RENEWAL OF THE BOTTOM WATERS OF THE KURIL BASIN IN THE SEA OF OKHOTSK

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The process of the bottom waters renewal in the Kuril Basin in the Okhotsk Sea was investigated much less than the process of intermediate water formation and still is not clear in detail. It is known that Kuril Basin water consists of Pacific water coming into the Okhotsk Sea through the Bussol Strait at the level of about 2300 m (Moroshkin, 1966). In cited paper K.V. Moroshkin supposed that observed increase in oxygen concentration in Kuril Basin of the Okhotsk Sea is explained by intensive water downwelling.

Yasuoka (1967) reported that oxygen increases in considered depth range toward the bottom and, therefore the lower oxygen is not due to stagnancy. He proposed that it could be explained by modification with deep oxygen-minimum layer waters and relatively fast renewal of the bottom waters.

S.C. Riser (1996) hypothesized that there is a deep inflow from the Pacific ocean through the Bussol Strait at depth of approximately 2200 m. Below that depth, the Okhotsk Sea waters are unventilated. By comparing oxygen and silica profiles in the Pacific ocean and the Okhotsk Sea near the Bussol Strait, Riser found that the Okhotsk Sea is lower in oxygen and higher in silica than the Pacific at depths of below the Bussol Strait sill. This is in agreement with the idea that this water originates in the Pacific ocean. In the deep Okhotsk Sea, it is suggested that the oxygen decreases due to biological consumption and the silica increases due to remineralization of silica at depth.

Freeland *et al.* (1996) presumed that the properties of the seawater in the Pacific ocean at depth of 2000 m and near the bottom in the Kuril basin are identical, and that deep water is freely exchanged across the Bussol Sill. From the fact of existing of strong steady slope of isopycnals with near bottom values of density entering the Okhotsk sea on the section P1W through the Bussol Strait and the absence of return flow he concluded that the survey actually caught a deep water replacement event in the action.

Actually, the vertical distribution in hydrographic and hydrochemical properties in the Kuril Basin shows slight monotonic increase of oxygen concentration and salinity and monotonic decrease in potential temperature from deep waters to the bottom (~2500-3400 m). This can indicate a degree of bottom water ventilation with cold waters containing more oxygen.

New information concerning this question was obtained during the cruise of R/V "Marshal Gelovany" on joint Russian-German project "Kuril & Okhotsk Sea Marine Experiment" (KOMEX) in August-October, 1999 (Fig. 1). Due to broad scientific objectives of geological, geochemical, paleoceanological, hydrological investigations of this project, all CTD stations were performed down to the depth of 5-10 m above the bottom. The probe used was SeaBird 911 with oxygen and transmissivity sensors and SeaBird 32 twelve position Rosette system with 10 one liter Niskin bottles.

On station 6 (Fig. 1) carried out in the Kuril Basin the positive anomaly of oxygen content (84-88 μM/kg) in comparatively thin (~90 m) near bottom layer has been revealed. This anomaly corresponds to the potential temperature anomaly in mixed layer with potential temperature of 1.6025 °C and thickness of 30 m, which is less than potential temperature of waters above by 0.005 °C (Fig. 2).

The vertical distribution of hydrographic and hydrochemical properties in Kuril Basin deep and bottom waters (Fig. 3) shows increase in oxygen and silicate concentration and salinity and decrease in potential temperature with increasing in potential density anomaly.

What is the reason of such anomaly and such behavior of water properties? Small thickness of temperature anomaly allows to make the following suggestions: this layer was formed recently (alternatively the near bottom mixing and heat transport would destroy it); process of supplying of dense water with higher oxygen content is continuing now.

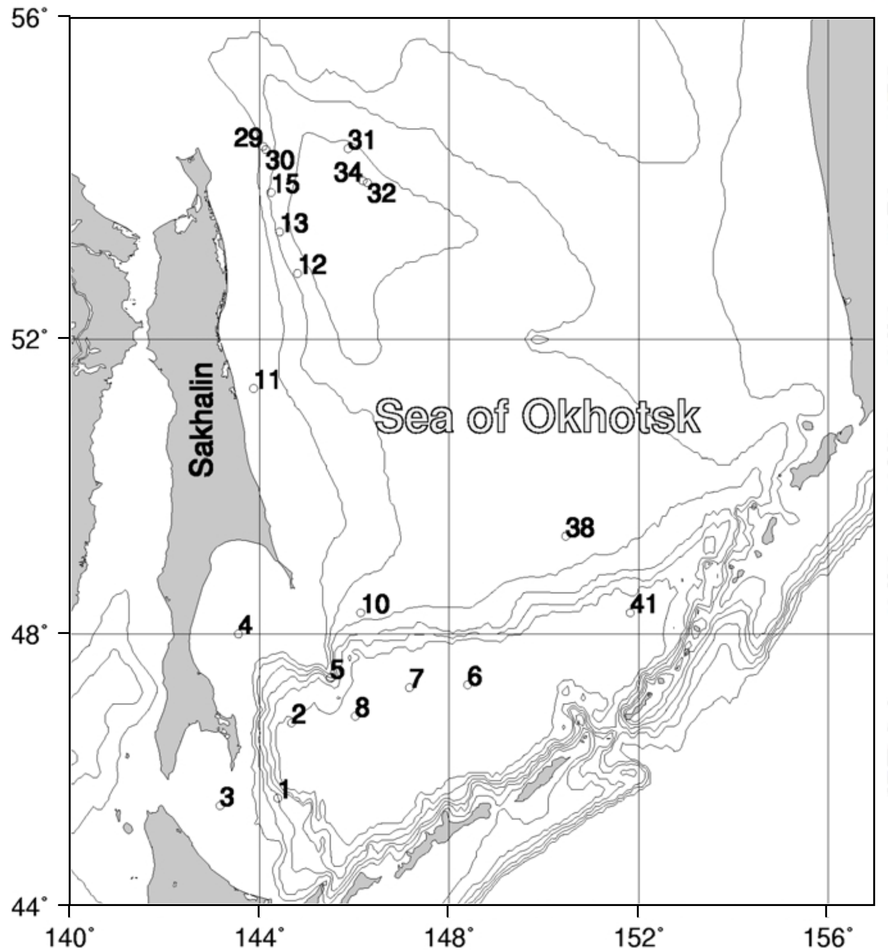

Fig. 1. Positions of CTD stations during the cruise of R/V "Marshal Gelovany" in August-October, 1999

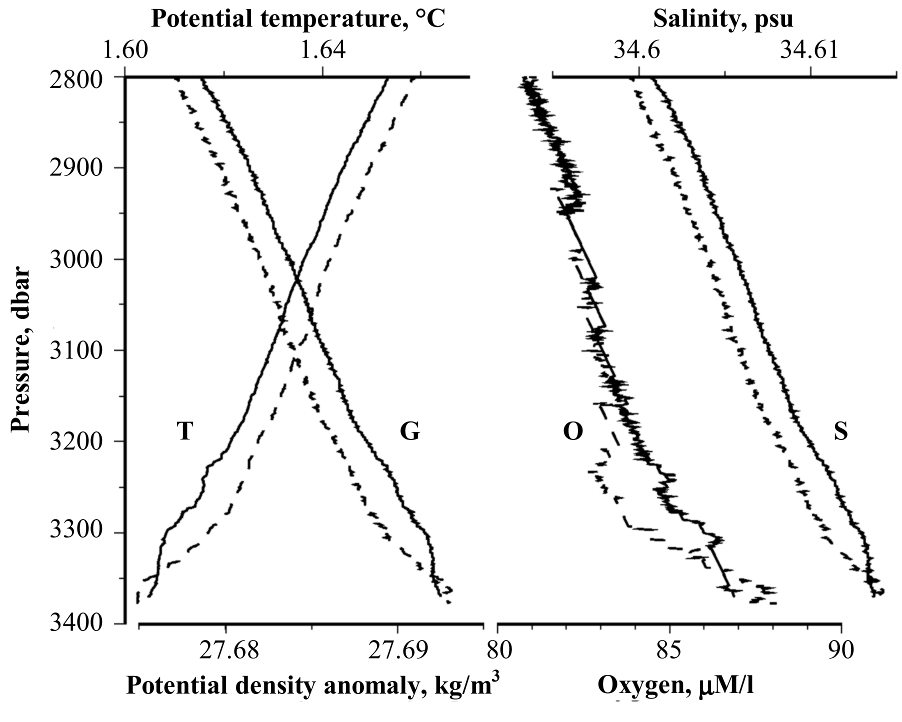

Fig. 2. Vertical distribution of potential temperature (T), salinity (S), potential density anomaly (G) and oxygen concentration (O) at stations 6 (dashed line) and 7(solid line)

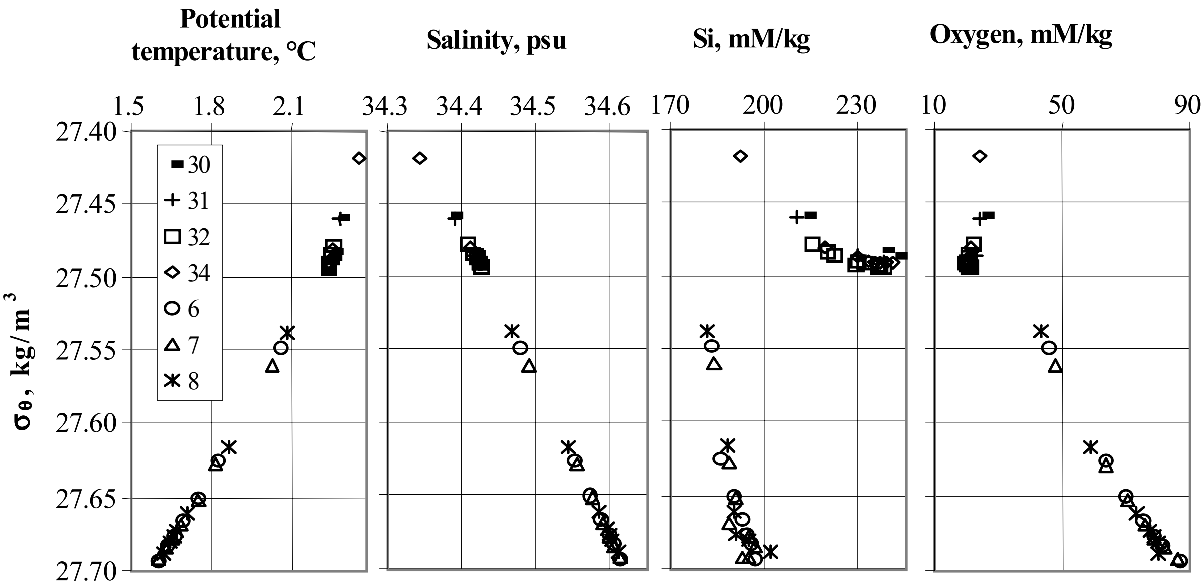

Fig. 3. Potential temperature (left), salinity, silicate and oxygen (right) versus potential density anomaly of deep and bottom water

The most probable source of this near bottom anomaly water is water of Pacific ocean entering the Okhotsk Sea through the Bussol Strait. This water could not come from the surface, because its density σ_θ=27.69 is significantly higher than possible density which is known to be observed as the result of modification of the surface water of the Okhotsk Sea (Talley, 1991). Besides that it has *higher* salinity and *lower* temperature than these of surrounding waters. If dense anomaly originated somewhere on the surface due to winter surface cooling it should have *lower* temperature and *lower* salinity than these of surrounding waters, like we observe in the Japan Sea bottom water anomalies near Primorye coast.

This density water supply cannot be permanent alternatively temperature, salinity, density gradients in Kuril Basin at the depth of about 2400-3400 m will be practically absent. However, hydrographic data show increase in density in this layer by about 0.03 σ_θ. Potential density anomaly at the level of the deepest sills in the Okhotsk Sea of about 27.6. The Bussol Strait is about 2300 m deep and allows free passage of water with densities σ_θ=27.65 (Talley, 1993). The maximum density observed over the sill of the Krusenshtern Strait (1920 m) was 27.634 (Zhabin & Gladyshev, 1998). In the Pacific ocean the depth of isopycnal 27.693 is found 200-300 m below the sill depth.

This means that anomaly dense waters can from time to time enter the Okhotsk Sea in certain periods due to seasonal and inter-year variability of water properties around the Bussol Strait. Abrupt topography changes in this area can significantly change the depth of potential density anomaly 27.7 by the intensive water dynamics in this region.

Episodic supply of dense water in the thin easily destroyed near bottom layer seems to play an important rope in bottom and deep water renewal in the whole Kuril Basin. Existence of new near bottom temperature, density and oxygen anomalies described above shows that near bottom layer is not a stagnant zone and that process of the near bottom water renewal in Kuril Basin is continuing now.

For explanation of water supplying scheme it is possible to use scheme of Yasuoka (1968) or Freeland *et al.* (1997) with additional comment that highest densities possibly may occur episodically only in certain time intervals: once a year or even during several years.

Estimation of the Renewal Time

We can roughly estimate the bottom water exchange time in the Kuril Basin applying vertical speed component value *W*, following Coachman *et al.* (1999), who did this for the Bering Sea deep waters in Aleutian basin (Central basin). Equation of *Silica Model* they used for the Bering Sea is:

$$U\frac{\Delta Si}{\Delta X}+W\frac{\Delta Si}{\Delta Z}=K_Z\frac{\Delta^2 Si}{\Delta Z^2}+Rb+Rw, \tag{1}$$

where the following parameters were estimated and accepted:

$Kz=6.8\cdot10^{-4}$ m^2/s – vertical eddy conductivity;

$U=4.2\cdot10^{-4}$ m/s – speed of flow;

$Rw=20\cdot10^{-10}$ μM/s – water column regeneration from diatom “rain”,

$Rb=82\cdot10^{-10}$ μM/s – sediment-water interface regeneration;

$W=2\cdot10^{-7}$ m/s=6.3 m/a – vertical advection speed component of flow.

It requires about 150 years for a parcel to move 1000 m upward with vertical velocity $2\cdot10^{-7}$ m/s. The renewal time estimation for Kuril Basin bottom waters has the same value as for Central Bering Sea bottom waters, obtained by Coachman, as we have there the same value ΔZ ~1000 m and apply the same W. As the volume of Kuril Basin below 2300 m estimated from ETOPO5 5 min topography data is about $1.5\cdot10^5$ km^3 this exchange time estimation lead to inflow of about 1 Sv of dense water per year for this simple one-dimension model. If we also take into account horizontal movement of water parcels, the renewal time should be a little higher and can be estimated as value about 200 years.

Another possibility to estimate the renewal time scale is to use tracer’s balance of supply to Kuril Basin new waters. In future we can refine the renewal time considering also silica flux from “diatom rain” and bottom remineralization rates on the basis of equation of silica balance shown above. Similar approach can be applied to the balance of oxygen supply and consumption. After finishing tritium/Helium-3 measurements of samples taken during the expedition this estimation can further be improved.

Conclusions

Observed near bottom oxygen and temperature anomalies and inclination of property/depth characteristics show that:

- process of supplying dense water with higher oxygen content is continuing now;
- Kuril Basin is not a stagnant zone;
- episodic supply of dense water in the thin near bottom layer seems to play an important role in the process of bottom and deep water renewal in whole Kuril Basin;
- simple estimation of the Kuril Basin deep water renewal time is about 200 years, and corresponding water supply for Pacific ocean into Kuril Basin is about 1000 km^3/year.

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