Thermocline distributions in the Kuroshio and adjacent regions

Kanehito TAKEUCHI* and Tadao TAKAHASHI**

Abstract

The topographic features of the thermoclines, i. e., the surface thermocline and the main thermocline, south of Japan in summer of 1966 are described on the bases of the results of CSK surveys. In this region, the surface thermocline can be found in the layer between 15 m and 35 m depths under a condition of wind velocity less than 15 kt during past 24 hours. Under a condition of wind velocity over 15 kt during past 24 hours, the surface thermocline can be found in the layer 5-10 m deeper than the case of weak wind. In the regions around 30°N, 130°E, 24°N, 130°E and 33°N, 139°E fairly large vertical temperature gradients reaching to 250 m are recognized. The currents corresponding to these thermoclines are assumed on dynamical bases, and the eastward current along the parallels of 23°N, 24°N and 25°N can be recognized in the layer above the surface thermocline, while the westward current can be recognized in the layer between the surface thermocline and the main thermocline. The most frequent value of the vertical temperature gradient for the surface thermocline exists between 12°C/100 m and 13°C/100 m and the frequency decreases gradually as apart from this value, and accounts for 30.9 % at a range from 10°C/100 m to 14°C/100 m. The most frequent value of the veitical temperature gradient for the marn thermocline exists between 2.5°C/100 m and 3.0°C/100 m, and the frequency accounts for 78.8 % at a range from 2.5°C/100 m to 3.5°C/100 m.

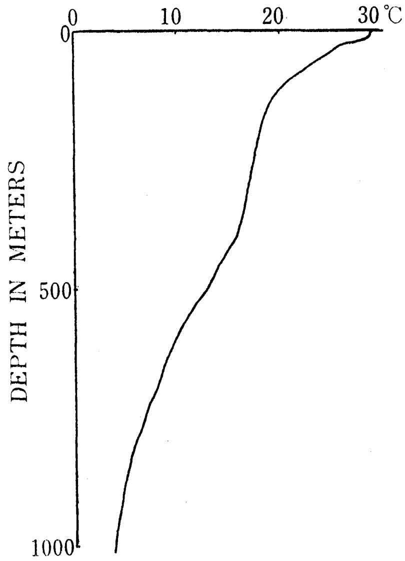
1. Introduction.

It is known already that there exists the surface and the main thermoclines in this region, and by revealing the depths of these thermoclines, we can estimate the water movement after taking approximate geostrophic current into consideration. The surveys for CSK were made at 178 stations in the region 20°N to 35°N, 120°E to 143°E from June to September in summer of 1966. The results of serial oceanographic observations of temperature by 13 reserch vessels are examined. In this paper, the topographic features of the thermoclines associated with the movement of water are discussed.

2. Method of Data analysis.

The thermocline depth is derived from temperature distribution based on reversing thermometer data from surface to a depth of 1000 m. An example of

* Laboratory of Geology, Faculty of Education, Kagoshima University.
** Laboratory of Oceanography, Faculty of Fisheries, Kagoshima University.



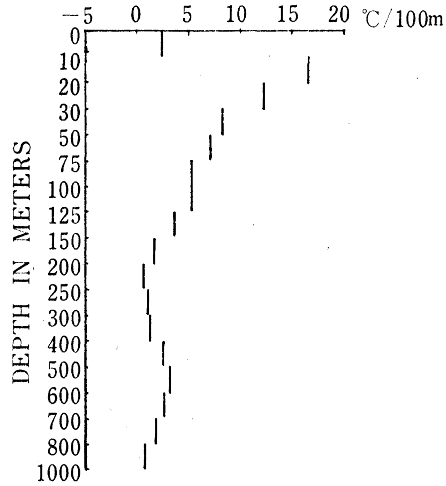
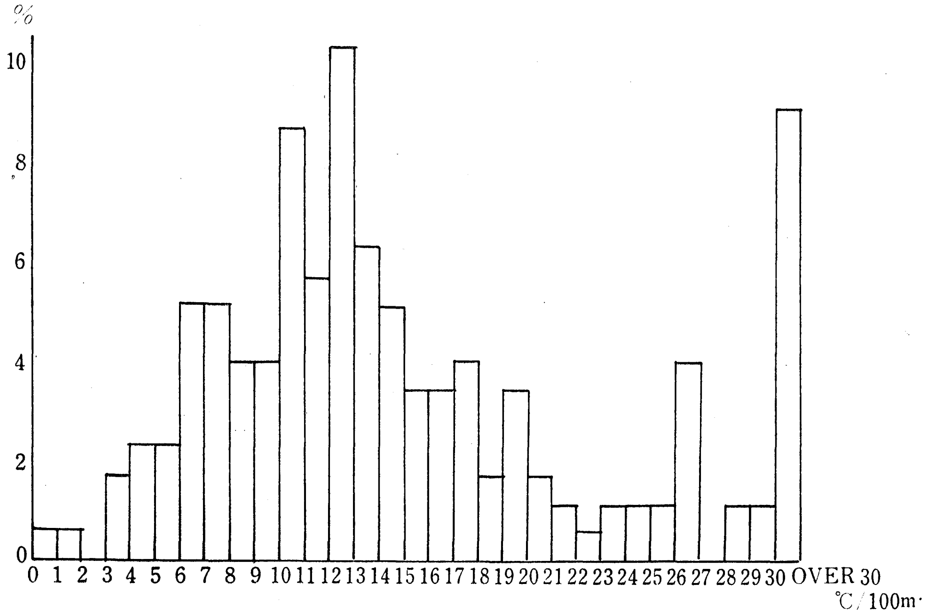


Fig. 1(a) Fig. 1(b)

An example of Vertical temperature distribution (a), and vertical temperature gradient (b) corresponding to (a).

vertical temperature distribution is shown in Fig. 1(a). We introduce G_T as defined by following relation, $G_T=\frac{\Delta T}{\Delta D}$ where G_T is vertical temperature gradient, ΔT and ΔD are temperature difference and depth interval respectively between upper and lower observing depths. We have defined the depths of surface thermocline and main thermocline as that depths where G_T is largest above 300 m and G_T is largest below 300 m respectively. G_T corresponding to Fig. 1(a) is shown in Fig. 1(b). This depth of 300 m can be taken for a boundary depth of



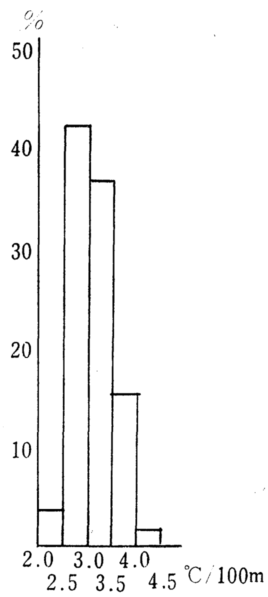


Fig. 2(a) Fig. 2(b)

The frequency distribution of vertical temperature gradients of the surface thermocline (a), and of the main thermocline(b).

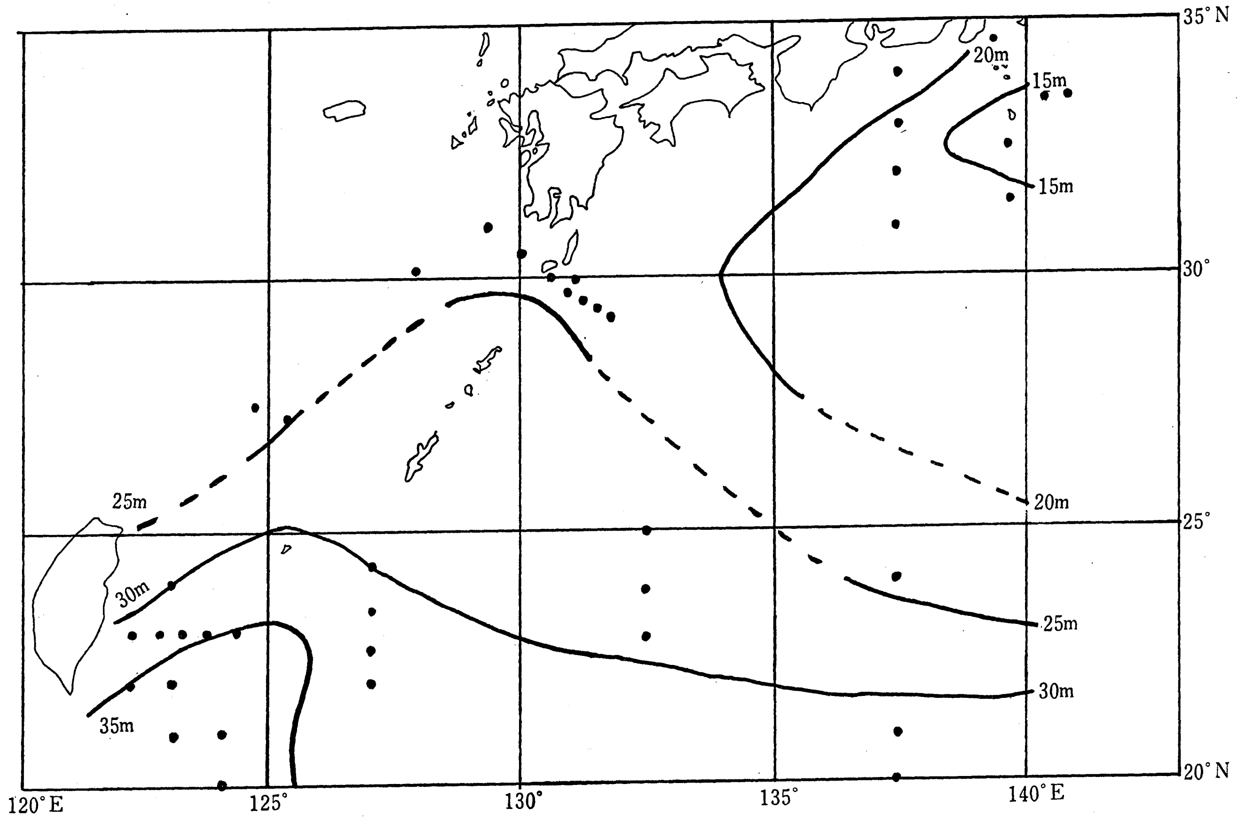


Fig. 3. The surface thermocline topography under a conditon of wind velocity less than 15 kt during past 24 hours.

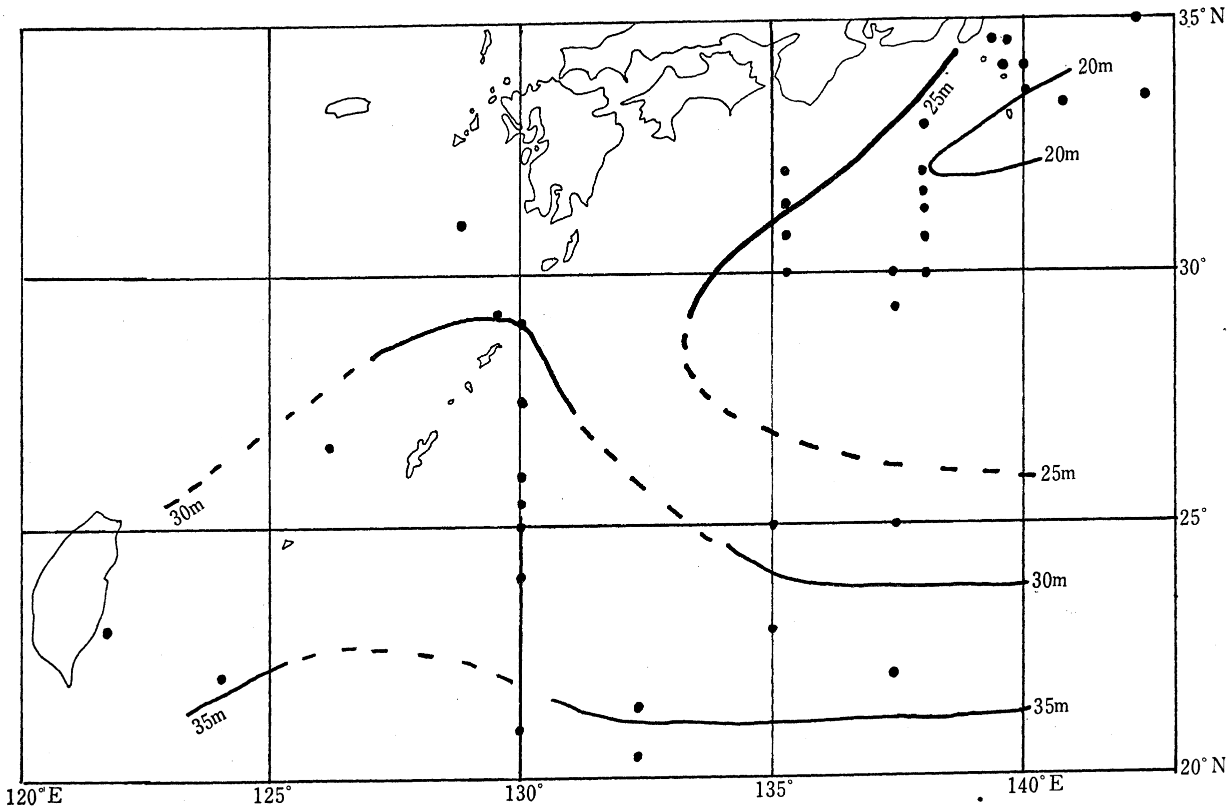


Fig. 4. The surface thermocline topography under a condition of wind velocity over 15 kt during past 24 hours.

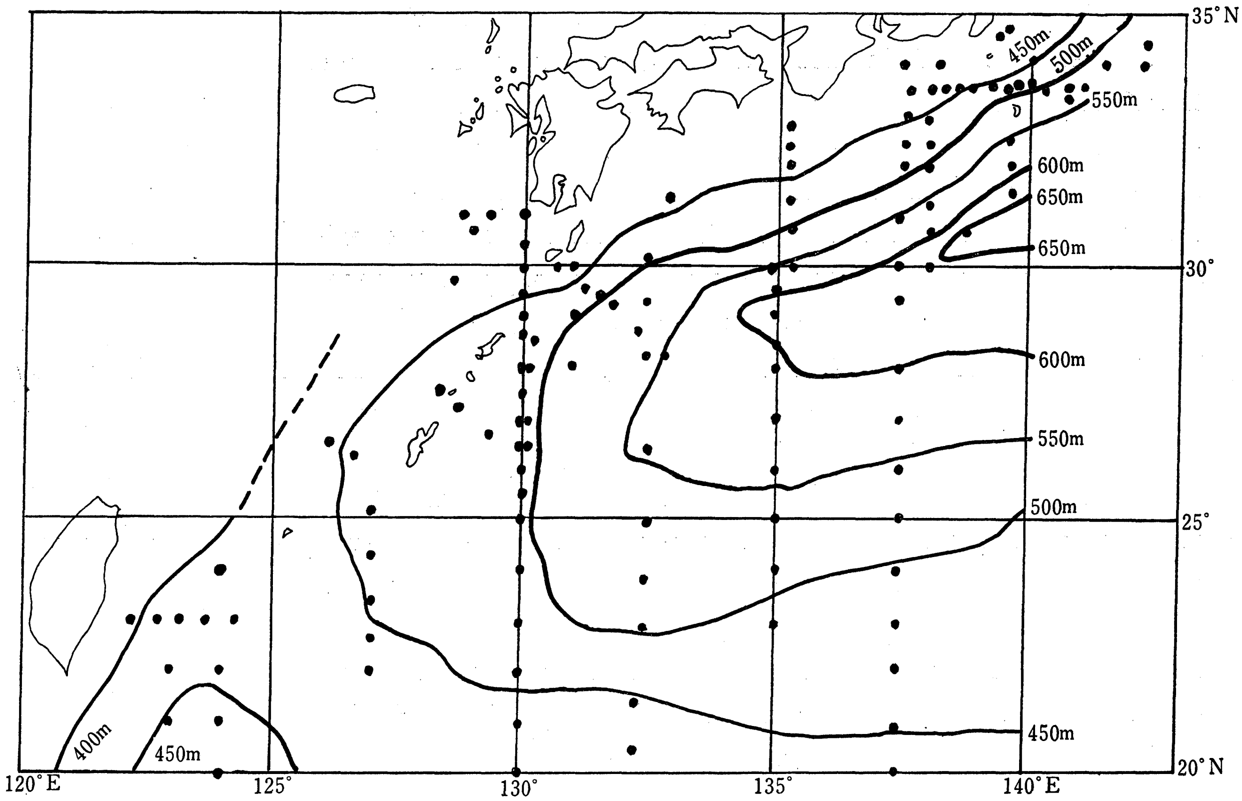


Fig. 5. The main thermocline topography.

surface thermocline and main thermocline, i. e., there exists no surface thermocline below 300 m and no main thermocline above 300 m. Fig. 2(a) and (b) show the frequency distributions of G_T for the surface thermocline and the main thermocline respectively. We make full use of Fig. 1(a) and (b) concurrently to determine the depths of surface thermocline and the main thermocline. Fig. 3 shows the topography of the surface thermocline under a condition of wind velocity less than 15 kt during past 24 hours and Fig. 4 shows the topography of the surface thermocline under a condition of wind velocity over 15 kt during past 24 hours. However we can obtain wind data at only the time when the temperature was observed and only one weather map within last 24 hours, so we can't rely much upon wind data. Fig. 5 shows the topography of the main thermocline, which is very stable to compare with the surface thermocline.

3. Discussion of Results.

The surface thermocline depth is possible to change by following effects: (1) dynamical mixing by wind, (2) water movement by advections, (3) convections by heat loss or heat gain, (4) effects of bottom topography in shallow water, (5) internal waves. We have poorly wind data, so we can't say much about wind effect. We also can't discuss about convections by heat loss or heat gain and internal waves for lack of suitable data. The surface thermocline lies in a layer from a depth of 15m to that of 35 m, under a condition of wind velocity less than 15 kt during past 24 hours. The surface thermocline depth is 35 m in the area off east part of Formosa, and it gradually goes shallower along the axis of the Kuroshio to reach a layer of 15 m depth around the point of 34°N, 139°E, as shown in Fig. 3. Under a condition of wind velocity over 15 kt during past 24 hours the surface thermocline can be found in the layer 5-10 m deeper than the case of weak wind, as shown in Fig. 4. And this is the effect of the shearing stress of wind which causes the turbulent mixing in surface homogeneous layer, consequently the surface thermocline depth becomes deeper.

The main thermocline topography is shown in Fig. 5 and in the region dealt with it can be found in the layer between 400 m and 650 m depth. In the region off southeast part of Formosa and the region around the point of 31°N, 139°E, main thermocline distributes in the layers of 450 m and 650 m respectively. The depth of main thermocline in these regions are deeper than those of surrounding regions. The main thermocline topography lies round the point of 31°N, 139°E except near Formosa, and its intervals are large in southern part and are small in northern part of that point. The main thermocline contours run zonally in southern part of 31°N, 139°E, and run from WSW to ENE in northern part of 31°N, 139°E. In the region near Formosa, the ridge of Miyako and Yaeyama Islands are considered to be affected.

Water movement is assumed on dynamical bases due to the thermocline as a discontinuous layer. In Fig. 5, westward current can be expected around 22°N to 27°N, it is the end of the North Equatorial Current and is continued to the Kuroshio. In Fig. 3 and Fig. 4, eastward current can be expected around 22°N to 24°N. Consequently in the region around 22°N to 24°N, there are eastward current in the layer above the surface thermocline and westward current in the layer between the surface thermocline and the main thermocline.

In the region around 30°N, 130°E, 24°N, 130°E and 33°N, 139°E, fairly large vertical temperature gradients associated with surface thermocline reaching to 250m are recognized. An example is shown in Fig. 6(a) and (b), in which fairly large vertical temperature gradient reaches to a depth of 150m. There are 17, 8, 17 observation points with such states in the regions around 30°N, 130°E, 24°N, 130°E and 33°N, 139°E respectively. These discontinuous layers are fairly steady states in these regions. These processes are caused due to mainly the wind effects and secondarily the effects of bottom topography but around 30°N, 130°E, the depth is over 3000 m so the effect of bottom topography can hardly affect the surface homogeneous layer. The surface homogeneous layer depth also fluctuates in accordance with internal waves. However detailed processes of such discontinuous layers associated with surface thermocline reaching to 250 m can't be revealed.

The vertical temperature gradient of the surface thermocline varies from

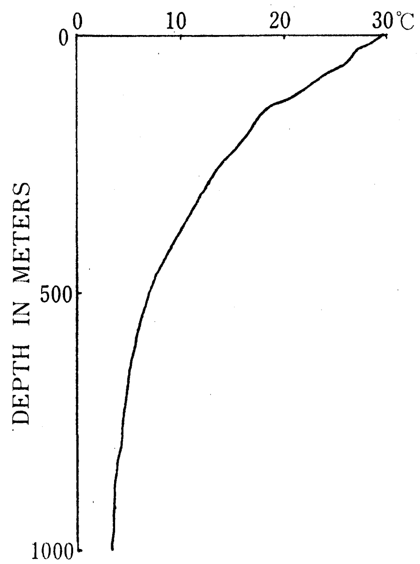


Fig. 6(a)

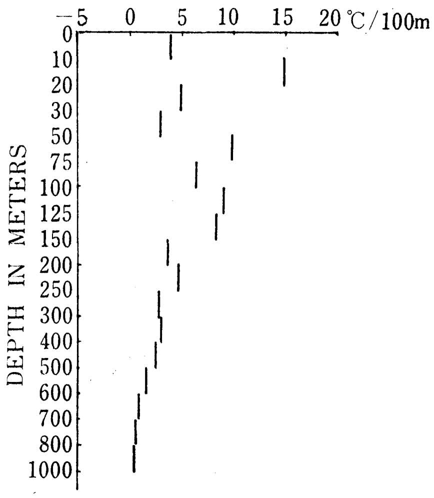


Fig. 6(b)

An example of vertical temperature distribution (a), and vertical temperature gradient (b) in which a fairly large vertical temperature gradient reaching to a depth of 150m is recognized.

0.5°C/100 m to 50.5°C/100 m. The most frequent value exists between 12.0°C/100m and 13.0°C/100 m and the frequency decreases gradually as apart from this value, and accounts for 30.9 % at a range from 10.0°C/100 m to 14.0°C/100 m. The vertical temperature gradient of surface thermocline can be considered to vary by the same effects as these in surface thermocline. However the frequency distribution of vertical temperature gradient of surface thermocline in Fig. 2(a) can be taken as a typical pattern in this region in summer. The vertical temperature gradient of the main thermocline varies from 1.35°C/100 m to 4.19°C/100 m. The most frequent value exists between 2.5°C/100 m and 3.0°C/100 m and its frequency accounts for 42.3 %. At a range from 2.5°C/100 m and 3.5°C/100 m it accounts for 78.8 %. The range of the vertical temperature gradient of the main thermocline is very small as compared with that of the surface thermocline. The frequency distribution of temperature gradient of main thermocline can be considered as much stable. The frequency distribution of vertical temperature gradients of the surface and the main thermoclines, are shown in Fig. 2(a) and (b).

4. Conclusion.

The surface thermocline lies in a layer from a depth of 15 m to that of 35 m under a condition of wind velocity less than 15 kt during past 24 hours in south of Japan in summer of 1966. Under a condition of wind velocity over 15kt during past 24 hours, the surface thermocline lies in a layer 5-10 m deeper than the case of weak wind by the effect of the shearing stress of the wind which causes the turbulent mixing in surface homogeneous layer. The main thermocline lies in the layer between 400 m and 650 m depths. The main thermocline contours lie round the point of 31°N, 139°E except near Formosa, and its intervals are large in southern part and small in northern part of that point. The main thermocline contours run zonally in southern part of 31°N, 139°E, and run from WSW to ENE in northern part of 31°N, 139°E. In the region near Formosa, the ridge of Miyako and Yaeyama Islands are considered to be affected. In the region around 22°N to 24°N, there are eastward current in the layer above the surface thermocline and westward current in the layer between the surface thermocline and the main thermocline. In the region around 30°N, 130°E, 24°N, 130°E and 33°N, 139°E, there are fairly large vertical temperature gradients associated with surface thermocline reaching to 250 m. However detailed processes of such discontinuous layers can't be revealed.

The vertical temperature gradient of the surface thermocline varies from 0.5°C/100 m to 50.5°C/100 m. The most frequent value exists between 12°C/100m and 13°C/100 m and the frequency decreases gradually as apart from this value, and accounts for 30.9 % at a range from 10°C/100 m to 14°C/100 m. The vertical temperature gradient of the main thermocline varies from 1.35°C/100 m to 4.1°C/100 m. The most frequent value exists between 2.5°C/100 m and 3.0°C/100 m and its frequency accounts for 42.3 %. At a range from 2.5°C/100 m to 3.5°C/100 m, it accounts for 78.8 %.

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