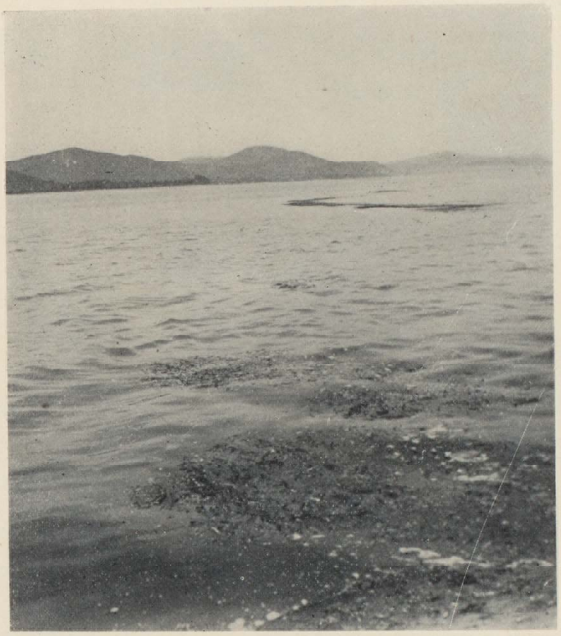
Photo. 1.



"Siome" in the Mikawa Bay on July 17, 1935 which runs along the 5m. isobathymetric line off Hime Sima.
(Photo. by M. OKADA).

Photo. 2.



"Siome" near the Cape of Seisin, in Northern Tyōsen in June, 1932.
(Photo. by M. UDA).

Researches on "Siome" or Current Rip in the Seas and Oceans.

By

M. Uda

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Introduction. A comparatively narrow stretched band, which appears on the sea-surface with singular rippling and is commonly accompanied by foams and other drifting-bodies of various kind,* [1] is called "Siome" (潮

* An example of "Siome" accompanied by foams and drifting-dusts is presented in Phot. 1 (PL. I) by M. Okada.

(1) 岡田光世: 近海の海況に關する二三の問題. 科學 Vol. 6. No. 10. 1936. p. 454.

目）* (locally called by other names "Sioai" (潮合),* "Siobuti" (潮縁),* "Sio-no-Tatakai" (潮の闘ひ),* "Siozakai" (潮境),* "Siodai" (シオダイ)* etc.) by fishermen and navigators of this country. It is equivalent to "Current Rip" or "Tide Rip," "Ripple" in English, "Stromkabbelung" or sometimes "Stromgrenze" in German, "Clapotis" or "Clapotage" in French and "Stromrafeling" in Dutch.

It is already noticed that "Siome" appears in many cases in coincidence with the zones, to which planktons, fish-shoals, whales etc. are accumulated and is consequently an important indicator for fishing-grounds.

In actual "Siome" the modes of appearance show so many varieties i. e. the grown up "Current Rip" breaking on the top of the wave, bubbling up (Aufwallen), or sometimes resembling to a boiling state (Kochenden), or as a train of vortices.(2)(3)

Moreover, we can hear noisy sound (Geräusch)** near "Siome," of which, according to A. Schumacher (1935), includes "noise" ("Rauschen," "Brüllen" and "Kochen"), rarely "roaring" ("Brüllen," "Zischen" etc.), even a record of sound heard from three seamiles distance.(4) Fishermen in the Kurosio region (e. g. in the vicinity of Idu Islands and Sionomisaki) tell us that the existence of vortices of several metres in diameter along the lines of "Siome" is frequently observed and the gill-net of flying-fish etc. is rolled like a ball and then sunk down to the lower depth as we see in a tornado.

The phenomenon of "Siome" is known to sea-farers from ancient times, i. e. M. F. Maury (1858) described it as a wonderful phenomenon on the sea(5) and G. F. Neumeyer (1875, 1906) supposed it as the collision and

(2) E. Römer. Anhäufung stationärer Stromkabbelungen in der west-africanischen Gewässern. Ann. d. Hydr. 63, 1935, S. 10-17.

(3) E. Römer. Örtlich-periodisch auftretende Kabbelungen an der mexikanischen und mittelamerikanischen Westküste. Ann. d. Hydr. Zweites Köppen Bd. 1936. S. 55-65.

* The above common words used in Japan may be considered to involve the following meaning i. e. "Siome" a peculiar striae or pattern which is met with on the sea, "Sioai" the zone of collision between two currents of different origin, "Siobuti" the marginal line of a current or a water-mass, "Sio-no-Tatakai" the fighting of two opposite currents, "Siozakai" the boundary between water-masses or currents, "Siodai" probably the corruption of "Siozakai" or "Sioai."

** The noisy sound is equivalent to that called "Siozai" (潮騒) in Japanese.

(4) A. Schumacher. Ueber Stromkabbelungen, besonders in Guinea-Strom und seiner Umgebung. Ann. d. Hydr. LXIII, 1935, Hf. X. S. 373-382.

(5) M. F. Maury. Sailing directions. Washington, Bd. I, 1858, p. 327.

the struggle of two currents.[6] A. Schück (1889) considered that the cause of violent "Siome" lies in the rapid variation of the atmospheric pressure, in analogy to his theory of "Seebären."[7] O. Krümmel (1911) considered "Siome" as an unknown sort of wave which aroused at the boundary zone of two currents influenced by the mechanical resistance of sea-bottom.[8]

Proceeding on this line in detail, E. Römer (1935) recently noticed the frequent occurrence of "Siome" at the edge of the continental shelf (200 m. isobathymetric line) of Africa.[2] Those "Siome" have breadth of from less than 1 m. to hundreds of metres, rarely of several sea-miles and is elongated commonly to tens of sea-miles. On the otherhand A. Schumacher reported the existence of oily patch* (ölige Flecke) or "ölige Streifen" in the regions of divergence and frequently present there "bubbling up"

The peculiar phenomenon reported by J. W. Sandström (1905),[9] O. Pettersson (1908)[10] and H. Pettersson (1930)[11] as "Schaumrandphänomenon" occurring in the coastal water leeward to a steep cliff may be put in the category of "Siome." An example of such a phenomenon observed by the author[12] is shown in Photo. 2. (PL. I).

The phenomenon reported by S. Fujiwhara (1921) with photograph at the flood gate of a lake communicated with a sea in the vicinity of Bergen which formed a line of discontinuity between the sea-water of tidal flood having comparatively larger velocity and density invading into the fresh water is also an example of "Siome" and led him to the establishment to his theory of vortex development from horizontal to vertical axis according to the general principle of tendency towards symmetry.[13]

A similar phenomenon named as "Rheinbrech" shows, by photograph-

(6) G. v. Neumeyer. Anleitung zur wissensch. Beobacht. auf Reisen. 1875 & 1906.

(7) A. Schück. Haben die hohen Stromwellen des Meeres und Seebären der Ostsee gleiche Ursache? Hansa Zs. f. Seewesen. 26 1889, S. 197.

(8) O. Krümmel. Handbuch der Ozeanographie. Bd. II. 1911, S. 526.

(9) J. W. Sandström. Svenska Hydrografisk Bibliogiska Kommis. Skrifter, Hf. II, 1905. Ann. d. Hydr. XXXVI, 1906, p. 6.

(10) O. Pettersson. Über Strömungen. Veröfftl. d. Inst. f. Meeresk. Hf. 12, 1908.

(11) H. Pettersson. Über das sogenannte Schaumrandphänomenon. Meddelander Fran Göteborgs Högskolas, Oceanografiska Inst. 2. Göteborgskungl. Vetenskap och vitterhets-sämmhälles Handlingar Femte Följden. Ser. B. Bd. 2, No. 2. Oct. 1930.

(12) 宇田道隆: 長塚節の歌と海洋不連續線潮目. 科學第 4 卷第 7 號. 昭和 9 年. p. 50.

(13) S. Fujiwhara. The natural tendency towards symmetry of motion and its application as a principle of meteorology. Quarterly Journal of Roy. Meteor. Soc. 1921.

* It may be equivalent to "Siobuti" (潮斑) called by fishermen in this country.

ing, a series of vortices on the boundary zone of Rhein water flowing out the Bodensee.[14]

The periodic pattern in a striate form of columnar vortices in liquid by thermal convection shown by T. Terada experimentally[15][16][17] brought an important clue on the mechanism of "Siome" in the ocean called "Simazio" (縞潮)* by the fishermen in the North-Eastern region in this country. Following in this line of research S. K. Banerji and V. M. Ghatage undertook the experiments on the mechanism of vortices produced by thermal discountinuity in liquid, and obtained very interesting results as we quoted later [18].

The line of discontinuity between two water-masses of different kinds coincides in most cases with "Siome" as a line of discontinuity between currents. In the North Atlantic Ocean the Cold Wall as a front of Labrador Current against the Gulfstream was proved to fit well in the line of convergence (Subarktische Konvergenz) by A. Defant, G. Böhnecke and others (1930)[19][20] basing on the results of "Meteor"-Expedition. Similar result has been obtained by the study of H. U. Sverdrup.[21]

In this country the first description of "Siome" is found in the report

(14) H. J. Elster u. W. Einsele. Beiträge zur Hydrographie des Bodensees. Int. Rev. d. ges. Hydr. u. Hydr. Bd. 35. Hf. 416, 1937.

(15) T. Terada & K. Hattori. Some experiments on motion of fluid. Part IV. Rep. of Aeronaut. Res. Inst. Tokyô Imp. Univ. No. 26, 1927.

(16) T. Terada & others. Some experiments on periodic columnar forms of vortices caused by convection. Ibid. No. 31, 1928.

(17) T. Terada & M. Tamano. Further researches on periodic columnar vortices produced by convection. Ibid. No. 53, 1929.

* "Simazio" means the striped pattern of cold and warm waters or currents. As an example of it in Gulfstream off Cape Hatteras, the reader is referred to the following.

(17)' G. Dietrich. Über Bewegung und Herkunft des Golfstromwassers. Veröff. d. Inst. f. Meeresk. Neu Folge A. Hf. 33. 1937. S. 56.

(18) S. K. Banerji & V. M. Ghatage. On discontinuous fluid motion under different thermal conditions. Indian Jour. of Phys. Vol. VII Part III, 1932, pp. 166-228.

(19) A. Defant. Bericht über die ozeanographischen Untersuchungen des Vermessungsschiffes "Meteor" in der Dänmark Strasse und in der Irminger See. Sitz. ber. d. Preuss. Akad. d. Wiss. Phys. Math. Klasse, 1930 XVI & 1931 XIX.

(20) G. Böhnecke, E. Hentschel u. H. Wattenberg. Über die hydrographischen, Chemischen und biologischen Verhältnisse an der Meeresoberfläche zwischen Island u. Grönland (Ergebnisse einer Fahrt mit dem Vermess. Schiff "Meteor" in Aug. 1929). Ann. d. Hydr. 1930. S. 233.

(21) H. U. Sverdrup. Wie entsteht die Antarktische Konvergenz? Ann. d. Hydr. LXII, 1934, S. 315.

of fishery investigation in 1892[21]' as a conspicuous boundary of water-masses in spring in the seas off Ibaragi Pref. T. Kitahara (1913, 1918, 1923)[22] propounded his theory that "fish-shoals are concentrated in the vicinity of the line of "Siome" which is the contact zone and collision line of two oceanic currents. The skillful whalers know well the actual zone of frequent occurrence of "Siome" and in April the occurrence of "Siome" accompanied with violent current and with feature like a boiling state on sea-surface.[23][22]

The facts of accumulation of planktons, fish-shoals and seabeasts were recorded in literature as "Tierstrom,"[3] "Zoologenparadise,[24] "Productionen," "Ansammelungen"[25] etc., and moreover "Stark Meerleuchten" due to the accumulation of luminescent nektons, or the discoloured water caused by the densely concentrated planktons.[3]

As can be seen from the historical sketch of "Siome" given above, the main problems of this phenomenon in the actual seas and oceans still remain unsolved, particularly in the waters adjacent to Japan, in spite of the remarkable complicated hydrography due to the intermingling of cold and warm currents, hitherto the researches in this line are very scarce.

The aim of the present paper lies in the following: on the basis of the oceanographical surveys and investigations in the waters adjacent to Japan and the experimental study of "Siome" to bring the nature and the mechanism of "Siome" under broader light than ever. The results may have many applications to the fields of fisheries and agriculture, also to the nautical problem and marine engineering.

Chapter I. Distribution of "Siome" in the Waters adjacent to Japan.

(1) Distribution of Water-masses of Several Kinds and their Boundaries in the Waters adjacent to Japan. In the seas and oceans there exist several water-masses which are comparatively homogeneous for the physical and chemical properties, forming surface of discontinuity between them. Of course, in the actual case of line of and surface of discontinuity,

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(21)' 水產豫察調查報告. 第 3 卷第 2 册. 常陸海 p. 14. 農商務省. 明治 25 年 4 月刊行.

(22) 北原多作: 漁村夜話. 1921 pp. 308. 及「海洋調查と魚類の洄游」水產講習所海洋調查部 1918. 北原多作: 明治 45 年及大正元年捕鯨船金華山丸船長の報告に就て. 漁業基本調查報告第 3 册 1913.

(23) 綿貫覺: 太平洋北部海流と魚類及鮭鱒と膃肭獸. 水產界 1931. Oct.

(24) H. Thorade. Methoden zum Studium der Meereströmungen. 1933, S. 3027.

(25) A. Steuer. Planktonkunde. 1910, S. 594.

it is not a geometrical discontinuity but a physical one, showing variation of definite quantity in a narrow interval.

Table 1 and Fig. 1 indicate the general distribution of watermasses and their boundaries in the seas adjacent to Japan on the basis of the data shown in the Semi-annual Report of Oceanographical Investigation published by our Imp. Fish. Expt. St.[26][27][28][29][30][31][32]

Glancing over Fig. 1 we can find the remarkable discontinuity of water-temperature, i. e. in the Japan Sea between the water-mass belonging to the North Tyōsen Cold Current-System and that to the Tusima Warm Current-System, in the North Pacific Ocean between the water-masses of Oyasio and Kurosio. Also, the remarkable discontinuity of salinity is found along the zone of continental shelf between the saline water-mass of Kurosio and the water-mass of low salinity in the China Sea. In Seto-Naikai we see a line of discontinuity between the water-mass of low salinity characteristic to Seto-Naikai and oceanic water-mass (relatively saline and very warm to the former in winter). In the case of gulf or bay, e. g. Wakasa Bay,[33] Ise Bay,[34] Mutu Bay,[35] Ōmura Bay[36] and Sagami Bay[37] etc. the boundary between the coastal and oceanic waters in the vicinity of the entrance of that bay, especially in the upper-stream portion near the cape.

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(26) M. Uda & G. Okamoto. Of the monthly oceanographical chart of the adj. seas of Japan. Part I. Jour. Imp. Fish. Expt. St. No. 1, 1930. & Part II. Ibid. 1931.

(27) M. Uda. Hydrographical researches on the normal monthly conditions of Oyasio and Kurosio-area. Ibid. No. 3, 1933.

(28) M. Uda. Hydrographical researches on the normal monthly conditions in the Japan Sea, the Yellow Sea and the Okhotsk Sea. Ibid. No. 5, 1935.

(29) M. Uda & N. Watanabe. Hydrographical researches on the normal monthly conditions of the Seto-Naikai. Ibid. No. 3, 1933.

(30) M. Uda. The results of simultaneous oceanographical investigations in the Pacific Ocean adj. to Japan made in Aug., 1933. Ibid. No. 6, 1935.

(31) M. Uda. Hydrographical studies based on simultaneous oceanog. surveys made in the Japan Sea and its adj. waters during May and June, 1932. Rec. Oceanog. Works in Japan. Vol. VI. No. 1, 1934.

(32) M. Uda. Results of simultaneous oceanographic investigations in the Japan Sea and its adj. waters during Oct. and Nov., 1933. Jour. Imp. Fish. Expt. St. 1936.

(33) M. Uda. Hydrographical investigations in the seas adjacent to Wakasa Bay. Rec. Oceanog. Works in Japan. Vol. IV, No. 1, 1933.

(34) Journal of oceanograpby. Imp. Marine Obs., Kōbe. Vol. V, No. 1, 1933.

(35) Ibid. Vol. VII, No. 1, 1934.

(36) Ibid. Vol. VIII. No. 1, 1935.

(37) M. Uda. Results of hydrographical investigations in the Sagami Bay etc. Jour. Imp. Fish. Expt. St. No. 8, 1935.

Table 1. Principal Water-masses distributed in the Seas adjacent to Japan.

(Abbreviated notations: θ—water temperature. S—salinity, D—transparency, F—colour of the sea in Forel's scale, $\theta_{0\,m.}$ $S_{0\,m.}$ & $\theta_{100\,m.}$ $S_{100\,m.}$ water temp. & sal. at the sea surface & at a depth of 100 m. resp. θ, $S > \approx < X$—θ, S greater than, nearly equal, less than X resp.)

Pacific Ocean	Oyasio Water	$S \approx 33.3‰$. Usually $S < 33.7‰$ & almost always $< 34‰$. $\theta_{0\,m.} < 15°C$. $\theta_{00\,m.}$ commonly $< 10°C$ and in spring $< 8°C$. Dichotherm Water $0°$~$2°C$. $D < 15$ m. and often < 10 m. F IV~VIII. $O_2 > 7$ cc/l. Rich in nutrient Salts (SiO_2 etc.) Distributed normally in the region northerly to the E. off Kinkazan. Subarctic Water-mass. (In winter the front lies near Tyōsi)
	Kurosio Water	$S > 34.3‰$. in spring $S > 34.6‰$, its max. $\approx 35‰$. $\theta 15°$~$30°C$. $D > 25$ m. (except in spring Idu Is.-region $D < 15$ m.), F I~II, $O_2 \approx 5.5$ cc/l. pH 8.3. Distributed southerly to the E. off Tyōsi. Equatorical Water-mass south to the region from Bonin to Formosa+ Subtropical Water-mass (Riukiu~Idu)+Water-mass in the NE region of Japan.
China Sea Water		$\theta 20°$~$30°C$ in summer, $\theta < 10°C$ in winter, $S_{0-15\,m.} < 33.7‰$ (N. Yellow Sea 31~32.5‰). Below the 30 m. depth S 32.2~32.5‰. (even in summer 7°~10°C). $F > IV$. $D < 20$ m. (≈ 10 m.). Distrib. in the shallower region than 100 m. depth.
Okhotsk-Sea Water		Cold and low Salinity. $\theta_{0\,m.} < 20°C$. In summer dichothern water at the depths from 50 m. to 100 m. $\theta < 0°C$, S 32.3~33‰, $\theta_{min.} \approx -1.6°C$. $S_{0\,m.} < 33‰$, $F > IV$. $D < 15$ m. Central region exists off the east coast of Karahuto.
Japan Sea	Cold Curr. Water	North Tyōsen Cold Curr.-Sys. S 33.7~34.2‰. $D < 10$ m. $F \approx V$, Centred off the north and east coast of Tyōsen from 25 m. to 50 m. depths ($\theta < 10°C$). Liman Cold Curr.-Sys. along the Continental Side, west of Karahuto.
	Tusima Warm Curr. Water	S 34.3~34.8‰, and $S > 34.1‰$ in general. In summer 0~25 m, depths covered by the water of low salinity due to the inflow of the China Sea Water. $S_{max.}$ (in April and May) 34.6~34.8‰. $\theta_{100\,m.} > 10°C$. D almost > 20 m. $F \approx III$. Distributed in the southern and central part of the Sea and along the coast of Japan Proper. Origin: A Branch of Kurosio. Branches: East Tyōsen Warm Current, Tugaru and Sōya Warm Current.
	Deep Water	Below the depth of 200 m. $\theta 0°$~$1°C$ ($< 5°C$). $S \approx 34.1‰$. (along the coast of East Tyōsen, about 34.05‰). pH 7.8~7.9. O_2 5.4~5.9 cc/l. O_2%67-70. Rich in nutrient salts. Origin: Watermass sunk in the northern part of the Sea in winter.

Seto-Naïkai	Inland Water	Inner region of Ōsaka Bay, along Tokusima Pref. N. of Harima-Nada. Hirosima Bay, Buzenkai etc. $S<32‰$. Region influenced by fresh water.
	Oceanic Water	$S>34‰$. $D>10$ m. Origin: from Bungo-Suidō, Kii Suidō (Branch of Kuroiso) and from Simonoseki Strait (Branch of Tusima Current).
Coastal Water		Coastal region shallower than about 200 m. depth, $S<34‰$, $F>$IV, $D<15$ m. in general.
Seasonal Variation in General		$\theta_{0\,m.}$ max. in Aug.~Sept., min. in March in the year. $\theta_{100\,m.}$ max. in Oct.~Dec., min. in March~June. S in general, high in winter, low in summer (exept the high S in summer in the northern sea off Hokkaidō.) D two min. (in spring and autumn) and the min. in spring is more conspicuous. In southern district $D_{max.}$ in summer and in northern $D_{max.}$ in winter are more marked.

At the boundary between the water-masses belonging to the cold and warm currents in the Japan Sea and in the North Pacific Ocean, the chemical constituents (dissolved oxygen, silicate etc.), transparency and colour of the sea vary discontinuously in accord with the variation of water temperature and salinity.[30][31][32]

Actually the regions where remarkable discontinuity of watermasses is met with, are in the Japan Sea the region west to the Tugaru Strait and the region west to 134°E along the east coast of Tyōsen, and in the Pacific Ocean starting from Tyōsi or Kinkazan stretched in a NE direction in the region west to 154°E. Those lines of discontinuity are seen between the cold southerly current flowing along the coast under the influence of deflecting force due to the earth's rotation, and the warm current flowing in the offing of it. They resemble well to the line of discontinuity in the Atlantic Ocean, formed between the Labrador Current together with East Greenland Current and Gulf-Stream with its elongations.

Since such a boundary of discontinuity (Grenzfläche) tends to vanish gradually through the mixing and turbulence of the water-masses, the maintenance for the stationary state of the boundary of discontinuity should be due to the supply and compensation of water-mass by the currents on both sides of the boundary. Or in other words, since in each water-mass the following equation is satisfied

$$\frac{\partial S}{\partial t}=D\Delta S-\mathrm{div}(S\mathfrak{v}) \qquad (1)$$

where S denotes some quantity belonging to a water-mass, t time, D the coefficient of diffusion, and v the velocity of current. In the case of $\frac{\partial S}{\partial t}=0$ v must exist when D exists actually.

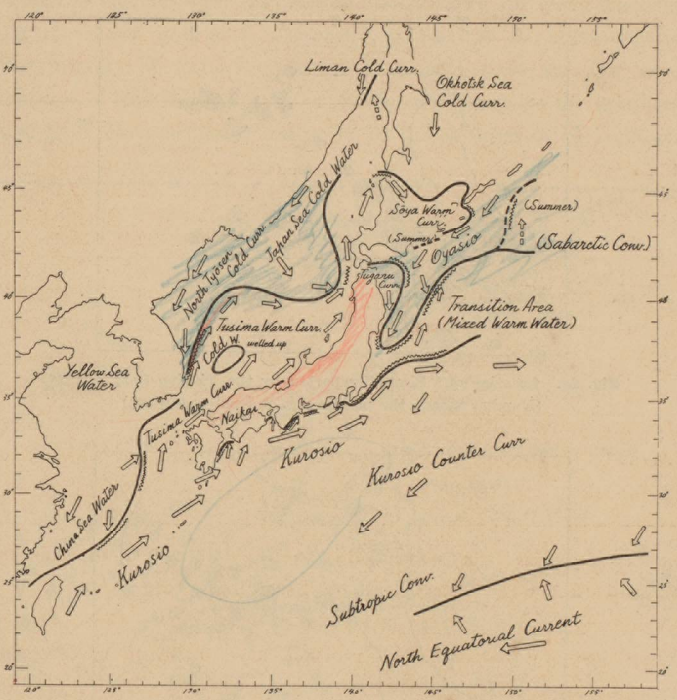


Fig. 1. General Distribution of Water-masses and their Boundaries in the Seas adjacent to Japan.
(Explanation: Arrows denote the direction of current, thick line the line of discontinuity, zigzag line the conspicuous portion of convergence.

(2) The distribution of currents and their boundaries in the waters adjacent to Japan.

In order to show the distribution of water-temperature, salinity, transparency and colour of the sea in a vast region clearly, it is the best to investigate simultaneously by the collaboration of many research-vessels in a short interval.

As the results of such simultaneous surveys carried out by our fisheries authorities in the waters adjacent to Japan we have synthetic current-chart as well as the boundaries of currents shown in Fig. 1.[30][31][32][38] From that

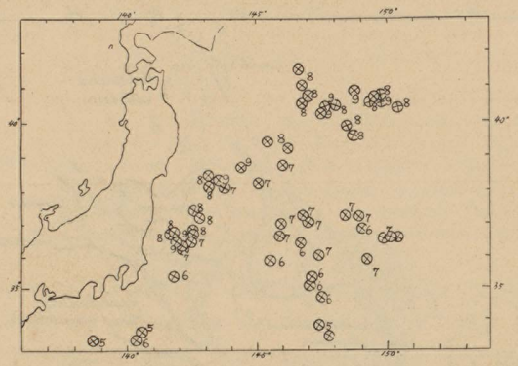


Fig. 2a. Location of "Siome" reported by the Fishing-Boat in 1936.
(Number means the month e. g. 8 denotes August.)

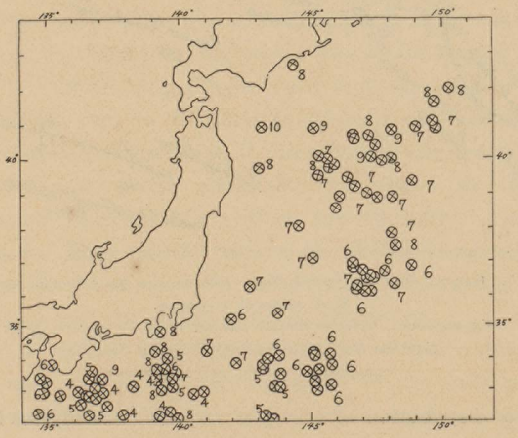


Fig. 2b. Location of "Siome" reported by the Fishing Boat in 1937.
(Number means the month e. g. 7 denotes July.)

we can recognize the region of convergence and divergence of stream-lines adjoining to each other.

(3) The zone of the most frequent occurrence of "Siome."

The observed positions of "Siome" reported by our fishing-vessels in 1936 and 1937 and that observed by the author on board of Sōyōmaru were plotted in Fig. 2 and 3. The zones of the most frequent occurrence of "Siome" thus obtained coincide with the lines of discontinuity for water-temperature, salinity etc. shown in Fig. 1. Generally, contrary to the many experiences the discontinuity of water-temperature or density there are few accurate observations of the discontinuity of the currents such as the measurement reported by H. Rauschelbach[30] owing to its difficultiness of the equipment.

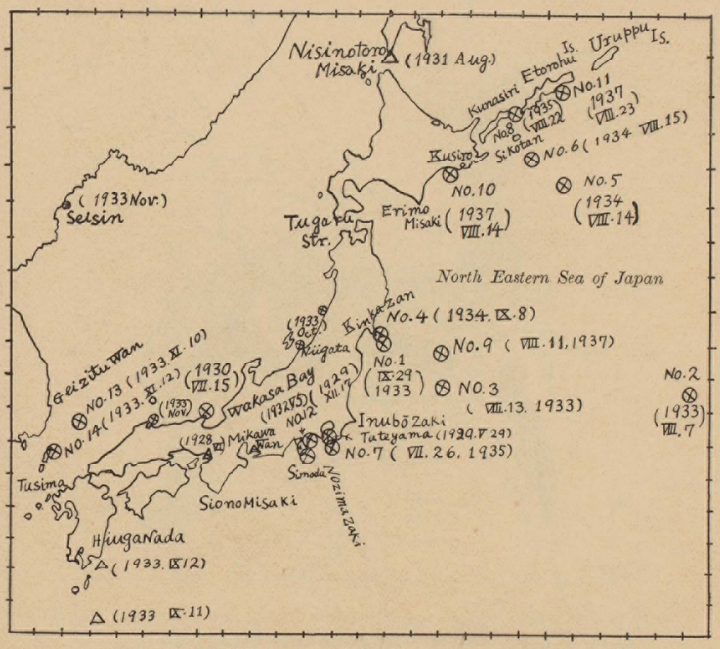


Fig. 3. Location of "Siome" cited in this paper which was observed by the present author ⊗ and that observed by others △.

The wellknown regions where they observe "Siome" frequently are the following: in the Atlantic, Pentland Firth, the Strait of Gibraltar, the margin of the Gulf-stream off the east coast of America, in the Agulhass Current and the Guinea Current, Equatorial Current etc., and in the Pacific, particularly in the seas adjacent to Japan, the vicinity of the

capes washed by Kurosio, such as in Hiuga-Nada, Kii-Suidō, Kumano-Nada, Sagami Bay, the entrance of Tōkyō Bay, off the east of Inubōzaki and Kinkazan, in summer the sea along the coast of islands of Sikotan, Etorohu and Uruppu in Kurile Islands, and seas off Geizitu Bay of the east Tyōsen. etc.

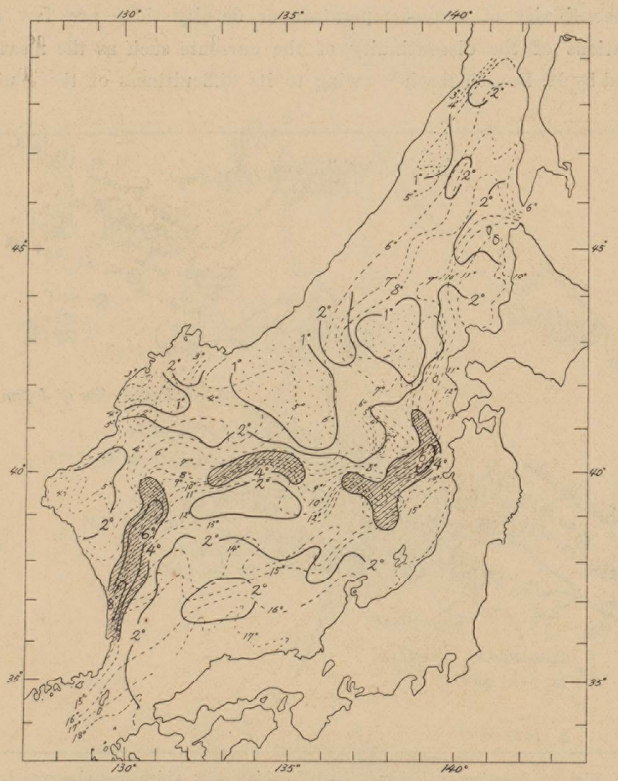


Fig. 4a. Isotherms and their Gradients (°C per 30 *SM.*) at a Depth of 25 m. in June, 1932 in the Japan Sea.
(Dotted and full line denote isotherm and isoline of temperature-gradient respectively.)

(38) M. Uda. Hydrographical fluctuation in the North-Eastern Sea-region adjacent to Japan of the North Pacific Ocean. (A results of simult. oceanog. invest. in 1934-1937). Jour. Imp. Fish. Expt. St. No. 9, 1938.

(39) H. Rauschelbach. Gezeitenstrombeobachtungen im Ostfriesischen Gatje 1927. Ann. d. Hydr. 1931. S. 1-7.

(4) **The Wavy Form of the Line of Discontinuity and the Degree of Discontinuity.** Basing on the results of the simultaneous oceanographical surveys Fig. 4, similarly to the "Meteor"-Expedition in the North

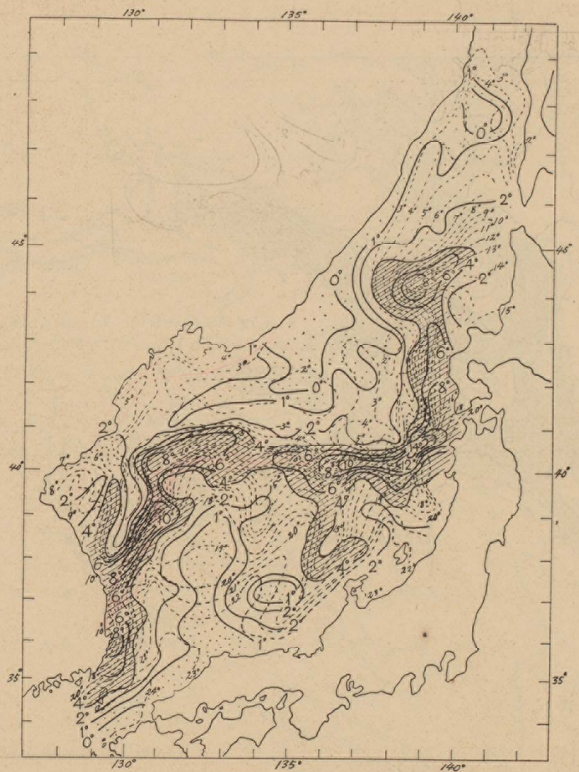


Fig. 4b. Isotherms and their Gradients (°*C* per 30 *SM.*) at a Depth of 50 m. in October, 1933 in the Japan Sea.
(Dotted and full line denote isotherm and isoline of temperature-gradient respectively.)

Atlantic,[19] we can see that the line of discontinuity shows a wavy form, increasing its amplitude from one end to the another contrary to the decrease of the degree of discontinuity. This facts fit well to the experimental results obtained by S. K. Banerji and G. H. Ghatage.[18]

(18) (19) l. c. p. 310.

Adopting the gradient of isolines for the measure of the degree of discontinuity, and in the case of water-temperature plotting the distribution of temperature-gradient, we have the curves shown in Fig. 4.

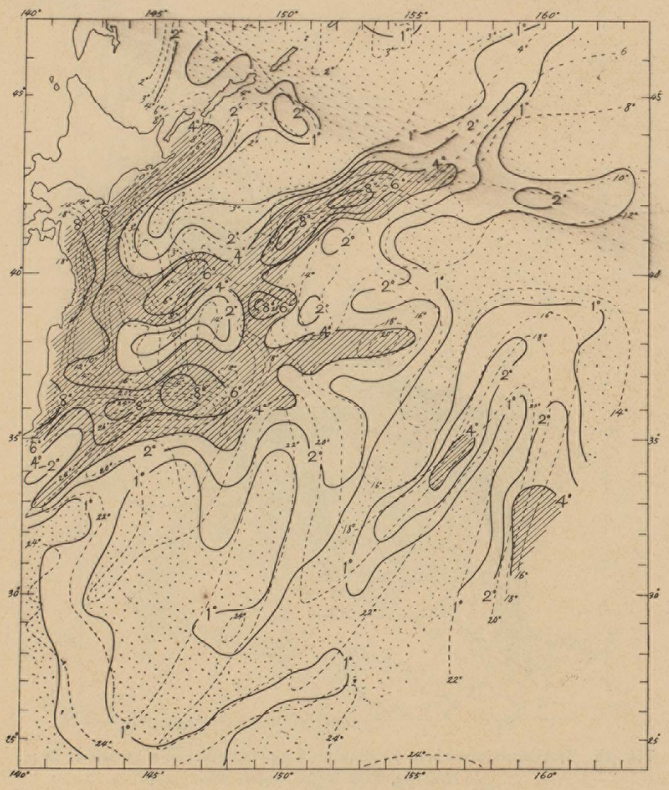


Fig. 4c. Isotherms and their Gradients (°*C* per 30 *SM.*) at a Depth of 50 m. in August, 1935 in the North Pacific Ocean.
(Dotted and full line denote isotherm and isoline of temperature gradient respectively.)

Table 2 indicates the example of the conspicuous gradient of water-temperature, the assigned wave length and mean amplitude of the wavy line of discontinuity.

Table 2. Elements of Wavy Form of the Boundary Zone between Warm and Cold Water-masses.

(θ: Water Temperature, S Salinity)

Sea-District	Time	Position of Zone	Depth, θ or S	Grad. per 10 *SM.*	Wave-Length	Wave-Ampl.	Number of Convolution	Ampl./Length
					Ca *SM.*	*Ca* *SM.*		*Ca*
Japan Sea	1932 June	Geizitu Bay～West to Tugaru Strait	50 m. θ	4.5°	100	40–60	4	0.5
	1933 Oct.	„	50 m. θ	2°～4.7°	110–140	50–80	4	0.5
Yellow Sea	1932 June	Saisyū-Tō～Kiirun	0 m. S	0.6‰	120	60	5	0.5
Pacific Ocean	1933 Aug.	S. to Hokkaidō	0 m. θ	1.5°	150	80	3	0.5
	1934 Aug.	38°～40° N.	„	1°	120	80	4	0.7
	1935 Jan.	near 40° N 36°～38° N.	„	1° 1°～2°	120 150	100 60	2 3	0.8 0.4
	„ Feb.	35°～39° N.	„	1.4°～0.7°	140	60–80	4	0.5
	„ Mar.	near 40° N.	„	1°～1.5°	180–220	70	3	0.35
	„ Aug.	43°～47° N.	„	1°	160–200	70	4	0.4
	„ Aug.	38° N.	„	0.7°	200	100–140	3	0.6
	„ Nov.	near 40° N.	„	0.5°	150	40–60	3	0.3
	1936 Jan.	37° N.	„	1°	200	70	2	0.35
	„ Feb.	36°～38° N.	„	1°	150	60	2	0.4
	„ Aug.	38° N.	100 m. θ	1°	200	100	4	0.5
	„ Nov.	36°～38° N.	0 m. θ	1°	240	100–150	4	0.5
	1937 Feb.	36°～38° N.	„	0.5°	100	60	2	0.6
	„ Aug.	36°～38° N.	100 m. θ	2°～0.7°	220	80	5	0.4

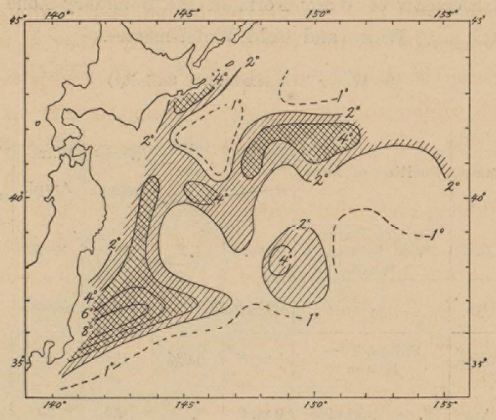


Fig. 4d. Isotherms and their Gradients (°C per 30 *SM.*) at the Surface in March, 1935 in the North Pacific Ocean.
(Dotted and full line denote isotherm and isoline of temperature-gradient respectively.)

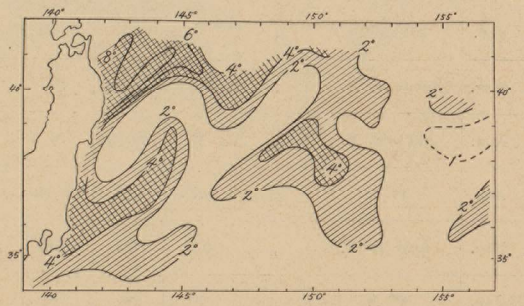


Fig. 4e. Isotherms and their Gradients (°C per 30 *SM.*) at the Surface in November, 1935 in the North Pacific Ocean.
(Dotted and full line denote isotherm and isoline of temperature-gradient respectively.)

Chapter II. Vorticity and Convergency accompanied with the Line of Discontinuity in the Seas and Oceans.

(1) Horizontal Distribution of Vorticity and Convergency.

According to A. Defant (1929) the vortices produced on the boundary between two opposite currents in cyclonic sense have the convergent

character which closed in a singular point and is partially stationary and partially migrative (e. g. the vortices south off Newfoundland).[40] The similar discussion is made by v. Bjerknes and his associates in the theory of cyclone and considered a cyclonically rotating vortices on the boundary between the cold and warm air-masses.[41] Studying the surface of discontinuity between the stratified waters having the same density but velocity opposite to each other mathematically, in the case of initially the disturbed surface of separation is supposed to be a sine curve, L. Rosenhead (1931) gave a solution involving a symmetrical sine term of Rayleigh form increasing its amplitude continuously plus the secondary small term which grows asymmetrically.[42] According to the experimental results made by S. K. Banerji and G. H. Ghatage, on the discontinuous boundary of density or water-temperature in both cases of horizontal and vertical movements we see the line of discontinuity varying to asymmetrical type and ending to vortices.[18]

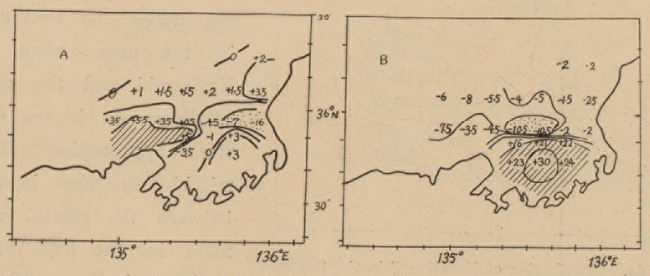


Fig. 5. Distribution of ζ and K in the Wakasa Bay in June 11-16, 1930.
A. Convergence K. (+ means convergence, + divergence respectively.)
B. Rotation ζ (+ means anticyclonic, − cyclonic rotation respectively.)

Now, we will plot the distribution of vorticity and convergency around the line of discontinuity in the seas adjacent to Japan.

Let the vorticity be ζ

(40) A. Defant. Stabile Lagerung Ozeanischer Wasserkörper und dazu gehörige Stromsysteme. Veröff. Inst. Meeresk. Univ. Berlin. Neufolge A. Hf. 19, 1929. S. 7.

(41) v. Bjerknes and others. Physikalische Hydrodynamik mit Anwendung auf die Dynamische Meteorologie. 1933. S. 510, 517.

(42) L. Rosenhead. The formation of vortices from a surface of discontinuity. Proc. Roy. Soc. London. Vol. 134A. 1931, pp. 170-192.

$$\zeta = (\mathrm{rot}\,\mathfrak{v})_z = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} = \frac{1}{A}\oint_s \mathfrak{v}_s\, ds \qquad (1)$$

and convergency be K

$$K = \mathrm{conv}\,\mathfrak{v} = -\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) = -\,div\,\mathfrak{v} = \frac{1}{A}\oint \mathfrak{v}_n\, ds \qquad (2)$$

where $\mathfrak{v}$ denotes the velocity, u, v its $x-$, $y-$components, A and s the area and the periphery of the closed curve considered.

In order to evaluate ζ and K practically, we adopt the method taken by S. Fujiwhara.[43] Fig. 5a and 5b show the distribution of ζ, K in the Wakasa Bay computed from the current-chart obtained by the simultaneous survey in mid July 1930 with the collaboration of four research-vessels.[33] We can notice the convergence in the upper-stream near Kyōgasaki and the portion of divergence in the down-stream approaching to Etizen-misaki on the boundary between the coastal water-mass in the bay rotating anticyclonically and the water-mass belonging to the Tusima Current rotating cyclonically. Moreover, we found "Siome" on the line of convergence, showing a clear boundary zone which is actually proved by a conspicuous discontinuity of water-colour and accumulation of drift-algae and foams etc.

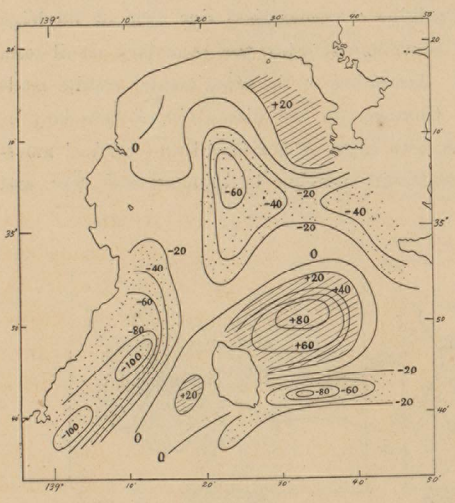


Fig. 6a. Distribution of Rotation ζ in the Sagami Bay in Winter of the Normal Year.
(+ means anticyclonic, − cyclonic rotation respectively.)

From similar investigation for the currents in the Sagami Bay,[37] we see the portion of convergence in the upper-stream near Tumekizaki where "Siome" frequently occurs and the portion of divergence in the down-

(43). S. Fujiwhara and others. On vorticity in the atmosphere as a weather factor. Jap. Journ. of Fac. of Se. Vol. III. Part 2. 1935.

stream adjoining to it, on the boundary between the coastal water rotating cyclonically in the bay and the water-mass belonging to the Kurosio Warm Current (see Fig. 6).

Next, utilizing the materials obtained by the simultaneous observation in the Pacific Ocean in August 1935,[38] we carried out the approximate evaluation of ζ and K for the area including the line of discontinuity on the basis of the well-known formula[44]

$$v_0 - v_1 = \frac{d_a - d_b}{2\omega L \sin\varphi} \qquad (3)$$

which was deduced from the circulation theory by v. Bjerknes on the assumption of stationary current and the negligible friction, and obtained Fig. 7. Remembering the notice given by A. Defant that the prescribed formula does not fit to the line of discontinuity and the streamlines make a definite angle with the isopyknals corresponding to the vorticity, we have avoided the line of discontinuity itself and utilized the area circumscribed to the line of discontinuity somewhat distant from it. From Fig. 7 we recognize at once that in the region around the line of discontinuity in the North-eastern Sea of Japan in summer K develops conspicuously and the positive and the negative values of ζ distribute consecutively near the line of discontinuity, respectively.

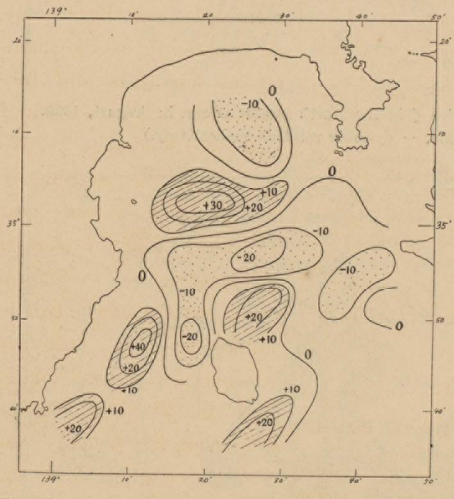


Fig. 6b. Distribution of Convergence K, in the Sagami Bay in Winter of the Normal Year.
(+ means convergence, − divergence respectively.)

The distribution of ζ, K indicated in Fig. 8 which was plotted on the

(44) A. Defant. Dynamische Ozeanographie. 1929 (S. 120).
(19) A. Defant (1931) l. c. p. 310.

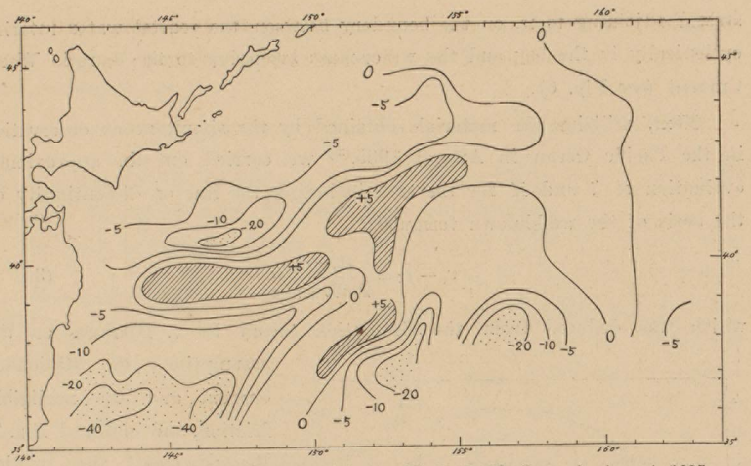


Fig. 7a. Distribution of Rotation ζ in the North Pacific Ocean in August, 1935.
(+ means anticyclonic, − cyclonic rotation respectively.)

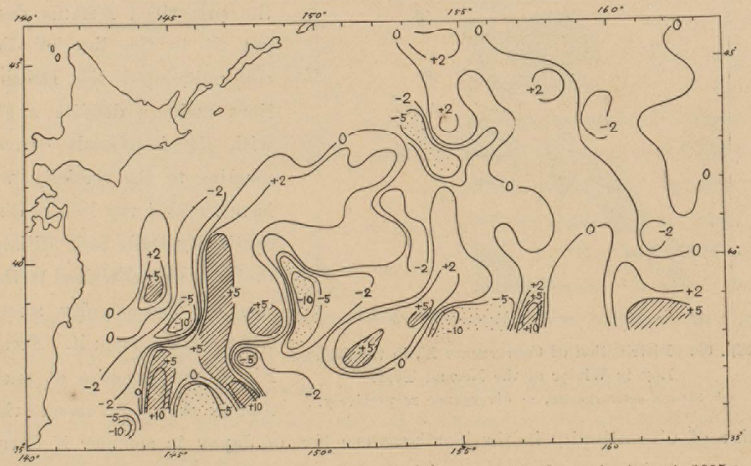


Fig. 7b. Distribution of Convergence K in the North Pacific Ocean in August, 1935.
(+ means convergence, − divergence respectively.)

basis of the currents estimated from the records of plying drift-nets and long-lines in fishing (summarized in the years from 1924 to 1933),[45] coin-

(45) M. Uda. Oceanic currents estimated from the records of plying the drift-nets and long-lines in fishing. Bull. Jap. Soc. of Sc. Fish. Vol. 3, 1934. p. 93.

cides fairly well with the results shown in Fig. 7. Proceeding further, the distribution of turbulency in the sea-water θ defined by K. Suda

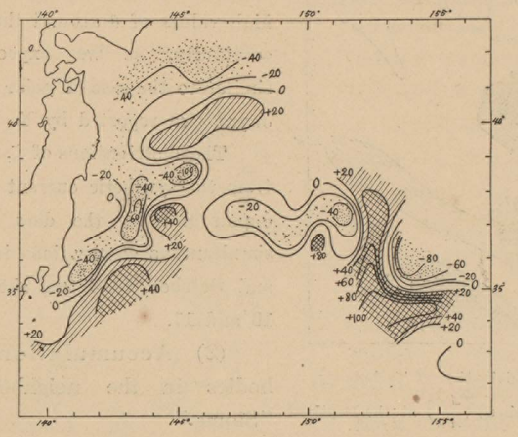


Fig. 8a. Distribution of Rotation ζ in the North Pacific Ocean on the Basis of Currents estimated from the records of Plying Drift-Nets and Long-lines in Fishing (1924–1933)
(+ means anticyclonic, − means cyclonic rotation respectively.)

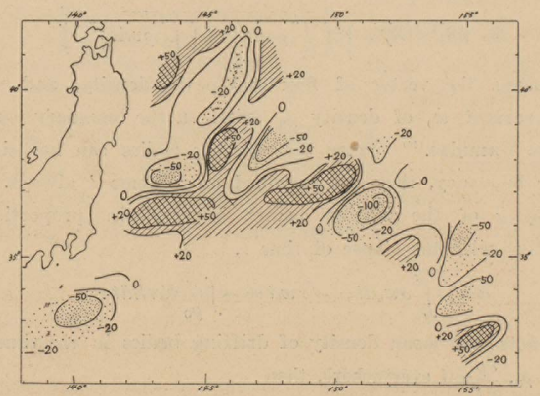


Fig. 8b. Distribution of Convergence K in the North Pacific Ocean on the Basis of the Currents estimated from the Records of Plying Drift-Nets and Long-Lines in Fishing (1924–1933).
(+ means convergence, − divergence respectively.)

$\theta=\dfrac{1}{4\omega^2\sin^2\varphi}\left(\dfrac{\partial\rho}{\partial y}\right)^2\Big/\left(\dfrac{\partial\rho}{\partial z}\right)$ in the case of density current[46] was investigated for the layer of 25 m. depths in August 1935 in the Pacific Ocean with the results in Fig. 9 and it shows the high values of θ around the line of discontinuity, as we expected before, similar to the case of polar front in the Japan Sea reported by K. Suda.[46]

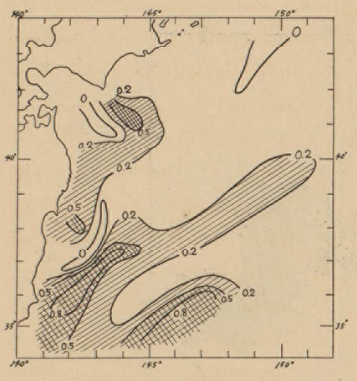


Fig. 9. Distribution of Turbulency $4\omega^2\theta=\left(\dfrac{\Delta\rho}{\Delta y}\right)^2\Big/(\sin\varphi)^2\left(\dfrac{\Delta\rho}{\Delta z}\right)$ at the Depth of 25 m. in the North Pacific in August, 1935.

The distributions of ζ, K evaluated from the synthetic current chart in the Japan Sea on the data due to the simultaneous observations in June 1932 and October 1933 are shown in Fig. 10 and 11.

(2) Accumulation of drifting bodies in the neighbourhood of "Siome."

In general, when the convergence exists on the line of discontinuity $K>0$, it follows

$$\left.\begin{aligned} w_0&=\frac{1}{\rho_0}\operatorname{div}S,\\ S&=\sqrt{S_x^2+S_y^2}=\sqrt{\left(\int_0^h\rho u\,dz\right)^2+\left(\int_0^h\rho v\,dz\right)^2}\end{aligned}\right\}\qquad(4)$$

where S means the vector of flux and ρ the density, and naturally a descending current w_0 of density ρ_0 exists on the boundary corresponding to the above formulae.[44] Since the drifting bodies can not sink with w_0 owing their bouyancy, they are remained on "Siome" always. Then the accumulation a of the drifting bodies increases in proportion to the quantity of w_0 with the elapse of time t,

$$a=-\int_0^t\sigma w_0\,dt=-\bar{\sigma}\,\bar{w}_0 t=-\int\frac{\sigma}{\rho_0}\operatorname{div}S\,dt\qquad(5)$$

where $\bar{\sigma}$ denotes the mean density of drifting bodies in the time-interval t. Now, if $\rho=\rho_0$, $\dfrac{\partial\rho}{\partial t}=0$ everywhere, then

(46) K. Suda. On the dissipation of energy in the density current (2nd. paper). Geophys. Mag. Tokyo, Vol. X. No. 2. 1936. p. 162. 及 須田皖次: 海流の亂流度に就て「海と空」Vol. 15. No. 1. 1935.

$$\alpha = -\int \sigma\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)dt = \bar{\sigma}Kt \qquad (6)$$

Or in other words, α increases in proportion to K with the elapse of time t. Conversely, if the line of discontinuity be a divergent one, then the accumulation of the drifting bodies existed on the boundary at $t=0$ diminishes in proportion to K with the elapse of time t. Actually the accumulation of drifting dusts, foams, timbers, algae and planktons on "Siome" observed by sea-farers are considered to obey such mechanical action and even the dense concentrated fish-shoals of bonito and skipper etc. in many cases are also interpreted by such a mechanism.[47][48]

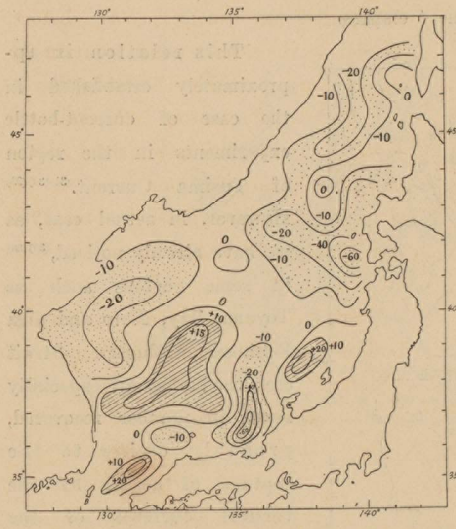


Fig. 10 a. Distribution of Rotation ζ in the Japan Sea in June, 1932.
(+ means anticyclonic, − cyclonic rotation respectively.)

The convergence of stream-line on sandy bottom brings to the accumulation of sand drift* which is important from the point of harbour engineering.

Generally, in the ocean current the density of drifting bodies is considered to vary by two-dimensional diffusion approximately.

Then, taking a_x and a_y the coefficients of diffusion in the direction of

(44) l. c. p. 325. A. Defant (1929) S. 42.

(47) M. Uda. Locality of fishing centre and shoals of "Katuo," correlated with the contact zone of cold and warm current. Bull. Jap. Soc. of Sc. Fish. Vol. 4. No. 6. Mar. 1936.

(48) M. Uda. Fishing centre of "Samma," correlated with the head of Oyasio Cold Current. Bull. Jap. Soc. of Sc. Fish. Vol. 5. No. 4, 1936.

* In Chapter IV (1) Fig. 19, on the bottom of tank we see an accumulated band formed by wetted alminium powder and saw-dusts to the line of convergence at x_s' which suggests us some mechanism of sand-drift.

$x-$ and y axes respectively, we have[49]

$$\sigma=\frac{1}{2t}\,e^{-\frac{\frac{(x-vt)^2}{a_x^2}+\frac{y^2}{a_y^2}}{4t}} \tag{7}$$

i. e. the isoline $\sigma=$const. represents an ellipse, progressing in the direction of x with the velocity v as time t elapses.

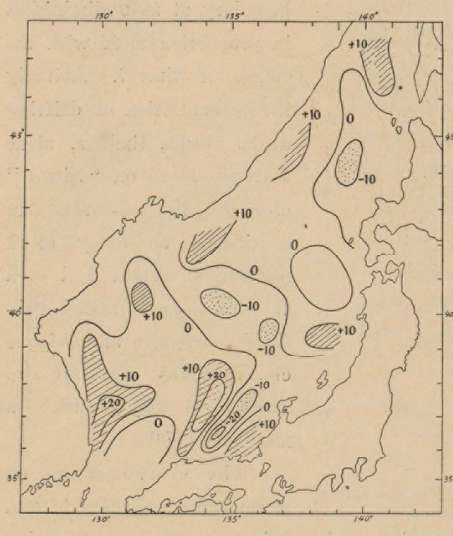


Fig. 10 b. Distribution of Convergence K in the Japan Sea in June, 1932.
(+ means convergence, − divergence respectively.)

This relation is approximately established in the case of current-bottle experiments in the region of Tusima Current.[31][32][33] However, in actual case, as we have already noticed,[31][33] in some regions such as Toyama Bay, Noto and Oga Peninsula, Tugaru Strait etc., the bottles are especially much in number recovered, probably owing to the capture of bottles by the vortical currents or the accumulation of them on converging line of the currents about peninsula. That is the case corresponding to the distribution of convergence K above mentioned in an area or on a line.

Similarly in the Pacific Ocean, assuming the distribution of the convergence K $\left(\text{such that } K=K_0 \sin\left\{\frac{2\pi(x-b)}{L}+\frac{\pi}{4}\right\}\right)$ on the sinus line $\left(y=a \sin\frac{2\pi(x-b)}{L}+k\right)$ of the boundary (polar front) of cold and warm current, we can approximately interprete mechanically the previously mentioned accumulation of fish-shoals etc.[47][48]

(49) M. Uda. Distribution of drifting bodies in the ocean current. Bull. Jap. Soc. of Sc. Fish. Vol. 4. No. 5. 1936. (地球物理學文献抄 1936. 參照)

(31) (32) (33) l. c. 312.

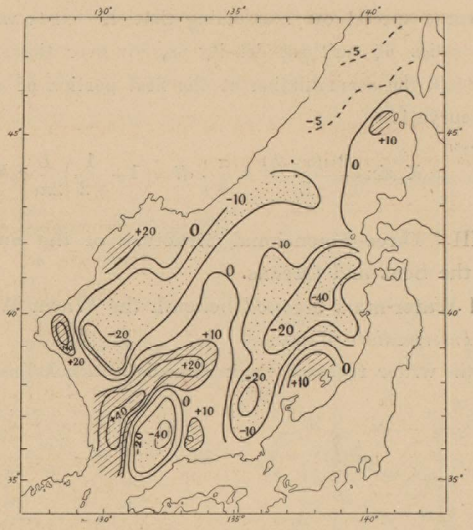


Fig. 11 a. Distribution of Rotation ζ in the Japan Sea in October, 1933.
(+ means anticyclonic, − cyclonic rotation respectively.)

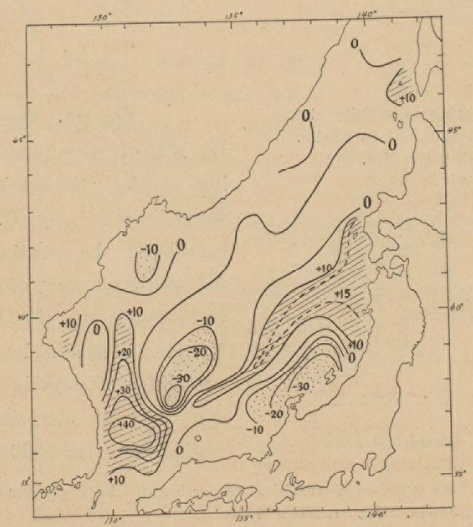


Fig. 11 b. Distribution of Convergence K in the Japan Sea in October, 1933.
(+ means convergence, − divergence respectively.)

Let us treat a special case: assuming that K exists when $x>b$ and that drifting bodies of uniform density σ_0 all over the surface starting from $x=0$ at $t=0$, the accumulation at the first portion of convergence on the undulated curve is

$$\alpha_1=\int_{\frac{b}{v}}^{\frac{8b+3L}{8v}}\sigma_0 K_0\sin\left\{\frac{2\pi(x-b)}{L}+\frac{\pi}{4}\right\}dt=\left(1+\frac{1}{\sqrt{2}}\right)\frac{L}{2\pi v}\sigma_0 K_0 \qquad (8)$$

Chapter III. Three-dimensional Structure of the Surface of Discontinuity in the Seas and Oceans.

(1) Cold Water-mass creeped beneath the Warm Water-mass.

(a) *The Intermediate Water.*

Formerly the writer reported the intermediate dichohaline layer beneath

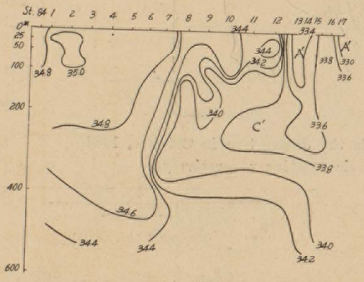


Fig. 12 a. Distribution of Salinity at the Section from Nozimazaki to Kusiro. (St. No. is shown in Fig. 13.) a. March in 1935.

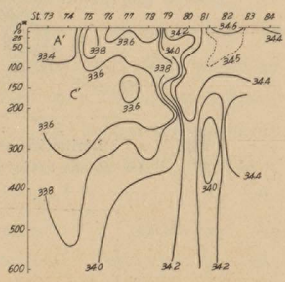


Fig. 12 b. November in 1935.

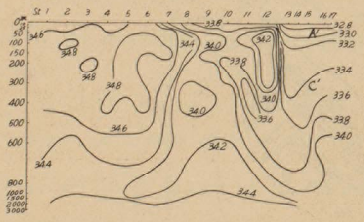


Fig. 12 c. August in 1935.

the Kurosio water-mass[50] corresponding to the "Subarktische Zwischenstrom" called by G. Wüst[51] and considered the stratification due to the southerly flow of Oyasio-Undercurrent beneath the Kurosio water. It was ascertained from the investigation by captain R. Sigematu[47] and also by our simultaneous investigation from 1933 to 1937 in the

(50) M. Uda. On some oceanographical researches of the sea water of Kurosio. Rec. Oceanog. Works in Japan. Vol. II. No. 2. 1930.

(51) G. Wüst. Schichtung und Tiefenzirkulation des Pazifischen Ozeans. Veröff. d. Inst. f. Meeresk. Neu Folge A. Hf. 20. 1929.

North Pacific Ocean.[30][38] Fig. 12 shows the exemplary distribution of salinity at the section of the North-Eastern Sea of Japan obtained from the recent investigations in March, August and November respectively. The position of observing stations surveyed by "Sōyō-maru" is indicated in Fig. 13.

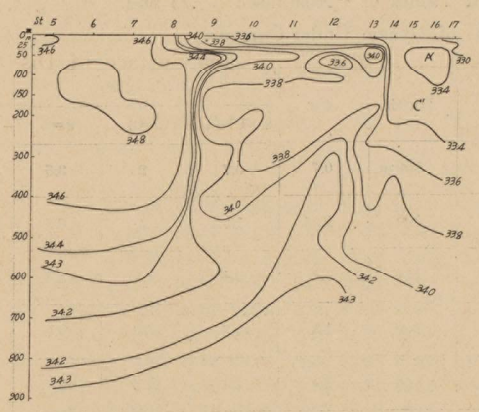


Fig. 12 d. August in 1937.

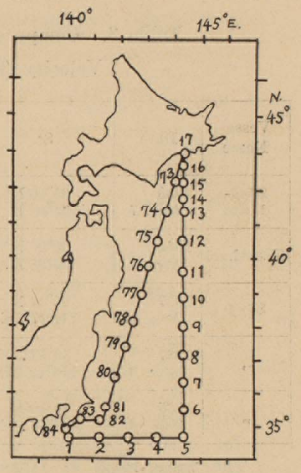


Fig. 13. Observing Station of "Sōyō-maru" from January in 1935 to November in 1937. (Figures represent the St. No.)

Of course, as already noticed by H. Thorade[53] we can not infer the stream-lines immediately from the distribution of salinity at the section without the ellimination of the influence of the turbulent mixing. But it may be correctly said that the form of isohalines showing the intermediate water can not be maintained without the compensation by the current.

Let A be the "Austausch" of a matter S, ρ the density of sea water, z the axis vertically downward to depth, u the velocity of Oyasio-Undercurrent in horizontal direction and t the time, then in the quasi-stationary state we have

(52) R. Sigematu. Some oceanographical investigation of the results of oceanic survey carried out by H. I. J. M. S. Mansyū from April 1925 to March 1928. Rec. Oceanog. Works in Japan. Vol. IV. No. 1. 1932.

(30) (38) l. c. p. 312, 318.

(53) H. Thorade. Strömungen und Zungenförmige Ausbreitung des Wassers. Gerl. Beit. z. Geophys. Bd. 34. Köppen Bd. III. 1931.

$$\frac{\partial S}{\partial t} = \frac{A}{\rho}\frac{\partial^2 S}{\partial z^2} - \frac{\partial (uS)}{\partial x} \qquad (1)$$

Evaluating ρ, $\frac{\partial^2 S}{\partial z^2}$, $\frac{\partial S}{\partial x}$ in the sectional distribution of salinity and putting in (1), we get u and A as tabulated in Tab. 3.

Table 3. Computed Values of "Austausch" (A) and Velocity (u) of Oyasio Under-Current.

Vessel Name	Date	St.	Depth	A/u	A (C. G. S)		
					$u=1^{cm/sec}$	$u=3$	$u=5$
Sōyō-Maru	1933 Aug. 7	35°10′N 152°30°E	700 m	0.7	0.7	2	3.5
Komahasi	1933 Aug. 13	30°20′N 157°38′E	500	1.35	1.35	4	6.8
Sōyō	1937 Aug. 13	39°38′N 144°27′.7E	150	0.4	0.4	1.2	2.1
"	1937 Mar. 9	39°33′.5N 145°12′.5E	200	1.8	1.8	5.4	9.0
"	1935 Nov. 21	39°46′N 142°58′.2E	150	2.4	2.4	7.2	12

The water-mass of Oyasio Under-current starts from the Oyasio-water-mass above the 200 m. depth lying in the region adjoining to the line of discontinuity and moves to south, then owing to the greater density *in situ* compared to the Kurosio water (see Tab. 4) sinks down to the below of the Kurosio water gradually. The distribution of the layer depth of intermediate water and minimum salinity of that layer are shown in Fig. 14. The most conspicuous season of intermediate water in the North-eastern Sea-region of Japan may be from spring to summer, and in the sea-region south to the Idu Islands in the season from summer to autumn.[27]

Now, estimating the averaged inclination γ of the boundary of discontinuity from the surface of the station 50*SM*. east off Kamaisi in Iwate Pref. to the depth of 500 m. off Ōaraizaki in Ibaraki Pref. about 160*SM*. distant from the former, we have $\gamma=0°06'$.

On the other hand, putting $v=1$ cm./sec., $v'=50$ cm./sec., $\rho=1.025$, $\rho'=1.0235$, $\varphi=38°$N. in the following equation ($l=2\omega\sin\varphi$, $g=$accel. of gravity)

(27) l. c. p. 312.

$$\gamma = \tan^{-1}\left(\frac{l}{g}\,\frac{\rho' v' - \rho v}{\rho - \rho'}\right) \qquad (2)^{*)}$$

We have $\gamma = 0°08'$.

Hence the formula (2) holds fairly well in practical case.

Table 4. Difference of Density *in situ* of Kurosio and Oyasio Waters.

(θ: Water Temperature °C, S: Salinity ‰, $\sigma_{s\theta D} = (\rho_{s\theta D} - 1) \times 10^3$, $\Delta\rho = \Delta\sigma_{s\theta D} \times 10^{-3}$)

St.	11 (39°48'N 149°41'E)			28 (43°17'N 150°57'E)			Diff. betw.	7 (36°06'N 144°10'E)			Diff. betw.	
Date	1933. VIII. 7			1933. VIII. 13			St. 28 & 11	1935. VII. 28			St. 10 & 7	St. 14 & 7
Depth	θ	S	$\sigma_{s\theta D}$	θ	S	$\sigma_{s\theta D}$	$\Delta\rho \times 10^5$	θ	S	$\sigma_{s\theta D}$	$\Delta\rho \times 10^5$	
m												
0	22.80	34.00	23.25	12.20	32.65	24.75	+150	24.6	34.56	23.15	+ 65	+124
10	22.70	33.95	23.30	11.99	32.68	24.86	+156	24.6	34.65	23.27	+ 60	+134
25	20.02	34.16	24.26	10.59	32.83	25.32	+106	23.04	34.81	23.84	+142	+195
50	15.00	34.58	25.90	2.37	32.95	26.57	+ 67	18.73	34.94	25.30	+131	+140
100	10.96	34.33	26.74	1.72	33.20	27.05	+ 31	17.02	34.97	25.96	+101	+105
150	8.00	34.12	27.32	1.91	33.47	27.51	+ 19	16.72	34.92	26.24	+ 98	+122
200	6.35	33.91	27.62	2.38	33.60	27.91	+ 29	16.49	34.92	26.51	+105	+128
300	4.64	33.87	28.28	3.00	33.80	28.39	+ 11	16.20	34.87	26.99	+112	+134
400	3.38	34.02	29.03	3.00	34.05	29.08	+ 5	15.00	34.77	27.65	+118	+137
500	3.42	34.11	29.58	3.15	34.06	29.58	0	12.00	34.58	28.69	+ 72	+ 90
600	3.56	34.14	30.07	2.88	34.11	30.11	+ 4	9.61	34.40	29.39	+ 60	+ 76

St.	10 (38°46.7'N. 144°19.5'E.)			14 (41°41.5'N. 144°21.0'E.)			29 (43°10'N. 150°45'E.)			Diff. betw.		
Date	1935. VII. 29			1935. VII. 30			1935. VII. 5			St. 14 & 10	St. 29 & 7	St. 29 & 10
Depth	θ	S	$\sigma_{s\theta D}$	θ	S	$\sigma_{s\theta D}$	θ	S	$\sigma_{s\theta D}$	$\Delta\rho \times 10^5$		
m												
0	19.1	33.39	23.80	13.1	32.41	24.39	12.2	32.56	24.68	+ 59	+153	+ 88
10	18.99	33.39	23.87	12.88	32.57	24.61	11.18	32.70	25.02	+ 74	+175	+105
25	13.10	33.40	25.26	7.79	32.84	25.79	8.05	32.86	25.72	+ 53	+ 88	+ 46
50	8.35	33.90	26.61	2.41	33.10	26.70	2.65	33.10	26.87	+ 9	+150	+ 26
100	6.20	33.67	26.97	1.16	33.21	27.11	1.02	33.26	27.16	+ 14	+120	+ 19
150	4.30	33.52	27.22	1.59	33.39	27.46	1.93	33.53	27.41	+ 24	+117	+ 19
200	4.10	33.59	27.56	2.27	33.57	27.79	2.08	33.68	27.90	+ 23	+139	+ 34
300	4.85	33.98	28.11	2.68	33.71	28.33	2.89	33.93	28.50	+ 22	+151	+ 39
400	4.00	33.98	28.83	2.97	33.97	29.02	2.87	34.03	29.08	+ 19	+143	+ 25
500	3.70	34.03	29.41	2.95	34.07	29.59	2.92	34.15	29.66	+ 18	+ 97	+ 25
600	3.70	34.09	29.99	2.86	34.16	30.15	2.86	34.29	30.25	+ 16	+ 86	+ 26

*) (42) l. c. p. 323. A. Defant (1929) S. 100.

(b) *The Water-mass of Dichotherm Layer and Mesotherm Layer.*

In summer in the intermediate layer of about at a depth of 100 m. (generally in a depth from 50 m. to 200 m.) in the region of Oyasio Current stretched to the distance of 200-300 SM. off the coast of Hokkaidō and Tisima, and in Okhotsk Sea,**) we find the dichotherm layer(54)(55)(56) i. e. the zone of minimum water-temperature of about 1°C or below and of salinity about 33.3‰, O_2 about 7 cc/l.

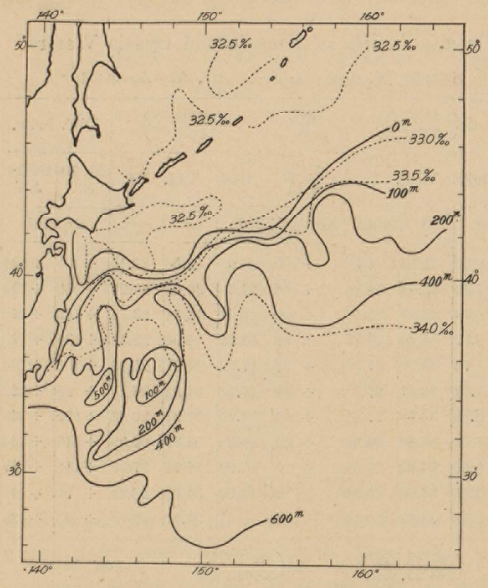


Fig. 14. Distribution of the Depths for Dichohaline Water (Intermediate Layer) and the Minimum Salinity at that Depth in August, 1935 in the North Pacific Ocean.
(The former is represented in full line and the latter in dotted line.)

That is identified with the water-mass lying in the surface layer of the region above mentioned in winter from the coincidence of water-temperature, salinity, dissolved oxygen and density *in situ*.

It should be the water-mass which sunk down to the mid depth due to the vertical convection in the upper water layer in winter by air cooling at the sea-surface and is detected in summer. However, the upper layer in summer is warmed by the influence of solar radiation and the prosperity of warm current. Also, from our investigation it is considered that for the dichotherm water found

**) The dichotherm water in the western region in the Okhotsk Sea along the east coast of Karahuto is very cold and its temperature below 0°C (frequently below −1°C), lying just beneath the freezing region in winter.

(54) 丸川久俊: オホーツク海海洋漁場調査報告, 漁業基本調査報告, No. 6, 7,8. 1918. 1919.
(55) 須田暁次: 日本近海表面水温の異常分布に就て, 産業氣象調査報告 Vol. IV. No. 1. 1933.
(56) 宇田道隆: 東北海區に於ける中冷水の分布, 成因, 運動.「海と空」Vol. XV. No. 12. 1935.

in the region in summer off the coast of Hokkaidō, Aomori, Iwate and Miyagi Pref., although one part of the water-mass sunk from the surface layer of that region in winter, the main part of it comes from the dichotherm water produced in the northern sea-regions, namely in Okhotsk Sea and the waters adjacent to Tisima in winter.

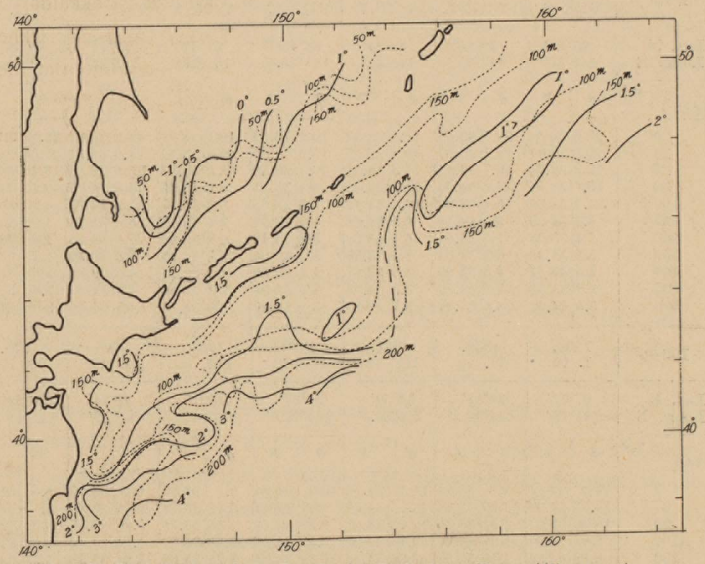


Fig. 15. Distribution of the Depths for Dichotherm Layer (Minotherm) and the Minimum Water Temperature at the Depth (°C).
(The former is represented in dotted line and the latter in full line.)

As we see in Fig. 15, the dichotherm water transported by the cold current from the source region in winter stretches to the southern region remarkably and clearly show the principal cold current area. However, in Fig. 15 we can observe the rise of water-temperature in the dichotherm layer by the influence of mixing of water-mass in the upper warm layer accompanied with the increase of depths from north to south. In this place it is notable that in the neighbourhood of the line of discontinuity down to the warm current the prescribed intermediate minimum of salinity ("*intermediate water*") just coincides with the depth of the minimum water-temperature (*dichotherm water*) (See Tab. 5.) This fact proves us

Table 5. The Coincidence of the Depths of Dichotherm Layer and Dichohaline Layer in the Boundary Zone of Cold and Warm Current.

(θ: Water Temperature, S: Salinity observed by Sōyō-maru.)

Date	1934. VIII. 6		1934. VIII. 7		1934. VIII. 7		1935. VIII. 28		1935. VIII. 3		1935. VIII. 28		1935. VIII. 28	
Lat. N Long. E	39°00′ 145°39′		39°20′ 147°39′		39°34′ 148°39′		38°46.7′ 144°19.5′		41°52′ 151°13′		38°17′ 142°23′		36°44′ 141°45.5′	
θ,S / Depth	θ	S	θ	S	θ	S	θ	S	θ	S	θ	S	θ	S
0m	20.6	34.34	21.7	33.66	19.9	33.33	19.1	33.39	19.1	33.03	24.2	34.00	23.30	33.60
10	20.6	34.11	21.7	33.57	19.8	33.37	19.0	33.39	19.0	33.15	24.0	34.11	22.64	33.60
25	19.2	34.38	20.7	34.11	17.8	34.31	13.1	33.39	13.2	33.55	20.8	33.80	13.36	34.11
50	15.5	34.54	14.2	34.54	15·2	34.51	8.4	33.91	4.9	**33.35**	14.0	34.23	10.12	34.00
100	11.4	34.38	10.8	34.29	12.3	34.42	6.3	33.68	3.2	**33.35**	11.3	34.25	4.90	33.58
150	8.3	33.93	8.4	34.18	8.9	34.20	4.6	33.53	**2.4**	**33.35**	8.6	33.96	4.00	33.58
200	7.4	33.93	7.6	34.04	6.1	33.02	**3.8**	**33.49**	3.8	33.66	7.1	33.96	**1.98**	**33.55**
300	5.5	33.86	6.5	34.04	**1.8**	**33.50**	5.2	33.98	2.9	33.75	**3.3**	**33.66**	2.15	33.60
400	**2.5**	**33.57**	**4.0**	**33.96**	3.3	33.87	4.1	33.98	4.1	33.95	4.0	33.95	2.68	33.88
500	3.7	33.93	4.5	34.22	3.9	34.08	3.7	33·98	3.3	34.00	4.1	34.09	3.03	33.96
600	3.9	34.08	3.8	34.22	3.7	34.22	3.7	34.09	3.0	34.11	4.1	34.16	3.02	34.13

Date	1936. I. 10		1936. II. 11		1936. III. 12		1936. III. 12		1936. III. 12		1936. I. 22		1936. II. 23	
Lat. N Long. E	37°11′ 144°46′		38°37′ 144°22.5′		38°59′ 144°33.5′		39°37′ 144°27.5′		40°27′ 144°24.5′		40°24′ 143°17′		35°52.5′ 141°18 5′	
θ,S / Depth	θ	S	θ	S	θ	S	θ	S	θ	S	θ		θ	S
0m	10.9	34.34	3.7	33.44	13.3	34.76	10.0	34.34	5.5	33.80	6.2	33.69	8.5	34.00
25	10.95	34.09	3.59	33.46	13.2	34.67	9.87	34.34	5.47	33.73	6.15	33.66	8.49	34.13
50	10.99	34.07	2.44	**33.35**	12.60	34.61	9.80	34.43	5.36	33.75	5.96	33.57	8.51	34.05
100	8.84	34.07	**1.97**	33.46	9.66	34.29	9.49	34 38	5.38	33.75	5.58	33.58	8.51	34.11
200	6.58	34.05	2.48	33.51	7.86	34.13	7.39	33.95	**3.75**	**33.69**	**2.97**	**33.28**	7.09	33.87
400	**2.91**	**33.91**	2.88	33.95	**3.26**	**33.73**	**2.71**	**33.75**	4.66	34.09	**2.55**	33.62	**3.53**	**33.08**
600	3.39	34.42	2.98	34.09	3.53	34.02	3.13	34.04	3.38	34.00	2.96	33.93	3.67	33.84

Date	1936. VII. 31		1936. VII. 31		1936. XI. 11		1936. IX. 2		1936. XI. 28		1936. XI. 27		1937. III. 23	
Lat. N Long. E	37°08.5′ 144°34.5′		37°59′ 144°32′		37°53′ 144°27′		37°02′ 142°32′		37°38′ 142°09′		40°30.5′ 143°19.0′		39°01′ 142°54′	
θ,S / Degth	θ	S	θ	S	θ	S	θ	S	θ	S	θ	S	θ	S
0m	23.3	33.24	23.5	33.37	15.4	33.57	24.9	33.44	13.1	33.55	13.0	33.64	10.0	34.14
10	21.53	33.93	23.40	33.39	15.31	33.57	24.24	33.40	12.83	33.55	12.86	33.68	—	—
25	16.74	34 49	16.13	33.95	15.32	33.58	10.84	33.37	12.50	33.62	12.83	33.68	8.89	—
50	13.75	34.51	11.78	34.14	15.31	33.62	7.38	33.66	12.31	33.69	12.84	33.71	6.28	32.57
100	10.92	34.49	9.04	34.04	7.92	33.93	4.66	33.77	8.33	33.95	12.12	34.68	**3.68**	**33.28**
150	9.86	34.42	**6.41**	**33.82**	6.44	33.86	4.19	33.49	5.70	33.73	10.45	33.98	—	—
200	7.03	34.14	7.57	34.14	5.16	**33.71**	**3.00**	**33.44**	**3.82**	**33.62**	8.34	34.00	**1.96**	**33.42**
300	**2.61**	**33.96**	5.46	34.14	**3.31**	**33.80**	4·20	33.82	4.36	33.91	**2.58**	**33.46**	—	—
400	3.00	**33.95**	**3.15**	**33.95**	**2.93**	**33.80**	4.12	33.93	4.31	34.05	2.88	33.58	4.15	33.46
500	3.18	34.07	3.30	34.05	3.91	34.00	3.83	33.98	3.93	33.98	2.76	33.73	—	—
600	3.45	34.16	3.58	34.22	3.73	34.14	—	—	3.60	33.98	2.99	33.80	3.76	34.16

Table 6. Example of Conspicuous Mesotherm Layer in the Boundary Zone of Warm and Cold Current.

Date		1937. I. 13	"	"	1937. I. 21	"	1937. II. 21	1937. II. 22
Lat. N.		41°42.1′	42°06′	42°30′	40°41′	39°58′	41°21.5′	39°39′
Long. E.		144°09.5′	144°11′	144°16′	143°30′	143°14′	143°48.5′	143°19′
Water Temp. °C	om.	3.1	2.6	3.1	9.4	9.4	7.0	4.3
	25	3.07	2.72	3.63	9.34	9.30	7.07	4.47
	50	3.27	3.26	**4.49**	9.29	9.35	6.91	4.46
	100	**3.85**	**3.72**	**4.46**	9.35	9.38	5.37	4.39
	200	2.84	3.07	4.05	**10.95**	**10.12**	**6.75**	**6.20**
	400	2.09	2.05	2.02	**10.67**	5.64	6.03	3.71
	600	3.05	2.99	2.85	6.23	2.50	2.56	4.24

the nature and the reality of Oyasio-Undercurrent.

The southern limit of dichotherm water fluctuates with the prosperity and decay of Oyasio-Undercurrent.[56] Oyasio itself flows southwards along the coast of the North-Eastern region of Japan most strongly in the surface layer in winter, however, in late spring to mid summer it flows southwards through the intermediate layer of the North Eastern Sea-region of Japan from autumn to winter, similar to the case of polar current in the North Sea and in the Norwegian Sea discovered by Helland Hansen.[57][58]

It seems that the growth of Oyasio-Undercurrent in summer correlates with the prosperity of the north-going warm current in the upper layer in summer. In short, coming to summer the general circulation in the vertical section of the northern seas becomes vigorous and decays in autumn every year.

In the northern seas we can see the mesotherm layer beneath the dichotherm layer, commonly lying at the depths from 300 m. to 500 m. and of water-temperature above 3°*C*, warmer and more saline than in the above layer. It is probable to consider that the origin of the mesotherm water may be in the sinking of warm water-mass transported to north with higher salinity. In winter of 1937 a remarkable mesotherm layer was found in the sea-region off Aomori Pref. in the vicinity of the line of discontinuity

(57) B. H. Hansen. Zur Ozeanographie des Nordmeeres. Publ. d. Circ. 1904.
(58) B. H. Hansen & Nansen. The norwegian sea. (Rep. of Norwegian Fish. and Mar. Invest.) 1909. p. 260.

between the water-mass belonging to Tugaru Current and that belonging to Oyasio (Tab. 6).

(c) *Spring Layer of Dissolved Oxygen and the Decrease of Current Velocity.*

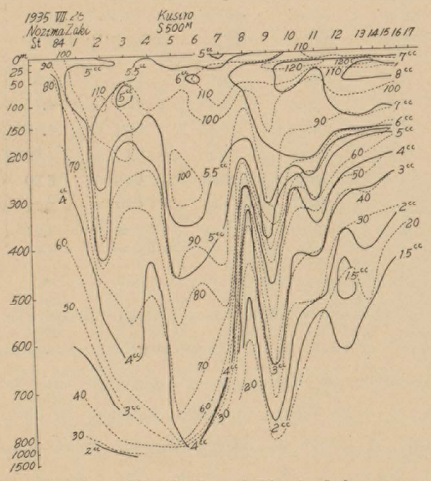


Fig. 16 a. Distribution of Dissolved Oxygen and its % of saturation at the Section from Nozimazaki to Kusiro in August, 1935 ("Sōyō-maru"). (O_2 cc/l. in full line and 100 O_2/O_2' in dotted line.)

We can recognize the spring layer of dissolved oxygen from the data obtained by H. M. S. "Komahasi" and "Sōyōmaru" as indicated in Fig. 16. This corresponds to the lower part of intermediate layer for salinity. It is inferred that the sudden decrease of dissolved oxygen with depth is due to the very feeble horizontal flow in the layer between the south-going Oyasio Undercurrent and the north-returning deep current and also due to the increase of the vertical stability or salinity with the increase of the depth.

In fact isotachen at the section (Fig. 17) indicates the decrease of the current velocity at this depth. Here it is noted that according T. Nomitsu[59] the depth corresponding to the so-called "Grenzfläche" due to difference of density does not always coincide with the depth of no current layer, rather the latter in the deeper generally.

It is clear that the depth at a maximum of dissolved oxygen and depth at which O_2 begins to decrease suddenly indicates a gradual increase from north to south (see Fig. 16).

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(44) l. c. p. 325. A. Defant (1929) S. 113.

(59) T. Nomitsu. On the so-called "Grenzfläche" due to the difference of density. Mem. of the Coll. of Sc. Kyōto Imp. Univ. Ser. A, Vol. X. No. 3. 1927.

The conclusion is that Oyasio-Undercurrent descends obliquely to the southern lower depth carrying the water of rich dissolved oxygen.

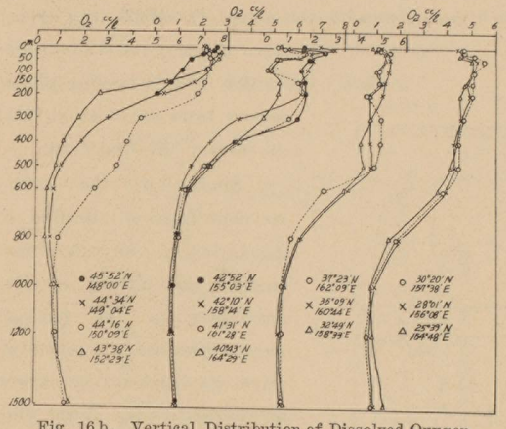


Fig. 16 b. Vertical Distribution of Dissolved Oxygen from North to South in August, 1933. ("Komahasi") in the North Pacific Ocean.

(2) Coupling of Warm and Cold Water-mass Distributed on the Oceanographical Section.

Glancing over the section of water-masses in the North-Eastern Sea of Japan along the line of discontinuity, coupled distribution of warm and cold water-masses as shown in Fig. 18.

The dichotherm water (the nucleous of the water-mass belonging to the cold current) adjoining to the left-hand (west) of warm current exists and between them a clear surface of discontinuity appears.

The cold water at the depth of dichotherm layer invades into the upper warm water, while the warm water-mass covers the cold water-mass at its right-hand (east) side. Hence the inclination of the surface of discontinuity is steep at the left-hand (west) portion of warm water-mass and gradual at the east of it. The circumstance of the invasion of the cold water into the upper warm water can be interpreted by the following discussion after A. Defant[44] that when the light water-mass in the upper layer (warm water-mass) rotates rapidly in cyclonic sense at the left-hand (west) side of the head of warm current the heavy cold water-mass welled up at the centre of the vortex, while at the right-hand (eastern) side of warm current a slow vortex rotates in anticyclonic sense. In this case the inclination of the surface of discontinuity is given by the following formula.

$$\tan\gamma = -\frac{l}{g}\frac{\rho v-\rho' v'}{\rho-\rho'} - \frac{1}{rg}\frac{\rho v^2-\rho' v'^2}{\rho-\rho'} \qquad (3)$$

Putting the observed values of Fig. 17 (St. 4∼7), $\rho=1.0278$, $\rho'=1.0251$, $v=3$ cm./sec., $v'=30$ cm./sec., $\varphi=39°$N. and $r=50$ SM. in (3), we can compute $\gamma=0°3.5'$ which coincides with the actual ($\gamma=0°02'$ i. e. 100 m. descent per 100 SM.) well. In this case the value of the second term amounts to 4% of that of the first term.

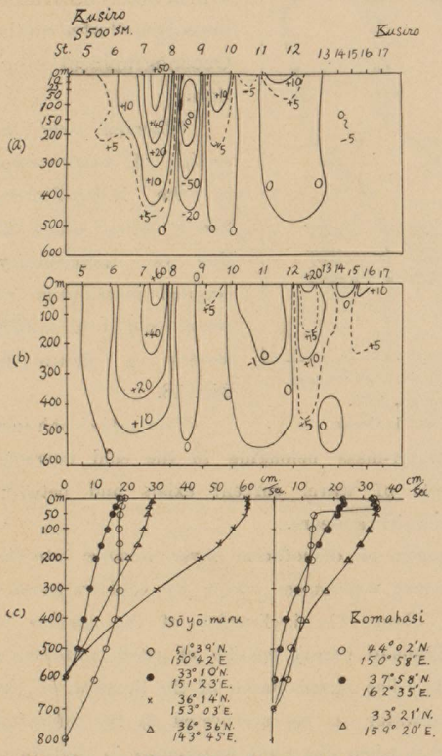


Fig. 17 a, b. Distribution of Computed Current Velocity (cm./sec.) from Bjerknes's Theory in August of 1935 and 1936 respectively at the Section South 500 SM. off Kusiro.
(+, − mean current flowing in a direction of east and west, respectively.)
Fig. 17 c. Vertical Distribution of the Velocity v Computed from Bjerknes' Theory in August, 1933 in the North Pacific Ocean.

Similar to the asymmetrical form of the line of discontinuity on the sea-surface the surface of discontinuity in the vertical section between the cold and warm water-masses represents an asymmetrical form and suggests us the important clue to solve the three-dimensional structure of "Siome."

When we look at the longitudinal section for the zone of discontinuity (Fig. 12) there appears a conspicuous discontinuity at two steps, corresponding to the polar front and the secondary polar front called by K. Suda.[46] That is the water-mass belonging to the Oyasio Current consists of the cold but comparatively light water-mass A′ of low salinity having its origin in the melting water of snow and ice in the upper layer of the northern sea above the depths of 25–50 m.

and the dichotherm water C' of relatively constant salinity in the lower layer of the depths from 50 m. to 200 m. contact with the Kurosio water-mass and forms the surface of discontinuity above mentioned. On the boundary the vortex around the horizontal axis obeying to the mechanism as pointed out by K. Suda is considered.(46)

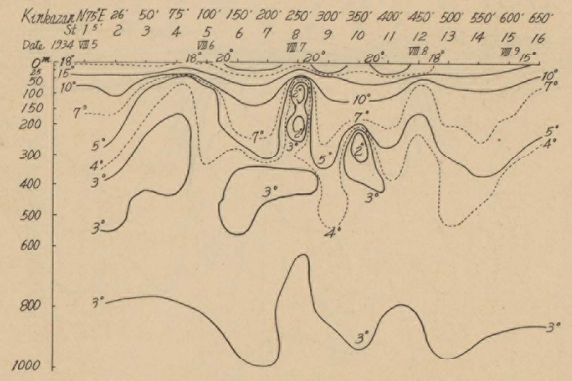


Fig. 18 Example of Coupling Appearance of Cold and Warm Water-masses at the Section of the Region around the Line of Discontinuity.
a. Water Temperature at the Section N 57° E off Kinkazan in August, 1934.

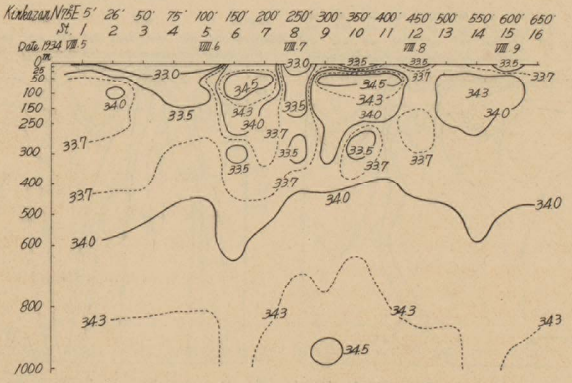


Fig. 18 b. Salinity at the Section of N 57° E off Kinkazan in August, 1934.

(3) **Convergence in the Upper Layer and Divergence in the Lower Layer on the Surface of Discontinuity.**

According to A. Defant[40] and G. Wüst,[51] the line of discontinuity presented as an intersection of sea-surface and the surface of discontinuity is

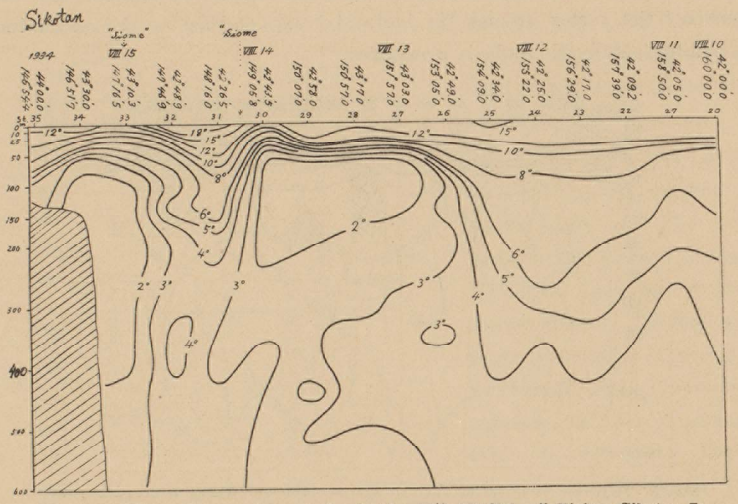


Fig. 18 c. Water Temperature at the Section E/S 650 SM. off Tisima Sikotan Is. in August, 1934.

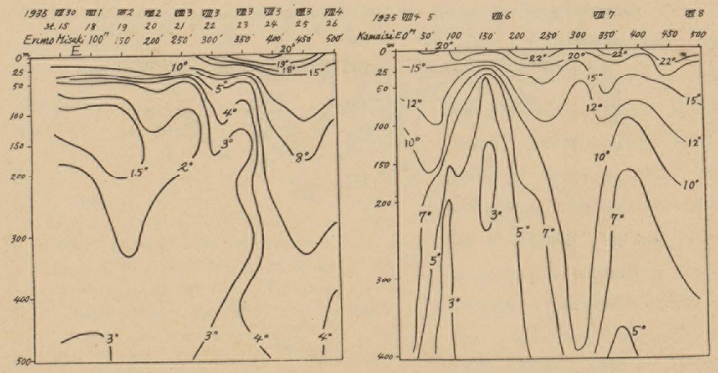


Fig. 18 d. Water Temperature at the Section E. off Erimo-Misaki in August, 1935. (left)
Fig. 18 e. Water Temperature at the Section E off Kamaisi in August, 1935. (right)

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(46) l. c. p. 328. (50) l. c. p. 332. (51) l. c. p. p. 332.

considered to be identical with the line of convergence called "Subarktische Konvergenz." Inspecting at the section in Fig. 12 we may infer "Stratospherische Zirkulation" below the line of discontinuity as the zone of salinity of 34–34.4‰ contracted in the upper and the intermediate layer but spreaded in the lower layer shows the divergence of stream-lines at the depths from 400 m. to 600 m.

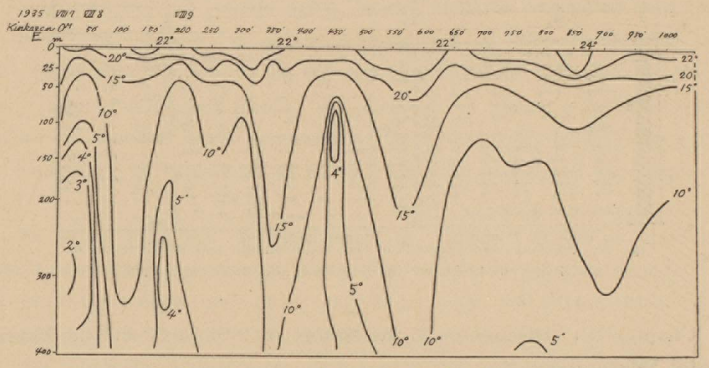


Fig. 18 f. Water Temperature at the Section E off Kinkazan in August, 1935.

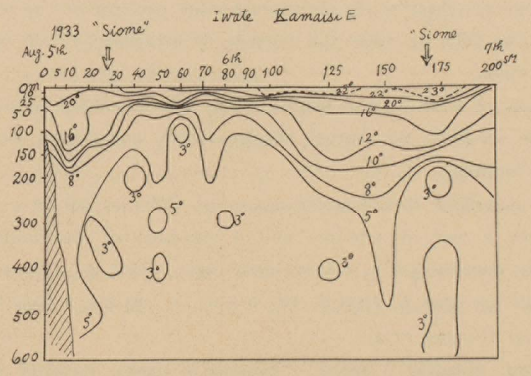


Fig. 18 g. Water Temperature at the Section E off Kamaisi in August, 1933.

For comparison in the model-experiment of "Siome" described in Chapt. IV. the divergence of the stream-lines at the bottom of the tank contrary to the upper convergence of the stream-line at x_s (See Fig. 19).

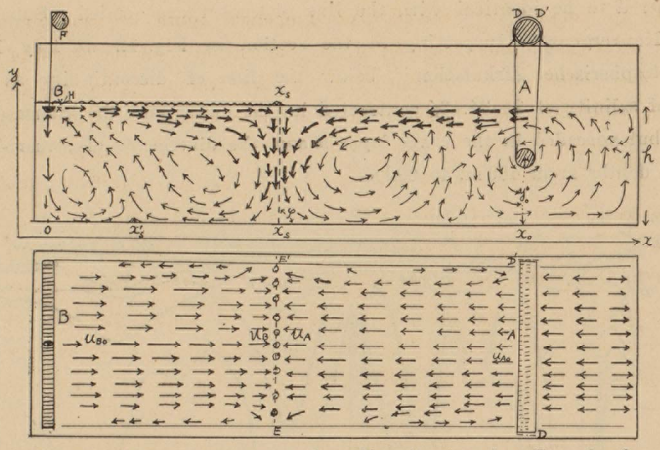


Fig. 19. Showing Arrangement of our Expe iments and an Example of the Sketch of "Siome" in Side-View and Horizontal-View.

Chapter IV. Discussion on the Nature of "Siome" and the Experimental Study about it.

(1) **Experimental Study of "Siome."** In the field of current we are ordinarily able to observe the divergence and convergence of stream-lines, and also in the field of mass the contact or stratification of water-masses of different kinds.

The works of Prandtl and others show that a surface of discontinuity in a fluid is unstable, so that it changes wavy and finally into a three-dimensional vortices.

On the boundary of the water-masses of different kinds in the actual ocean, we see a row of vortices and a complicated distribution of the oceanographic elements, i. e. water-temperature, currents and salinity etc. Meanwhile we are able to classify the origin of "Siome" into two sorts of dynamical and thermal origin.

In general, so-called "Siome" contains so many varieties of different features. Commonly an abrupt change of current is accompanied with the sudden variation of water-mass at "Siome," but sometimes they occur independently. Moreover, often different from the ordinary rippling "Siome," in the surrounding of rippling waves a smooth oily anbd is observed.

As an example of "Siome" of dynamical cause we can quote the famous experiment undertaken by J. W. Sandström[60] on the action of wind upon the boundary of discontinuity in the water-stratum of different densities, and also the experiment made by Hachey on this line.[61]

With regard to the "Siome" of thermal origin T. Terada and others reported in the experimental studies of columnar vortices.[16][17] Recently S. K. Banerji and G. H. Ghatage[18] have gotten an interesting results on the nature of "Siome" amid the water-masses of different densities and have found that the greater the difference of the water-temperature between the water-masses is, the smaller the diameter of vortex produced on the surface of boundary tends and rapidly the vortex grows in accordance with the experience in the actual ocean as previously mentioned in Chapter I. (4).*

In order to study the mechanism of "Siome" which is originated from simply dynamical causes, the writer undertook the experiments[62] in the water-tight glass tank (1 m. long, 30 cm. wide and 30 cm. deep) under the guidance of Dr. T. Terada and Dr. M. Tauti.

The summarized results are as follows: The effective current as well as progressive wave was sent on the water surface by the oscillator B with a variable frequency against the current sent from the rotating cylinder A. Then, a modelled "Siome" was clearly recognized on the line of convergence between the two opposite currents.

On the line of "Siome" powders and saw-dust floated on the water-surface were accumulated in a peculiar band (see Fig. 19).

Though appeared macrospically as a band of no current "Siome" on the surface EE' was microspically constructed with a minute vortices of vertical axes.

When the circulation in the tank are always in a stationary state, it is necessary that the components of the velocity normal to the boundary

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(60) J. W. Sandström. Dynamische Versuch mit Meerwasser. Ann. d. Hydr. 1908.

(61) H. B. Hachey. Movements resulting from mixing of stratified waters. J. Biol. Board. Can. Vol. I. No. 2. 1934. pp. 134-143.

(16) (17) (18) l. c. p. 310.

(62) M. Uda. An experimental study of "Siome" or Current-Rip as a train of horizontal vortices. Bull. Jap. Soc. Sc. Fish. Vol. V. No. 1, 1936. pp. 5-11.

* The reader is referred to (3) (f). in the present chapter.

surfaec between two circulations is nill, while the pressure must be equal on both sides of that surface. These are respectively the kinematical and dynamical boundary conditions. It follows at once that on both sides of the zone of " Siome " the velocity normal to the line of " Siome " must be equal in speed and opposite in direction.

Since the stream-lines in x-, z-plane, as shown by thick arrows in Fig. 19, diverge in the form of the nearly exponential curves with the distance from the point just above A or B towards the boundary at x_s, the velocity of the surface current u may also be diminished nearly exponentially with the distance of travel.

Denoting the quantities on both sides of " Siome " with suffixes A and B respectively, we have for the velocity in x-direction, or u.

$$-u_A=-u_{A_0}e^{-\lambda_A(x_0-x_s)}=u_B=u_{B_0}e^{-\lambda_B x_s} \tag{1}$$

where the second suffix 0 is referred to the quantities immediately above the centre of A or B, and λ_A and λ_B are constants depending on viscosity μ.

From (1) we have

$$x_s=\frac{\lambda_A}{\lambda_A+\lambda_B}x_0+\frac{1}{\lambda_A+\lambda_B}\log\frac{u_{B0}}{-u_{A0}} \tag{2}$$

Next, varying the number of rotation of cylinder A and the frequency of oscillator B, the position of oscillator and the rotator x_0, y_0, H, the depth of liquid h and the viscosity μ of the medium successively, the experimental results obtained can be all explained by the above formula (2). Accordingly by the relative variation of the strength of the two opposite currents the position of " Siome " x_s moves to and fro. (Refer to Chapter V.) In this case the value of convergence $K=2u_B$.

Denote the $x-$ and z-components of the velocity by u and respectively, and the corresponding components of the resultant force per unit mass of the medium by X and Z respectively. Then the variation of the pressure p along the boundary surface between two circulations is

$$dp=\rho(X-\dot{u})dx+\rho(Z-\dot{w})dz \tag{3}$$

But, since $p_A=p_B$ on the boundary, $dp_A=dp_B$, and since in this case of the tank experiment $\dot{u}_A=\dot{u}_B=\dot{w}_A=\dot{w}_B=0$, we have

$$\tan\gamma=\frac{dz}{dx}=\frac{X_A-X_B}{Z_A-Z_B} \tag{4}$$

In almost all cases in the present experiments, $Z_A\fallingdotseq Z_B\fallingdotseq g$ and the

slope of the boundary is $\frac{\pi}{2}$. But, when h was great, γ became less than $\frac{\pi}{2}$, suggesting that $X_A - X_B$ and $Z_A - Z_B$ have different signs.

Thus it was justified that the position of "Siome" is supposedly observable at the margin of upwelling i. e. of a diverging region on the sea surface (for example the rippling sea region accompanied with the upwelling cold water and "Siome" at its margin near Nisinotoromisaki of Karahuto).*

In the ocean considering "Siome" due to the dynamical cause between the water-masses of different density ρ_A, ρ_B, the slope of the boundary is given by the following equation.

$$\tan \gamma = -\frac{2\omega \sin \varphi}{g} \frac{\rho_A v_A - \rho_B v_B}{\rho_A - \rho_B} \qquad (5)$$

i. e. since ρ_A and ρ_B are nearly equal to 1 the slope of the boundary γ is nearly proportional to the difference of velocity $(v_A - v_B)$ and inversely proportional to the difference of density $(\rho_A - \rho_B)$.

(2) Oceanographical observations of "Siome."

The examples of "Siome" of which the author had opportunities of making his own observation on the sea-surface during the navigations in 1929–1937 on board of "Sōyōmaru" are as follows.

(*a*) *In the Pacific Ocean.*

(No. 1) During 11.30–12.30 on Sept. 29, 1933 in the sea-region south to Kinkazan a comparatively conspicuous "Siome" of broad breadth running in a direction from W to ESE is observed. At about 12.30 scarcely disturbed white waves on the line of "Siome" are also seen.

As we see in Tab. 7 the difference of water-temperature between two stations near "Siome" at the depths of from 25 m. to 100 m. amounts to 2°–6°C for the distance about 23 SM. Just on the north side of "Siome," there was a current in a SE direction and abundance of drift-algae and planktons.

(No. 2) During 15.30–16.34 on Aug. 7,1933 in the neighbourhood of the station (36°35′N, 153°16′E) we observed a chopping waves on the sea-surface, when the easterly current was very strong against the east wind of Beaufort 3. In this case also, although the water-temperature in the upper

* Refer to (63) Journal of Oceanography, Kōbe. Vol. III. 1932. p. 539. Ibid. Vol. VII. 1935. p. 495.

Table 7. "Siome" on IX. 29. 1933 in the Pacific Ocean.

St. No.		a	b	c	Diff. betw. St. b & a	Diff. betw. St. c & b
Lat. N. Long. E.		37°42.9′ 141°41′	38°02.5′ 141°54.5′	38°05′ 141°56.5′		
Time		7.55— 8.33	11.50— 12.10	12.30— 12.43		
Water Temp. (C°)	0 m	20.45	19.80	19.03	−0.65	−0.77
	25	20.63	18.32	18.34	−2.31	+0.02
	50	20.47	14.80	17.25	−5.67	+2.45
	100	14.66	12.85	13.23	−1.81	+0.38
	150	9.94	9.89	11.32	−0.05	+1.43
Salinity (‰)	0 m	34.18	33.82	33.86	−0.36	+0.04
	25	34.05	33.77	33.75	−0.28	−0.02
	50	34.02	33.91	33.98	−0.11	+0.07
	100	33.98	34.22	34.02	+0.24	−0.20
	150	34.00	34.04	34.13	+0.04	+0.09
Depth		375 m	(300 m)	288 m	—	—
Wind		NNE 2	N 1	N 1	—	—
Wave		2∼3	0∼1	0∼1	—	—
Transp. Color		19 m III	13 m IV∼V	15 m III	−6 m +(I∼II)	+2 m −(I∼II)
Air Temp.		16.8	18.7	16.9	+1.9	−1.8
N. B.		"Siome" at 11.30 & "Siome" at 12.30 (Wave 3) on it				

layer above the depth of 25 m. is comparatively uniform, for the water-temperature at the depths of from 50 m. to 600 m. and the salinity above the depths of 500 m. a remarkable difference between St. 8 and St. 9 as shown in Tab. 8 is observed.

(No. 3) At p.m. 3h. on Aug. 13, 1933 in the vicinity of (36°49′N. 144° 08′E.) a "Siome" about 10 m. of breadth and of several sea-miles in length stretched in a direction from SW to NE is observed, which was accompanied with chopping waves aroused by strong current and yellow-greenish water-colour due to the densely concentrated planktons.

In this case resembling to that of No. 2, as indicated in Tab. 9 a great difference of water-temperature at depths from 100 m. to 600 m. and of salinity at depths from 50 m. to 400 m. between St. 22 and 23 were seen.

(No. 4) At 10 h. on Aug. 5, 1934 at the station of N75°E 6 SM. distant

Table 8. "Siome" on VIII. 7, 1933.

St. No.		8	9	Diff. betw. St. 9 & 8
Lat. N. Long E.		35°52′ 152°50′	36°35′ 153°16′	
Time		8.25	15.26	
Water Temp. (°C)	0 m	26.2	25.7	−0.5
	10	26.13	25.60	−0.53
	25	26.03	25.57	−0.46
	50	21.31	18.63	−2.68
	100	18.30	12.76	−5.54
	150	17.41	10.48	−6.93
	200	16.94	9.41	−7.53
	300	16.42	5.71	−10.71
	400	14.48	4.89	−9.59
	500	11.64	4.52	−7.12
	600	8.45	4.45	−4.00
	800	4.57	4.03	−0.54
Salinity (‰)	0 m	34.63	34.34	−0.29
	10	34.63	34.31	−0.32
	25	34.67	34.36	−0.31
	50	34.70	34.36	−0.34
	100	34.85	34.34	−0.51
	150	34.85	34.14	−0.71
	200	34.83	34.14	−0.69
	300	34.74	33.80	−0.94
	400	34.52	33.82	−0.70
	500	34.40	33.98	−0.42
	600	34.13	34.07	−0.06
	800	34.07	34.25	+0.18
Transp.		30 m	26 m	−4 m
Color		II	II	0
Air Temp.		26.0	26.6	+0.6
N. B.		Computed vel. betw. St. 8,9 1.2 kn., Wave E 3		

Table 9. "Siome" at 15 h. on VIII. 13, 1933 in the Pacific Ocean.

St. No.		22	23	Diff. betw. St. 23 & 22
Lat. N. Long E.		36°36′ 144°20′	36°15′ 143°13′	
Date Time		13 th 13 h	14 th 1 h	
Water Temp. (°C)	0 m	27.5	27.7	+0.2
	10	26.52	27.65	+0.13
	25	25.33	27.03	+1.70
	50	21.23	22.14	+0.91
	100	16.21	19.57	+3.36
	200	10.99	17.04	+6.05
	400	7.86	12.88	+5.02
	600	5.06	10.28	+5.22
Salinity (‰)	0 m	34.51	34.51	0.00
	10	34.49	34.43	−0.06
	25	34.51	34.45	−0.06
	50	34.52	34.76	+0.24
	100	34.63	34.85	+0.22
	200	34.29	34.79	+0.50
	400	34.29	34.49	+0.20
	600	34.31	34.31	0.00
Air Temp.		27.5	25.6	−1.9

from Kinkazan we have found a "Siome," where water-temperature has fallen from 19°C to 18.5°C and the swim of dolphins and whales were seen.

(No. 5) In the afternoon Aug. 14, 1934 in the vicinity of the station (42°30′N. 148°30′E.) we encountered a splendid sight of "Siome" which runs in a direction from NE to SW forming several bands, so to speak, like dykes in the field and is associated by the remarkable change of water-temperature during the progress from 10.7°C at 11 h. to 19°C at 14 h. and 19.3°C at 16 h. and the swim of whale. In this case it is obvious from Tab. 10 that abruptly the water temperature rises about 10°C in the distance of 20 SM. and also salinity 0.5–1.7‰, dissolved oxygen in the upper water layer above the depths of 100 m. decreasing 1.5–3 cc/l., colour of the sea of

Table 10. "Siome" at 14 h.~16 h. on Aug. 14 and at 7 h on Aug. 15 in 1934 in the Pacific Ocean.

St. No.		30	30′	31	32	33	Diff. betw. St. 31 & 30′ (30)	Diff. betw. St. 33 & 32
Lat. N. Long. E.		42°44′ 149°06′	42°48′ 148°56′	42°27′ 148°16′	42°49′ 147°47′	43°10′ 147°17′		
Date Time		VIII 14 7.00	" 11.14	" 17.25	" 23.00	VIII 14 7.00		
Water Temp. (°C)	0 m	10.3	10.7	18.8	19.4	11.2	+8.1	−8.2
	10	9.5	9.9	17.0	19.1	9.3	+7.1	−9.8
	25	5.9	6.4	15.0	11.0	6.2	+8.6	−4.8
	50	2.2	2.9	12.6	5.5	5.0	+9.7	−0.5
	100	2.0	1.8	7.1	4.4	1.7	+5.3	−2.7
	150	1.7	—	6.2	4.8	1.2	(+4.5)	−3.6
	200	1.8	—	4.2	3.2	1.2	(+2.4)	−2.0
	300	2.6	—	3.0	3.6	1.9	(+0.4)	−1.7
	400	3.1	—	2.6	4.1	1.9	(−0.5)	−2.2
	500	2.8	—	3.7	3.3	2.6	(+0.9)	−0.7
	600	2.7	—	3.6	3.2	3.0	(+0.9)	−0.2
	800	2.7	—	2.9	2.9	3.1	(+0.2)	+0.2
	1000	2.5	—	2.8	2.7	2.8	(+0.3)	+0.1
Salinity (‰)	0 m	32.75	32.66	32.84	32.97	32.66	+0.18	−0.31
	10	32.66	32.77	33.35	32.83	32.70	+0.58	−0.13
	25	32.86	32.92	34.60	33.04	32.83	+1.68	−0.21
	50	33.22	33.04	34.36	33.04	33.19	+1.32	+0.15
	100	32.86	33.44	33.90	33.56	33.22	+0.46	−0.34
	150	33.35	—	33.75	33.64	33.21	(+0.40)	−0.43
	200	33.44	—	33.60	33.50	33.30	(+0.16)	−0.20
	300	33.71	—	33.59	33.89	33.49	(−0.12)	−0.40
	400	33.91	—	33.69	33.92	33.80	(−0.22)	−0.12
	500	34.05	—	34.11	34.02	33.76	(+0.06)	−0.26
	600	34.14	—	34.23	34.08	34.06	(+0.09)	−0.02
	800	34.28	—	34.25	34.24	34.33	(−0.03)	+0.09
	1000	34.43	—	34.32	34.32	34.34	(−0.11)	+0.02
Dissolved Oxygen (cc./L)	0 m	7.32	—	5.88	5.99	7.53	(−1.44)	+1.54
	10	7.69	—	6.15	5.94	—	(−1.54)	—
	25	8.07	—	5.35	5.92	—	(−2.72)	—
	50	7.32	—	4.66	6.68	7.37	(−2.66)	+0.69
	100	9.51	—	6.36	6.36	6.31	(−3.15)	−0.05
	150	5.51	—	5.94	5.99	—	(+0.43)	—
	200	4.98	—	6.25	5.94	—	(+1.27)	—
	300	3.06	—	5.03	4.01	—	(+1.97)	—
	400	1.62	—	3.70	2.84	—	(+2.08)	—
	500	1.46	—	2.63	2.26	—	(+1.17)	—
	600	1.51	—	2.61	1.24	—	(+1.10)	—
	800	0.87	—	0.92	0.93	—	(+0.05)	—
	1000	0.98	—	0.97	0.98	—	(−0.01)	—

Forel's scale from V to III, pH increasing 0.1–0.3, and the nutrient salts (P_2O_5, SiO_2, $N_2O_5-N_2$) decreasing 10–40% of their values during the course from the side of cold water to the side of warm water near "Siome."

(No. 6) At 7 h. on Aug. 15, 1934 as indicated in Tab. 10 corresponding to the fall of water-temperature about 10°C a "Siome" was found at St. 33, associated with flocks of sea-birds. On the same day about at 11 h. the

Table 11. "Siome" at 14h. on July 26, 1935 in the Pacific Ocean.

St. No.		1	84	Diff. betw. St. 1 & 84
Lat. N. Long. E.		34°37′ 140°21′	34°51.2′ 139°54.2′	
Date Time		VII 26. 17.12-18.23	" 13.50-14.06	
Water Temp. (°C)	0m	26.8	23.5	+3.3
	10	26.75	23.41	+3.34
	25	25.23	21.25	+3.98
	50	24.34	17.21	+7.13
Transp.		26 m.	11 m.	−15 m.
Color		II	IV	+II

Table 12. "Siome" at 17h. on Aug. 22, 1935 in the Kunasiri Strait

St. No.		69	70	Diff. betw. St. 70 & 69
Lat. N. Long. E.		44°31′ 146°40′	43°44.5′ 147°06′	
Date Time		VIII. 22 17.00	" 22.50	
Water Temp. (°C)	0m	15.1	10.8	−4.3
	10	14.40	10.19	−4.21
	25	13.03	6.87	−6.16
	50	8.10	4.86	−3.24
	100	3.67	2.54	−1.13
Salinity (‰)	0m	32.72	32.99	+0.27
	10	32.90	32.99	+0.09
	25	33.35	33.37	+0.02
	50	33.37	33.39	+0.02
	100	33.35	33.35	0.00

Table 13. "Siome" at 20h. on Aug. 11, 1937 in the Pacific Ocean.

St. No.		8	9	Diff. betw. St. 9 & 8
Lat. N. Long. E.		37°05′ 143°56′	37°55′ 144°00′	
Date Time		VIII 11 14.17-15.00	" 21.48-23.50	
Water Temp. (°C)	0m	27.4	24.8	−2.6
	10	27.49	24.80	−2.69
	25	26.56	19.22	−7.34
	50	23.69	13.77	−9.92
	100	19.92	9.45	−10.47
	150	18.47	6.77	−11.70
	200	17.17	5.08	−12.09
	300	15.63	5.87	−9.76
	400	13.80	3.69	−10.11
	500	11.09	3.92	−7.17
	600	9.63	3.40	−6.23
Salinity (‰)	0m	34.38	33.62	−0.76
	10	34.36	33.63	−0.68
	25	34.36	33.80	−0.56
	50	34.63	34.42	−0.21
	100	34.78	33.98	−0.80
	150	34.97	33.75	−1.22
	200	34.76	33.69	−1.07
	300	34.72	34.11	−0.61
	400	34.61	33.93	−0.67
	500	34.45	34.11	−0.34
	600	34.25	34.22	−0.03

water-temperature has risen again to 17°C and shoals of tunny and dolphin were seen on the sea.

(No. 7) At p.m. 2h. on July 26, 1935 at the St. 84 south 3 SM. from Nozimazaki we saw a zone of white waves of pyramidal form aroused by strong oceanic current which runs from south to north.

Passing through that, an abrupt change of water-temperature between the coastal water and Kurosio water as shown in Tab. 11 was experienced.

(No. 8) At p.m. 5h. on Aug. 22, 1935 in the Kunasiri Strait "Siome" running in a direction from north to south with a shoal of tunny was observed. Neighbouring to that "Siome" we saw a great difference of water-temperature between the water-mass belonging to the Sōya Warm

Current (St. 69) and that of Oyasio (St. 70). (See Tab. 12).

(No. 9) At about p. m. 8 h. on Aug. 11, 1937 in the vicinity of the station (37°40′N. 144°03′E.), in spite of no wind we saw a zone of white waves on the sea surface and felt the rolling of the ship when passing over it. As was expected, currents in the upper layer, water-temperature and salinity in the sub-surface layer on both sides of this zone (between St. 8 and 9) indicates a great difference. (See Tab. 13.) It is proved

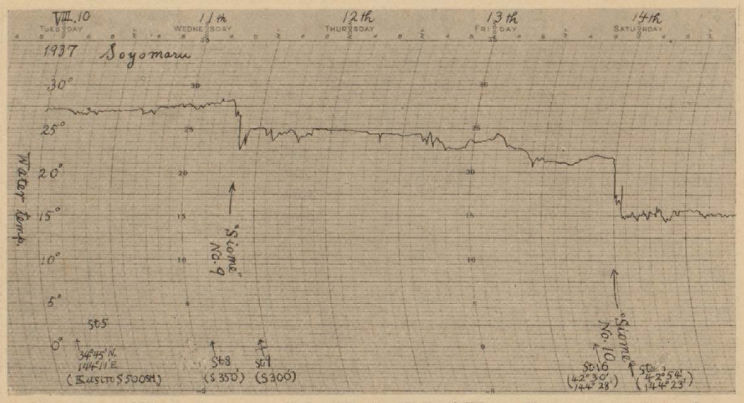


Fig. 20 a. "Siome" accompanied with the Fall of Water Temperature shown in the Self-Recording Thermograph in the Cruise of "Sōyō-maru" in Aug.. 1937.

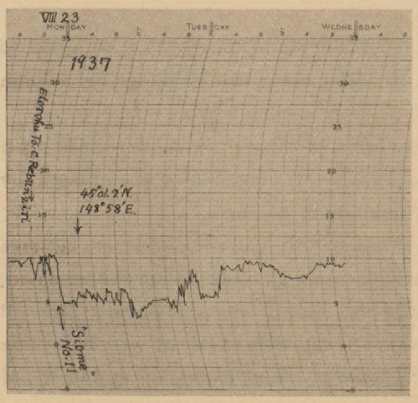


Fig. 20 b.

also by the self-recording thermograph in Fig. 20 a.

(No. 10) At 11 h. on Aug. 14, 1937 passing through south off Kusiro, we observed a "Siome" accompanied with rippling white waves and shoals of skipper with associates of seabirds near by, at which the water-temperature at St. 17 has fallen 4°C in comparison to that of St. 16 (Tab. 14). Similar to the case of No. 9 a sudden fall

Table 14. "Siome" at 11 h. on Aug. 14, 1937 in the Pacific Ocean.

St. No.		16	17	Diff. betw. St. 17 & 16
Lat. N. Long. E.		42°30.5′ 144°28′	42°54′ 144°23′	
Date Time		Aug. 14 7.26-8.05	" 11.13-.24	
Temp. (°C)	0 m	21.9	17.9	−4.0
	10	21.81	12.49	−9.32
	25	12.96	11.83	−1.13
	50	8.59	8.83	+0.24
Sal. (‰)	0 m	33.31	32.65	−0.66
	10	33.33	33.03	−0.30
	25	33.51	32.97	−0.54
	50	33.73	33.35	−0.38
Transp. Color		17 m IV	7.5 m V~VI	−9.5 m +(I~II)

of water-temperature is clearly shown in the self-recording thermograph of Fig. 20 a.

(No. 11) On Aug. 23, 1937 near the station east 20 SM. off Rebunsirimisaki of Etorohu Is. corresponding to the change of water-temperature from 10.8°C at 12 h. and beyond 10°C at 13 h. fallen to 5°C at 14 h., we have observed a rippling "Siome" at 13 h. 20 m. (See Fig. 20 b).

(*b*) *In the Sagami Bay.*

(No. 12) At 10.15 on Dec. 17, 1929 near the station (35°7′2″N. 139°13′30″E. off Manaduru a "Siome" associated with foams and ripples, running in a direction from SW to NE was observed.

Also, off Manaduru, at 11.30 on May 5, 1932 we saw a "Siome" associated with drift-algae and shoals of tunny. On the same day at p. m. 5 h. off Simoda water-temperature has changed suddenly from 16°C to 21°C in the course of navigation of 7 SM.

(*c*) *In the Japan Sea.*

(No. 13) During 9.40–10.27 on Nov. 10, 1933 in the neighbourhood of station (35°40′N. 130°28.5′E.), we have found a "Siome" associated with accumulation of dusts, running in a direction from north to south and also with a shoal of mackerel, where water-temperature in the upper layer above a depth of 100 m. changes 1°–3°C compared to that of St. 73 as shown in Tab. 15.

(No. 14) At 14 h. on Nov. 12, 1933 at the station NE to Tusima a rippling "Siome" associated with a remarkable abundance of planktons and turbidity of sea-water and also with a shoal of mackerel was found. In this case also, the water-temperature and salinity above a depth of 50 m. varies suddenly in the vicinity of St. 80 as shown in Tab. 16.

(3) On the nature of "Siome."

The "Siome" appeared in the seas and oceans actually is in general not

Table 15. "Siome" at 9.40 Nov. 10, 1933 in the Japan Sea.

St. No.		73	74	75	Diff. betw. St. 74 & 73
Lat. N. Long. E.		35°50′ 131°12.5′	35°40′ 130°28.5′	35°34.2′ 130°03.5′	
Date Time		XI. 10 4.25	" 9,40-10,27	" 13.45	
Water Temp. (°C)	0m	18.4	19.3	19.8	+0.9
	10	18.36	19.41	19.50	+1.05
	25	18.36	19.22	10.63	+0.86
	50	18.06	19.21	19.57	+1.15
	100	14.20	17.29	15.96	+3.09
	150	6.78	7.14	0.97	+0.36
	200	2.05	1.00	0.45	−1.05
	300	0.54	0.43	—	−0.11
	400	0.31	0.26	—	−0.05
	500	0.16	0.22	—	+0.06
	600	0.20	0.17	—	−0.03
	800	0.16	0.14	—	−0.02
Salinity (‰)	0m	33.51	33.60	33.60	+0.09
	10	33.60	33.62	33.60	+0.02
	25	33.44	33.62	33.60	+0.18
	50	33.66	33.62	33.64	−0.04
	100	34.49	34.49	34.38	0.00
	150	34.25	34.29	34.11	+0.04
	200	34.11	34.13	34.13	+0.02
	300	34.11	34.11	—	0.00
	400	34.13	34.11	—	−0.02
	500	34.14	34.09	—	−0.05
	600	34.13	34.13	—	0.00
	800	34.11	34.11	—	0.00
Depth		920 m	1093 m	210m	—
Air Temp.		14.7°	19.6°	20.5°	+4.9°

simple but of complicated structure. There is as to speak, a compound "Siome" involved several striaes of small "Siome" such as shown in the example No. 1 in the preceding paragraph.

However, by the above investigations we can find several characteristics common to "Siome."

(*a*) *Convergency of "Siome."*

Summarizing the matters obtained by observations and experiments. it is

Table 16. "Siome" at 14 h. on Nov. 12, 1933 in the Japan Sea.

St. No.		79	80	Diff. betw. St. 80 & 79
Lat. N. Long. E.		34°53.2′ 129°26.9′	34°41′ 129°45′	
Date Time		XI 12 11.03	„ 14.26	
Temp. (°C)	0m	17.1	18.85	+1.75
	10	16.92	18.14	+1.82
	25	18.44	18.71	+0.27
	50	18.48	18.56	+0.08
	100	15.11	16.94	+1.83
	150	14.97	—	—
Sal. (‰)	0m	33.08	33.62	+0.54
	10	32.74	33.53	+1.79
	25	33.08	33.51	+0.43
	50	33.40	33.68	+0.28
	100	34.16	34.23	+0.07
	150	34.47	—	—
Depth		184 m	112 m	—
Transp.		17 m	11.5 m	−5.5 m
Color		IV	V	+I
Air Temp.		13.0	15.0	+2.0

concluded that both "Siome" having its origin in the dynamical and thermal causes are due to the discontinuity of currents on the surface, in the case when the discontinuity is a line of convergence or divergence the "Siome" lies on it or on the line of convergence at the margin of upwelling area.

Or in other words, the "Siome" of primary character is associated always with the convergence of currents and in this meaning it may be named as the "Siome" of the first kind. The "Siome" accompanied with the area of divergence (such as oily patch) is the same one to the "Siome" of the first kind. However, since the convergence is subject to the area of divergence, distinguishing from the "Siome" of the first kind it may be named as the "Siome" of the second kind. Most of the "Siome" in the vicinity of the region around the submarine elevation (e. g. bank, ridge) are considered to be due to upwelling current caused by the presence of them.

Further, in the case of so-called "Tide-Rip" and "Siome" shown in the examples No. 2, 3, 9 in (2), though the discontinuity of water-masses is not seen in the upper layer, a marked discontinuity in the sub-surface layer exists and on the sea-surface a rippling band associated with the accumulation of drifting-bodies at its margin is seen. It may be named as the "Siome" of the third kind.

Corresponding to the increasing velocity of oceanic current more than above 1.5 knot ripples may be usually seen on the sea-surface caused by the disturbance due to the concentration of stream-lines and as a kind of Helmholtz wave on the surface boundary between sea and atmosphere under the frictional resistance of the air. Further, in the very strong oceanic current

of velocity more than above 3 knot it is considered that the ripples above mentioned may grow unto a breaker (so-called " Sionami " 潮浪 or " Stromwellen ")[65] usually. Moreover in the case when the wind-wave was superposed on such a strong current it becomes to show a ragged sea called " Kabbeliger See "[64] or " Kreuz-See "[64] according to the strength of wind.

(*b*) *Discontinuity of water-mass on both sides of " Siome."*

Ordinarily, the first stage of " Siome " in its development is the existence of the two currents opposite in direction against a boundary surface. In actual case the two are generally subject to the displacemeut of water-masses having each different origin (e. g. warm and cold water or coastal water of low salinity and oceanic water of high salinity), it is natural to find an abrupt change of water-temperature, salinity, colour and transparency of the sea near the boundary of " Siome." (See the examples in the preceding paragraph). But the discontinuity of the water-mass is not the necessary condition for the appearance of " Siome " and sometimes we can find " Siome " accompanying no sensible variation of the skalar oceanographic elements (water-temperature etc.)[11] (e. g. " Siome " aroused by wind in a homogeneous water-mass).

Basing on the facts for the origin of " Siome," it is correctly considered to classify " Siome " into those of the thermal and dynamical causes.

(*c*) *Accumulation of drifting-bodies on " Siome."*

As one of peculiar characteristics of " Siome," a band of gathered drifting-bodies as mentioned in Chapter II. (2) is perfectly due to the convergence of currents and not the necessary condition for the essence of " Siome," but a dependent phenomenon of it.

Or in other words, although the convergence of currents and the rippling as its results exist, such a peculiar band of drifting-bodies might not be found without the existence of the drifting-bodies itself. In some cases after the " Siome " has already vanished the band of accumulated substances in the stage of diffusion is remained on the sea-surface, so long as the disturbances such as wind-wave etc. does not occur. The accumulation of drift-

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(64) G. Thiel. Über Stromkonvergenzlinien und Kabbelungen. Ann. d. Hydr. 1937. S. 109, 110.

(65) Auffallende Stromgrenz im Stillen Ozean. Ann. d. Hydr. 1904. S. 435.

(11) l. c. p. 309.

ing substance may have more or less the effect of lessening the rippling.

(*d*) *Appearance of the rippling "Siome" and its variation.*

In the case when the two opposite currents are not strong, at first on the very calm sea-surface we recognize a hair-like[65] or a string-drawn line[65] and then corresponding to the increase of velocity it develops to a narrow zone on the sea-surface like dykes in a field. Such an appearance probably due to the optical difference with regard to the reflection of the sun ray from the water-surface sensibly elevated just on the line of convergence, i. e. an inclined surface to level.

The more the current becomes stronger, we can recognize gradually ripples forming a band on the sea-surface as if in the case of a stream flowing from one direction suddenly checked by a wall (e. g. in the case when the stream was driven to a wall by wind).

The stronger the rippling becomes with the increase of the current-velocity, some noisy sound associated with rippling can be heard.

Further developing the rippled "Siome," the waves like pyramidal form disturb the sea more and more, until representing a feature like a boiling state on the sea-surface with violent noise and splushing even on the board of boat.[66] In particular, when the wind-wave superposed on such a rippling "Siome," we see breakers just on that line.

The reason may be explained as follows qualitatively:

The wind-wave proceeds in a trochoidal form with the current in the same direction and coming at "Siome" the wave is checked by the opposite current suddenly and probably the wave form changes from the one to the another at that boundary. As the result of it the ratio of wave-height to wave-length increases suddenly at the boundary and when it exceeds over the critical value the breaker occurs.

Frequently we see a smooth oily band at the line of "Siome" surrounded by the wind-waves. It may perhaps be presented by the ellimination of irregular rippled waves in "Siome" by the superposition of wind-waves on them, just as the wake behind the course of a moving ship. Of course, there may be the case of oily band caused by upwelling. It is hoped that the present problem may be investigated further by the experiment.

(66) Stark Stromkabbelung. Ann. d. Hydr. 1905. S. 522.

(*e*) *Noise associated with "Siome."*

Similar to the case of the noise in the rippling river (セヽラギ), the sound aroused by the irregular rippling on "Siome" (潮騒(シオザイ)) is felt as the noise of the complicated sorts which are yet studied neither theoretically nor experimentally and is submitted to the future researches. The sound as if the boiling noise is supposed to be due to the combination of the breaking sound of bubbles and the striking sound of the splush at the time of violent rippling. The noise reported as "roaring"[4] may be perhaps due to the sound caused by a train of breaker on "Siome," by the mechanism as formerly studied by T. Terada[67] for the case of dune. The speculations thus proposed should be checked in future by the accurate measurements.

(*f*) *Vortices on "Siome."*

In our experiment previously mentioned, it was proved that the "Siome" can be substituted by a train of vortices around horizontal axis and the vortices around the vertical axis are also associated with "Siome" produced between the two opposite currents. As we know from the researches of meteorology,[46] it is considered that the line of "Siome" tends to wavy due to its unstability and then vortices are produced at the undulated portions and after the growth at length they are occuluded.

The fact that the larger the gradient of the water-temperature etc. becomes, the more the vorticity increases, was proved by the experiment of S. K. Banerji[18] and by the results of our observation in the sea.

This can be explained as follows:

Suppose that two water-masses of density ρ_1, ρ_2 and of water-temperature θ_1, θ_2 respectively flow opposite in direction each other with velocity u_1, u_2 at a distance L. Then, utilizing the Bjerknes's formula (3) in Chapter II, we have

$$\zeta = \mathrm{rot}\, v = \frac{u_1+u_2}{L} = \frac{d_2-d_1}{2\omega L^2 \sin\varphi} = \frac{\int \frac{gdp}{\rho_2} - \int \frac{gdp}{\rho_1}}{2\omega L^2 \sin\varphi} = \frac{\rho_1-\rho_2}{\rho_1\rho_2}\,\frac{1}{2\omega L^2 \sin\varphi}\int gdp \tag{6}$$

Since $\rho_1\rho_2 \fallingdotseq 1$ and approximately $\rho_1 \propto \theta_1$, $\rho_2 \propto \theta_2$, it becomes in this case,

(4) l. c. p. 308. (46) l. c. p. 328. (18) l. c. p. 310.

(67) 寺田寅彦: 海鳴に就て. 氣象集誌, 第 34 年, 1-5 頁. 1915. (Sc. Pap. T. Terada Vol. VI. p. 83 參照).

$$\zeta \propto \frac{\rho_1 - \rho_2}{L} \propto \frac{\theta_1 - \theta_2}{L} \qquad (7)$$

Or in other words practically, vorticity in the region near the line of discontinuity is proportional to the gradient of water-temperature.

In the adjacent region of the line of discontinuity in the North-Eastern Sea of Japan, we see the area of convergence near the boundary zone between the cyclonic and anticyclonic rotations, and adjoining to it the area of divergence. Since the "Siome" appears in the area of convergence, by the three-dimensional view it is considered that the stream-lines descend first in the area of convergence at the margin of cyclonic vortical current in the upper layer of the warm water-mass and then ascend in the area of divergence neighbouring to the right-hand side (east) of convergence spirally.

The thickness of the warm water in this case is considered plausible to take about 50m. In the section cutting the sub-surface layer near the line of discontinuity, we can see the cold water-mass creeping into depths of several hundred metres in the southern sea from the surface in the northern sea. Therefore, a great "Siome" between cold and warm water-masses in three-dimensional view may be considered as the phenomenon appeared in the area of convergence which was produced by the spiral stream in a couple of cyclonic and anticyclonic vortices resembling to a doublet of sink and source of hydrodynamics. S. Fujiwhara has already remarked that a "Siome" consists of a chain of vortices as its nucleus in a elongated S form.[13]

(*g*) *Topographical condition inducing the production of "Siome"*. By the experience of sea-farers it is a well-known fact that in some region corresponding to a special bottom or coastal configuration "Siome" is produced frequently. However, hitherto there is no satisfactory experiments on this problem.

"Siome" occurs frequently between the current and the counter current produced by the obstacle such as promontory or island in the down-stream region behind them. Also, at the estuary of a river (e.g. Sinanogawa, Tonegawa etc.) between the sea water and the fresh water, or on the margin of continental shelf the frequent occurrence of "Siome" is known.[1][2][3] The latter on the margin of continental shelf can be interpreted as follows:

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(1) (2) (3) l. c. p. 307, 308.

According to V. W. Ekman (1928)[68] "currents produced by gravity in homogeneous water when the sea-surface is inclined to the horizon, when running from a deeper towards a shallower part on the sea or vice versa were proved to be subject to a 'topographical effect'[69][70] causing them to deviate *cum sole* or *contra solem* respectively (i. e. to the right or to the left in the northern latitudes). Likewise a current not moving due east or west would be subject to a 'planetary rotational effect'[69][70] causing it in most cases to deviate eastwards. The two effects combined would govern the actual course of the current." Now let us apply this theory to the case of the boundary between the water-mass belonging to Kurosio *B* and the water-mass in the China Sea of low salinity *A* at the margin of the continental shelf in a direction of *NW* off Riukiu (Fig. 21 a). Proceeding from a deeper *B* towards a shallower *A* beyond *C*, owing to the increase of deflecting force due to the earth rotation turns the course suddenly in clockwise and the currents along the continental shelf of the 200m. isobathymetric line. On the other hand the water-mass *A* coming to *C* with uniform velocity, then turning its direction suddenly in counter-clockwise along the isobathymetric line near the continental shelf. In this way, the boundary *C* between the water-masses *A* and *B* is maintained, and accordingly at the portion of convergence "Siome" appears. However, on the edge of the coastal narrow shelf it should be considered that the frequent occurrence of "Siome" corresponding to the convergence at *C* may have its cause in the vertical circulation in *A* by wind* or the discharge of the river water, and sometimes in the upwelling area in *B* (see Fig. 21 b).

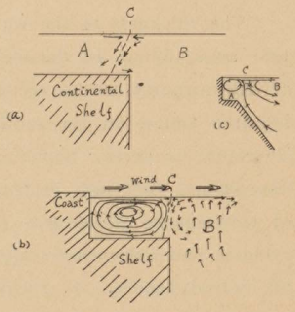


Fig. 21. Shematic Representation of "Siome" in Connection with the Bottom Configuration.

(68) V. W. Ekman. Note on the theoretical courses of ocean currents. Journal de Conseil. Bd. 3, No. 1. 1928.

(69) V. W. Ekman. Über Horizontal Zirkulation bei wind-erzeugten Meeres-Strömungen. Ark. f. astr. o. fys. Bd. 17. No. 26. 1923.

(70) V. W. Ekman. A survey of some theoretical investigations on ocean currents. Journal de Conseil. Bd. 3. No. 3. 1928.

* The stream-lines in Fig. 21 b was plotted with reference to the following paper by K. Hidaka. (71)

The "Siome" may be also aroused by such a circulation as shown in Fig. 21 c after the diagram plotted by G. Dietrich.[17]

Chapter V. Transgression of the surface of discontinuity in the ocean in relation to the fluctuation of the hydrographical conditions.

As we see in the example (2) in this chapter, "Siome" does not fixed to a place in general and the movement of the front is the usual case.

That is, if the current on one side of the surface of the discontinuity between two currents becomes stronger, the boundary surface of equilibrium for push is renewed successively and is apparently displaced to a direction. This coincides with the experimental results as shown in (1) of the preceding chapter, and the position of the boundary x_s is the function of the ratio of the current velocity on both sides of "Siome".

When the transgression of the surface of discontinuity corresponds to the interchange of the water-masses of different kinds, we see a marked change of hydrographical conditions at that regions around the boundary.

(1) General discussions.

Now, in general, let us consider the surface of discontinuity

$$f(x,\ y,\ z,\ t)=0 \tag{1}$$

Then

$$f(x+dx,\ y+dy,\ z+dz,\ t+dt)=0,\quad \frac{\partial f}{\partial t}dt+\frac{\partial f}{\partial x}dx+\frac{\partial f}{\partial y}dy+\frac{\partial f}{\partial z}dz=0$$

Accordingly

$$\frac{\partial f}{\partial t}=-\boldsymbol{V}\cdot\nabla f \tag{2}$$

If the displacement velocity of the boundary $\boldsymbol{V}$ be constant and the angle between the vector $\boldsymbol{V}$ and ∇f be small, then

$$\frac{\partial f}{\partial t}\propto\nabla f \tag{3}$$

That is to say, the time-variation of some quantity is proportional to the gradient of the space-distribution of that quantity. For example, if the boundary of water-masses displaces Δx in the interval Δt with the velocity V through the region of temperature-gradient $\frac{\partial\theta}{\partial x}$ the ultimate change of water-temperature $\Delta\theta$ is $\frac{\partial\theta}{\partial x}\Delta x$ i. e. $\frac{\partial\theta}{\partial x}V\Delta t$.

(71) 日高孝次: 吹送循環流に關する研究 (其一). 「海と空」第 17 卷, 第 10 號, 昭和 12 年 10 月.

Again, if $\Delta f = \text{const.} = k$

$$\frac{\partial f}{\partial t} \propto V \tag{4}$$

Assuming that $V = V_0 \sin nt$, the mean variation of f in the time-interval T is

$$\overline{\Delta f} = \frac{1}{T}\int_0^T \frac{\partial f}{\partial t} dt = \frac{kV_0(1-\cos nT)}{T} \tag{5}$$

Next, we will consider the above results, reducing into the more convenient form for the practical investigation.

Assuming that the line of discontinuity between two water-masses for the attribute Φ (any one of water-temperature, salinity, dissolved oxygen, colour and transparency of the sea etc.) moves to x-direction, and the curve Φ when $t=0$ shows $\Phi_0 = f(x)$ and has gradient in x-direction. If the curve displaces ξ in x-direction at $t=t$, holding the same initial form, then it becomes $\Phi_t = f(x-\xi)$.

Accordingly the difference between the values of the initial curve and that of the moving curve for the boundary $\Phi_0 - \Phi_t = f(x) - f(x-\xi)$.

Next, let us suppose that such a moving curve follows an pendulum-like motion from an extremum point $\xi = 0$, $(t=0)$ to another extremum point $\xi = l$, $(t=\tau)$, then

$$\Phi_0 - \Phi_\tau = f(x) - f(x-l) \tag{6}$$

Or in other words. the variation in the interval of a period due to such a movement of front is represented by the difference of $f(x)$ corresponding x at $t=0$ in the initial curve and $f(x-l)$ corresponding to $x-l$. Therefore in such a case the timely-amplitude of variation is mainly determined by the spatial distribution of $f(x)$.

For example, let us consider the annual displacement of the boundary between the warm and cold water-masses, such that $t=0$ corresponding to September, $t=\tau$ to March and in the interval between them following a sinus change $\xi = l \sin t$.

As a simplest case as shown in Fig. 22 a, assume that

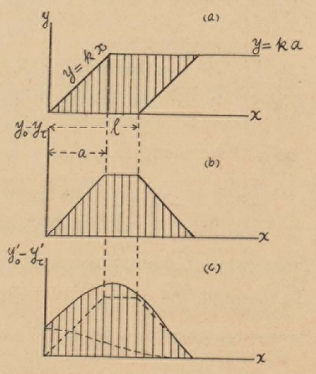


Fig. 22. Shematic Representation of the Yearly Amplitude Caused by the Movement of a Discontinuous Boundary

$$\left.\begin{aligned} \Phi = f(x) &= kx + c \quad (a > x > 0) \\ &= ka + c \quad (x > a) \\ &= c \quad (x < 0) \end{aligned}\right\} \tag{7}$$

we can obtain easily by geometrical procedure as shown in Fig. 22 b,

$$\left.\begin{aligned} \Phi_0 - \Phi_\tau &= kx \quad (a > x > 0) \\ &= ka \quad (l \geq x \geq a) \\ &= ka - kx \quad (l + a > x > l) \end{aligned}\right\} \tag{8}$$

Though in the above discussion we have considered the form $\Phi = f(x)$ constant for time, generally we should consider it as a function of time. Therefore, the total variation is the sum of variation due to simple displacement of front and the time-variation at that place. We have

$$\Phi_0' - \Phi_\tau' = \{(f_1(x) - f_1(x-l)\}_{t=0} + \{f_2(x, \tau) - f_2(x, o)\} \tag{9}$$

where the second term means the factor due to the solar radiation and increases the value from south to north in actual case. (See Fig. 22 c).

(2) The examples of observation for the displacement of "Siome."

(a) Passage of "Siome" as a boundary between different water-masses.

(No. 1) At p. m. 1.30 on May 29, 1929 during the anchorage of "Sōyō-maru" in the Tateyama Bay the author found the appearance of a conspicuous "Siome" stretched from Daibōzaki to Takanosima.(72) The line

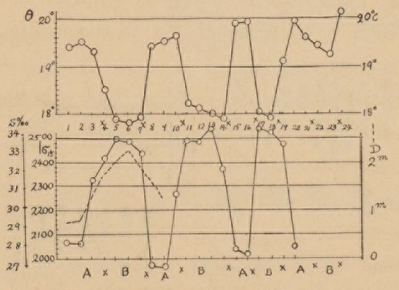


Fig. 23a. Observation of "Siome" associated with the spring of Water Temp. (θ), Salinity (S), and Transparency (D) in the Tateyama Bay during p. m. 1.50–2.20 on May 29th, 1929.
(× ....the time across the "Siome")

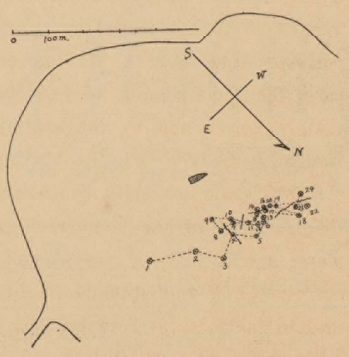


Fig 23 b. Observation of "Siome" in the Tateyama Bay.

(72) 宇田道隆: 潮目現象の觀測に就て,「海と空」第 9 卷, 第 11 號, 1929, p. 78.

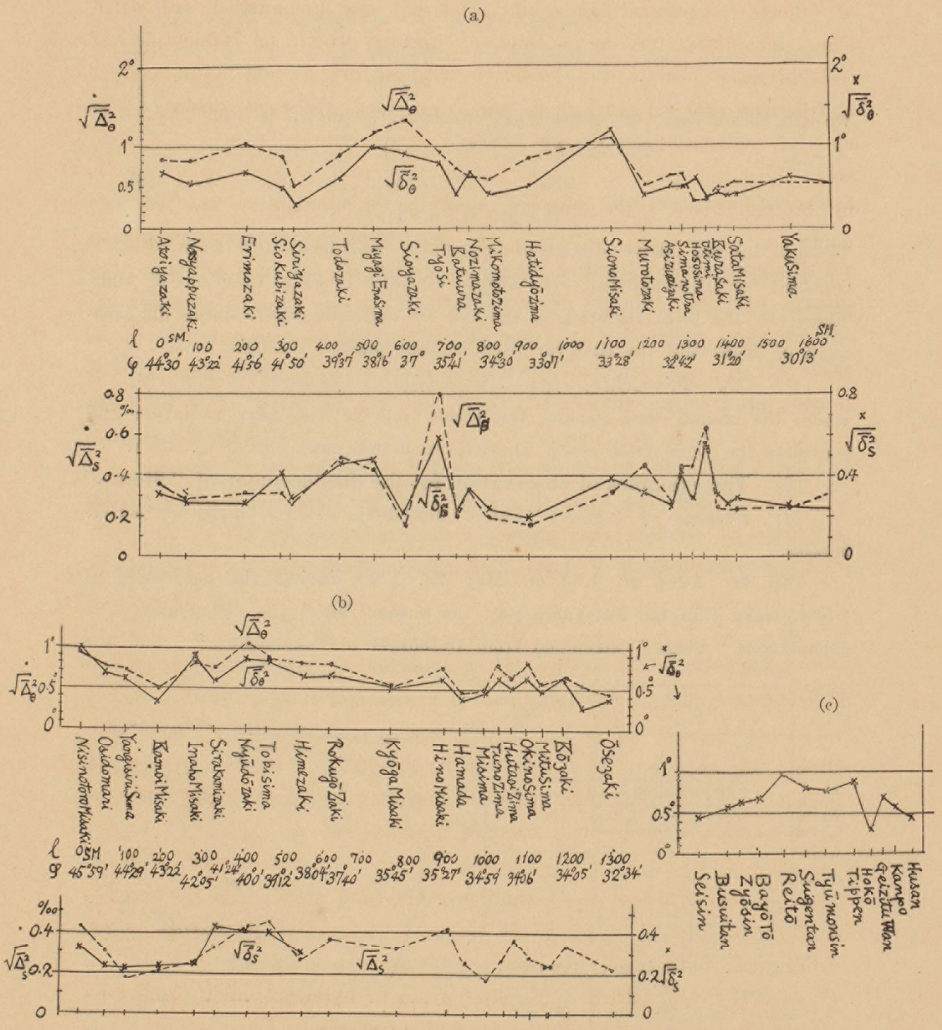


Fig. 24. Fluctuation of Water Temperature and Salinity during about Twenty Years.

(As to $\sqrt{\Delta\theta^2}$, $\sqrt{\Delta s^2}$, $\sqrt{\delta\theta^2}$, $\sqrt{\delta s^2}$ see p. 368 in text.)

(a) Along the Coast of the Pacific Side of Japan.

(b) Along the Coast of the Japan Sea on the Japan Proper Side.

(c) Along the Coast of the Japan Sea on the Tyōsen Side.

of "Siome" continued like a oily band and was accumulated with drift-algae and dusts, forming a band of breadth 0.5 m. on "Siome" and corresponding just to the boundary between the oceanic water-mass of bluish-green colour disturbed by wind-waves and the calm coastal water-mass of yellowish-green colour clearly. Moreover, the band of "Siome" was moving from coast to offing with a velocity about 0.8 knot. Immediately, by the motor-boat the author undertook the observation across "Siome" going and returning several times and obtained the result shown in Fig. 23 i. e. a marked difference of water-temperature about 2°C and salinity 6.5‰ across "Siome."

The "Siome" was probably produced by the convergence in the upper layer of two currents i. e. between the oceanic water of comparatively low temperature, transparent and high salinity driven by the SW.-wind into the bay and the coastal turbid water flowing out from the bay by the ebb-current.

(No. 2) During the current measurement in the Ōsaka Bay on board of "Syunpūmaru" on June 4 and 8, 1928 K. Hidaka (1930) found an abrupt change of water-temperature amounting to about 2°C on the self-recording thermograph with the passage of "Siome" accompanied by drifting-straw and wood etc. and concluded the displacement of the vertical surface of the thermal discontinuity.[73]

(No. 3) G. Thiel has reported the sudden change of the current in direction from 56° to 356° and in velocity from 0.5 knot to 0.9 knot at the transit of "Siome" as the line of convergence passed by the anchored ship without the change of water-temperature and the running direction of "Siome" just in coincidence with the direction of the resultant force of the forces worked on the both sides of "Siome."[64]

(No. 4) By the accurate current-measurement H. Rauschelbach (1931)[39] has reported the abrupt change of the velocity and direction of the currents on both sides of a moving "Siome" noted as a band of foams on the sea surface and shown an obvious line of convergence.

(3) Relation between the fluctuation of hydrographical conditions and the displacement of the surface of discontinuity.

(73) K. Hidaka. Jour. of Oceanography, Kōbe. Vol. I. No. 3. 1930. pp. 190-192.
(64) l. c. p. 358. (34) l. c. p. 312.
(74) 岡田武松: 本邦の年平均氣溫の不同に就て, 天氣と氣候. 第 3 卷, 1936, p. 196.

As to the period of the cycle of the fluctuation in the hydrographical conditions year by year, it is not yet distinct today.

Considering the case of statistical fluctuation, after the investigation of air temperature by T. Okada,[74] as a measure of deviation we may adopt

$$\sqrt{\overline{\delta^2}}=\sqrt{\frac{\sum(\text{the value in some year}-\text{that of normal year})^2}{\text{the number of the statistical year}}}$$

$$\sqrt{\overline{\Delta^2}}=\sqrt{\frac{\sum(\text{the value in some year}-\text{that of the preceding year})^2}{\text{the number of the statistical year}}}$$

and evaluated them for the water-temperature and salinity in the adjacent waters of Japan (Fig. 24).

Examining in Fig. 24, on the Pacific side we recognize a maximum of fluctuation in the region along the coast of Miyagi and Hukusima Pref.

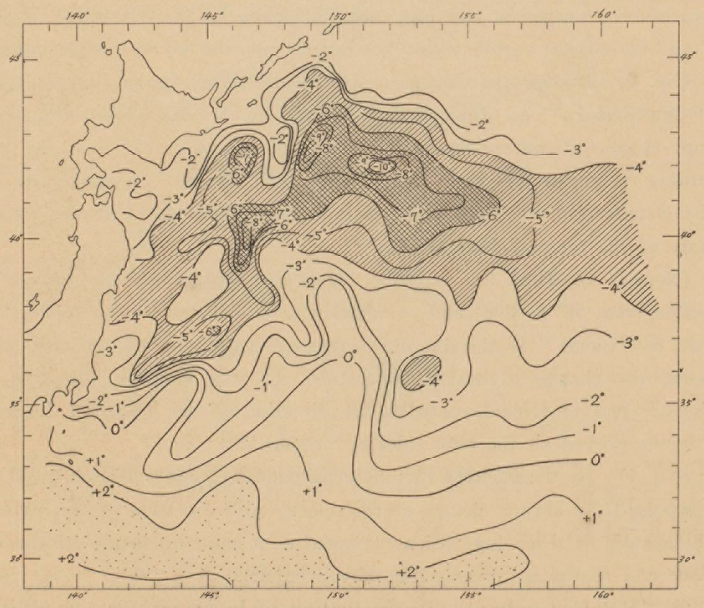


Fig. 25. Distribution of the Difference of Surface Water Temperature in August, 1933 and that in August, 1934.
(+ means the water temperature in 1934 higher than that in 1933 and − vice versa.)

and in the neighbourhood of Erimomisaki corresponding to the interchange between the water-masses belonging to Kurosio and Oyasio and also that of

Tugaru Current and Oyasio. On the other hand on the Japan Sea side in the zone nearly the same latitudes a maximum of fluctuation is met with in the sea adjacent to Pref. Akita and in the sea adjacent to Kankyō-Nandō respectively.

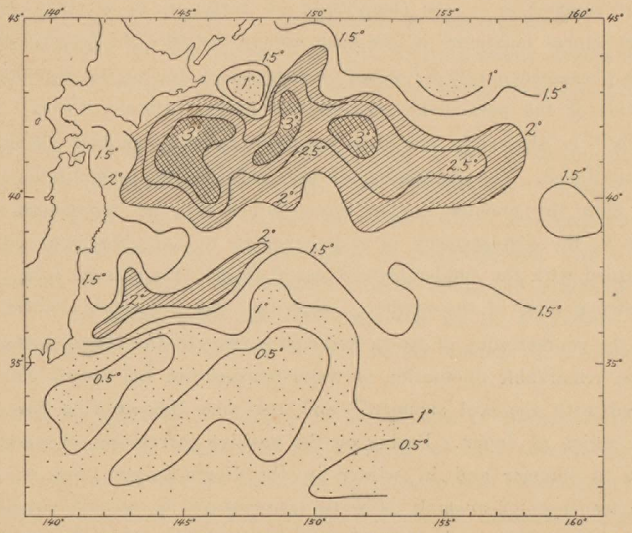


Fig. 26. Distribution of Yearly Fluctuation of Water Temperature in the North Pacific Ocean Computed for the Surface Water in August during the Five Years from 1933 to 1937.

Next, investigating the data got by the off-shore observation, as we see in Fig. 25 that the difference of water-temperature in the North Pacific Ocean in August, 1934 (abnormaly cold year) compared to that in August, 1933 (abnormaly warm year) shows its maximum zone around the line of discontinuity off the coast of Aomori, Iwate and Miyagi Pref. Again, examining the distribution of fluctuation $\sqrt{\overline{\delta^2}}$ of water-temperature in August during the five years from 1933 to 1937 its maximum is found on the zone around the line of discontinuity as indicated in Fig. 26 distinctly. The results of the investigation for the amplitude of the variation of water-temperature and salinity in a normal year is nearly the same as above mentioned.[27][28]

(27) (28) l. c. p. 312.

Similarly, regarding to the maximum of the yearly fluctuation of water-temperature for each four seasons respectively, the results of investigation were also nearly the same. The seasonal change of water-temperature (from winter to spring and so on) and the change of water-temperature from winter to summer in a year (amplitude of variation in a year) are also found to appear maximum in the zone around the line of discontinuity.

The phenomenon called "oceanic transgression due to the expansion and contraction of the permanent water-masses in the Atlantic Ocean" by E. le Danois[75] is ultimately put into the same category as the phenomenon above mentioned. The fluctuation of the hydrographical conditions accompanied with the moving line of discontinuity e.g. the water-mass corresponding to the displacement of tidal current or the movement of front accompanied with the sudden meteorological change (the passage of a cyclone or the strong blow of the southerly wind etc.) can be treated similarly.

In the contact zone of warm and cold current in the North-Eastern Sea of Japan remarkable fluctuation of water-temperature and oceanic current is correlated with the cool summer[76] and the poor rice crop in the North-Eastern region of Japan. Basing on the positive correlation of water temperature in summer and in winter in the North-Eastern Sea of Japan and the transport of anomaly of water-temperature by oceanic current, we are now able to forecast in some degree the displacement of the surface of discontinuity in that sea-region i.e. the yearly fluctuation of water-temperature in summer at a time preceding half a year.[75][38]

Summary and conclusion. The distribution of "Siome" in the adjacent waters of Japan is usually found in the region around the line of discontinuity for the water-masses and currents, and particularly notable in the contact zone of cold and warm current in the North-Eastern Sea of Japan.

The wavy form of the line of discontinuity including "Siome" is its characteristic correlated with the vorticity around "Siome" and the vorticity is usually proportional to the degree of discontinuity.

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(75) E. le Danois. Les Transgressions Oceaniques. Rev. Trav. Office des Pêches Marit. T. VII. Fasc. 4. Paris 1934. pp. 359～469,

(76) 岡田武松: 改稿第二版「氣象學」第 2 卷 1935 pp. 236～243.

(77) T. Okada. Note on the Correlative Oscillations of the Surface Water Temp. of the Oyasio and the Kurosio. Mem. Imp. Mar. Obs. Vol. VI. No. 2. 1936.

Evaluating Rotation and Convergence in the Pacific Ocean, in the Japan Sea, in the Wakasa Bay and in the Sagami Bay, we have recognized that the line of discontinuity running through the neutral boundary between the positive and negative rotations and that the distribution of "Siome" coincides in most cases with the distribution of Convergence.

With regard to the accumulation of drifting-bodies associated with "Siome" as an ordinary feature of it, discussion was given to the mechanism of it.

By longitudinal and lateral sections of the surface of discontinuity the three-dimensional structure of "Siome" was inferred i.e. "Siome" at the line of convergence appeared on the sea-surface which was constructed by the spiral stream-lines, may be considered to resemble well with a doublet as a couple of positive and negative vortex (sink and source in hydrodynamics). It agrees with the fact remarked by S. Fujiwhara that a "Siome" consists of a chain of vortices as its nucleus in a elongated S-form.

Special consideration has given to the surface of discontinuity in the North-Eastern Sea of Japan and the creeping of cold current under the warm water was proved by the facts of intermediate (dichohaline) water, dichotherm water and the vertical distribution of dissolved oxygen and current-velocity with the computation of inclination of the surface of discontinuity and the ratio of "Austausch" to current velocity in the Oyasio Current.

Summarizing the oceanographical observations of "Siome" and the experimental studies about it, the author discussed on the nature of "Siome" and classified "Siome" into three kinds, namely the "Siome" of the first kind caused by pure convergence, the "Siome" of the second kind caused by convergence due to upwelling (divergence), and the "Siome" of the third kind caused by the strong current, so to speak apparent "Siome", corresponding to the discontinuity of water-masses in the sub-surface layer. The dependent features of "Siome", ripples and breakers on "Siome", noisy sound, oily patch etc. were explained in the developing stage of "Siome".

The frequent occurrence of "Siome" in relation to the bottom configuration, particularly on the margin of the continental shelf was mentioned in connection with its mechanism.

Lastly the actual examples of the moving surface of discontinuity including "Siome" and the accompanied change of hydrographical conditions were discussed and shown in the adjacent waters of Japan.

By the present study we have some progress in the nature and the mechanism of "Siome" or current-rip in the seas and oceans than ever and are able to find a broad application in the field of fisheries and agriculture etc. However, several unsolved problems are remained in future i. e. on the distributions and the features of "Siome" modified by the various topographical (coastal and bottom) configuration and the optical, acoustical, also hydrodynamical properties associated with "Siome" on the lines of experimental and theoretical researches and the problem of lateral mixing of water-masses on the line "Siome".

In conclusion, I wish to express my hearty thanks to Dr. T. Okada, and Prof. Dr. S. Fujiwhara, who gave me many kind advices and kindly read through the paper, and to late Prof. Dr. T. Terada and Dr. M. Tauti who have first given the present problem and guided the experiment about it with zealous encouragement, also to Dr. K. Hidaka and Mr. M. Okada who gave me many useful instructions and advices during the course of investigation.