TRANSPORTS IN THE PACIFIC EQUATORIAL COUNTERCURRENT

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF THE
UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE
IN OCEANOGRAPHY
JUNE 1966

By
Thomas Robert Kendall

Thesis Committee:

Klaus Wyrtki, Chairman
Vernon E. Brock
Brian F. Pasby
Charles W. Thomas
George P. Woollard

We certify that we have read this thesis and that in our opinion it is satisfactory in scope and quality as a thesis for the degree of Master of Science in Oceanography.

THESIS COMMITTEE

Klaus Wyrtki
Chairman

Geo. P. Woollard

V. E. Brock

Charles W. Thomas

ABSTRACT

5Est 77

Volume transports in the Pacific Equatorial Countercurrent have been estimated by geostrophic methods. A thermoclinic method using only bathythermograph sections to estimate transports is introduced and evaluated. Compilation of transports in the countercurrent along 79 hydrographic sections and estimated transports along 50 bathythermograph sections are presented. It is shown that the average transport of the countercurrent decreases almost linearly from approximately 40 million cubic meters per second in the western portion of the Pacific Ocean to termination at the coast of Central America. No conclusive variations of seasonal transports were found.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

INTRODUCTION

The Pacific Equatorial Countercurrent flows from west to east across the entire Pacific Ocean, a few degrees north of the equator. It is relatively narrow, 300 to 700 kilometers wide, and it separates the broader, westward-flowing North and South Equatorial Currents. As such, it acts as a boundary between the great anticyclonic gyres of the North and South Pacific. Surface components of the countercurrent have been recognized and presented on charts for over a century. However, analysis of the volume transports has only recently been initiated.

Geostrophic transports have been estimated by Sverdrup et al (1942), Jerlov (1956), Austin et al (1956), and Tsuchiya (1961). Knauss (1961) demonstrated that velocity measurements in the countercurrent agree with geostrophic calculations to a first approximation. These results suggest that geostrophic transports, a function of the slope of geopotential surfaces, are a measure of actual transports. Montgomery and Stroup (1962), in a more comprehensive analysis, discuss volume transports as derived from geostrophic calculations. In addition to summarizing previous studies, they demonstrate agreement with measured current values.

Extensive efforts have been made in recent years to collect oceanographic data in the Pacific equatorial regions, resulting in a large accumulation of bathythermograph and, to a lesser extent, hydrographic data. A method will be introduced by which transports in the countercurrent can be estimated solely from bathythermograph data. A comparison between geostrophically calculated transports and values derived from the thermal structure will demonstrate the validity of this new method.

THERMOCLINIC TRANSPORT

A meridional section of the countercurrent is characterized by a sea surface sloping away from the equator and an underlying thermocline which slopes toward the equator. (See Figure 1.) The thermal gradient is greatest between 25° and 15° centigrade, with the 20° centigrade isotherm indicating the mean, as shown in Figures 2 through 5. This thermocline separates two distinct water densities, a well-mixed upper layer and a stable lower layer. If it can be shown that a relationship exists between the slope of the thermocline and geostrophic transport, it may be possible to infer an estimate of actual transport, as suggested by Wyrtki (1964).

If the ocean consists of two density layers separated by a thermocline with the lower layer at no motion, then the eastward velocity component u in the upper layer according to Sverdrup et al (1942) is given by

$$fu = gi_y \frac{\Delta\rho}{\rho} = g\frac{\Delta\rho}{\rho}\frac{\Delta Z}{\Delta y} \tag{1}$$

where $f = 2\omega \sin\phi$ is the Coriolis parameter, g is the acceleration of gravity, ρ the density, $\Delta\rho$ the density difference between the upper and the lower layer, and $i_y = \frac{\Delta Z}{\Delta y}$ is the slope of the boundary between the two layers in the meridional direction. The volume transport T_{bt} to the east in the upper layer is given by

(2) $$T_{bt} = u\bar{Z}\Delta y$$

where $\bar{Z}$ is the average depth of the upper layer and Δy is the meridional width of the countercurrent. From equations 1 and 2 follows

(3) $$T_{bt} = \frac{g}{2\omega\sin\varphi}\cdot\frac{\Delta\rho}{\rho}\cdot\bar{Z}\Delta Z$$

For the meridional section described in Figure 1, this is

(4) $$T_{bt} = \frac{g\Delta\rho}{4\omega\rho}\;\frac{(Z_S - Z_N)(Z_S + Z_N)}{\sin\bar{\varphi}}$$

where Z_S and Z_N are the depths of the upper layer at the south and north boundaries of the countercurrent. Consequently, a relationship between the transports in the upper layer (T_{bt}) and values of Z_S and Z_N should exist, having the form

(5) $$T_{bt} = k\,\frac{(Z_S - Z_N)(Z_S + Z_N)}{\sin\bar{\phi}}$$

where

$$k = \frac{g\Delta\rho}{4\omega\rho}$$

For the countercurrent, the magnitude of k can be estimated. Assuming a density $\rho_1 = 1.023$ for the upper layer and $\rho_2 = 1.027$ for the lower layer, $g = 9.81$ meters per second squared, and $\omega = 0.729\text{x}10^{-4}$ per second, gives $k = 1.5\text{x}10^{2}$ meters per second. By comparison between geostrophic transports and values of Z_S and Z_N, it should be shown that such a factor k exists and is applicable at least to certain portions of the countercurrent.

GEOSTROPHIC TRANSPORT

A total of 79 hydrographic sections were used to calculate geostrophic transport in the countercurrent. An arbitrary level of no motion was chosen at 500 meter depth. Montgomery and Stroup (1962) sustained a level at 300 meters and suggested that deepening the base would lower the calculated transport. Austin et al (1956) selected 400 meters, having previously shown that a deeper reference level at 500 meters did not significantly change the velocity profile in the region of the countercurrent. Jerlov (1956) states that appreciable current velocities are found as deep as 400 meters, the layer of no motion falling between 500 and 900 meters. Sverdrup (1944) used 700 meters with the note that accidental errors of observation exercise a greater influence at depths below this level.

The equation utilized in this study to compute geostrophic transport T_g is

$$T_g = 10 \sum_{y} \frac{1}{\bar{f}} \sum_{Z} (\Delta\bar{D}_A - \Delta\bar{D}_B)\Delta Z \tag{6}$$

where ΔD is the anomaly of dynamic height at the individual hydrographic station and ΔZ is the interval between standard depths. The summation is done vertically between adjoining hydrographic stations, an average Coriolis parameter for the respective stations has been used, and then individual columns have been added to obtain the total transport of the countercurrent. Entire columns of negative transport have not been included in the summation. In the lower portions of the countercurrent near the northern and southern boundaries, occasionally geostrophic flow to the west is observed. This flow has been included in the transport computations, but sections where its effect is greater than 10% are marked in Table I by the symbol +. The results of the geostrophic computations are given in Table I.

In some instances, the hydrographic sections are limited, and may not completely cross the countercurrent. The implications are that transport estimates may be low. These limited sections are noted in Figures 8 and 9. Arcs of a circle at the end of a section indicate the limit of data sampling.

Data sources not referenced in the text are included in the bibliography.

RELATIONSHIP BETWEEN THERMAL STRUCTURE AND FLOW

In order to demonstrate that geostrophic currents and transport are in fact associated with the upper layer in the thermal structure of a meridional section of the countercurrent, Figures 2 through 5 have been prepared. The vertical distribution of temperature at the northern and at the southern boundary of the countercurrent shows the division into an upper layer of high temperature and a lower layer with temperatures less than 10° centigrade. The 20° centigrade isotherm represents approximately the center of the thermocline and, therefore, is a measure of the thickness of the upper layer. It is evident from the four figures that the depth of the upper layer decreases across the Pacific Ocean from west to east, being more than 150 meters thick at 142° east longitude (Figure 2) and less than 100 meters at 115° west longitude (Figure 5). On the right-hand side of each of the four figures, the differences of dynamic heights across the countercurrent are plotted as a function of depth. Their distribution demonstrates that the strong flow in the countercurrent is concentrated in a relatively shallow layer near the sea surface and that this layer corresponds to the warm layer in the thermal structure. On the basis of these comparisons, it can be justified to compare geostrophic transports with the thickness of the upper layer and the slope of the thermocline.

COMPARISON BETWEEN GEOSTROPHIC AND THERMOCLINIC TRANSPORTS

Geostrophic transports calculated according to equation 6 will be compared with thermoclinic transports according to equation 5. Define a transport function as

$$(7) \qquad \left[\frac{T_{bt}}{k}\right] = \frac{(Z_S - Z_N)(Z_S + Z_N)}{\sin\bar{\varphi}}$$

Evaluation of this transport function requires the knowledge of the depths of the 20° centigrade isotherm Z_S and Z_N at the south and north boundaries of the countercurrent and its mean latitude $\bar{\phi}$. Dividing geostrophic transport by the transport function gives an estimate of the factor k.

$$\frac{T_g}{\left[\frac{T_{bt}}{k}\right]} = k$$

Data for calculation of the transport functions are taken from the same hydrographic sections for which geostrophic transports have been computed. The depths of the 20° centigrade isotherm are obtained by linear interpolation. In a few cases, the bounds of the slope of the thermocline did not coincide with the bounds of the dynamic heights of the sea surface. In order that the method be consistent with subsequent evaluation of independent bathythermograph sections, the geostrophic transport is calculated within the bounds of a sloping sea surface, and the mean latitude for the transport function is taken midway between the bounds of the lowest and highest ends of the sloping thermocline. The values of the transport function are also listed in Table I.

A plot of geostrophic transport versus the transport function is presented in Figure 6 and shows a more or less linear relationship. The straight line with a factor of $k = 1.5 \times 10^2$ meters per second corresponds with the previously estimated value of k. Factor k versus longitude is given in Figure 7. Three distinct regions are noted. From 180° east to 120° west longitude, the values cluster about k = 1.5. To the west of 180°, the values are more dispersed though k = 1.5 may be inferred. Between 110° west and 85° west, values of k are much larger. It is in this eastern oceanic region that the countercurrent finally disperses, as shown in the maps of surface currents by Wyrtki (1965).

This study indicates that volume transports in the countercurrent may be estimated from meridional sections of bathythermograph data. The only information required are the depths of the lowest and the highest points in the thermocline (20° centigrade isotherm) and the mean latitude.

RESULTS

The equation for thermoclinic transport has been applied to 50 bathythermograph sections and the estimated thermoclinic transports are listed in Table II. A factor $k = 1.5x10^2$ meters per second was used throughout. A summary by month and against latitude and longitude of countercurrent sections used in this study is presented in Figures 8 and 9. Positions and ranges are mapped. Calculated transports in millions of cubic meters per second are indicated. Circled identification numbers refer to Tables I or II. South and/or north end points of limited sections are indicated by arcs of a circle.

Transports as a function of longitude are presented in Figure 10. The method of calculation and limited sections are noted. The distribution of transports suggests an upper bound which seems to be a more or less linear function with longitude. Figure 7 shows k factors around $6x10^2$ meters per second for the interval 110° west to 85° west. If such a factor is applied to the bathythermograph sections in this interval, the estimated transports notably exceed that upper bound. Mean transports for increments of longitude are illustrated in Figure 11. An average flow of 40 million cubic meters per second west of 180° decreases to 20 million cubic meters per second by 140° west longitude. Volume transports clearly decrease as the countercurrent flows eastward. Sverdrup et al (1942) had suggested to the contrary.

Some seasonal variations in the transports with longitude are presented in Figure 12 and Table III. In the western equatorial Pacific Ocean, the flow appears to be a regular feature. In mid-ocean, transports seem to be strong during September through February and weak March through August. At its eastern extremity during March through May (Figure 12) decrease of values indicate that the countercurrent would terminate before reaching 100° west longitude. Flow east of 100° west is in evidence during other seasons.

ACKNOWLEDGEMENTS

I would particularly like to thank Professor Klaus Wyrtki, who presented the idea of a relationship between the sloping thermocline and the transport, and who later provided the name, thermoclinic transport. I also wish to thank Mr. Gunter Seckel for his assistance during the preparation of this material. This study was financially supported under contract number 15950 with the Bureau of Commercial Fisheries.

BIBLIOGRAPHY

Austin, Thomas S. "Mid-Pacific Oceanography III, Transequatorial Waters August—October." *Special Scientific Report, U. S. Fish and Wildlife Service*, Fisheries, No. 131. 1954.

__________. "Mid-Pacific Oceanography, Part V, Transequatorial Waters, May—June 1952." *Special Scientific Report, U. S. Fish and Wildlife Service*, Fisheries, No. 136. 1954.

__________. "Oceanography of the East Central Equatorial Pacific as Observed during Expedition Eastropic." *Fishery* Bulletin of the Fish and Wildlife Service, 60 (no. 168). 1960. pp. 257-282.

__________, E. D. Stroup, and M. U. Riakel. "Variations in the Equatorial Countercurrent in the Central Pacific." *Transactions American Geophysical Union*, *37*(5), 558-564.

Bruneau, L., N. G. Jerlov, and F. F. Koczy. "Physical and Chemical Methods." *Reports of the Swedish Deep-Sea Expedition 1947-1948* (edited by Hans Pettersson), *III*, 99-112. Goteborg: Elanders Boktryckeri Aktiebolag, 1957.

Capurro, Luis R. A., compiled by. *Oceanographic Observations in the Intertropical Region of the World Ocean during IGY and IGC*, Part IIa, No. 3. College Station, Texas: IGY World Data Center A, Oceanography, Agricultural and Mechanical College of Texas, 1961.

__________. *Oceanographic Observations in the Intertropical Region of the World Ocean during IGY and IGC*, Part IIb, No. 3. College Station, Texas: IGY World Data Center A, Oceanography, Agricultural and Mechanical College of Texas, 1961.

Cromwell, Townsend. "Mid-Pacific Oceanography, January through March, 1950." *Special Scientific Report, U. S. Fish and Wildlife Service*, Fisheries, No. 54. 1951.

__________. "Mid-Pacific Oceanography II, Transequatorial Waters, June—August 1950, January—March 1951." *Special Scientific Report, U. S. Fish and Wildlife Service*, Fisheries, No. 131. 1954.

Fleming, J. A., H. U. Sverdrup, C. C. Ennis, S. L. Seaton, and W. C. Hendrix. "Observations and Results in Physical Oceanography, Graphical and Tabular Summaries." *Carnegie Institution of Washington Publication*, 545, Scientific Results of Cruise VII of the *Carnegie* during 1928-1929 under the Command of Captain J. P. Ault, Oceanography, I-B, 225-252. 1945.

Hida, Thomas S. and Joseph E. King. "Vertical Distribution of Zoo-plankton in the Central Equatorial Pacific, July--August 1952." Special Scientific Report, U. S. Fish and Wildlife Service, Fisheries, No. 144, 1955.

Iversen, Edwin S. and Howard O. Yoshida. "Longline Fishing for Tuna in the Central Equatorial Pacific, 1954." Special Scientific Report, Fisheries, No. 184. 1956.

Jerlov, N. G. "The Equatorial Currents in the Pacific Ocean." Reports of the Swedish Deep-Sea Expedition 1947-1948 (edited by Hans Pettersson), 3, Physics and Chemistry, Appendix and 127-154. Goteborg: Elanders Boktrycheri Aktiebolag, [1956].

Kagoshima University, Faculty of Fisheries. Oceanographical Observations Made During the International Cooperative Expedition EQUAPAC in July--August, 1956 by M. S. Kagoshima-maru. 1957.

Knauss, John A. "The Structure of the Pacific Equatorial Countercurrent." Journal of Geophysical Research, 66, 143-155. 1961.

Montgomery, R. B. and E. D. Stroup. Equatorial Waters and Currents at 150° W in July--August 1952. Baltimore: The Johns Hopkins Press, 1962.

Murphy, Garth I. and Tamio Otsu. "Analysis of Catches of Nine Japanese Tuna Longline Expeditions to the Western Pacific." Special Scientific Report, U. S. Fish and Wildlife Service, Fisheries, No. 128. 1954.

__________ and Richard S. Shomura. "Longline Fishing for Deep-swimming Tunas in the Central Pacific, 1950-1951." Special Scientific Report, U. S. Fish and Wildlife Service, Fisheries, No. 98, 1953.

__________ and Richard S. Shomura. "Longline Fishing for Deep-swimming Tunas in the Central Pacific, January--June 1952." Special Scientific Report, U. S. Fish and Wildlife Service, Fisheries, No. 108. 1953.

__________ and Richard S. Shomura. "Longline Fishing for Deep-swimming Tunas in the Central Pacific, August--November 1952." Special Scientific Report, U. S. Fish and Wildlife Service, Fisheries, No. 137. 1955.

Scripps Institution of Oceanography. "Data Collected by

Scripps Institution of Oceanography Vessels on EQUAPAC Expedition, August 1956." Data Report. Reference No. 57-25. La Jolla: University of California, 1957.

Shizuka Prefectural Fisheries Experimental Station. *EQUAPAC: Oceanographic and Meteorological Data, Daifujimaru, June 28-October 1, 1956*. [1957].

Shomura, Richard S. and Garth I. Murphy. "Longline Fishing for Deep-swimming Tunas in the Central Pacific, 1953." *Special Scientific Report, U. S. Fish and Wildlife Service*, Fisheries, No. 157. 1955.

Stroup, E. D. "Mid-Pacific Oceanography, Part IV, Transequatorial Waters, January--March 1952." *Special Scientific Report, U. S. Fish and Wildlife Service*, Fisheries, No. 135. 1954.

Sverdrup, H. U. "Results Within Physical Oceanography." *Carnegie Institution of Washington Publication*, 545, Scientific Results of Cruise VII of the *Carnegie* During 1928-1929 under the Command of Captain J. P. Ault, Oceanography, I-A, Observations and Results in Physical Oceanography, 83-148. 1944.

__________, M. W. Johnson and R. H. Fleming. *The Oceans, Their Physics, Chemistry and General Biology*. New York: Prentice-Hall, 1942.

Thomson, C. Wyville and John Murray. *Report on the Scientific Results of the Voyage of H.M.S. Challenger*. *Physics and Chemistry*, Vol. I, Part III, Her Majesty's Stationery Office, London, 1884.

Tizard, T. H., H. N. Moseley, J. Y. Buchanan, and John Murray. "Report on the Deep-Sea Temperature Observations of Ocean-Water Taken by the Officers of the Expedition." *Report on the Scientific Results of the Voyage of H.M.S. Challenger During the Years 1873-1876*, *Physics and Chemistry*, I (3). London: Her Majesty's Stationery Office, 1884.

Tsuchiya, Mizuki. "On a Simple Method of Estimating the Current Velocity at the Equator." Oceanographic Society of Japan, 11 (1), 1-4. 1955.

Wooster, Warren S. and Townsend Cromwell. "An Oceanographic Description of the Eastern Tropical Pacific," Bulletin of the Scripps Institution of Oceanography of the University of California, 7 (3), 169-282. Berkeley, 1958.

Wyrtki, Klaus. "Surface Currents of the Eastern Tropical Pacific Ocean." Inter-American Tropical Tuna Commission, Bulletin, IX (5), 271-304. 1965.

Wyrtki, Klaus. "The Thermal Structure of the Eastern Pacific Ocean." *Deutsches Hydrographisches Institut*, Reihe A (8°), Nr. 6. 1964.

TABLE I.

TRANSPORT FUNCTIONS OF THE PACIFIC EQUATORIAL COUNTER-CURRENT

Ship / Cruise	Hydrographic Cross-Section (P.E.C.C.)	Geostrophic Transport ($10^6 m^3$/sec.)	Transport Function ($10^4 m^2$/sec.)	Factor K (10^2)	I. D. No.
ALBATROSS (Oct.1947)	4°49'N 130°52'W – 9°50'N 128°13'W	39.83	29.1	1.37	18
ALBATROSS (Nov.1947)	5°47'N 149°42'W – 8°43'N 148°36'W	23.36	17.0	1.37	19
ALBATROSS (Dec.1947)	2°54'N 173°17'W – 8°40'N 169°28'W	61.60+	34.2	1.80	20
S.F. BAIRD Eastropic (Oct.1955)	7°02'N 115°40'W – 12°05'N 116°09'W	12.50	7.2	1.74	48
S.F. BAIRD Eastropic (Oct.1955)	6°22'N 115°24'W – 10°58'N 115°58'W	10.74+	7.4	1.45	49
S.F. BAIRD Eastropic (Nov.1955)	7°33'N 87°21'W – 8°24'N 87°35'W	3.44	0.6	5.73	50
S.F. BAIRD Eastropic (Nov.1955)	7°51'N 84°34'W – 9°13'N 84°51'W	1.43+	0.6	2.38	51
S.F. BAIRD Eastropic (Nov.1955)	6°54'N 84°21'W – 8°54'N 84°42'W	1.19+	1.8	.66	52
S.F. BAIRD Eastropic (Dec.1955)	3°49'N 90°37'W – 8°54'N 89°36'W	13.42	1.9	7.10	53
S.F. BAIRD CRD (Nov.1959)	6°45'N 86°44'W – 8°17'N 88°16'W	5.73+	1.0	5.73	71
S.F. BAIRD Tethys (June 1960)	4°34'N 130°58'W – 7°47'N 129°37'W	15.90	9.9	1.60	72
S.F. BAIRD Tethys (July 1960)	4°57'N 142°55'W – 9°45'N 146°48'W	20.60	11.5	1.79	73
CARNEGIE 7 (May 1929)	4°22'N 176°33'W – 8°05'N 178°48'W	3.73+	9.3	.40	76

TABLE I. (Continued)

TRANSPORT FUNCTIONS OF THE PACIFIC EQUATORIAL COUNTER-CURRENT

Ship / Cruise	Hydrographic Cross-Section (P.E.C.C.)	Geostrophic Transport ($10^6 m^3/sec.$)	Transport Function ($10^4 m^2/sec.$)	Factor K (10^2)	I. D. No.
CARNEGIE 7 (Oct.1929)	3°01'N / 149°46'W – 10°05'N / 139°44'W	42.43	27.4	1.55	75
DAIFUJI-MARU (July 1956)	3°00'N / 175°11'E – 7°30'N / 162°36'E	43.50	29.7	1.46	16
DAIFUJI-MARU (Aug.1956)	4°14'N / 142°41'W – 10°00'N / 141°24'W	23.80	15.8	1.51	16A
HOKUSEI-MARU 3 (Jan.1958)	1°52'- 6°28'N / 135°00'E	22.50	25.9	.87	27
HOKUSEI-MARU 3 (Jan.1958)	2°50'N / 136°26'E – 7°36'N / 135°57'E	10.59	17.7	.60	28
HORIZON Eastropic (Oct.1955)	6°01'N / 120°46'W – 11°00'N / 120°56'W	11.84	6.6	1.79	54
HORIZON Eastropic (Oct.1955)	8°00'- 9°58'N / 111°30'W	6.73	2.8	2.40	55
HORIZON Eastropic (Oct.1955)	5°40'-10°00'N / 111°00'W	7.46	5.6	1.33	56
HORIZON Eastropic (Nov.1955)	7°54'N / 89°15'W – 9°29'N / 88°25'W	1.34	0.3	5.36	57
HORIZON Eastropic (Nov.1955)	6°55'N / 83°38'W – 9°00'N / 84°32'W	4.89	2.0	2.45	58
HORIZON Eastropic (Nov. 1955)	4°05'N / 77°45'W – 6°52'N / 78°54'W	4.71	2.8	1.68	59
HORIZON Eastropic (Dec.1955)	4°08'N / 102°02'W – 9°03'N / 104°34'W	19.92	3.0	6.64	60
HORIZON Equapac (Aug.1956)	2°59'- 6°30'N / 157°00'E	47.26	26.2	1.80	10

TABLE I. (Continued)

TRANSPORT FUNCTIONS OF THE PACIFIC EQUATORIAL COUNTER-CURRENT

Ship / Cruise	Hydrographic Cross-Section (P.E.C.C.)	Geostrophic Transport ($10^6 m^3$/sec.)	Transport Function ($10^4 m^2$/sec.)	Factor K (10^2)	I. D. No.
HORIZON Equapac (Aug.1956)	1°56'- 8°01'N 164°00'E	45.65+	18.6	2.45	11
HORIZON Downwind (Oct.1957)	3°14'N – 7°08'N 130°03'W – 129°16'W	26.52	12.4	1.66	63
HORIZON Downwind (Feb.1958)	2°00'N – 10°02'N 115°32'W – 118°58'W	18.23	7.9	2.31	64
HORIZON Dorado (July 1959)	7°32'- 9°47'N 120°00'W	7.85+	5.3	1.48	69
HORIZON Dorado (July 1959)	6°00'-10°00'N 120°00'W	6.30+	6.0	1.05	70
HORIZON Step I (Dec.1960)	1°59'-10°05'N 95°00'W	15.42+	3.1	4.97	74
KAGOSHIMA-MARU Equapac (Aug.1956)	3°02'- 8°00'N 130°00'E	68.45	28.1	2.44	14
KAGOSHIMA-MARU (April 1958)	4°00'- 7°00'N 151°00'E	25.65	10.3	2.49	33
KAGOSHIMA-MARU (April 1958)	2°00'N – 9°59'N 153°00'E – 151°00'E	68.83	21.2	3.25	34
KEITEN-MARU Equapac (July 1956)	1°49'- 6°00'N 135°00'E	86.38	47.5	1.82	15
SATSUMA Equapac (Aug.1956)	2°03'- 6°27'N 151°00'E	37.45	27.6	1.36	23
SATSUMA Equapac (Aug.1956)	2°13'N – 6°32'N 150°00'E – 147°49'E	20.68+	19.1	1.08	24
SATSUMA Equapac (Aug.1956)	2°04'N – 5°03'N 141°05'E – 142°19'E	58.58	44.0	1.33	25

TABLE I. (Continued)

TRANSPORT FUNCTIONS OF THE PACIFIC EQUATORIAL COUNTER-CURRENT

Ship / Cruise	Hydrographic Cross-Section (P.E.C.C.)	Geostrophic Transport ($10^6 m^3$/sec.)	Transport Function ($10^4 m^2$/sec.)	Factor K (10^2)	I. D. No.
SATSUMA Equapac (Aug.1956)	2°03'- 6°30'N 140°00'E	39.85	29.1	1.37	26
SATSUMA (Feb.1958)	4°00'- 7°00'N 147°00'E	15.80+	15.2	1.04	32
H.M. SMITH 2 (Feb.1950)	6°07'-11°03'N 172°00'W	24.78	15.6	1.59	1
H.M. SMITH 2 (Feb.1950)	6°00'- 9°55'N 158°00'W	20.20	12.9	1.57	2
H.M. SMITH 5 (Aug.1950)	5°00'N – 9°00'N 158°00'W – 157°55'W	22.06	18.8	1.17	3
H.M. SMITH 5 (July 1950)	3°00'- 8°00'N 172°00'W	25.77	18.0	1.43	5
H.M. SMITH 8 (Jan.1951)	3°02'- 9°00'N 158°00'W	28.69	18.9	1.52	4
H.M. SMITH 8 (Feb.1951)	4°58'N – 6°44'N 165°35'W – 165°23'W	16.71	10.7	1.56	6
H.M. SMITH 8 (Mar.1951)	4°56'-10°02'N 172°00'W	19.65	15.9	1.24	7
H.M. SMITH 11 (Sept.1951)	5°00'-10°00'N 150°00'W	26.4	20.2	1.31	8
H.M. SMITH 14 (Jan.1952)	4°00'- 8°00'N 155°00'W	22.06+	20.5	1.08	9
H.M. SMITH 33 (Mar.1955)	4°06'- 7°23'N 140°00'W	10.40	9.7	1.07	9
H.M. SMITH 35 (Aug.1956)	6°09'- 9°59'N 134°45'W	13.85	12.1	1.14	21

TABLE I. (Continued)

TRANSPORT FUNCTIONS OF THE PACIFIC EQUATORIAL COUNTER-CURRENT

Ship / Cruise	Hydrographic Cross-Section (P.E.C.C.)	Geostrophic Transport ($10^6 m^3$/sec.)	Transport Function ($10^4 m^2$/sec.)	Factor K (10^2)	I. D. No.
H.M. SMITH 35 (Oct.1956)	3°57'- 9°59'N 160°00'W	41.02	22.4	1.83	22
H.M. SMITH 38 (Mar.1957)	2°01'N / 145°06'W – 8°56'N / 149°53'W	15.46	14.2	1.09	62
H.M. SMITH 45 (April 1958)	1°00'- 3°01'N 140°00'W	11.08+	14.4	.77	65
H.M. SMITH 45 (April 1958)	1°30'- 3°26'N 140°00'W	0.75+	0.9	.82	66
STRANGER Equapac (Aug.1956)	4°02'- 9°00'N 167°00'W	41.23	25.0	1.65	13
STRANGER Equapac (Sept.1956)	4°00'- 8°09'N 175°00'W	35.80	21.5	1.67	12
STRANGER Doldrums (Aug.1958)	5°00'- 7°00'N 107°25'W	24.63	7.8	3.16	67
STRANGER Doldrums (Aug.1958)	4°55'-10°00'N 107°00'W	20.94	11.7	1.79	68
TAKUYO (Jan.1958)	1°01'- 8°26'N 153°00'E	67.23	20.4	3.30	29
TAKUYO (Feb.1958)	2°02'- 8°30'N 151°00'E	36.64	19.4	1.89	30
TAKUYO (Feb.1958)	1°50'- 6°04'N 149°00'E	39.15	16.3	2.40	31
UMITAKA-MARU (Nov.1958)	2°26'- 4°59'N 135°00'E	42.53	17.8	2.39	35
VITYAZ 25 (July 1957)	1°31'- 4°33'N 154°00'E	38.96	22.1	1.76	36

TABLE I. (Continued)

TRANSPORT FUNCTIONS OF THE PACIFIC EQUATORIAL COUNTER-CURRENT

Ship / Cruise	Hydrographic Cross-Section (P.E.C.C.)	Geostrophic Transport $(10^6 m^3/sec.)$	Transport Function $(10^4 m^2/sec.)$	Factor K (10^2)	I. D. No.
VITYAZ 25 (Aug.1957)	1°54'N / 148°22'E – 3°57'N / 148°01'E	32.15	23.4	1.37	37
VITYAZ 25 (Aug.1957)	2°30'- 4°00'N / 140°00'E	32.01	14.1	2.27	38
VITYAZ 25 (Aug.1957)	0°59'N / 134°32'E – 4°34'N / 134°58'E	70.57	38.2	1.85	39
VITYAZ 25 (Aug.1957)	2°38'N / 128°27'E – 6°10'N / 131°50'E	39.12	17.3	2.61	40
VITYAZ 25 (Sept.1957)	2°38'N / 128°27'E – 5°11'N / 126°53'E	31.18	20.1	1.55	41
VITYAZ 26 (Nov.1957)	1°08'N / 173°00'W – 8°34'N / 174°07'W	37.93	24.8	1.53	42
VITYAZ 26 (Feb.1958)	2°56'N / 172°43'E – 9°23'N / 173°36'E	64.37	34.4	1.87	43
VITYAZ 27 (April 1958)	2°58'- 9°38'N / 142°00'E	48.50	25.3	1.92	44
VITYAZ 27 (April 1958)	3°32'- 7°51'N / 143°30'E	77.43	23.6	3.28	45
VITYAZ 27 (April 1958)	5°01'- 8°00'N / 145°00'E	17.84	15.5	1.15	46
VITYAZ 27 (April 1958)	5°27'N / 143°33'E – 6°14'N / 143°28'E	12.07	3.1	3.89	47
VITYAZ 27 (April 1958)	2°58'- 5°59'N / 145°00'E	37.87	19.8	1.91	77
VITYAZ 27 (May 1958)	2°52'- 5°02'N / 135°30'E	32.07	16.5	1.94	78

TABLE I. (Continued)

TRANSPORT FUNCTIONS OF THE PACIFIC EQUATORIAL COUNTER-CURRENT

Ship / Cruise	Hydrographic Cross-Section (P.E.C.C.)	Geostrophic Transport ($10^6 m^3$/sec.)	Transport Function ($10^4 m^2$/sec.)	Factor K (10^2)	I.D. No.
VITYAZ 27 (May 1958)	7°00'N / 135°20'E – 8°40'N / 138°06'E	5.99+	5.0	1.20	79

TABLE II.

THERMOCLINIC TRANSPORT OF THE PACIFIC EQUATORIAL COUNTER-CURRENT

Ship / Cruise	Bathythermal Cross-Section (P.E.C.C.)	Thermoclinic Transport ($10^6 m^3$/sec.)	I. D. No.
Acapulco Trench (Oct.1954)	5°45'-10°30'N 126°00'W	27.0	101
S.F. BAIRD Capricorn (Feb.1953)	4°15'- 8°30'N 124°00'W	17.1	102
U.S.S. BARTON (July 1946)	2°00'- 6°45'N 164°30'E	25.8	103
CAVALIERI (Aug.1952)	4°15'- 7°00'N 140°00'W	7.2	104
CHALLENGER (Mar.1875)	2°15'N / 146°16'E - 7°45'N / 144°20'E	34.2	105
CHALLENGER (Aug.1875)	5°54'N / 147°02'W - 9°28'N / 150°49'W	16.2	106
GILBERT 1 (May 1952)	5°30'- 7°30'N 120°00'W	6.2	107
GILBERT 1 (June 1952)	5°30'- 8°45'N 130°00'W	19.7	108
GILBERT 15 (Mar.1954)	5°15'- 7°15'N 110°30'W	2.2	109
GILBERT 15 (April 1954)	4°00'- 8°30'N 155°00'W	18.9	110
Japanese (Feb.1935)	5°00'- 7°00'N 136°00'E	16.3	111
Japanese (Jan.1936)	4°30'- 6°30'N 138°00'E	44.7	112
Japanese (Feb.1936)	4°00'- 8°00'N 149°00'E	50.0	113
U.S.S. LAFFEY (July 1946)	4°00'- 6°45'N 167°30'E	27.9	114
MANNING 11 (Feb.1952)	4°30'- 8°30'N 180°00'	28.8	115
MANNING 11 (Feb.1952)	2°30'- 6°45'N 155°00'W	34.9	116
MANNING 11 (Mar.1952)	3°00'- 4°15'N 169°00'W	4.7	117
MANNING 12 (Aug.1952)	5°00'- 8°30'N 150°00'W	19.9	118
MANNING 13 (Oct.1952)	6°15'N / 152°30'W - 10°00'N / 153°30'W	23.5	119
MANNING 13 (Nov.1952)	3°15'- 4°30'N 168°30'W	4.8	120
MANNING 14 (Feb.1953)	3°45'- 8°15'N 150°00'W	31.5	121
MANNING 14 (Mar.1953)	2°30'- 3°00'N 140°00'W	2.8	122

TABLE II. (Continued)

THERMOCLINIC TRANSPORT OF THE PACIFIC EQUATORIAL COUNTER-CURRENT

Ship / Cruise	Bathythermal Cross-Section (P.E.C.C.)	Thermoclinic Transport ($10^6 m^3$/sec.)	I. D. No.
MANNING 15 (May 1953)	7°00'-10°00'N / 150°00'W	0.8	123
MANNING 15 (June 1953)	3°30'- 7°15'N / 170°00'W	11.7	124
MANNING 16 (Aug.1953)	3°15'- 9°30'N / 155°00'W	20.2	125
MANNING 16 (Aug.1953)	4°30'- 9°00'N / 160°00'W	23.1	126
MANNING 18 (Dec.1953)	4°15'- 8°30'N / 155°00'W	44.0	127
SERRANO (May 1949)	5°15'N / 125°00'W - 10°30'N / 123°30'W	5.1	128
SERRANO (May 1949)	4°15'- 8°15'N / 125°30'W	7.1	129
SHELLBACK (May 1952)	6°00'N / 119°00'W - 8°30'N / 120°30'W	2.1	130
SHELLBACK (June 1952)	4°45'- 7°30'N / 97°30'-98°00'W	9.8	131
SHELLBACK (July 1952)	2°30'- 5°00'N / 85°00'W	5.5	132
SHELLBACK (Aug.1952)	4°15'N / 89°00'W - 9°00'N / 88°30'W	3.8	133
SHELLBACK (Aug.1952)	4°30'N / 102°00'W - 9°00'N / 104°30'W	9.4	134
H.M. SMITH 2 (Feb.1950)	1°30'-10°00'N / 172°00'W	47.5	1
H.M. SMITH 2 (Feb.1950)	5°00'- 9°30'N / 158°00'W	25.5	2
H.M. SMITH 5 (July 1950)	3°45'- 7°00'N / 172°00'W	25.0	5
H.M. SMITH 5 (Aug.1950)	5°00'- 9°30'N / 158°00'W	28.9	3
H.M. SMITH 7 (Oct.1950)q	5°45'N / 157°00'W - 10°00'N / 158°00'W	34.9	139
H.M. SMITH 7 (Nov.1950)	5°30'N / 159°00'W - 9°00'N / 158°15'W	38.6	140
H.M. SMITH 8 (Jan.1951)	4°00'- 7°30'N / 158°00'W	40.5	4
H.M. SMITH 8 (Feb.1951)	5°00'- 6°45'N / 165°30'W	15.2	6
H.M. SMITH 8 (Mar.1951)	4°00'- 7°30'N / 172°00'W	37.4	7
H.M. SMITH 11 (Sept.1951)	5°30'- 8°00'N / 150°00'W	18.2	144

TABLE II. (Continued)

THERMOCLINIC TRANSPORT OF THE PACIFIC EQUATORIAL COUNTER-CURRENT

Ship / Cruise	Bathythermal Cross-Section (P.E.C.C.)	Thermoclinic Transport ($10^6 m^3$/sec.)	I. D. No.
H.M. SMITH 11 (Sept.1951)	3°30' - 8°30'N 150°00'W	34.3	8
H.M. SMITH 14 (Jan.1952)	5°30' - 9°30'N 155°00'W	25.5	9
H.M. SMITH 14 (Feb.1952)	4°00' - 8°30'N 180°00'	28.3	147
H.M. SMITH 14 (Mar.1952)	3°15' - 6°00'N 169°00'W	22.3	148
H.M. SMITH 15 (May 1952)	4°30' - 8°30'N 140°00'W	16.4	149
H.M. SMITH 15 (June 1952)	5°00' - 8°00'N 140°00'W	14.6	150
H.M. SMITH 15 (June 1952)	5°00' - 8°00'N 140°00'W	16.0	151
H.M. SMITH 15 (June 1952)	4°45' - 8°45'N 140°00'W	18.7	152
H.M. SMITH 16 (July 1952)	5°00' - 8°45'N 150°00'W	22.1	153
H.M. SMITH 18 (Oct.1952)	5°15'N 120°00'W - 9°15'N 121°00'W	27.9	154
H.M. SMITH 18 (Nov.1952)	5°45' - 8°45'N 131°00'W	40.7	155
H.M. SMITH Equapac (Oct.1955)	5°30'-10°45'N 110°00'W	9.5	156
H.M. SMITH Equapac (Oct.1955)	3°00' - 5°30'N 140°00'W	9.6	157
TENYO-MARU (Aug.1951)	1°00' - 7°00'N 150°00'E	27.4	158
TENYO-MARU (Sept.1951)	2°00' - 9°30'N 160°00'E	25.7	159

TABLE III.

TABULATED TRANSPORTS BY MONTH AND LONGITUDE

	LONGITUDE								
	120°E	140°E	160°E	180°	160°W	140°W	120°W	100°W	80°W
JANUARY		23 11 45	67		29 22				
FEBRUARY		16 16 50 39	37	64 29 28 25	17 20 35	32	17	18	
MARCH		34		20 22 5	15	10 3		2	
APRIL		49 12 77	18 38 26 69		19	11 1			
MAY		32 6		4	1	16	7 5 2 6		
JUNE				12		19 15 16 20 16		10	
JULY		86	39 26 28	44 26	22	21	6 8		6
AUGUST	68 39	71 32 40 59 27 21	32 37 47 46		41 23 22 20	20 16 24 7 14		25 21 10 4	
SEPTEMBER		31	26	36	26	18			
OCTOBER					41 35 24	42 10 40 27	27 12 28 13 11 7 7	10	
NOVEMBER		43		38 5	39	23 41		1 6 3 1 1 5	5
DECEMBER					62 44			20 15	13

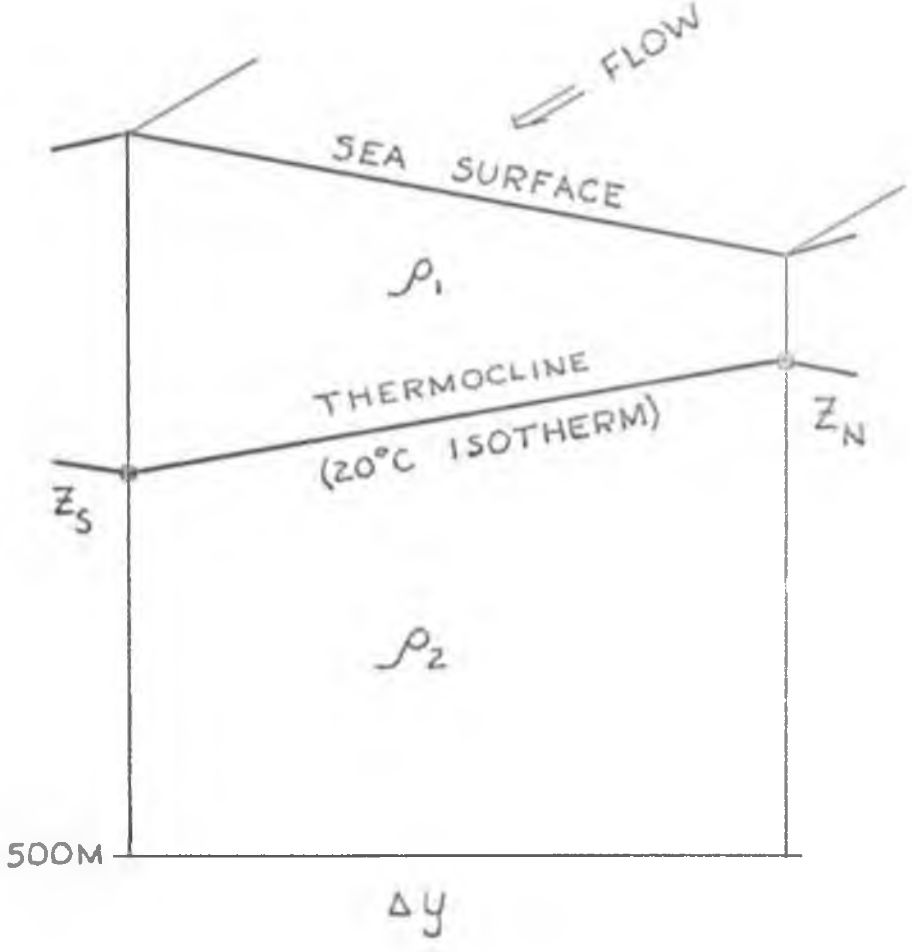

FIGURE 1. MERIDIONAL SECTION OF THE PACIFIC EQUATORIAL COUNTERCURRENT

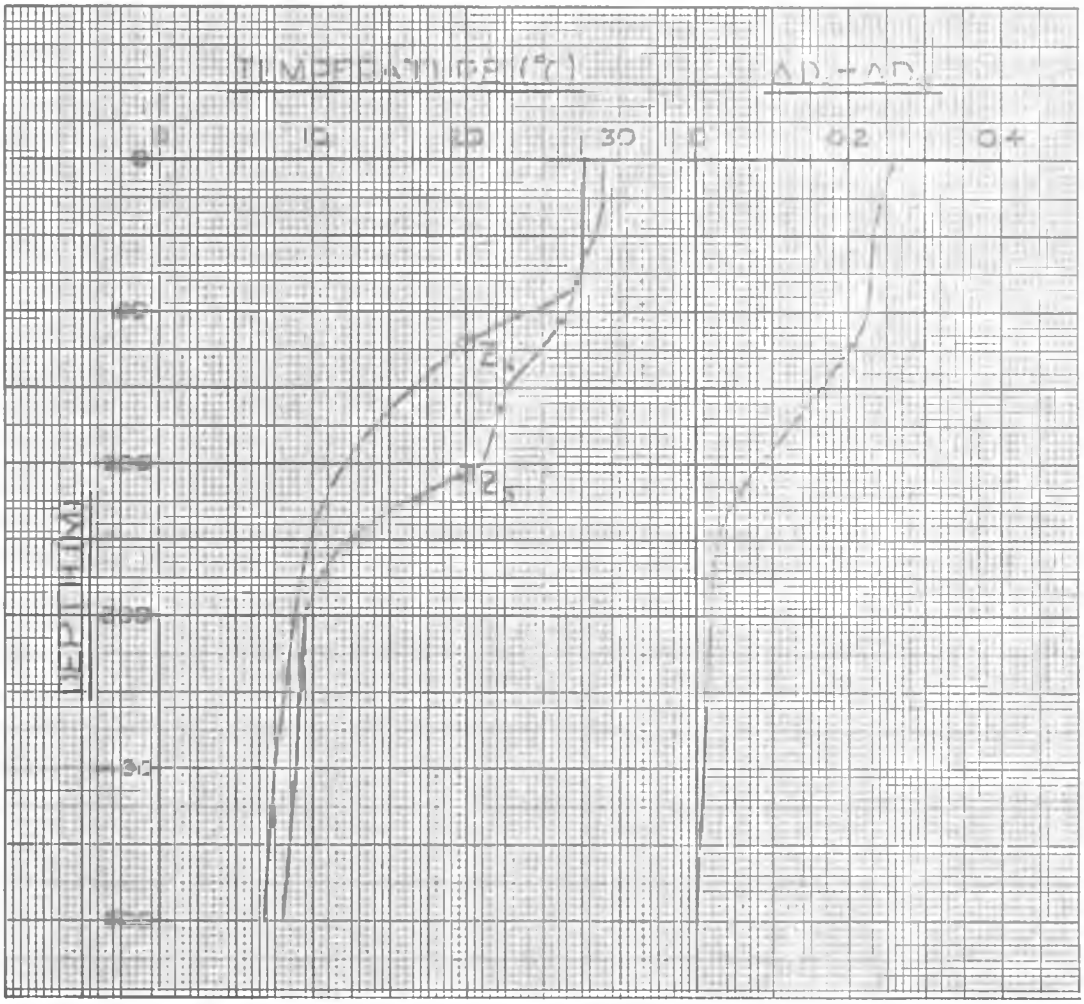

FIGURE 2. VERTICAL DISTRIBUTION OF TEMPERATURE AT THE NORTHERN AND SOUTHERN BOUNDARY OF THE COUNTERCURRENT AND OF THE DIFFERENCE OF DYNAMIC HEIGHT BETWEEN THESE TWO LOCATIONS FROM THE SURFACE TO 500 METER DEPTH ALONG A VITYAZ SECTION AT 142°E (IDENTIFICATION NO. 44)

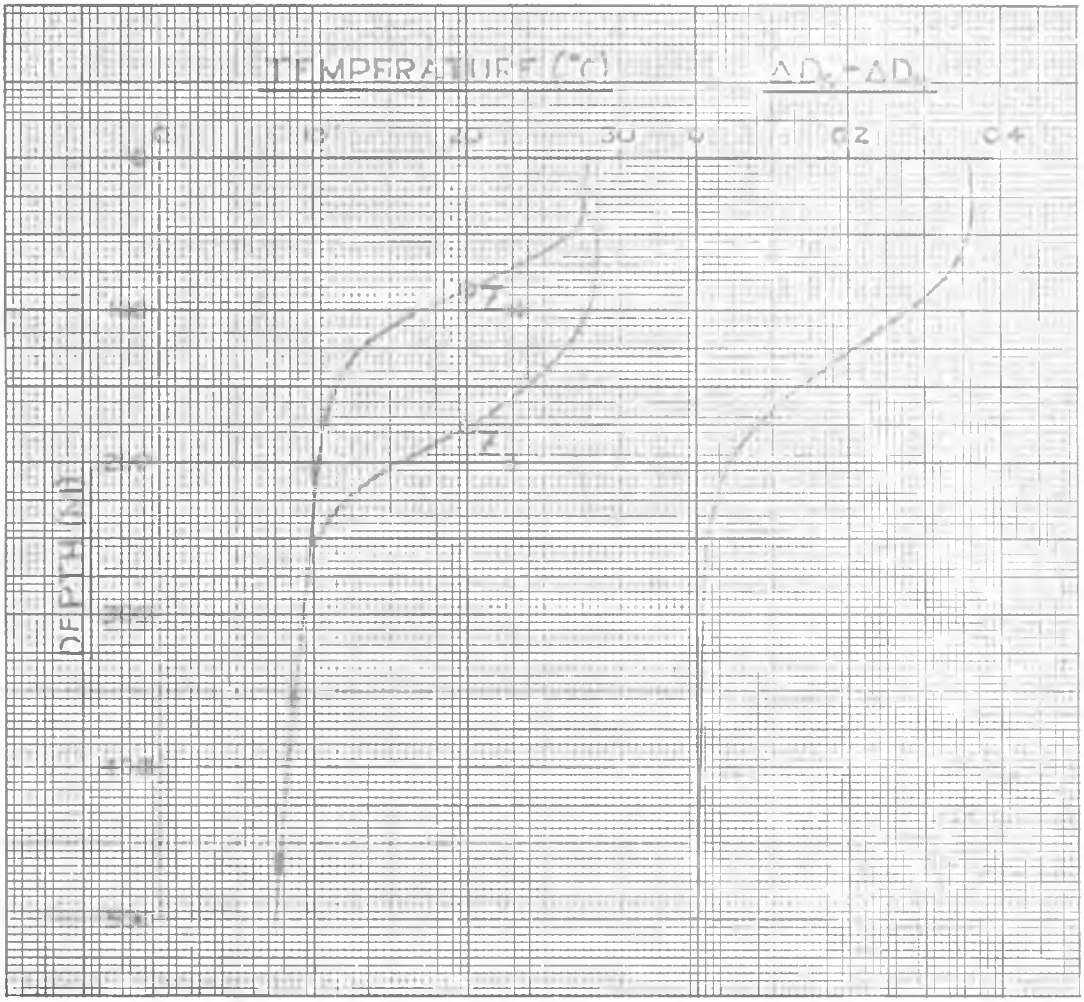

FIGURE 3. VERTICAL DISTRIBUTION OF TEMPERATURE AT THE NORTHERN AND SOUTHERN BOUNDARY OF THE COUNTERCURRENT AND OF THE DIFFERENCE OF DYNAMIC HEIGHT BETWEEN THESE TWO LOCATIONS FROM THE SURFACE TO 500 METER DEPTH ALONG A STRANGER SECTION AT 175°W (IDENTIFICATION NO. 12)

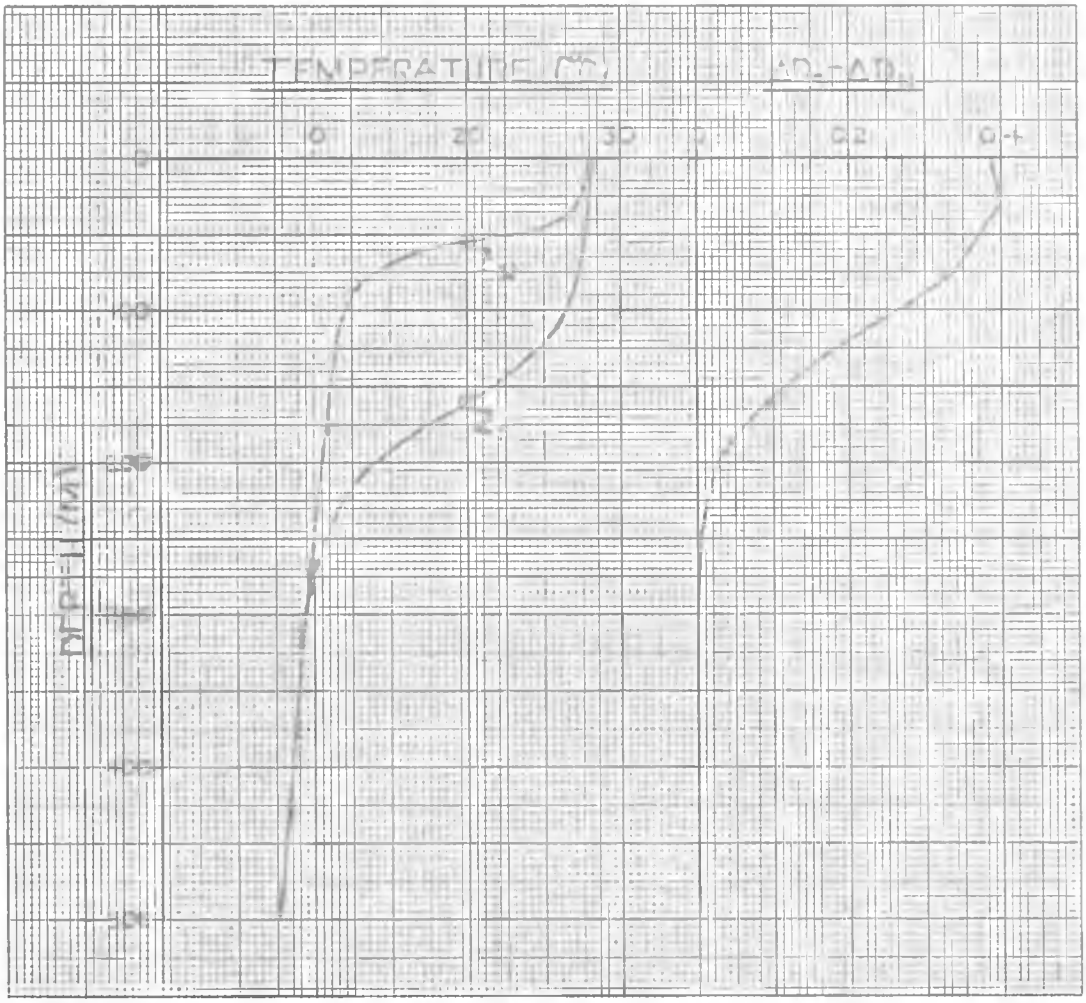

FIGURE 4. VERTICAL DISTRIBUTION OF TEMPERATURE AT THE NORTHERN AND SOUTHERN BOUNDARY OF THE COUNTERCURRENT AND OF THE DIFFERENCE OF DYNAMIC HEIGHT BETWEEN THESE TWO LOCATIONS FROM THE SURFACE TO 500 METER DEPTH ALONG A HUGH M. SMITH SECTION AT 150°W (IDENTIFICATION NO. 8)

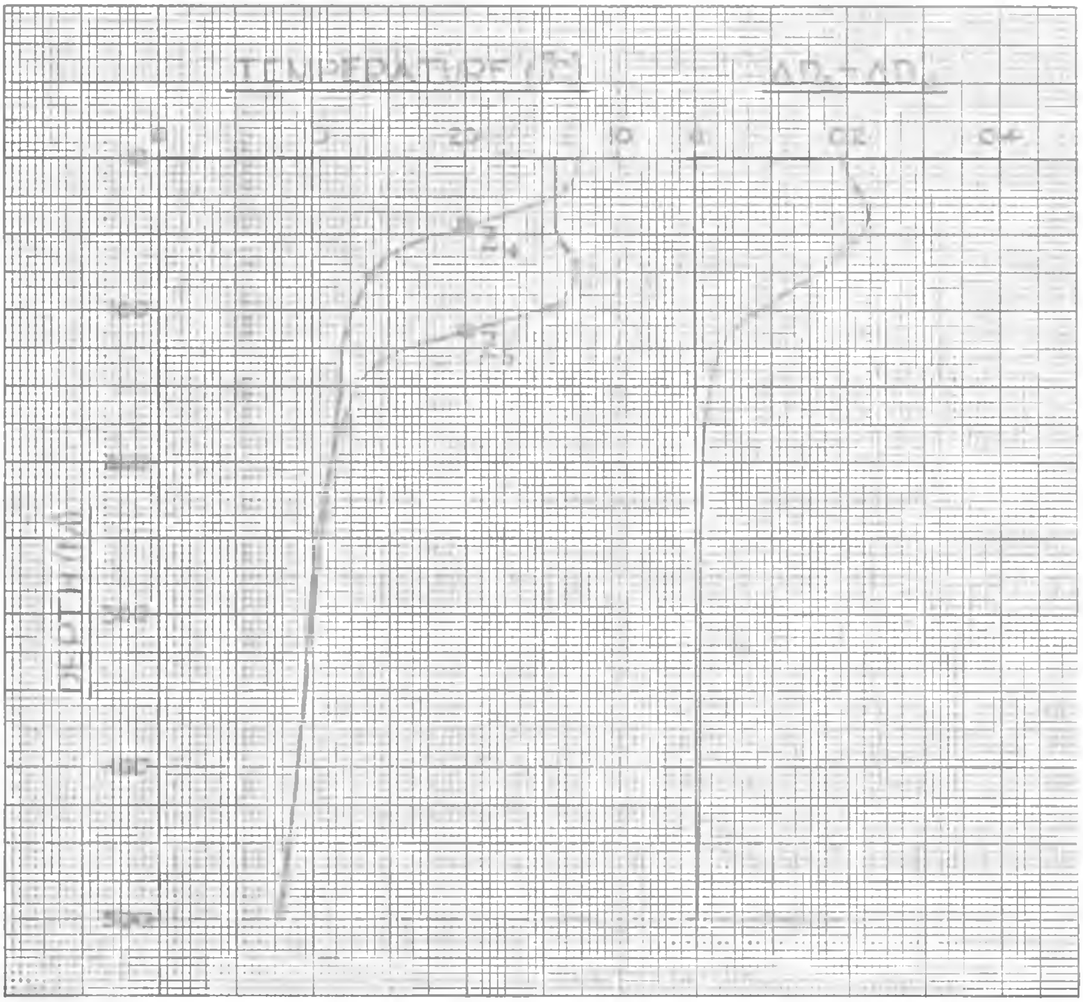

FIGURE 5. VERTICAL DISTRIBUTION OF TEMPERATURE AT THE NORTHERN AND SOUTHERN BOUNDARY OF THE COUNTERCURRENT AND OF THE DIFFERENCE OF DYNAMIC HEIGHT BETWEEN THESE TWO LOCATIONS FROM THE SURFACE TO 500 METER DEPTH ALONG A S. F. BAIRD SECTION AT 115°W (IDENTIFICATION NO. 49)

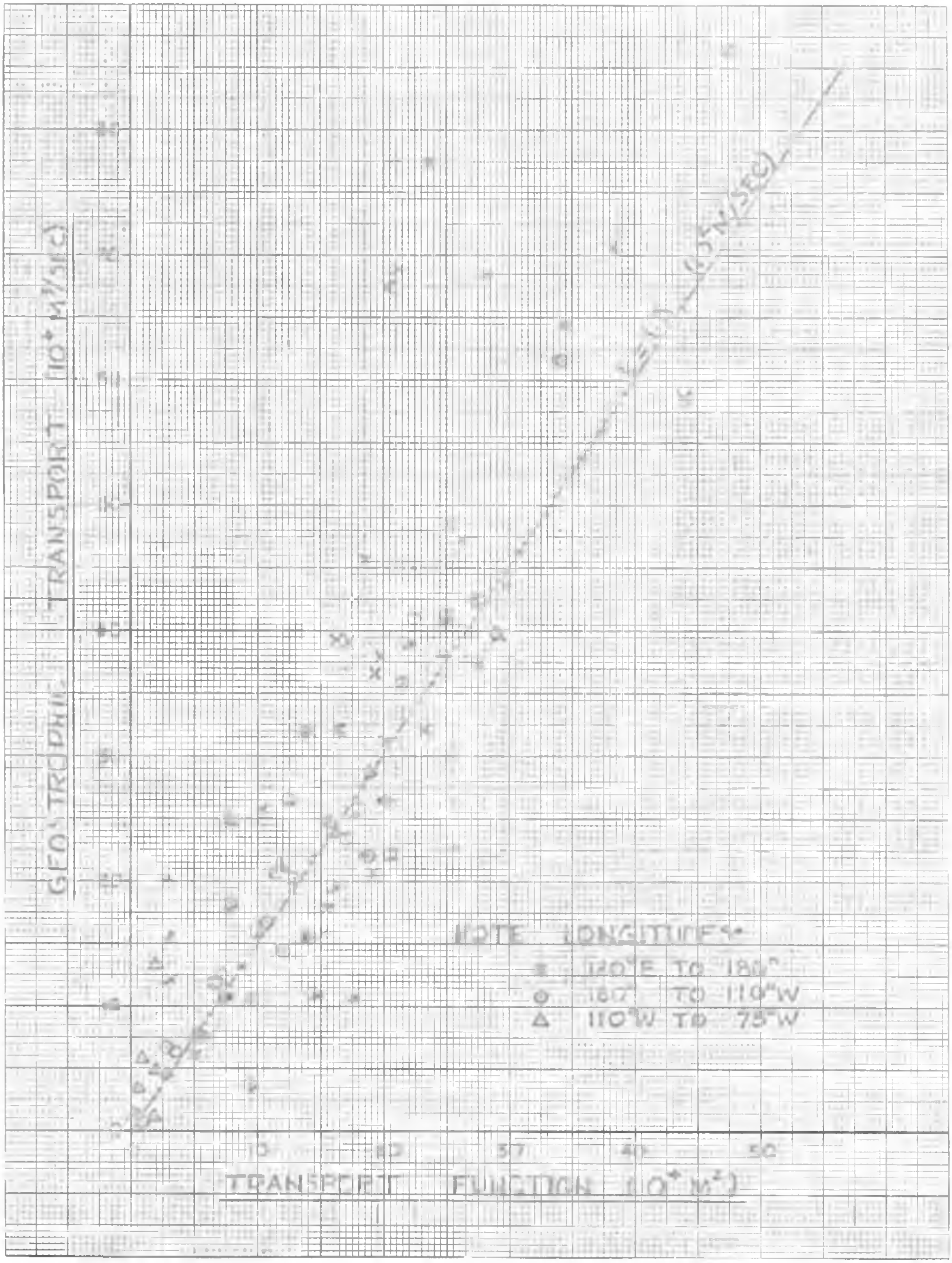

FIGURE 6. GEOSTROPHIC TRANSPORT VERSUS TRANSPORT FUNCTION WITH LONGITUDE REGIONS AND A FACTOR K = 1.5 NOTED

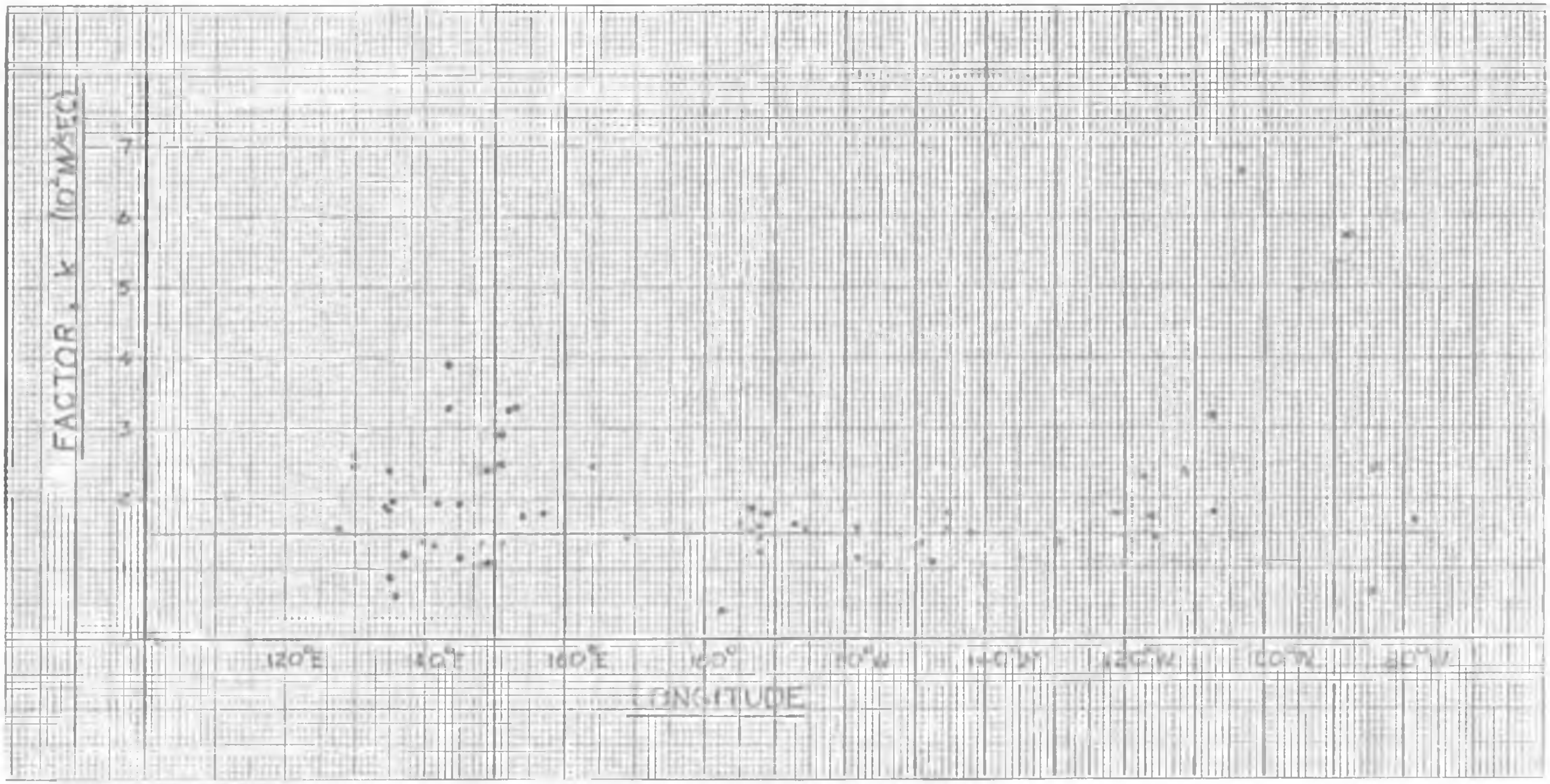

FIGURE 7. FACTOR K VERSUS LONGITUDE

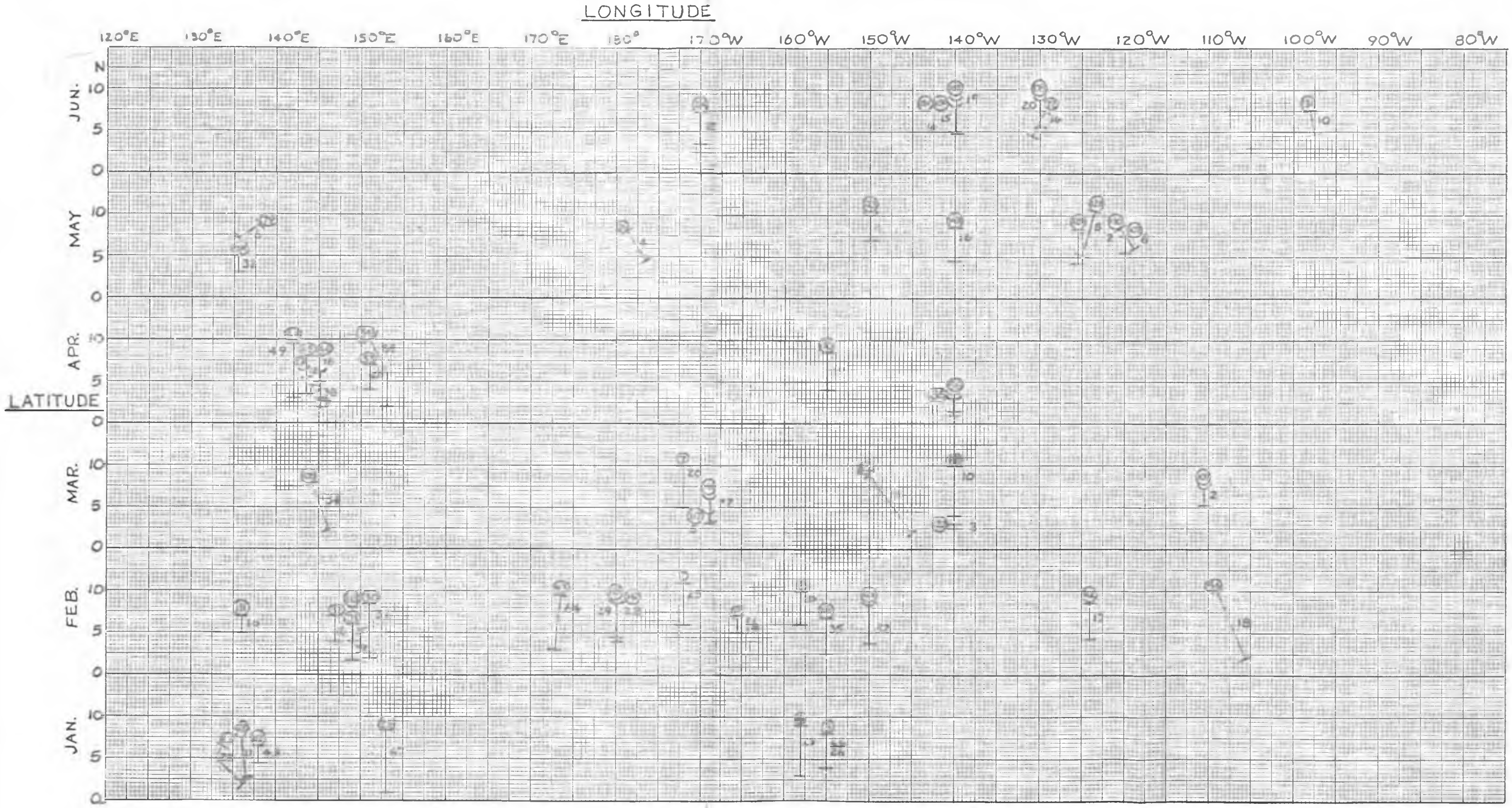

FIGURE 8. POSITIONS OF COUNTERCURRENT SECTIONS INDICATING RANGE AND TRANSPORT MAGNITUDES ($10^6 M^3$/SEC.) FOR THE MONTHS OF JANUARY THROUGH JUNE. CIRCLED IDENTIFICATION NUMBERS REFER TO TABLES I AND II

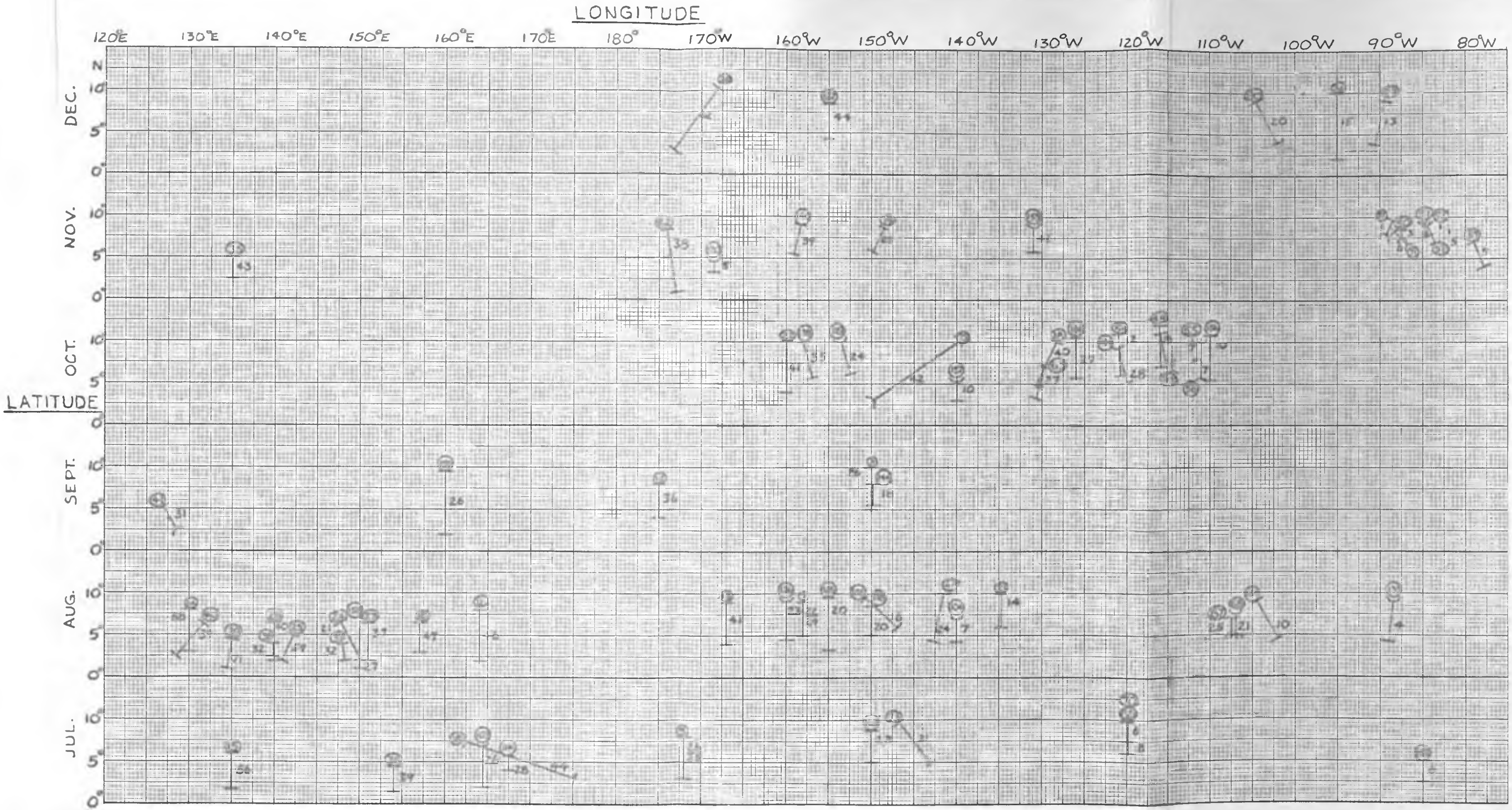

FIGURE 9. POSITIONS OF COUNTERCURRENT SECTIONS INDICATING RANGE AND TRANSPORT MAGNITUDES ($10^6 M^3$/SEC.) FOR THE MONTHS OF JULY THROUGH DECEMBER CIRCLED IDENTIFICATION NUMBERS REFER TO TABLES I AND II

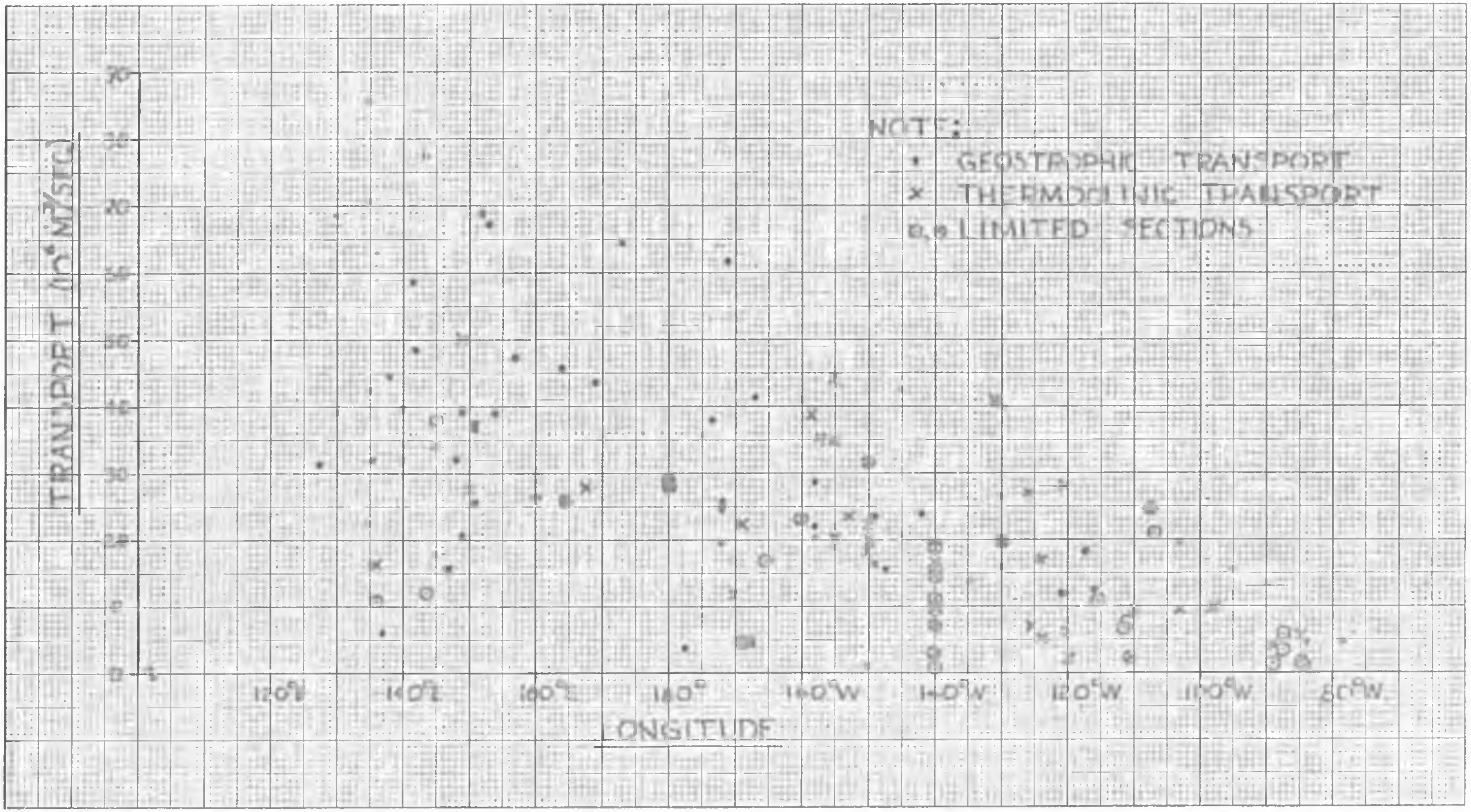

FIGURE 10. GEOSTROPHIC AND THERMOCLINIC TRANSPORTS VERSUS LONGITUDE WITH LIMITED SECTIONS NOTED

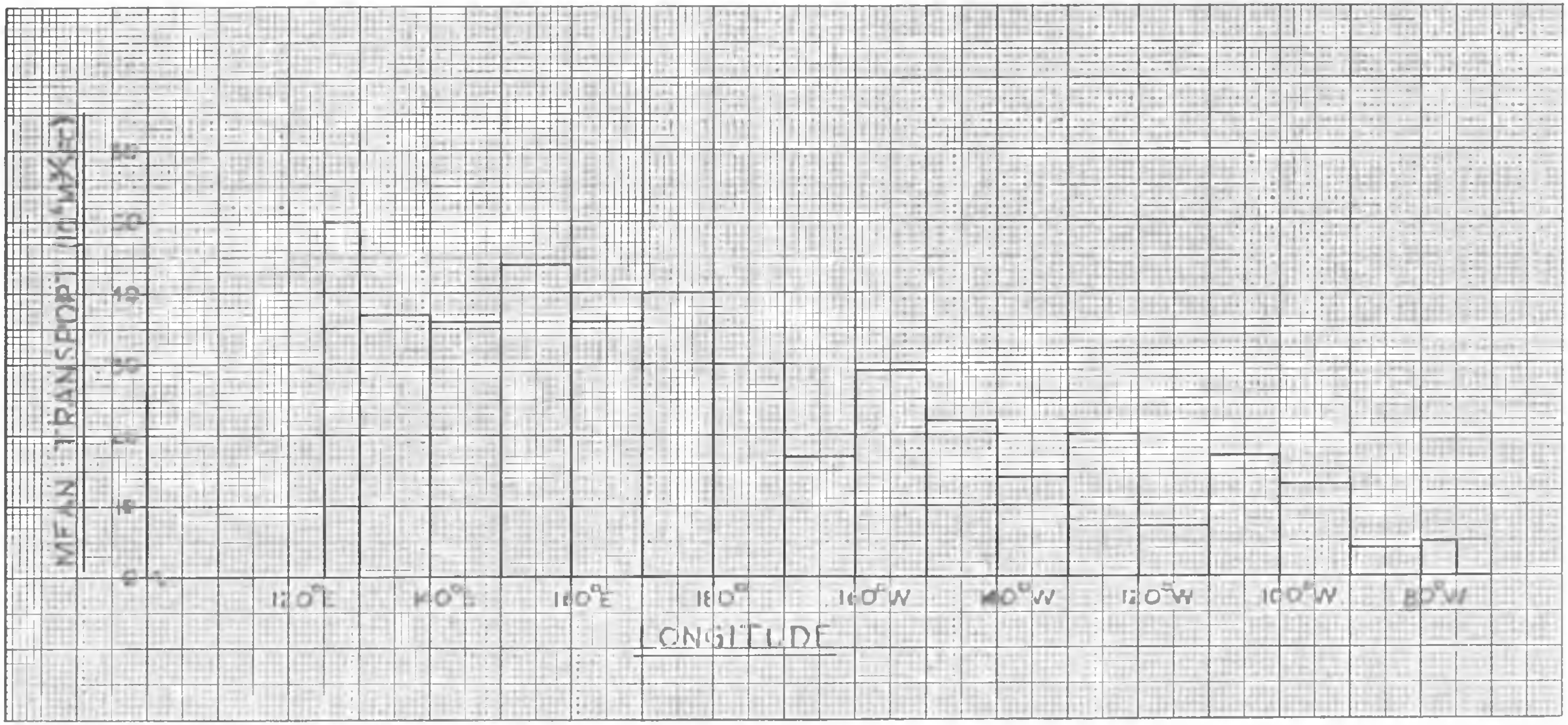

FIGURE 11. MEAN TRANSPORTS FOR INCREMENTS OF LONGITUDE

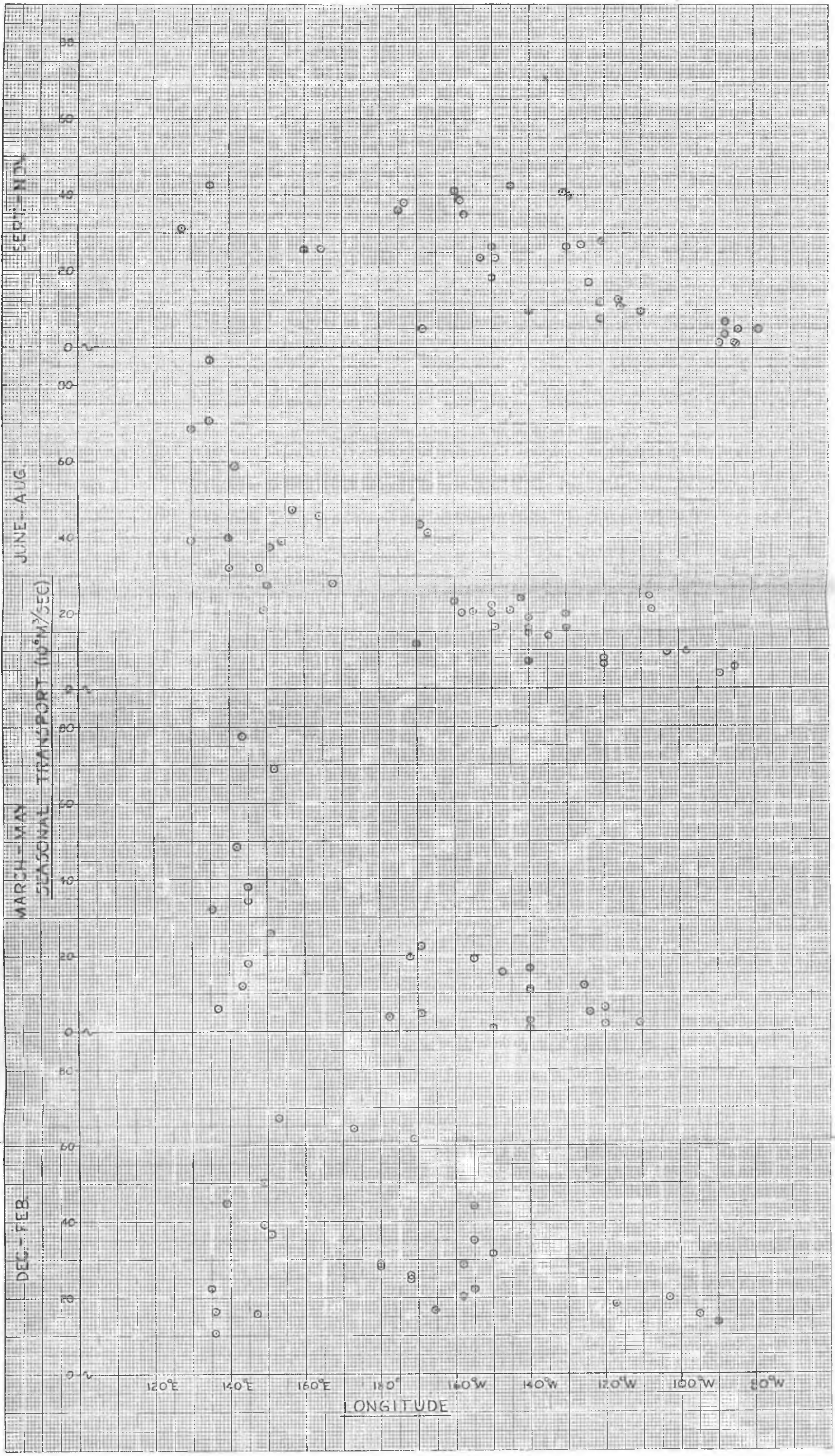

FIGURE 12. SEASONAL TRANSPORTS VERSUS LONGITUDE