Dispersion of surface waves along various paths to Uppsala, Sweden

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PART II
ARCTIC AND ATLANTIC OCEANS

INTRODUCTION.

In continuation of Part I (Santo 1962), group velocity dispersion of surface waves along various oceanic paths to Uppsala, Sweden, will be reported in this paper. Materials and the method used are quite similar to the previous ones, i. e. group velocities of Love and Rayleigh waves were obtained from records by ultra-long-period Press-Ewing seismographs for the shocks with numbers 00-60 and 61-90, and for the other shocks from the records by long-period Benioff seismographs at the Seismological Institute, Uppsala, Sweden. In order to give characteristic numbers to the dispersion data along every oceanic path, they are compared with the classified curves which the writer has obtained previously (see Fig. 1 of Part I) along other oceanic paths. Love wave dispersion curves are denoted by Roman numerals and Rayleigh wave curves by Arabic numerals.

DISPERSION OF SURFACE WAVES IN THE ARCTIC OCEAN.

Travelling paths are shown in Fig. 1 in which solid lines with double circle epicenters and dashed lines with filled circle epicenters respectively mean those along which both Love and Rayleigh waves and only Rayleigh waves are well developed. Data about the shocks are presented in Table I after the Preliminary Reports of U.S.C.G.S. Diagrams *a*) and *b*) in Fig. 1 show some examples of Rayleigh wave dispersion along

Table 1 – List of shocks for arctic region

h — focal depth, *M* = magnitude, *D* — distance

No.	District	Date	Origin Time (G.M.T.)	Epicenter	*h* km	*M*	*D* km
06	Off coast of Oregon	June 23 1961	$08^h55^m55.2^s$	43.9°N 128.9°W	56	—	8100
44	Vancouver Island region	Oct. 29 1961	09 12 15.7	49.0 N 128.7 W	16	—	7570
22	Queen Charlotte Islands	Sept. 08 1961	04 52 10.3	51.8 N 131.2 W	54	—	7320
122	Queen Charlotte Islands	July 04 1960	04 28 33	52 N 131.5 W	—	6.5	7300
23	Kenai Peninsula	Sept. 05 1961	11 34 37.3	59.8 N 150.6 W	44	6	6700
94	Kodiak I., Alaska region	Dec. 09 1961	02 15 22.0	56.3 N 153.9 W	31	5.5	7100
143	Alaska Peninsula	May 13 1960	16 07 12	55 N 161.5 W	—	—	7250
27	Fox Islands, Aleutian Is.	Aug. 29 1961	14 51 14.2	52.2 N 170.8 W	41	5	7560
37	Fox Islands, Aleutian Is.	Aug. 08 1961	12 18 18.9	50.9 N 170.7 W	24	6	7725
126	Fox Islands, Aleutian Is.	Sept. 02 1960	22 02 48.9	52.0 N 171.4 W	49	6	7600
01	Severnaya Zemlya region	June 29 1961	22 01 21.0	85.0 N 97.3 E	11	—	3300
121	Andreanof Is., Aleutian Is. . . .	July 03 1960	20 20 46	50.5 N 177 W	—	6.5	7700
24	Andreanof Is., Aleutian Is. . . .	Sept. 04 1961	09 49 10.7	51.4 N 178.1 W	35	6	7575
20	Andreanof Is., Aleutian Is. . . .	Sept. 11 1961	02 46 43.3	51.3 N 179.7 W	15	—	7560
113	Rat Islands, Aleutian Is.	Aug. 04 1960	07 34 53.8	51.4 N 179.1 E	83	—	7550
90	Rat Islands, Aleutian Is.	Dec. 30 1961	00 39 24.0	52.3 N 177.7 E	52	7	7430
02	Near Is., Aleutian Is.	June 26 1961	14 47 26.1	52.4 N 174.5 E	60	—	7400
68	Near Islands, Aleutian Is. . . .	May 17 1961	19 29 19.3	52.0 N 173.9 E	21	6.5	7420

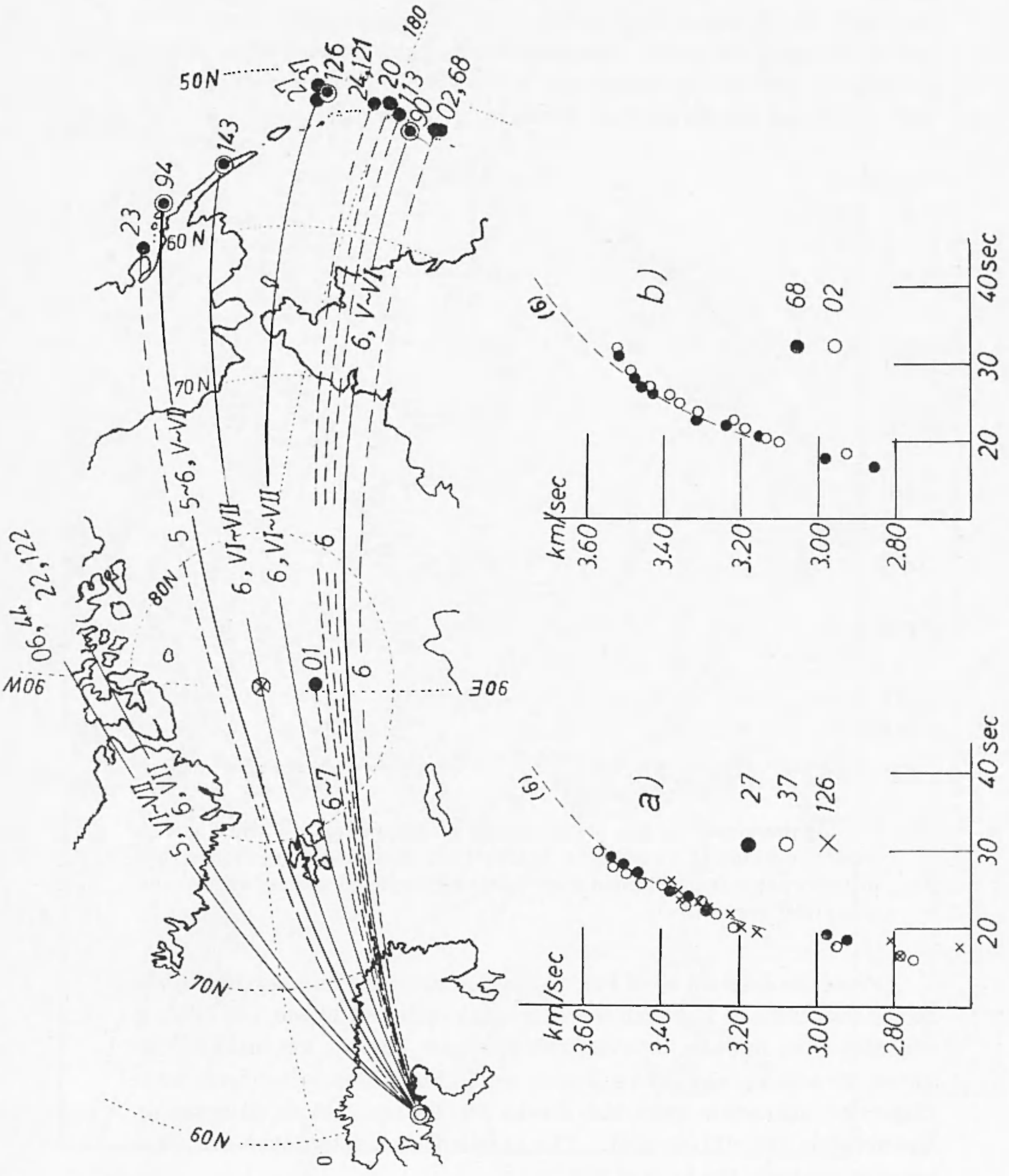

Fig. 1 – Travelling paths of surface waves in the Arctic Ocean. *a*), *b*) Examples of Rayleigh wave dispersion along similar paths.

approximately the same paths. As expected, these data lie exactly on the same curve. The classified dispersion curve (6) is given for comparison. Thus, we assign a characteristic number (6) to the dispersion of Rayleigh waves along these paths. The dispersion data along other paths, arranged clockwise, are given in diagrams *a*) and *b*) in Fig. 2. In order to prevent the complexity of the figures, some of the dispersion data which can be represented by others, were omitted.

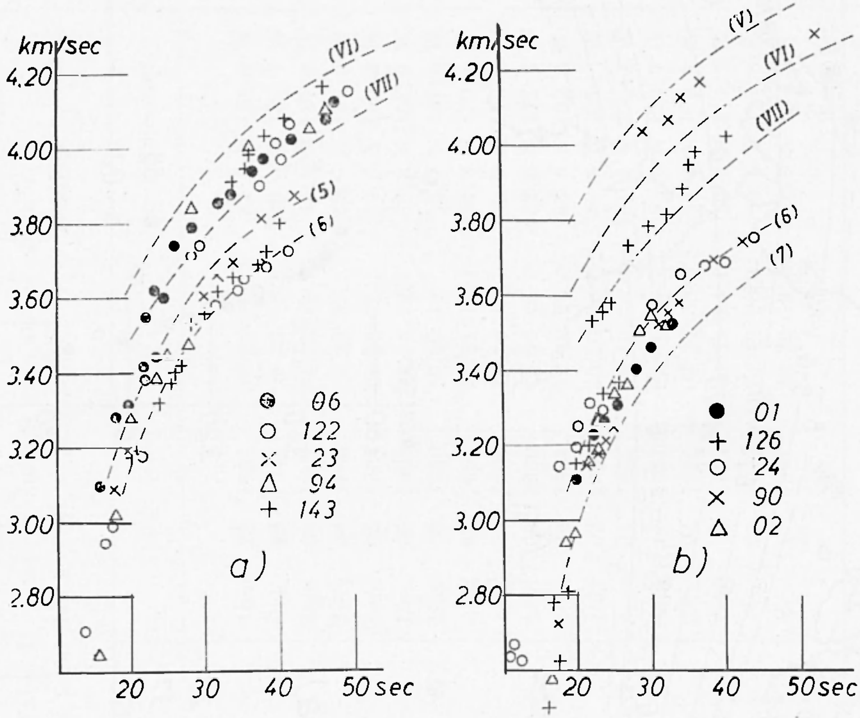

Fig. 2 – Dispersion of surface waves in the Arctic Ocean. Dashed curves with two kinds of numbers in brackets are classified dispersion curves of Love waves (with Roman numerals) and Rayleigh waves (with Arabic numerals) respectively.

From the diagram *a*) of Fig. 2, the characteristic number (6) is given to the dispersion of Rayleigh waves from the shocks 122 and 143. When the dispersion data lie between two reference curves, for instance between (5) and (6), a notation (5-6) is used. For instance, for Love wave dispersion characters from the shocks 06, 94 and 143 in diagram *a*), the notation (VI-VII) is used. The numbers thus determined are given on every path in the map of Fig. 1.

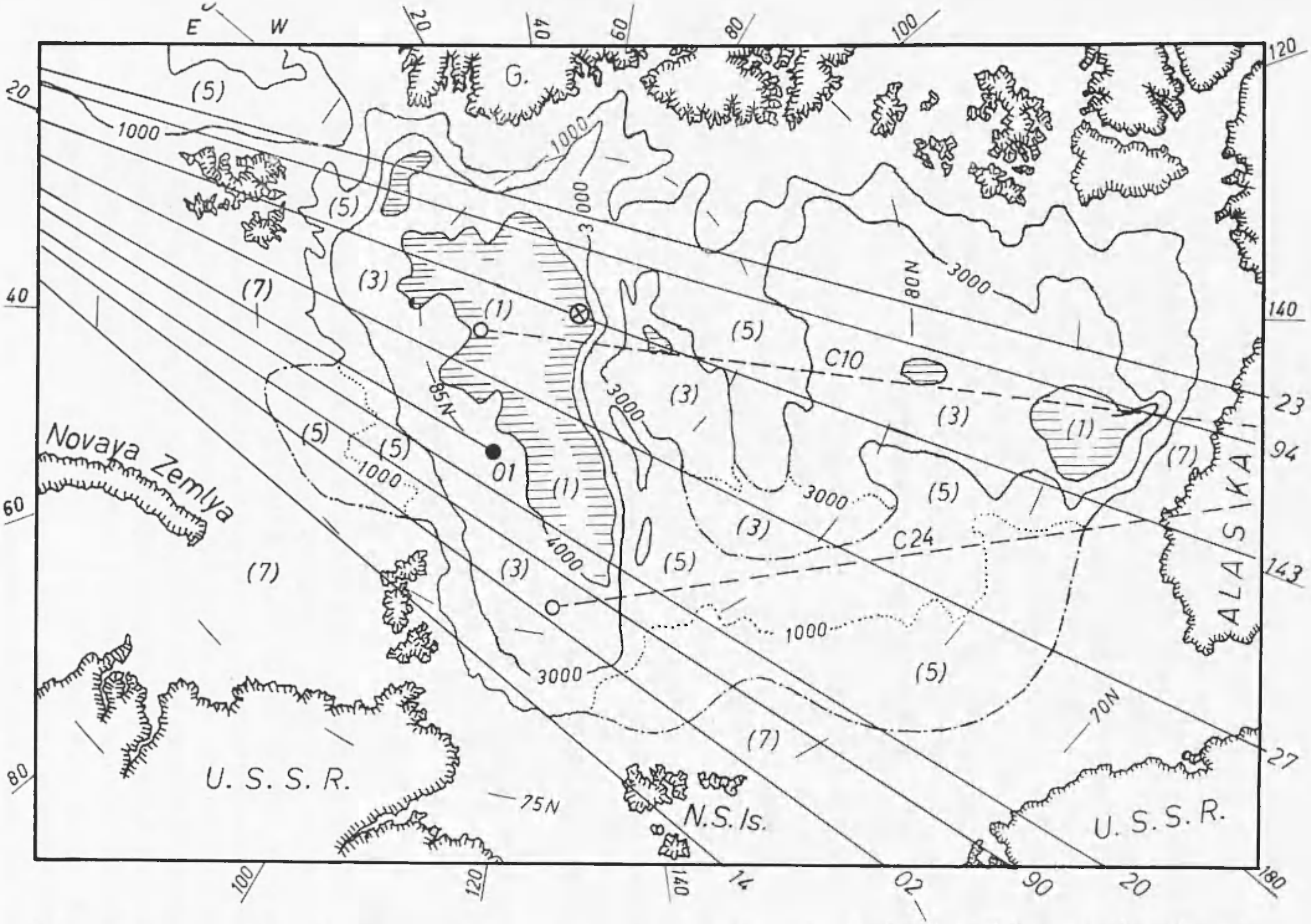

Fig. 3 – Division of Arctic Ocean into four regions (1), (3), (5) and (7) with Rayleigh wave dispersion characters (1), (3), (5) and (7) respectively. Uppsala is situated in left upper direction of this figure. North Pole is represented by a circle with cross, and the lower part of the map corresponds to Asia. Depth contours of 1000 m, 3000 m and 4000 m correspond mostly to the boundaries of the four regions. In some parts, however, boundaries have been shifted to such positions as are shown by dotted lines. The paths C 10 and C 24 are after Oliver, Ewing and Press (1955 *a*).
G: Greenland, N.S.Is.: New Siberian Islands.

Previously, the author divided the southwestern Pacific area into four regions (1), (3), (5) and (7) with Rayleigh wave dispersion characters (1), (3), (5) and (7) respectively (Santô 1961). The same method was applied to the Arctic Ocean area.

At first, the depth contours of 1000 m, 3000 m and 4000 m in Fig. 3, modified from the Time Atlas (London Press 1959), were supposed to be the boundaries of the four regions (7), (5), (3) and (1) respectively. As group velocities of Rayleigh waves with the dispersion characters (7), (5), (3) and (1) are known for each period, the travel times of Rayleigh waves along each path, and accordingly the resulting group velocities V(calc.) were found for each period. These values were compared to the observed velocities V(obs.). After that, the preliminary boundary lines were moved so as to make V(calc.) agree as nearly as possible with V(obs.).

This procedure was performed for eight representative paths from 23, 94, 143, 01, 27, 20, 90 and 02. The remaining part of the first five (outside the map in Fig. 3), which passes over continent or sea regions shallower than 1000 m, is considered to be region (7). The remaining part for the other three paths from 20, 90 and 02 passes over rather deep sea region in the western part of the Bering Sea. Therefore, the same suppositions as for the Arctic Ocean are made for these parts. The values of V(calc.) are quite the same as V(obs.) along the four northern paths from 23, 94, 143 and 01 without any corrections of the preliminary boundaries, but they are smaller than the latter along the other four paths from 27, 20, 90 and 02. In order to approach V(calc.) to V(obs.) along these four paths, path lengths over any region with low group velocities must be decreased. As these paths occupy a region with more than 3000 m depth in the western part of the Bering Sea, such corrections have to be made in the Arctic Ocean area.

Suitable boundaries were found, after several trials, by shifting some parts of the preliminary boundaries (represented by dotted curves in Fig. 3) to those shown by dashed-dotted lines. In Table II, the path lengths of each region (D_1, D_3, D_5 and D_7) finally obtained along every path are given, with values in bracket referring to the Bering Sea. V(calc.) as obtained from the final division map along nine paths in all (one path from 14 treated as a continental path in Part I is added for reference) are given for three different periods in Table III. As is seen in this Table, V(calc.) are quite the same as V(obs.), which means that our division map is quite suitable for satisfying all the dispersion data of Rayleigh waves in the Arctic Ocean.

Oliver, Ewing and Press (1955 *a*) observed Rayleigh wave dispersion along three paths in the Arctic. Excluding their path C 74 because of limitation to too small period range, the other data along two paths C10 and C24 are used also in the present work. The paths are shown in Fig. 3 by dashed lines and *Di* and *V*(calc.) or *V*(obs.) for these paths are added in Tables II and III. The present division is found to be quite satisfactory also for these data. Oborina's (1961) results also agree.

Table II – TRAVELLING PATH LENGTHS (IN km) FOR EACH REGION ALONG EVERY PATH.

No.	D_1	D_3	D_5	D_7	D
23	90	1990	2100	2520	6700
94	290	1530	1750	3530	7100
143	740	1420	230	4860	7250
27	490	980	1150	4940	7560
01	0	380	250	2670	3300
20	260	1270 (660)	1850 (390)	4180	7560
90	0	1520 (840)	1260 (200)	4650	7430
02	150 (150)	1290 (680)	1050 (50)	4910	7400
14	0	0	370	6470	6840
C24	0	260	1280	1430	2970
C10	640	1070	540	1050	3300

Furthermore, the same authors studied the appearance of Lg along many paths crossing the Arctic Ocean. Their observations are also satisfactorily explained if we consider the regions (1) and (3) to prevent the propagation of Lg.

Another point must be added here concerning the relation between the depth of the sea and the dispersion character of Rayleigh waves.

Table III – Calculated V(calc.) and observed V(obs.) group velocities (in km/sec) of Rayleigh waves along different paths for three different periods.

t_i — travel time within each region, i = 1, 3, 5, 7.

	T = 25 sec							T = 30 sec							T = 35 sec						
No	t_1	t_3	t_5	t_7	Σt_i	V (calc)	V (obs)	t_1	t_3	t_5	t_7	Σt_i	V(calc)	V(obs)	t_1	t_3	t_5	t_7	Σt_i	V(calc)	V(obs)
23	23	526	584	788	1921	3.49	3.45	22	515	567	740	1844	3.63	3.60	22	506	500	720	1798	3.73	3.74
94	74	405	487	1100	2066	3.44	3.44	72	396	473	1040	1981	3.58	—	72	390	463	1010	1935	3.67	—
143	188	376	64	1510	2138	3.39	3.36	185	367	61	1430	2043	3.55	3.54	183	362	61	1390	1996	3.63	3.63
27	125	259	320	1530	2234	3.38	3.36	122	253	311	1450	2136	3.54	3.55	121	249	304	1410	2084	3.63	—
01	0	100	70	830	1000	3.30	3.29	0	98	68	786	952	3.47	3.46	0	97	66	763	926	3.56	3.56
20	66	336	515	1300	2217	3.41	3.41	65	328	500	1230	2123	3.56	3.57	65	324	490	1195	2074	3.65	3.67
90	0	403	350	1443	2196	3.38	3.30	0	393	342	1365	2100	3.54	3.50	0	387	333	1330	2050	3.62	3.62
02	38	342	292	1525	2197	3.37	3.35	37	334	284	1445	2100	3.52	3.50	37	329	278	1405	2049	3.61	—
14	0	0	103	2010	2113	3.24	3.26	0	0	100	1904	2004	3.41	3.40	0	0	98	1850	1948	3.51	3.49
C24	0	69	356	445	870	3.41	3.40	0	67	346	420	833	3.57	—	0	66	339	409	814	3.65	—
C10	163	284	150	326	923	3.58	3.64	160	277	146	309	892	3.70	—	159	272	143	300	874	3.78	—

In previous investigations (Santo 1961), the writer found that on the western side of the Andesite line, Rayleigh waves still exhibit a dispersion character of (3) even in a sea region deeper than 4000 m. This was considered characteristic for the crustal condition on the western side of the Andesite line. On the eastern side of that line, Rayleigh waves show " purely oceanic dispersion character " of (1) in sea regions deeper than 4000 m. Our present division map of the Arctic Ocean tells us that Rayleigh waves have a purely oceanic character (1) only in regions of more than 4000 m depth. Though the writer has not finished his studies of the relation between the depth of the sea and the dispersion character of Rayleigh waves in the whole vast area east of the Andesite line, i. e. in the ordinary Pacific Ocean area, the Arctic Ocean seems to have the same relation between sea depth and crustal condition as the Pacific Ocean excluding its south-western part. This suggestion agrees with the section of the crust across the region (1) as given by Hope (1958) according to Demençkaya.

It must also be noticed from the division map that there are a few exceptional regions in which the crustal condition may be a little more oceanic than to be expected from the sea depth. These regions are limited by dotted and dashed-dotted curves in the map. For instance, the region from New Siberian Islands (N.S. Is.) towards southeast has the characteristic number (5) instead of (7), which is expected from the sea depth, shallower than 1000 m.

The bathymetric map in Fig. 3 was modified from the Time Atlas (London Press 1959). There is another much more detailed map, given by Heezen and Ewing (1961), based upon Soviet data. Comparing these two maps, there are some slight differences. But it was found that these differences were so small as to be of no consequence for our conclusions.

Dispersion of surface waves in the Atlantic Ocean.

Travelling paths of surface waves and data of shocks are given in the map of Fig. 4 and in Table IV respectively.

An interesting fact can be recognized in the Rayleigh wave dispersion in diagram *b*) of Fig. 4 for several Chile shocks. That is, the group velocities in longer period range are somewhat depressed compared to the classified curves (5) and (6). In Part I the same feature was recognized along paths through the southern part of the Mid-Atlantic

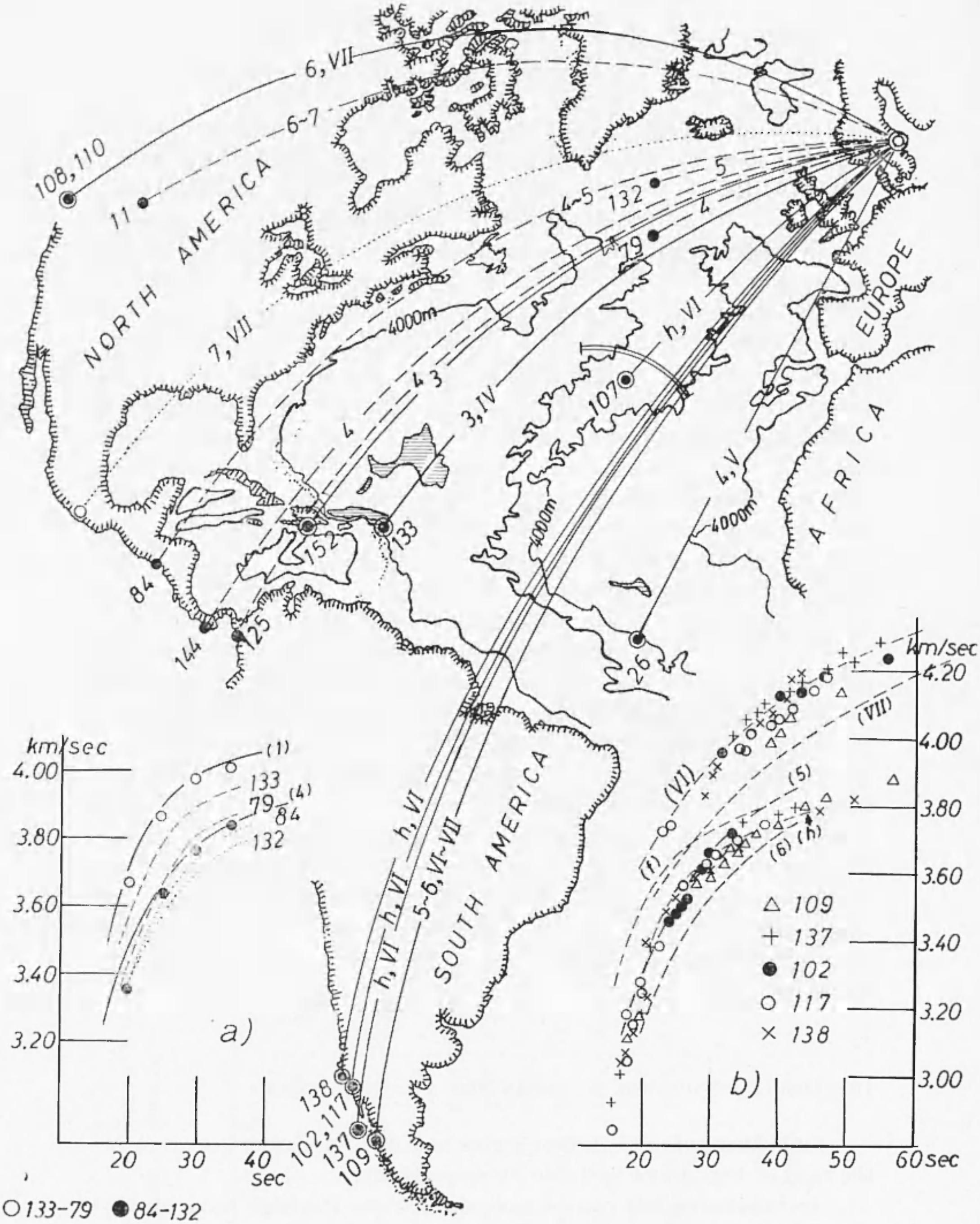

Fig. 4 – Travelling paths of surface waves in the Atlantic Ocean. Depth contour in the ocean corresponds to a depth of 4000 m, and the hatched region indicates depths exceeding 6000 m. Double arc line north of epicenter 107 is the refraction profile by Ewing and Ewing (1959). A dotted line over the North American continent is the path along which surface wave dispersion was observed by Båth (1959).

a) Calculated group velocities of Rayleigh waves between two epicenters (133-79), (84-132).

b) Dispersion from Chile shocks. A reference curve (*h*) means the smoothed dispersion curve from 107 to Uppsala (see Fig. 5-*a*).

Table IV – List of shocks for Atlantic region

No.	District	Date	Origin Time (G.M.T.)	Epicenter	h km	M	D km
132	North Atlantic Ocean	Oct. 06 1960	$19^h55^m42.2^s$	58.2°N 31.6°W	63	—	2775
79	North Atlantic Ocean	Apr. 30 1961	07 33 53.5	52.0 N 31.9 W	38	5.5	3100
107	North Atlantic Ocean	June 08 1960	16 19 48	35 N 35 W	—	—	4660
26	Atlantic Ocean	Aug. 30 1961	03 35 07.7	7.0 N 33.2 W	69	—	7230
84	El Salvador	Apr. 12 1961	22 20 33.6	13.1 N 88.9 W	122	6	9670
144	Off south coast of Panama . . .	Mar. 28 1960	00 13 38	7.5 N 82 W	—	6.5	9840
125	Colombia-Panama border	Sept. 19 1960	19 01 25.4	6.9 N 77.5 W	66	6	9640
152	Near south coast of Dominican Republic	June 08 1962	01 00 24.2	18.5 N 70.5 W	63	6.5	8160
133	Leeward Islands	May 31 1960	11 02 20	18 N 62 W	—	6.5	7730
138	Near coast of Chile	Nov. 01 1960	08 46 01.9	38.4 S 74.4 W	97	7	13700
102	Chile	June 20 1960	12 59 40	39.5 S 73 W	—	7	13700
117	Near coast of Chile	Aug. 13 1960	14 14 57.7	39.7 S 74.8 W	61	—	13850
137	Off coast of Chile	May 25 1960	08 34 33	45 S 76 W	—	6.5	14350
109	Near coast of Chile	June 06 1960	05 55 44	45.5 S 73.5 W	—	7	14280
108	Off coast of Northern California .	June 06 1960	01 17 48	41 N 125 W	—	5.5	8325
110	Off coast of Northern California .	Aug. 09 1960	07 38 22.6	40.0 N 126.6 W	25	—	8480
11	Central Idaho	June 11 1961	17 13 45.5	44.5 N 114.8 W	25	—	7650

Ridge. It is quite natural to assume the special feature to result from the special crustal condition beneath the Mid-Atlantic Ridge. This suggestion is ascertained by the Rayleigh wave dispersion from shock 107, of which the path covers the northern part of the Mid-Atlantic Ridge. The dispersion data from this shock are shown in diagram *a*) of Fig. 5. In this diagram, data for other shocks along the Mid-Atlantic Ridge are also given. Considering the path, Rayleigh wave dispersion from shock 107 only is expected to belong to a special type. We denote this by (*h*), which is also shown in diagram *b*) of Fig. 4 for comparison.

In the diagram *a*) of Fig. 5, the southern two shocks 107 and 26 only could supply us with Love wave dispersion data. The path from 26 contains the larger percentage of oceanic region and exhibits a more oceanic type (V) than the former (VI). The characteristic curve (V) corresponds to a theoretical curve B, calculated by Yamaguchi (personal communication; see also Yamaguchi and Kizawa 1961) for a crustal model as shown in the right hand of Fig. 5. Rayleigh wave dispersion from shock 26 is also more oceanic (4) than from 107.

Diagram *b*) in Fig. 5 shows the dispersion of Love waves from shocks 152 and 133 and Rayleigh waves along paths over the western part of the Atlantic Ocean. Love wave dispersion data agree well with an oceanic reference curve (IV) which also corresponds to a theoretical curve A calculated by Press and Ewing (1955) for a crustal structure as shown in the right hand of Fig. 5. The dispersion of Rayleigh waves is most continental (4-5) along the path from 84 to Uppsala, which passes very near the eastern coast of North America, and most oceanic (3) along the paths from 152 and 133 to Uppsala, which pass near the deep sea region with a depth of more than 6 km. All these results are quite reasonable.

From two pairs of Rayleigh wave dispersion data for (84, 132) and (133, 79), regional group velocities of Rayleigh waves between these epicenters have been calculated. The results are given in Fig. 4 *a*) by filled and open circles respectively. They agree well with the classified curves (4) and (1) respectively.

Though they contain only a small part of North Atlantic Ocean, the dispersion data from 108, 110 and 11 are shown in the diagram *c*) of Fig. 5. In the same diagram, the dispersion data (triangle marks) obtained by Båth (1959) along a path, marked by a dotted line in Fig. 4, are added. His data belong to (VII) for Love and to (7) for Rayleigh wave dispersion respectively.

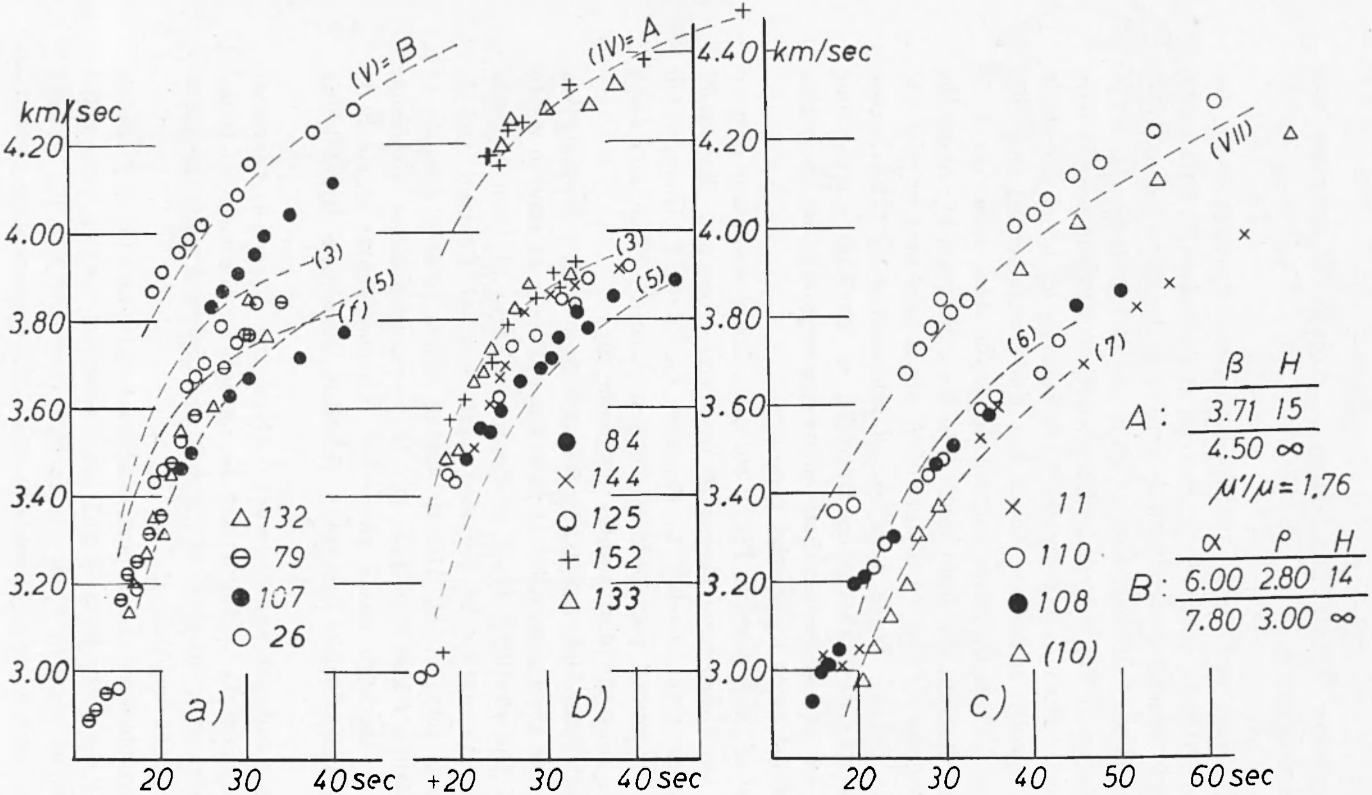

Fig. 5 – *a*) Dispersion for shocks in the Mid-Atlantic Ridge. Rayleigh wave dispersion from shock 107 (filled circles) show a special type, for which the symbol (*h*) is used.
b) Dispersion data for the Atlantic Ocean.
c) Dispersion data along paths through Canada and Greenland.
α and β: velocities of P and S waves in km/sec respectively.
H: thickness of the layer in km.
ρ: density in gm/cc.
μ'/μ: ratio of rigidity between lower and upper medium.

SOME DISCUSSION ABOUT THE CRUSTAL CONDITION BENEATH THE ATLANTIC OCEAN.

Oliver, Ewing and Press (1955 *b*) determined Rayleigh wave dispersion along Atlantic paths by the records at Palisades (P), Ottawa (O) and Kew (K). Similar determinations were made by Berckhemer (1956) by the records at Palisades, Kew, Lisbon (L) and M'Bour (M). The paths are shown in Fig. 6 by solid lines together with the present ones (dashed lines). Their data are plotted in diagrams *a*), *b*), *c*) and *d*), in which the velocity scales are about ten times exaggerated over the original ones. These diagrams contain dispersion data from shock 7*b* to Palisades (diagram *a*)), from shock 8 to Kew (diagram *b*)), along the paths V (diagram *c*)) and VI (diagram *d*)) which pass over or near the Mid-Atlantic Ridge. These data are all represented by filled circles. It is noteworthy that the group velocities of Rayleigh waves along these paths are all depressed in their long period range without exception, i. e. they all belong to the special type (*h*).

As most of these paths in Fig. 6 contain a large percentage of deep sea region, their dispersion characters are typical oceanic. Especially Rayleigh waves from shock 8 to Palisades, Ottawa and Lisbon, which pass over the central part of northwestern Atlantic Basin and Cape Verde Basin, show the most oceanic character (0).

Any path from Chile shocks, for instance from 138, to Uppsala can be divided into three segments: 1) from the epicenter to 4000 m depth contour off the northern coast of South America, 2) from Uppsala to 4000 m depth contour off the southwest coast of England and 3) the remaining segment of Atlantic Ocean which mostly consists of the Mid-Atlantic Ridge (see Fig. 4). If we assume some dispersion characters of Rayleigh waves along the two continental segments 1) and 2), we can calculate the group velocities along the Mid-Atlantic Ridge.

We have not yet any knowledge about the dispersion character along the segment 1). But it may be natural for the moment to assume the dispersion character (8'), which was observed along the Asian continental paths (see Part I).

We have observed the dispersion characters (4) and (5) of Rayleigh waves along the paths from 79 and 132 respectively, which occupy the same region as segment 2) in the present case (see Fig. 4). Taking into account that segment 2) contains much higher percentage of conti-

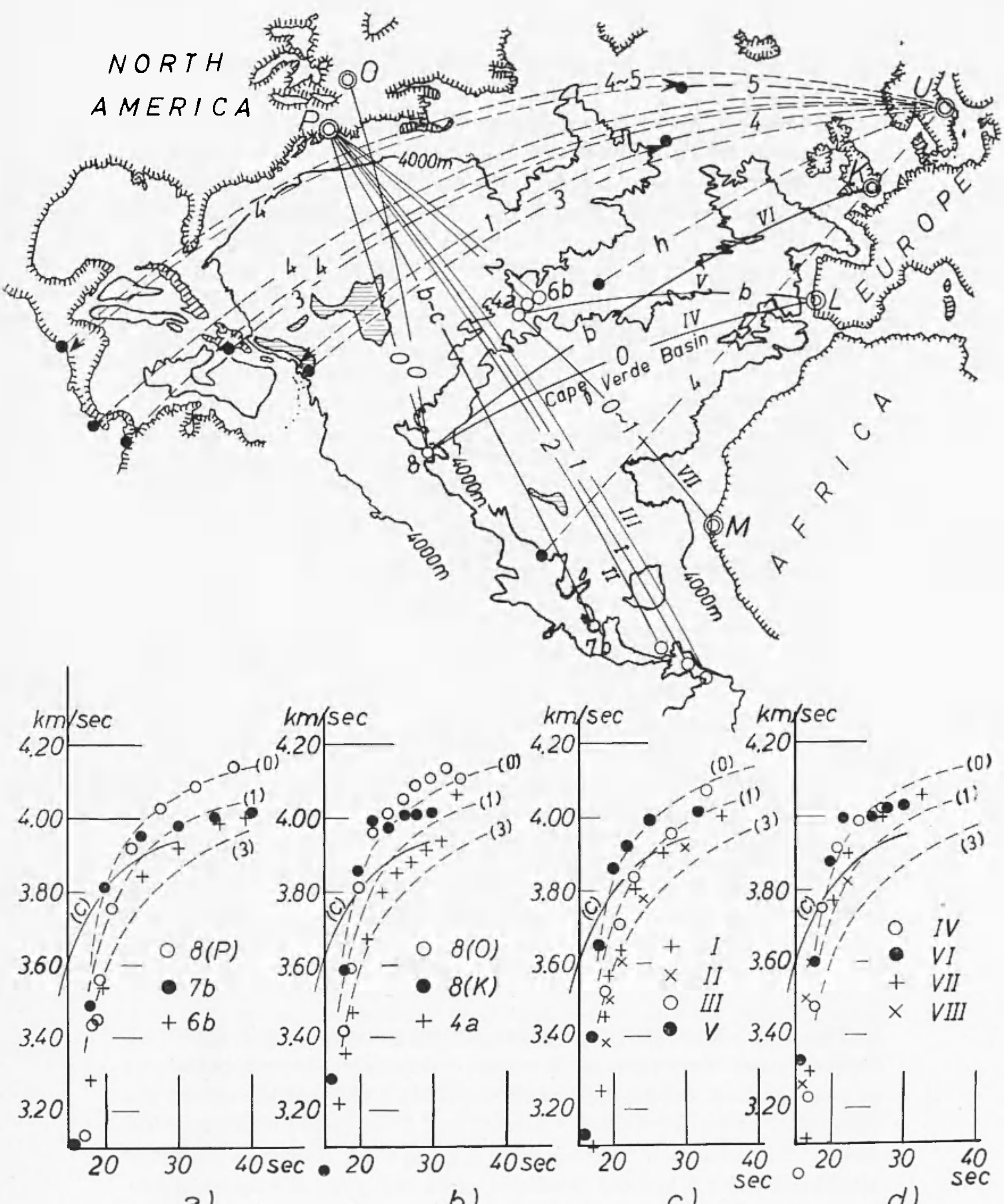

Fig. 6 – Travelling paths of Rayleigh waves over the Atlantic Ocean from other authors (solid lines) together with the present ones (dashed lines). Shock numbers or the name of paths follow the original papers. Six observation stations are marked by double open circles. Two regional dispersion curves, (1) and (4), of Rayleigh waves between two pairs of epicenters (133-79) and (84-132) respectively, shown in Fig. 4-*a*), are given. *a*), *b*) Rayleigh wave dispersion data by Oliver, Ewing and Press (1955 *b*). *c*), *d*) Rayleigh wave dispersion data by Berckhemer (1956).

nental structure than these two, the dispersion character (6) may be assumed for the segment 2).

The path lengths along the three segments D_1, D_2 and D_3 are approximately 6000 km, 2000 km and 5700 km respectively. We can then calculate the travel times and group velocities of Rayleigh waves along the segment 3) (Table V). The results are plotted by filled circles

Table V – NUMERICAL DATA OF THE CALCULATION AND THE RESULTING GROUP VELOCITIES OF RAYLEIGH WAVES ALONG THE CENTRAL MID-ATLANTIC RIDGE.

T = period; V — observed group velocity of Rayleigh waves along the total path; V_1 and V_2 = assumed group velocities of Rayleigh waves along the segmens 1) and 2), D = total path length; D_1, D_2 and D_3 = path lengths along the segments 1), 2) and 3) respectively; V_3 = calculated group velocity of Rayleigh waves along the segment 3).

	Group velocity (km/sec)			Travel time (sec)				
T	V	V_1	V_2	D/V	D_1/V_1	D_2/V_2	D_3/V_3	V_3
45	3.78	3.62	3.78	3620	1655	530	1435	3.97
40	3.74	3.55	3.72	3660	1690	538	1432	3.98
35	3.69	3.45	3.62	3710	1740	553	1417	4.02
30	3.61	3.30	3.51	3800	1820	570	1410	4.04
25	3.48	3.11	3.35	3940	1930	598	1412	4.03
20	3.28	2.94	3.12	4180	2040	641	1500	3.80

in Fig. 7-*a*). Two curves are given for comparison in this figure. A dashed-dotted curve (*c*) is a dispersion curve observed along paths over or near the East Pacific Rise (Santo and Båth 1962) and the dotted is a theoretical curve calculated by Kovach and Press (1961) for their model 1588. This consists of a water layer 4.1 km thick overlying a crust of total thickness 5.2 km and consisting of three layers; the upper mantle has fourteen layers, including a 33 km thick low-velocity layer beginning three km below the Mohorovicic discontinuity.

In Part I we found that Rayleigh wave dispersion from shock 21 (Sandwich Islands region, 56.1°S, 27.3°W, Sept. 08, 1961) also showed a special type (*f*). We can then make the same investigation assuming the dispersion character of Rayleigh waves along the continental part, from Uppsala to the 4000 m depth contour off southwestern coast of Africa (see the central map of Fig. 7). In this case, a characteristic

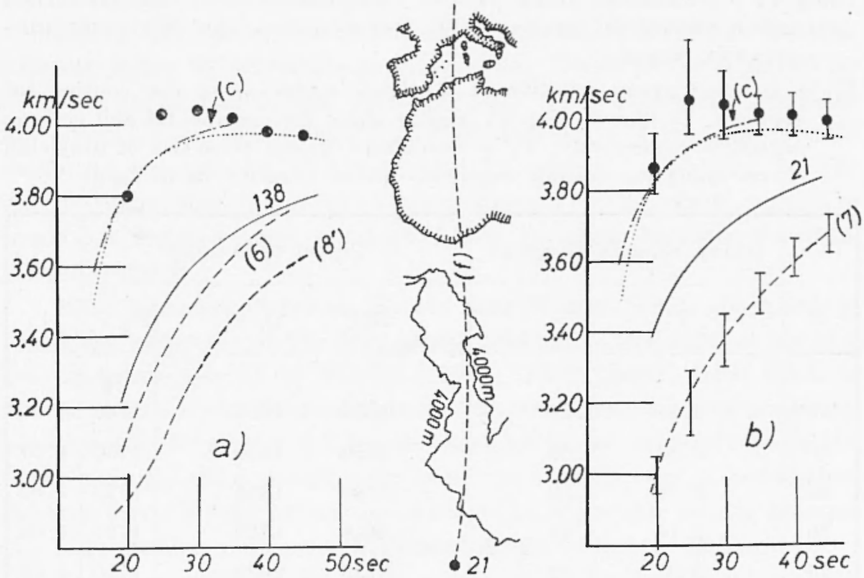

Fig. 7 – *a*) Filled circles: calculated group velocities of Rayleigh waves along a path over the central Mid-Atlantic Ridge.

Solid curve: observed dispersion of Rayleigh waves from 138.

Dashed curves: assumed dispersion of Rayleigh waves along the two continental paths.

Dotted curve: theoretical dispersion after Kovach and Press (1961) for the model 1588.

Dashed-dotted curve: Classified curve (*c*).

b) Similar to diagram *a*) but for shock 21.

Upper and lower limits of vertical bars around the curve (7) mean the group velocities of Rayleigh waves when they follow the characteristic curves of (6-7) and (8') respectively, and lower and upper limits around filled circles mean the corresponding result.

Middle map: A part of the travelling path from 21 (dashed line). Location of Ridge is indicated by the depth contour of 4000 m.

curve (7), slightly more oceanic than (8') was assumed for the continental segment, because the characteristic numbers (6) to (7) were found for other parts of Africa (Part I). The group velocities of Rayleigh waves as calculated for the oceanic segment containing the southern part of the Mid-Atlantic Ridge are given in Table VI and Fig. 7-*b*). It is interesting to note, that the results are nearly the same as in the previous case.

Table VI – NUMERICAL DATA OF THE CALCULATION AND THE RESULTING GROUP VELOCITIES OF RAYLEIGH WAVES ALONG THE SOUTHERN MID-ATLANTIC RIDGE.

V_1 = assumed group velocity of Rayleigh waves along the continental segment, D_1 and D_2 = path lengths along the continental and oceanic segments respectively, V_2 = calculated group velocities of Rayleigh waves along the oceanic segment. Other notation as in Table V.

	Group velocity (km/sec)		Travel time (sec)			
T	V	V_1	D/V	D_1/V_1	D_2/V_2	V_2
45	3.84	3.68	3500	1765	1735	4.00
40	3.81	3.60	3530	1800	1730	4.01
35	3.76	3.50	3580	1855	1725	4.02
30	3.70	3.38	3640	1920	1720	4.04
25	3.61	3.22	3730	2020	1710	4.06
20	3.40	3.00	3960	2163	1797	3.87

It is important to know to what extent the calculated dispersion along the purely oceanic segments is influenced by the assumed dispersion along other segments. For this purpose, the group velocities of Rayleigh waves along the continental segment in the second case were changed in the range shown by vertical bars around the curve (7). In Fig. 7-*b*) upper and lower limits of vertical bars around the curve (7) mean the group velocities of Rayleigh waves when they follow the characteristic curves of (6-7) and (8') respectively, and lower and upper limits around filled circles mean the corresponding calculated results. The calculated group velocities of Rayleigh waves lie very well on the theoretical curve, when we assume (6-7) curve along the continental segment. As the continental segment in this case contains both the Mediterranean Sea and a water-covered region south of Africa, velocities lower than curve (7) are unlikely for this segment. This means that oceanic velocities higher than the dots are unlikely. In any case, the special dispersion character found for Rayleigh waves, i. e. the depressed group velocities in the longer period range, is predominant both along the central and the southern Mid-Atlantic Ridge. Moreover, if the assumptions made for other segments are correct, they are both similar to that along the Eastern Pacific Rise.

Ewing and Ewing (1959) studied the crustal structure on the Mid-Atlantic Ridge by refraction measurements. Their profile is shown by a double arc in Fig. 6, near epicenter 107. They observed remarkable low compressional velocities (7.2-7.3 km/sec) under a layer of basaltic rock with the velocity of 5.15 km/sec in average. Referring to the gravity anomalies found by Vening Meinesz (1948), they suggest a « root », a massive layer as thick as 30 km just beneath the Mid-Atlantic Ridge.

More recently, Talwani, Heezen and Worzel (1961) discussed in detail the structure of the Mid-Atlantic Ridge in the light of the new gravity measurements by Worzel (1959). They present three kinds of crustal models under the assumption of the usual values of compressional velocity and density of 8.2 km/sec and 3.4 gm/cc respectively in the upper mantle. The model considered most likely, has a bell-shaped inserted layer of 7.00 km/sec and 3.05 gm/cc above the mantle beneath the Ridge with a maximum thickness of approximately 15 km.

Tryggvason (1961) also found a layer of 7.4 km/sec from his study of travel times of body waves from four earthquakes in the central part of the sea area between Greenland and Norway. This 7.4-layer was found by the same author (Tryggvason 1962) also from dispersion of surface waves along the northern Mid-Atlantic Ridge including Iceland. He supposed that this 7.4-layer might belong to the mantle, although its wave velocity is significantly lower than usually found in the upper mantle.

From the refraction data by Raitt and Shor, Menard (1960) suggests that the mantle with a low velocity might ascend beneath the Eastern Pacific Rise.

The present results of Rayleigh wave dispersion along paths over the Mid-Atlantic Ridge agree with these models at least in one respect, i. e. they indicate a rather shallow discontinuity beneath the Ridge. Furthermore, the calculated group velocities of Rayleigh waves along the Mid-Atlantic Ridge, given in Fig. 7, require a low-velocity layer beneath the Ridge.

CONCLUSIONS.

Dispersion of Love and Rayleigh waves of the first mode were investigated along various paths in the Arctic and Atlantic Ocean by means of records at Uppsala. The Arctic Ocean is divided into four regions (1), (3), (5) and (7) with the Rayleigh wave dispersion characters (1), (3), (5) and (7) respectively (Fig. 3). The boundaries of the four regions coincide approximately with the depth contours of 4000 m, 2000 m and 1000 m respectively, expect in some areas of the eastern part of the ocean. The crustal structure of the Arctic Ocean thus exhibits the same relation to the depth of the sea, as found earlier for the Pacific Ocean, east of the Andesite line. It is also suggested that the region with more oceanic crustal structure than the region (3) may prevent the propagation of Lg waves.

For the Atlantic Ocean, we have reached the following conclusions:

1) Along the whole of the Mid-Atlantic Ridge, Rayleigh waves show a special dispersion character, which agrees well with the existence of a « root » under the Mid-Atlantic Ridge, which Ewing and Ewing (1959) suggest by their refraction measurements.

2) The crustal structure in the southern part of northwestern Atlantic Basin and Cape Verde Basin are as oceanic as in the central part of the Pacific Ocean.

3) The crustal structure in the northern part of Atlantic Ocean corresponds in average to dispersion character (5).

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SUMMARY

Group velocity dispersion of surface waves of the first mode along various oceanic paths is investigated by means of records at Uppsala. The Arctic Ocean can be divided into four regions according to the character of Rayleigh wave dispersion. Rayleigh waves which pass over or near the Mid-Atlantic Ridge show a special dispersion character, the same as found along paths over or near the Eastern Pacific Rise.

RIASSUNTO

Presso l'Università di Uppsala, è stata studiata, a mezzo di sismogrammi, la dispersione del primo modo della velocità di gruppo delle onde superficiali, lungo tragitti oceanici.

Per il tipo di dispersione delle onde di Rayleigh, l'Oceano Artico può essere diviso in quattro zone.

Le onde di Rayleigh che attraversano o sfiorano la dorsale Media-Atlantica, hanno un particolare tipo di dispersione, lo stesso che è stato trovato per i tragitti che interessano l'Oceano Pacifico Orientale.

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