in other Quaternary glaciation and uplift areas. The conditions in Greenland were, he thought, of special interest, as that country is still covered by a thick ice-sheet, whereas corresponding Quaternary glaciation areas, such as the Fennoscandian-Baltic, have now practically nothing left of their previous ice-sheets. The author was also interested in this matter, as he had in a previous paper (1927) touched upon the isostatic conditions in Greenland, in connection with the huge weight of ice still resting upon that country.

During the expedition it soon became evident that a pronounced and commonly distributed shore-line level existed at the height of about 25 metres above sea-level. This level was consequently measured through accurate levellings at various suitable points. In the following these results will be presented, together with a treatment of the older shore-line measurements, which it was natural to deal with in this connection.

Raised Shore-lines in Southeast-Greenland.

Introduction.

From Southeast-Greenland, or the country between the district of Julianehaab in the south and the district of Angmagssalik in the north, there are no observations whatever relating to late-quaternary changes in the level of the land. The naturalists of the Danish Holm Expedition 1883—85, the Norwegian H. Knutsen and P. Eberlin say expressly that they observed no traces of an upheaval of the land. Knutsen writes (1889, p. 249): "Terraces and shore-lines higher than the recent level of the sea, I have not seen"; and Eberlin (1889 p. 260) says: "Although a negative result only, it deserves perhaps to be mentioned that on practically the whole stretch here dealt with no trace whatsoever of a postglacial uplift of the coast has been observed. Such traces were observed neither on the entire part of the east coast here dealt with nor on the west coast south of Unartok Fjord[1]; they seem to occur not until Unartok is reached and then to continue in the more northern part of the Julianehaab district". Even if the recent literature on the subject has paid a certain amount of attention to these reports by Eberlin and Knutsen, there has been every reason to assume that here, too, an uplift of the land has taken place. The Danish geologist Axel Jessen (1896) takes it for granted that traces of an uplift will be found on the southern east coast, and the author of the present paper also anticipated the same.

I wish to say, however, that nowhere in any other area of uplift, Spitsbergen included, have I seen a coast of such a length where the traces of the late-Quaternary uplift on the average are so feebly developed and little traceable as in the part of Southeast-Greenland visited by the expedition. This may have something to do with the dominant rocks, which chiefly consist of hard granites, the steepness of the slopes, and, particulary, with the scarce occurrence of loose material.

On the outermost barren coast, facing the sea directly, I have nowhere seen shore-lines, but just on entering the fjords, where there is a little

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[1] Unartok(Unatok) Fjord is situated in the Julianehaab district on the west coast, at about 60° 30′ Lat. N.

more loose material, shore-lines and small terraces are evidently quite common, although, as a rule, not very conspicuous. Large and well developed river terraces I have never seen. The measured lines, are, as will appear from the descriptions, either excavated in loose material, towards their inner part sometimes also in the solid rock, or they represent small accumulation terraces.

Most lines have been measured starting from the upper seaweed-line, as this is the only stable level that is found almost everywhere, and which can be fixed without bias at points where there is a great difference between high and low water. The heights of the other lines also refer to the seaweed-line. All the measurements were carried out as levelling, with an ordinary levelling instrument kindly lent to the expedition by Professor Tor Eika of *Norges Tekniske Høiskole* in Trondheim. Some of the levellings were carried out by Eystein Lundbom, Lieutenant, Norwegian Navy, but most of them were done by the author. The position of the measured points have in every case been fixed by the author. The heights are measured in centimetres and rounded off to the nearest decimetre.

The Observations.

Tingmiarmiut.

No shore-lines were measured in this area, where we spent but a short time. However, in at least two places I saw it should be possible to find measurable lines. One locality is on a point chiefly consisting of morainic material one nautical mile northwest of Bjørnhamna. The point appeared to have been flattened by the sea to a small plain situated at a low altitude. Ruins of Eskimo houses were seen here, but I did not go ashore. The other locality is near our anchorage at Igdlormiut, where there is an isthmus across the long projecting peninsula. I crossed the place in the evening when there was much fog. On the highest point of the passage I found a small plain which appeared to have formed a kind of reef near the level of the sea between the outer part of the Igdlormiut peninsula and the mainland. I estimate the height to between 50 and 100 metres above sea-level, but this estimate is naturally extremely doubtful.

Umanak.

At Pilerkit in Umanakfjord there are indistinct river-terraces in the outer part of the valley. Across the mouth of the valley there is, further, a terminal moraine cut by the river, with an upper levelled surface, which — to judge from photographs is situated perhaps 12 metres above sea-level. Nowhere were found distinct level marks that could be used for measurements.

Locality 1: Innfjorden (Fig. 1). At several places in this small fjord there is a well-developed line that was measured on the north side, near the entrance to an inlet running northwards:

23.4 m. An overgrown small gravel terrace below a steep crag. Starting point: sea-level at spring tide with 1.0 metre added.

Locality 2: West side of the harbour at Vogtsbu. A little north of the house there is a level country with several gravel terraces:

13.9 m. Inner edge of gravel terrace.

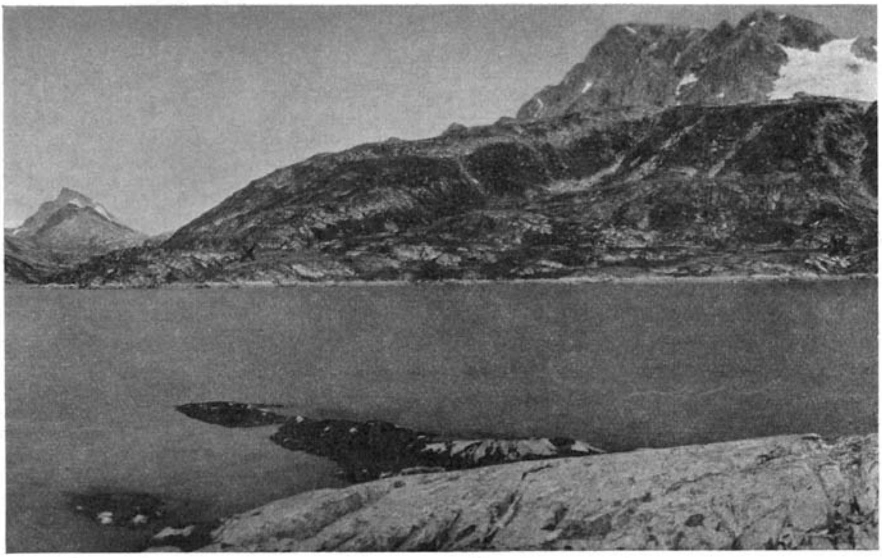

Fig. 1. Raised beach at a height of abt. 25 metres on the north side of Innfjorden, Umanak. The raised beach is marked by two crosses.

Th. Vogt phot. 15/8 1931.

18.4 m. Inner edge of gravel terrace.

25.2 m. Large, naked boulders at the inner edge of a broad gravel terrace. The most distinct and strong line.

28.0 m. Feeble line. Uppermost sea-mark. Starting-point sea-level at spring tide with 1.0 metre added.

Locality 3: East side of harbour at Vogtsbu, near No. 2 locality. The ground is steeper here.

25.4 m. Inner edge of a very distinct strand-line cut into morainic material.

27.1 m. Feeble line. Uppermost sea-mark.

Starting point: sea-level at spring tide with 1.0 metre added.

The difference of 1.0 metre between spring tide and sea weed-line was ascertained through direct measurement once for all in the area in question.

Akorninarmiut.

Locality 4: West side of Skjoldungen, just south of Moréneneset.

28.8 m. Distinct line cut into loose material in a rather steep, overgrown slope. Starting point 0.5 metre below ordinary spring tide. No seaweed-line here.

This line is interesting as it can be traced to a quite fresh terminal moraine. This moraine belongs to a small local glacier, having had its maximum extension quite recently, and the boulders from the moraine have been dumped covering the shore-line.

Localities 5—9: At Finnsbu where we had more time at our disposal than anywhere else on account of bad weather and other circumstances, strand-lines were measured at 5 different localities. These are all situated quite near to one another around Heimenhamna, the distance between the extreme points being only a little more than a nautical mile. The country at Finnsbu is low and has small hills with crags and ridges, and loose material between. The rock is frequently quite fractured, and the strand-lines may be cut into the solid rock at their inner edge. Starting-point for all measurments was the seaweed-line.

Locality 5: North side of Heimenhamna.

25.3 m. A small shore-ridge between two crags.

A horizontal gravel surface between the crags was of the height of 23.0 metres.

Locality 6: North side of Heimenhamna, at a small creek in the northwestern part of the harbour, a little on the inside of the preceding locality.

10.8 m. Inner edge of small gravel terrace.

25.4 m. Pronounced line visible in several places around the harbour. Inner edge of terrace, probably somewhat cut into solid rock in the inner part.

44.0 m. Distinct line.

74.6 m. A distinct, but irregular cut, partly in the solid rock.

Locality 7: At the station, Finnsbu.

8.7 m. Inner edge of a small gravel terrace. The house is placed on this terrace (7.9 metres).

Locality 8: Heimenhamna. Innermost northwestern creek.

9.2 m. Somewhat uncertain line.

14.1 m. do.

19.4 m. do.

23.4 m. do.

28.0 m. do.

Many small crags separated by level ground makes all the lines somewhat uncertain, or in any case less easy to fix accurately.

Locality 9: Heimenhamna. Innermost southeastern creek.

8.2 m. Small, but very distinct line in loose material.

24.7 m. Very distinct small shore-ridge, consisting of small pebbles. Immediately above, the loose material was cleaned off the rock by the surf. This line was the one most exactly fixed at this level in Finnsbu.

On the northeast side of Trollfjorden, in the outer part of the fjord, there is a horizontal cut, which is either a broad strand-line in the solid rock, or a ledge marking a structure surface of the rock. As I was not ashore here, the question could not be settled. To judge from photographs the elevation is about 165 metres above sea-level.

Locality 10: Mouth of Eidsdalen at Kangerdlikajik, on the east side of the river.

8.2 m. Inner edge of distinct small river terrace.

15.3 m. Boulders outwashed by the surf, at the inner edge of distinct small terrace.

24.1 m. Small pebbles and boulders, outwashed by the surf, at the inner edge of small gravel terrace. The most distinct of the three lines. Starting-point: seaweed-line.

Locality 11: A little east of the mouth of Eidsdalen in Kangerdlikajik, some 100 metres out of No. 10 locality.

9.6 m. Strand-line cut into loose material, not quite distinct, but rather good.

23.9 m. Shore-ridge consisting of rounded gravel and of boulders, washed out by the surf, and, above, with naked rock, washed clean by the sea. Very distinct line. Starting point: seaweed-line.

Locality 12: Anchorage in a large bay on the east side of Steinfjorden.

22.7 m. Pebbles at the inner edge of a gently sloping terrace, with a rich, green vegetation. Just above the pebbles the rocks are naked and water-washed.

Starting-point: Seaweed-line.

Umivik.

The author observed no old strand-lines in this area. Apart from recent moraines, practically no loose material was found at the points visited by us. However, it is quite certain that old strand marks will be found on the low and ice-free peninsula Nunarsuak in the inner part of Nansenfjorden.

Quaternary fossils have not been found anywhere in the area visited. It is true that good sections were rare, but I searched in vain at least a couple of sand deposits where shells might be expected to occur. I quite believe that the occurrence of quaternary shells must be rare in the area visited, as it is in the Angmagssalik district where, according to Ad. S. Jensen (1905, p. 313), Chr. Kruuse during his stay of one year there looked for Quaternary shell without finding the least trace.

Discussion of the Lines and the Gradient.

As it will appear from the table below seven different shore-lines have been measured, viz. 9 metres line, 14 metres line, 19 metres line, 25 metres line, 28 metres line, 44 metres line, and 75 metres line. Amongst these lines the 25 m-line is undoubtedly the strongest and most pronounced. Wherever shore-lines were observed, this line was found, excepting No. 7 locality at Finnsbu, where the ground does not reach that altitude. In four localities it was also the only line that was observed. My general impression is that it represents a trangression-line, or a level where the sea remained stationary for a considerable period. With its typical shore ridges and quite strong excavations in the ground it has the same general features as, e. g., the *Tapes*-line in North-Norway.

The next strongest line is the 9 m-line which is also quite well marked, and has been observed in a number of localities. The lines 14 m and 19 m

Raised Shore-lines in Southeast-Greenland.

No.	Locality	Heights in metre above the sea-level (fucus line).						
1	Innfjorden	-	-	-	23.4	-	-	-
2	Vogtsbu	-	13.9	18.4	25.2	28.0	-	-
3	—	-	-	-	25.4	27.1	-	-
4	Moréneneset	-	-	-	28.8	-	-	-
5	Finnsbu	-	-	-	25 3	-	-	-
6	—	10.8	-	-	25.4	-	44.0	74.6
7	—	8 7	-	-	-	-	-	-
8	—	(9.2)	(14.1)	(19.4)	(23.4)	(28.0)	-	-
9	—	8.2	-	-	24.7	-	-	-
10	Eidsdalen	8.2	15.3	-	24.1	-	-	-
11	—	9.6	-	-	23.9	-	-	-
12	Steinfjorden	-	-	-	22.7	-	-	-
Average of the observations		9.1	14.4	18.9	24.8	27.7	44.0	74.6
		Averages for each locality:						
1	Innfjorden	-	-	-	23.4	-	-	-
2—3	Vogtsbu	-	13.9	18.4	25.3	27.5	-	-
4	Moréneneset	-	-	-	28.8	-	-	-
5—9	Finnsbu	9.2	(14.1)	(19.4)	24.7	(28.0)	44.0	74.6
10—11	Eidsdalen	8.9	15.3	-	24.0	-	-	-
12	Steinfjorden	-	-	-	22.7	-	-	-

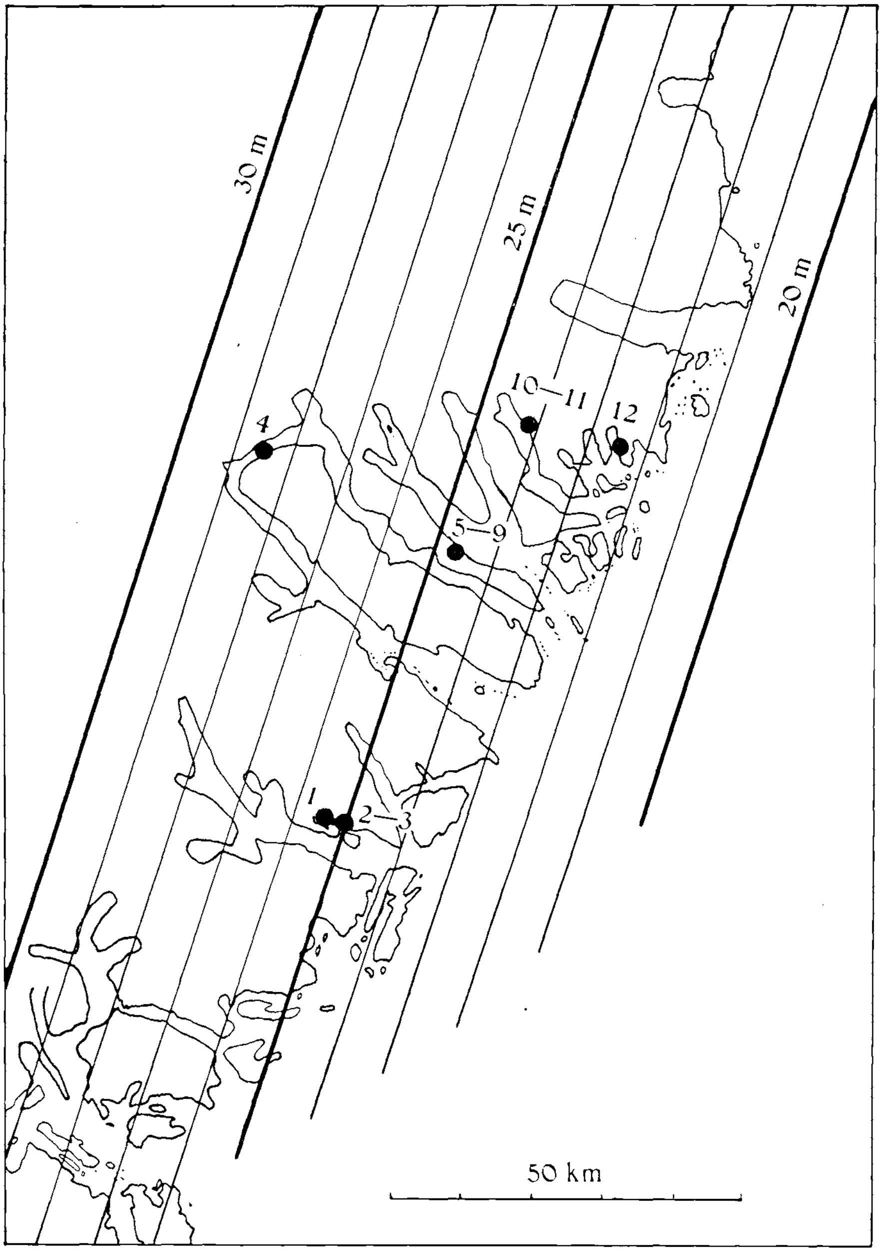

Fig. 2. Map of a part of Southeast-Greenland with localities of the measured shore-lines, and the isobases for the 25 metres line (e-line).

lines are, on the contrary, feeble and appears to demand favorable conditions to be formed. The same thing can be said about the 28-line, which is a quite feeble line, and so close to the 25-line that we might term it a doubleline. However, no mistake should be possible as the lines have a very different character. The very strong incised shore-line on Morénenenset at the height of 28.8 metres corresponds undoubtedly to the strong lines in Vogtsbu at the heights of 25.2 and 25.4 metres, and not to the feeble lines there at 28.0 and 27.1 metres. About the lines situated at a higher level only a few observations are available from a section not particularly favourably situated, but both lines are evidently quite well defined.

Only the 25-line has been measured at so many favourably situated points that it is possible to construct the plane of the shore-line. The direction of the isobases can be fixed from measurements at the localities Eidsdalen, Finnsbu and Vogtsbu situated at a considerable distance from each other. The heights of the line are here 24.0, 24.7, and 25.3 metres. Each of these values represents the average of two or more certain measurements which correspond well; and as the points are nearly situated on the same isobase-line, the direction of this can be found with quite a high degree af accuracy. The resulting direction is: S 19° W—N 19° E. It is of interest to note that this direction does not quite conform with the trend of the coast at Umanak and Akorninarmiut where the lines were measured. The local inward bending of the coast at Tingmiarmiut and Ikermiut is of no importance for the direction of the isobases. However, the abovementioned direction corresponds very well with the general trend of the coast and it is only to be expected that local deflections of the coastline are of no importance. (See fig.s 2 and 12.)

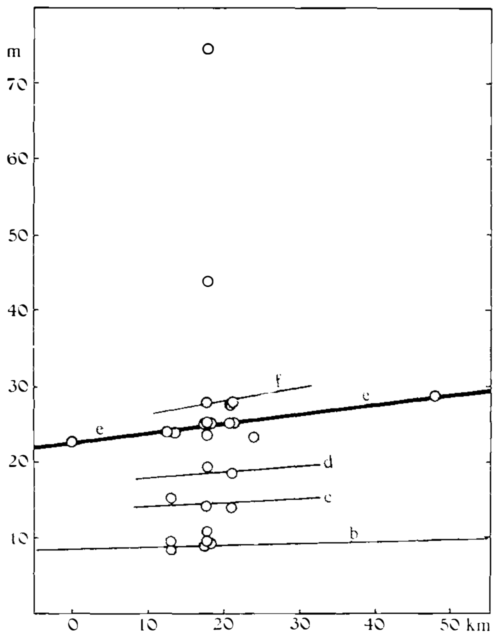

Fig. 3. Shore-line diagram from Southeast-Greenland in a section W 20° N—E 20° S. The letters b—f design the connections with shore-lines from other areas in Greenland.

The gradient of the 25-line can be determined by projecting the heights on a line running in the direction W 19° N—E 19° S, representing a section at right angles to the direction of the isobases.

In addition to the heights at the mentioned localities we can use as a basis for the determiation the height 22.7 metres in Steinfjorden near the outer coast and 28.8 metres on Morénenéset at the head of the fjords. The last figures represents only single measurements, but it is to be noted that both measurements were carried out on excellent and certain lines. The result is a gradient of 0.127 metres per kilometre or 1 metre in 7.85 km., and it is remarkable how well all five values agree. See fig. 3 and particularly fig. 4. The greatest variation of the mentioned five values is only 0.25 metre from the drawn line representing the average. The value 23.4 metre at Innfjorden

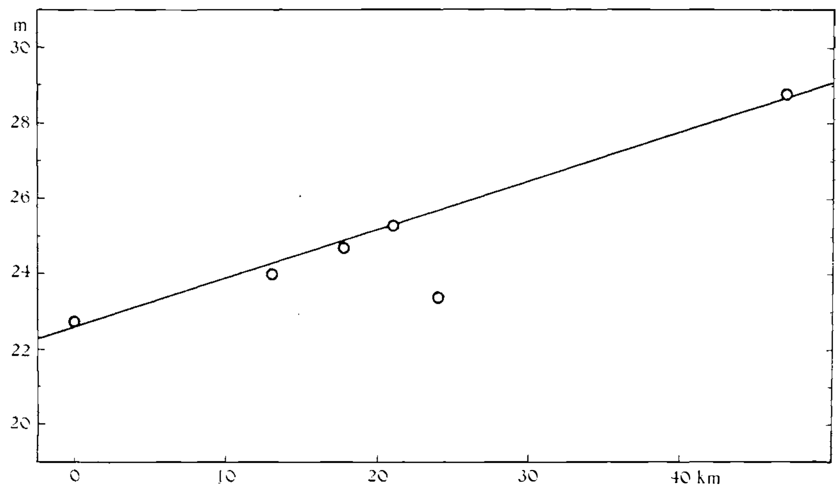

Fig. 4. Diagram of the 25 metres line (e-line) in Southeast-Greenland, on a larger scale than Fig. 3.

lies outside the general continuity, as it is 2.3 metre too low compared with the other five figures. There is, however, a reason for this. Whereas the five mentioned values have been obtained through measuring distinct shore-lines, the measurement at Innfjord refers to a small horizontal surface situated below a steep rocky wall, and it seems probable that this level has been formed in shallow water, as loose material has been scanty. The Innfjord locality was not a fortunate choice, which I did not realise until I had measured the line.

The general result is then that the shore-lines in Greenland, too, shows an inclination in the direction at right angles to the general trend of the coast, which of course was only to be expected. But this gradient, 0.127 metre per kilometre for the 25 metres-line is remarkably small when compared with similar gradients within the Scandinavian-Baltic area of uplift, a feature which we shall deal with later on.

Raised Shore-lines in other parts of Greenland.

Introduction. The Material.

In the preceding chapter we have arrived at a shore-line rising from the height of 21 - 22 metres at the outer coast, to 29—30 metres at the head of the fjords, with a gradient of 0.127 metre per kilometre. It may be compared with shore-lines in Norway, having about the same height above sea-level at the outer coast and it will then be found that the gradient is remarkably small. A further comparison, however, is not possible without knowing, at least approximately, the age of the 25 metres line on Southeast-Greenland. Material for such a determination is, however, not available from this part of Greenland, and the question arises: Is it possible to trace this line in other areas in Greenland with sufficient of quaternary fossils to allow a determination of the age? It is of particular importance to establish a connection to the area around Disco where excellent work of this kind has been carried out by Ad. S. Jensen and Poul Harder (1910).

I have therefore, as far as possible, collected from the available literature, data about shore-line measurements on the west coast of Greenland between 60° and 72° lat. N. This material will be found put together in tables on pp. 16—19.

Approximate observations — those given in 10-metres — have, as a rule, been left out. Otherwise they will be found in brackets. The heights given in feet have been converted to metres with one decimal. Some of the figures may therefore give the impression of an accuracy that the observations do not possess, and which is not claimed by the observers. The starting point for the measurements has undoubtedly generally been high-water mark. When comparing them with the measurements on Southeast-Greenland a small correction should be added to the figures given in the tables. Where the starting point has been mean highwater the correction can reasonably be estimated at +0.5 metre, and +1.0 metre if the starting point was spring-tide.

Otherwise most of the measurements were carried out with an aneroid barometer with often considerable errors. Levelling has, as far as can be ascertained, only been carried out in the south, where Axel Jessen levelled at 13 stations in the Julianehaab district and K. J. V. Steenstrup at 2 stations in the Arsuk area. Nearly all the measurements are taken from A. Kornerup (1879, 1881), K. J. V. Steenstrup (1881, 1883, 1901, 1909) Axel Jessen (1896) and Helgi Pjetursson (1898). Some of the measurements by Steenstrup have also been published by Jessen (1896).

The various points were plotted on a map and the heights projected in a section as far as possible at right angles to the trend of

Raised Shore-lines and Terraces in West Greenland between 60° and 72½° Lat. N.

No.	Locality	Observer	Heights in meter above the sea-level. l = levelling, a = aneroid measurements
	Julianehaab District		
1	Niverfik, Kitsigsut	Jessen	34.3 l 45.4 l 52.6 l
2	Nanortalik	—	10.5 l
3	Kekertarsugsuk, N. of Nanortalik	—	17.7 l
4	C. Egede, Sermersok	—	22.7 l
5	Igdlorsuit, —	—	48.4 l
6	Koromiut, —	—	45.0 l
7	Kalitaut, —	—	43.0 a
8	Niakornak, N. of Kanajormiut	—	25.8 l
9	SW-side of Anoritok	—	28.2 a
10	W-side of —	—	53.3 l
11	Igdlorpait	—	31.1 a
12	Unartok Island	—	38.3 l
13	Sydprøven	—	35.2 a
14	Southern Umanartut	—	47.0 l
15	Northern —	—	16.2 a
16	Umanartut	—	35.2 a
17	Kekertarsuak, Torsukatak Fjord	—	34.1 a 39.0 l 45.0 l
18	Akia	—	27.2 a
19	Kekertarsuak (Kobberøen)	Steenstrup	19.8 a
20	Julianehaab	Jessen	39.7 a
21	Kagsiarsuk, Igaliko Fjord	Steenstrup	21.8 a
-	— —	Jessen	29.0 l 40.5 l
22	Inugkuagsak, —	Bruun	(15.7 a)
23	Igaliko, —	Steenstrup	44.9 a 52.8 a
-	— —	Jessen	30.5 a 44.6 a 45.5 l
24	Narsak	Steenstrup	47.1 a
25	Siorasuit, Tunugdliarfik	—	6.3 a
26	Kagsiarsuk, —	—	39.2 a
-	— —	Holm	37.7 (a)
27	North of Kordlortok, —	Steenstrup	(26 a)
28	Tunuarmiut, —	—	110.8 a
29	Niakornak, Northern Sermilik	Jessen	28.3 a
30	Karmat, —	—	35.3 a
31	Ekaluit, —		51.0 a
-	— —	Bruun	(31.4 a)
32	Mouth of Tasiusak, —	—	(18.8 a)

Literature: K. J. V. Steenstrup (1881, 1909), Gustav Holm (1883), Axel Jessen (1896), Daniel Bruun (1896).

No.	Locality	Observer	Heights
	Frederikshaab District		
33	Arsuk Storø	Steenstrup	11.0 a 15.3 a 18.6 a 24.1 a 57.6 a
34	Arsuk	—	14.2 a 32.7 a 37.0 a 65.7 a
35	Ikerasak, Arsuk Island	—	94.1 a
36	Langenes, Arsuk Fjord	—	54.3 a
37	Fox Harbour, —	—	50.4 a
38	Okotalik, Tornarsukløbet	—	35.7 l
39	Tasiusak, Sermilik	—	32.7 a
40	Ekeluit, Kvannefjord	—	76.3 a
41	Nerutussok	—	45.4 a
42	Kagssat Kingua	—	33.9 l 49.6 l

Literature: Axel Jessen (1896).

No.	Locality	Observer	Heights in meter above the sea-level. Aneroid measurements
	Godthaab and Sukkertoppen Districts		
43	Kakarssuak, Agdlumerasat	Kornerup	192
44	Naujarssuit, —	Steenstrup	57.4
45	Ilivertalik, Aniggok	Kornerup	8.5 17 29 59 101
46	Kingua, Græedefjorden	Steenstrup	48.3
47	Marrak, —	-	43.3 51.5
-	— —	Kornerup	13
48	Sanerata tima	—	13
49	Alangordlia	—	11
50	Karajup Kingua	Steenstrup	35.3
51	Kingua i Ameragdla	Kornerup	60 106
52	Majuala, Ujaragssuit	Jensen	(6.3) (25.1) (56.5) (91.1) (103.5) (128.6)
53	Lakseelven, —	—	(53.3)
54	Kangia, inner part	—	(18.8)

Literature: A. Kornerup (1879), J. A. D. Jensen (1889), Axel Jessen (1896).

No.	Locality	Observer	Heights
	Holsteinsborg District		
55	Søndre Kangerdlugssuak, middle part of	Kornerup	36.0 36.3 63.6 74.5 82.6 102.6
56	Nagtoralinguak	—	86 5
57	Præstefjeldet	-	25 2
58	Akungnak	—	25.6
59	Inugsulinguak (Inugsugsulik)	—	5.0
60	Natarnivinguak	—	47.4
61	Isortuarsuk	—	51.3 119.2
62	Ekalugsuak	—	10
63	Isortok, inner part	—	48.2
64	Ilivilik Valley	Pjetursson	ca. 10 ca. 32 ca. 50
65	Akuliaruserssuak, Ekalugsuit	—	22
66	Nagssugtok Fjord, middle part of	—	10—11 54 65
67	Nagssugtok Fjord, head of	Kornerup	6.3 10.1
68	Arfersiorfik, head of	Pjetursson	83

Literature: A. Kornerup (1881), Helgi Pjetursson (1898).

No.	Locality	Observer	Heights
	Egedesminde District		
69	Agto	Pjetursson	21.4 21.5 ca. 25 31.5 32 42.5
70	Rifkol (Umanak)	—	34—35 47 53 57.5 68
71	Ikerasak	—	33 60 nearly 70 86 90
72	Ivnarsulik	—	20 22.6 32 55
73	Simiutarssuak	—	41 57
74	Ikerasarssuk	-	39
75	Alangorssuak	—	26.5 33.5 40—41 45 59
76	Igniarfik portage place	—	10—11
77	Aulatsivik, Arfersiorfik	—	8
78	Aulatsivik portage place	-	35
79	Tinutekarsak	—	44
80	Okaitsorssuit, Arfersiorfik	—	20—25 63 91
81	Sagdlerssuak	—	30 39.5 50 57 60
82	Inugsulik	—	ca. 30 46.5
83	Ipernik	—	56 77
84	Augpiletok	—	22.5 31.5
85	Kangatsiak	—	11 27 ca. 30 ca. 35
86	Kangatsiak Fjord	—	36 68 88 94
87	Tunugdlek Bay	—	15
88	Tasiussak Kakak	—	97

No.	Locality	Observer	Heights in metre above the sea-level. Aneroid measurements
	Egedesminde District		
89	Ivnalik	Pjetursson	37.5
90	Portussut	—	34.5
91	Kekertarssuatsiak	—	10 20.5 31.3 ca. 80—90
92	Aussat	—	33
93	Niakornak, Aumat	—	20 28 59 71 91
94	Usugtalik	—	11 62
95	Egedesminde Island	—	28 50
96	Manitsok	—	34.5 50.7 62.7 64.8 90 98 99.2 108
97	Hunde Island	—	8 8—10

Literatur: Helgi Pjetursson (1898).

The Disco Island Area

98	Imerigssok, Kronprinsen Islands	Pjetursson	11.3 16.8 27 27.8 28.4 35 5 40 5
99	Kaersorssuak, —	—	11 33.5
100	Ivnarsulik, —	—	11.9 22 28.8
101	Kidlit, —	—	16
102	Okak, —	—	16.1
103	Nunarssuak, —	—	(23) 26.5 32 32 34.3 35 36 47 66.1 (70) 71.6 76.8 77
104	Lyngmarksdal, near Godhavn	—	10—11 33 (53)
105	East of Lyngmarken, —	—	11 (27.5) 41 54.8
106	Godhavn	—	29.7
107	Røde elv, near Godhavn	Steenstrup	22.5
108	Per Dams skib (Skarvefjeld)	—	(22) (38) (76)
109	Brede dal	—	13.2 37.3
110	Sinigfik	—	12 2 62.0
111	East of Sinigfik	—	4.5 19 38
112	Marrak	—	11
113	Skansen (Aumarutigssat)	—	8.6 12—15 26 26.3 40.4 42 49.4 88.7
114	Flakkerhuk	—	31.5 98.1
115	Isunguak	—	12 5 14 6 33.8 39.7
116	Napassuligssuak	—	36.7
117	Igdlorpait	—	25.8
118	Igdloluarssuit	—	39.8
119	Perdlertut, Nordfjord	—	25.8 83 2
120	Head of Nordfjord	—	22 0 25.1
121	Kagsigissat	—	c. 10.0
122	Jernpynten, Mellemfjord	—	24.0
123	Head of Mellemfjord	—	41.7
124	Ivisarkut	—	2 2 6.5 30.5
125	Northern Laksebugt	—	37.3
126	Kagsimavik, Disco Fjord	—	89
127	Nangissat, —	—	29
128	Sioranguak, —	—	47 48.5
129	Kugssuak, —	—	7.7 28.5 53.9 79.3
130	Akuliaruserssuak,	—	177
131	East of Kivitut, —	—	127
132	Ungorsivik	—	(c 2) (c 6)
133	Niakornak	—	(44.8)
134	Ritenbenk Island	Pjetursson	42 3
135	Tasiusak, at Torsukatak	Steenstrup	51.1 129 8

Literature: K. J. V. Steenstrup (1883, 1901), Helgi Pjetursson (1898).

No.	Locality	Observer	Heights in metre above the sea-level. Aneroid measurements
	Umanak and Upernivik Districts		
136	Pagtorfik	Steenstrup	59.6
137	Ikorfat	—	c 6
138	Kusininguak	—	101.0
139	Kugsinek, Svartenhuk Peninsula	—	12.5
140	Between Maligiak and C. Cranstown	Drygalski	c 10
141	Southern Upernivik	Steenstrup	39.6
142	Head of the Uvkusigsat Fjord	—	150.0

Literature: K. J. V. Steenstrup (1883), Erich von Drygalski (1897).

the isobases. The greatest difficulty was to find this direction, and the final results were obtained only after several tests.

A cursory examination of the available shore-line material shows that a whole series of different lines have been measured, probably about 15 to 20 different lines in West-Greenland, but of those only the five lowermost, here called *a*—*e*, have been used for connecting purposes. None of these lines have the authors emphazised as main lines, but by using statistical methods it is possible to get an idea of the intensity of the cutting of the sea: the strongest lines will normally be most frequently measured.

As stated in a previous chapter, in Southeast-Greenland the 25 metres line or the *e*-line is the strongest line. From below we have here, the following "line-spectrum" (the quite low *a*-line was not found in SE.-Greenland): First the distinct 9 metres line or *b*-line, then the more feeble *c*- and *d*-lines; with the strong *e*-line next. These characteristics may — with care — be applied in the working out of the connections. In constructing the various shore-line diagrams it is further of importance that the order of magnitude of the gradient is known from Southeast-Greenland, giving, in fact, the key to the diagrams. It is also of importance that the isobasic lines in the various areas are situated in the continuation of each other.

The connections were based on these methods, and even if the results are not entirely certain, the correspondence obtained throughout the coast from Southeast-Greenland, around Cape Farvel and northwards to the Svartenhuk peninsula is so good that I consider the result as undoubtedly the most probable solution.

We have on the west coast two areas with many and good shore-line measurements. One area in the south at Julianehaab where the material, in the first instance, is due to Axel Jessen and then to K. J. V. Steenstrup. The second area is the Disco Island and surroundings where the measurements were carried out by Steenstrup and also by Helgi Pjetursson.

Between these areas the measurements are not so good and rather scattered.

The Julianehaab Area.

It is not possible to construct the trend of the isobases from the shore-line measurements in this area. As a result of various trial-

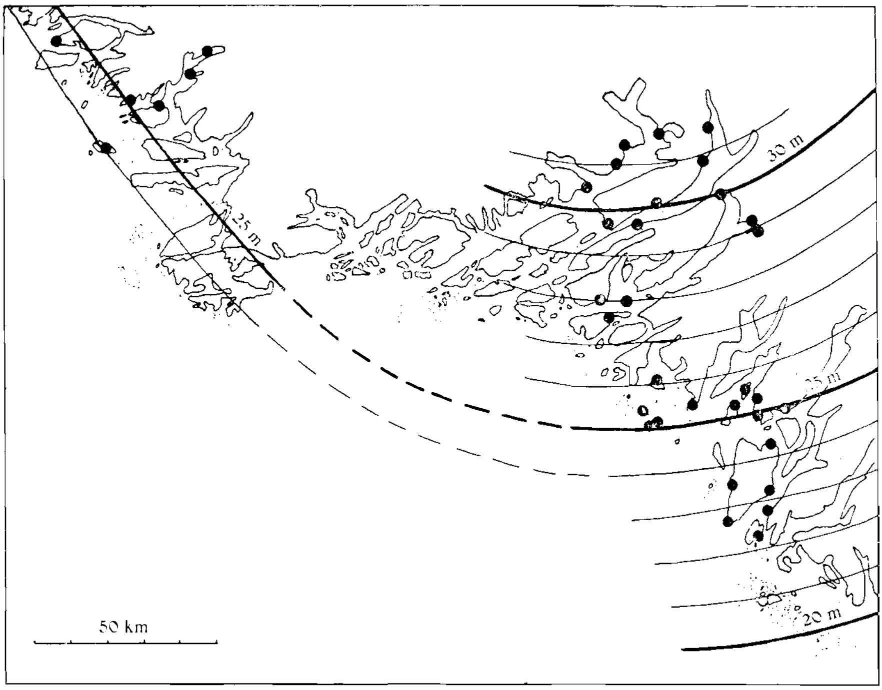

Fig. 5. Map of the Julianehaab and Arsuk areas, with localities of the measured shore-lines, and the isobases for the e-line.

connections, paying due attention to the shore-lines in Southeast-Greenland as well as farther north on the westcoast, I have found that the isobases here have roughly an east-westerly trend. The projecting piece of land at Cape Farvel, between the fjords Igaliko and Danell is of slight or no importance to the run of the isobases, this being also quite natural when taking a large view of the whole problem. The *e*-line isobases will be seen from fig. 5, where also the various survey stations have been plotted. These correspond to Nos. 1—32 in the table on p. 16 and will be found to the right in fig. 5. The observation points have then been plotted on a section roughly at right angles to the trend of the isobases (Fig. 6).

The line which it is most natural to compare with the 25 metres line in Southeast-Greenland is called the *e*-line. It also seems to be the first strong line, counted from below, measured at 7 points, whereas the *a*-, *b*-, *c*- and *d*-lines have only 1, 1, 3 and 4 measuring points. A good correspondance is thus also abtained in the line-diagrams, and the run of the isobases becomes even and reasonable. The heights of the two lines are also about the same, viz. 22 metres at the outer coast, and about 30 metres in the fjords farther inland.

The gradient of the *e*-line at Julianehaab, is computed at 0.076 metre per kilometre or 1 metre in 13.16 kilometre. The section at a right angle, to the trend of the isobases has then been placed in the direction N 10° W—S 10° E and the computation is based on the following three levelled altitudes: 22.7 metres at Cape Egede; 25.8 metres

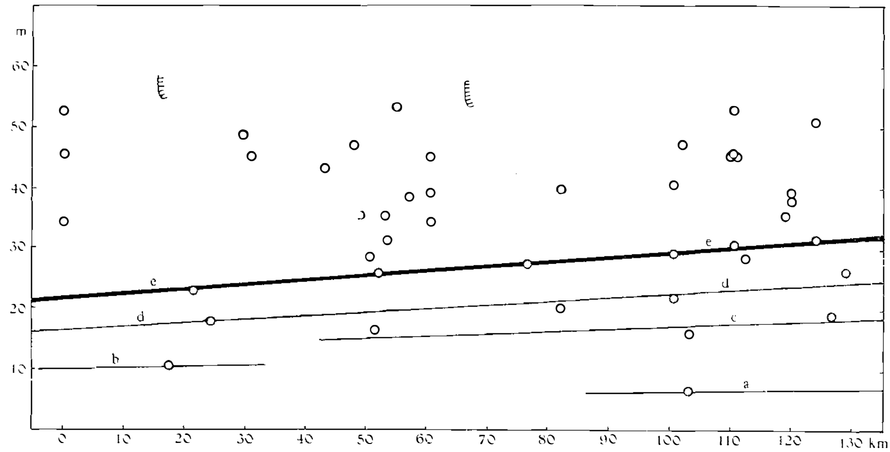

Fig. 6. Shore-line diagram from the Julianehaab area, in a section N—S.

at Niakornak; 29.0 metres at Kagsiarsuk. These values, and also the four barometer readings in localities Nos. 18, 23, 29 and 31 (27.2, 30,5, 28.3 and 31.4 metres) fit very well on a slightly inclined shore-line plane having the mentioned gradient.

The value of the gradient found is even less than in Southeast-Greenland, where the inclination of the corresponding line was 0.127 metre per kilometre.

Otherwise it is possible to distinguish about 10 or 11 shore-lines at Julianehaab. As will be seen from the shore-line diagram fig. 6 there are three lines situated at different distances from the coast and reaching an altitude of fully 50 metres above sea-level. One line lies at the height of 52.6 metres at Niverfik, one of the islands of the group Kitsigsut off the coast. Further inland another line has the altitude 53.3 metres at Anoritok, whereas at Igaliko at the head of the fjord a third line reaches 52.8 metres.

It was previously believed that these three lines together formed a horizontal shore-line, an interpretation which is no longer natural or holds good, when the inclination of the shore-lines towards the sea has been proved.

It is extremely likely that the uplift of the land took place when the ice receded, and that the fjord tracts were still covered with ice when the outer coast was ice-free. This supposition — a natural one according to the available material — has been indicated on fig. 6.

From the inner parts of the fjords are reported one observation concerning a very high line, on 110.8 m at Tunuarmiut. This value lies, however, outside the generel continuity, and with Axel Jessen it may be reason to assume that this shore-line was carved out by an icedammed lake.

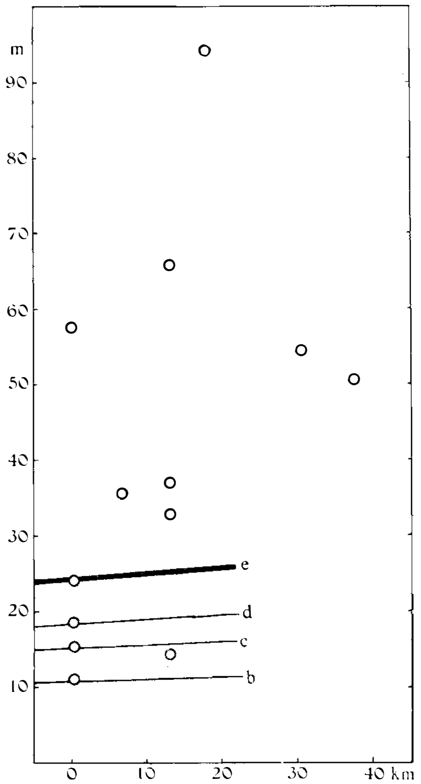

Fig. 7. Shore-line diagram from the Arsuk area, in a section N40°E–S40°W.

The Arsuk Area.

This area is closely related to the Julianehaab area, as will be seen from fig. 5 when the localities of the tract have been plotted to the extreme left on the map. The localities correspond to Nos. 33—38 in the table on p. 16. The level 24.1 metres on Arsuk Storø is in all probability identical with the *e*-line. Otherwise it may be referred to the shore-line diagram fig. 7, where the rather few measurements from this area has been plotted.

The Area at Disco Is. and Vicinity.

Thanks to the careful barometer measurements of K. J. V. Steenstrup and also of Helgi Pjetursson, the Disco-area is as regards shore-lines the best investigated area, apart from Julianehaab. In fig. 8 the localities Nos. 98—135 have been plotted in the northern and upper part of the map. The heigts of these localities are projected on a section placed in the direction W 10° S—E 10° N (see, shore-line diagram, fig. 9).

Here it is reasonable to compare the line marked e with the 25 metres line on Southeast-Greenland. It appears to be the strongest line with the *b*-line coming next in strength, just as in Southeast-Greenland.

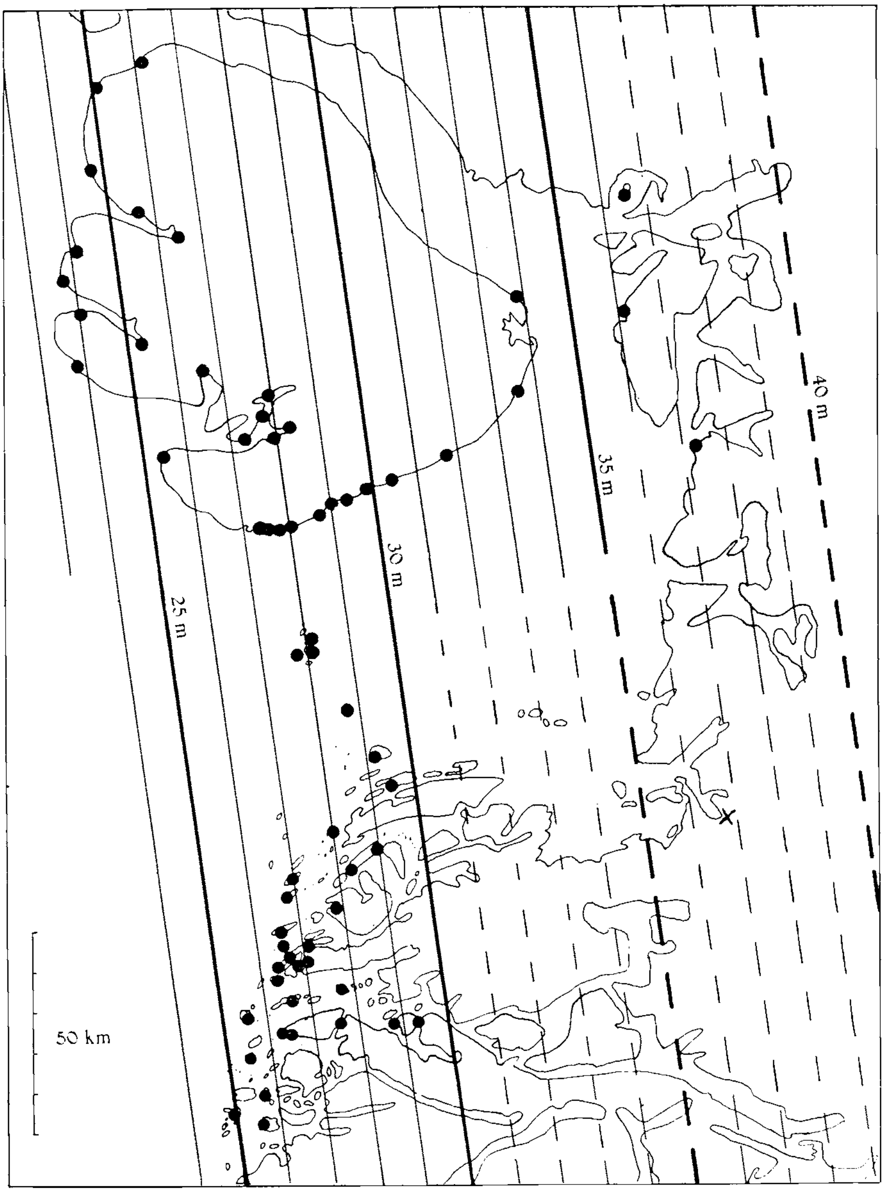

Fig. 8. Map of the Disco and Egedesminde areas, with localities of the measured shore-lines, and the isobases for the e-line.

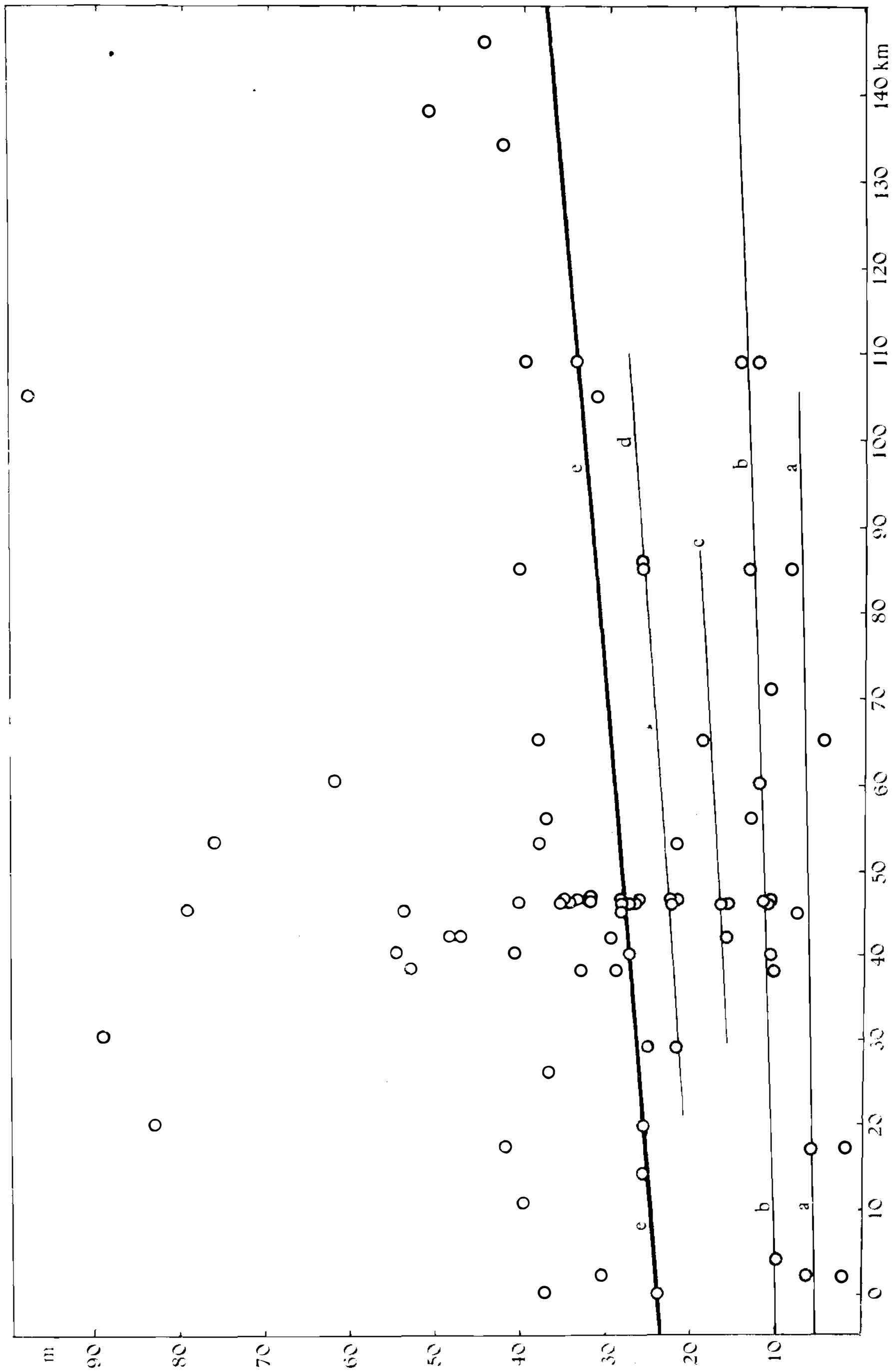

Fig. 9. Shore-line diagram from the Disco area, in a section W 10° S—E 10° N.

To the lines *a*, *b*, *c*, *d* and *e* corresponds a number of 5, 12, 4, 7 and 15 measured points, respectively.

As mentioned below, the trend of the isobases may be computed to be S 10° E—N 10° W. This direction coincides in the main with the general trend of the coast, and thus we also get a natural connection between the isobases in the Julianehaab and Arsuk area. At Disco, too, the height of the *e*-line becomes some twenty metres at the outer coast.

The following height measurements are referred to the *e*-line: 24.0, 25.8, 25.8, 25.1, 29.0, 27.5, 29.7, 28.5, 27, 27.8, 28.4, 28.8, 26.5, 31.5 and 33.8, corresponding to localities Nos. 122, 117, 119, 120, 127, 105, 106, 129, 98, 100, 103, 104 and 105.

Based on these measurements the gradient of the *e*-line may be computed at 0.093 m per km, a value lying between the value in Southeast-Greenland (0.127 m per km) and at Julianehaab (0.076 m per km).

The gradient of the quite low *b*-line may be computed at about 0.034 m per km. As regards the higher lines the connections between the various measuring points are uncertain, and these lines are not plotted in the diagram.

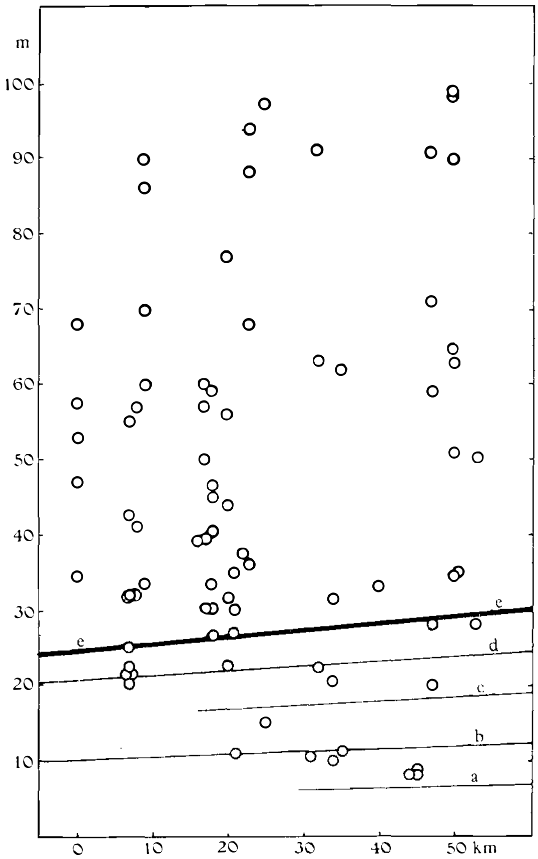

Fig. 10. Shore-line diagram from the Egedesminde area, in a section W 10° S—E 10° N.

The two lines *b* and *e* are connected in the formula

$$b = 0.365e + 1.2$$

where *b* and *e* signify the heights of these lines above sea-level in metres.

The Egedesminde Area.

The shore-lines in Disco Is. may be traced southwards to the Egedesminde district, as the numerous measurements on Kronprinsen Islands form a connecting link.

Around Godhavn and in the inner part of Discofjord we have some measurements of the *e*-line in the height of about 28 metres (localities: Nos. 105, 106, 127 and 129). On Kronprinsen Islands there has been made a series of measurements of the *e*-line in the same height (in localities Nos. 98, 100 and 103) leading to the *e*-line at the height of 28 metres farther south, around Egedesminde (in localities Nos. 93 and 95).

The trend of the *e*-line isobases is based upon the following heights: Four between 24.0 and 25.8 metres on the outer side of Disco Island (in localities Nos. 117, 119, 120 and 122), and three between 25 and 27 metres in the Egedesminde district (in localities Nos. 69, 75 and 85). As said above, this gives a trend of the isobases amounting to N10° W—S 10° E.

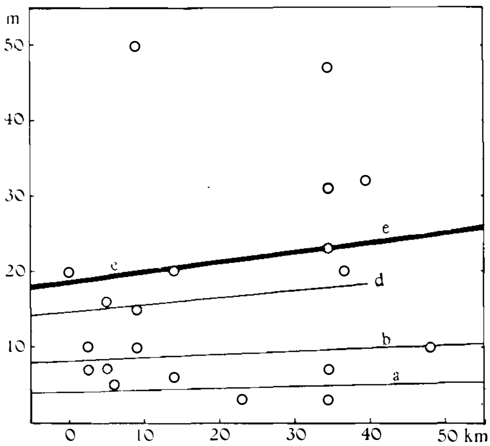

Fig. 11. Shore-line diagram from the Angmagssalik area, in a section N 45° W—S 45° E.

The localities in the Egedesminde district are shown in fig. 8 (southern part of the map), whereas the shore-line diagram will be found in fig. 10.

Statistically 3, 4, 2—3, 6—7 and 5 measurements correspond with the lines *a*, *b*, *c*, *d* and *e*. This is not quite in agreement with the general rule otherwise used, as more lines corresponding with the *d*-line than the *e*-line have been measured. On the other hand it is difficult to connect the lines on Disco and at Egedesminde otherwise than here stated; nor can the general rule claim to be a binding one. There are so many lines on Greenland, so that it will always be in some degree fortuitous which line is measured, and will also depend upon the distribution of the loose material.

Throughout the region between Egedesminde in the north and Arsuk in the south the measurements are more scattered and, apparently, of a more heterogeneous character. We have here a series of very old measurements of broad, ill-defined terraces. Yet in the Holsteinborg area the height 22 metres in locality No. 65, and 32 metres in locality No. 64 seems to correspond with the *e*-line. However, the material here is too scanty and heterogeneous to merit further treatment.

The Angmagssalik Area in East-Greenland.

A few measurements of terraces and shore-lines were carried out in the summer of 1902 by the botanist Chr. Kruuse (1912) in this area. The measurements have apparently been carried out with an aneroid, and as the figures have partly been rounded off to the nearest 5 or 10 metres they are in that respect rather approximate.

A list containing the measurements of Kruuse will be found below. The shore-line diagram has been constructed by projection on a section running N 45° W (Fig. 11). The line here designated as the *e*-line, probably corresponds with the 25 metres line in Southeast-Greenland, as a reasonable run of the isobases is only possible on this assumption. The following measurements are referred to the *e*-line: 20 metres on Grusø; abt. 20 metres in Kangerdluarsikajik; 23 metres at Sierak.

The shore-line material from the northern part of the east coast, north of abt. 70° Lat. N. will not be dealt with in this paper.

Raised Shore-lines and Terraces in Angmagssalik District.

No.	Locality	Observer	Heights in meter above the sea-level
1	Grønlænderpynt, Tasiusak	Kruuse	3
2	Adloedal, C. Dan	–	7 10
3	Norsit	—	7.3 16
4	North side of great island to the north of C. Dan	-	6
5	Head of Ikerasausak		10
6	Sierak	–	3 7 23 31 47
7	Head of Tasiusak Misutok	—	ca. 32
8	East side of —	–	20
9	Kangerdluarsikajik	—	ca. 20
10	Grusø	–	ca. 20
11	North side of Storø	—	ca. 5
12	East side of Nordfjord	—	10 15 50

Literature: Chr. Kruuse (1912).

The Climatic Conditions during the Formation of the raised Shore-lines.

In several West Greenland localities subfossil shells of mollusca have been found, allowing certain deductions to be made concerning the climatic conditions during the rise of the land. Papers dealing with this question in general have been published by Ad. S. Jessen (1905); Ad. S. Jensen and Poul Harder (1910). A shorter summary has been written by O. B. Bøggild (1917).

In 1884 J. A. D. Jensen (1889) discovered a warmth-loving fauna at a small height above sea-level at Ikerasarsuk in Ikerlokfjord in 66° 48′ Lat. N., and on the Nepisat Is. in Evighedsfjord in Lat. about 65° 50′. In both localities occurred *Anomia ephippium*, not found living in Greenland. In the first locality occur other southern forms, too, such as *Littorina obtusata*, *Littorina rudis* and *Mytilus edulis*. The

Littorina-forms have their present northern limit in West Greenland in latitude 69° and 73° north respectively, whereas *Mytilus* ranges still farther north. The heights of the two fossil localities were 7.8 and 4.7 metres respectively. The height of the shore-lines are not known in detail in this area, but the *e*-line must be situated at the altitude of ca. 25 metres in both places, corresponding to the height of the *b*-line of about 10 metres. The warmth-loving fauna thus extends nearly up to the *b*-line.

In 1902 M. C. Engell (1904, 1905) discovered the warmth-loving form *Zirphœa crispata* (neither is this species found living in Greenland) at a low level above the sea at Orpigsok (Orpigsuit) in the southeastern part of Disco Bay, lat. 68° 37′ N. The find was further described by Ad. S. Jensen (1905). The Quaternary geology of this locality was also investigated by Ad. S. Jensen and Poul Harder (1910). The latter authors discovered *Zirphœa* together with *Anomia ephippium* in beach gravel up to about 10 metres above sea-level. Engell states that he has discovered *Zirphœa* 11—12 metres above sea-level in a layer of sand above a *Mytilus*-layer. Here, too, the two species occurred together with rather southern forms such as *Littorina rudis*, *Littorina palliata*, *Tectura testudinalis*, *Tellina baltica* and *Mytilus edulis*.

Exact heights of the old shore-levels are not found published from Orpigsok. From the isobase map fig. 8 where Orpigsok is marked with a cross, it will be seen that here the *e*-line should occupy a position 36—37 metres above sea-level. This fits in well with the approximate height of what is apparently the largest terrace in this area. Amund Helland (1876, p. 114—115) thus mentions a terrace at the height of about 30 metres at Lerbugten and Sandbugten at Klaushavn, a little north of Orpigsok. A terrace from Lerbugten at Pinguarsuk south of Klaushavn more than 100 feet (31.4 metres) high is mentioned by P. L. P. Sylow (1883). Engell (1904, 1909) gives the height of a terrace at Tasiussak near Klaushavn at 30—40 metres above sea-level. In his first paper he states the terrace height at Orpigsok to be 30 metres, in the second he gives the height as the same as at Tasiussak. Jensen and Harder (1910) find the terrace height at Orpigsok to be 30—40 metres. If the height of the *e*-line here is assumed to be 36—37 metres, the *b*-line should then be 14½ metres, and it appears that the warm fauna here too is distributed towards this line.

Jensen and Harder arrive at the conclusion that a climatic optimum was reached when the shore-level was about 10 metres higher of Orpigsok, as the *Zirphœa*-fauna occur in littoral deposits up to this height. It is not quite clear from the descriptions whether the shore deposits with *Zirphœa* are overlain by younger sediments or not. From the conclusions of Jensen and Harder, and especially from the figure on p. 406 in their paper, it is, however, evident that the authors do not assume a later submergence of the land, apart from the recent sinking.

According to their opinion the terraces at the height of 30—40 metres must be considerably older than the *Zirphæa* fauna.

According to the available data it is extremely probable that the warm fauna with *Zirphæa* and *Anomia* is associated with the level of the *b*-line. At Ikerasarsuk and on Nepisat there was a pure littoral fauna with *Littorina*-forms up to the level of the *b*-line. The same thing applies to Orpigsok where there is a littoral fauna in shore-gravel. It is therefore justifiable to designate the *b*-line as the *Zirphæa*-line in Greenland.

The climate at the time of the *e*-line level of the sea was already quite warm. Jensen and Harder mention "that we have met with the first, sparse traces of this fauna [to which *Zirphæa* belongs] in strand-formations at a height of about 30 m". This refers to observations not published.

It is, however, clear that they refer to neither *Zirphæa* nor *Anomia* but to somewhat southern species of the accompanying fauna complex. Jensen and Harder assume, as is also evident from the figure on p. 406 in their paper, that the climate was warmer than it is now, when the sea reached a line 30 metres above the present level. This level lies, as will be seen, near the *e*-line level. This agrees very well with the present author's observations from Moréneodden in Southeast-Greenland. The 25 metres line (*e*-line) was here found to extend right up to a quite fresh recent moraine, and appeared to continue underneath it. This shows that the 25-line was incised during a period with a warmer climate than the present.

At Orpigsok Jensen and Harder discovered an older fauna with, *inter alia, Mølleria costulata* and *Pecten islandicus* indicating a climate of about the same character as the present. The authors discovered this fauna in a number of localities, but never higher than 50 metres above sea-level. The fauna mentioned by Quervain (Q. and Mercanton 1925) from the Holsteinsborg district is probably contemporaneous with the latter. In the localities Kuk and Sarfanguak (lat. 66° 48′ and 66° 53′ N) Quervain found 40 metres above the sea a temperate fauna with, *inter alia*, *Buccinum undatum*, *Pecten islandicus*, *Tellina baltica* and *Mytilus edulis*. Of these, the *Buccinum* species has in West Greenland its northern limit as far south as 70° Lat. N., and the fauna suggests a climate like the present. In these two localities the *e*-line should, according to computations, be situated about 26—29 metres above sea-level. From the older literature one might think that this temperate fauna was possibly found in still higher layers. Thus K.J. V. Steenstrup (1883) mentions shells of *Cardium minimum* and *Mytilus edulis* from Pagtorfik, but it is not clear whether these shells really have been found as high as 59.6 metres, as suggested in the table in that paper.

Still older is the extreme Arctic fauna with *Yoldia arctica* found at Orpigsok and other points. Jensen and Harder assume that the *Yoldia* fauna corresponds to a sea-level about 100-metres higher than the present. The highest shore-marks measured on the east side of Disco Bay are at the level 129.8 metres (Steenstrup's measurement at Tasuissak near Torsukatak), and it is perhaps probable that the *Yoldia*-fauna, too, lived in the period corresponding to this somewhat higher level.

Comparison between the Greenland and Fennoscandia Areas of Upheaval.

Connection of the raised Shore-lines.

A comparison between the later Quaternary level changes in Greenland and Scandinavia raises problems of general geological and isostatic interest. The two areas are similar in so far as both the Greenland and Fennoscandian-Baltic areas of glaciation during the last Ice Age have about the same size, but differing in respect of the fact that in Greenland a huge ice cap still covers the country, whereas in Scandinavia practically all the ice has disappeared.

Nansen (1890, 92) estimated the thickness of the Greenland ice cap at 1700—2000 metres at least in the central part, and this rough estimate has been confirmed by the extremely important and interesting measurements of the ice thickness carried out by the Greenland expeditions of Alfred Wegener in 1929 and particularly in 1930—31 (1932). The measurements from the Section Umanak—Scoresby Sound showed an ice thickness of not less than 2500—2700 metres in the central area of the inland ice, a surprisingly high figure despite the previous estimate by Nansen. The weight of the inland ice is undoubtedly great enough to make itself felt isostatically. The present author has previously (1927, 1931) pointed out that the recent subsidence of Greenland is in all probability due to the increased weight of the inland ice, following the post-glacial warm period. As is well known, Scandinavia is at present in a period of uplift, and this rise is undoubtedly to be regarded as a direct continuation of the uplift due to the melting of the ice sheet of the last glacial epoch. There is thus a considerable difference between the movements of the too areas. These problems may be followed up by making a general investigation of the glacial and post-glacial changes in level.

The synchronisation of the changes is based upon the following considerations: On the one hand we may use the climatic changes, as reflected in the molluscan fauna of the sea, and which then becomes fixed as regards level. To start with, we must in any case assume that the general run of the climatic changes in the two areas is the same. This is not certain, but extremely probable. The other basis for a comparison is of a more absolute character. According to the latest investigations, inaugurated by the epoch-making paper by Fridtjof Nansen (1922), it is possible to split the level changes of Quaternary glaciation areas in two components: one representing the movement of the land itself, and one representing the changes in the level of the sea. Whereas the movement of the land may be different in the various areas, the changes in the level of the sea are everywhere constant. The old shore-lines then represent the interference between these two movements, and the cutting of a certain shore-line will be dependent upon a change in the sea-level. We have thus in the shore-lines an excellent means of exactly correlating the proper motions of the two areas, as well as the changes of the water level. We should then, theoretically, be able to check the first assumption as to the synchronism of the climatic changes, but this implies a more detailed knowledge of the shore-lines of the two areas then we now have.

The climatic changes in West Greenland may, especially after the investigations of Jensen and Harder (1910), be supposed to have had the following course (the heights refer to the east side of Disco Bay): When the sea reached 100—130 metres the climate was extreme Arctic; when at 50 metres or a little higher it was like the present one, and somewhat warmer than now when the sea was at 30 metres; considerably warmer when at 10—12 metres. It is reasonable to assume that the level of the *e*-line corresponds to a climate somewhat warmer than the present, whereas the *b*-line or the *Zirphœa*-line is the upper limit of the climate at its warmest. The climatic optimum ocurred apparently on the level interval below the *Zirphœa*-line.

When making a comparison with Scandinavia we may use as a faunistic starting point the standard section at Oslo, so well known from the careful investigations of W. C. Brøgger and P. A. Øyen. The Arctic *Portlandia* period (205—175 metres above sea-level) was followed by the sub-arctic *Littorina* period (175—142 metres above sea-level); during the subsequent *Pholas*-period (142—95 metres above sea-level) the climate apparently became much like the present. In order to estimate the time when the climate was similar to the present one we have the support of the following observations: Øyen (1916) has found *Isocardia cor* (only located a few specimens now found living in the Oslofjord), up to the height of 90 metres at Grorud near Oslo. As *Isocardia* prefers a depth of 20—80 metres, this would indicate a water level of at least 110 metres above the present when the climate was probably similar to that we have now. Further, at Grorud Bjørlykke (1900) has found *Pholas candida* at the height of 120—130 metres, and as *Pholas* preferably lives in quite shallow water just below the tide mark, it is very likely that *Pholas* lived at a stand of the sea at very much the same level. Until recently *Pholas* was only known in Norway as a fossil, but has now been found living in the Trondheimfjord by C. Dons (1926). This species has probably migrated to the Oslofjord at the time when the climate was similar to the present, but perhaps a little cooler. It is thus probable that the climate became like the present about the middle of *Pholas* time or roughly at about 120 metres.

The temperature has then apparently risen gradually during the *Mactra* period (95—70 metres), and particularly during the *Tapes* period (70 47 metres), to reach an optimum in *Trivia* times (47—22 metres), and probably also during the upper *Ostrea* times (22—11 metres). The change to a colder climate occured when the sea-level was 10 metres or a little less higher than the present one. The change corresponds to the passage from sub-boreal to sub-atlantic time.

A correlation of the two areas will naturally lead to the *b*-line or *Zirphæa*-line in Greenland corresponding to the *Trivia*-line in Norway (line T 1 of Grønlie, and a 7 of Tanner). These two lines will then form the upper limits of the most warmth-loving fauna. The Greenland *e*-line must probably be correlated with the *Tapes*-line in Norway, corresponding to the *Littorina*-limit in the Baltic areas. Also in Greenland the climate of the *e*-line must have been somewhat warmer than the present, and in both areas the lines are, counted from below, the first real strong met with.

During the gradual improvement of the climate from Arctic to one rather warm, we get a climate like the present at a fairly considerable height above the *e*-line in Greenland and above the *Tapes*-line in Norway. The possibility also exists that the *Zirphæa*-line corresponds with the *Tapes*-line and the *e*-line with, e. g., the *Mactra*-line in Norway, but the available material undoubtedly makes the former assumption the more probable. Thus, *Zirphæa cristata* is a rather warmth-loving species, which in Norway has its northern limit near the border between the Finnmark and Troms counties. Were it possible or even probable that *Zirphæa* would be found living in more northern or eastern localities in Norway, there is a strong probability that this boreal species belongs to that fauna which lived in Greenland when the climate had its optimum. To this should be added the fact that the *Zirphæa*-line is much more feebly developed than the *b*-line. Everything considered, there are strong reasons for the above correlation. The Quaternary material from the east coast of Greenland north of lat. 70° N. has not been dealt with in this paper. Just one observation from the northern part of the east coast should be mentioned, viz. a find by A. G. Nathorst (1901) of *Mytilus edulis* up to 25 metres above sea-level on Geographical Society Island in lat. 73° 4′ L. N. On the east coast the present northern limit of *Mytilus* is 66° 30′ lat. N. but otherwise it is found rather far to the north, to Melville Bay on the west coast of Greenland, and, in Arctic Europe, in any case to the southern part of Novaya Zemlya. The lower limit for the development of fertile eggs is also, according to Runnstrøm, rather low for this species: about + 4°. A small improvement of the climate with a considerable reduction of the amount of ice along the east coast of Greenland, would, we must believe, push the northern limit of *Mytilus* far to the north; it is reasonable to include the mentioned find in the fauna of the *e*-line. If the 25 metres-isobase is drawn across or a little east of the mentioned locality, the isobase-system of the *e*-line will also occupy the same position here with regard to the coast as everywhere else on Greenland.

The Gradients.

As we have found that the *e*-line on Greenland, probably corresponds with the *Tapes*-line in Scandinavia, it will be useful to deal with the question of the gradient somewhat more in detail.

From fig. 12 it will be seen that the isobases of the *e*-line lie at a greater distance from each other on the west coast than on the east coast, or, in other words, the gradient is somewhat less in the west than in the east. There may be several reasons for this. We find that on the west coast the banks extend farther seawards than on the east coast. When during the maximum extent of the ice the level of the sea was 100—150 metres lower than now, the inland ice extended much farther from the present coast in the west than in the east before a calving ice front was formed. At present the ice-shed is situated nearer to the east than the west coast in the southern and middle part of Greenland, as has been shown by the expeditions of Nansen, Quervain, Høygaard and Mehren. A corresponding distribution of the inland ice during the last ice age may well have taken place. These factors would both involve a shorter distance from the maximum of load to an area without any load in the east than in the west. This would cause the value of the gradient to become somewhat larger in the east than in the west. It is also possible that the glaciation and depression of the land on the other side of Davis Strait and Baffin Bay (Labrador, Baffin Is., Devon Is., and Ellesmere Land) have been contributing factors. A crucial question is whether the areas of depression on Greenland and on Baffin Is., etc. has extended so far into Baffin Bay that this branch of the sea has also been weighed down. A consequent rise of the sea-bottom, together with the uplift of the two adjacent land areas, would in that case cause the gradients to become less than normal.

Now the extrapolated zero-isobase of the *e*-line on West-Greenland is situated near Cape Dier on Baffin Land, and one would think that

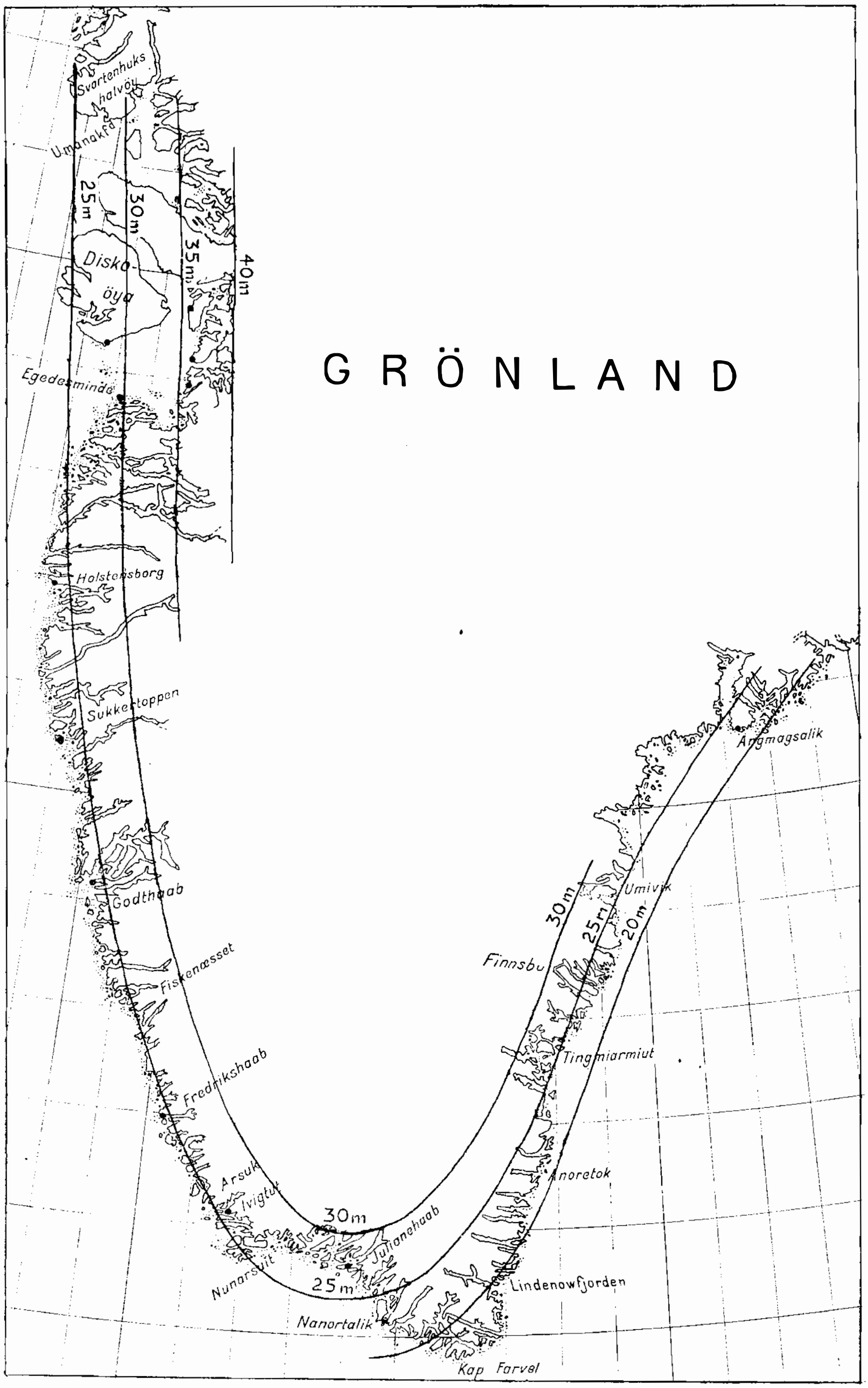

Fig. 12. Map with the isobases of the e-line (the *Tapes*-line) for a part of Greenland.

the whole bay between had been depressed. There is, however, a peculiar complication on Greenland — as will be seen from the last chapter of this paper — making it impossible to use ordinary extrapolation to find the real zero-isobase here. Even if it is impossible to say anything definite about the realities, all the mentioned factors will, at any rate, tend to a smaller gradient on West-Greenland than on East-Greenland, conforming with the result obtained.

The Scandinavian-Baltic uplift area is assymetrical with regard to the gradients, with greater values in the west than in the east, which is also evident from the isobase-maps figs. 73 and 74 in Tanner (1930). It is almost certain that this is due to the pronounced assymetric position of the ice-shed and to the fact that the glacier front was bordered by the open sea in the northwest and calved here, whereas in the southeast there was a normal melting-off. Towards the northwest the thickness of the ice-cap has diminished rapidly, whereas the rate of decrease towards the southeast has been slow and gradual.

In the table below will be found grouped together the values of the *Tapes*-line gradient in Scandinavia-Balticum and the gradients of the *e*-line in Greenland. The gradients for the first areas have been worked out from the isobase map fig. 74 in Tanner (1930). We have then only considered those parts of the *Tapes*-line situated 20 metres above sea-level.

The Gradient of the *Tapes*-line in metres per kilometre in the Scandinavian-Baltic area of uplift.

Western area		Eastern area	
Oslo—Southland	0.21	East-Finnmark	0.18
Westland	0.26	Kola	0.13
Northland	0.27	Carelia	0.14
Troms	0.25	The Baltic	0.16
West-Finnmark	0.21	West-Sweden	0.20

The gradient of the *e*-line in metres per kilometres on Greenland.

Eastern area		Western area	
Southeast-Greenland	0.127	Julianehaab	0.076
		Disco area	0.093

The proper comparative value is the normal gradient of the west coast of Norway (The „Westland“) where the gradient amounts to 0.26 metre per kilometre. In Southeast-Greenland it is 0.127 metre per kilometre. The gradient of the *Tapes*-line is thus roughly twice as high as the *e*-line gradient. On West Greenland the gradients are also considerably less than the corresponding ones in the southeast of the Scandinavian-Baltic area.

The area of the ice-cap during the last glacial age was about the same in both areas (abt. 3 mill. sq. kilometres), and one is therefore — to a certain extent — permitted to compare the gradients directly. The fact that the gradients are so much smaller in Greenland than in Scandinavia undoubtedly seems to show that Greenland now is more submerged than Scandinavia.

The Depression of Greenland in Sub-atlantic Time.

The changes in level of Greenland after the time of the *e*-line (*Tapes*-line time) can be followed numerically by means of the height of the shore-lines in Greenland and Scandinavia. The procedure will be clear from an example, e. g. the *e*-line at the height of 28 metres above sea-level, being the level of this shore-line at Godhavn. According to the formula computed previously:

$$b = e \cdot 0.365 + 1.2$$

is the corresponding height of the *b*-line 11.4 metres, and the vertical distance between the two lines thus 16.6 metres.

In Norway the difference in height between the *Tapes*- and *Trivia*-lines will be 16.6 metres, when the first line is situated at 48.1 metres, and the second 31.5 metres above sea-level. This has been computed from a preliminary formula worked out by the author:

$$T_1 = T \cdot 0.743 - 4.2$$

where T_1 is the height of the *Trivia*-line, and T the height of the *Tapes*-line above sea-level in metres. It is then assumed that Godhavn is submerged $48.1 - 28 = 20.1$ metres, or $31.5 - 11.4 = 20.1$ metres more then the corresponding point in Norway.

What this numerical computation involves can be explained in the following way: By locating two points, one in Greenland and one in Scandinavia where the difference between simultaneous lines is the same, one has also found the two points where the proper motion of the two lands is identical in the period in question. The average speed at which the two points have been raised in the time interval (between the formation of the two lines) is the same at both points, irrespective of a change in the level of the sea during the same period. The normal upheaval of Scandinavia goes on after *Trivia*-time, and as a result of the proper motion of the land, and the change in level of the sea, the present state is reached. It is now possible to compute the final result of the motion proper of Greenland if the upheavel continued in the same manner as it did in Scandinavia.

The computation shows that the motion proper of Greenland has not continued since the time of the *b*-line, as in Scandinavia. The conditions have changed in the interval, causing the land at Godhavn to lie 20.1 metres deeper than it would have done if the normal rise of the land had taken place. The reasons for these changed conditions are in all probability the increased ice-load of Greenland after *b*-line time. This increased weight must bear some relation to the change in climate for the worse, which occurred at the passage from sub-boreal to sub-atlantic time.

As previously maintained by the present author (1927), there is every reason to believe that the ice-sheet was considerably less towards the close of the warm sub-boreal period than it is to-day when the climate is colder. At any rate, in Scandinavia the sub-boreal period was also rather dry, whereas the time that followed was moist. As a result of the sub-atlantic cold, and possibly also more moist, climate the ice-cap of Greenland increased in extent and thickness. That the glaciers have considerably increased is also supported by certain facts. Thus A. G. Nathorst (vide A. E. Nordenskiöld 1885, pp. 327—328) found turf just in front of and below a glacier in the extreme arctic Cape York area. As maintained by the author in 1927 it is probable that it is this increased weight of the ice-cap which is the cause of the recent subsidence of Greenland and Spitsbergen.

The colder sub-atlantic climate occurred during the last part of the period of land upheaval in Scandinavia, when the shore-line at Oslo was situated about 10 metres or a little less above sea-level.

We may therefore assume that the increased weight of ice in Greenland caused the last part of the normal rise here to stop so that it never occurred, and the ice-cap has then depressed the land. It is possible to present these considerations numerically, and the 20.1 metres at Godhavn, representing the amount by which the land is lying too deep, may be split up into two components. According to Gunnar Holmsen (1920) the change of climate occurred when the water level was situated 7.3 metres above sea-level in the Oslo tract. This statement will be used in the computation below. The position of the line of the climatic change relative to the *Tapes*-line is given in the formula

$$x = T \cdot 0.0938 + 0.8$$

where x represents the height of the line of the climatic change, and T the height of the *Tapes*-line in metres above sea-level. If $T = 48.1$ metres (corresponding to $e = 28$ metres) we find a value for x of 5.3 metres.

As a first approximation we may assume that this value represents the last remnant of the elevation that did not occur in Greenland. The actual subsidence at Godhavn should then amount to $20.1 - 5.3 = 14.8$ metres. According to Gams and Nordhagen it is assumed that the change in climate took place about 850 B. C. If the subsidence of the land commenced about that time we get a sinking of 14.8 metres in 2750 years, or on the average 0.54 metres in the century.

The undoubtedly best measurements of the recent subsidence of Greenland are from Godhavn. which have been used above as a numerical example. F. Froda (1925) levelled here from a bench mark to 13 points on the *Balanus*-line, and found for the period 1897—1923 an average subsidence of 0.15 metres, corresponding to 0.58 metres in a century. This figure agrees exceedingly well with the computed value: 0.54 metres.

A less exact determination of the subsidence has been carried out by K. J. V. Steenstrup (1905) at Ivigtut. Using photographs of the seaweed-line Steenstrup recorded a sinking of 0.25 metres in the years from 1876 to 1904, corresponding to a subsidence of 0.89 metres in a century. To judge from the run of the isobases the *e*-line at Ivigtut lies about 26 metres above sea-level, and the computed value of the subsidence will then amount to 0.45 metres per century. The agreement is not a very close one, but the measurement of the sinking is without doubt much more inaccurate than in the first case.

The computations above are based upon certain simplifications which should be explained in a few words. The subsidence is assumed to commence contemporaneously with the change of climate, whereas, of course, it takes some time before the ice-cap has increased to such an extent as to make itself isostatically felt. The sinking of the land must therefore be somewhat retarded in relation to the change of climate. This factor will tend to increase the computed average speed of the sinking. On the other hand, P. A. Øyen has assumed a somewhat colder climate already at the time of the lower *Ostrea*-line, at a level which at Oslo is situated 11 metres above sea-level. This factor will diminish the computed speed of the sinking. The computations carried out above are undoubtedly somewhat simple, and must necessarily be so, but the excellent agreement with the observed facts certainly seems to show that we are on the right path.

Some further Consequences.

For the benefit of future investigations of the Greenland shorelines and the isostasy there, it is of interest to follow up the consequences of the views put forward above. In the first instance, reference may be made to fig. 13, representing a normal diagram of some of the shore-lines in Scandinavia. The *Portlandia*-line, or the *M*-line of Grønlie has been used as a reference line and is plotted in a 45° position. The other lines have been plotted relatively to the *Portlandia*-line. The position of the *Littorina*- and *Pholas*-line must be regarded as temporary. The *Mactra-* and *Tapes*-line have been plotted according to the formulas previously given by the author (1930 a and b).

$$F = M \cdot 0.560 - 14.4 \text{ and}$$
$$T = M \cdot 0.322 + 3.3$$

where *F*, *T* and *M* represent the height of the *Mactra-*, *Tapes-* and *Portlandia*-line above sea-level in metres. The last formula is in close agreement with the one given by Nansen (1922). The two lines inter-

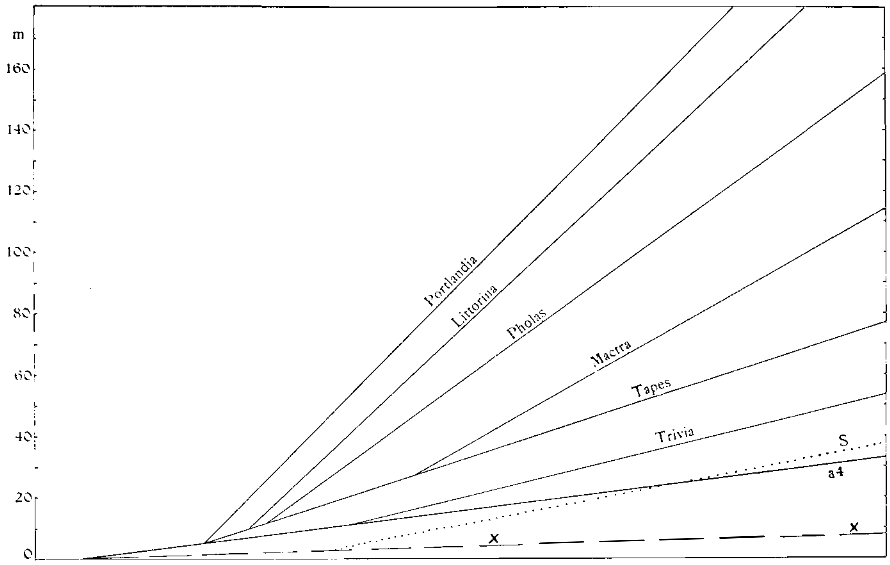

Fig. 13. Shore-line spectrum from Scandinavia with some of the most prominent lines. On this diagram the present sea-level in Greenland (S) is plotted from its position relative to the *Tapes-* and *Trivia*-line.

sect at 27.3 metres, as previously proved by the author[1]. The *Trivia*-line (T_1) and the a_4-line have been plotted according to the formula

$$T_1 = M \cdot 0.239 - 1.7$$
$$a_4 = M \cdot 0.123 + 4.5$$

the latter line is correlated with the a_4-line of Tanner, No. 3 line at Folla of Grønlie, and with the inner part of the T_1-line of Grønlie in Ofoten. The broken line at the foot of the diagram does not represent an incised shore-line, but the climatic change at the passage from sub-

[1] That a point of intersection does exist at about this height was found almost simultaneously by V. Tanner (Geologists meeting in Copenhagen June and July 1928, see Tanner (1930, p. 258)) and by the present author March 28, 1928 in a University paper (Vogt 1930 b, p. 11—16). Tanner dealt with the *Tapes*-line and the *Clypeus*-line, the intersection point of which he found at the altitude of 27.64 metres, whereas the author used the intersection point between the *Tapes-* and *Mactra*-line. Both authors applied similar graphs.

boreal to sub-atlantic time. The line has been plotted according to the formula

$$x = M \cdot 0.0302 + 1.1\,.$$

On this normal diagram from Scandinavia the present sea-level on Greenland has been projected. The starting point is the fact that the *e*- and *b*-line on Greenland is contemporaneous with the *Tapes*- and *Trivia*-line in Norway. Otherwise we may refer to the last chapter. The stippled line *S* in fig. 13 indicates the present level of the sea in Greenland, projected on the Scandinavian diagram. For Greenland *S* represents the zero level, whereas the *Trivia*- and *Tapes*-line corresponds to the *b*- and *e*-line respectively.

In the diagram the *S*-line has been plotted according to the formula

$$S = M \cdot 0.192 - 6.5\,.$$

On this diagram the *S*-line occupies the position it would if Greenland had completed its upheaval in the same way as has Scandinavia. It will be seen that the *S*-line intersects the abscissa considerably farther to the right than the *Tapes*-line and *Trivia*-line (or the *e*-line and *b*-line). This seems a startling feature. It means that the area of the sub-atlantic subsidence had a much smaller diameter than the subsidence area during the last ice age. This is, of course, only what must be expected, as the ice-cap of the last ice age had a much larger extent than the present ice-sheet.

The intersection point between the *S*-line and the *x*-line can be regarded as the zero-isobase of the sub-atlantic subsidence. It is computed to be situated at an *e*-line of 16 metres, *i. e.* a short distance off the coast (cf. fig. 12). At Cape Farvel it touches the coast, and according to the computation the coast-line should then be stationary here.

e-line heights in metre	Calculated subsidence of Greenland in metres per century
16.0	0
20	0.18
25	0.40
30	0.63
35	0.85
40	1.08

In the table above is given the computed subsidence for various values of the height of the *e*-line. It will be seen that the subsidence increases very rapidly from the coast and landwards. Whereas the height of the *e*-line is doubled from 20 to 40 metres, the amount of subsidence is increased six times in the same distance, from 0.18 to

1.08 metres in the century. In future investigations of the subsidence in Greenland it is well to bear this peculiarity in mind.

In fig. 14 some of the particular shore-line measurements in Greenland have been plotted in a diagram corresponding to fig. 13. The measurements which have been considered are from Southeast-Greenland,

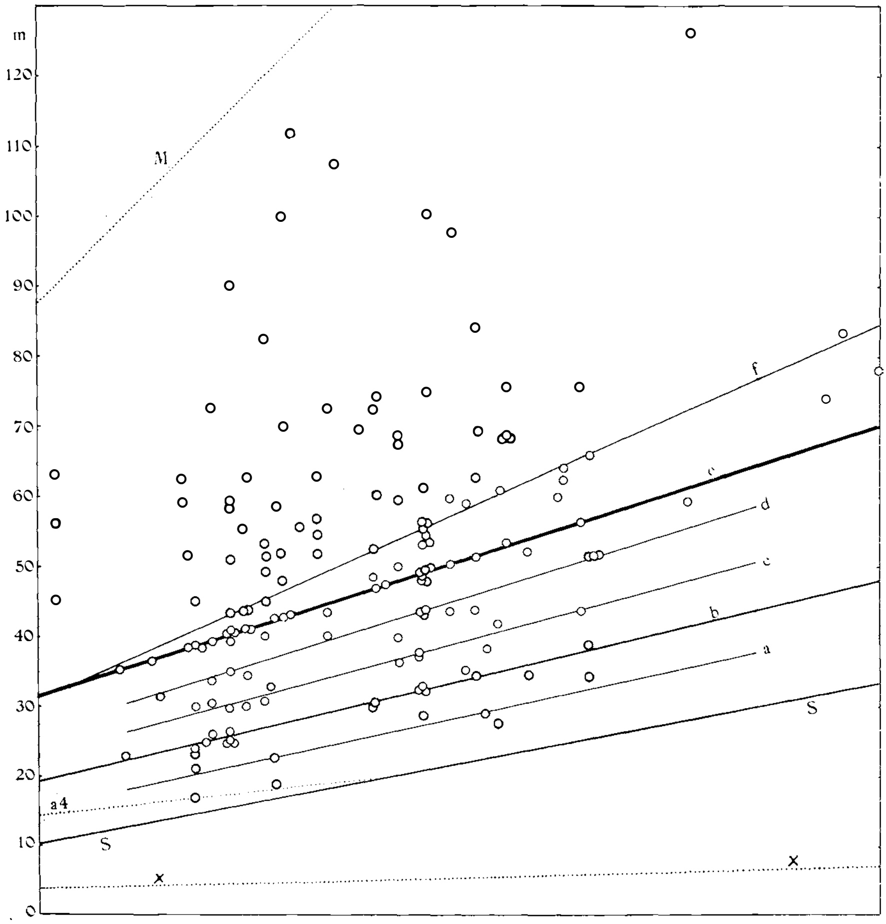

Fig. 14. Shore-line diagram with the measurements from Southeast-Greenland, Julianehaab with Arsuk and the Disco areas, plotted in the right part of the diagram Fig. 13. S—S = the present sea-level in Greenland plotted from its position relative to the *Tapes*- and *Trivia*-line in Norway; a—f = the lowermost raised shore-lines in Greenland; M and a_4 = The *Portlandia*-line, and the a_4-line of Tanner in Norway; x—x = the climatic change between sub-boreal and sub-atlantic time in Norway.

Julianehaab with the Arsuk tract, and from the region of Disco Is. Some higher shore-line values have not been included. Of shore-lines above the *e*-line, it is hardly possible to identify other than the lowermost — here marked *f* — with any degree of certainty. This line seems to intersect the *e*-line in the same way as the *Mactra*-line cuts the

Tapes-line in Scandinavia, but this must be corroborated by future observations.

From figs. 13 and 14 it will be seen that the *S*-line has a stronger inclination than the a_4-line which it intersects. The consequence of this feature is that it may happen that the lowermost shore-line in the coastal regions of Greenland may have a gradient "the wrong way": the shore-line rises towards the sea, instead of landwards. This most extraordinary consequence of the sub-atlantic subsidence should also be remembered in future work here. A region particularly well suited to such an investigation is the Cape Farvel area.

As will be understood the above is the consequence of the zero-isobase of the sub-atlantic depression area being situated so much nearer the coast than the zero-isobase of the depression of the last ice age. The diameter of the first area is so much less than that of the former, and the lowest shore-lines of the subsidence will then be subject to a stronger sub-atlantic depression in the central than in the marginal parts.

Trondheim in December 1932.

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