A DETERMINATION OF THE SUBSIDENCE OF THE LAND AT ANGMAGSSALIK

BY

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WITH 3 FIGURES IN THE TEXT

Both on the east coast and on the west coast of Greenland Dr. THERKEL MATHIASSEN and RICHARD BØGVAD have found a large number of ruins of houses which at flood-tide are in part under water, a fact which shows that in modern times a sinking of Greenland is taking place. In the case of the west coast F. FRODA and J. EGEDAL have made calculations of the magnitude of the subsidence, whereas on the east coast no measurements have been made so far which can give any information how fast the land is sinking there.

The failure to make any actual determination of the subsidence of the land on the east coast of Greenland so far, is due to the fact that the exploration of this part of Greenland did not start until the latter part of the 19th century. One of the first expeditions reaching the Angmagssalik district was "The East Greenland Expedition" 1883—85 under the leadership of Lieutenants of the Royal Navy (as they then were) G. F. HOLM and T. V. GARDE. During the wintering of the expedition at Angmagssalik 1884—85 a number of tidal observations were made in the spring of 1885. As these tidal observations were made with great accuracy, it was possible on the basis of them to obtain a determination of the presumed subsidence in this place by a repetition of the tidal observations. In order, however, to use the observations from 1885 the fixed point to which these observations were referred had to be found.

Description of the Places of Tidal Observations in 1885 and 1950.

In 1884—85 the Gustav Holm expedition did not winter in the place where the present colony Angmagssalik is situated, but on a peninsula named Tasîssârssik kitdleq, often called "Gustav Holms Ø" (65°37′ N., 37°24′ W.). This peninsula is situated 11 km. E.N.E. of the colony Angmagssalik on the northwestern side of the mouth of Angmagssalik Fjord. The peninsula is marked with a cairn (A) about 2 m high, which in 1885 was erected on its uppermost top (see fig. 1 a). Furthermore, in 1943 a tall wooden sea-mark painted red was erected near the highest point of the peninsula a little south of the cairn.

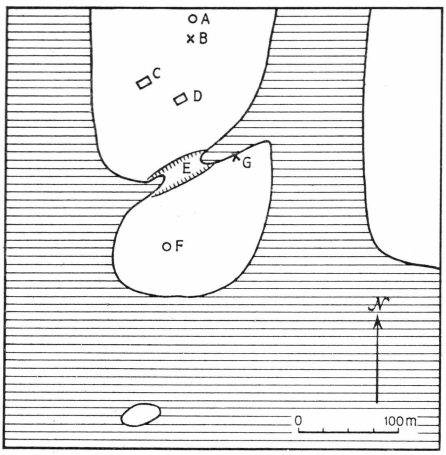

Fig. 1 a.

The southernmost part of Gustav Holms Ø.

A Cairn at the uppermost top of the peninsula.
B Sea-mark.
C Present house.
D Ruin of old winterhouse.
E Cleft.
F Old fixed point below cairn.
G New fixed point and station of 1950.

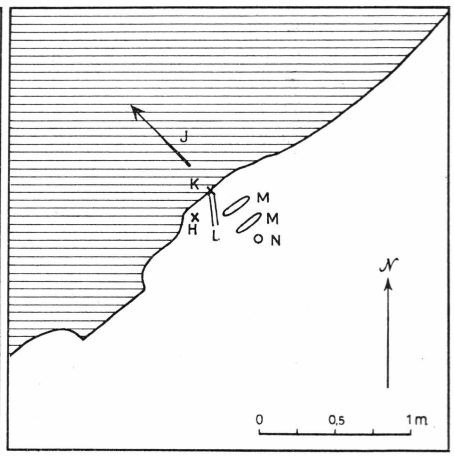

Fig. 1 b.

Situation of new fixed point and station of 1950.

H New fixed point.
J Direction towards sea-mark.
K Zero-point of station.
L White stripe in rock.
M Faint natural steps in rock.
N Cairn marking station of 1950.

The southern part of the peninsula is separated from the rest of it by a cleft (E) 5—10 m deep. This cleft is continued towards the east in a small rather deep creek. The tidal observations were in 1885 and 1950 made on the southernmost part of the peninsula thus cut off. It was not possible to find the exact place of the tidal observations in 1885, as it was not marked in any way. These observations, however, were referred to a fixed point (F) placed on the uppermost point of the above-mentioned southern part of the peninsula, the difference in height between the zero-point of the observations and the fixed point having been measured in 1885. In his diary on May 13th, 1885, GUSTAV HOLM described the fixed point as follows:

"Levelled to the top of the peninsula situated in true S.S.W. of the house. The zero-point of the tidal observations was used as a starting-point. Carved a cross on the uppermost top and cast some lead into the centre of the cross."

By examinations at the place in the summer of 1949 the fixed point was found, although with some difficulty. The carved cross was easily recognizable, but the lead cast into the centre of the cross had

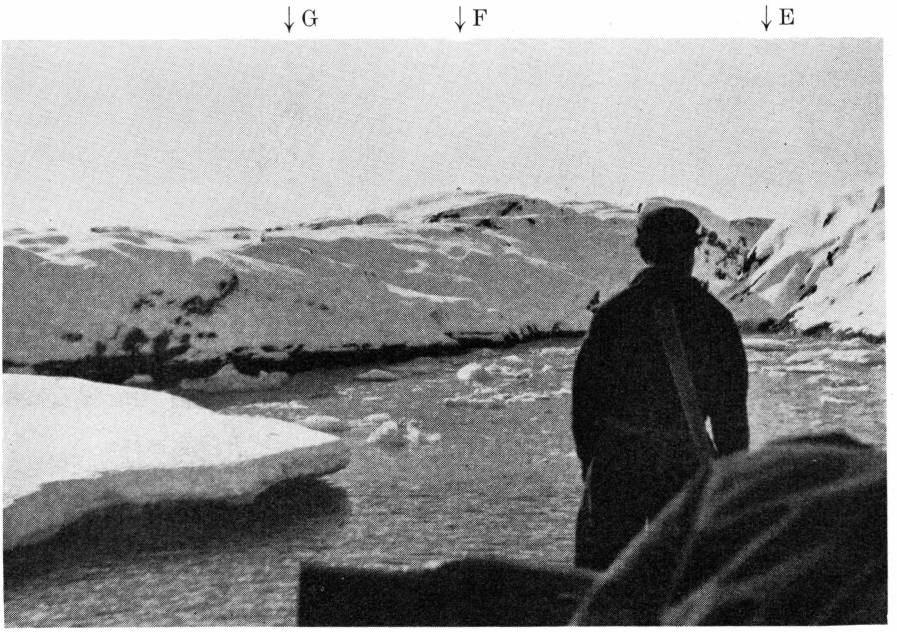

Fig. 2. Southernmost part of Gustav Holms Ø as seen from the creek towards the south.
The arrow E points towards the cleft (E).
The arrow F points towards the cairn (F) covering the old fixed point on the highest point of the south end of the peninsula.
The arrow G points towards the new fixed point and the station (the cairn N now found here had not yet been erected, when the photo was taken).

disappeared and instead there was a hole about 2 cm deep. In order to find the fixed point more easily again later on, a cairn about $\frac{1}{2}$ m in height (F) was on this occasion erected above it.

At another visit to the place on October 4th, 1949, another place of measuring (G) was chosen. The small creek found in continuation of the cleft (E), must be considered suitable for the performance of tidal observations, as closely east of it there is a small island which protects the creek from the heaviest sea. About 20 m east of the cleft there is on the southern side of the creek a wall of rock, which at a breadth of about one metre is completely vertical and 2.8 m in height from the bottom to the top, so that the water never retires from it, but still at high water may rise somewhat above it. The rock bends off abruptly above, and its surface is nearly horizontal on the outmost $\frac{1}{3}$ m.

This wall of rock was chosen as station. To mark this, a hole about 2 cm deep carved through by a cross about 5 cm broad was carved on the nearly horizontal surface of the rock near the edge to function as a new fixed point (H) (see fig. 1 b). About 25 cm east of this new fixed

point a white stripe in the rock (L) pass over its edge (seen most easily when the rock is wet). As the edge of the rock is very sharp, exactly this place might be used as zero-point (K) of tidal observations.

In order to find this station (K) and thus the new fixed point (H) more easily, another cairn (N) (about $\frac{1}{2}$ m high) was built in 1950 immediately above the station, about 2 metres behind it. The station and the fixed point used at the measurements in 1950 then are found where the line of sight (J) from the last-mentioned cairn (N) to the red sea-mark (B) on the top of the peninsula cuts the edge of the rock on the southern side of the creek.

On October 4th, 1949, the following differences in level were measured:

From the old fixed point (F) to the new fixed point (H): F—H = 1181.3 $\pm$ 0.4 cm.

From the new fixed point (H) to the zero-point of the observations of 1950 (K): H—K = 16.6 $\pm$ 0.1 cm.

The Carrying Out of the Tidal Observations.

In the period of April 11th to May 16th, inclusive, 1885, a number of tidal observations at high and low water were made between 6 and 22 o'clock local time. The measurements, which were made by the later colony manager of Angmagssalik, JOHAN PETERSEN, were carried out as follows: the height of the water was measured direct by placing a rule vertically on a projection of rock under the water. With this projection as the zero-point a measurement of the height of the water was made every 10 minutes from about one hour before to one hour after flood- and ebb-tide. When the results afterwards were plotted in a diagram, it was possible, by tracing a curve through the points, with great accuracy to determine the highest and lowest waters and the exact time of these. (The tidal observations carried out by the same expedition at Nanortalik in 1883—85 were treated in the same way). (J. EGEDAL, p. 37).

In 1950 the tidal observations were made during the period August 8th—14th, inclusive. In order to obtain a large number of observations in a short time the height of the water was measured every full hour from 6 to 20 o'clock, inclusive, East Greenland time (GMT — 2 hours). The observations were made in the way that the vertical distance from the place on the edge of the rock where the white stripe passes it to the surface of the water was measured with a rule. The surface of the edge of the rock was used as the zero-point.

Calculation of the Mean Sea-Level.

The heights of the sea-level measured were first all of them reduced for air pressure, being referred to the pressure 760 mm (reduced to

45° lat.). The correction K for the air pressure P was calculated from the formula

$$K = (P - 760.0) \cdot 1.32 \text{ cm.}$$

As the observations in both periods were not carried out through all the 24 hours, it was not, on account of the harmonic constituents K_1, P_1, and O_1, possible to find the mean sea-level in each of the two periods simply by taking the mean value of the heights of the sea-level reduced for air-pressure.

If, on the other hand, the amplitude H and the phase-lag g or $\varkappa$ for all the most significant harmonic constituents of the tide are known, it is possible, as the time of observation is known for all observations, to calculate the height of the sea-level in relation to the mean sea-level in each single case. By subtracting this value from that observed and corrected for air-pressure it is possible for each of the two periods of observation to obtain a large number of determinations of the mean sea-level. If we take the mean value of these, we shall for each period get an accurate measure for the mean sea-level. As the observations in 1885 and 1950 were not made in the same season, the mean sea-level thus calculated must be corrected for the effect of the tidal constituents S_a and S_{sa}. If, finally, the corrected mean sea-levels are calculated for each of the periods 1885 and 1950 in relation to the old fixed point, it is possible by comparing these to obtain a direct determination of the presumed subsidence of the land during the intervening years.

Unfortunately there are not yet a sufficiently large number of tidal observations from this district for a calculation of the constants of the harmonic constituents, still less the seasonal changes. It was therefore necessary on the basis of the existing observations to determine the constants of the harmonic constituents in a special way. As the constants are known for a large number of Greenland stations (J. EGEDAL, p. 34), all these were entered on a map for each significant harmonic constituent, and from these maps it was possible by interpolation to determine the constants valid for the Angmagssalik district.

By using these values it appeared, however, that they were far from being correct, since, as was to be expected, particular conditions obtain in the Denmark Strait.

By changing the constants in a special way it proved possible to attain to a number of constants the values of which agreed, at any rate sufficiently, not only with the observations on "Gustav Holms Ø" in 1885 and 1950, but also with the observations made at the colony Angmagssalik.

The values found for the constants of the harmonic constituents are as follows:

	M_2	S_2	N_2	K_2	K_1	O_1	P_1
H cm	101	32	13.5	9	16	5	6
g°	145	187	135	187	100	47	100
$\varkappa^\circ$	128	172	117	172	93	38	93

At the calculation of the contribution of the various harmonic constituents to the height of the tide this formula was used:

$$f \cdot H \cdot \cos(E - g).$$

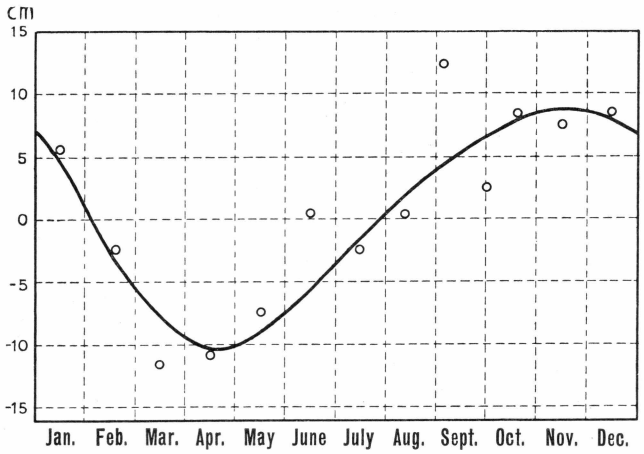

Fig. 3. Annual variation of mean sea-level at Julianehaab reduced for air-pressure.

f (which gives the correction of H for the long-periodic fluctuation of the amplitude) and E (an angle increasing with time) were for the observations of 1950 taken from The Admiralty Tide Tables, Part II, 1927. For the observations of 1885 the corresponding values were found by extrapolation of these tables.

As the observations of 1885 and 1950 were not made in the same season, it was, as mentioned above, necessary to correct the means of sea-level found for each observation period for the effect of the annual and semiannual terms S_a and S_{sa}. As the constants of these terms are not known for any place on the east coast of Greenland it was necessary to use the values valid for Julianehaab.

Fig. 3 shows a curve of the annual variation of the mean sea-level at Julianehaab. The points plotted in the diagram are the values calculated for the mean sea-level by J. EGEDAL (J. EGEDAL, p. 31) for certain periods (nearly the individual months) at Julianehaab 1933—34 and reduced for air-pressure. From the curve traced, the corrections for annual variation were read, but in order to examine whether too great errors were entered in the result by using these values also for the Angmagssalik district, the average correction for each of the periods $^{11}/_{4}$—$^{16}/_{5}$

and $^{8}/_{8}$—$^{14}/_{8}$ were plotted on a map together with the corresponding corrections calculated for the places on the northern Atlantic where they are known. It appeared that the corrections for S_a and S_{sa} at Angmagssalik must be of very nearly the same magnitude as those at Julianehaab.

Calculation of the Subsidence of the Land at Angmagssalik.

Observations $^{11}/_{4}$—$^{16}/_{5}$ 1885:

The mean of 69 readings corrected for air-pressure and tidal variations as determined from the seven harmonic constituents gave the following result:

Mean sea-level	160.0 ± 1.2 cm
Correction for annual variation	10.0 ± 2 cm.
Corrected mean sea-level	170.0
Difference in level between zero-point and old fixed point	1484.0 ± 0.5 cm
Height of old fixed point over corrected mean sea-level	1314.0 ± 2.4 cm

Observations $^{8}/_{8}$—$^{14}/_{8}$ 1950:

Mean of 92 readings corrected for air-pressure and tidal variations as determined from the seven harmonic constituents gave the following result:

Mean sea-level in relation to new fixed point	− 112.9 ± 0.7 cm
Correction for annual variation	− 2.0 ± 2 cm
Corrected mean sea-level	− 114.9
Difference in level between new and old fixed point	1181.3 ± 0.4 cm
Height of old fixed point over corrected mean sea-level	1296.2 ± 2.2 cm

Height of old fixed point over mean sea-level:

1885	1314.0 ± 2.4 cm
1950	1296.2 ± 2.2 cm
Subsidence of the land	17.8 ± 3.2 cm

The standard deviation stated must be considered with a certain reserve as it does not give any information about a possible systematic error.

As 65.29 years have passed between the observations the subsidence of the land in relation to the mean sea-level is

$$2.7 \pm 0.5 \text{ mm per year.}$$

It will be possible to calculate the subsidence of the land per year with considerably less uncertainty on the basis of the same observations when later a sufficient number of tidal observations from Angmagssalik made regularly will be available for a calculation of the exact constants for the harmonic constituents and particularly for a more accurate determination of the annual variation.

In 1940 J. EGEDAL, on the basis of tidal observations determined the subsidence of the land at Nanortalik in South Greenland at 3.9 mm per year (J. EGEDAL, p. 42).

The value here found for the subsidence of the land at Angmagssalik is also considerably lower than that for the subsidence of the west coast of Greenland, as F. FRODA in 1923 by a measurement of the movements of *balanus*-stripes calculated the subsidence at Godhavn at 5.8 mm per year (F. FRODA, p. 51).

I want to offer my best thanks to Mr. J. EGEDAL for good advice and guidance, which have been of invaluable importance for the accomplishment of the calculations. Furthermore, I want to thank Mr. H. U. BLINKENBERG, Meteorological Inspector in the Weather Service of the Greenland Department, for the readiness with which he placed personnel from the weather station of Angmagssalik at my disposal for the carrying out of the tidal observations. Finally I offer my cordial thanks to Mr. AAGE DAHL, Chief Assistant, and Mr. N. O. WESTERLUND, Telegraph Operator, who with interest and care made the readings, and to everybody at Angmagssalik who has contributed to the successful accomplishment of the work.

LITERATURE

BØGVAD, RICHARD: Quaternary Geological Observations etc. in South-East and South Greenland. Meddelelser om Grønland. Vol. 107, No. 3, p. 25. København 1940.

FRODA, F.: Some Observations made in North-Greenland 1923. Meddelelser om Grønland. Vol. 59, No. 4. København 1924.

GABEL-JØRGENSEN, C. C. A. & EGEDAL, J.: Tidal Observations made at Nanortalik and Julianehaab in 1932—34. Meddelelser om Grønland. Vol. 107, No. 2. København 1940.

HOLM, G. & GARDE, V.: Beretning om Konebaadsexpeditionen til Grønlands Østkyst 1883—85. Meddelelser om Grønland. Vol. 9, pp. 53—144 and p. 339. København 1889.

MATHIASSEN, THERKEL: Inugsuk. A Mediaeval Eskimo Settlement in Upernivik District, West Greenland. Meddelelser om Grønland. Vol. 77, No. 4. København 1930.

— Ancient Eskimo Settlements in the Kangâmiut Area. Meddelelser om Grønland. Vol. 91, No. 1. København 1931.

— Contribution to the Archaeology of Disko Bay. Meddelelser om Grønland. Vol. 93, Nr. 2. København 1934.

— The Former Eskimo Settlements on Frederik VI's Coast. Meddelelser om Grønland. Vol. 109, No. 2. København 1936.

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