SECTION

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G-1

A FIRST LOOK AT SOME WAVE AND WIND DATA FROM TRAWLERS

By

J.A. Ewing[1] and N. Hogben[1]

ABSTRACT

The paper presents some of the early results obtained from the analysis of wave and wind observations made by selected trawler skippers. It would be premature to draw any firm conclusions from the sample of data so far analysed but it is encouraging to find already a meaningful picture emerging from the data.

INTRODUCTION

Seakindliness is particularly important for trawlers. Model tests in waves can greatly help the designer to achieve good seagoing qualities but they must be coupled with knowledge of the sea conditions both average and extreme to be encountered in service. At present, knowledge of conditions in the northern fishing grounds where distant water trawlers operate is very inadequate. A scheme has therefore been organised (in collaboration with the White Fish Authority and the Ministry of Agriculture, Fisheries and Food) for collecting systematic sea data observations from selected trawler skippers. Accounts of this scheme and the preliminary studies made to explore the reliability and the practical problems and techniques of observation have been given in the references (Hogben and Chaplin, 1961; Hogben, 1962; Hogben, 1963). The present paper takes a first look at some of the observations which have meanwhile been collected from the selected trawler skippers. The analysis carried out of the data so far available was intended mainly to test analysis procedure and to examine various forms of presentation and interpretation. It has been thought worth recording however because already the outline of a useful picture of sea conditions is appearing.

THE ANALYSIS

The Observations

The trawler skippers who have kindly agreed to cooperate in this research have been supplied with guidance notes and accessories such as stop watches to help them in making the observations. The guidance notes and procedure recommended have been based on a study of the Marine Observer's Handbook and on the experience gained from the special visual observation trials (Hogben, 1962). The observations are recorded on data sheets using a "ticking" principle for ease of subsequent coding onto punched cards. A sample is shown (Fig. 1) and it will be seen that there is space for 15 sets of observations on each sheet.

Data processing

The punching of the cards is being carried out by the Combined Tabuluting Installation of the Stationery Office and each set of observations is punched on one card; the cards are being sorted using a machine in Mathematics Division, National Physical Laboratory. At the time of writing (June, 1963) there are about 1,100 punched cards recording observations mainly from four trawlers.

Choice of season and area

Each card bears the date, time and geographical position of observation and for convenience the cards are sorted (following the practice of the Meteorological Office) into months and classified according to the Marsden system of numbered 10 degree squares of sea area. For this preliminary analysis it was decided to choose those cards for the months of December, January and February and for the area shown in Fig. 2, which covers Marsden Squares 217, 218, 219, 251, 252,

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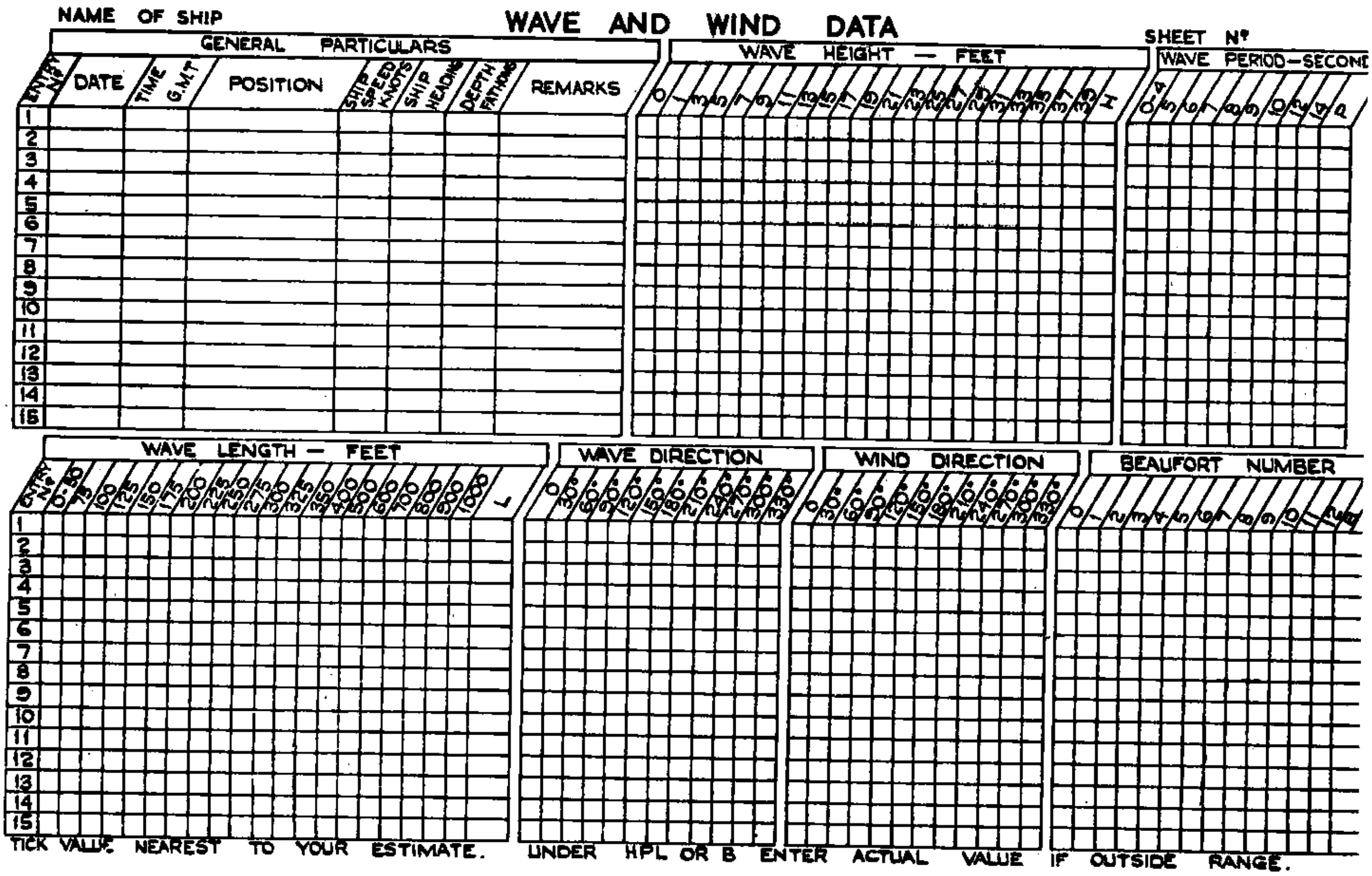

NAME OF SHIP

WAVE AND WIND DATA

SHEET Nº

GENERAL PARTICULARS

ENTRY Nº | DATE | TIME G.M.T | POSITION | SHIP SPEED KNOTS | SHIP HEADING | DEPTH FATHOMS | REMARKS

WAVE HEIGHT — FEET

0 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 H

WAVE PERIOD—SECONI

0-4 5 6 7 8 9 10 12 14 P

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

WAVE LENGTH — FEET

ENTRY Nº 0-50 75 100 125 150 175 200 225 250 275 300 325 350 400 500 600 700 800 900 1000 L

WAVE DIRECTION

0 30° 60° 90° 120° 150° 180° 210° 240° 270° 300° 330°

WIND DIRECTION

0 30° 60° 90° 120° 150° 180° 210° 240° 270° 300° 330°

BEAUFORT NUMBER

0 1 2 3 4 5 6 7 8 9 10 11 12 B

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

TICK VALUE NEAREST TO YOUR ESTIMATE. UNDER HPL OR B ENTER ACTUAL VALUE IF OUTSIDE RANGE.

FIG. 1.

285, 286 and 287. The number of cards satisfying these conditions was found to be 334; the subsequent sorting operations were carried out using this group of cards.

Tabular presentation of results

Tables 1, 2, 3 and 4 show the distributions of wave height/wave period, wave height/wave direction, wave/direction/wave period and wind direction/Beaufort Number respectively.

These four tables represent the basis for Fig. 2 and contain more information than is shown in this figure. In Tables 2, 3 and 4 the total number of observations is less than 334; this is because some entries on the data sheets did not have an observation of one of the two variables concerned.

Graphical presentation of results

In addition to tables of the results it is desirable to have a picture of wave and wind conditions occurring in various sea areas; Fig. 2 has been constructed with this in view.

The small graphs shown in Fig. 2 have been drawn using information given in Tables 1-4.

Graph (a) shows the 2-way cumulative frequency curves for wave height and wave period together with three wave period/wave direction roses.

Graph (b) gives information on the steepness of waves - the curves show the probability of exceeding a given wave height when the wave length is specified.

Graph (c) shows the Beaufort Number/wind direction rose. Below the rose is a small table giving the frequency of occurrence of various Beaufort Numbers for all wave directions.

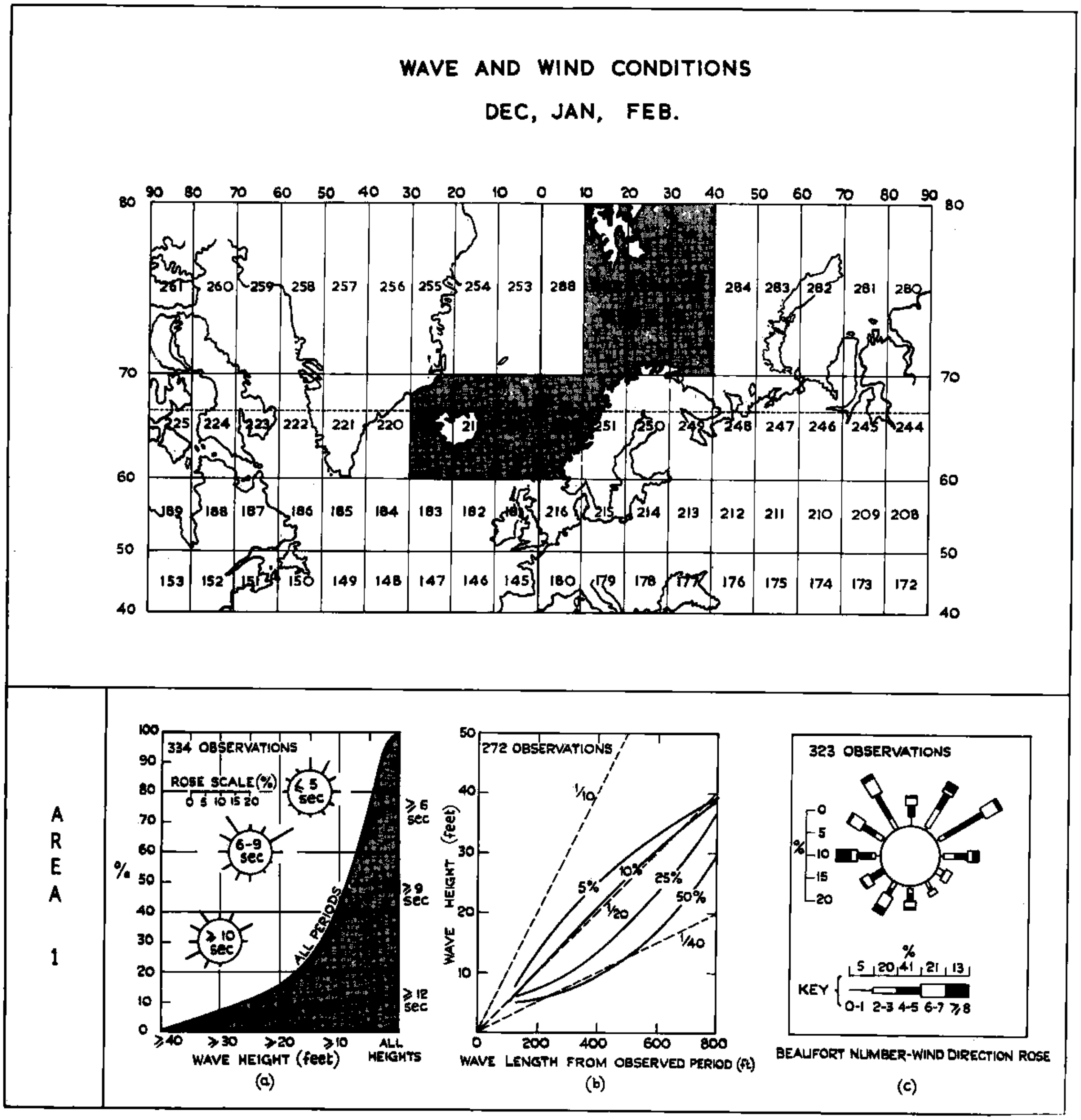
WAVE AND WIND CONDITIONS
DEC, JAN, FEB.
90 80 70 60 50 40 30 20 10 0 10 20 30 40 50 60 70 80 90
80
70
60
50
40
261 260 259 258 257 256 255 254 253 288 284 283 282 281 280
225 224 223 222 221 220 21 251 250 249 248 247 246 245 244
189 188 187 186 185 184 183 182 181 216 215 214 213 212 211 210 209 208
153 152 151 150 149 148 147 146 145 180 179 178 177 176 175 174 173 172
AREA 1
334 OBSERVATIONS
ROSE SCALE (%)
0 5 10 15 20
≤ 5 sec
6-9 sec
≥ 10 sec
ALL PERIODS
≥ 6 sec
≥ 9 sec
≥ 12 sec
%
100 90 80 70 60 50 40 30 20 10 0
≥40 ≥30 ≥20 ≥10 ALL HEIGHTS
WAVE HEIGHT (feet)
(a)
272 OBSERVATIONS
WAVE HEIGHT (feet)
50 40 30 20 10
1/10
5%
10%
1/20
25%
50%
1/40
0 200 400 600 800
WAVE LENGTH FROM OBSERVED PERIOD (ft)
(b)
323 OBSERVATIONS
%
0 5 10 15 20
KEY
%
5 20 41 21 13
0-1 2-3 4-5 6-7 ≥8
BEAUFORT NUMBER-WIND DIRECTION ROSE
(c)

FIG. 2

TABLE 1. WAVE PERIOD (SEC)

WAVE HEIGHT (FEET)	0-4	5	6	7	8	9	10	12	14	Totals
0(0.00m)	11									11
1(0.31m)	13	5		2		2				22
3(0.91m)	23	12	9	7	2					53
5(1.52m)	7	10	6	4	18	8	7			60
7(2.13m)		2	4	4	5	9	2	2		28
9(2.74m)			4	3	6	4	16	2		35
11(3.35m)				1	6	3	9	3		22
13(3.96m)					2	7	7	3		19
15(4.57m)			1		2	5	11	3	1	23
17(5.18m)					1	1	3			5
19(5.79m)				1	2	5		1		9
21(6.40m)					2	2	1			5
23(7.01m)					1		3	1		5
25(7.62m)						1	2	3		6
27(8.23m)			1				4	1		6
29(8.84m)						2				2
31(9.45m)							1			1
33(10.06m)								2		2
35(10.67m)							2	7		9
37(11.28m)							1	2		3
39(11.89m)									4	4
40(12.19m)								1	2	3
45(13.72m)									1	1
TOTALS	54	29	25	22	47	49	69	31	8	334

TABLE 2. WAVE DIRECTION (DEG)

WAVE HEIGHT (FEET)	000	030	060	090	120	150	180	210	240	270	300	330	Totals
0(0.00m)	8	1											9
1(0.31m)	1	2	2	5	2	2	1	1	2		3		21
3(0.91m)	3	9	7	8	3	2	3	2	1	2	5	6	51
5(1.52m)	1	10	15	3	2	3	2	1	3	4	4	10	58
7(2.13m)	3	3	6	2			1	5	3	2	1	2	28
9(2.74m)	2	2	7	2			1	1	6	4	7	3	35
11(3.35m)	3	1	7						6	1	1	3	22
13(3.96m)	2	1	4	2		1			1	1	2	5	19
15(4.57m)			2	4	1		1	1	5	2	1	6	23
17(5.18m)							1			1		3	5
19(5.79m)	1	1	1	1				1		2	2		9
21(6.40m)	1		1			1				1		1	5
23(7.01m)				1			1			2	1		5
25(7.62m)							1	1	1		3		6
27(8.23m)		1	1			1		1			1		5
29(8.84m)							1	1					2
31(9.45m)								1					1
33(10.06m)			1							1			2
35(10.67m)		1	1	1		1	1	2		1		1	9
37(11.28m)							1					2	3
39(11.89m)								2		2			4
40(12.19m)		2										1	3
45(13.72m)		1											1
TOTALS	25	35	55	29	8	11	15	20	28	26	31	43	326

TABLE 3. WAVE PERIOD (SEC)

WAVE DIRECTION (DEG)

	0-4	5	6	7	8	9	10	12	14	Totals
000	12	1		1	1	2	6	2		25
030	10	8	2	2		4	4	3	2	35
060	6	3	2	5	16	8	12	3		55
090	8	2	2	2	5	3	6	1		29
120	5	1	2							8
150	1	3	2		1	2	1	1		11
180		2	1	1	5	2	4			15
210	1		2	2	2	5	2	4	2	20
240	1		1	3		6	12	5		28
270	3	2	1	1	6	3	4	3	3	26
300	3	2	1	3	8	3	6	5		31
330	2	3	5	2	3	11	12	4	1	43
TOTALS	52	27	21	22	47	49	69	31	8	326

TABLE 4. BEAUFORT NUMBER

WIND DIRECTION (DEG)

	0	1	2	3	4	5	6	7	8	9	10	Totals
000	7		1		4	3	2	3	1			21
030	1	1	7	9	6	6	2	1	3	2	1	39
060		1	1	5	20	11	5	7	3			53
090		2	2	7	5	4	1	2	4	1		28
120			3	3	3			2				11
150			2	2	1	2	2	1	1			11
180		1	1	2	3	2	2	3	2			16
210			4	1	2	3	3	3	3	2	1	22
240					4	7	3	1	2			17
270		3	1	2	2	8	3	2	7	4		32
300		1	2	2	6	8	2	7	2			30
330				8	8	12	8	3	3	1		43
TOTALS	8	9	24	41	64	66	33	35	31	10	2	323

In almost all cases the wave and wind directions given in each entry of the data sheets were found to be the same. It was therefore not considered necessary to give roses of wave height/wave direction corresponding to Table 2 since the Beaufort Number/wind direction rose was available in graph (c), and also there was found to be good correlation between wave height and Beaufort Number (Fig. 3).

Study of the relations between wave height/Beaufort Number and wave/length/wave wave length calculated from wave period

A separate study was carried out to investigate the relationship between wave height/Beaufort Number and wave length/wave length calculated from wave period. All the cards available at the time were used and sorting operations were carried out. Tables 5 and 6 show the results.

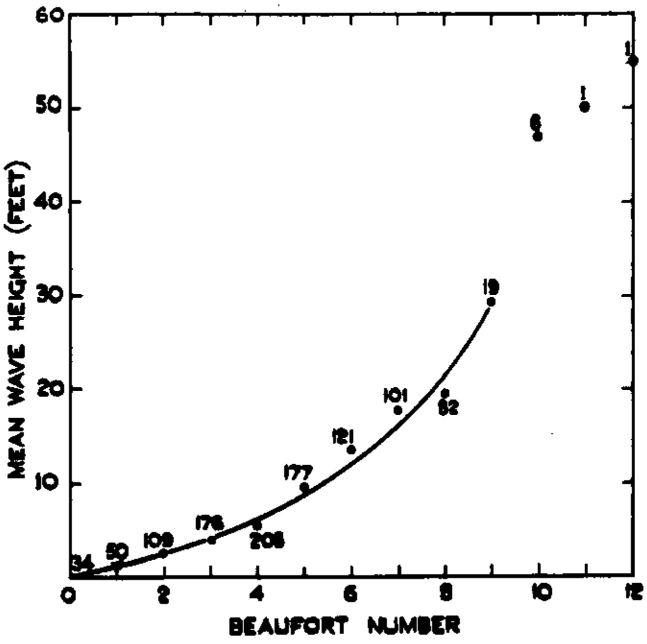

FIG. 3

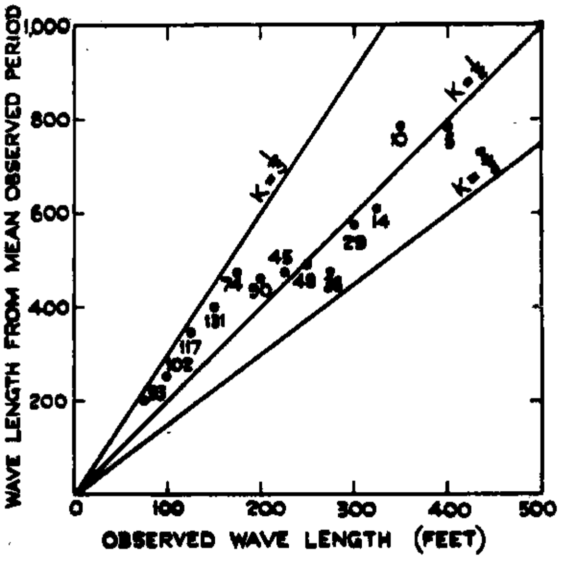

FIG. 4

Wave height/Beaufort Number

From Table 5 the mean wave height for each Beaufort Number was calculated and the results plotted in Fig. 3. The number adjacent to each point in Fig. 3 gives the number of observations at that Beaufort Number. A curve has been drawn through the points up to Beaufort 9.

This figure could be used to predict the wave height in a given area if the wind force is known.

Wave length/wave length calculated from wave period

Table 6 was used to determine the mean wave period corresponding to each observed wave length. The wave length corresponding to the mean wave period was then calculated using the classical formula

TABLE 5. BEAUFORT NUMBER

WAVE HEIGHT (FEET)	0	1	2	3	4	5	6	7	8	9	10	11	12	Totals
0(0.00m)	33	27	16	2	2	2		2						84
1(0.31m)		18	35	26	16		1	1	1					98
3(0.91m)		2	40	89	38	9	1	1						180
5(1.52m)	1	2	14	41	75	18	6	2	2					161
7(2.13m)			2	8	40	26	9	6	3					94
9(2.74m)			1	4	29	42	14	3	6					99
11(3.35m)				3	8	35	13	10	5					74
13(3.96m)						26	14	8	6					54
15(4.57m)			1	3		18	24	21	18	2				87
17(5.18m)		1				1	18	1	6					27
19(5.79m)							10	3	6	3				22
21(6.40m)							7	3	7	3				20
23(7.01m)							2	6		1				9
25(7.62m)							2	15	2					19
27(8.23m)								12	1					13
29(8.84m)								4	2					6
31(9.45m)								1	1					2
33(10.06m)								2	2					4
35(10.67m)									9	2				11
37(11.28m)									5					5
39(11.89m)										5	1			6
40(12.19m)										3				3
42(12.80m)											1			1
45(13.72m)											1			1
50(15.24m)											2	1		3
55(16.76m)											1		1	2
TOTALS	34	50	109	176	208	177	121	101	82	19	6	1	1	1085
Mean wave height (ft)	0	1.0	2.4	3.8	5.5	9.5	13.6	17.8	19.3	29.4	46.8	50	55	
Mean wave height (m)	0.00	0.31	0.73	1.16	1.68	2.90	4.15	5.43	5.88	8.96	14.26	15.24	16.76	

TABLE 6. WAVE PERIOD (SEC)

	0-4	5	6	7	8	9	10	12	14	Totals	Mean Period
50(15.2m)	200	47	16	7	4	1	5			280	-
75(22.9m)	2	42	21	6	9	6	6		1	93	6.3
100(30.5m)	3	8	32	22	23	7	5	2		102	7.0
125(38.1m)		3	20	17	26	25	22	4		117	8.2
150(45.7m)	1	2	5	24	28	13	46	10	2	131	8.8
175(53.3m)		1	3	13	16	5	14	14	8	74	9.6
200(61.0m)				5	27	14	29	11	4	90	9.5
225(68.6m)				1	15	8	11	8	2	45	9.6
250(76.2m)				1	7	18	10	11	1	48	9.8
275(83.8m)					2	17	13	3		35	9.6
300(91.4m)						5	13	11		29	10.6
325(99.1m)						2	5	7		14	10.9
350(106.7m)							2	4	4	10	12.4
400(121.9m)							1	2	2	5	12.4
500(152.4m)									1	1	14.0
TOTALS	206	103	97	96	157	121	182	87	25	1074	

$$\lambda = \frac{gT^2}{2\pi} \quad \text{where} \quad \lambda - \text{wave length}$$

$$T - \text{wave period}$$

Figure 4 shows the graph of wave length calculated from mean wave period against (observed) wave length. Also drawn are straight lines corresponding to the ratios of

$$K \equiv \frac{\text{observed wave length}}{\text{wave length from mean wave period}} = \frac{1}{3}, \frac{1}{2} \text{ and } \frac{2}{3}$$

It is seen that all the points lie between the two lines K = 1/3 and K = 2/3 and that at short wave lengths the points lie close to the line K = 1/3. This finding is in agreement with results shown in (Hogben, 1962).

The value of K depends on the nature of the wave spectrum. When the spectrum contains only a narrow band of frequencies and is also long-crested then K is close to unity. The theoretical value of K for a Neumann spectrum (modified by a factor $\cos^2\theta$ to give the angular dispersion of the waves) has been given (Pierson, 1954) as K = 2/3.

NOTE ON APPLICATIONS

An indication of the practical applications of data of this type has been given (Hogben, 1961) but it may be useful to include here some further comments. Data about sea conditions in the fishing grounds are of interest from many different points of view and no doubt will be of value to trawler operators as well as to designers. Here in Ship Division, NPL, they are to be used partly for planning the waves to be generated in the tank for seakeeping tests and partly as information to be applied to miscellaneous design problems and to be available for consulting purposes. The most immediate and clearcut application is to the planning of wave generation.

In the tank in Ship Division, tests studying such features as speed loss, motions and wetness can be conducted in regular or irregular waves as occasion demands and the irregular waves can be given any required spectral and statistical characteristics (Ewing, 1962). Thus for example it is possible to generate spectra which represent the sea likely to be generated by a given wind force (according to a Darbyshire, 1961; or Neumann, 1953; formulation). Spectra can also be set such that the estimates of mean height and period likely to be made by an observer will have any chosen values. Hence it is possible to generate wave spectra representing average or extreme conditions in a given area in terms of observed wave and wind data such as have been described.

CONCLUDING REMARKS

It would be premature to draw any elaborate or firm conclusions from the sample of data so far analysed. It is encouraging however to find already a meaningful picture emerging in a form which has direct application to the planning and interpretation of trawler tests in waves. It is also of interest to note results such as the relation of Beaufort Number and wave height in Fig. 3 and the relation of wave length and wave length calculated from wave period in Fig. 4 which have a wider and more fundamental significance.

ACKNOWLEDGEMENTS

This paper is presented by permission of the Director of the National Physical Laboratory and the Chairman of the White Fish Authority. Grateful acknowledgement is made for the cooperation of the Ministry of Agriculture, Fisheries and Food, the Combined Tabulating Installation of the Stationery Office and Mathematics Division, NPL.

The authors wish to express particular appreciation to all members of the above organisations who contributed to this work and also to the trawler skippers, Captain W. March (*Portia*), Captain Wood (*Arctic Vandal*), Captain W.G. Hardie (*Arsenal*), Captain J. Gower (*Cape Adair*), and Captain E.A. Binnington (*Ernest Holt*) for their patient efforts in collecting the data.

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G-2

RELATIONSHIP BETWEEN DRIFT-ICE, ATMOSPHERIC CIRCULATION AND FISHING POSSIBILITIES OFF SOUTHEAST GREENLAND DURING THE FIRST HALVES OF THE YEARS 1959-1963

By

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ABSTRACT

In spite of the big ice-drift along the coast of Southeast Greenland during the first half of the year, German trawlers have developed a surprisingly steady fishery since 1959. The study of all ice reports revealed that the ice is moved extensively by the wind. Westerly winds drive the ice seaward, often beyond the edge of the shelf, winds from north to east squeeze the ice against the coast leaving the banks ice-free. Twenty-four hours after the wind shifts to a westerly direction, the ice appears on the fishing banks.

The surprisingly low frequency of 14.7% ice-days (average for 1959-63) is the result of the specific atmospheric circulation over the Greenland area causing frequent N, NE and E winds (62% frequency). Westerly winds are mostly caused by lows moving towards Denmark Strait. Years with much ice show an Atlantic low shifted northward, years with little ice show a stronger developed Greenland "high" and a "low" shifted southward. Compared with the period from 1900 to 1939 the atmospheric circulation and the NE wind component were intensified in 1959-63.

Large quantities of ice are transported southward by the East Greenland Current during the first half of the year. Judging from the "Atlas of Ice-Conditions" and the reports on the first research and scouting trips (since 1955) it was doubtful if ice conditions would allow a more or less continuous trawl fishery during the first half of the year within the region from 60°N to 63.30°N (Fig. 1). However, Icelandic scouting trips found Fylkir Bank and Bille Bank already free from ice at the end of May and June 1957. Also early in May, and at the end of June 1958, five German trawlers succeeded in fishing on the Tordenskjold Bank, unhampered by ice. Early in May, 1959, a new attempt was made and in spite of some obstructions by ice, many trawlers fished there without interruption until 10 June. Then all ships were driven away from Tordenskjold Bank by ice and did not return until December, despite their good fishing.

After this first start of a successful fishery off Southeast Greenland a scouting trip in early winter 1959 found, from 10 to 18 December, the waters off South Greenland covered with ice at an extremely early date (Fig. 1), while the banks off Southeast Greenland were entirely ice-free. This scouting trip again revealed very good fishing possibilities off Southeast Greenland and by the end of December 1959 the first winter landings were made. Repeated attempts in January 1960 failed owing to unfavourable ice conditions. But since 14 February 1960, German trawler captains have succeeded in developing a more continuous and paying fishery for redfish and cod, though temporarily hampered or interrupted by ice.

A second scouting trip in April-May 1960 offered the opportunity for studying very different ice conditions and the relation between the specific ice situation and atmospheric circulation. On 16 April all German trawlers were driven from Tordenskjold Bank by eastward moving ice. From 19 to 21 April the biologist of this scouting trip sketched the extreme, eastern ice-edge (Fig. 2) showing ice at a distance up to 56 nautical miles from land. Eleven days later, when the ship returned from West Greenland, the ice was only 4 1/2 to 6 1/2 miles from the coast. All banks were free from ice and the trawlers had already resumed fishing by 23 April.

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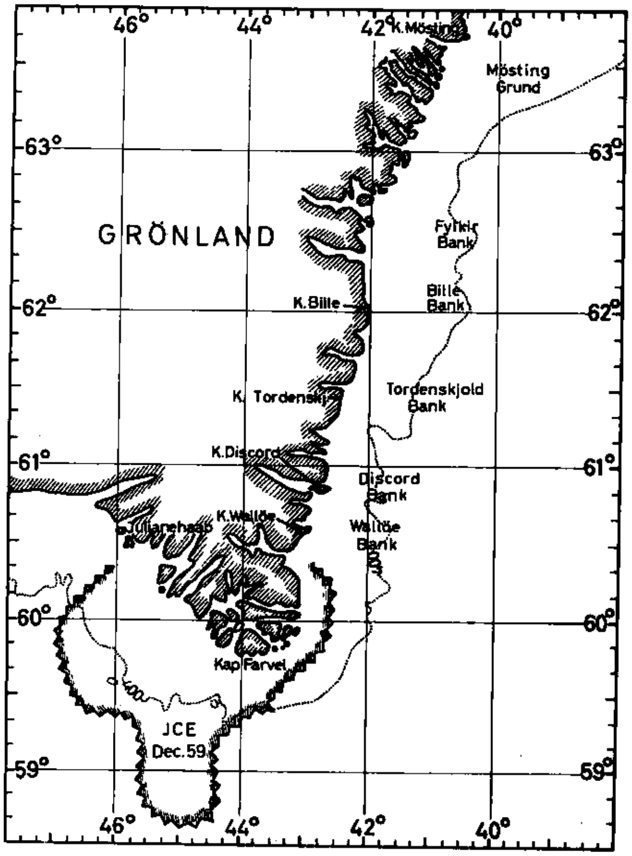

Fig. 1. The fishing banks off SE Greenland.

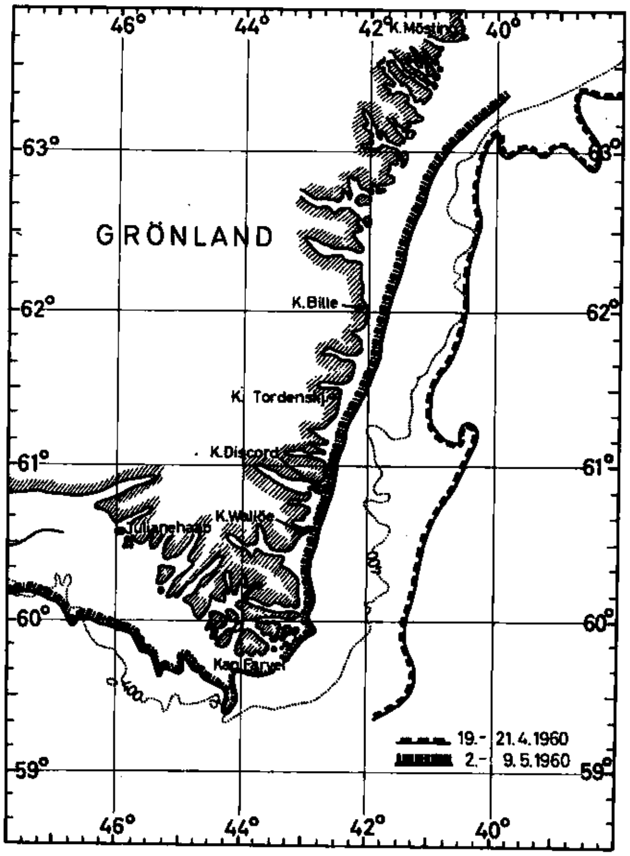

Fig. 2. The boundaries of ice off SE Greenland, 19-21 April and 2-9 May,1960.

The study of atmospheric circulation during this period and the examination of 78 reports of "ice on the fishing ground" given by German trawlers from the Southeast Greenland area in 1959-63 showed clearly that the movement of the ice is greatly affected by the wind. N, NE and E winds drive the ice clear of the banks and towards the coast while westerly winds drive the ice seaward again but seldom beyond the border of the shelf. The study of the ice reports showed further that usually within 24 hr after the winds had changed to a westerly direction the ice appears on the fishing ground hampering or stopping fishing activity. In some cases, when NE winds prevailed for longer periods a dead calm or light variable winds were sufficient to disperse the ice which was pressed against the coast in a seaward direction towards the fishing grounds.

Despite the immense ice masses transported southward during the first half of the year, ice is surprisingly rare on the Southeast Greenland banks which are from 28 to 45 miles from the coast. The reason is that NE winds, blowing at frequent intervals, accelerate the transport of ice and press it towards the coast. Table 1 (compiled from the daily weather reports of the trawlers, in the "catch reports" and "ship's observations", as well as the "weather charts" of the meteorological office) shows that on 62.6% of the days when German trawlers fished off Southeast Greenland, winds were blowing from the N, NE, or E. Winds from this northeastern quadrant were thus twice as frequent as winds from the other three quadrants together.

In the beginning, before the captains knew about the high frequency of NE winds off Southeast Greenland, they left the area when the ice approached and often they did not return for a long time. Today, after some years of experience, the trawlers rarely leave the Southeast Greenland area. When ice makes fishing impossible they move northward to evade the ice. This is because the southern banks (Walloe, Discord, Tordenskjold) are covered with ice earlier and usually in a heavier form than the northern grounds (Bille, Fylkir, Mösting). Two or three days later, when the wind has again changed to NE, they return to fish on the more productive, southern banks.

TABLE 1. FREQUENCY OF WIND DIRECTIONS AND OF ICE (IN DAYS AND PERCENT) ON THE SOUTHEAST GREENLAND FISHING GROUNDS IN THE FIRST HALVES OF THE YEARS 1959-1963.

	1959	1960	1961	1962	1963	1959-63
	7 May- 11 June	10 Feb.- 18 June	21 Jan.- 18 June	8 Jan.- 27 June	1 Jan.- 17 June	
N, NE and E winds	16(47%)	77(77%)	67(66%)	84(58%)	92(59%)	336(62.6%)
Other directions	14(41%)	19(19%)	28(27%)	51(35%)	56(36%)	168(31.3%)
Light variable winds or dead calm	4(12%)	4(4%)	7(7%)	10(7%)	8(5%)	33(6.1%)
Total days	34	100	102	145	156	537(100%)
Ice-days	5(15%)	9(9%)	17(17%)	30(21%)	18(12%)	79(14.7%)

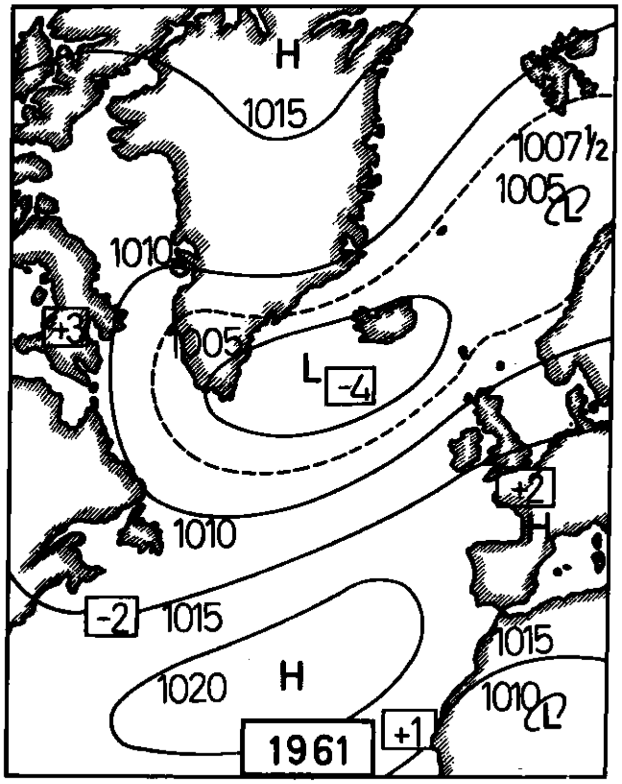

Fig. 3. Mean atmospheric pressure (in mb) and position of centres of anomalies, 1961.

The study of atmospheric circulation in the Greenland area gives a further insight into the ice and wind conditions. Charts of yearly and monthly mean atmospheric pressure distribution show that Greenland lies mostly within the range of a more or less well-developed high. A zone of low pressure extends from the south of Greenland east-north-east far beyond Iceland, usually with the centre over the Irminger Sea. The position of Southeast Greenland fishing grounds at the southeastern flank of the Greenland high or at the northwestern side of the Atlantic low explains the frequency of the NE wind situation (Fig. 3). Generally speaking, the lows coming from Newfoundland and Labrador pass Greenland to the south on their way to Europe. A few lows turn in a north-east track off South Greenland and move towards Denmark Strait, particularly when a strong high is blocking the eastward track. Studying the "days with ice" reported in 1959-63 shows that two-thirds of the SW to NW wind conditions, which carry the ice to the fishing grounds, were caused by cyclones moving toward Denmark Strait. Moreover an ice situation may result from a stationary high south or southeast of Greenland. Such an anticyclone develops S and SW winds off Southeast Greenland, and often small lows are guided along the Northwest and North side of such a high into the Icelandic area. In very rare cases, a low can move westward in the Irminger Sea, and then, when it is a low pressure system consisting of several secondaries, it becomes stationary in the southern Irminger Sea and the secondaries move in a counterclockwise circle.

Table 1 shows that the rapid development of the German fishery off Southeast Greenland in 1960 was especially favoured by a pronounced NE situation (77% of all days) with only 9% ice-days (average 1959-63 = 14.7%). A comparison of Fig. 3 with Fig. 4 demonstrates further, that, in 1960 when the Greenland high was stronger, the Atlantic low was less developed and shifted slightly to the south. The positive centre of anomalies over Greenland in 1960 showed, with 6 millibars(mb) the highest value of yearly anomalies from 1959-62 in the northern hemisphere. This pronounced NE situation in 1960 is even more evident from the monthly charts of mean pressure distribution. Already in October and November, 1959 (Fig. 5), a considerable, additional NE wind was blowing (+8 mb anomaly over South Greenland). In February, 1960 (Fig. 6), the NE situation was still more pronounced (+20 mb against -13 mb anomaly). These high pressure deviations not only account for the exceptionally early accumulation of ice around South Greenland in December 1959 (Fig. 1) but also for the rapid development of the German fishery on the Southeast Greenland banks.

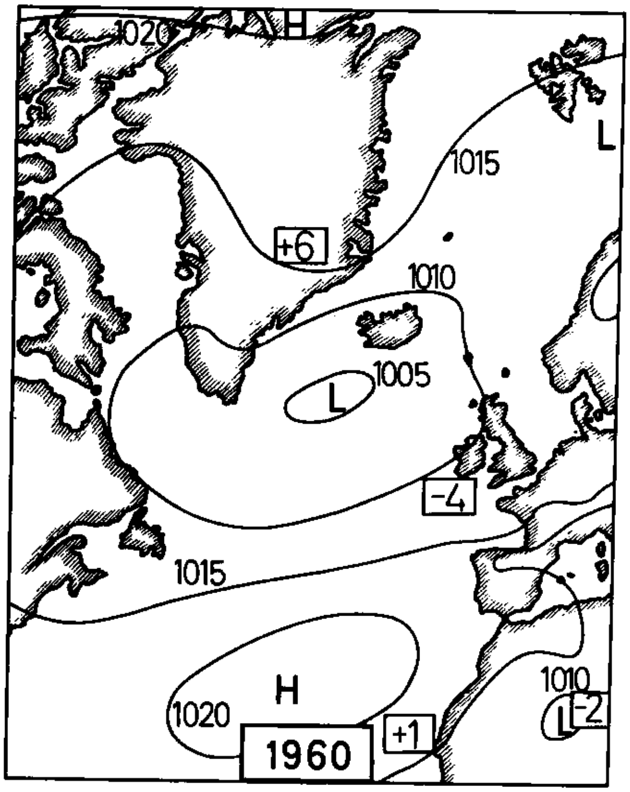

Fig. 4. Mean atmospheric pressure (in mb) and position of centres of anomalies, 1960.

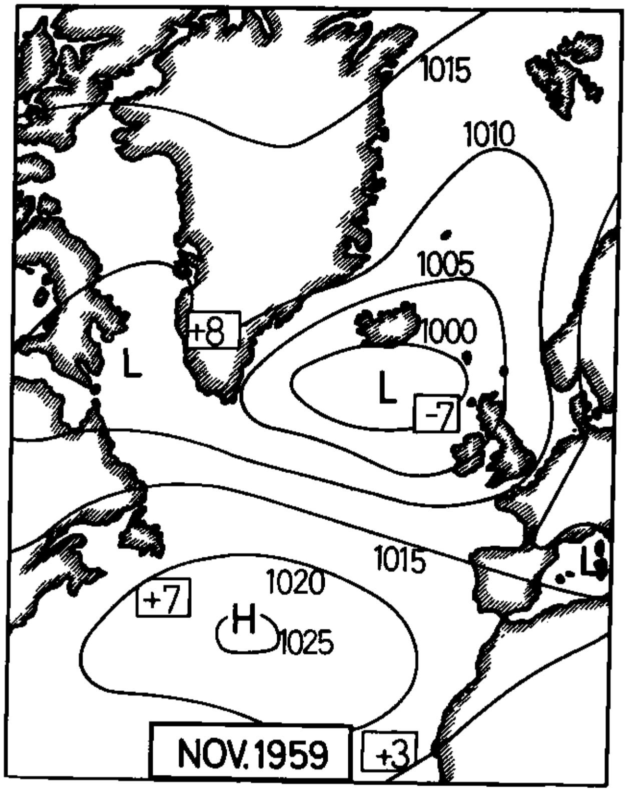

Fig.5. Mean atmospheric pressure (in mb) and position of centres of anomalies, November, 1959.

In contrast to 1960 which had little ice, 1962 was, to the present, the year with the most ice (21%). Ice was reported particularly frequently in January and February, mainly from 30 January to 16 February (11 ice-days). Lows moving steadily toward Denmark Strait caused westerly winds which brought the ice. Several times trawlers reported "steaming because of ice". The mean pressure distribution in January and February 1962 indicated a distinct northern position of the zone of low pressure (Fig. 7 and 8). In March, however, no ice hampered the trawlers owing to a big high which began developing over Greenland on 28 February. In this month, all Greenland lay within the 1,020 mb and North and East Greenland lay above 1035 mb (Fig. 9). On several days the extremely high pressure of 1,060 mb was found in the centre of the high! The centre of the Atlantic low was

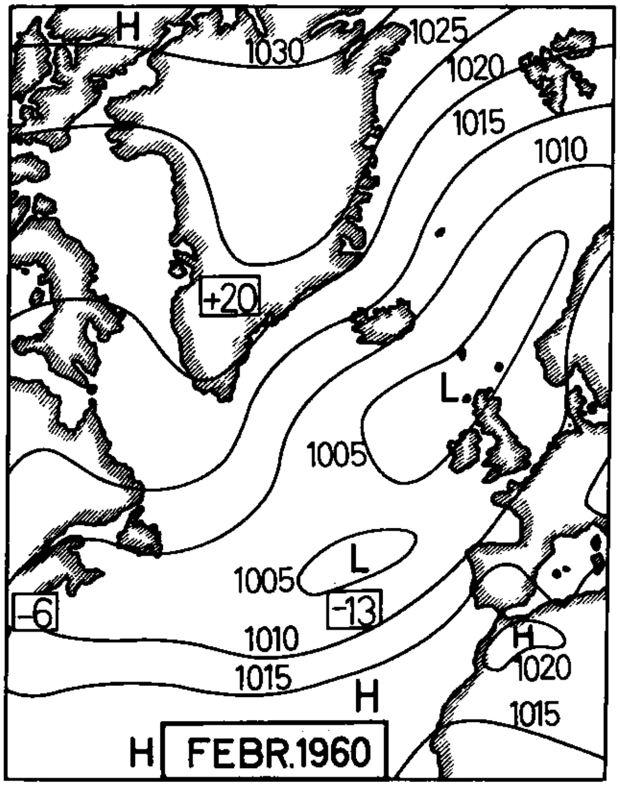

Fig. 6. Mean atmospheric pressure (in mb) and position of centres of anomalies, February 1960.

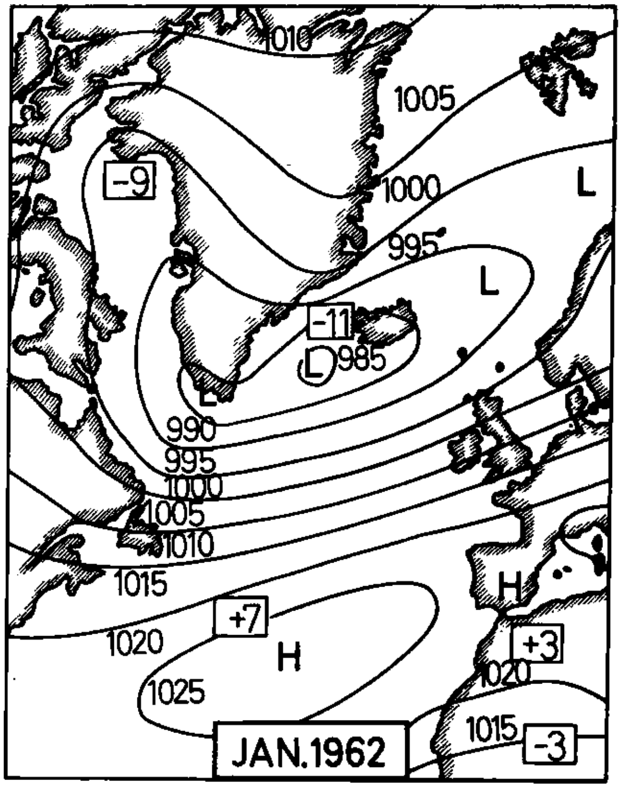

Fig. 7. Mean atmospheric pressure (in mb) and position of centres of anomalies, January 1962.

shifted more than 1,200 miles to the south as compared with the two preceding months. A positive centre of anomalies of +22 mb. over Greenland was opposed by a negative centre of -16 mb. near Weather Ship D. Such pronounced contrasts of atmospheric pressure led, of course, to a considerable crowding of isobars off South Greenland giving persistent, strong NE gales. The Southeast Greenland fishing grounds in March 1962 were entirely free from ice, but from 1 to 19 March the trawlers were only able to fish on two days! In May and June, however, the pressure situation was similar to that of January and February. May and June again had a high ice frequency of 26%.

These examples of varying atmospheric circulation show that fishing in the Southeast Greenland area is favoured by a somewhat extended high. However, the extreme atmospheric pressure differences between the Greenlandic high and the Atlantic low which keep the fishing banks free from ice, hamper fishing more by high winds than by pronounced ice conditions, for the normal distribution of pressure over Greenland leads already to considerable wind velocity and high waves off Southeast Greenland.

This study of the ice conditions off Southeast Greenland revealed a mean ice frequency of only 14.7% during the first halves of the years 1959-63, thus allowing a more or less steady fishery on the Southeast Greenland banks. The question is: Was the atmospheric circulation during these five years normal or were the years favoured by an increased NE wind component? Comparison of the mean pressure distribution during the first halves of the years 1900-39 (Fig. 10) and 1959-63 (Fig. 11) shows a marked dislocation of the centre of the low from South Greenland to the southern Irminger Sea and a considerable increase in the Greenland high and thus an intensification of the pressure diffences in the years 1959-63. The approximate doubling of the pressure differences (from 5.7 mb. to 9.9 mb.) and the dislocation of the low caused a considerable strengthening of the NE wind component. It is suggested that during the recent five years this additional wind has caused a diminished ice frequency on the banks, an accelerated ice transport to the south and consequently a smaller ice belt off Southeast Greenland. The stronger NE winds in 1959-63 must have produced

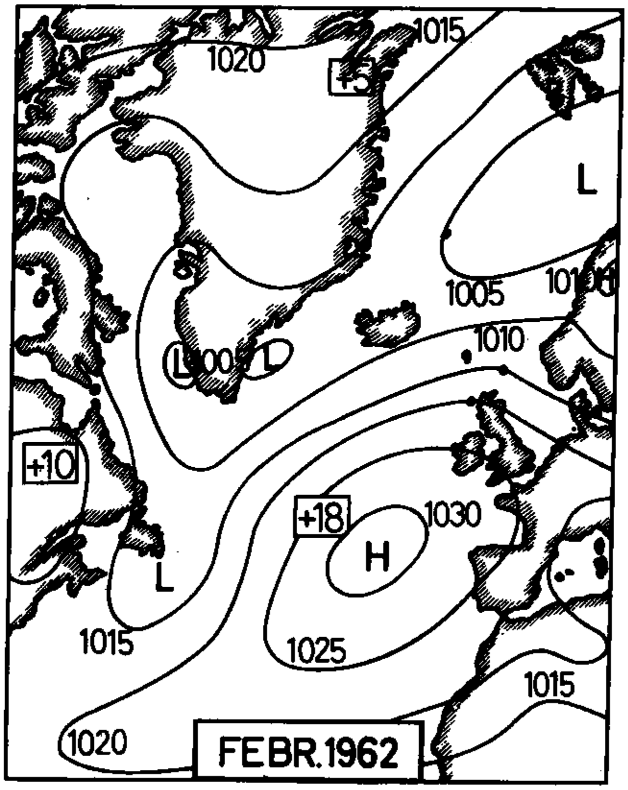

Fig. 8. Mean atmospheric pressure (in mb) and position of centres of anomalies, February 1962.

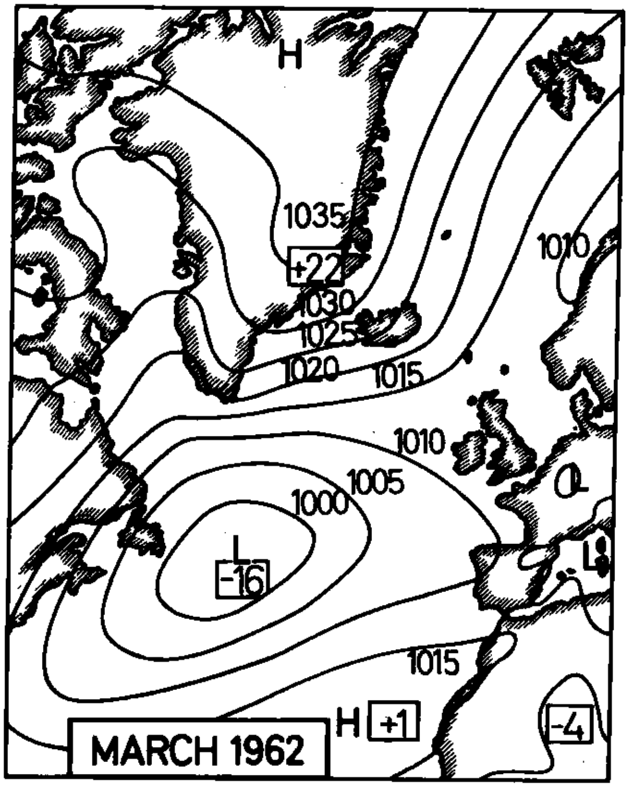

Fig. 9. Mean atmospheric pressure (in mb) and position of centres for anomalies, March 1962.

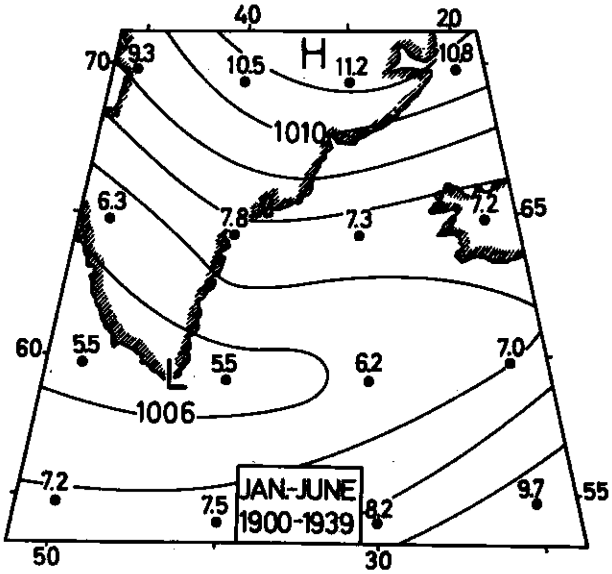

Fig. 10. Mean atmospheric pressure (in mb) in January-June 1900-1939.

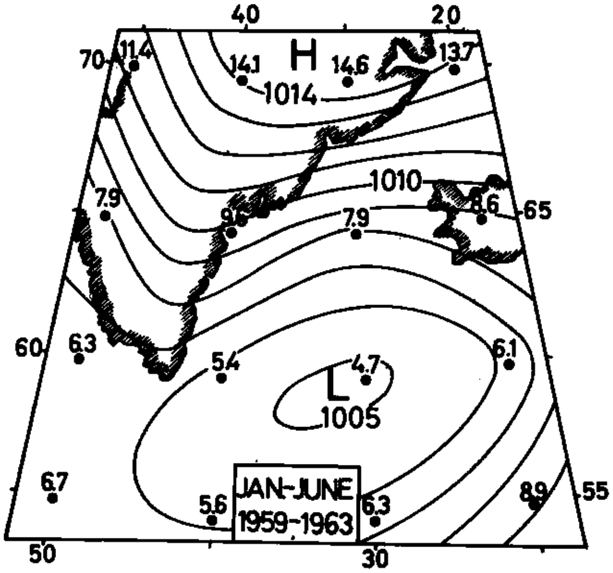

Fig. 11. Mean atmospheric pressure (in mb) in January-June 1959-1963.

(compared with 1900-39) an additional drift-current towards the coast across the direction of the two main currents. For example, a NE wind of wind-force 6 produces a drift-current on the surface of 0.4 knots, not in a southwestern direction, but in a more western direction, for in the northern hemisphere a drift-current turns to the right, as was first observed by Nansen and proved by Ekman (in theory, a 45° deviation). Off Southeast Greenland, NE winds are often blowing constantly for several days and, mostly with high velocity, this drift-current also influences the deeper water layers. But owing to the high latitude of Greenland the drift-current can only effect at the very utmost the first 100 m. Thus this additional current has no direct influence on the catches of the trawlers operating off Southeast Greenland in depths of 200 - 500 m. But the drift-current must have an influence on the fish stocks, for this current changes more or less the environment for eggs, larvae and plankton in the upper water layers. Further research will show whether there exists a correlation between a strengthened atmospheric circulation and the development of the new East Greenland stock of cod. Other open questions are: Were the years 1959-63 favoured by a relatively small ice-outflow from the Arctic Ocean? Which factor is more significant for fishing possibilities off Southeast Greenland, the total quantity of southward drifting ice or the wind-direction factor? Is it possible to forecast the quantity of ice in the coming year or years?

According to Nusser the ice-outflow of the Arctic Ocean is correlated with the atmospheric circulation over the Pacific sector of the Arctic Ocean and a forecast could be made three years in advance. In my opinion the study of atmospheric circulation should be increased with close collaboration between fishery scientists and meteorologists.

Finally, attention must be drawn to a very dangerous fishing practice connected with the fact that the movement of ice depends greatly on the wind. During a pronounced W wind situation an open water channel is formed, often more than 10 miles wide behind the ice belt moving towards the sea. Some young and ambitious captains then risk steaming in the southernmost part of Southeast Greenland behind the ice in order to fish behind the ice belt. This fishery is mostly very successful. But, even when weather forecasts are carefully observed, this fishery is very dangerous owing to the rapidly changing ice. This daring practice may lead some day to an ice tragedy, for even the most modern, big trawlers are not fitted with sufficient ice protection to allow then to break through a Greenland ice belt.

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G-3

CHANGES IN THE BEHAVIOUR OF FISH DUE TO ENVIRONMENT AND MOTIVATION AND THEIR INFLUENCE ON FISHING

By

H. Mohr[1]

ABSTRACT

The behaviour of fish with respect to availability and vulnerability to fishing is influenced by their surroundings and motivations which are both subject to fluctuations. Regular and predictable changes are caused by the planetary (seasonal, lunar, diurnal) cycles, while irregular changes are usually due to abnormal weather and hydrographical conditions. An increased activity is generally favourable and a reduced activity unfavourable for a passive gear, and vice versa for an active gear. Social behaviour patterns like shoaling are of great relevance for many fishing methods. The presence of other species too may influence the reactions especially in the case of prey or predators.

INTRODUCTION

Most large fisheries of the arctic and temperate zones are seasonal ones or at least show considerable fluctuations. The main reason for this is that the species concerned only form concentrations of sufficient density under special conditions. This is usually the case on the spawning, feeding or wintering grounds. The corresponding physiological conditions of the animals are caused by an endocrine rhythm which, in the extra-tropical areas, is regulated by the different temperature and light conditions. Therefore, the adult animals of a special population are, in the same season, subject to the same physiological condition and motivation. For marine organisms another planetary cycle, that of the moon, is important, especially because of its influence on the tidal phenomena, but also by its changing light. Besides, a "direct" influence of the moon is sometimes assumed. Furthermore, the change of day and night is of great relevance for the activity of animals. In the polar zones this cycle is interrupted temporarily.

These regular changes are influenced by several factors which are difficult or impossible to predict. These are especially the weather and hydrographical conditions which differ widely from year to year. Lastly biological factors in the environment, such as the presence of shoaling partners, prey organisms or predators, may influence the behaviour of animals.

All these factors are superimposed upon the normal cycles and vary them in their temporal course and intensity. The interplay may result in an increase or a decrease of the activity of the animals which is often decisive for success in fishing. But one can not classify these factors simply in two sections which affect the capture either positively or negatively. This depends on the gear and method used. Generally speaking, an increased activity is favourable and a lowered activity unfavourable for a passive gear, and vice versa for an active gear.

In this paper some examples of the points mentioned above are presented, mainly from the literature but also from personal observation. It is not attempted, and often even impossible, to discuss and analyse the behaviour patterns which may be involved, because in most cases we have insufficient information. More detailed descriptions and theoretical explanations may be found in the literature cited.

INFLUENCE OF THE PLANETARY CYCLES

The course of the seasons, by its change of temperature and light conditions causes a change in the surroundings and inner conditions of a fish which are usually so complex, that it is difficult

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to identify the proper reason for altered behaviour in field experiments. Changed reactions to nets of different colours can often be explained by the seasonal water colour caused by plankton organisms (Mohr, 1963) or the lowered light intensity in winter (Aslanova, 1959). By comparing the trawler's echo charts and the records of the "netzsonde", non-spawning shoals of herring were observed to react strongly to the gear, whereas spawners remained completely passive. The most striking seasonal change in availability of fish is associated with the sexual drive, which causes mass movements and concentrations (Woodhead, 1963,*a* and *b*) in so many and well-known cases, that specific examples are unnecessary here. These are most important pre-conditions for commercial fisheries, but the behaviour changes at the time of spawning influence the method of capture. For example, many species do not actively feed at this time and, therefore, bait is quite ineffective. Also, the reactions of the fish to stimuli unrelated to spawning are less strong at this time and, therefore, the conditions are usually most suitable for an active fishing gear. With a special type of one-boat midwater trawl, herring could never be caught successfully except in the spawning season, but then catches up to 20 tons were made in a few minutes (Mohr, 1963).

The lowered temperature in the winter often causes a lowered activity in fish. This is obvious in the attacks of sharks on men, which in the extratropical zones occur only in the hot season, when the water temperature is higher than 21°C. Further, spent herring are also easier to catch with a pelagic trawl than pre-spawners, probably because of their physiological condition (Balls, 1961). Besides spent herring stay in higher layers in day-time and their reactions to light change completely (Mohr, 1963; Richardson, 1960). Therefore, their availability to the bottom trawl and pelagic trawl depends a good deal on the season. A similar change from a demersal to a pelagic stage seems to take place in the cod after spawning. In the area of the Lofoten Islands practically no spent cod are caught by the bottom trawl (Trout, 1957).

The moon, by its strong influence on the tides, is a factor of great relevance for the behaviour of fish (as well as for the operation of the gear). In the Southern North Sea the herring shoals are cigar-shaped with the long axis in the line of the tidal stream (Bolster, 1958, 1962). Driftnets, therefore, should be set across this line in order to meet as many shoals as possible. Midwater shoals of herring in this area usually drift along the stream but demersal shoals, which are in visual or immediate contact with the bottom (or other stationary objects), stem the tide (Jones, 1959, 1962, 1963). Therefore, a bottom trawl is more effective when towed with the stream. On the other hand, a midwater trawl should be as, or even more effective when towed against the current. However, the catches are, in fact, usually better when the trawl is towed with the stream. The reason may be that the frightened herring swim against the water current (as many other species do) or they are in visual contact with the bottom (perhaps indirectly through stationary shoals below).

Landing statistics show that a maximum in the drifter catches of herring coincides with the full moon (Jens, 1952; Savage and Hodgson, 1934). Obviously the "swim" is stronger at this time. Whether this phenomenon is due to the light intensity or to a "direct" influence of the moon is unknown. It is said to happen too when the sky is completely clouded. Also, a strong influence of the moon is known on the spawning cycles of a Californian smelt, the common eel and a number of lower marine animals. The catches of migrating silver-eels in the German rivers and parts of the Baltic Sea in the few days of the waning half moon are up to ten times better than during full moon, and it seems to be proved that neither the light change nor the tides are the main factors for the increased migrating activity (Jens, 1952).

The changing light intensity between day and night is responsible for the diurnal vertical migrations which occur in many fishes. This phenomenon is observed not only in the "pelagic species", such as herring and hake (Balls, 1951; Lucas, 1936; Mucinic, 1933; Richardson, 1960), but also in the so-called "demersal" or "semi-demersal" species, such as redfish, cod, saithe, haddock and many flatfish (Seydlitz, 1962; Schmidt, 1955; Woodhead, 1960). In the same species there are often large differences in the direction and magnitude of this vertical movement depending on the maturity stages (Richardson, 1960; Woodhead, 1960). In most cases, the adult fish stay in deeper layers during the day. This is the reason that herring are traditionally caught in day-time with the bottom trawl and at night-time with pelagic gears. With a midwater trawl one can theoretically reach them in all layers. The over-wintering herring in the Norwegian Deep area can be caught in day-time very successfully by a two-boat midwater trawl but, during their vertical movement in dusk and dawn, they are so active that only poor catches are possible. Even during the stationary phase, below the surface, at night the herring avoid the gear by going deeper immediately before the net reaches them, as can be seen clearly in echo-charts (Mohr, 1963). In the case of some flatfish, big differences, which are probably due to different reactions to the gear, occur between the night and day catches.

For example, bottom-trawl catches of soles on the same ground at night are twice as large as daytime ones. Aquarium experiments show that it is likely that, in day-time, the soles react to a disturbance by burying deeper into the seabed, whereas, in the night, they roam freely over the ground. Plaice are caught in considerably higher numbers just after sunrise. Since the plaice is a visual feeder, it may be entirely occupied in feeding at this time (Woodhead, 1960).

IRREGULAR FACTORS

The regular, periodic behaviour is influenced by many scarcely predictable factors which contribute to the short term fluctuations in the commercial fisheries. Most of these factors are associated with the weather and hydrographical conditions which are subject to numerous, irregular changes. The extreme conditions, which hinder or even prevent fishing altogether, are not mentioned further. As stated above, the catch by driftnets is much better when the fleet is set across the direction of the tidal stream; but to do this depends on the direction of the wind (Bolster, 1962; Craig, 1960). During a spell of very clear weather at the end of the winter season off the South Norwegian Coast the herring were so close to the seabed in day-time that the midwater trawls usually became damaged and therefore failed, whereas the bottom trawls, which had very poor catches earlier, now had big ones (Mohr 1963). The direction of the wind also influences the abundance of fish in this area. When the wind shifts to a southern direction, the fish shoals always disappear completely within a few hours. Probably they have dispersed in all layers (v.Brandt and Steinberg, 1962). A similar relation to the wind is observed in the case of the Lofoten saithe. Yet here the catches are two to three times larger when the wind comes from south. The coinciding "internal waves", rather than the direction of the local wind, are supposed to be the main reason for the dispersion of the fish. These "internal waves" are fluctuations of the isothermal lines in the water and are caused by cyclones hundreds of miles away, in the open Atlantic (Schmidt, 1955).

As mentioned above, the temperature conditions influence the abundance of fish as well as their behaviour with respect to the gear. This is very evident in the coincidence of extremely big landings of soles with severe winters. At these times the fish are concentrated in the warmer areas and their avoiding reactions to the trawl, in day-time, decrease or cease at low temperatures (Woodhead, 1960). The effect of temperature on the distribution of herring and roundfish in both the horizontal and vertical directions is well-known (Craig, 1960; Dietrich *et al.*, 1959; Schubert, 1950; Tokarew, 1958). The uncertain conditions in the tuna fishery in the North Sea and the decrease in the cod fishery in the Barents Sea caused by low temperatures are also mentioned (Rodewald, 1960). In 1963, exceptionally good catches were made by drifters in the Western North Sea at times when the trawlers made only poor catches. This was due to the cold water masses at the bottom, which were avoided by the herring (Schubert, 1963). Eels do not feed until the water has reached a temperature of 9°C. After the past, severe winter the eel fishery, with bait, in the estuaries and rivers of Germany began nearly two months later and was very poor.

INTERSPECIFIC AND INTRASPECIFIC INFLUENCES

In addition to abiotic and intrinsic biotic factors (physiological condition and motivation), a number of extrinsic biotic factors also influence the behaviour and vulnerability of fish stocks, especially their shoaling. Here we must distinguish between aggregations and shoals in a narrower sense. In contrast to an aggregation, a shoal is a polarized group of fishes which moves and reacts as a whole (Breder, 1959). In the feeding period, herring form big concentrations in suitable places but the driftnet catches are often poor because the "shoaling pressure", which drives them blindly into the nets, is lacking. Small migrating shoals often bring better results (Tokarew, 1958). The pre-spawners and spawners usually form aggregations too, which shoal temporarily during their vertical migration. In the night they disperse in all directions near the surface. As long as no "swim" takes place, they are caught in small numbers on both sides of the fleet. Yet at a certain time, only once in 24 hours, if at all, the "swim" occurs. Time and intensity seem to depend on tide and moon-phase. Often the "swim" lasts only a very short time but 5,000 - 250,000 herring are caught by a single fleet (Graham, 1931). In the "swim", shoaling takes place, because the fish push from the same direction into the net. The "swim" is supposed to be a sudden panic in the fish. Different intrinsic or extrinsic factors are assumed to govern this panic. In a recently published article, the theory is discussed that the lack of oxygen in the dense concentrations of fish during the time of slack water may be the reason (Kalle, 1963).

In fishing with rod and hook for tuna, fish in small shoals are usually most voracious and their activity stimulates even tuna with full stomachs to take the bait (Inoue, 1959; Hotta *et al.*, 1959). The presence of other species may also influence the availability of fish. Examples, in which feeding organisms cause concentrations and behaviour changes have been reported (Hardy *et al.*, 1936; Tokarew, 1958). Tuna seem to trust in the watchfulness of porpoises and in the case of purse-seining one must be careful not to excite the latter. In some areas sardines are only available for purse seining when they are driven to the surface by dolphins (Cushing, 1959). Even in the cod-end of trawls, predatory species may cause panic and hence a higher rate of escapement or meshing of fish (Clark, 1963).

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G-4

BOTTOM CONTOURS AND NATURE OF GROUNDS AND THEIR SIGNIFICANCE FOR TRAWL FISHING

By

I.K. Avilov[1]

ABSTRACT

This paper describes the correlation between trawl fishing and the bottom topography and the nature of grounds in the ICNAF area. The author shows that the main factors governing the formation of relief deal with processes of subaerial erosion and glacial abrasion and the main sources of material for the formation of grounds are the underlying morainic deposits. Different rates of change under the influence of the hydrodynamic processes result in different concentration of stone material in deposits and in some areas glacial clay and solid rock are also exposed. The author gives an appraisal, for various parts of the ICNAF area, of the suitability of the grounds for trawl fishing. In this respect the area off West Greenland is considered to be the most difficult, while toward the South the conditions are better. In comparison with other regions of the North Atlantic, which were formed under the same conditions, the ICNAF area is the most complicated one.

Past experience has shown that trawl fishing depends to a considerable extent on bottom topography and the nature of bottom deposits (grounds).

Although the surveyed areas of the Northwest Atlantic, including the regions of West Greenland, and the coasts of Labrador, Newfoundland and Nova Scotia (Fig. 1) are substantially uniform, the individual sectors differ notably among themselves.

The formation of the present bottom contours and deposits and of their characteristic features took place under the influence of numerous factors, some of them referring to the remote past. Our present knowledge about the development of oceanic sectors of this area of the Atlantic is entirely based on geology and the history of formation of its shores. This knowledge, apparently can only be applied confidently to the shelf and partly to the upper sectors of the continental slope *i.e.*, to the areas of the bottom involved in trawl fishing. Some additional information on the history of development of this area is being provided by detailed studies of underwater topography.

The northwestern part of the Atlantic was essentially formed during the Pre-Cambrian age, under the influence of ancient folding. It includes the Canadian Crystalline Shield, the marginal zone of which forms the Labrador Coast, and the central part of Greenland. The sectors of the ocean bottom between Labrador and Greenland,— Davis Strait and the Labrador Sea, — should be considered as a part of the same area. During the Paleozoic age, mountain structures of Caledonic and Hercynian orogeneses appeared along the periphery of the zone of Pre-Cambrian folding. Appalachian structures and their extensions on the bottom of the Atlantic Ocean represented by Nova Scotian and Newfoundland banks, including the Newfoundland Grand Bank and Flemish Cap Bank, were probably formed in the main in the Caledonian age. Many sectors of the surveyed area of the Atlantic were subsequently subject to numerous fractures and were broken by granite intrusions.

The West Greenland Coast is composed mainly of ancient gneisses, crystalline schists and intrusive granites. In the area of Disko Island, basalts and Tertiary sedimentary strata are developed. The Labrador Coast is built up of granites, granodiorites and gneissose granites. In the area of Newfoundland the prevailing rock types are of sedimentary complex.

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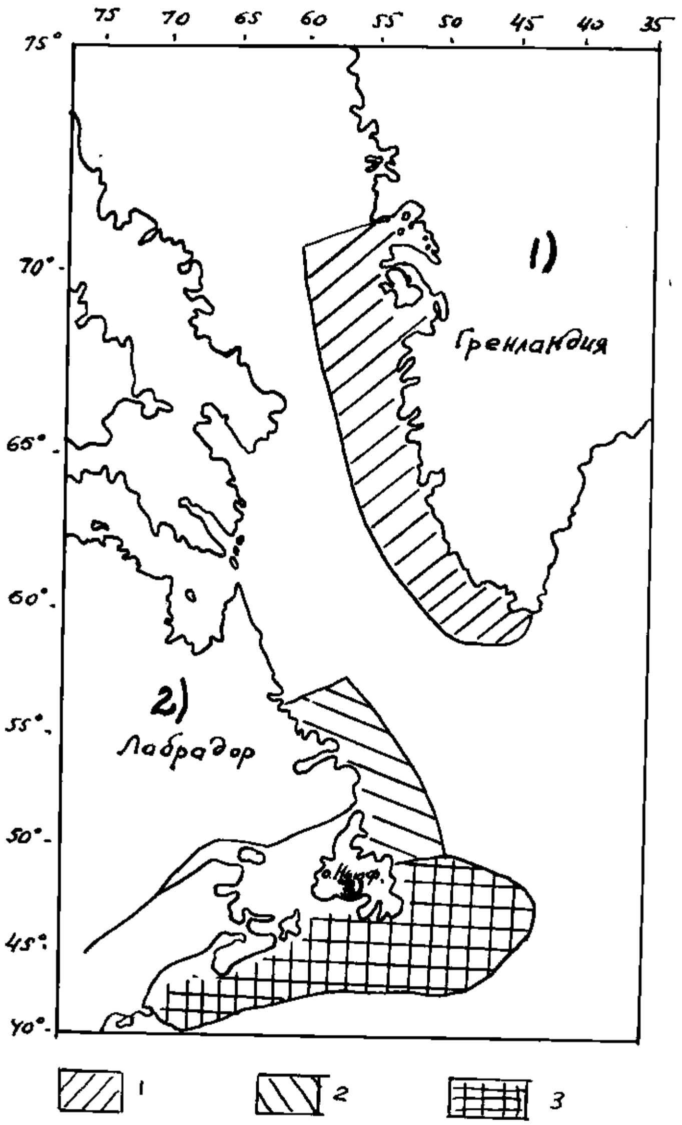

Fig. 1. Fishing areas in the Northwest Atlantic 1) The West Greenland Area 2) The Labrador Area 3) The Newfoundland and Nova Scotia Area.

(English translation of place names
1 — Greenland,
2 — Labrador,
3 — Newfoundland Island).

At the time of Alpine folding the northwest Atlantic was subject to multiple depressions of surface level and fractures which basically shaped the present contour. The appearance of the Davis Strait and Labrador Sea should also be referred to that period (Neogen). The subsequent effect of powerful processes of subaerial river erosion and glacial abrasion on the underlying surface resulted in its notable transformation and in the appearance of topographic forms peculiar to these processes.

We believe that the processes of subaerial erosion and glacial abrasion played a more important role in the formation of the present topography of land than all the other factors mentioned above. The duration of these processes must also have been a factor of some importance for the formation of the relief. The marked differences in the topography of the northern and southern sectors of this area should evidently be explained by the duration of the effect of the above factors and by their varying intensity, determined primarily by variations in isostatic movements in individual sectors of the area. A brief description of their topography is given below.

The topography of the West Greenland Coastal zone is characterised by an Alpine landscape. The ice-free area of the shore, from 1.5 to 180 km wide, represents a system of massifs crushed by faults, with peaks up to 1,600 m high. The coast is dissected by numerous fjords up to 100-180 km long, with depths reaching 500 m in estuaries. The shores are bordered with numerous islands making up a wide belt of skerries.

The Labrador Coast is much less dissected. The surface of Labrador represents a plateau from 400 to 800 m high, with individual peaks standing out. The shore line of the Labrador Peninsula is uneven, indented with fjords and bays, but dissected to a much lesser degree than that in Greenland. The Newfoundland Island's relief is still more smoothed out. The plateau, occupying its surface is from 400 to 500 m high. The height of the remaining extended elevations, known as mountain ranges, does not exceed 805 m. On Nova Scotia, low-lying hilly plains prevail. Its shores are dissected with bays which often look like fjords but are still smaller than those on Newfoundland.

Bottom contours

Although the shelf and the continental slope have much in common, there are also marked differences between them. The width of the shelf and continental slope is variable. The general tendency of the shelf to widen from north to south in some sectors of the Northwest Atlantic is reversed. The nature of dissection of the shelf into individual banks isolated from each other and from the shore, typical for the entire Area, varies markedly by regions. The gradients and the nature of dissection of the continental slope also vary.

Off the west coast of Greenland, for example, the width of the shelf decreases abruptly from north to south. Whereas off Disko Island depths of less than 500 m extend 70 to 90 miles from the coast in the south then extends about half that distance. In contrast, the width of the shelf off Labrador more than doubles from north to south, *i.e.*, from 60 miles near northern Hamilton Bank to 150 miles in the area off Belle Isle Bank. Still farther south, in the latitude of the northern Newfoundland Bank, the width of the shelf reaches 200 miles, and it even exceeds that range on the Grand Newfoundland Bank. To the west of the Grand Bank the width of the shelf decreases and levels off, to 110-120 miles, but farther west in the Gulf of Maine, the shelf considerably widens again.

The depths at the edge of the shelf and of the surfaces of the banks also vary. In Davis Strait, north of its sill (64°N), the edge of the shelf is found at an average depth of 160-180 m, whereas in the southern part of the shelf it increases to depth of 230-240 m. The depths of location of the banks vary accordingly, but within a somewhat wider range. Off the north Labrador Coast the edge of the shelf is located at a depth of about 300 m and in the area off Belle Isle Bank, almost 100 m deeper. At the latitude of the northern Newfoundland Bank, the boundary between the continental shelf and continental slope is found at a still greater depth. The depths of location of the surfaces of the banks vary in a similar way. The minimum depths of northern Hamilton Bank are a little less than 100 m; of Hamilton Bank, about 150 metres; of Belle Isle Bank, around 200 m, and of northern Newfoundland Bank, more than 200 m.

The Grand Bank, with depths mostly less than 90 m, is an exception. The depth of its boundaries varies. In the northeast corner its edge is located at a depth of 200-300 m; in the southeast, it is at 70-80 m; in the south, at 110-120 m, and in the west, at 100 m. Off Nova Scotia it is also at about 110 m.

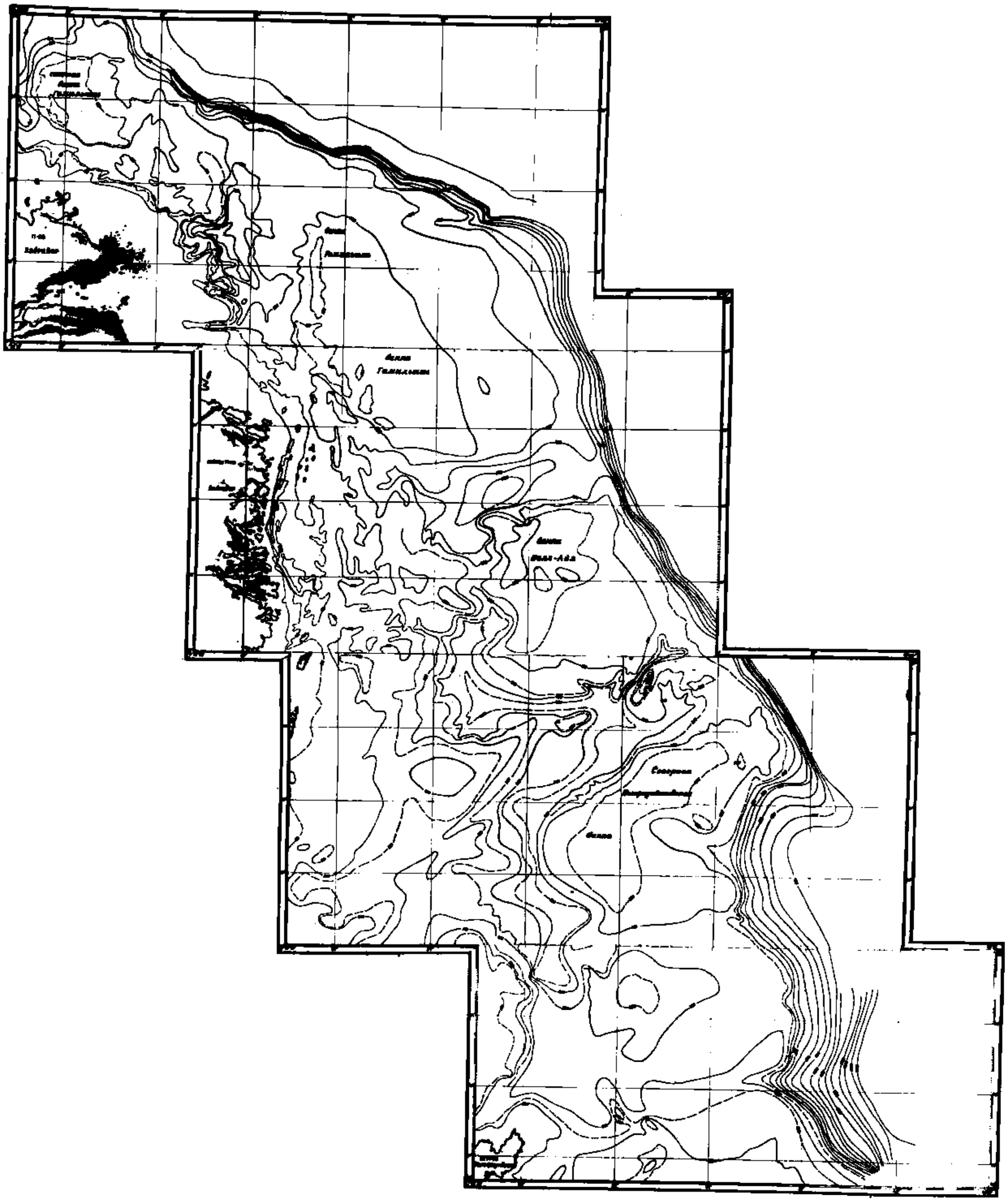

Fig. 2. Bottom contour in the Labrador area.

(English translation of place names — 1) Northern Hamilton Bank, 2) Labrador Peninsula, 3) Hamilton Bank, 4) Labrador Peninsula, 5) Belle Isle Bank, 6) Northern Newfoundland Bank, 7) Newfoundland Island).

The northern part of the West Greenland Shelf, north of Danas Bank, is divided by longitudinal depressions (extending along the shores) into larger, outer and a smaller, inner (coastal) part. The longitudinal depressions do not communicate and are usually quite deep; their depths greatly exceed the depths of the shelf, reaching at some places 500-600 m; their slopes are steep (up to 20-22°) and much dissected.

The outer part of the shelf, north of Danas Bank, and its southern sectors are divided by transverse depressions (running normally to the shore), which represent ancient river valleys, transformed to a considerable extent by Quaternary glacial ice, into individual banks. These transverse depressions, usually have straight and steep slopes (up to 14-15°) and sometimes are more than 200 m deep. In the southern sectors of the West Greenland Shelf, where it is narrow, and partly in its northern zone, the underwater valleys are found on a line with the fjords of Greenland, actually representing their extensions on the bottom of the sea. In the sectors where logitudinal depressions are developed such a relation is difficult to track, since the transverse valleys connect the longitudinal depressions (to which estuaries of a group of fjords are bound) with the open part of the Davis Strait. Most of the transverse valleys have underwater sills located near the edge of the shelf.

Commercial banks are located in the wide outer zone of the shelf. The sizes of the banks decrease greatly from north to south,(*e.g.* the area of Store Hellefiske Bank, within the 100 m isobath, is 15.5/thousand sq. km, and that of Frederikshaab Bank in the south is 0.2 thousand sq. km). In the northern part of the West Greenland Shelf, banks are located somewhat off its outer edge, whereas south of latitude 64°N they are located right on the edge. With the decrease in the area of the banks, the degree of dissection of their surfaces and slopes increases considerably.

The entire area of the shelf south of Frederikshaab Bank represents an undulated valley, intricately dissected with diversely oriented hills and ridges whose relative heights range from 50-100 m.

Practically nothing is known of the continental slope in the coastal area of West Greenland; but judging by the nature of the continental slope in East Greenland and by the structure of the continental slope in the southern part of the West Greenland Coast, where it is much indented, as well as by some other indications, it is safe to assume that its structure is complicated, except maybe for the sectors on the slopes adjacent to the banks.

The structure of the shelf off the Labrador Coast is similar to that off Greenland, except for the much larger sizes of the banks, depressions and other forms of bottom contour (Fig. 3). Longitudinal depressions, extending to a distance of 20-50 miles from the shore can be traced all along the investigated part of the Labrador Coast (south of 56°N); they have gentle gradients and their genesis is somewhat different from that of the depressions off Greenland. Maximum depths of the individual troughs in the longitudinal depressions also reach 500-600 m.

Transverse depressions, (the valleys dividing the shelf into individual banks), are wider and deeper than those on the Greenland Shelf; they have assymetrical slopes, and are often narrowed in their estuarine portions near the continental slope from which they are usually separated by a wide elevation (sill) having relative height of 150-200 m.

All of the topographic features of the Labrador Shelf are more subdued in relief and, accordingly, have gentler gradients than those of the Greenland Shelf. The continental slope is also gentler, especially in its upper zones. Its steepest sector is observed in the north of Hamilton Bank. Farther southwards, east of Hamilton and Belle Isle Banks, the continental slope smoothes out, its maximum gradient not exceeding 4° 20'. Near northern Newfoundland Bank the slope becomes still smoother (up to 1°), and remains so all the way to the northern zones of the Grand Bank.

It is unnecessary to dwell at length on the topography of the Newfoundland and Nova Scotian banks as they have already been described in previous publications; it should only be mentioned that these areas are characterised by the same topographic features as those described above, apart from being still more subdued in relief. This can be explained by a shorter period of exposure to the effect of Quartary glacial ice, and a longer period of influence of marine abrasion after the end of glaciation. The effect of these processes on the continental slope was quite different. It was, evidently, subject to highly intensive dissection, both during and after the period of glaciation. As a result, and because of somewhat different geology as compared with the northern areas, the

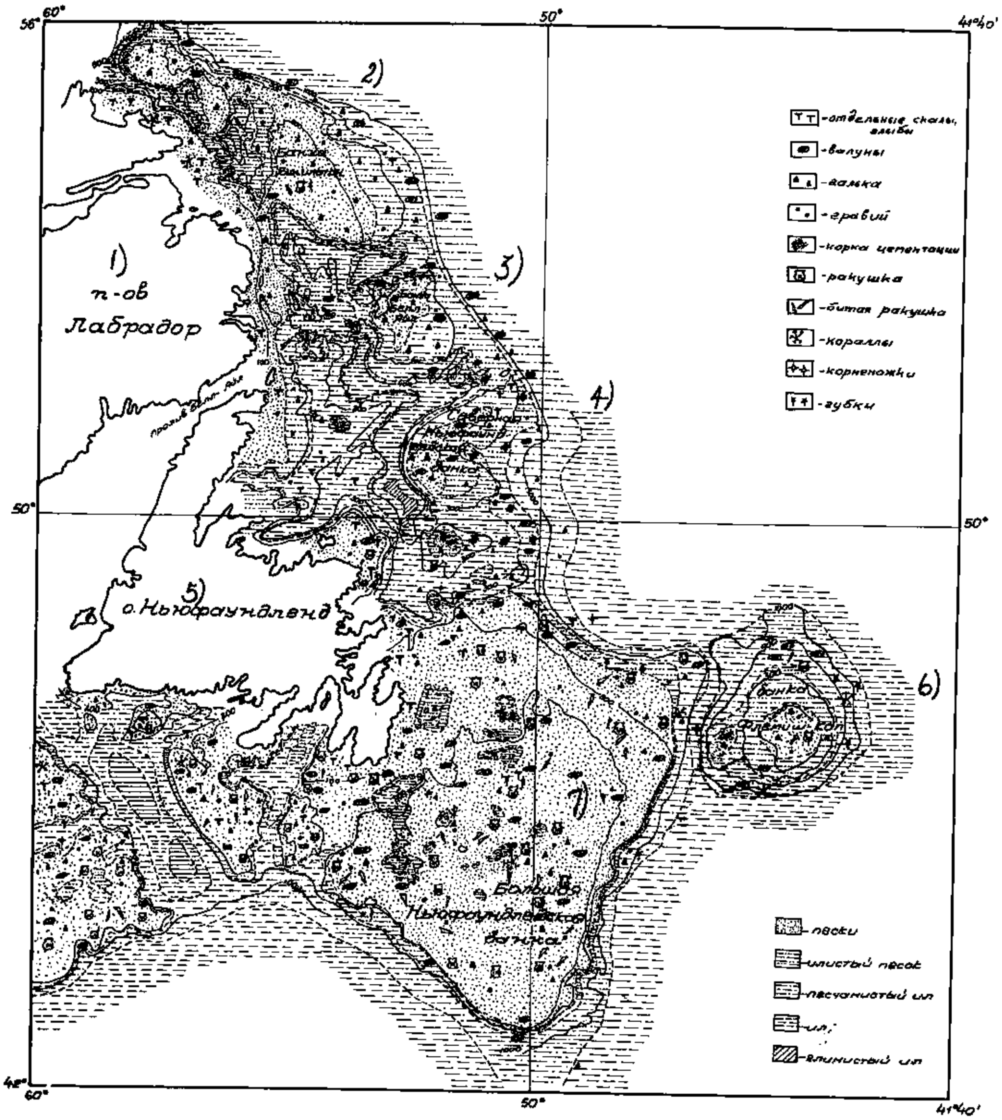

Fig. 3. Sketch map on bottom contour and distribution of bottom deposits in the Labrador and Newfoundland areas.

(English translation of key to the items in the order presented on the map —

1) individual rocks, blocks,	9) rhizopods
2) boulders,	10) sponges,
3) pebble,	11) sand,
4) gravel,	12) clay sand,
5) cement crust,	13) sandy silt,
6) shell,	14) silt,
7) crushed shell,	15) clay silt)
8) corals,	

(English translation of place names —1) Labrador Peninsula, 2) Hamilton Bank, 3) Belle Isle Bank, 4) Northern Newfoundland Bank, 5) Newfoundland Island, 6) Flemish Cap Bank, 7) Grand Newfoundland Bank).

continental slope along the Newfoundland and Nova Scotian banks is very steep and dissected by a continuous network of underwater canyons with peculiar longitudinal and transverse sections. The gradients of the side walls of the valleys are from 10° to 16°; in some places they develop into cliffs. The angle of gradient of the continental slope varies within a narrow range. The southern slope of the Grand Bank is somewhat gentler than the eastern one, around 5.5° at depths from 100 - 1500 m. In the Nova Scotian area, gradients of the slope range from 2° 20' to 5° 50'. The valleys observed on the slope do not usually extend onto the shelf; individual canyons, however, penetrate far into its depths. The greatest of them is the well known Gully Canyon which crosses the entire area of the shelf and reaches the shores of Nova Scotia.

Bottom deposits

In the areas discussed above, the great variety of the morphology of the bottom, varying climatic, hydrochemical and other conditions and uneven solid discharge, resulted in the accumulation and formation of diverse bottom deposits. Since the underlying strata, represented mainly by morainic deposits which cover almost the entire surface of the shelf and part of the continental slope, were the primary source of sedimentary material, the bottom deposits have many characteristics in common.

The whole of the North West Atlantic is characterised by a predominance of coarse sediments with the inclusion, almost everywhere, of coarse stone material, the amount of which generally decreases from north to south. The concentration of stone material in sediments is caused primarily by erosion of the underlying strata, the intensity of which is higher in the narrow and indented sectors of the shelf. In the coastal zones of the shelf, increase in its content should be often attributed to stones brought by ice. Such stones are usually notable for their angularity. High activity of water in the narrow and indented zones of the shelf may even result in complete removal of sand clay and formation of stony ground; in some cases solid rock can also be exposed. As an obvious example of formation of stone ground we can point out the appearance of boulder-pebble accumulations off the West Greenland shores; they line the bottom and slopes of the valley which cuts through the Danish Sill from the south and through the tops of some banks. Zones of boulder-pebble and pebble-gravel grounds can, evidently, be found on the southern, West Greenland banks,too. In the western zone and on the western slope of the Grand Bank the presence of pebble-gravel ground was revealed by underwater photography. Pebble-gravel deposits with admixture of echinus tests are observed in the eastern part of Grand Newfoundland Bank and in the Labrador coastal zone. Fields of stony ground (gravel-pebble-boulder) are found in the Nova Scotia area on a number of banks and crests, amidst the depressions of the shelf. Continuous accumulations of boulders are observed in the coastal zone of this area. Individual rocks are found in the coastal zone of the entire area of the Northwest Atlantic under investigation, as well as on the Grand Bank in the region of Woolfell, Eastern Shoal elevations and Virgin Rocks.

The greater part of the surface of the Shelf is covered with sand of various grades and composition. The marginal zones of the banks are covered with silt sand replaced by sandy silt on the continental slope. Sandy silt covers the greater part of the depressions between the banks and between the inner (coastal) and the outer zones of the shelf. Finer ground, silt and clay silt occupy the depressed zones of the shelf protected against water movements and are found at greater depths on the high seas.

As it has already been mentioned above, all coarse-grained grounds, including sandy silt, contain some stone material with individual boulders and blocks. Some blocks weigh several tons and obstruct the trawl fishery more than anything else. Boulders are usually buried in sand on all the southern West Greenland banks. On the northern Greenland banks boulders are encountered in their peripheral zones only, mostly on their outer slopes.

In the Labrador area and in the areas farther to the south the boulder content in the sedimentary deposits of the shelf and continental slope is much lower. In the Labrador area they are concentrated in the marginal zones of the banks and on the continental slope as well as in the coastal zone of the shelf. Boulders are quite frequent on the northern and southwestern slopes of Flemish Cap. On the Grand Bank they occur almost everywhere, considerable concentrations being observed in its northeastern marginal zone, in the centre (near the above mentioned rocky banks Woolfell etc.), and near the southern end of Newfoundland Grand Bank. On the Nova Scotian banks, boulders are concentrated mostly in the sandy areas.

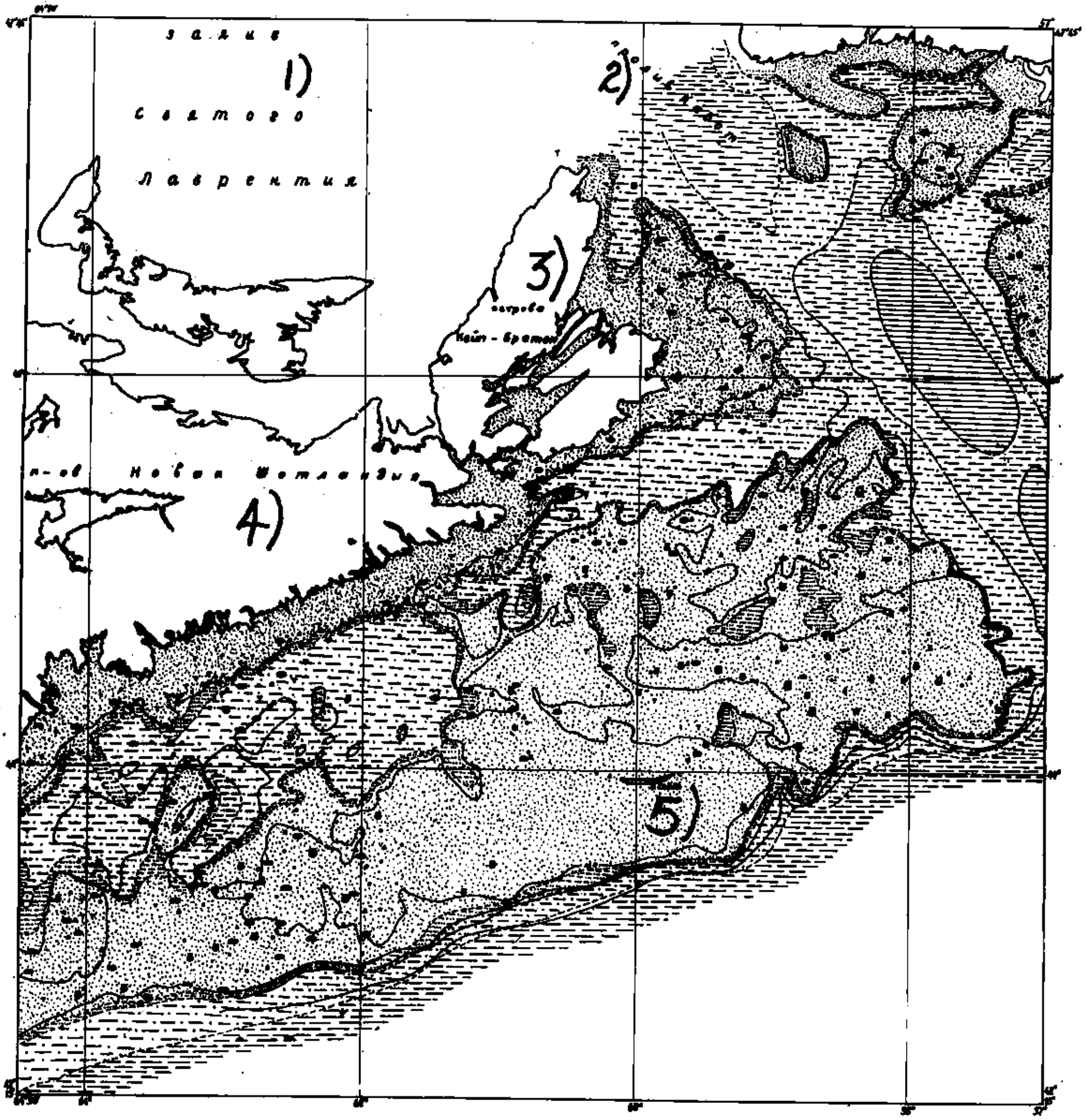

Fig. 4. Sketch map on distribution of bottom deposits in the Nova Scotia area.

(English translation of place names —1) Gulf of St. Lawrence, 2) Cabot Strait, 3) Cape Breton Island, 4) Nova Scotia Peninsula, 5) Sable Island.)

The underlying morainic glacial deposits, represented by tight, tough bluish clay are exposed on the steep slopes of some banks. In most cases, however, they are covered by a thin layer of sediments. In the West Greenland area clay outcrops are encountered on the slopes of Fiskenaes Bank, at a depth of 100 m and are especially abundant on the slopes of Danas Bank at depths of 200-250 and 230-300 m. On the slopes of Frederikshaab Bank they are exposed at depths of 200-350 m. Glacial clays are also found on the continental slope off Labrador and on Newfoundland Grand Bank. On the Grand Bank clays also occur on the slope of the trough separating it from the coast.

Solid rocks are exposed on the bottom in many places along the continental slope in this part of the Atlantic.

The characteristics of the bottom contour and ground, cited above reveal that part of the surface of the shelf and, to a lesser degree the upper zones of the continental slope can be fished with existing trawling gear. At the same time it becomes evident that some sectors of the bottom offer great difficulties and some others make trawl fishing impossible. The areas with grounds containing individual boulders also make trawl fishing very difficult. According to rough estimations, they occupy about one-fifth of the total fishing area in this part of the Atlantic. Areas covered with solid rocks or with solid rocks exposed in the form of individual cliffs should be classified as bottom surfaces which can not be exploited with present gear. They include rocky zones of the West Greenland banks, Newfoundland Grand Bank and coastal (inner) zones of the shelf throughout the whole of the Northwest Atlantic.

The areas of the bottom covered with sediments containing large numbers of large-size boulders and, evidently, some stony sectors of the bottom containing glacial clays in which trawl boards may stick should be also excluded from the potential trawl fishing area for the time being.

To those areas in which trawl fishing is impossible should also be added the regions characterised by a high degree of dissection and steep gradients, *viz.*, the continental slope of the Grand Bank (beginning from its northeastern corner), the entire continental slope off Nova Scotia, part of the southern slope of Flemish Cap, the slopes of some depressions on the Nova Scotian Shelf, the slopes of a number of longitudinal depressions off Greenland and, apparently, some sectors of the Greenland continental slope, particularly those adjacent to the estuarine portions of transverse valleys.

Trawl fishing can also be obstructed by the accumulations of some immovable living organisms whose development depends not only on hydrological, hydrochemical and other conditions, but also on the contour of the bottom and the nature of grounds. The well known coral thickets surrounding the entire Flemish Cap Bank at depths of 300-700 m and most abundant on its eastern and southern slopes, provide a good example.

The above characteristics of fishing areas in the Northwest Atlantic indicate that the area off West Greenland is the most difficult to exploit because of the contour of its bottom and the nature of its grounds. The Labrador coastal area seems to be definitely better, but the most favourable conditions exist on the Newfoundland and Nova Scotian banks. It is thus obvious that there are considerable areas in the Northwest Atlantic which cannot be exploited by the present trawling fleets, but can be considered as reserve fishing grounds. Individual sectors of the continental slope, up to 1000 m, also constitute reserve grounds. The most promising of these may prove to be the Flemish Cap slopes, the northeastern slope of the Grand Bank, the entire area of the continental slope from Hamilton Bank to northern Newfoundland Bank, and part of the West Greenland slope.

A comparison of the Northwest Atlantic with other North Atlantic areas formed under similar conditions, shows that the area in question has a much more complicated bottom contour and the nature of its grounds is less favourable for trawl fishing. This is further aggrevated by severe climatic and navigational conditions.

In conclusion, it should be pointed out that our knowledge of the bottom contour and grounds in the fishing areas of the Northwest Atlantic are extremely superficial and, except for the southern areas (Newfoundland Grand Bank and Nova Scotia), cannot meet the requirements of the commercial trawling fleet. Therefore, further investigations of this complex and important part of the World Oceans are necessary. It seems that particular attention should be paid to the continental slope.