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EXPERIMENTAL VERIFICATION OF THE GEOSTROPHIC WIND EQUATION

J. M. Sharp, Department 5140

November 14, 1952

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ABSTRACT

Test procedures, instrumentation, and results of 13 flight tests specifically designed to check the accuracy of the geostrophic wind equation are discussed. Tests were conducted at altitudes in the vicinity of 25,000 feet and each flight covered a distance of the order of 100 air miles and/or an average period of 25 minutes. The results of the tests show that the geostrophic wind equation permits altitude control with a standard deviation not exceeding 55-60 feet for distances of 100 nautical miles and/or periods of one-half hour.

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EXPERIMENTAL VERIFICATION OF THE GEOSTROPHIC WIND EQUATION*

The geostrophic wind equation relates the slope of an isobaric surface to the wind existing at that surface. The purpose of this report is to explain the application of the equation and the purpose for which the tests described herein were conducted.

Anyone familiar with meteorological charts is aware that a constant pressure surface is not a constant altitude surface. The contour lines on a constant pressure chart join those geographical points at which the pressure level of interest occurs at the same altitudes above sea level. Therefore, if an aircraft flies at constant pressure along a contour line, it flies at constant altitude; whereas, if it flies at constant pressure across contour lines, it gains or loses altitude depending upon whether its course is toward a low or high pressure area. Further, it has been established that the wind flows in a counterclockwise direction around a low pressure center and in a clockwise direction around a high pressure center in the northern hemisphere. Therefore, if an aircraft experiences right drift during a flight it must be headed toward a low pressure area and must be losing altitude if it is flying at constant pressure. The geostrophic wind equation attempts to relate the amount of cross wind to the change in altitude such that winds may be computed from observations of height change or vice versa.

The geostrophic wind equation is based upon the two fundamental assumptions that (1) the pressure distribution in the atmosphere is static and (2) the isobars have zero curvature. The equation derived on the basis of these assumptions is

$$\Delta h = \frac{W_n d \sin\phi}{21.47}$$

where Δh = Change in absolute altitude in feet, positive for left drift and negative for right drift

W_n = Component of wind normal to true heading in knots

d = Air distance flown in nautical miles

ϕ = Latitude

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*The geostrophic wind equation and its application to pressure navigation are unclassified. Its application to nonradiation type fuzing of airburst weapons is Confidential Restricted Data. The location and coverage of radar stations of the Western Air Defense Force, which can be deduced from the contents of this report, are Secret Security Information (nonrestricted data).

The range of application of these assumptions is obviously limited; however, the equation has been used extensively in pressure navigation procedures with good success. In pressure navigation, the equation is used in reverse to the way it is written above in that Δh is a measured quantity and W_n the computed quantity. The successful use of the equation in navigation is really adequate proof of its validity; however, it does not establish the order of accuracy that can be expected from the equation for the particular application to be discussed here.

Sandia Corporation has been interested in the equation as a means of establishing the relative altitude of an aircraft above a target, particularly as applied to strategic bombing. An accurate determination of relative altitude is essential to the success of a time-of-fall or distance-of-fall fuzing system for airburst weapons. The manner in which the equation is used in establishing relative altitude is merely that of computing, from wind observations, the change in altitude of an aircraft flying at constant pressure after an initial absolute altitude has been established by a radio altimeter measurement taken over a flat surface of known altitude. A theoretical evaluation of the errors in the geostrophic wind equation together with a detailed description of its use in connection with relative altitude determinations are included in SC-2439(TR), Time-of-Fall Fuzing System Feasibility for Strategic Bombing, by C. E. Buell, dated August 1952. The results of the tests described herein are presented not so much to substantiate the error analysis presented by Buell as to demonstrate this method of altitude control and provide experimental evidence of its usefulness.

Participating Agencies

The tests were conducted under the direction of A. W. Boldyreff and the author, both of Department 5140, Sandia Corporation. Dr. Boldyreff established test procedures and requirements; the author participated in flight tests as the Sandia representative in charge of the tests.

The flight tests and the greater part of the data reduction were conducted by U. S. Air Force personnel with representatives of three major commands participating. Test procedures and requirements were furnished the 4925th Test Group (Atomic) which handled the coordination of USAF facilities and conducted the tests. Because of the necessity for conducting the tests over the ocean and the requirement for several experienced navigators to conduct the tests, Mather Air Force Base, Sacramento, Calif., was chosen as the test base and the Aerial Observer - Bombardier School at Mather was requested to furnish navigators for the tests. It was further decided that the course of the test aircraft during about one-half of the runs should be determined by Loran and during the remainder by radar; therefore, the participation of Air Defense Command radar stations in the Seattle area was requested. All agencies cooperated to the fullest extent. Officers participating directly in the flight tests were:

4925th Test Group (Atomic)

Maj. V. J. Schneider - Project officer in charge of tests
Capt. F. M. Early - Pilot
Capt. E. R. Follensbee - Co-pilot

AOB School

Capt. E. T. Yoeman - Navigator
Capt. J. Lambert - Navigator
1st Lt. J. D. Green - Navigator
Capt. Husztek - Navigator

Flight Test Requirements

Several requirements are imposed on a flight test program which is directed toward an experimental evaluation of the geostrophic wind equation. In general, these requirements originate with the necessity of controlling the variables in the equation, measuring those variables with greatest possible accuracy and obtaining test conditions which permit observations for sufficiently large values of the variables. These fundamental concepts must be analyzed in view of the type of aircraft available, the type and accuracy of navigation instrumentation on that aircraft, the type of ground instrumentation available for navigation, the capability of communications equipment both in the aircraft and at ground stations, and especially in view of the accuracy of the radio altimeter.

The best radio altimeter available for these tests was the SCR-718C. If proper alignment and operating procedures are followed, this instrument has a standard deviation in true altitude measurement of 35-40 feet at the altitude at which the tests were conducted. Fortunately, its use in connection with these tests is that of measuring a differential change in altitude and not true altitude; consequently, that portion of the standard deviation arising from systematic errors such as incorrect adjustment of the zero altitude position, incorrect calibration, etc is cancelled. Since the magnitude of the systematic error is not known, one can only state that the standard deviation is less than that quoted for absolute altitude measurements. A lower limit can be ascribed to the standard deviation, however, based simply on the readability of the visual altitude presentation of the SCR-718C. The smallest graduation of the SCR-718C altitude dial is 50 feet; this fact coupled with the flutter of the oscilloscope 'pip' imposes a limitation on readability of 20-25 feet. Also, the SCR-718C is somewhat limited in altitude range; it was not considered that flights over 30,000-35,000 feet were feasible because of this limitation.

The aircraft used for the flights was B-50 No. 168 assigned to the 4925th Test Group (Atomic). Aircraft equipment used in the tests consisted of Loran, a Mk-15 Norden bombsight, magnetic and gyroscopic compasses, astrodome, Kollsman airspeed indicators and altimeters, and HF and VHF communications. Ground stations consisted of the usual Loran installations and three radar stations equipped with long range warning and GCI radar with HF and VHF communications.

The object of the flight test program was, of course, to conduct an experimental check of the geostrophic equation. Therefore, it was necessary that the flights be such that a large change in altitude would be experienced while flying at constant pressure altitudes so that Δh be large as compared with errors in its measurement. Also, it was necessary that some flights be made wherein the change in altitude was a minimum.

Consideration of the objectives, general concepts, and test facilities available resulted in the following set of test requirements:

Flights must be conducted at high latitudes such that $\sin\phi$ does not seriously limit the magnitude of Δh. A minimum latitude of 40° was prescribed.

Flights must be conducted over a sufficiently long time period and distance that Δh may be large in view of the expected winds and also that times and distances comparable to those expected in application of this equation to strategic bomb fuzing be obtained. An average air distance of 100 nautical miles was prescribed.

Flights must be made only when winds at test altitude in excess of 50 knots are expected.

Flight test altitudes would range from 20,000-30,000 feet so that maximum wind would be obtained without exceeding the limits for SCR-718C reliability of operation. Those flights wherein the flight course was recorded by coast defense radar would be conducted in the immediate vicinity of 23,000 feet to assure continuous radar contact.

Flights must be conducted in a dynamically stable atmosphere. Areas where fronts of high turbulence exist must be avoided. A region having fairly straight isobars is necessary for obtaining a reasonably constant cross wind throughout a constant heading course of 100 air miles.

Flights must be conducted entirely over water such that continuous measurement of Δh during the flight is possible.

Constant pressure-altitude, airspeed, and heading must be maintained during each flight. The aircraft should not deviate by more than 100 feet in altitude, 5 mph in airspeed and 1° in heading during any test run. All measurements of Δh must be made at the same pressure-altitude if possible.

Drift measurements must be made periodically during each run. However, since drift measurements are difficult over water and since clouds at lower altitude may prevent such measurements, wind computations must be based primarily on the course record obtained by Loran or radar, the true heading maintained during flight, true airspeed, ground speed, and time measurements.

Each course of 100 nautical miles must be established by a minimum of ten Loran or radar fixes.

All aircraft instruments must be read simultaneously with Loran or radar fixes. Whenever possible, reading should be recorded automatically by means of a photo panel.

Flight Test Procedure

All missions were planned on the basis of a 12-hr weather forecast obtained from the Air Weather Service facility at Mather Air Force Base which also obtained by telephone supplemental current weather information from Fairfield-Suizon Air Force Base. The Weather Officer at Mather provided a prediction of winds and pressure distribution at the 300-mb level (approximately 30,000 feet) some six to eight hours prior to take off. A mission plan including eight to ten test runs was made on the basis of this prediction such that an equal number of minimum and maximum drift runs were to be made. Of course, winds at high altitudes are difficult to predict, particularly for ocean areas where only a minimum of weather information can be obtained. Flight plans therefore had to be altered in flight and test runs made on the basis of in-flight wind measurements.

All aircraft instrumentation was given a preflight calibration or ground check. The Loran set and the SCR-718C were calibrated by trained maintenance personnel from Mather prior to each take off.

Since it was necessary to record a large number of measurements simultaneously with radar and Loran fixes, flight logs were prepared for each of three sets of instruments. Three

navigators participated in each flight, each keeping one log. Navigators rotated jobs every second or third run; this was necessary to provide relief for the Loran operator because of the excessive eye strain resulting from making fixes continuously for periods of 20-30 minutes on each run. The 4925th Project Officer acted as First Navigator; as such he coordinated all recording and maintained contact with ground stations.

Loran flights were conducted in an area where the greatest resolution of the signals from each of two ground stations was possible. Radar flights were conducted in an area recommended by the Western Air Defense Force where continuous and accurate radar reception had been established by previous radar calibration flights. To provide continuous radar fixes for overwater flights of 100 miles it was necessary for three radars to participate in the tests.

With only minor exceptions, the test requirements listed in the previous section were fulfilled. These exceptions, all the result of the unpredictability of winds at high altitudes, were:

> The pressure field existing during tests was not as stable as desired. Data from two runs on Feb. 27, 1951 could not be used because they were conducted in an area where sharp curvature of the isobars occurred. A sharp isobar kink results in part of the run being made under minimum or low drift conditions and part under high drift conditions; consequently, an average value of W_n could not be established.
>
> In two cases the wind did not reach the desired velocity of 50 knots.
>
> In two cases the flight distance was substantially less than the required 100 nautical miles. A combination of adverse wind conditions and limited distance of radar coverage prevented obtaining both a 100-mile run and a completely overwater flight.

Summary of Results

The results of the 13 flights during which favorable test conditions were encountered are summarized in Table I. The ground distance listed in column (2) is measured from Loran or radar tracks of each flight. The wind listed in column (3) is computed from true heading, true airspeed, true course, and ground speed. The drift angle in column (4) is computed from true course and true heading. The figures shown in column (5) as theoretical Δh are computed from the geostrophic equation. The measured Δh shown in column (6) is the difference in true altitude at the beginning and end of the run as measured by the SCR-718C. Column (7) is the difference between the figures in columns (6) and (7); these figures represent the deviation between observed changes in altitude and those computed by means of the geostrophic equation.

In view of the errors in measurement, particularly of Δh, the differences shown in column (7) indicate errors in the geostrophic equation for only three runs. The errors computed for the other ten runs are 45 feet or less and deviations of this magnitude are within the probable error in measurement. Therefore, it is considered that the standard deviation of 55 feet computed on the basis of the figures in column (7) more nearly represents an upper limit for the standard deviation, and that the actual standard deviation is more likely that quoted by Buell in SC-2439(TR).

It must be emphasized that the standard deviation of Δh as computed from the geostrophic equation from true Δh is a function of both the elapsed time and distance traveled. The figures in Table I are representative only for times and distances of the order of magnitude of those

measured during these tests, that is, distances of approximately 100 miles and times of approximately 30 minutes. These results show that, for such times and distances, the assumption of a stable pressure distribution and straight isobars is justified and that the error arising from this assumption and from deviation of the geostrophic wind from actual wind is sufficiently small that this method of altitude control is acceptable.

TABLE I

Summary of Results of Flight Tests of the Geostrophic Equation*

(1) Run No.	(2) Ground distance	(3) Wind (knots)	(4) Drift angle (°)	(5) Theoretical Δh_T (ft)	(6) Measured Δh_M (ft)	(7) Difference ($\Delta h_T - \Delta h_M$)
			February 27, 1951			
1	92	98	15L	209	190	19
3	102	60	3L	53	-40	93
5	110	38	7L	125	80	45
6	133	58	11.5L	-216	-200	16
7	101	100	19.5L	289	180	109
			March 2, 1951			
1	107	74	18L	264	220	44
2	70	60	14R	-134	-110	24
3	93.5	58	11L	162	65	97
4	126.5	144	0.5R	-10	-20	10
5	98	130	14L	179	150	29
6	98	64	15.5L	206	225	19
7	72	40	4R	-41	20	21
8	108	56	0.5R	-5	0	5

Average deviation = 41 ft
Standard deviation = 55 ft

*All tests were made at altitudes between 22,480 and 27,350 feet and at latitudes between 40°50' and 48°25'.

APPENDIX A

The following tables and figures present all of the raw data taken during the flight tests necessary for the computation of Table I. These data are included not only to supplement the results presented in Table I but also to demonstrate (1) how well test conditions were controlled, (2) the completeness of the data, and (3) how Δh varied with small increments of time and distance.

Tables II and III show the data taken during the flights on Feb. 27, 1951. Table II includes the records of instrument readings at the pilot, co-pilot, engineer, and bombardier stations in the aircraft plus the records from the SCR-718C installed in the photopanel; the SCR-718C was read visually and recorded just prior to photopanel operation and all readings were subsequently checked against the film record. Table III is the record compiled by the navigator operating the Loran set. Figures 1 through 5 show the course of the aircraft on legs 1, 3, 5, 6, and 7 as plotted from the Loran fixes. The best straight line course through the plotted fixes is indicated. The straight line distance between the end points is that used as ground distance and the direction of this line is that used as the true course in all computations. Table IV summarizes the data necessary to compute Δh and indicates those corrections to the magnetic heading of the aircraft necessary to establish true heading. All aircraft compasses for which records were made were checked by astronomical observations prior to flying the first leg each day and were similarly checked periodically during each day's test. Two distance values are given for each leg; the top one is air distance and the bottom one is ground distance in each case. Two coordinates are given for each leg; the top one corresponds to the first fix and the bottom one to the last fix on each leg. Note that 12732W means 127°32' west latitude. Also the wind designated as 313/98 is that for a wind of 98 knots blowing from 313° as measured clockwise from true north.

Tables V, VI, and VII show the data obtained during the flights of March 2, 1951. Table V shows the same type of information as that in Table II. On March 2, coast defense radar was used to establish the course of the aircraft during legs 1 through 5 and Loran was used during legs 6 through 8. Table VI lists the range and bearing from the radars (code names Wild Bill, Gristmill, and Sheepman). The courses plotted from these radar fixes are shown in Fig. 6. Table VII lists the Loran fixes obtained during the last three runs. The courses plotted from the Loran fixes are shown in Figs. 7, 8, and 9. Table VIII shows the same type of information as that shown in Table IV.

Various symbols used throughout the tables follow:

CH	Compass heading	TH	True heading
IAS	Indicated airspeed	Var	Magnetic variation
MH	Magnetic heading	Dev	Magnetic deviation
TC	True course	TAS	True airspeed
GS	Ground speed		

TABLE II

Flight Data for Feb. 27, 1951*

Time	Photo panel CH	Pilot's IAS	Ind temp Eng	Ind temp Bomb	Pilot's MH	Co-pilot's MH	Pres air	SCR-718 radar alt	SCR-718 Δh
					Leg No. 1				
0958 1/2	259	194 1/2	-36	-37	259	255	28000	27100	
1005	259	196 1/2	-36	-36	259	253	28000	27120	
1010	259	196	-36	-36	260	255	28000	27150	
1015	259	196 1/2	-36	-36 1/2	259	254	28000	27190	
1020	259	201	-37	-37	260	255	28000	27250	
1024	259	198	-37	-37	260	255	28000	27290	+190
					Leg No. 2				
1029	336	198	-38	-39	335	335	28000	27290	
1035	336	199	-37	-39	335	336	28020	27260	
1040	336	196	-38	-39	334	334	28015	27260	
1045	336	197	-38	-39	335	335	28010	27250	
1050	334	204	-38	-39	334	334	28000	27200	
1055	336	200	-38	-39	335 1/2	336	28020	27140	
1100	336	198	-38	-39	335	335	28000	27100	-190
					Leg No. 3				
1107	255	201	-38	-38	255	251	28000	27100	
1112	255	200	-38	-38	255	250	28020	27080	
1117	254	198	-38	-39	255	250	28000	27080	
1123	254	196	-39	-38	256	249	28000	27080	
1128	255	200	-38	-38	256	250	28015	27080	
1133	256	198	-38	-38	256	249	28000	27060	-40
					Leg No. 4				
1143	150	196	-38	-38	150	152	27985	27140	
1149	150	196	-38	-38	150	156	28015	27200	
1154	151	197	-39	-38	150	154	28015	27200	
1159	151	200	-39	-38	150	153	28000	27250	
1203	151	197	-39	-38	150	153	28000	27250	+110
					Leg No. 5				
1205	150	198 1/2	-39	-38	150	154	28000	27270	
1211 1/2	151	196 1/2	-39	-38	150	151	28000	27320	
1217 1/2	151	196 1/2	-39	-38	150	153	28000	27360	
1224	151	197	-39	-38	150	154	28000	27350	
1227	151	196 1/2	-39	-38	150	158	28000	27350	+80
					Leg No. 6				
1236 1/2	045	198	-39	-38	045	055	28030	27350	
1245	045	197 1/2	-39	-40	045	054	28005	27350	
1250	045	194	-38	-38	045	053	27985	27290	
1255	046	197 1/2	-37	-38	045	057	28015	27220	
1300	045	198	-36	-38	045	053	28015	27190	
1305	045	199	-36	-38	045	054	28015	27150	-200
					Leg No. 7				
1339	225	196	-38	-38	225	216	28000	27170	
1345	225	196	-39	-38	225	214	27995	27210	
1350	224	198 1/2	-39	-38 1/2	225	215	28000	27250	
1355	225	197	-39	-39	225	214	28010	27290	
1400	225	198	-39	-38	224	213	28010	27310	
1403 1/2	225	197	-39	-38	225	212	28000	27350	+180

*Navigators were Schneider, Greene, and Lambert; pilots were Early and Follensbee.

TABLE III

Loran Data for Feb. 27, 1951*

Time	Station	Reading	Station	Reading
		Leg No. 1		
0958 1/2	2H3	1220	2H4	1180
1001 1/2	2H3	1272	2H4	1223
1004 1/2	2H3	1327	2H4	1247
1007 1/2	2H3	1361	2H4	1312
1010 1/2	2H3	1411	2H4	1344
1013	2H3	1432	2H4	1395
1016	2H3	1478	2H4	1428
1018	2H3	492	2H4	1474
1020 1/2	2H3	1522	2H4	1496
1024	2H3	1540	2H4	1531
		Leg No. 2		
1029	2H3	1593	2H4	1602
1031	2H3	1562	2H4	1673
1034	2H3	1395	2H4	1719
1037 1/4	2H4	1812	2H3	1333
1040	2H4	1888	2H3	1312
1042 1/2	2H4	1929	2H3	1272
1044 1/2	2H4	2013	2H3	1256
1047	2H4	2051	2H3	1221
1050	2H4	2154	2H3	1207
1052 1/2	2H4	2204	2H3	1174
1055	2H4	2327	2H3	1159
1057	2H4	2368	2H3	1138
1100	2H4	2500	2H3	1124
		Leg No. 3		
1107	2H4	2559	2H3	1145
1109	2H3	1160	2H4	2568
1112	2H4	2573	2H3	1184
1114	2H3	1195	2H4	2581
1116	2H4	2583	2H3	1209
1118	2H3	1218	2H4	2589
1120	2H4	2593	2H3	1232
1122 1/2	2H3	1246	2H4	2600
1124	2H4	2604	2H3	1253
1127	2H4	2611	2H5	2560
1130	2H5	2530	2H4	2623
1133	2H4	2628	2H5	2482

*Navigators were Lambert and Greene; pilots were Early and Follensbee.

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TABLE III (cont)

Time	Station	Reading	Station	Reading
		Leg No. 4		
1143	2H4	2422	2H5	2591
1146	2H5	2625	2H4	2305
1148	2H4	2361	2H5	2670
1150	2H5	2687	2H4	2195
1152	2H4	2042	2H5	2723
1155	2H5	2742	2H4	1979
1157	2H4	1988	2H5	2779
1159	2H5	2792	2H4	1948
1201	2H4	1919	2H5	2818
1203	2H5	2832	2H4	1847
		Leg No. 5		
1205	2H4	1801	2H5	2860
1207	2H5	2884	2H4	1715
1209	2H4	1675	2H5	2912
1212	2H4	1624	2H3	1795
1215	2H3	1848	2H4	1549
1217	2H4	1518	2H3	1905
1219	2H3	1948	2H4	1461
1221	2H4	1435	2H3	2028
1223	2H3	2060	2H4	1378
1225	2H4	1365	2H3	2138
1227	2H3	2188	2H4	1320
		Leg No. 6		
1236 1/2	2H3	2234	2H4	1226
1239 1/2	2H3	2223	2H4	1186
1242	2H3	2197	2H4	1168
1245	2H3	2180	2H4	1116
1248	2H3	2153	2H4	1093
1251	2H3	2111	2H4	1074
1253	2H3	2100	2H4	1048
1256	2H3	2058	2H4	1034
1259	2H3	2033	2H4	1010
1301	2H3	2002	2H4	1004
1305	2H3	1974	2H4	1001
		Leg No. 7		
1339	2H3	1657	2H4	1148
1341 1/2	2H3	1736	2H4	1163
1344	2H3	1828	2H4	1168
1347 1/2	2H3	1917	2H4	1184
1350 1/2	2H3	2012	2H4	1189
1353	2H3	2053	2H4	1199
1356	2H3	2132	2H4	1204
1358	2H3	2157	2H4	1209
1401	2H3	2229	2H4	1213
1403 1/2	2H3	2281	2H4	1218

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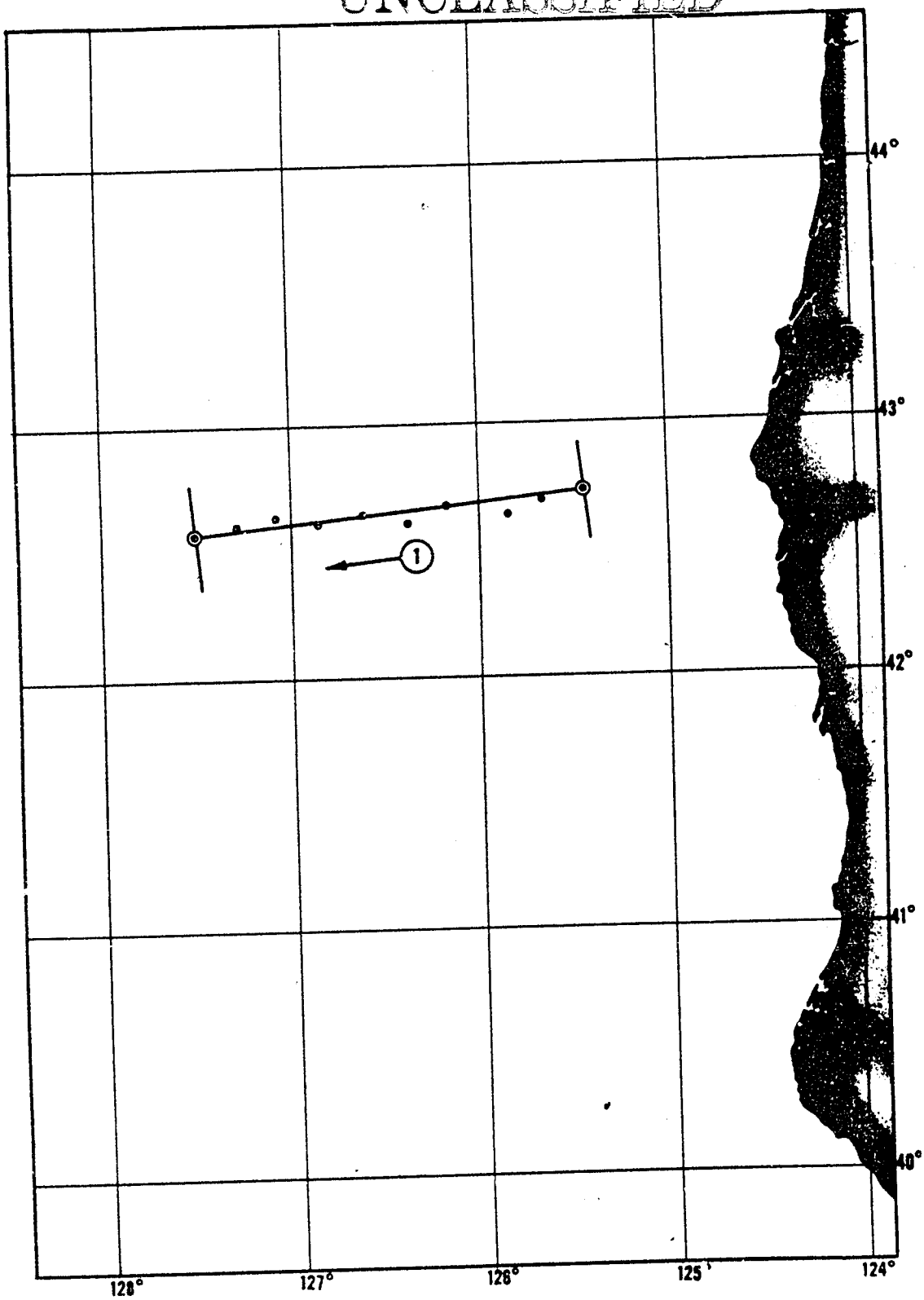

Fig. 1. -- Leg No. 1, Feb. 27, 1951

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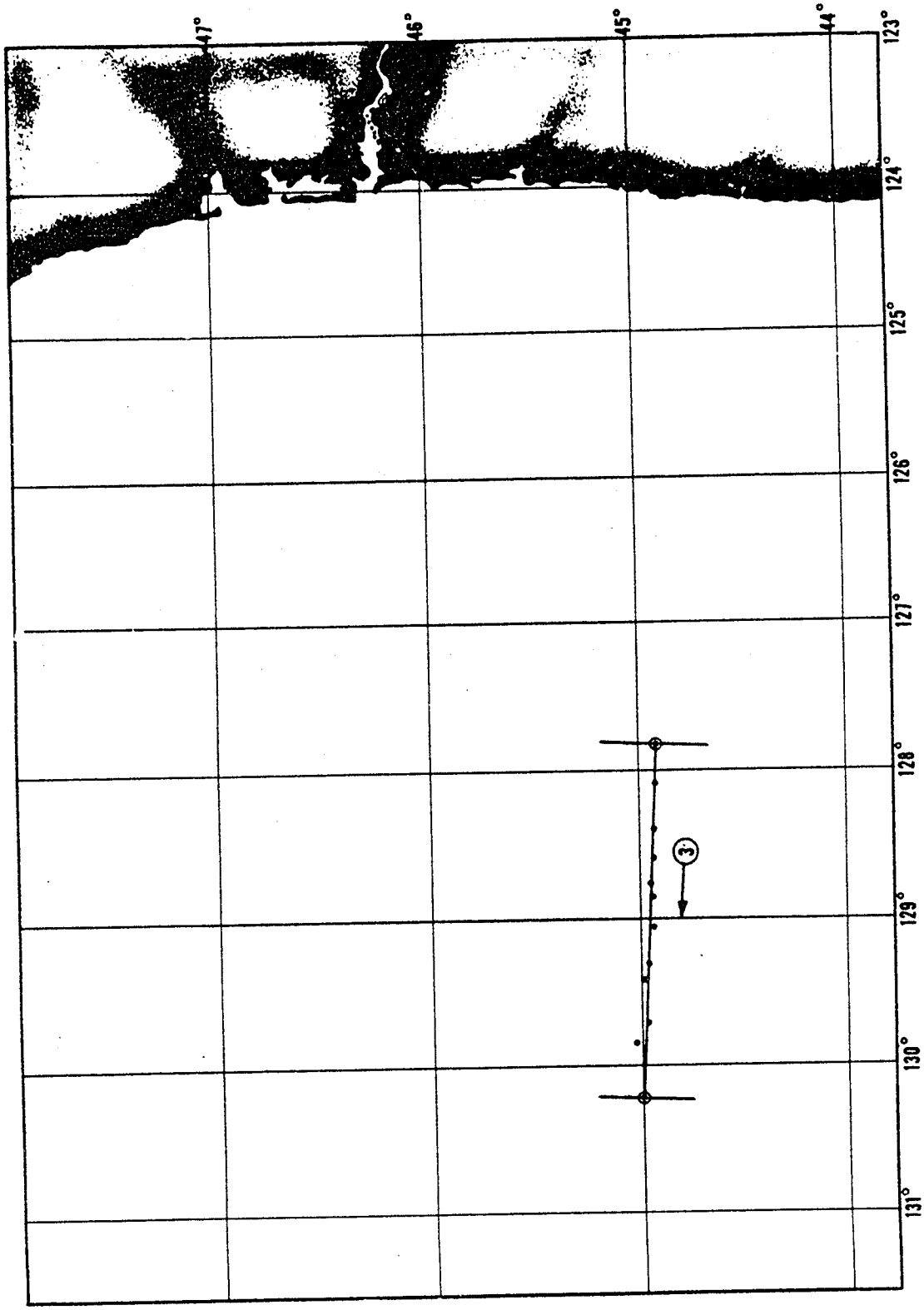

Fig. 2. -- Leg No. 3, Feb. 27, 1951

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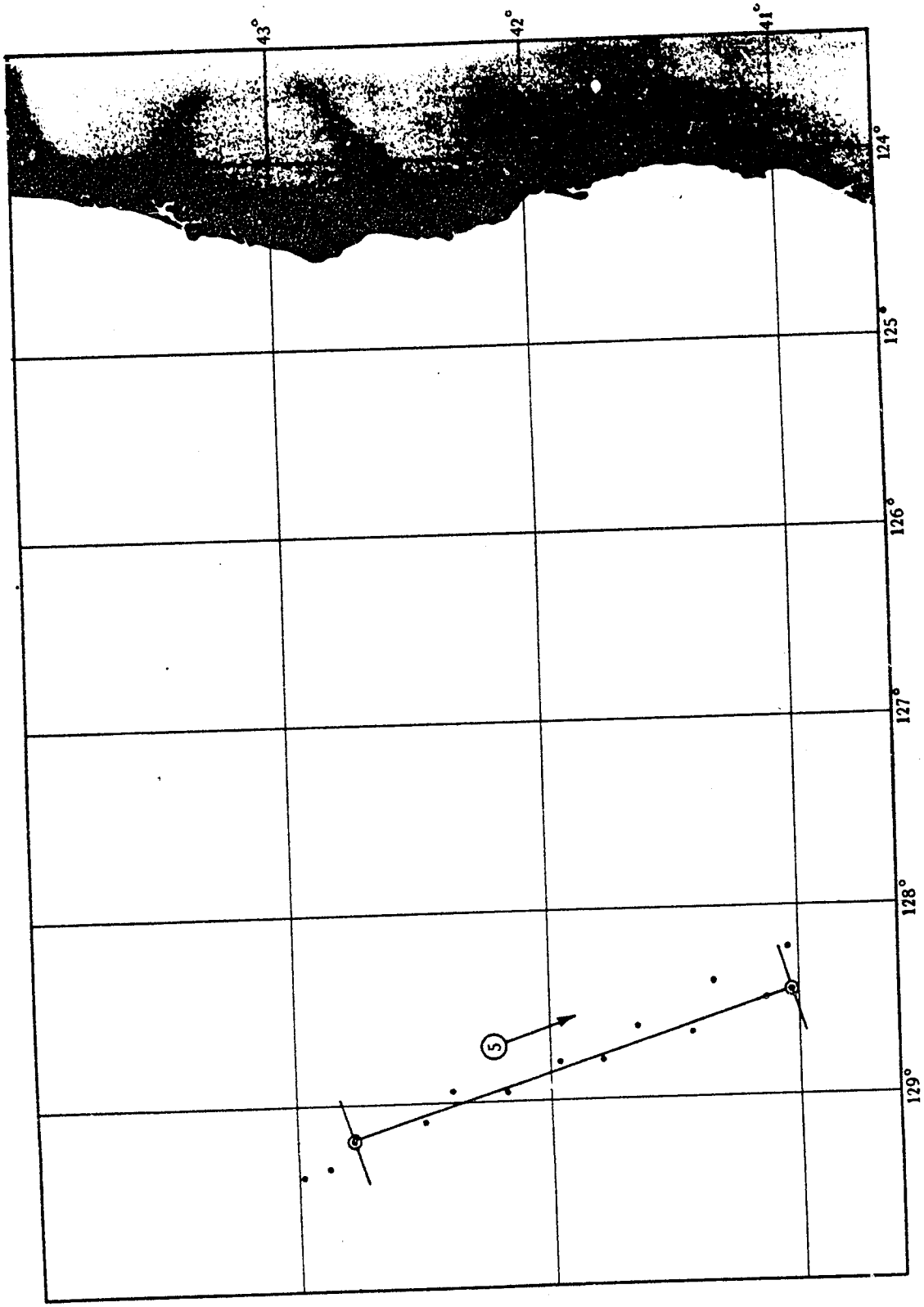

Fig. 3. -- Leg No. 5, Feb. 27, 1951

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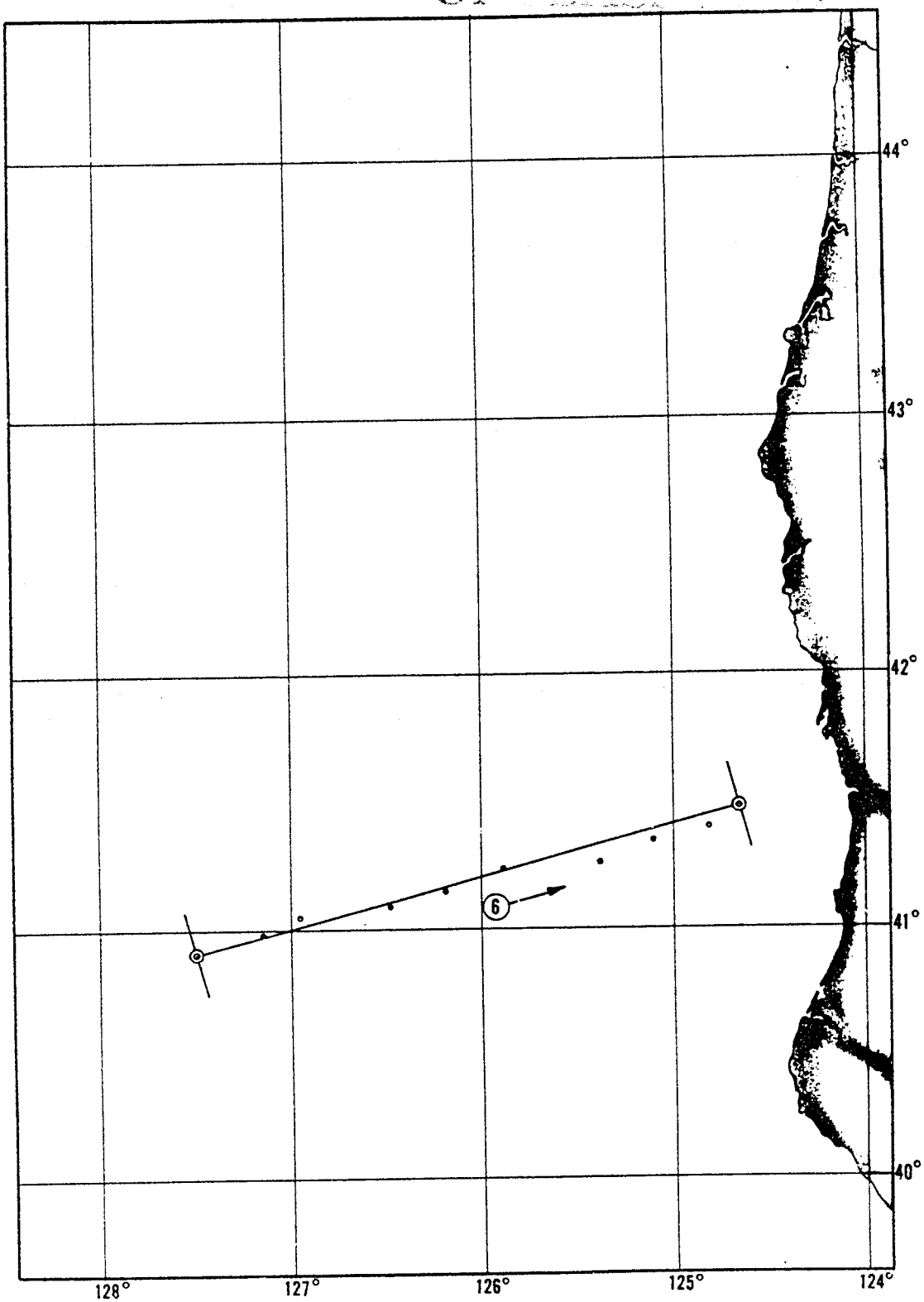

Fig. 4. -- Leg No. 6, Feb. 27, 1951

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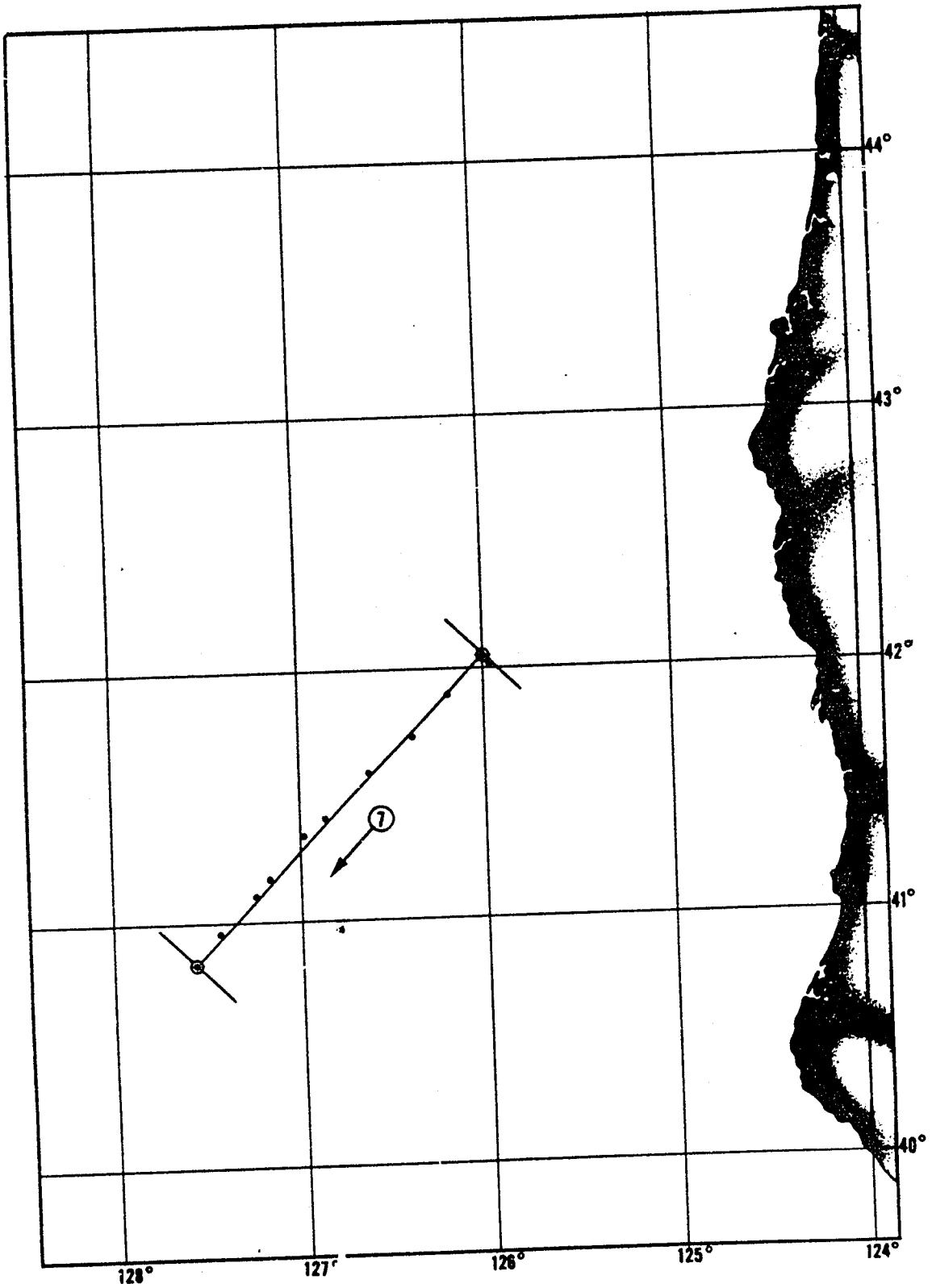

Fig. 5. -- Leg No. 7, Feb. 27, 1951

TABLE V

Summary of Flight Data for Feb. 27, 1951*

	TC	Drift	TH	Var	MH	Dev	CH	TAS	GS	Corr temp	Dist	Wind dir vel	Time	Coordinates
Leg No. 1 (SCR-718; 27100 to 27290, Δh = +190 feet)														
Photo panel	265	14 1/2	279 1/2	-21	258 1/2	+1/2	259	292		-42	124	313/98	0958 1/2	4244N 12521W
Pilot	265	15	280	-21	259	+1/2	259 1/2	292	216	-42	092		1024	4253N 12732W
Leg No. 2 (SCR-718; 27290 to 27100, Δh = 190 feet (occurred last 10 minutes)														
No information computed because of variable fixes and sudden changes in Δh														
Leg No. 3 (SCR-718; 27100 to 27060, Δh = -40 feet)														
Photo panel	273 1/2	3	276 1/2	-22	254 1/2	+1/2	255	295		-43	127 1/2	289/60	1107	4456N 12750W
Pilot	273 1/2	3 1/2	277	-22	255	+1/2	255 1/2		236	-43	102		1133	4500N 13013W
Leg No. 4 (SCR-718; 27140 to 27250, Δh = +110 feet)														
Same as No. 2. Suspect trough or isobar kink														
Leg No. 5 (SCR-718; 27270 to 27350, Δh = +80 feet)														
Photo panel	163	8	171	-20 1/2	150 1/2	+1/2	151	293		-45	107	267/41	1205	4247N 12911W
Pilot	163	6	169	-20 1/2	148 1/2	+1 1/2	150	293	300	-44	110	270/33	1227	4102N 12826W
Leg No. 6 (SCR-718; 27350 to 27150, Δh = -200 feet)														
Photo panel	076	-10 1/2	065 1/2	-20	045 1/2	1/2	045	294		-43	139	355/55	1236 1/2	4054N 12730W
Pilot	076	-12 1/2	063 1/2	-20	043 1/2	+1 1/2	045		281	-42	133	353/64	1305	4129N 12439W
Leg No. 7 (SCR-718; 27170 to 27350, Δh = +180 feet)														
Photo panel	225	19 1/2	244 1/2	-20	224 1/2	+1/2	225	292		-44	119	299/100	1339	4203N 12600W
Pilot	225	19 1/2	244 1/2	-20	224 1/2	+1/2	225		240	-44	101	299/100	1403 1/2	4050N 12734W

*Navigator -- Schneider; pilot -- Early

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TABLE V

Flight Data for March 2, 1951*

Time	Photo panel CH	Pilot's IAS	Ind temp Eng	Ind temp Bomb	Pilot's MH	Co-pilot's MH	Pres air	SCR-718 radar alt	SCR-718 Δh
					Leg No. 1				
1019	300	197	-28	-29	299	296	23000	22480	
1025	300	196	-28	-29	300	296	23000	22550	
1030	300	196 1/2	-28	-29	301	298	23000	22550	
1035	300	198	-28	-29	300	295	23000	22610	
1040	300	196	-28	-29	300	298	23000	22650	
1045	300	196 1/2	-28	-29	300	298	23000	22695	
1049	300	196	-28	-29	301	298	23000	22700	+220
					Leg No. 2				
1107	006	195	-27	-29	005	007	23000	22650	
1112	005	198	-27	-29	004	004	23000	22620	
1117	005	197 1/2	-27	-29	003	001	23000	22600	
1122	005	199	-27	-29	004	005	23000	22590	
1127	005	198	-27	-29	005	005	23000	22550	
1133	005	198	-27	-29	005	005	23000	22540	-110
					Leg No. 3				
1136	310	195	-28	-29 1/2	311	310	23000	22540	
1141	309	199	-28	-29 1/2	309	308	23015	22600	
1146	309	198	-28	-29 1/2	310	310	23000	22600	
1151	310	198	-28	-30	311	310	23000	22600	
1156	310	197	-28	-30	312	311	23000	22600	
1201	310	196	-28	-30	309	308	22985	22600	
1204	310	198	-28	-30	309	308	23005	22605	+65
					Leg No. 4				
1210	132	197	-28	-28	130	140	23015	22650	
1215	132	197	-28	-28	132	137	22985	22620	
1220	131	198 1/2	-28	-28	131	135	23015	22650	
1225	132	196	-28	-28	132	140	23020	22650	
1230	131	197 1/2	-28	-28	132	136	23020	22630	-20
					Leg No. 5				
1327	200	199	-28 1/2	-28	201	192	23000	22650	
1332	200	196	-28 1/2	-28	203	196	22980	22680	
1337	200	197	-28	-28	201	195	23000	22720	
1342	200	198	-28	-28	202	196	23015	22790	
1344	200	198 1/2	-28	-28	201	195	23000	22800	+150
					Leg No. 6				
1349	270	195	-28	-27	269	265	23000	22800	
1354	269	198	-27	-27	270	260	23015	22900	
1359	270	198	-27	-27	270	265	23000	22950	
2204	270	200	-27	-27	270	265	22980	22985	
2210	270	197	-27	-27	270	266	23000	23000	
2216	270	198	-27	-27	270	265	23000	23025	+225
					Leg No. 7				
1421	133	197	-26	-25	132	140	23015	23050	
1426	131	197	-26	-25	132	139	23020	23050	
1431	131	198	-26	-25	132	139	23000	23050	
1436	131	197	-26	-25	131	140	23000	23050	
1437	131	197	-26	-26	132	137	23000	23030	-20
					Leg No. 8				
1444	131	197	-26	-27	131	138	22980	22950	
1449	131	197	-26	-27	131	139	23000	22925	
1454	131	197	-26	-27	132	140	23000	22950	
1459	131	196	-26	-27	131	137	23000	22950	
1504	131	197 1/2	-26	-27	131	140	23000	22950	
1506	131	198	-26	-27	131	137	23000	22950	0

*Navigators -- Schneider, Yoeman, and Husztek; pilots -- Early and Follensbee

TABLE VI

Radar Data for March 2, 1951*

Time	Magnetic bearing	Range
Leg No. 1 (Radar Station Wild Bill)		
1019	172	57
1020	175	57
1021	180	55
1022	182	55
1023	186	54
1024	190	54
1025	192	54
1026	198	54
1027	200	54
1028	205	54
1029	208	54
1030	210	55
1031	215	57
1032	220	58
1033	223	60
1034	225	63
1035	228	63
1036	230	65
1037	232	67
1038	235	69
1039	238	71
1040	240	74
1041	242	75
1042	245	79
1043	246	80
1044	248	83
1045	250	85
1046	252	88
1047	253	90
1048	255	93
1049	256	95
Leg No. 2 (Radar Station Wild Bill)		
1107	258	79
1108	262	77
1109	265	75
1110	267	75
1111	269	74
1112	273	72
1113	275	71
1114	277	70
1115	279	69
1116	282	68
1117	284	67
1118	287	68
1119	290	68
1120	293	68
1121	295	68
1122	299	69
1123	300	70
1124	304	70
1125	307	72
1126	310	73
1127	311	74
Leg No. 3 (Radar Station Gristmill)		
1136	168	61
1137	171	58
1138	172	56
1139	175	55
1140	179	53
1141	182	52
1142	186	51
1143	190	50
1144	195	49
1145	199	48
1146	204	48
1147	207	47
1148	211	47
1149	216	47
1150	220	47
1151	224	48
1152	229	49
1153	232	49
1154	235	50
1155	239	51
1156	242	52
1157	245	53
1159	249	56
1200	254	60
1202	259	63
1203	261	66
1204	263	68
Leg No. 4 (Radar Station Gristmill)		
1210	251	68
1211	245	64
1212	240	62
1213	236	61
1214	230	60
1215	224	60
1216	219	60
1217	212	62
1218	207	64
1219	202	66
1220	197	68
1221	193	72
1222	189	76
1223	186	79
1224	182	82
1225	179	87
1226	175	92
1227	173	98
1229	170	107
1230	168	112
Leg No. 5 (Radar Station Sheepman)		
1327	200	45
1328	198	52
1329	196	56
1330	195	62
1331	194	68
1332	194	75
1333	193	81
1334	193	86
1335	192	92
1336	194	98
1337	190	103
1338	190	110
1339	190	115
1340	190	121
1341	190	126
1342	190	132
1343	190	138
1344	189	143

*Navigator -- Yoeman; pilot -- Early

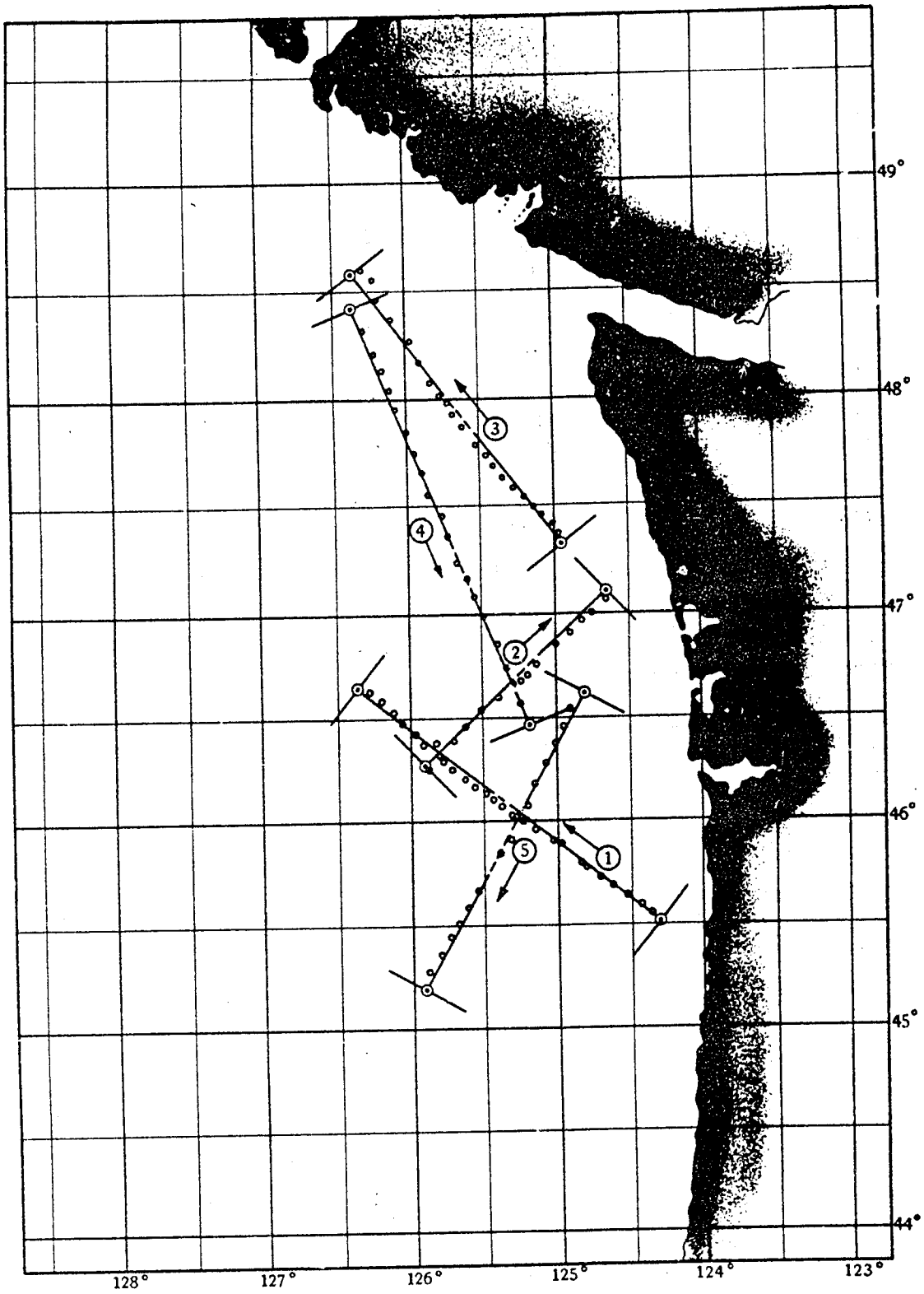

Fig. 6. -- Leg Nos. 1-5, March 2, 1941

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TABLE VII

Loran Data for March 2, 1951*

Time	Station	Reading	Station	Reading
		Leg No. 6		
1349	2H5	3110	2H4	2840
1351	2H5	3100	2H4	2842
1353	2H5	3040	2H4	2860
1357	2H5	2970	2H4	2852
1400	2H5	2922	2H4	2853
1402	2H5	2880	2H4	2855
1404	2H5	2828	2H4	2860
1407	2H5	2800	2H4	2864
1408	2H5	2780	2H4	2872
1410	2H5	2739	2H4	2871
1412	2H5	2712	2H4	2880
1414	2H5	2678	2H4	2880
1416	2H5	2642	2H4	2880
		Leg No. 7		
1421	2H3	1150	2H4	2702
1423	2H3	1162	2H4	2663
1425	2H3	1163	2H4	2605
1427	2H3	1177	2H4	2548
1429	2H3	1185	2H4	2460
1431	2H3	1190	2H4	2392
1433	2H3	1202	2H4	2305
1435	2H3	1221	2H4	2232
1437	2H3	1226	2H4	2152
		Leg No. 8		
2244	2H3	1278	2H4	1879
2248	2H3	1297	2H4	1718
2249 1/2	2H3	1344	2H4	1664
2251 1/2	2H3	1374	2H4	1588
2253	2H3	1398	2H4	1539
2254 1/2	2H3	1424	2H4	1485
2255 1/2	2H3	1449	2H4	1455
2256 1/2	2H3	1464	2H4	1424
2259	2H3	1511	2H4	1358
2300	2H3	1551	2H4	1319
2302 1/2	2H3	1610	2H4	1268
2304 1/2	2H3	1668	2H4	1224
2306	2H3	1710	2H4	1199

*Navigators -- Hustek and Yoeman; pilot -- Early

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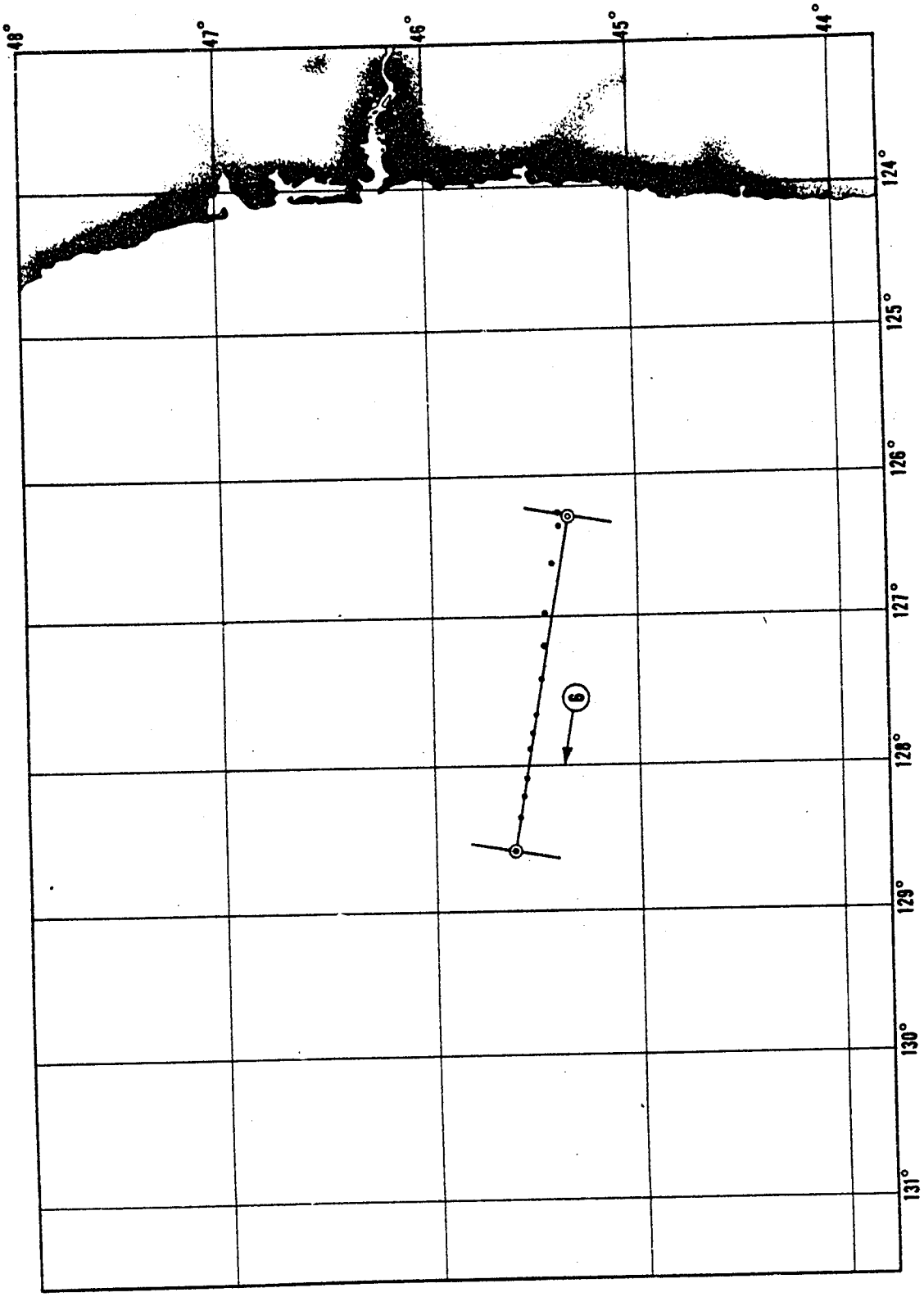

Fig. 7. -- Leg No. 6, Mar. 2, 1951

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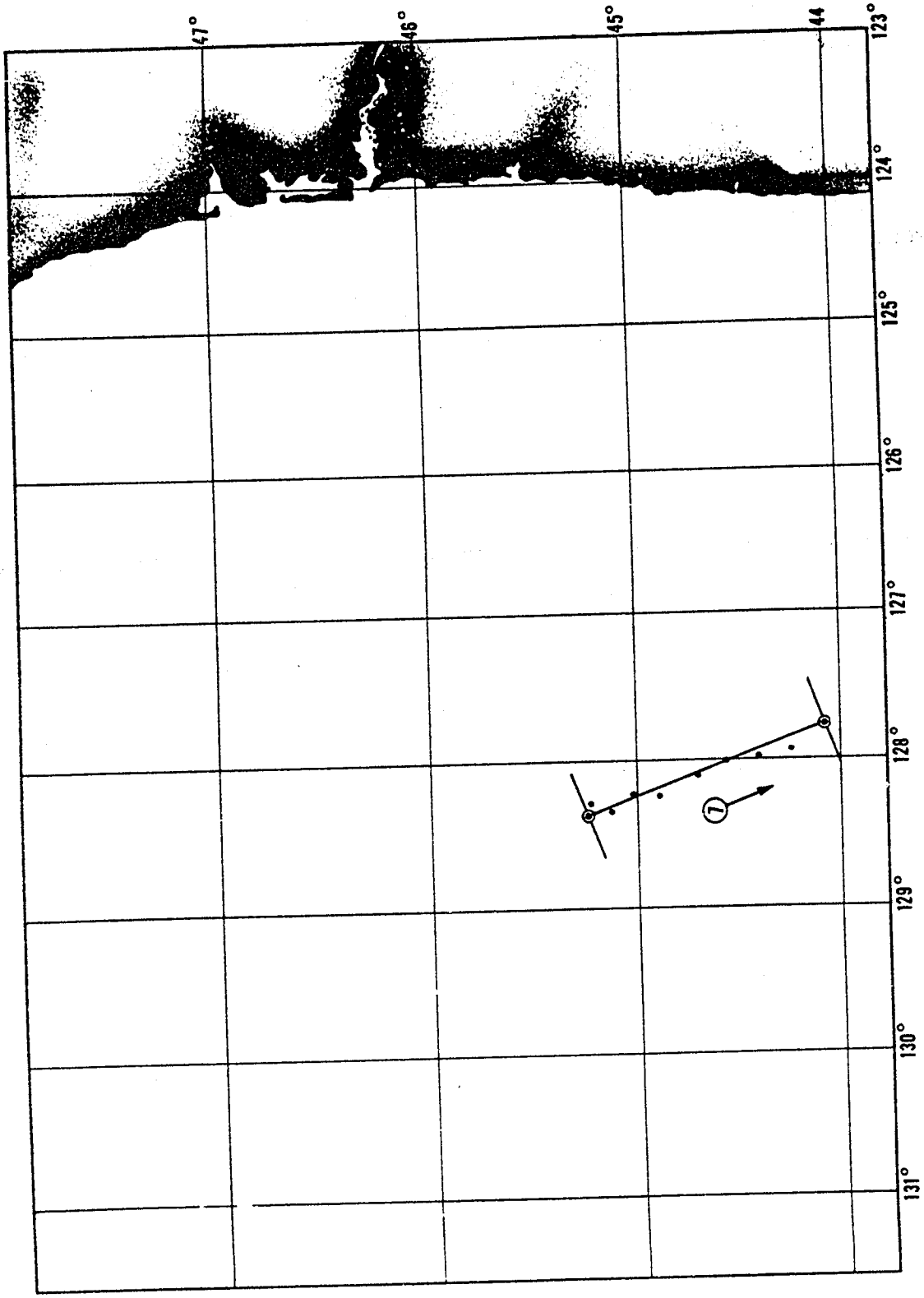

Fig. 8. -- Leg No. 7, Mar. 2, 1951

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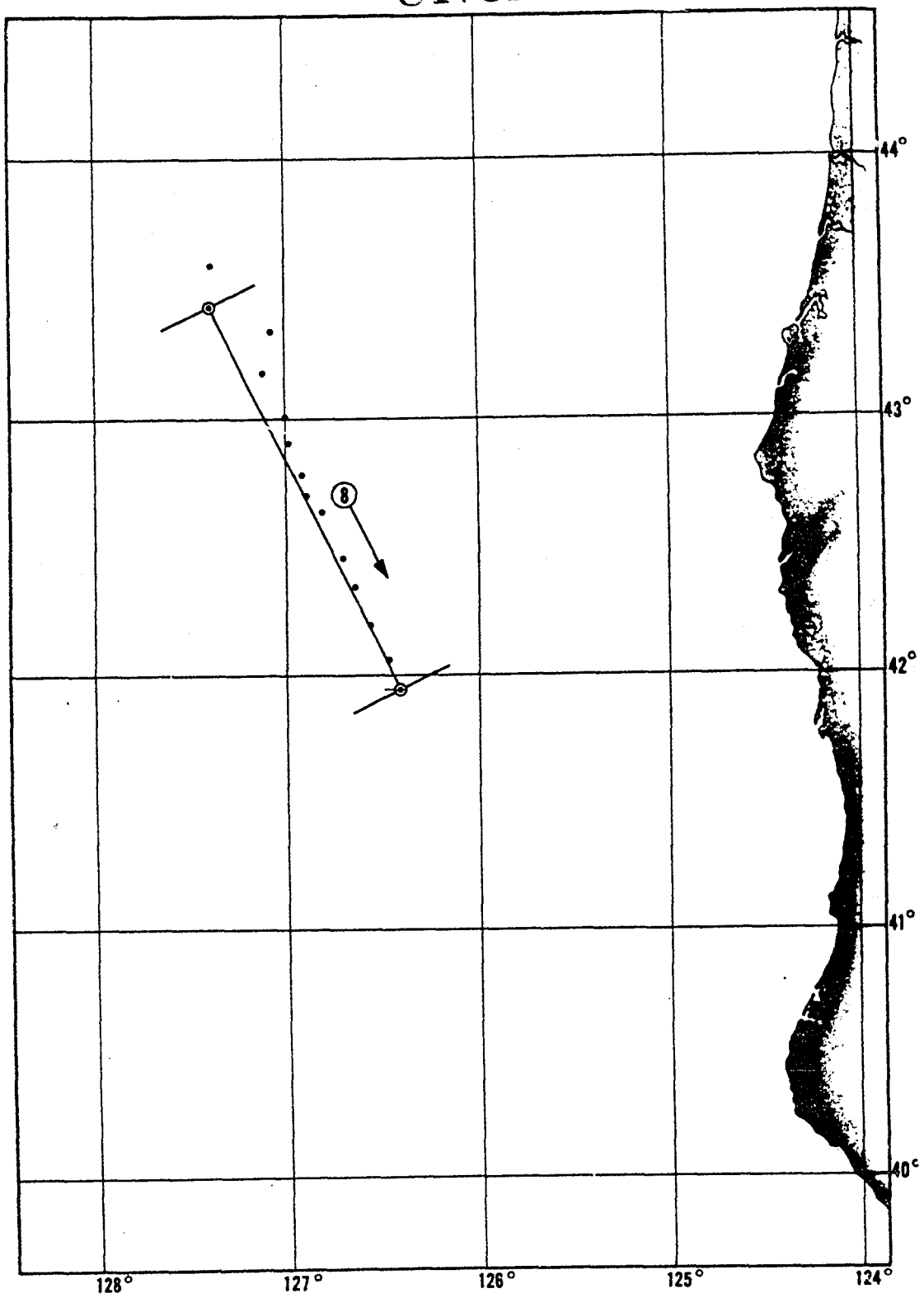

Fig. 9. -- Leg No. 8, Mar. 2, 1951

TABLE VIII

Summary of Flight Data for March 2, 1951*

	TC	Drift	TH	Var	MH	Dev	CH	TAS	GS	Corr temp	Dist	Wind dir vel	Time	Coordinates
Leg No. 1 (SCR-718; 22480 to 22700, Δh = +220 feet)														
Pilot	308 1/2	+18	326 1/2	-22 1/2	304	-4	300	236		-34	118	031/74	1019	4532N 12418W
Photo panel	308 1/2	+18	326 1/2	-22 1/2	304	-4	300	236	214	-34	107		1049	4638N 12621W
Leg No. 2 (SCR-718; 22650 to 22540, Δh = -110 feet)														
Pilot	043	-14	029	-23	006	-1	005	236		-34	79	333/60	1107	4646N 12554W
Photo panel	043	-14 1/2	028 1/2	-23	005 1/2	-1	004 1/2	236	210	-34	70		1127	4736N 12439W
Leg No. 3 (SCR-718; 22540 to 22605, Δh = +65 feet)														
Pilot	323	+11	334	-23	311	-1	310	237		-34	112	020/58	1136	4720N 12457W
Photo panel	323	+11	334	-23	311	-1	310		200	-34	93 1/2		1204	4835N 12622W
Leg No. 4 (SCR-718; 22650 to 22630, Δh = -20 feet)														
Pilot	158	-1/2	157 1/2	-22 1/2	135	-3	132	236		-34	79	338/143	1210	4825N 12622W
Photo panel	158	-1/2	157 1/2	-22 1/2	135	-3	132	236	337	-33	126 1/2		1230	4628N 12511W
Leg No. 5 (SCR-718; 22650 to 22800, Δh = +150 feet)														
Pilot	209	+14	223	-22	201	0	201	236		-34	67		1327	4637N 12448W
Photo panel	209	+14	223	-22	201	-1	200		345	-34	98	005/130	1344	4511N 12555W
Leg No. 6 (SCR-718; 22800 to 23025, Δh = +225 feet)														
Pilot	278 1/2	+15 1/2	294	-22	272	-2	270	237		-33	107	359/64	1349	4520N 12617W
Photo panel	278 1/2	+15 1/2	294	-22	272	-2	270		218	-33	98		1416	4537N 12835W
Leg No. 7 (SCR-718; 23050 to 23030, Δh = -20 feet)														
Pilot	160	-3 1/2	156 1/2	-21 1/2	135	-3	132	236		-32	63	006/40	1421	4515N 12822W
Photo panel	160	-4 1/2	155 1/2	-21 1/2	134	-3	131		270	-33	72	(with -4% drift)	1437	4405N 12747W
Leg No. 8 (SCR-718; 22950 to 22950, Δh = 0 feet)														
Pilot	155 1/2	-1/2	155	-21	134	-3	131	236		-33	86 1/2	337/58	1444	4326N 12724W
Photo panel	155 1/2	-1/2	155	-21	134	-3	131		294	-33	108		1506	4157N 12624W

*Navigator -- Schneider; pilot -- Early

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