BELT OF SALT WATER IN THE NORTH-WESTERN JAPAN SEA

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Introduction

The Japan Sea is located at the edge of the Asian continent, but it is a typical mediterranean sea because it is connected to boundaring seas only through shallow straits. Features of sea water of the Japan Sea (as against, for example, the Okhotsk Sea) are high contents of dissolved oxygen and low temperature of deep (below 300 m level) waters.

These features are observed during long period of time, therefore deep waters should be updated enough frequently and in large enough volume. Volume of deep water mass is about 85% of all water of the Japan Sea. And their characteristics change in very narrow limits: temperature from 0 °C up to 1 °C; salinity – from 34.05 psu to 34.08 psu.

The search of a place and mechanism of deep water formation dates back about 20 years already. Among places of its probable formation were specified the Peter the Great Bay, Tatar Strait and coast of Primorye province (Nitani, 1972; Vasiliev & Makashin, 1992; Wakatsuchi, 1996). As below 300 m level the sea is isolated from the surrounding seas, it was supposed that deep water mass was formed inside the sea by the salting of surface waters during ice formation. Surface water temperature in winter in the northern Japan Sea falls even below the temperature of these deep waters (up to -1.7 °C), but, except for in small bays, the salinity of coastal waters during ice formation does not rise more than 34.00 psu. Therefore, deep water cannot be updated by the salting of coastal waters during ice formation, as affirmed earlier (Nitani, 1972). The exact place of deep water formation is not found until now.

Except deep water in the Japan Sea 5 other waters are known: 2 surface waters, subsurface water of high salinity (Tsushima water), subsurface water of low temperature and intermediate water of low salinity. In cold northern and warm southern parts of the sea surface waters differ by temperature. Subsurface water of high salinity is brought into the sea by the Tsushima Warm current. Intermediate water of low salinity and cold subsurface water are formed in the Japan Sea.

Intermediate water of low salinity has been known for a long time (Miyazaki, 1953; Kajiura *et al.*, 1958), but in the Russian publications (for example, Leonov, 1960; Yakunin, 1989) it is not reflected. Cold subsurface water is known in all places where ice is formed in winter (for example, in the Okhotsk Sea and east of Kamchatka peninsula). Cold surface water, with the beginning of the summer warmth sinks, continues to exist during that whole season. In the Japan Sea this water recently, but only in Tartar Strait (Pogodin & Shatilina, 1994; Zuenko, 1994). Sometime it is possible to meet opinion that this water is absent in the Japan Sea (Zuenko & Yurasov, 1995). It is possible that such opinions are based on the fact that this water was not found in summer in the north-western Japan Sea. This contradiction that in winter in the north-western Japan Sea, ice is formed in noticeable volumes, but in a summer the cold subsurface layer is absent is not explained yet.

The study of water formation is closely connected to research of currents, as it is considered, that the distribution of water of the sea occurs by currents. As waters are referred to as homogeneous waters of large volume, it is useful to consider the existing representations about large-scale (spatial scale of 60 miles, and temporary scale – 1 month) currents – Fig. 1.

The Liman Current is usually shown as a continuous flow along the whole north-western coast of the Japan Sea (Sugimoto & Tameishi, 1992; Holloway *et al.*, 1995) or as some separated currents (Uda, 1934; Yarichin, 1982). But it is considered always as flow of cold and fresh water.

Between surface cold waters (in the northern part of the Japan Sea) and warm waters (in the southern part) one surface thermal front is considered only (Uda, 1952; Sugimoto & Tameishi, 1992).

Between the Liman Cold Current and Tsushima Warm Current in the area south of 46°N, in these papers stated the absence of any connection. Moreover, two extended zones were shown, interfering with any water exchange between them (Yarichin & Pokudov, 1982).

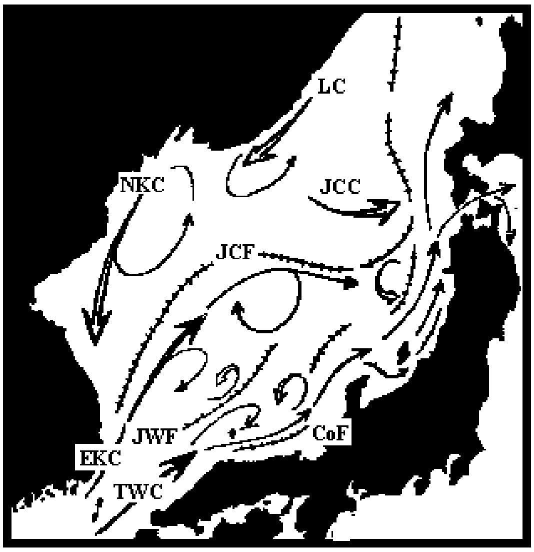

Fig. 1. Surface thermal fronts and currents of the Japan Sea (Uda, 1952)

Based on these schemes of currents it is not clear how to explain the frequent occurrence of subtropical fishes near Possiet (Rumyantsev, 1951) and concentration of flounder in winter to the south-east of Vladivostok. (Moiseev, 1946). The penetration of warm subtropical waters to Peter the Great Bay was explained by the chain of warm eddies along 131°E (Danchenkov *et al.*, 1997b). In this paper the explanation of another case is given.

The Data

The data resulting from the following winter expeditions have been used in this study: March 1-6, 1995; February 17-24, 1996; March 20 – April 7, 1997; February 22 – March 8, 1999.

The accuracy of measurements (CTD SEA-BIRD 911+) on the order was higher (0.001 °C on temperature and 0.0003 psu on salinity) than previous data of soviet time. The distribution of stations is given in Fig. 2.

Almost all stations were located in Russian economic zone. To obtain the permission to work in North Korean and, in the last years, Japanese economic zones, was nearly impossible. This difficulty regarding working in certain regions made it impossible to trace the connection of Tsushima current waters and waters near continental coast in detail. The area of research was limited from the west to the Korean economic zone (approximately on 131.5°E.), from the east – 137°E, and from the south – by 40°N.

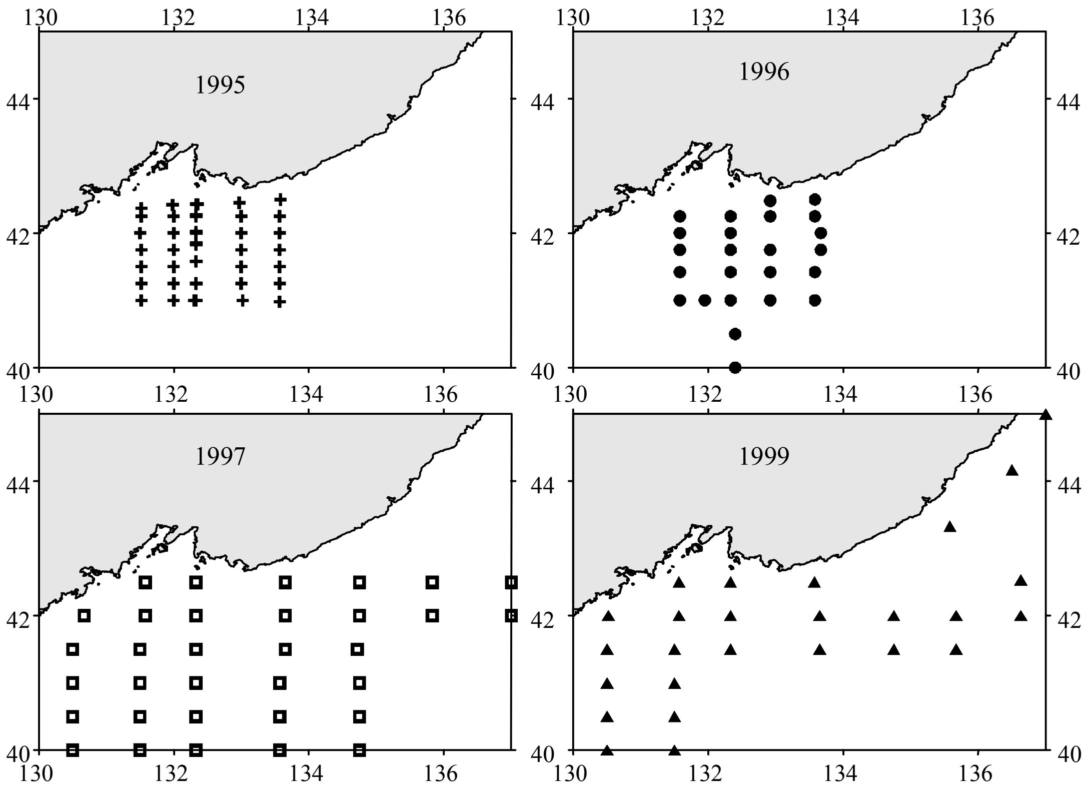

Fig. 2. Positions of oceanographic stations (winters of 1995-1999) used in this paper

The North-Western Thermal Front

Features of temperature distribution (Fig. 3, 4) are recently described for the North-western thermal front between points with coordinates 42°N, 131°E and 41°N and 133.5°E (Danchenkov *et al.*, 1997a). The large-scale area of cold water to the north is limited on the surface by 2 °C isotherm.

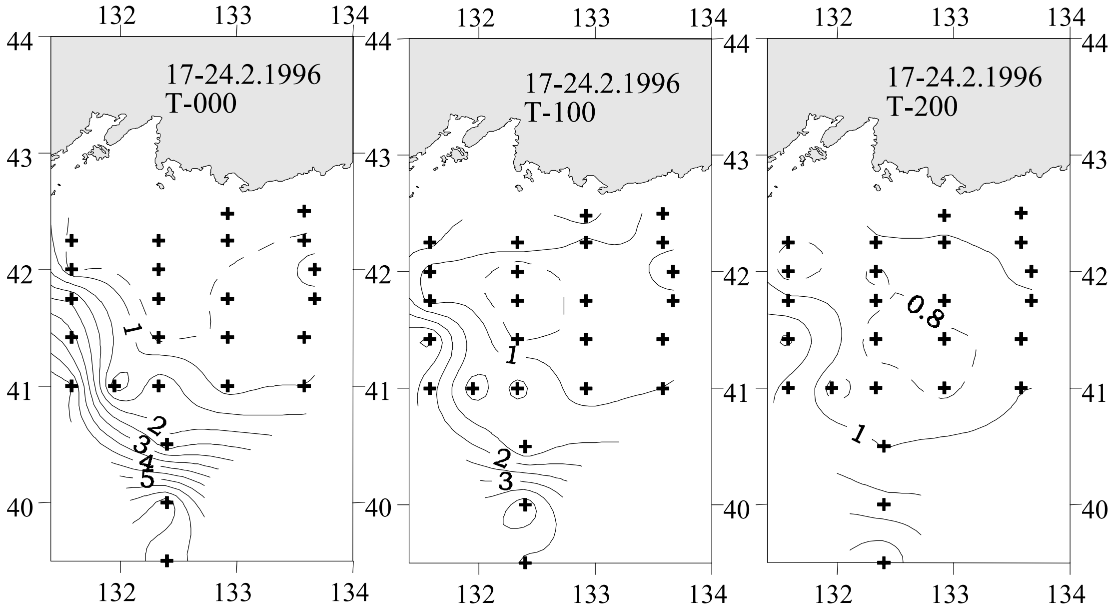

Fig. 3. The North-western thermal front at the surface, 100 m and 200 m levels in winter of 1996

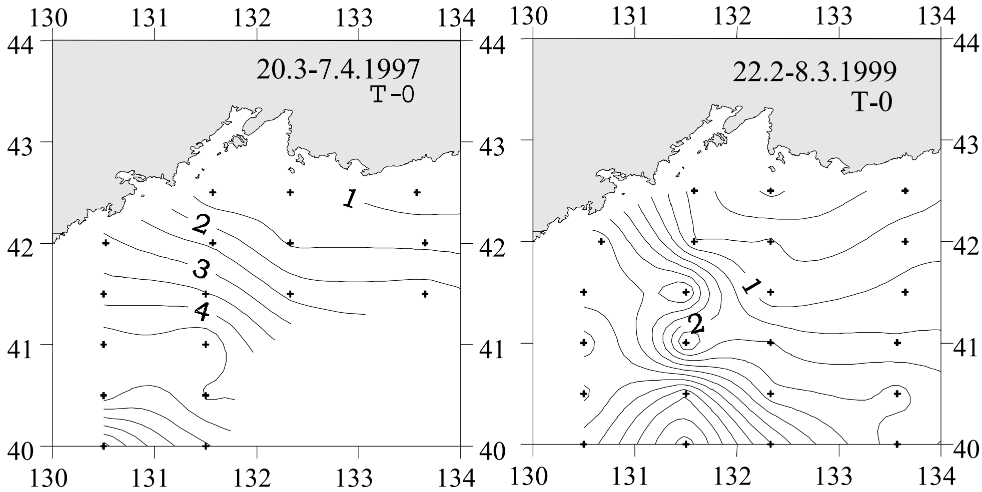

Fig. 4. The North-western thermal front at the surface in winters of 1997, 1999

This front is not a well-known Polar front that is usually picking out along 40°N (Isoda, 1994), but it is the special front between cold subarctic waters from the north and mixed waters from the south.

By isotherms along this front it is impossible to trace any connection between waters along Primorye coast and waters along North-Korean waters. In other words, we could not trace any marks of the so-called North-Korean Current in winters of 1995-1999.

In spite of the large spatial sizes of a zone of cold water, its center can be attributed to area to the south of Peter the Great Bay, where area of surface waters with negative temperature is the most extensive. From this area, cold waters are distributed under the influence of strong winds to the southeast, supporting North-western front from the north. From the south, the North-western front is supported by subtropical waters (Danchenkov *et al.*, 1997b).

The width of the thermal front at the surface (between 1 °C and 4 °C) is about 30 miles. In the North-western part, the front's width is less than in the south-eastern part.

On a section crossing the North-Western front on 132.3°E it can be seen that the North-Western front is an output on the surface of basic thermocline – Fig. 5.

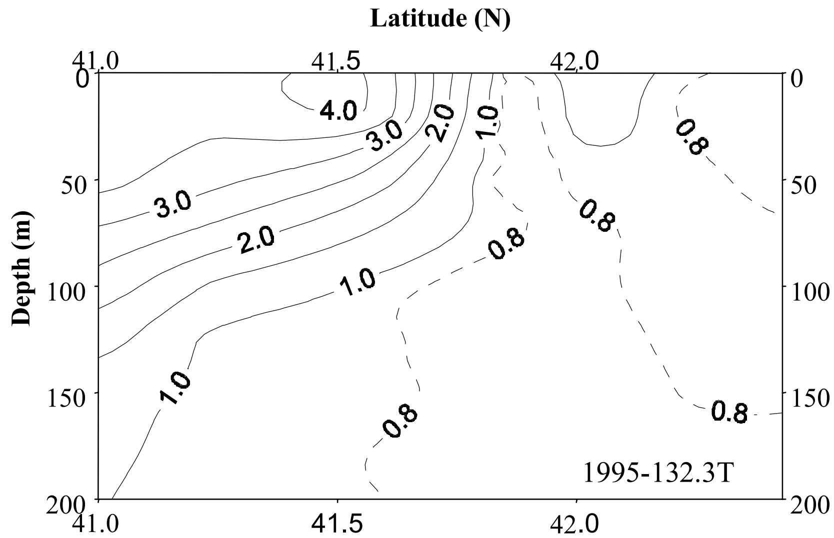

Fig. 5. Distribution of water temperature on 132.3E in March 1-6, 1995

To the south of the front water temperature climbs up to 8 °C, and to the north temperature can be considered constant (0-1 °C). Only along the coast the water temperature decreases to the water freezing temperature (approximately -1.7 °C). The spatial gradient of water temperature across the front is about 0.1 °C on 1 km.

Belt of Salty Water Along 42°N

Salinity of coastal waters in Peter the Great Bay is always characterized by low salinity (less than 34.00 psu in winter and less than 33.80 psu in summer). Because of this along the entire coast there is a salinity front, limited on the surface by 33.90 psu. This is demonstrated in Fig. 6.

Feature of a salinity field is a belt (tongue) of salty waters located between a continental slope and the North-western thermal front. It is limited on the surface by isohaline 34.00 psu, 34.02 (on 50 m), 34.04 (on 100 m) and 34.06 (on 200 m). Its core passes between 132°E and 133.5°E along 42°N.

From the north it is limited by coastal waters of low (less than 33.90 psu) salinity. The salinity inside the belt decreases from the east to the west. Therefore, it is possible to conclude that within the limits of this tongue the distribution of warm and salty waters occurs from east to west. In other words, between Hokkaido and Peter the Great Bay there is a flow of transformed subtropical water.

It differs from the known Liman current not only by temperature and salinity (in new flow it is much above), but also by position (Liman current was always shown as coastal flow).

Usually this salt water follows along 42°N up to the North-western thermal front. During the winter of 1997 it penetrated even into a shelf of Peter the Great Bay.

In the process of water transport from east to west, the salinity inside the belt (as well as the water temperature) lowered from 34.16 to 34.07 psu – Fig. 7.

From east to west in a core of the belt, the temperature decreased (in 1996 from 1.6 °C at 133.6°E up to 0.9 °C at 132°E), too. The width of the belt also decreased from east to west. The typical distribution of temperature and salinity on section crossing the tongue is submitted in a Fig. 8.

The isolated core of the belt (with temperature 0.8-0.9 °C and salinity more than 34.07 psu) settled down between the surface and the 300 m level. In winter of 1999 (Fig. 9) salinity in the core of belt was about the same (34.066 psu).

During winters from 1995 to 1999 measurements in Japanese economic zone couldn't be obtained. But the analysis of water temperature, salinity, density (Fig. 10), dissolved oxygen content (Fig. 11) and geostrophic currents near Hokkaido (Danchenkov & Aubrey, 1999) based on Russian data, shows that from Kamui Cape to the west during most part of any year there is a distribution of transformed subtropical water.

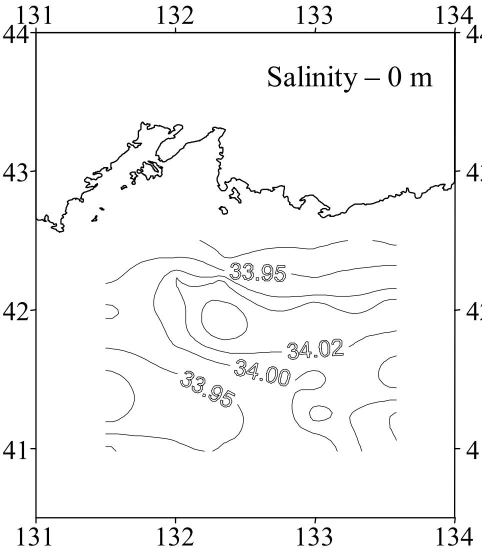

Fig. 6. Salinity at the surface and 100 m level in March 1-6, 1995

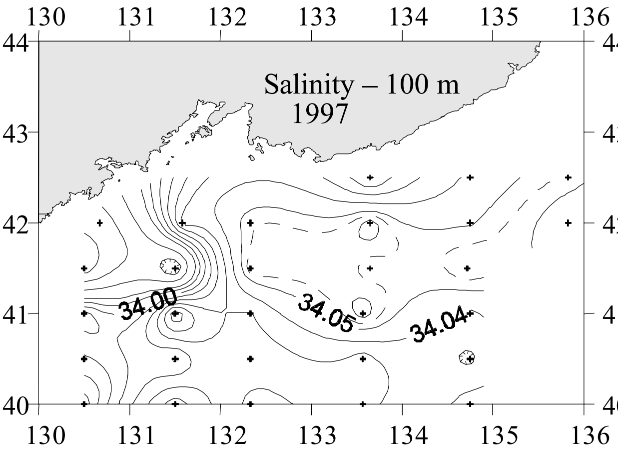

Fig. 7. Salinity at 100m level in winter of 1997 (up) and 1999 (down)

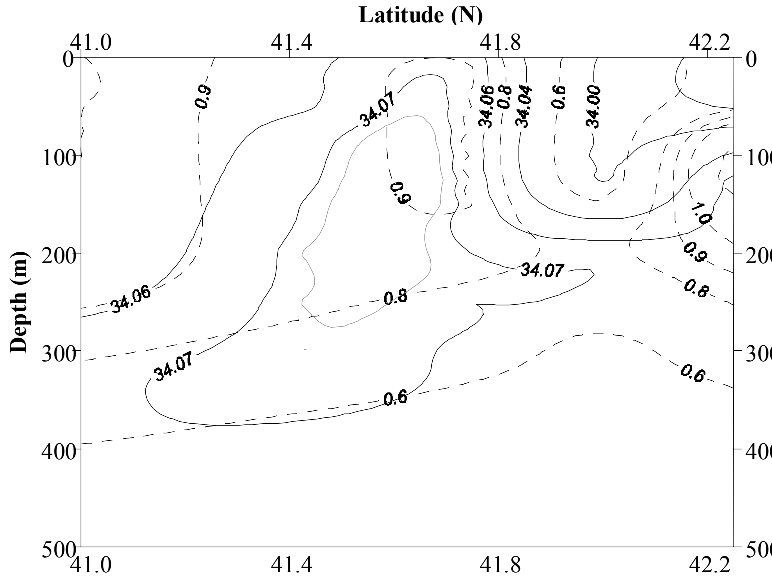

Fig. 8. Temperature and salinity on section between 41°N, 132.2°E and 42.°5N, 133.8°E in winter of 1996

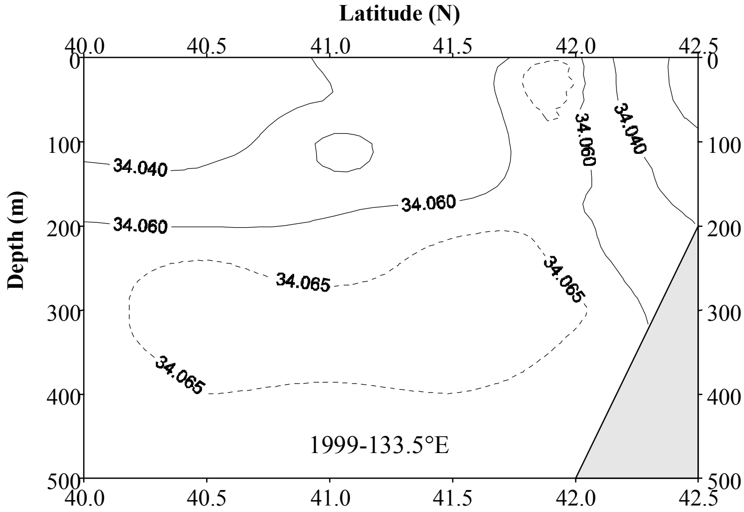

Fig. 9. Salinity on section 133.5°E in winter of 1999

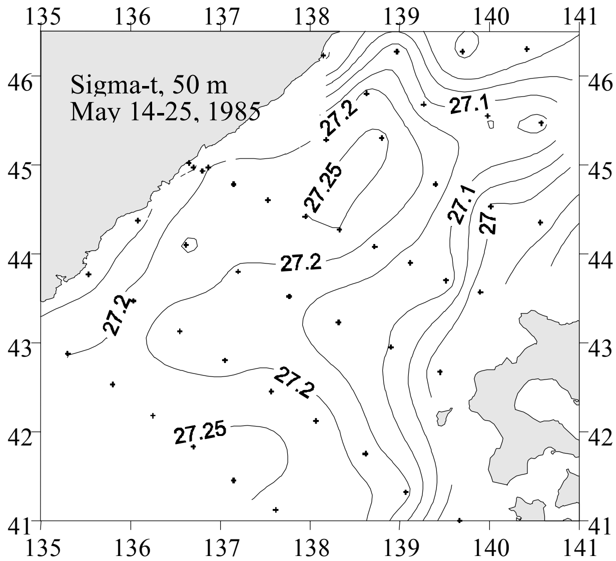

Fig. 10. Water density at 50 m level in May of 1985 (Danchenkov & Aubrey, 1999)

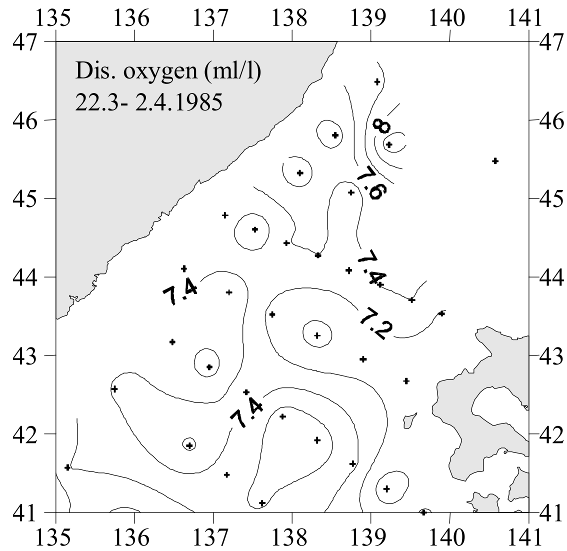

Fig. 11. Dissolved oxygen content at 50 m level in March of 1985

T(*S*)-Curves

On *T*(*S*)-curves, constructed for stations located on a section across the belt, two surface waters of a different origin differ.

One of them – water of low temperature and low salinity- represents coastal waters located to the north of the belt. These characteristics are almost the same despite that one of them (100 m depth) is allocated on the shelf and another one (720 m depth) is located on slope. Water of low salinity and high temperature is located near estuary of the Tumangan river. Surface water inside the belt has temperature a little higher and salinity – the same as characteristics of Japan Sea deep water. It allows to consider it as the source (one of sources) of deep water of the Japan Sea.

At sections 1crossed the belt (for example, in winter of 1995) temperature (0.2-0.7 °C) and salinity (34.05-34.08 psu) of surface water (41.8°N; 42°N) are consistent with the ones typical for deep water.

T(*S*)-curves of stations to the south of the belt are typical for warm subtropic water bordered North-western thermal front from the south. The deep water both to the south of the front, and to the north of it has the same values of temperature and salinity (0.2-0.8 °C; 34.06-34.07 psu).

During its transport inside the belt from the east to the west, temperature and salinity of transforming subtropical waters decrease (Fig. 12). The positions of stations in the Figure are marked by "+".

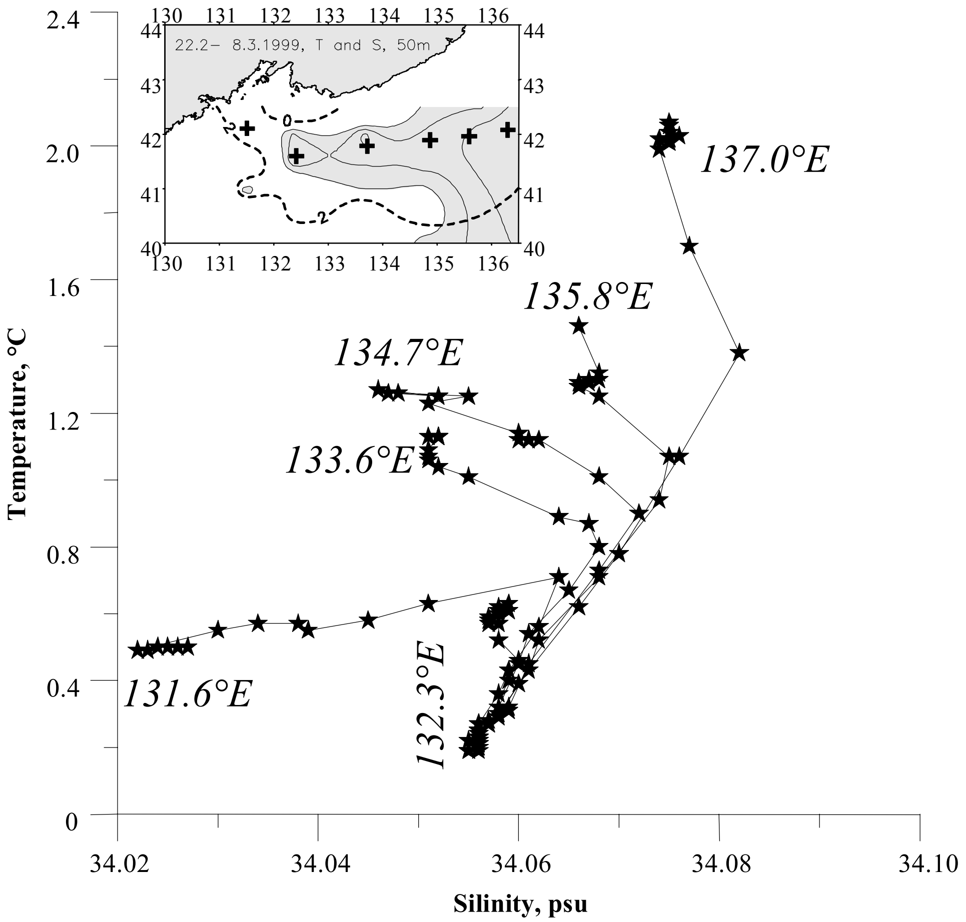

Fig. 12. T(S)-curves for waters inside the belt (winter of 1999)

Water temperature decreases from 2 °C to 0.5 °C and salinity decreases from 34.08 psu to 34.06 psu. Characteristics of the surface water change not only near the North-western front, but also along the whole way from 137°E to this front.

Discussion

The revealed distribution of salt water along 42°N allows to propose new mechanism of deep water formation. Warm water of the Tsushima current near Kamui Cape (Hokkaido) turns to the west forming a large-scale meander. Warm and salt waters from this meander are transported along 42°N to the North-western front. There the waters freeze the surface under the influence of strong offshore winds and mix with fresh and cold coastal water. Water temperature and salinity of subtropic water decrease and density increases to values typical for deep water. The newly formed water sinks to the surface of corresponded density. Water density typical for an area of deep water formation is presented in Fig. 13 and example of temperature and salinity distribution on the surface of equal density – in Fig. 14.

Surface of density 27.28 (on example of winter of 1997 – Fig. 14) is inclined to the south-west. Because of this a new water could penetrate from the surface in area of formation on deep levels in area of the North-western front.

At density level 27.32 (below 400 m) high temperature (more than 0.8 °C) and high salinity (more than 34.078 psu) were observed close to the coast but almost in the same place as at 27.28 level – Fig. 15.

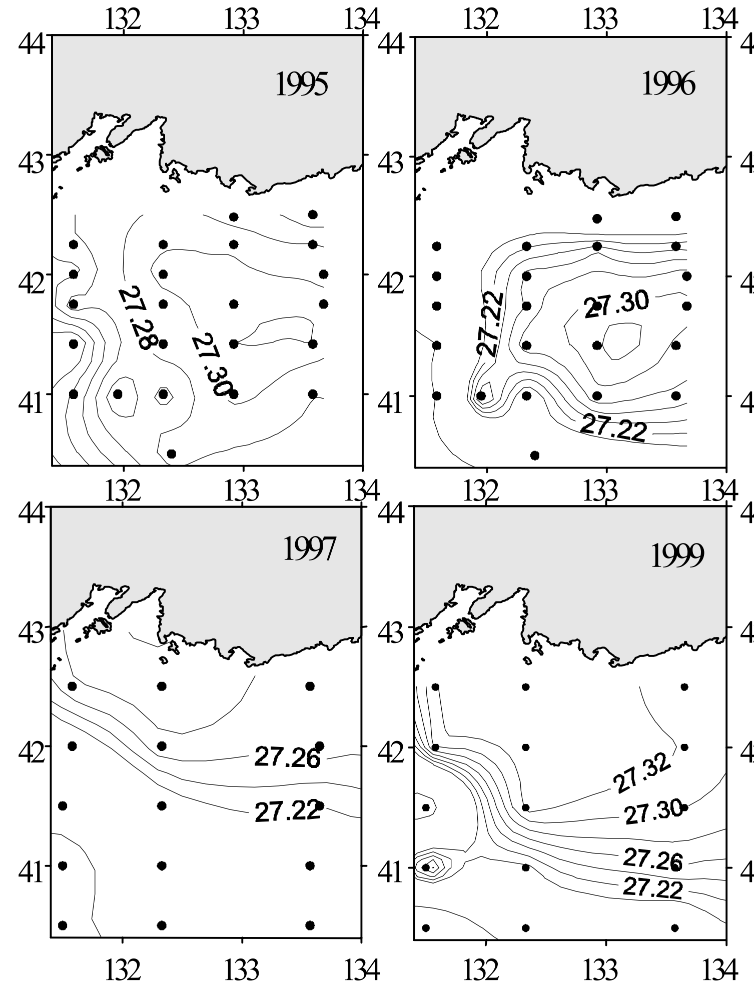

Fig. 13. Density of surface water in the north-western Japan Sea

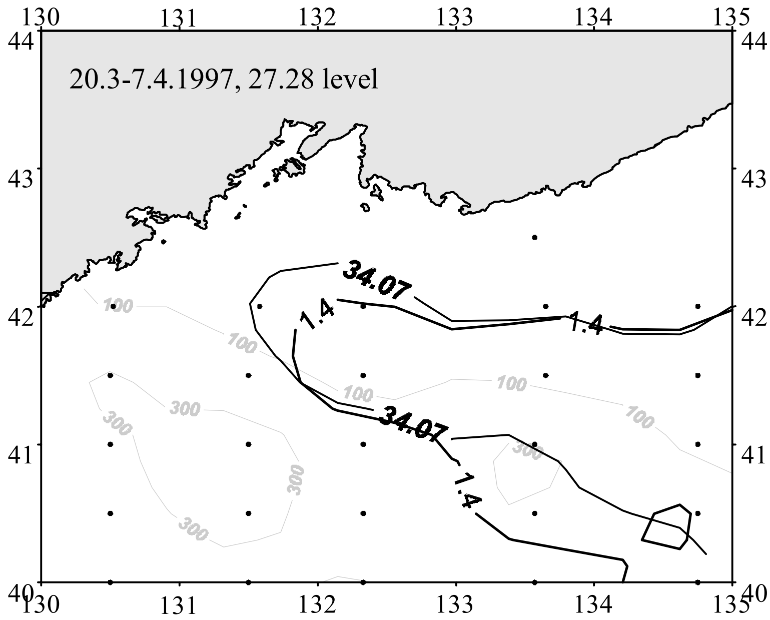

Fig. 14. Temperature and salinity on 27.28 density level and its depth in winter of 1997

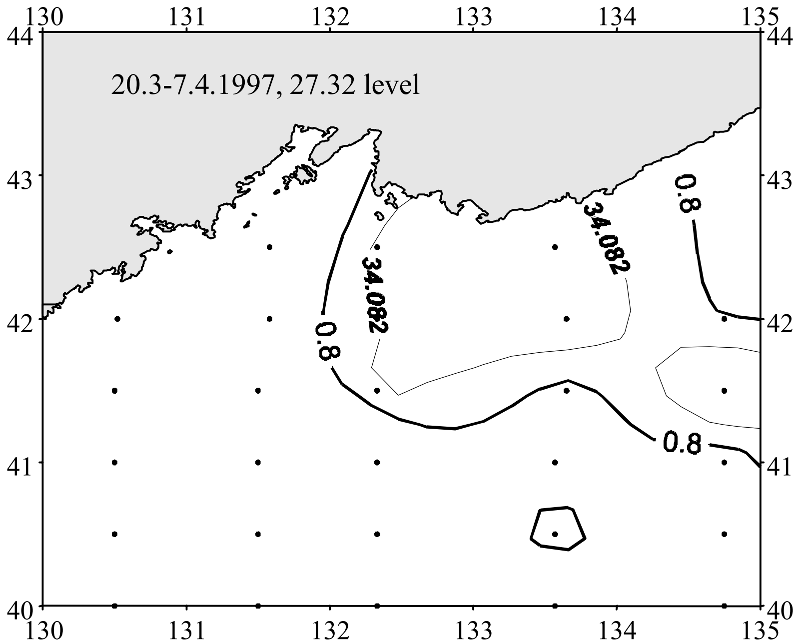

Fig. 15. Temperature and salinity on 27.32 density level in winter of 1997

The study of this belt of transformed water requires more time. But even now it is clear that this phenomenon is a unique feature of the Japan Sea. The distribution of these water characteristics allows to suppose existence of two new currents- westward along 42°N and south-eastward along the North-western front.

Conclusions

1) During winter, along 42°N in the Japan Sea, a belt of warm and salt water distributes from Hokkaido to the west.
2) Deep water of the Japan Sea is formed in process of the cooling of this water on the whole way from Hokkaido to the North-western thermal front.

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