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Some Considerations about Correlations between the West Greenland Stock of Cod and Environmental Factors

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The purpose of the present paper is to discuss whether it is possible to find so good correlations between the hydrographic conditions, especially the water temperature, and the cod year-classes, that we can hope to be able in the future to make predictions of the strength of the stock of cod based on the hydrographic conditions.

Correlation coefficients are used in the calculations mentioned below. I am aware that it is dangerous to conclude from significant correlation coefficients to causality but no doubt a more probable working hypothesis can be made when these correlations are taken into account than without them.

Long term variations in temperature and occurrence of cod in West Greenland Waters.

As it is well known the occurrence of cod in West Greenland waters has been periodic. Before about 1924 the cod was a rare fish at West Greenland, but from that time it occurred in greater and greater concentrations and extended its northern limit further and further northwards until it reached north of 72° in the late thirties and the fourties. In the fifties the northern limit has again moved southwards so that nearly no cod are caught north of the Disko Bay, and at that locality the cod fishery has decreased very much. Fig. 1, showing the yield of the Greenlanders' cod fishery, gives a good illustration of how suddenly the stock of cod has increased in the twenties.

Fig. 2 and 3 gives the variation of the surface temperature anomalies for West Greenland and South Greenland respectively (areas A-1 and B: Jens Smed, Ann. Biol.) presented as five years running means. The most pronounced feature in both curves is the strong and sudden increase in temperature in the twenties. In the late thirties the temperature decreased again and in the after-war years the temperature has been about 0.5 degree lower than its maximum value about 1930.

The increase of the stock of cod occurred nearly simultaneously with the rise in temperature and it seems reasonable to assume that it is the climatic improvement which has made it possible for the cod to extend its northern limit further northwards at West Greenland. The strong decrease of the cod fishery north of 69°N experienced in the last years may be a consequence of the drop of temperature after about 1940.

It is worth while to mention that a drop in temperature of only about 0.7°C from the value in 1946-50 would have brought the temperature back to the level for the years before 1920. We have possibly been very near a catastrophe for the West Greenland cod population, but fortunately the temperature now seems to be slightly increasing again.

It must be born in mind that in this presentation five years means of surface temperatures were used. The year to year fluctuations in the surface temperature are here to a high degree averaged out and it is probable that these averages fairly well represent the temperatures also in the deeper layers where the cod lives.

The fact that the cod appeared nearly simultaneously with the rise in temperature makes it probable that the cod which appeared at West Greenland in the middle twenties had migrated to this area. In 1924 Vedel Tåning, however, found good concentrations of cod fry off West Greenland. The 1924 year-class is possibly the first which has grown up in the West Greenland area.

Correlation coefficients between strength of cod year-classes and sea temperature.

If predictions of the strength of the cod stock should be made based on environmental factors, I think it will be necessary to make the predictions for the single year-classes. On the basis of information collected up to now, I will try to investigate if such a prediction with a reasonable small error is possible.

As comparative measure for the strength of year-classes the yield of the different year-classes in the Greenlanders' fishery up to 1946 is used (after Paul Hansen: "Studies on the Biology of the Cod in Greenlandic Waters". Rapp. Proc.-Verb. 123, p. 71). This is of course not a strictly quantitative measure, the two main errors are that the year-classes after 1934 were not yet outfished and that the fishing intensity has increased during recent years. These errors are working against each other and their combined effect is probably small, especially as only the year-classes between 1924 and 1937 are used in the correlation calculations.

It seems reasonable to assume that the cod is most sensitive to temperature changes during the larval stage. Consequently the correlation coefficient between strength of year-classes and the natural conditions during the larval stage of the respective year-class is calculated.

Table 1 gives the correlation coefficient between the cod year-classes from 1924 to 1937 and the surface anomalies in area A-1 for different months during the larval stage of the respective year-classes.

Table 1.

	April	May	June	July	August	September	April to August
r	0.14	0.24	0.16	0.32	0.23	0.04	0.24

None of these correlation coefficients are significant and they are so small that it is not worth while to calculate regression line and standard deviation.

The cod larvae are mainly distributed in the upper 50 metres and the reason for the low correlation coefficients could be that the surface temperature does not represent the temperature through this layer.

In June the cod larvae are mainly found over Fylla Bank and Lille Hellefiske Bank. The station in this area which has been worked most frequently in June is the international station r-2 over the shallow part of Fylla Bank, from which observations are available from the years 1924, 25, 26, 28, 34, 36, and 37. For these years, the temperature at 40 metres, the mean temperature surface to bottom (45 metres) and the surface temperature have been correlated with the cod year-classes. The result is shown in table 2.

Table 2.

June	t° 40 m	t° mean 0-45 m	t° surface	t°, 40 m corrected to 15/6
r	0.93	0.83	0.49	0.93

Both the correlation coefficient for the bottom temperature and that for the mean temperature are significant within the 0.02 significant level, but the correlation coefficient for the surface temperature is far from significant.

Most of these temperatures are based on single measurements taken at different dates. In ten years, observations are available for both June and July or twice in June. From these data the mean rise in temperature at 40 metres has been calculated to 0.029°C per day $\pm$ 0.029. By means of this value the temperatures at 40 metres at 15/6 have been calculated as well as the corresponding correlation coefficient, which, however, was found to be the same as the value found for the uncorrected temperatures.

The regression line for strength of cod year-classes on temperature were calculated for observed temperatures at 40 metres, corrected temperatures at 40 metres, and for mean temperatures 0-45 metres and are plotted in the diagrams figures 4 to 6. The standard deviation round the regression lines are estimated to 0.68, 0.64, and 1.08 million cod which should give a measure of the error with which predictions can be made from temperatures, if the correlation holds in the future.

Besides the temperature used in calculating the regression lines temperatures are available from the station on Fylla Bank from the years 1938, 1947, 49, 53, 54, 56, 57, 59, and 60. The temperatures are indicated as dotted lines on diagram 6. For 1950 a value interpolated from observations on May 17 and July 5 is indicated. Judging from the diagram the 47 year-class should have been very good and the 1950 relatively good, while the 38 and 49 year-classes should be without importance. This is in accordance with the fact that the 1947 and 1950 year-classes have, by far, been the most important in the last five years fishery at West Greenland. Recent years temperature observations show that the 1960, 57, 54, and 53 year-classes should be relatively good, the 59 year-class should be below mean, and the 56 year-class without any importance. The future will show if this prediction holds.

Correlations between number of cod larvae and temperatures in July.

In 1950 and 1952 to 59 four standard sections have been worked by the "Dana" in July in the area from Fylla Bank to Egedesminde with stramine hauls and temperature observations. From the four eastermost stramine stations in each section and from two stations between Lille and Store Hellefiske Bank the total number of cod larvae caught has been calculated. The values for the few missing stations have been interpolated using the average percentage of the number of larvae found at these stations. The reason why the results at the westermost stramine stations are not included is that the larvae found here probably never will be of benefit for the West Greenland cod population.

The table below shows the calculated numbers.

Year	1950	1952	1953	1954	1955	1956	1957	1958	1959
No. of cod larvae	554	90	474	78	64	37	1629	187	77

It is a question how well these numbers represent the total mass of cod larvae off West Greenland. The larvae are far from evenly distributed over the area. Thus in 1950, 319 larvae were caught on one station which is more than the half of all the 554 larvae caught on the 18 stations.

These numbers of larvae have been correlated with temperatures in July at surface, 20 metres and 40 metres over both Fylla Bank, Lille Hellefiske Bank, and Store Hellefiske Bank, but no significant correlations have been found. Unfortunately temperatures in June over Fylla Bank are only observed in five of these years. For these five years the number of larvae seems to be increasing with increasing mean temperature, surface to bottom, at Fylla Bank in June, but seems not to have correlation to the temperature here at 40 metres.

Correlation between year-class strength and barometric pressure differences.

As the cod eggs and fry are drifting with the currents the percentage of larvae which will contribute to the renewal of the West Greenland stock must, to some degree, depend upon the direction and velocity of the West Greenland Current. Off Fylla Bank this current separates into two branches, one branch following the Greenlandic shelf and continental slope northwards and another bending westwards towards Labrador. A great part of the cod larvae are carried away from Greenland by this westward branch and are no doubt lost for the Greenlandic stock of cod. This is clearly shown by our stramine hauls where big concentrations of larvae often are found as far west as 200 naut. miles from the coast at the Fylla Bank section.

It is reasonable to assume, that the relative strength of these two branches to some degree depends upon the onshore component of the wind off West Greenland. As measure of this wind component the difference in barometric pressure between Ivigtut at 61°N and Jacobshavn at 69°N is used. Monthly means of barometric pressure are published in the Danish "Meteorologisk Årbog" and the differences between these means and differences of mean April to June are correlated with the strength of cod year-classes for the years 1924 to 1937. The table below gives the result.

Month	March	April	May	June	July	Mean April to June
r	- 0.25	0.45	0.37	0.40	0.19	0.56

It is seen that from April, when most of the cod have spawned, the correlation coefficient is positive. None of the correlation coefficients are, however, significant to the 0.02 probability level. Consequently it is not possible from observations in this short series of years to draw conclusions about the influence of wind.

Correlations between surface temperature and temperatures in the layer where the cod is living.

It has been proposed to increase the number of surface temperature observations in the ICNAF area with environmental studies as purpose. Before such a program is started it would be reasonable to investigate if the surface temperature really represents the environment of the fish i. e. in this case the temperature where the cod is living.

In March, April, and May the cod is mainly found in the warm water of the Irminger Current at depth between 200 metres and 400 metres on the western slope of the Greenlandic banks. The number of hydrographic stations at this time and in this area is too small to allow a calculation of correlation coefficients between surface temperature and temperature in 200 and 400 metres but the stations show, that the warm Irminger water is overlayed by a quite different watertype of lower temperature and salinity so there is no reason to believe that the surface temperature will represent the temperature in the above mentioned depths with any reasonable accuracy.

In June, July, August, and September the cod is found over the shallow parts of the banks. Correlation coefficients between surface and bottom temperature (45 metres) have been calculated for Fylla Bank and are given below.

Month	June	July	August + September
No. of stations	21	23	12
r	0.77	0.51	0.35
σ regr.	0.62°	0.68°	0.56°
σ t_b	0.95°	0.77°	0.56°

In the table the standard deviations round the regression line of bottom temperature on surface temperature is given, as well as the standard deviation of the bottom temperatures.

It is seen that the error on the calculation of the bottom temperature from surface temperature is only slightly smaller than the variation in the bottom temperature, so such a calculation will be of no practical importance.

Conclusions.

Surface temperatures can, when averaged over sufficient many observations and over a number of years, give the main features of the long-term variations in an area, but such temperatures are hardly of much use in environmental studies, as they do not with sufficient accuracy represent the temperatures in the layer where the cod or their larvae live.

The bottom temperature in June over Fylla Bank and the mean temperature from surface to bottom in June at the same locality give high correlation coefficients with the cod year-classes, but it should be born in mind, that the calculations are based on a small number of observations. Nevertheless it seems reasonable to base future investigations on the hypothesis that temperature conditions during the larval stage has a major influence on the strength of the cod year-classes.

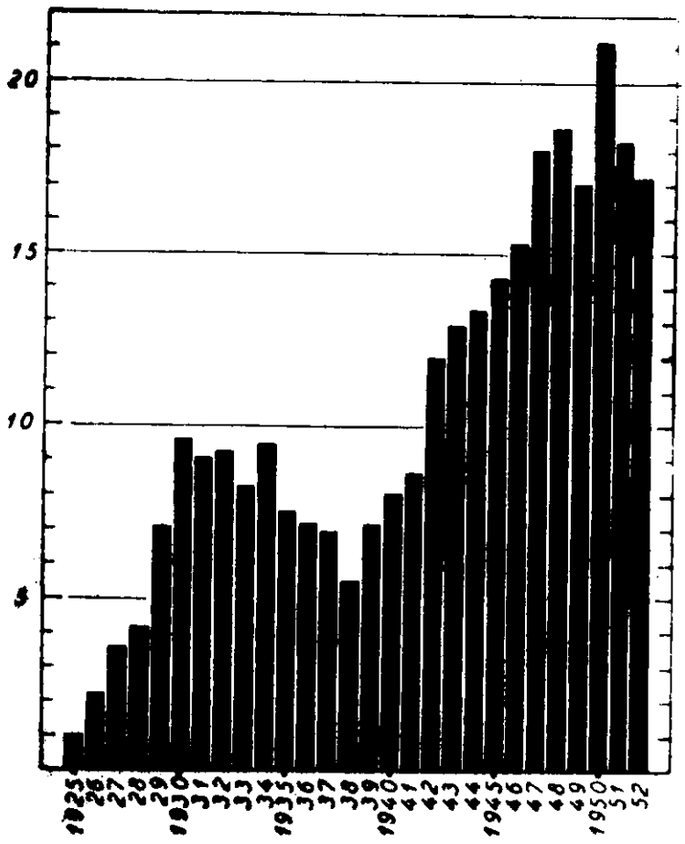

Figure 1. Yield of Greenlanders cod fishery 1925-1952.

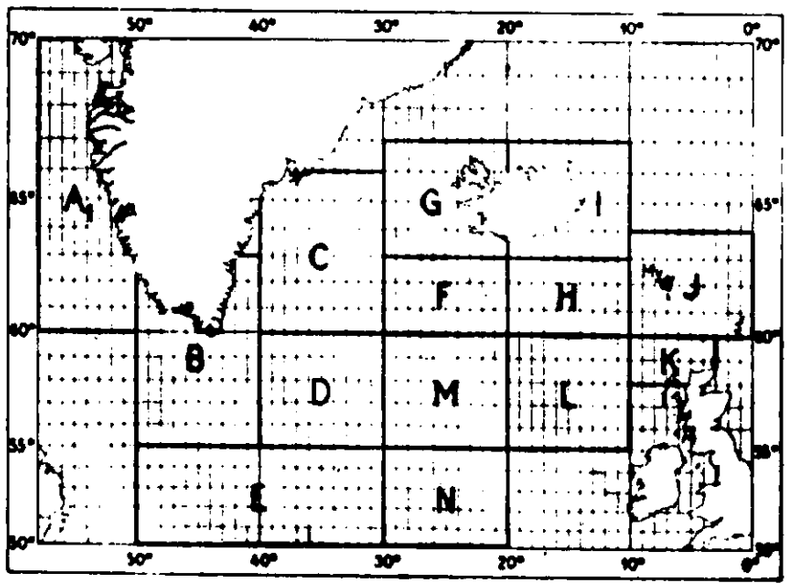

FIG. 2 a

Location of areas A_1 to N and of Station My.

Fig. 2. Area A_1 Mean April-September

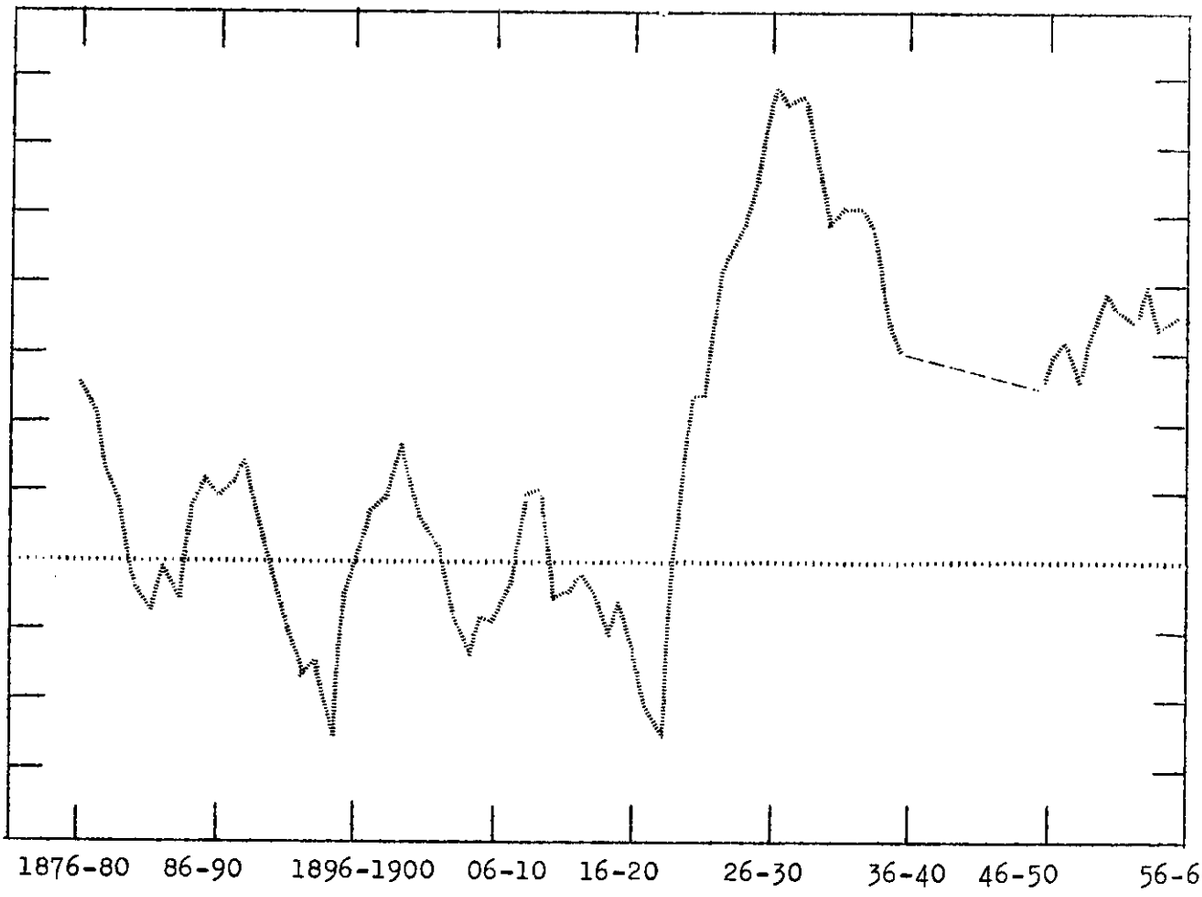

Fig. 3 Area B Mean April October

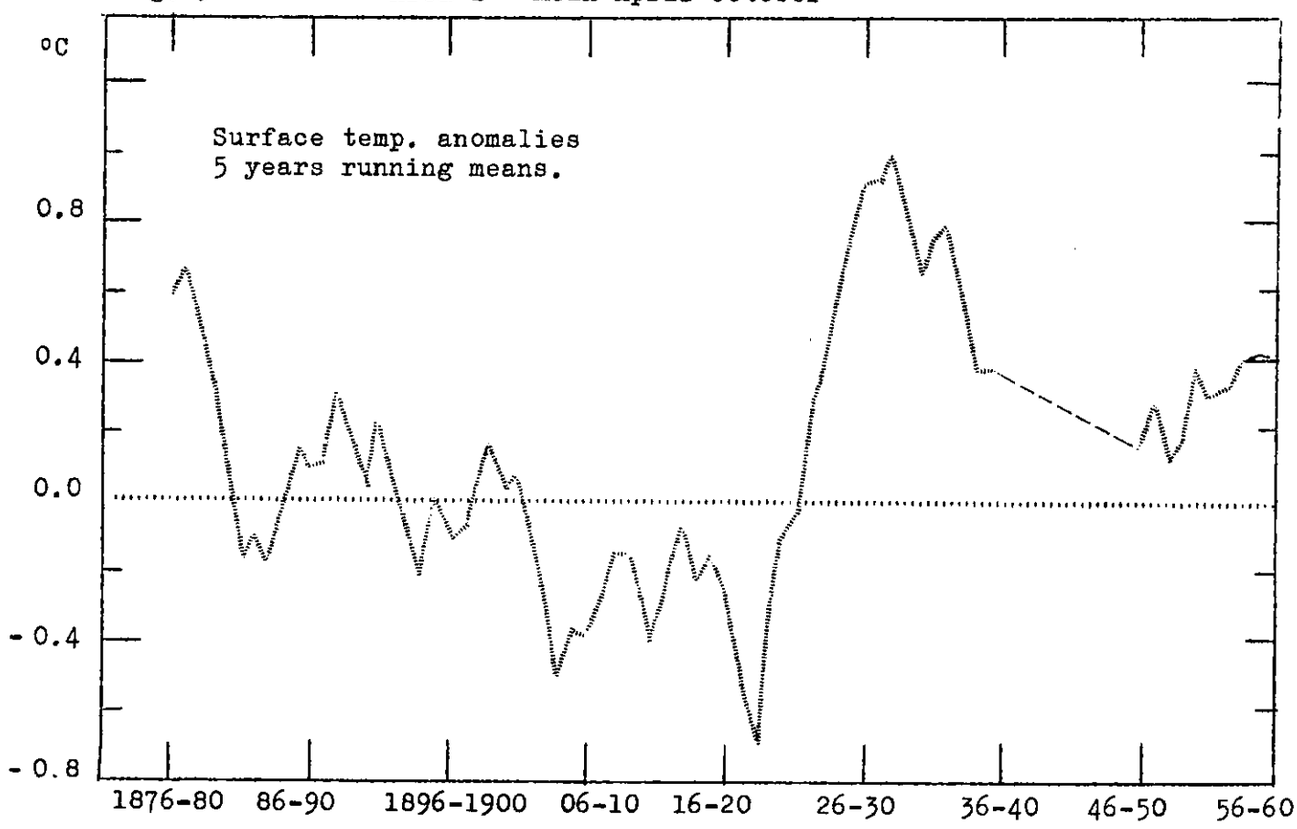

Fig. 4.

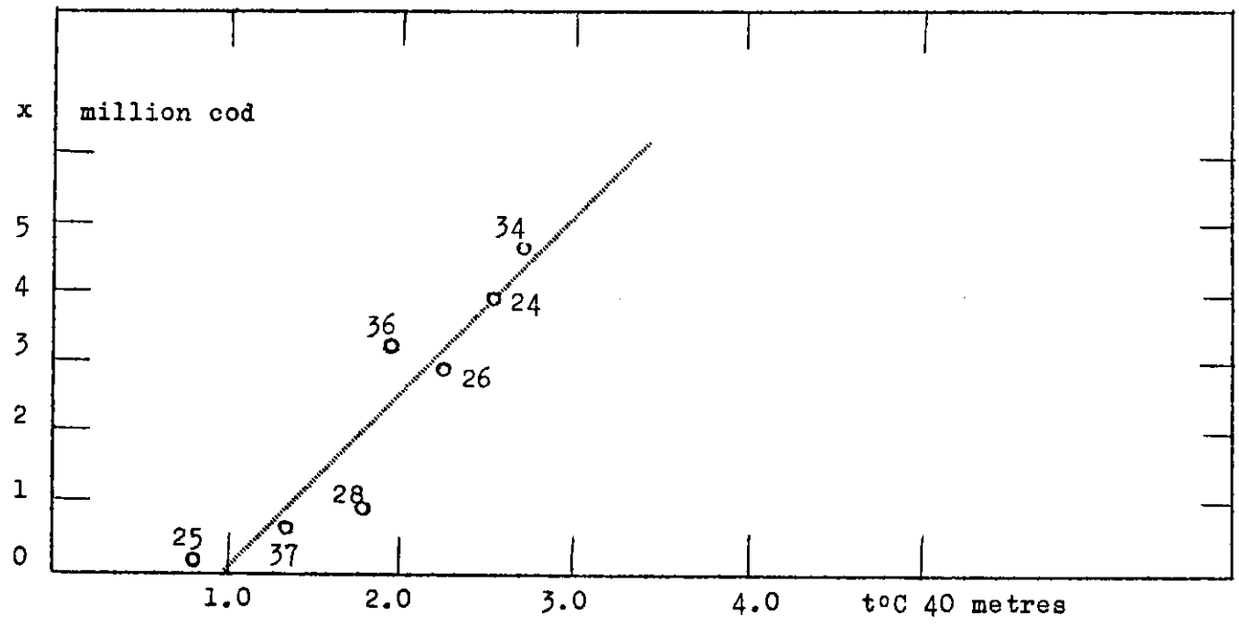

Fig. 5.

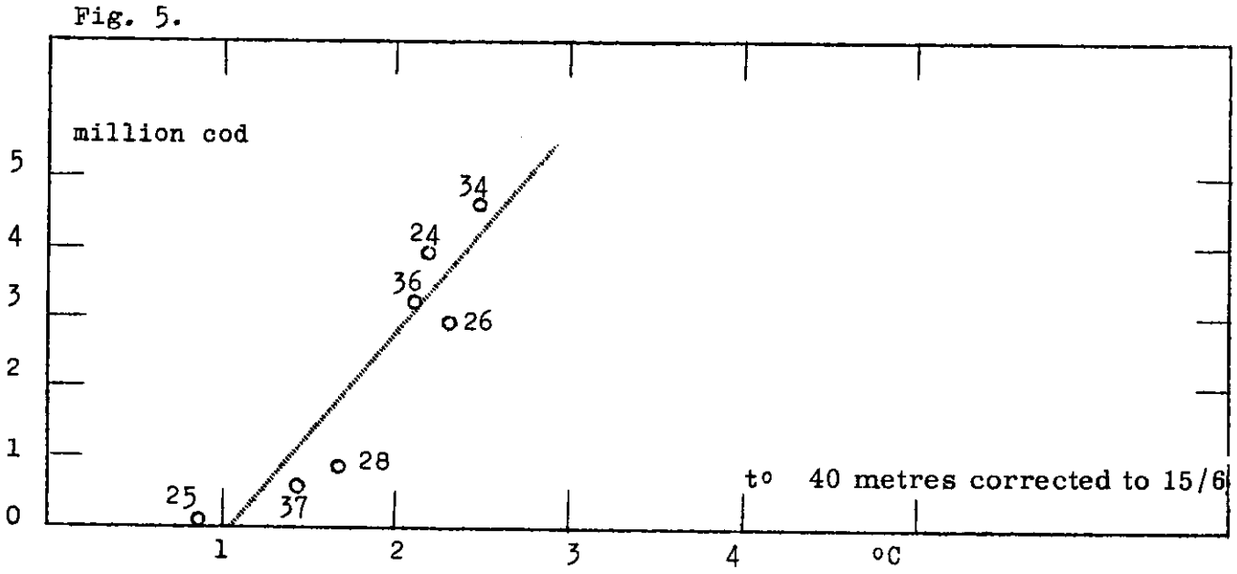

Fig 6.