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**REPORT ON OCEANOGRAPHIC INVESTIGATIONS
IN THE NORTHEAST PACIFIC OCEAN
DURING AUGUST 1956, FEBRUARY 1957, AND AUGUST 1957**

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INTRODUCTION

The last report¹ (Tully and Dodimead, 1957) reviewed the work in the subarctic region of the Northeast Pacific Ocean to autumn 1956. It was based on two mid-summer surveys (August 1955 and 1956). It summarized some of the principal oceanographic features and contained conjectures on the winter conditions and mechanism. Since then, two additional surveys have been accomplished, February and August 1957 (Fig. 1). In addition Bennett (1958) has prepared a comprehensive report on the oceanography of this region for the period, August 1955, and a report (Dodimead and Hollister, 1958) is in press on the results of drift bottle releases. As a result of these works some of the concepts have been clarified and modified.

This report deals primarily with the salinity and temperature structure and their distribution, water masses, and calculated currents. It emphasizes the seasonal and yearly variations for the period August 1956 through February to August 1957. A considerable amount of the previous evidence and description is repeated in order that this report may be coherent and self-sufficient. In addition, the structure and distribution of dissolved oxygen, inorganic phosphate, silicate, and nitrite, are briefly reviewed.

Sources of Data

Most of the data indicated in Figure 1 were collected by the Pacific Oceanographic Group and have been published in the manuscript data record series of the Fisheries Research Board of Canada (1957a, b, c; 1958).

The August 1956 survey was made in cooperation with the Department of Oceanography of the University of Washington, who examined the southeast part of the area. These data have been published (1957) and are included in the discussions.

It is also possible, with the data made available by the Faculty of Fisheries, Hokkaido University (1957) for the period July - August 1956, to compare the oceanographic features in the Northeast Pacific Ocean with those found in the vicinity of the Aleutian Islands, northward into the Bering Sea, from 175° W to 170° E longitude.

¹ To avoid repetition of the reference, it will be referred to as the "last report" throughout the text.

SALINITY

Figure 2 shows the observed salinity structure at ocean weather station PAPA (lat. 50° N, long. 145° W) during the periods of the three surveys, August 1956, and February and August 1957. As postulated in the last report, it is now evident that the salinity structure, with minor variations, is a permanent feature of this region.

There were two distinct zones (Tully, 1953), an upper and a lower zone. In the summer the upper zone was characterized by a near-isohaline layer extending to a depth of about 30 meters. This layer was coincident with the isothermal, or the wind-mixed layer, for normal summer wind conditions. Below this layer there was generally a small halocline, which was associated with the marked summer thermocline (Fig. 12), then a second near-isohaline layer extending to a depth of 100 meters. Below this was the principal halocline. This was the permanent feature in this upper zone structure. The bottom of the halocline extended to a depth between 150 and 200 meters. The salinity range in the halocline was about one part per thousand (32.8 to 33.8 ‰). Below the halocline the salinity increased more or less uniformly with depth to about 34.4 ‰ at 1000 meters. Below this, although not shown, the salinity increased by about 0.2 ‰ in the next 1000 meters.

In winter the secondary halocline was absent because of winter cooling and strong wind-mixing. These factors resulted in a near-isohaline layer extending to about 100 meters depth. Otherwise the salinity structure is the same as that observed in summer. Henceforth, the layer from the surface to the top of the permanent halocline will be referred to as the "surface layer".

This structure was found throughout the region northward of a subarctic boundary shown in Figure 1. South of this, in the Polar Front region the structure became irregular as it tended toward the subtropic type.

Figure 3 shows a sequence of salinity structures observed southward from this boundary during August 1956. The northern station (45) was typical of the salinity structure at PAPA, and shows that this structure was found at the western limit of the survey for this period. Southward of this, the halocline became less pronounced and there was, at the same time, a noticeable increase in the salinity at the bottom of the halocline. This resulted in a salinity minimum in the lower zone between 300 and 500 meters depth. This structure is typical of subtropic waters. Also in this southern region there were as many as three inversions of gradient in the surface layer. These data represent the transition between subarctic and subtropic waters, and are in the Polar Front region.

North of the boundary the structure was similar to that at PAPA, to the western limit of the data (175° E), except for an area centered on the Aleutian Islands and longitude 180° (Fig. 1). Here the marked halocline vanished. Instead there was a simple gradient of salinity, 33.2 to 34.0 ‰ from 100 to 400 meters depth.

Figure 4 shows the salinity distribution at 10 meters depth. It is generally representative of the regional variations in the surface layer. There was a salinity maximum in the Alaska Gyral which is a permanent feature of the region. Southward of this, the salinity decreased to a minimum, and then increased. There was a marked salinity gradient between latitudes 40° and 45° N in mid-ocean (August 1956 of Figure 4). This boundary was also present in 1955. It corresponds to the Polar Front which separates the subarctic from the subtropic water. The salinity decreased toward the coast all around the Gulf of Alaska. There was a marked minimum off the Washington coast, presumably associated with the Columbia River runoff.

The salinity was 0.2 ‰ greater in the winter than in the summer over most of the region. This is attributed, in part, to the mixing of the surface layer by the strong winter winds, and to the fact that land drainage is less through the coastal seaways during the winter than during the summer. This winter salinity increase corresponds to the winter decrease of freshwater content of the upper zone, which will be discussed.

It is noteworthy that during the period August 1957, there was no water of salinity less than 32.6 ‰ in mid-ocean as was the case in the previous summer.

The greatest salinity (33.1 ‰) occurred in an area centered on longitude 180°, just north of the Aleutian Islands. This corresponds to the anomalous structure mentioned earlier, and appears to be separate from the Alaska Gyral system. It was also observed in August 1953 (Misshima and Niskizawa, 1955) at which time it was more saline than shown here.

The salinity distribution at 100 meters depth is shown in Figure 5. This depth corresponds to the top of the halocline, or the bottom of the surface layer described in Figure 2. The conformation of the isohalines corresponds closely to those at 10 meters depth (Fig. 4) although the values are somewhat greater.

It is notable that high salinities were evident along the United States coast as far as Vancouver Island. These were associated with the small land drainage and tendency to upwelling along this part of the coast. Northward of Vancouver Island and around the Alaskan coast the salinities were markedly less than mid-ocean values. This is associated with the great land drainage in the area.

Figures 6, 7, and 8, show the vertical distribution of salinity in three selected sections (Fig. 1) in the region, for each period. Section 1 is generally an east-west section, terminating in the vicinity of the Strait of Juan de Fuca. Section 2 is also an east-west section, terminating in the vicinity of the Queen Charlotte Islands. Section 3 is a north-south section through the Alaska Gyral. These sections are shown to substantiate some of the features already described and also to show other important features.

All the sections show the marked halocline, generally between 100 to

200 meters, the bottom of which can be denoted by the 33.8 ‰ isohaline. They also show the constant gradient in the lower zone.

Sections 1 for each period show that, approaching the coast, the isohalines in the upper and lower zone rose toward the surface. This feature was especially marked in August 1957. The corresponding temperature sections (Fig. 16, 17, and 18) show the converse. The isotherms sloped downward approaching the coast. Thus approaching the coast there must be a transition from one water mass to another. This feature will be discussed again under water masses.

Sections 2, farther to the north, show that the isohalines were fairly horizontal with possibly a slight downward slope approaching the coast.

Sections 3 illustrate one of the most permanent features of this region, the existence of a dome in the lower zone in the Alaska Gyral, which is associated with the circulation (Sverdrup et al, 1942). Within the dome the upper zone was shallow and the salinity was high. The halocline was always continuous throughout the dome.

The southern part of Section 3, for August 1956, shows the salinity minimum in the lower zone between 300 and 500 meters depth.

Figure 9 shows two vertical sections across the Aleutian Island chain, from the Japanese data of 1956 (Hokkaido, 1957). The locations are shown in Figure 1. Section A, a north-south section along 175° E longitude shows the marked change in salinity structure. Stations 1 and 2 are similar to the structure at station PAPA. Northward the marked halocline deepens and degenerates to a regular gradient. Section B, along 172° W longitude also shows that north of the Aleutian Islands, the halocline structure degenerates.

FRESH WATER ACCUMULATION

The following analyses are confined to the subarctic area shown in Figure 1, where the salinity structure was similar to that at PAPA.

After Tully (1953) and Doe (1955), the salinity structure was examined by plotting observed values of salinity against the logarithm of the depth. From these plots the depth of the upper zone and the salinity value separating the upper zone from the lower zone were determined. The depth of the upper zone is denoted "D", and the salinity at "D" is the index salinity (I.S.).

The mean index salinities were:

for August 1955	-	33.79 ‰
August 1956	-	33.81 ‰
February 1957	-	33.85 ‰
August 1957	-	33.83 ‰

with a standard deviation of ± 0.06 ‰. For the coastal region in 1950 Doe (1955) reported a mean value of 33.75 ‰.

It is evident, from these and other analyses, that the upper and lower zones should be regarded as separate entities. Within the upper zone there were marked variations of salinity with depth. The low salinity is attributed to fresh water mixing with the underlying sea water of salinity 33.8 ‰. The lower zone generally showed a fairly constant gradient of increasing salinity with depth. Variations in the salinity with depth are attributed to physical processes associated with the circulation, and the distribution of mass, and the possible intrusion of different water masses into the region.

Figure 10 shows the depth of the upper zone. In the Alaska Gyral, "D" was less than 150 meters at all times. Southward of the Gyral, "D" generally increased to a maximum and then decreased. Off the coast of Washington and southern Vancouver Island, "D" was generally less than 175 meters, corresponding to the high salinities in this region. Northward along the coast, "D" increased, with a second maximum off southeastern Alaska. In winter, "D" was generally greater than in summer over most of the region. Tabata has shown this to be true at PAPA (personal communication).

Figure 11 shows the amount of fresh water in the upper zone. It represents the meters of fresh water mixed with the underlying sea water of the index salinity (33.8 ‰) required to produce the observed structure at each station.

The fresh water content was least in the Alaska Gyral. This area showed less seasonal and yearly variations than the rest of the area. Southward, the freshwater content increased to a maximum and then decreased conversely to the salinity. In the area north of latitude 50° N, the fresh water increased, from the Alaska Gyral shoreward, with maximum values off the southeast Alaska coast. This suggests that the freshwater contribution from Georgia Strait and the west coast of Vancouver Island flowed close to the coast and was not dissipated seaward to any great extent. However, as it moved up the coast, more fresh water was added to the system through the coastal seaways. This accumulation began to appear north of the Queen Charlotte Islands and farther to seaward, reaching a maximum off the southeast coast of Alaska. This observation is consistent with the calculated currents.

It is noteworthy that there was a second maximum off the coast of Washington between longitudes 130° to 140° W and latitudes 45° to 50° N, in the periods February and August 1957. It was also present in August 1956 but was displaced southward and eastward. It is suggested that this was an area of divergence, and that the associated physical processes resulted in an accumulation of fresh water, presumably originating from the Columbia River. This maximum, although not so evident was present in 1955 and therefore appears to be a permanent feature in this area.

In the summer, off Vancouver Island and the Queen Charlotte Islands, there were about 4.5 meters of fresh water in August, while in winter there

were about 3.0 to 3.5 meters. This suggests that the freshwater content was less in winter than in summer.

These figures suggest an accumulation of fresh water in the whole region. Jacobs (1951) reported that the excess of precipitation over evaporation is about 0.6 meter/year. Hence in this eastern subarctic area there is a 5 to 6 years' accumulation of fresh water. This confirms the previous report. It is evident that there must be a considerable degree of re-circulation of the upper-zone system. Later evidence shows that part of the water is re-circulated around the Alaska Gyral, and that part is re-circulated farther to westward.

TEMPERATURE

Figure 12 shows typical temperature structures at PAPA and at position A (Fig. 1) in the Gulf of Alaska.

In the summer, within the surface layer defined by the salinity structure, there was an isothermal layer extending to depths between 20 and 40 meters, corresponding to the upper isohaline layer. Then there was a sharp well-defined thermocline. Below this and coincident with the lower (main) halocline, there was generally a temperature inversion. This feature was stable since it always occurred in the halocline. Below this the temperature decreased gradually with depth to about 2.8° C at 1000 meters. Below this the temperature decreased about 1° C in the next 1000 meters.

In winter there were two distinct temperature structures. At PAPA, the structure showed an isothermal layer extending to about 100 meters depth, then a negative thermocline. Below this there was a very slight temperature inversion. In the Gulf of Alaska (Position A), the structure showed an isothermal layer, then a positive thermocline, which was stable because it occurred in the halocline. The regional distribution of these winter structures is shown in Figure 13. Northward and southward of the boundary line between these structures, the thermocline became more pronounced. The area of the positive thermocline is associated with the area of maximum cooling.

Over the region, the summer temperature structure is generally independent of the salinity structure in the upper zone, but anomalies such as temperature inversions, are possible because of the salinity structure. In winter the temperature structure is associated with the salinity structure.

The daily temperature observations at station PAPA have been examined by Hollister (1956). He showed that the annual temperature cycle was consistently recurrent, and the range of seasonal variation was nearly constant. The temperature cycle is shown in Figure 14. In mid-winter the surface waters are generally isothermal and may be somewhat colder than the deep waters. Spring warming becomes apparent in April when a thermocline develops at about 50 meters depth. This thermocline becomes more intense and deepens as warming continues through September. Surface cooling starts in

late September and continues through autumn while the thermocline becomes deeper and less marked until it vanishes in January. The annual temperature range at the surface is seven or more degrees centigrade. This decreases with depth to 120 meters where the range is less than one degree. This temperature cycle is reflected in the temperature structures shown in Figure 12.

The temperature distribution at 10 meters depth is shown in Figure 15. The principal feature is the "cold center" lying southwest of Kodiak Island. This is commonly regarded as the center of the Alaska Gyral. However, in summer the cold center did not generally coincide with the area of high salinity. In all periods the temperature increased southward and eastward from this cold center. Between PAPA and the coast, the temperatures were about 2° C warmer in August 1957 than in August 1956.

In winter, the configuration of the isotherms was generally east and west, with a slight northward slant approaching the coast. The cold center in the Alaska Gyral corresponded in position with the center of high salinity for this period.

Comparison of the summer and winter temperatures in this figure shows that the range of seasonal variation was nearly constant over most of the region, about 7° C, the same as at PAPA. This was also shown by Robinson (1956).

Figures 16, 17 and 18 show the vertical distribution of temperature, corresponding to the salinity sections shown previously.

The sections representing the summer periods (Fig. 16 and 18) show the marked thermocline in the surface layer between 30 and 100 meters depth. In winter (Fig. 17) the thermocline vanished and the water was near isothermal down to a depth of about 100 meters. The cross-hatching in these sections indicates the occurrence of the temperature inversions in the halocline.

Sections 1 (cf. Fig. 1) show that, in the southern part of the area, the isotherms dipped downward nearing the coast, whereas the isohalines rose upward. This behaviour has been attributed to a transition from one water mass to another.

Sections 2 for August 1956 and 1957 show that in the northern part of the area the isotherms dipped downward slightly toward the coast, similar to the isohalines for these periods. In February, the isotherms dipped down rapidly toward the coast similar to Section 1. Although not apparent in the salinity distribution alone, it is probable that water similar to that found in the southern region in August moved northward in February.

Sections 3 show the marked lower-zone dome in the Alaska Gyral. Southward of the dome the isotherms dipped downward from the surface layer but the gradient in the thermocline was nearly constant. That is, the temperatures in the thermocline increased toward the south.

Figure 19 shows two vertical sections across the Aleutian Islands chain (Fig. 1) from the Japanese data of 1956. These correspond to the salinity sections shown in Figure 11. In this region there was no evidence of a surface isothermal layer. Rather the halocline extended from the surface to about 80 meters depth. Below this the temperature was less than 4°C , and decreased to less than 2°C at 700 to 900 meters depth. This water was colder than any encountered at similar depths in the eastern North Pacific.

Close to the Aleutian Island chain there was a core of water warmer than 4°C , most marked at the eastern end. It has been suggested that this core represents water moving westward from the Gulf of Alaska.

Temperature Inversions

It has been shown, that within the halocline and below the thermocline, there were temperature inversions. This dicothermal structure was common over the whole region in August 1955 (Bennett, 1958). Also in August 1956 (Fig. 20) it was general over most of the region. However in August 1957 it appeared only in the north and coastal regions.

Doe (1955) proposed that these inversions marked the limit of winter cooling. If this is true then it would suggest that cooling in February 1957 was less than in the previous winter. This is confirmed at station PAPA. Figure 21 shows the mean monthly surface temperatures for the period 1950 to 1955. Superimposed on this are the mean monthly temperatures for 1956 and 1957. This figure suggests that the winter period, February 1957, was atypical, in that it was warmer than average. Cooling was less in this period than in the previous winter, with the result that minimum temperatures were lower in August 1956 than in August 1957. This was true for the whole region as shown in Figure 22, which shows that the minimum temperatures were about 0.5°C less in August 1956 than in 1957.

Figure 21 suggests that during both the summer surveys (1956, 1957) the temperatures were only slightly above normal. However, it has been shown that between PAPA and the coast the temperatures in August 1957 were about 2°C warmer than in August 1956. Further, at PAPA, Tabata (private communication) has observed that the heat content of the water (sub-surface temperatures) were greater in August 1957 than in the summer of 1956. This is illustrated in Figure 22 which shows the temperature structure at approximately the same position for both periods, between PAPA and the coast. Not only was water warmer at the surface, but it was warmer to at least the depth of the halocline. These high temperatures are probably due to the intrusion of surface waters into this area, from the Polar Front. If they were due to local heating, the effect would have been noticeable at PAPA and westward.

WATER MASSES

One convention for describing water masses is the temperature-salinity (T-S) diagram. In this, the waters are identified by the relation of the two properties without reference to depth. The salinity structure has been shown to be a permanent feature of this region, therefore the water masses were first classified according to the temperature in the halocline, an interval of 1° C being arbitrarily chosen. Secondly, the water masses were subdivided according to the T-S relationship in the lower zone, which were arbitrarily subdivided into three types. These classifications are shown in Figure 23. They are mean curves determined from a number of stations, plotted from 100 to 2000 meters depth. The indicated depths are representative values.

The first diagram shows the general classification. The second diagram shows T-S curves which are related to the general classification but exhibit some anomaly, such as a marked minimum temperature between 100 to 150 meters depth. There may be other types, especially to the westward. Some stations were classified in the above groups which might represent distinct types if more data were available.

Figure 24 shows the distribution of these water masses. Generally no sharp demarcation existed between them, rather there were transitions, from one type to the next, both in the upper and lower zone. The solid lines delimit the distribution as defined by the temperature characteristics in the halocline, regardless of the type or types in the lower zone.

Based on the classification in the upper zone, the general distribution of water types is the same in each period. The most pronounced feature is the occurrence of marked dicothermal structures, in the northern part of the region in August 1956, which have already been described. The dotted lines delimit the water masses in the lower zone. A somewhat bold interpretation has been made of the lower zone since it was common to find this zone contained two types of water.

The last report described the water masses in this region, and reported that the deep zone was similar within small limits over the whole region. However, as was suggested, more careful examination has shown that there were significant differences in the lower zone, particularly in the approaches to the continental shelf.

Off the coast of Washington and Vancouver Island there were marked changes in the T-S relationship in the lower zone, whereas over the rest of the area these were consistent. Evidently there was an intrusion of water from the south along the coast. This water mixed with the water from the west with the result that there was a transition from one type to the next. Evidently the intrusion of these waters was more pronounced in the winter than in the summer.

CALCULATED CURRENTS

Figure 25 shows the geopotential topography referred to the 1000 decibar surface. The currents are presumed to flow along the isobars and the speed is inversely proportional to the distance between them. Bennett (1958) has shown that there is movement at least to 2000 db. However the same general circulation pattern results, but the calculated speeds may be greater by 2 miles per day, than those shown.

These diagrams show that the general features of the circulation were persistent. The mid-ocean movement was from the west and toward the North American coast at a rate of less than 2 miles per day (4 cm./sec.). The main flow divided; part of the water, generally that north of latitude 45° N, moved northeast circulating around the Gulf of Alaska. The current became more intense to northward. Along the Alaskan peninsula, it became about 4 to 6 miles per day (8 to 12 cm./sec.). The current continued westward along the southern side of the Aleutian Islands.

The remainder of the mid-ocean drift turned southward to form the California current and subtropic circulation. As a result of this division, a region of divergence was formed off the Oregon, Washington, and Vancouver Island coast.

Despite the general similarities there were fairly marked differences between the three periods. The Gyral was smaller in extent in August 1957, than in the two previous periods. Associated with this there was a relatively strong current on the eastern side of the Gyral (long. 147° W). In the previous periods the strong current was closer to the coast. This suggests that the amount of water entering the area between PAPA and the coast increased from 1956 to 1957. This is implied in the sequence of geopotential topography which showed that the surface movement had veered to the north in the offshore parts of the area, during the year.

A recent report (Dodimead and Hollister, 1958) on the results of drift bottle releases in this region, confirmed this shift of the major flow. These data also showed that the surface movement was in accordance with the geostrophic flow, but there was a component, generally to the right, across the isobars.

The previous report hypothesized that the circulation within the Gulf of Alaska was winter-accelerated. This is not confirmed in the geopotential topography for this period. However it has been shown that this period was atypical (warmer than average) therefore it is possible that the winter wind systems may usually assist the flow. However it is suggested that the circulation in the Gulf of Alaska is influenced to a larger extent by the mid-ocean circulation. The data suggest that there was more water from the Polar Front entering the Gulf of Alaska during the year. During the year the region of division of trans-Pacific drift moved southward from about latitude 48° N to 45° N. Hence part of the water, formerly moving southward, has been incorporated in the northward movement. In any case, there is intrusion of southern water into the Alaska Gyral.

DISSOLVED OXYGEN

Generally the regional variation of dissolved oxygen near the surface is largely related to water temperature and wind mixing. In addition high concentrations may be partly due to phytoplankton activity near the surface. Low concentrations at depth may be attributed to zooplankton respiration and decomposition. The oxygen in the deep waters is generally related to the physical processes in this zone.

Figure 26 shows the dissolved oxygen structure at PAPA in February and August 1957. In the winter, there was an iso-oxy layer corresponding to the isothermal and isohaline layer, then a sharp gradient down to about 300 meters depth. The concentration then decreased to a minimum between 800 to 1000 meters, and then increased slightly with depth to about 0.10 mg.at./l. at 2000 meters depth. In summer, the oxygen structure was similar to that in winter, except that there was a fairly marked maximum at about 50 meters depth.

The distribution of dissolved oxygen for February and August 1957 is shown in Figure 27.

In February the isopleths generally showed the same configuration as the isotherms (Fig. 15). They ran generally east and west with a gradient of increasing concentration northward to the Alaska Gyral, the highest concentration being associated with the high-salinity - low-temperature water in this region.

In the summer the oxygen distribution showed random variation. Generally the concentrations were lower than in winter, probably due to the warm water conditions. The random variation in the surface waters can be attributed to the high biological activity during this period. This is especially true around the cold center.

Figures 28 and 29 show the vertical distribution of dissolved oxygen in the standard sections (Fig. 1) for each period. Generally the isopleths fluctuated in depth in much the same manner as the isohalines. There was an oxygen gradient between 100 and 300 meters depth as seen in the east-west sections (Sections 1 and 2).

Sections 3 through the Alaska Gyral show the marked lower-zone dome corresponding to the temperature and salinity distribution. Within the dome the isopleths were continuous and remained in the halocline through the dome.

The sections show that there was a maximum in the surface layer at about 50 meters depth in the summer. However in the winter, there was a very slight maximum and at a depth of about 30 meters. The oxygen minimum in the lower zone was generally between 800 to 1000 meters, except in the dome, where it was at a depth of 350 meters. The vertical distribution of oxygen was independent of the salinity and temperature structure except where physical processes were involved, such as in the dome; there the structure was evidently controlled by the same processes as salinity structure.

DISSOLVED NUTRIENTS

Phosphate

Figure 26 shows the vertical distribution of dissolved phosphate at PAPA. There was a fairly uniform surface layer, then a well-defined gradient to about 300 meters depth. Below this the concentration increased slightly with depth reaching a maximum of about $3.2 \mu\text{g.at./l.}$ at about 1000 meters, corresponding to the oxygen minimum. Below the maximum the concentration decreased slightly or was fairly constant with depth.

Figures 30 and 31 show the vertical distribution of phosphate during the winter and summer. These have similar general features to dissolved oxygen.

Figure 32 shows the distribution of dissolved phosphate at 10 meters depth. The isopleths show a similar distribution to oxygen. Concentrations in August were generally $0.5 \mu\text{g.at./l.}$ less than in February. During August the lowest concentrations were found along the coast. This corresponds to the area of highest zooplankton production. In winter, however, high concentrations are common in these areas.

Silicate

The vertical distribution of dissolved silicate in the standard sections (Fig. 1) is shown in Figures 33 and 34. The principal features are the high concentrations and the regular gradient with depth. There was no structure corresponding to the halocline or thermocline. However, like the temperature and oxygen, the isopleths rose toward the halocline from south to north. The distribution of silicate at 10 meters depth in February (Fig. 35) showed the same general configuration as the oxygen and temperature. The highest concentrations appeared in the Alaska Gyral, with the lowest concentrations in the southern and coastal waters.

In August the isopleths followed the same general pattern as the temperature distribution for this month (Fig. 15). The highest concentrations were in the center of the Gulf of Alaska. The lowest concentrations were found along the coast, like the phosphate concentrations. However the concentrations were lower than those in February by about $5 \mu\text{g.at./l.}$

Nitrite

Nitrite is generally associated with the decomposition of plankton. High values commonly occur a short distance below a productive photosynthetic zone. It is believed that high concentrations of nitrite indicate a region of recent high plankton productivity.

Typical summer and winter nitrite structures at station PAPA are

shown in Figure 26. In summer there was a relatively uniform surface layer, a marked maximum at 75 meters depth, and below this the concentration decreased rapidly to near zero at 200 meters depth. In winter the sharp maximum disappeared.

Observations at PAPA show that the maximum begins to develop in early summer (June) and is closely associated with the bottom of the thermocline. It becomes more intense and deeper until October. Thereafter, it is dissipated along with the thermocline.

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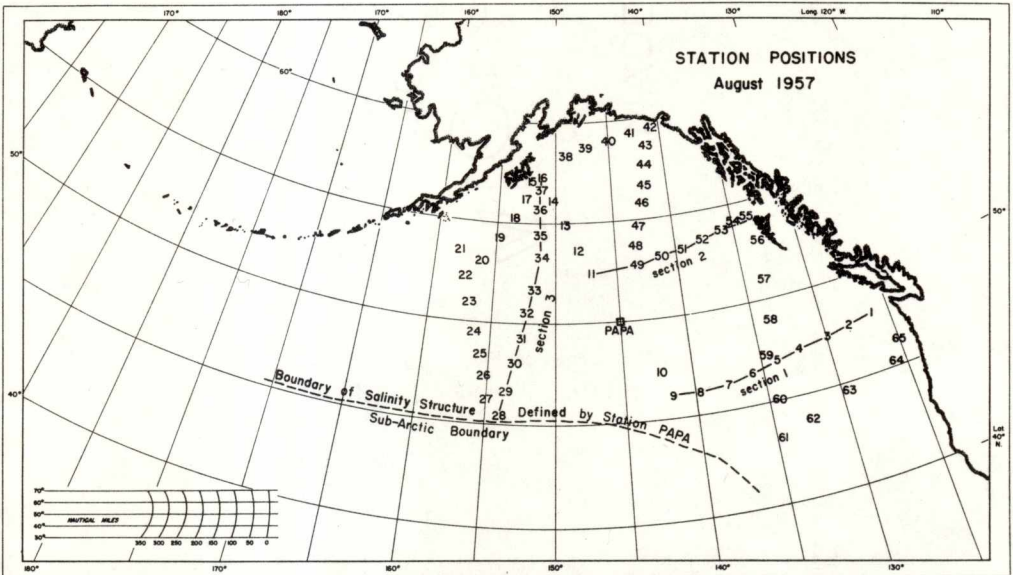
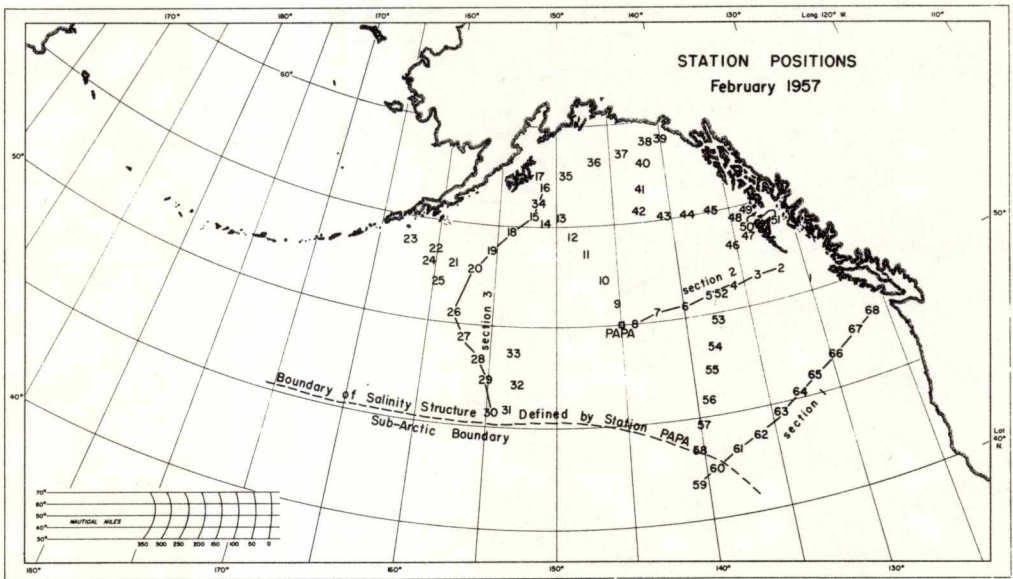
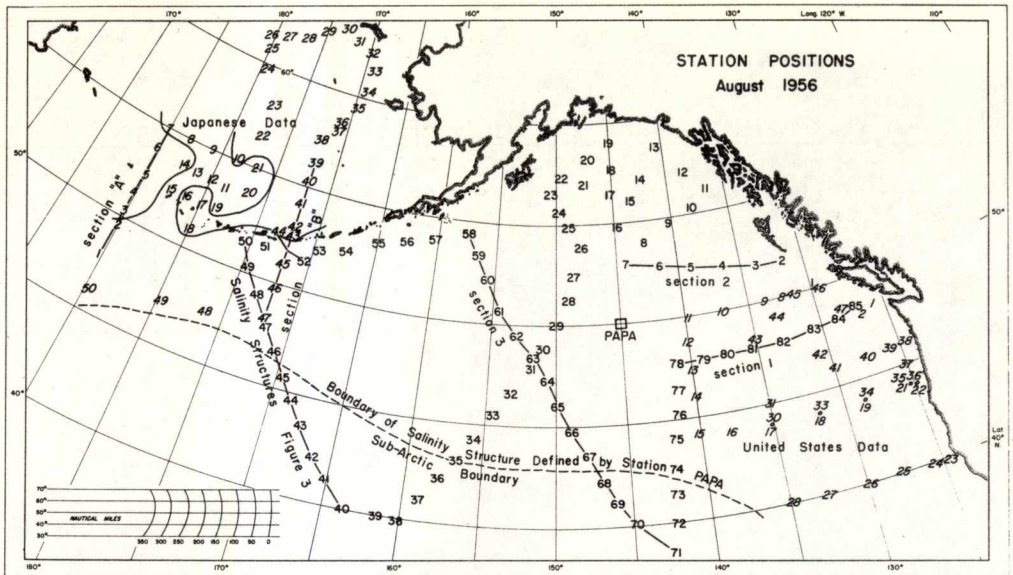


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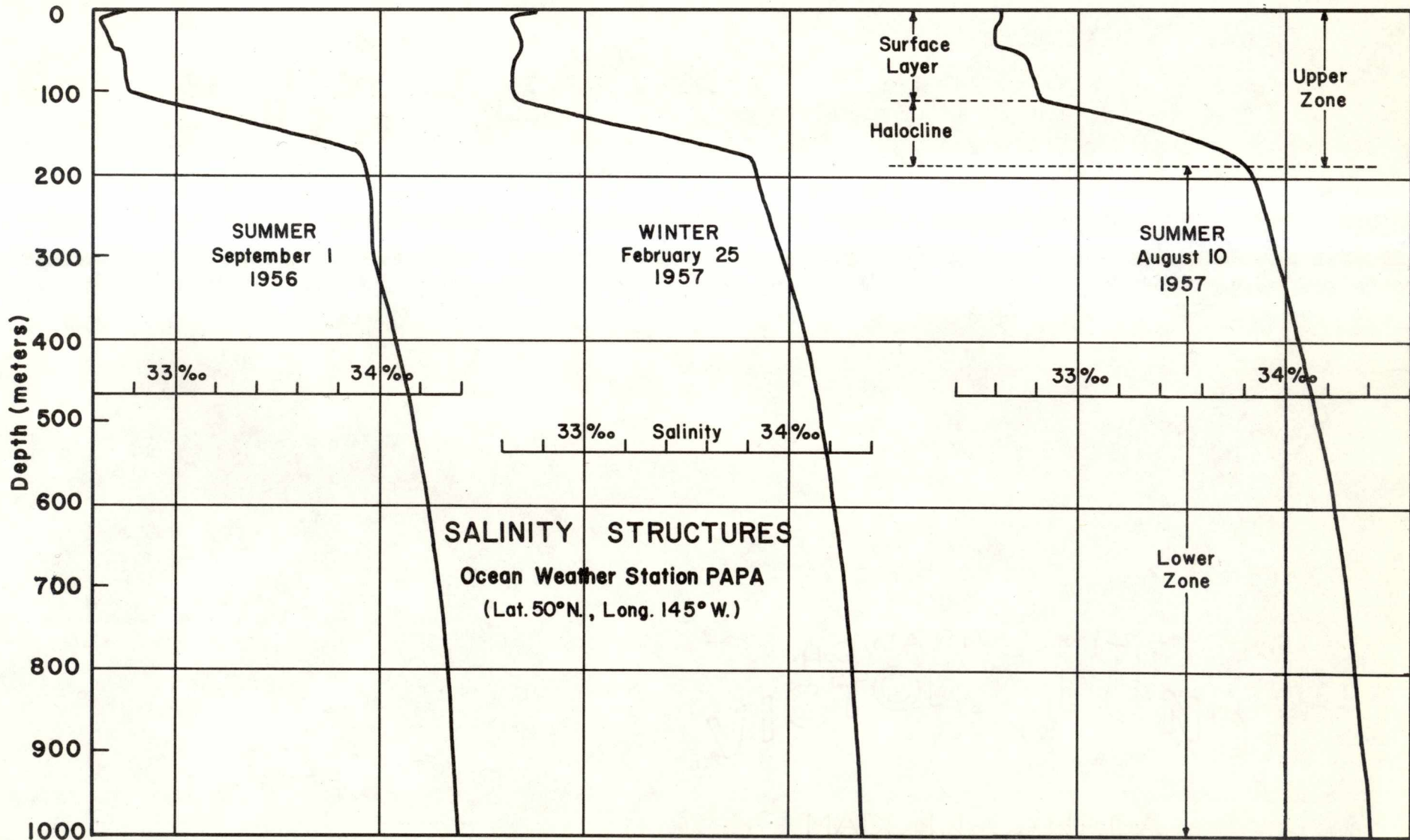


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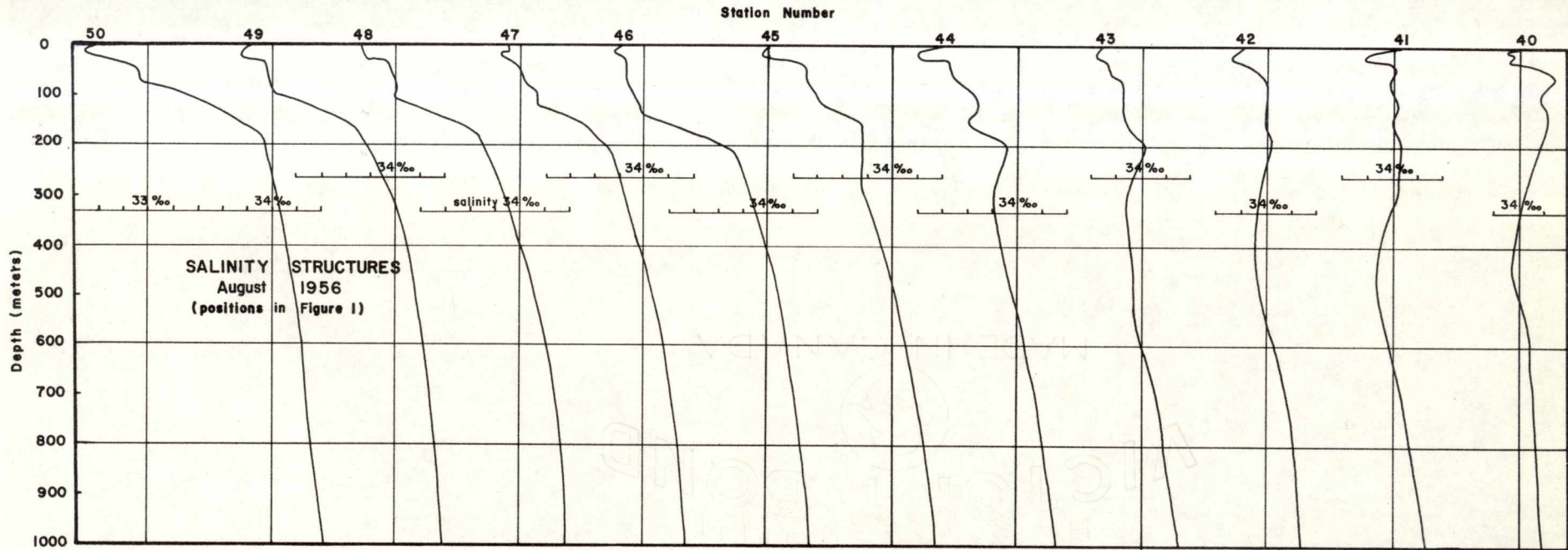


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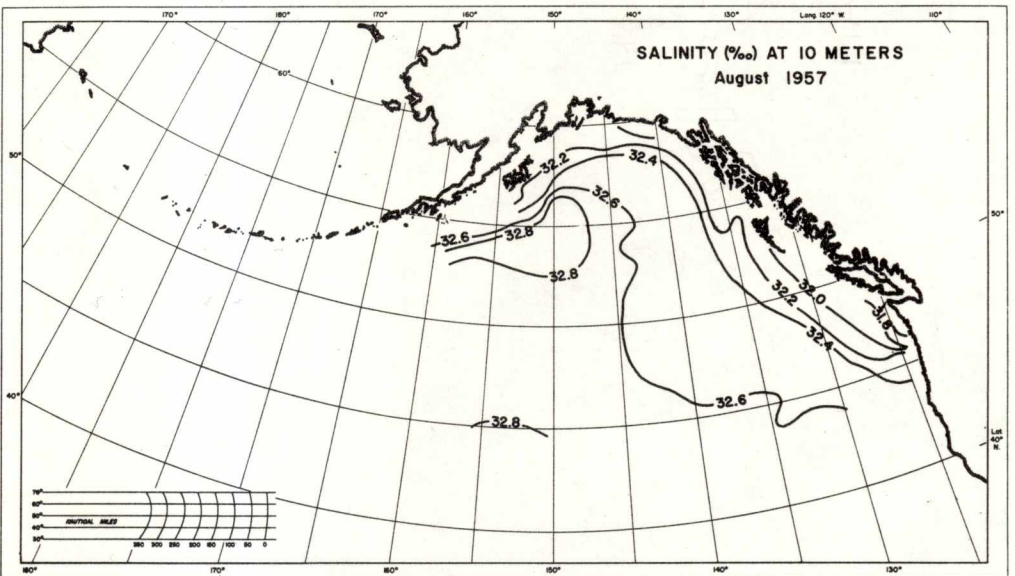
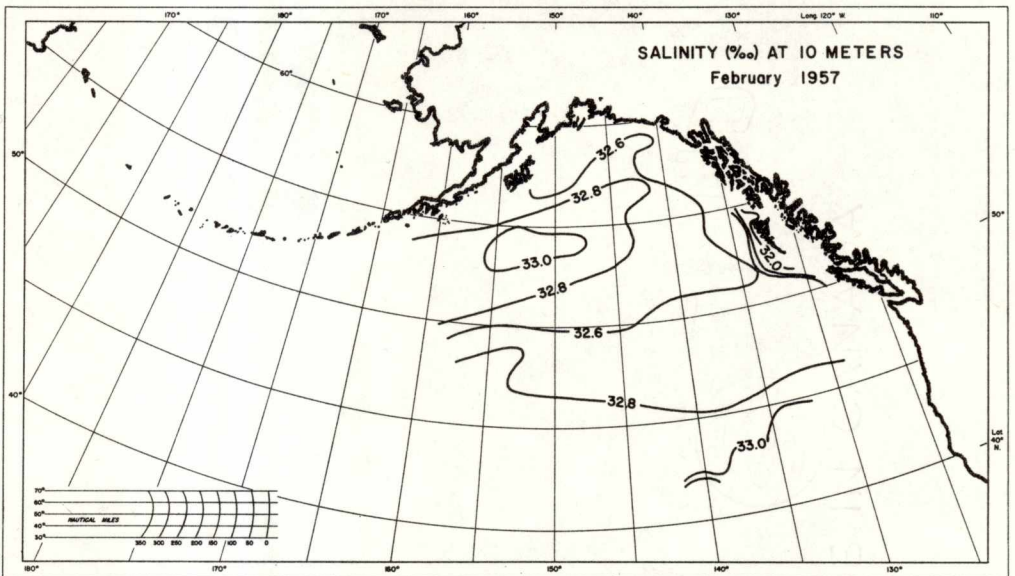
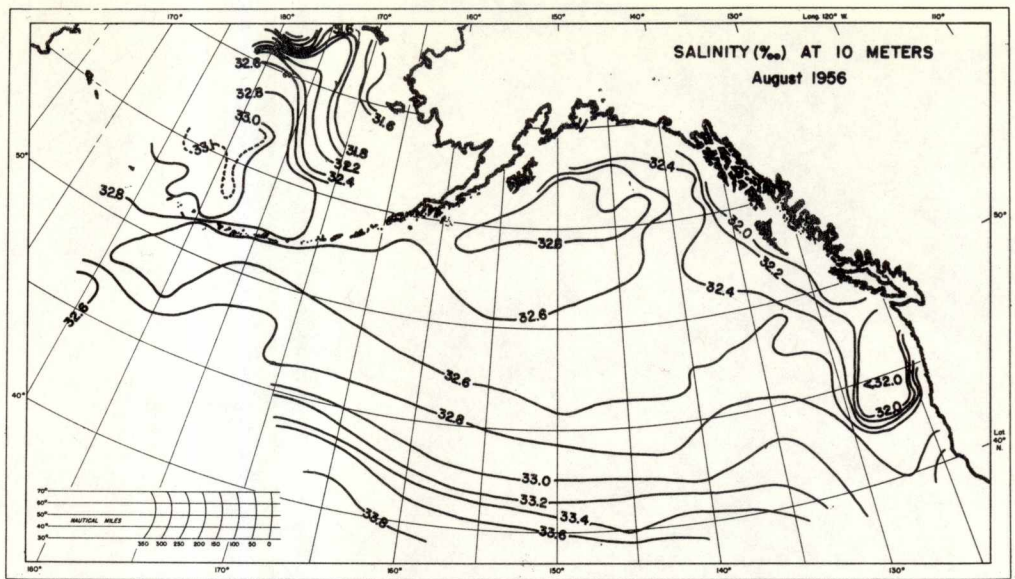


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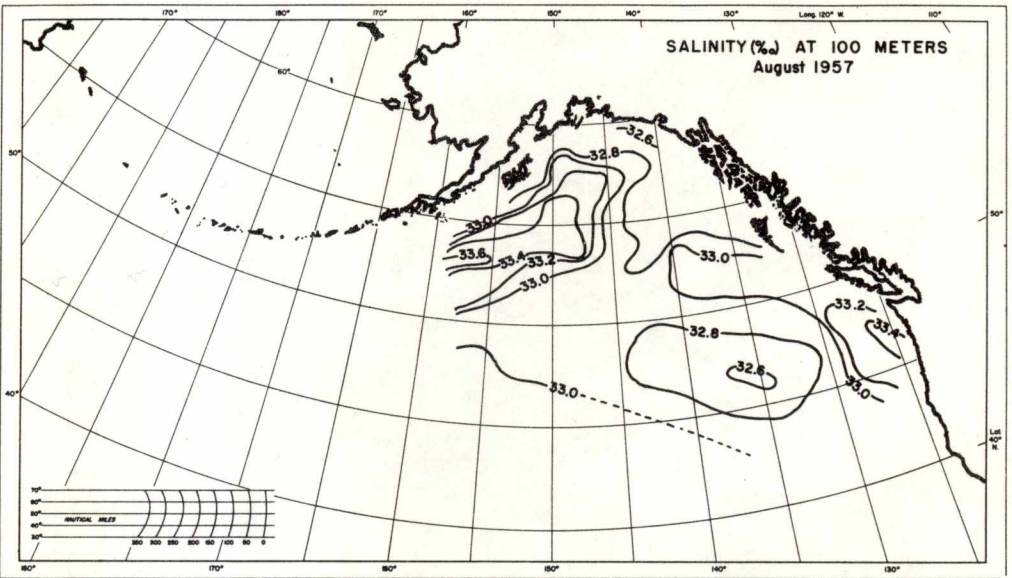
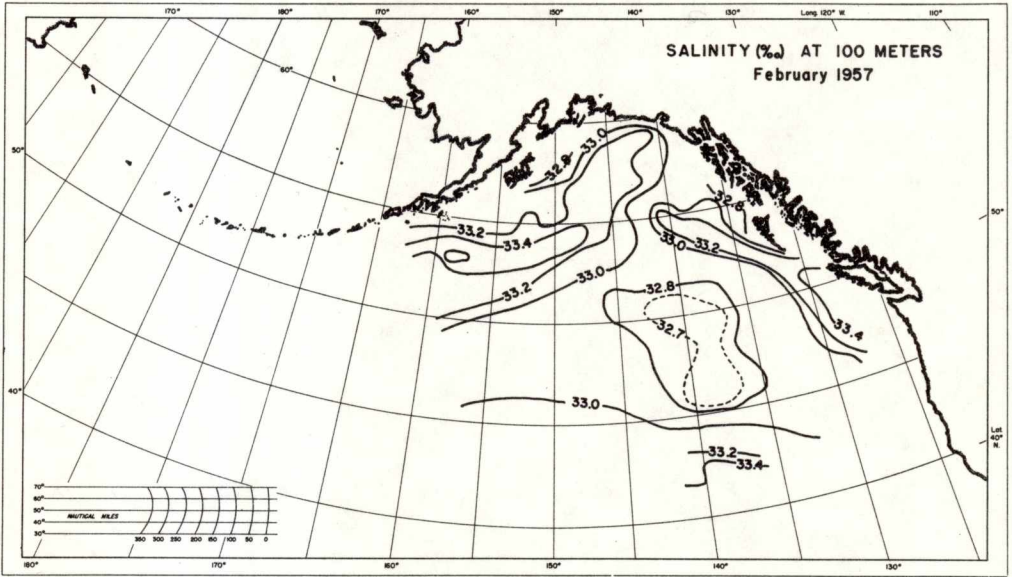
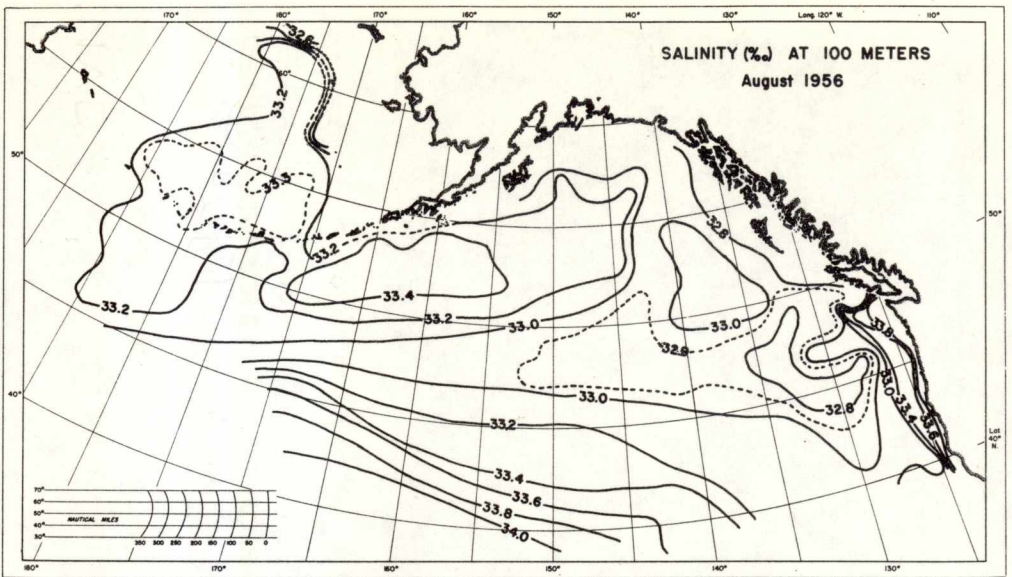


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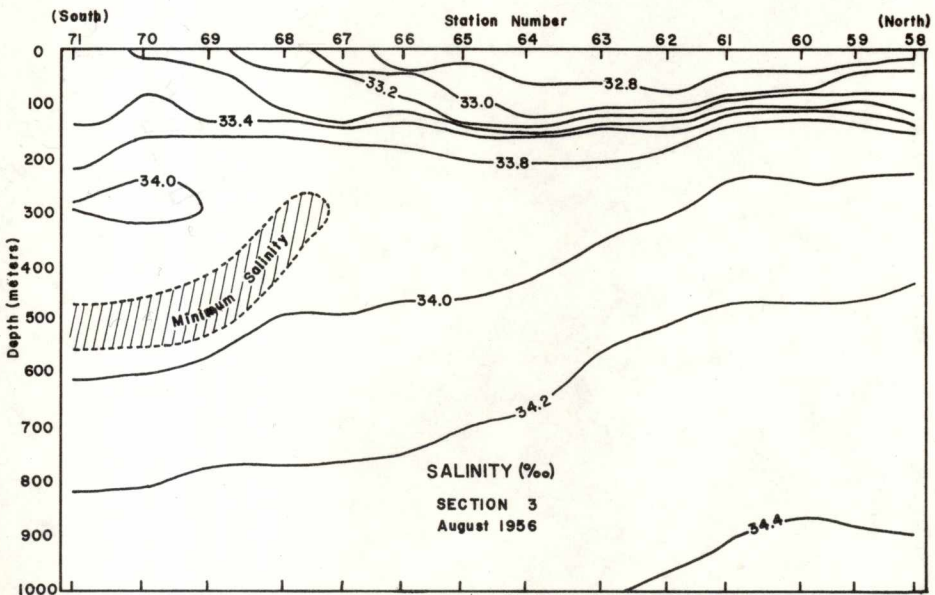
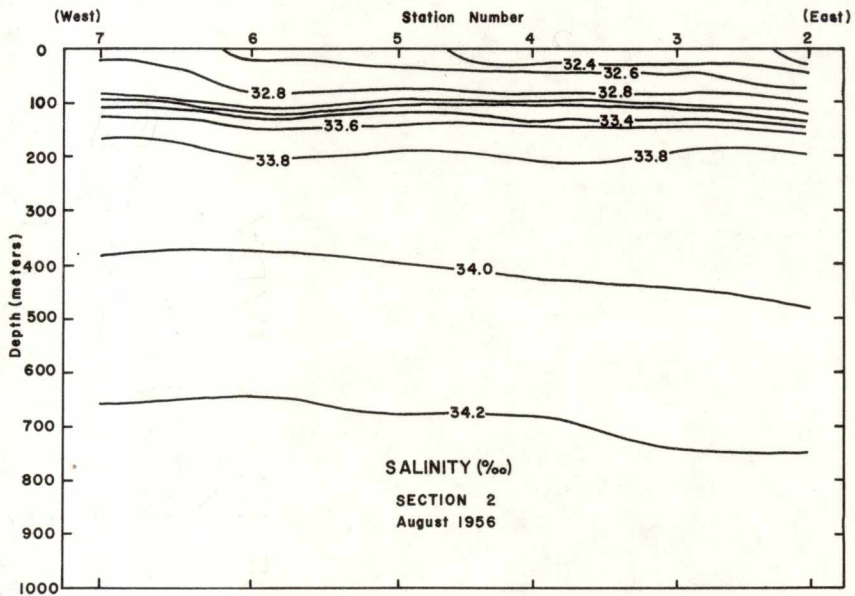
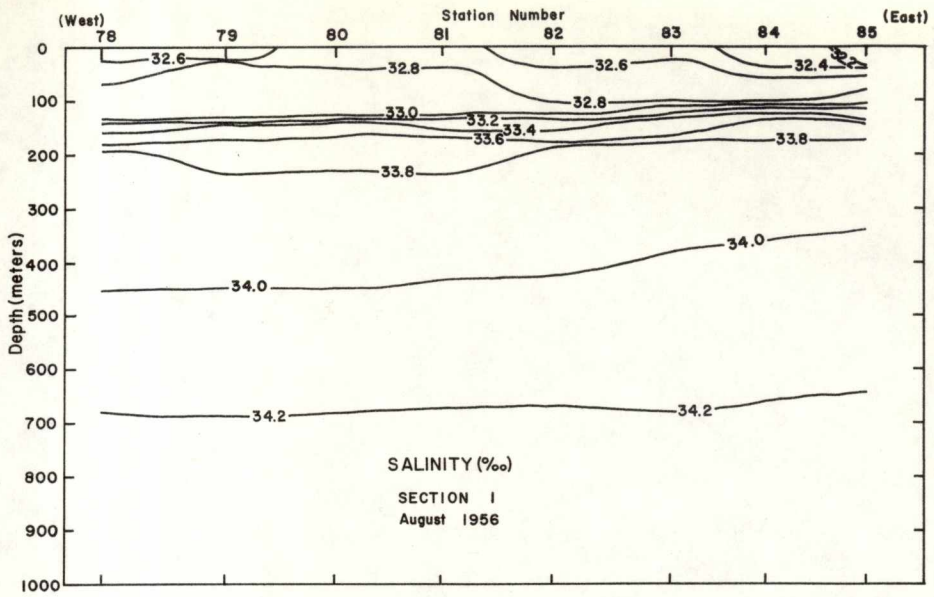


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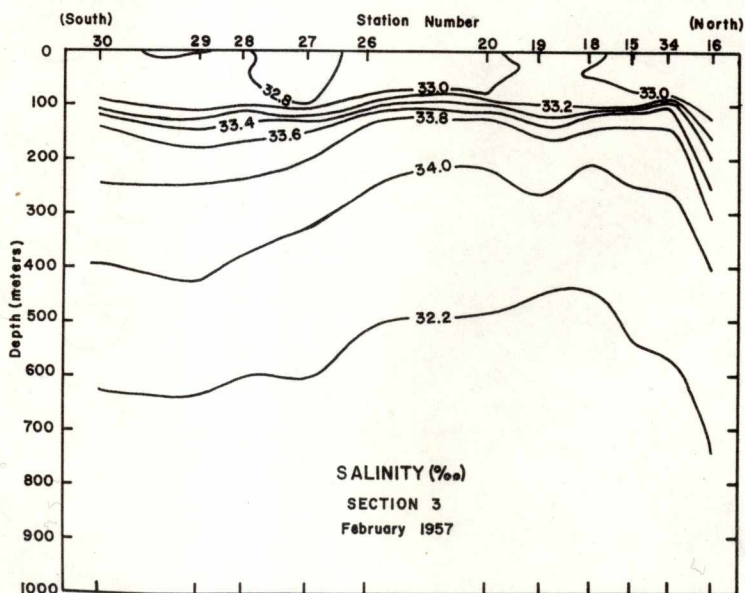
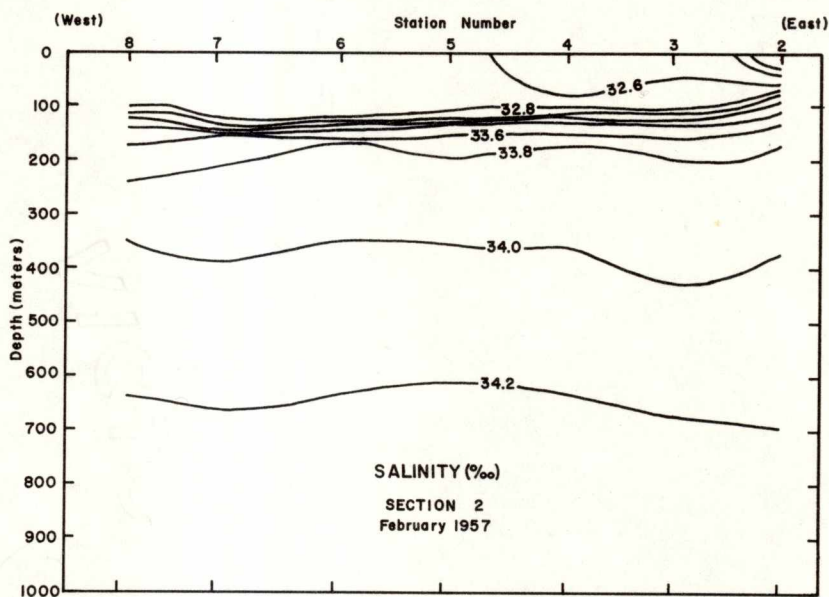
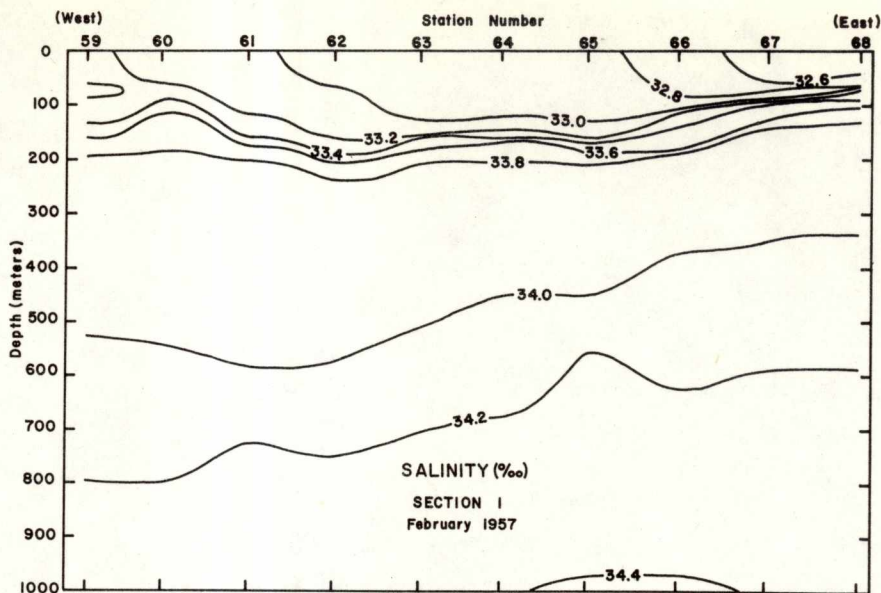


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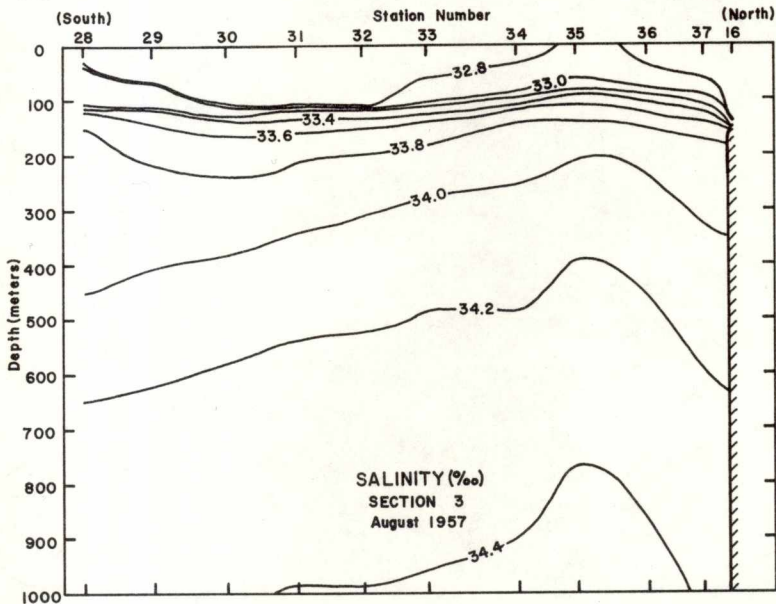
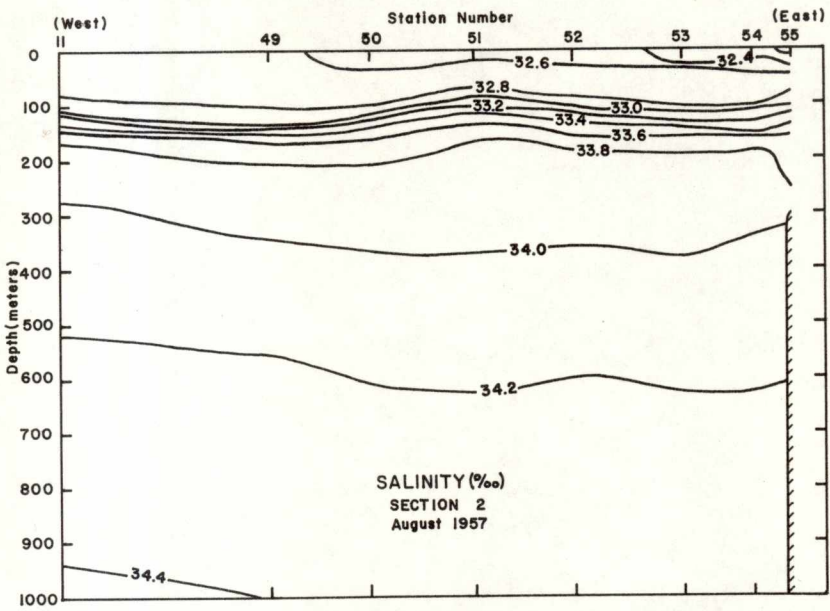
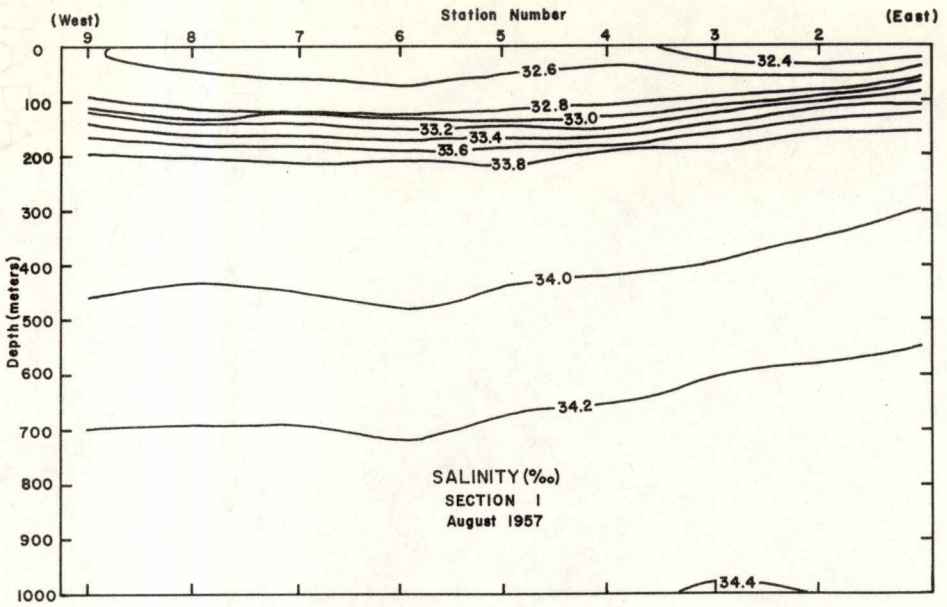


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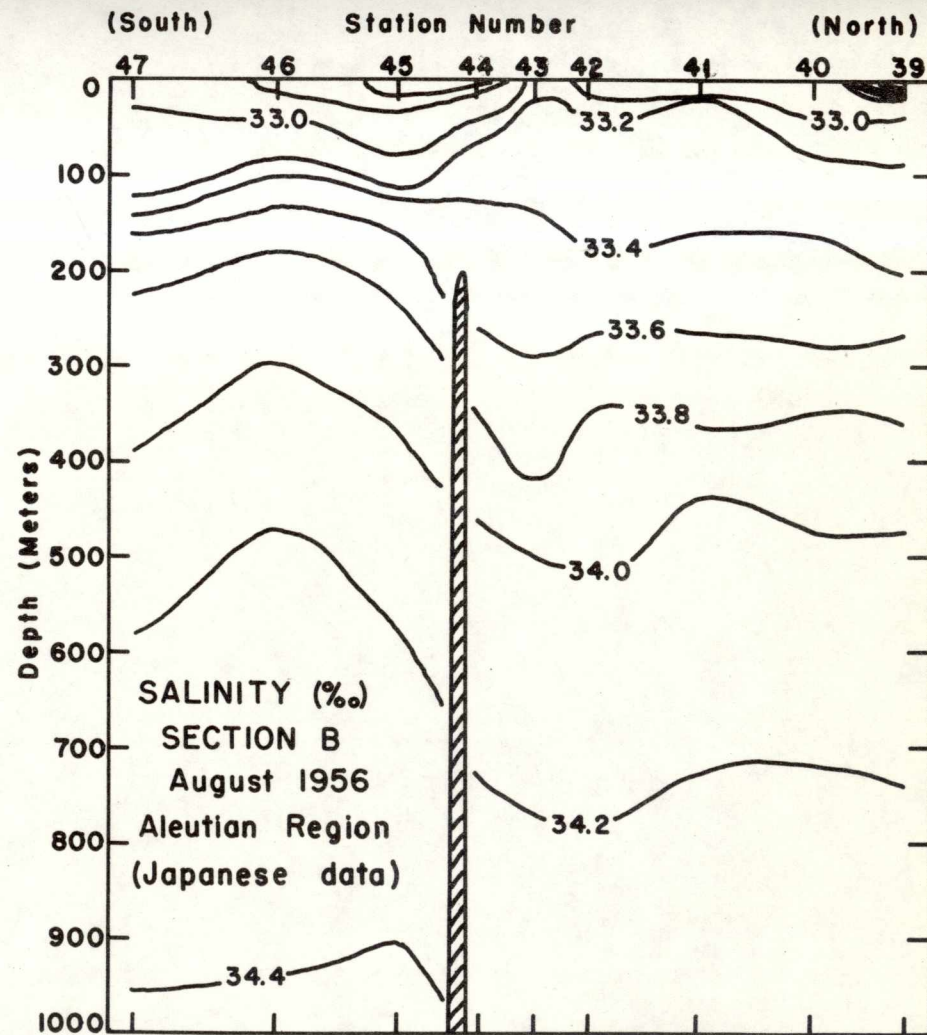
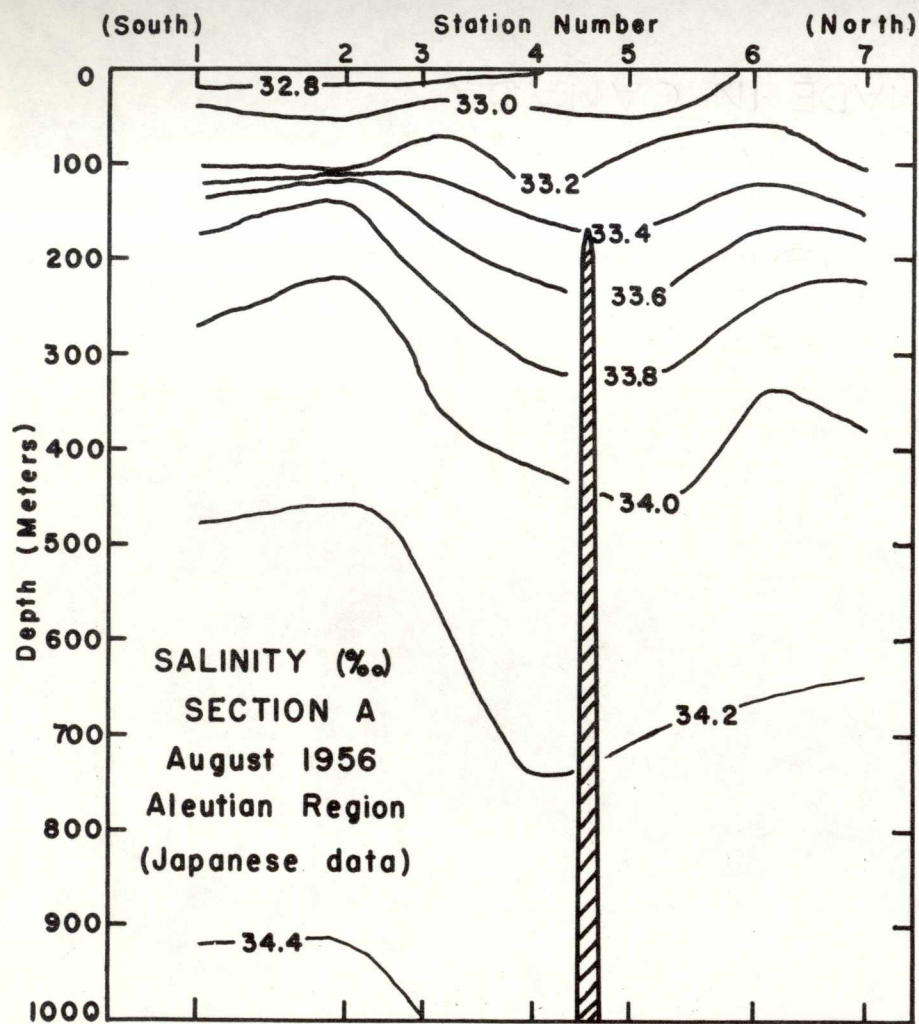


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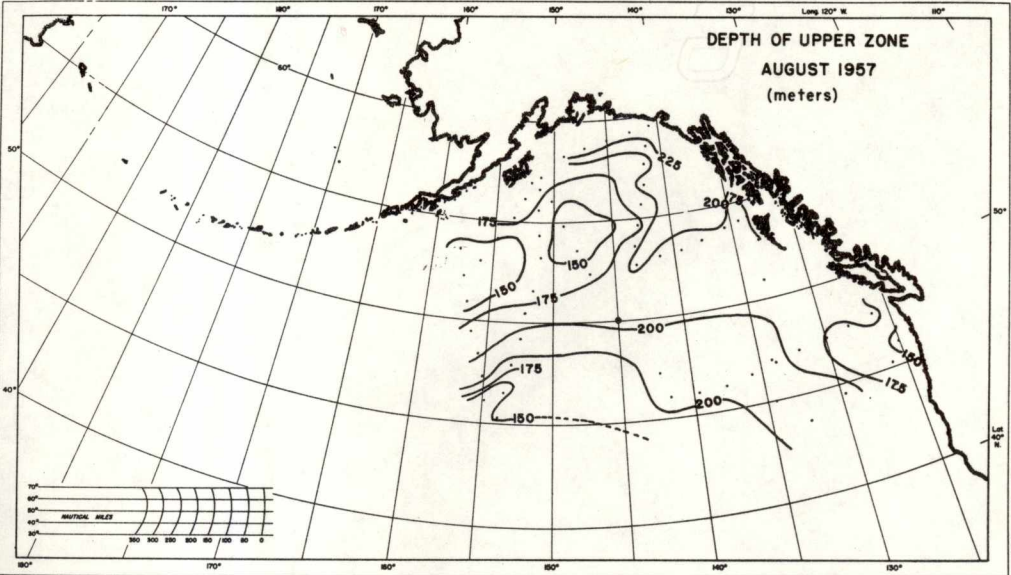
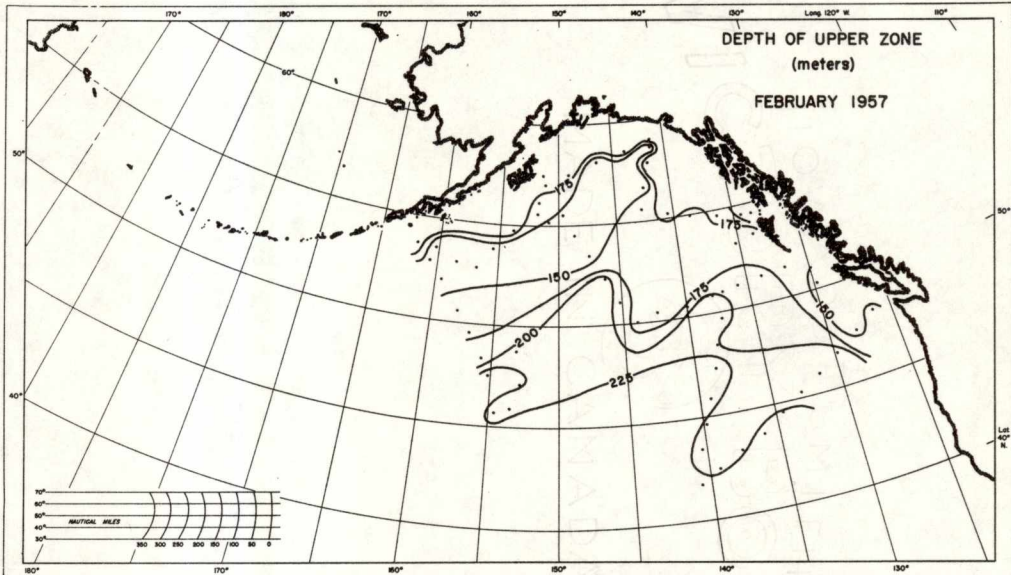
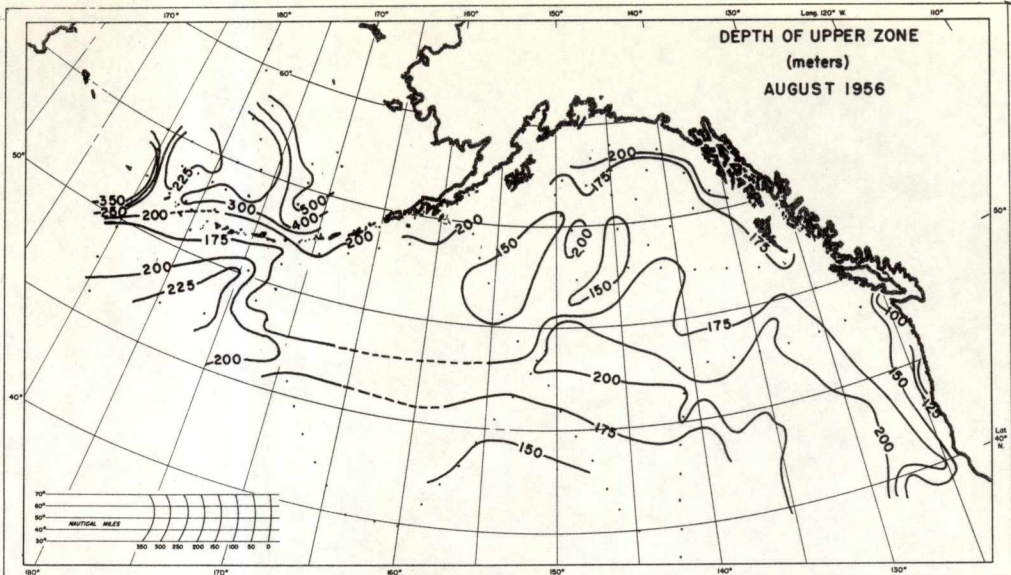


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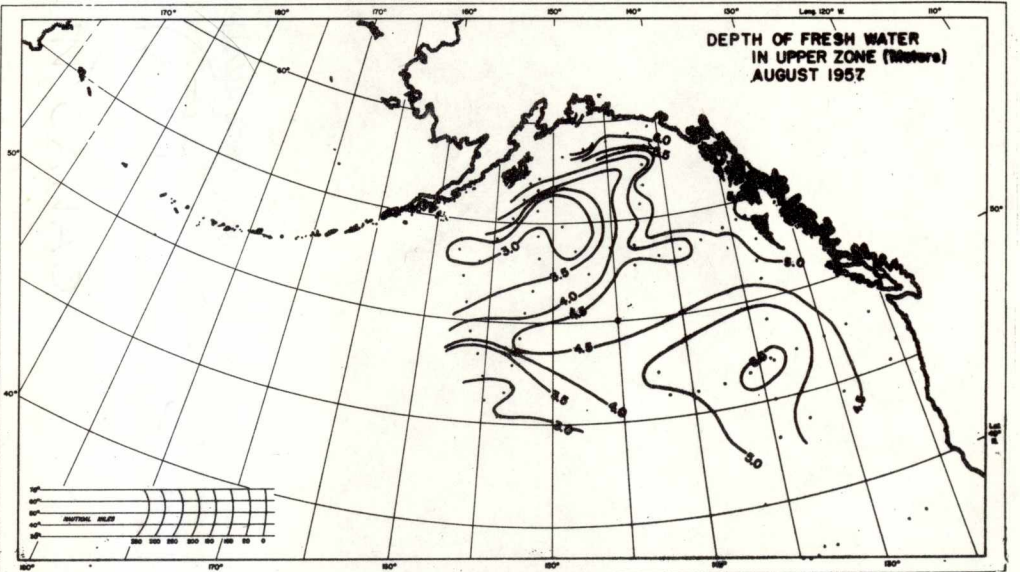
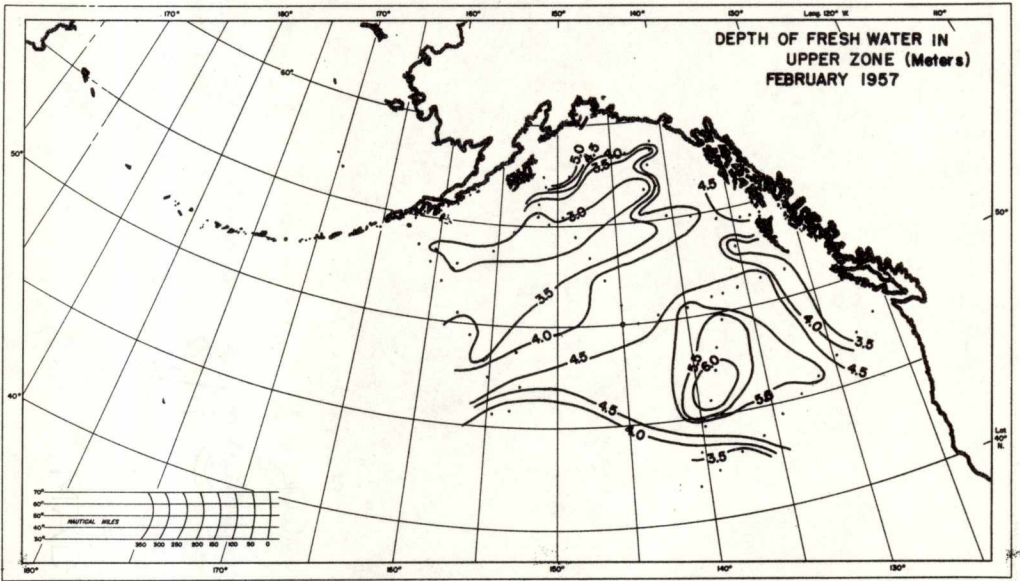
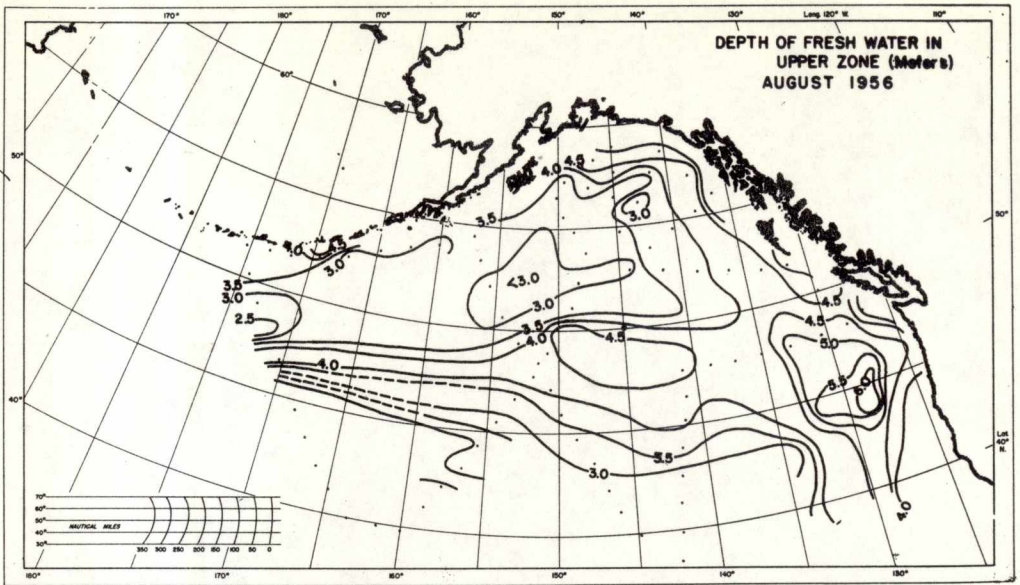


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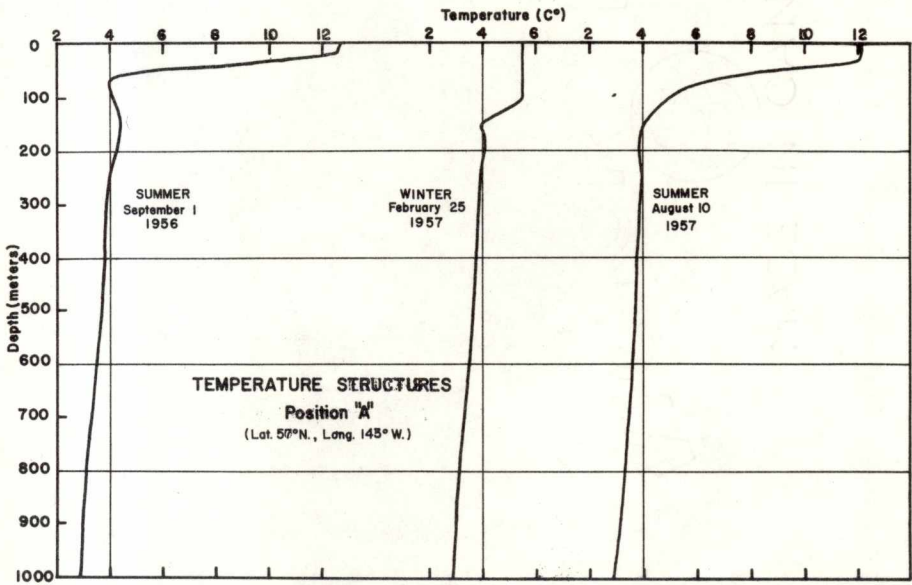
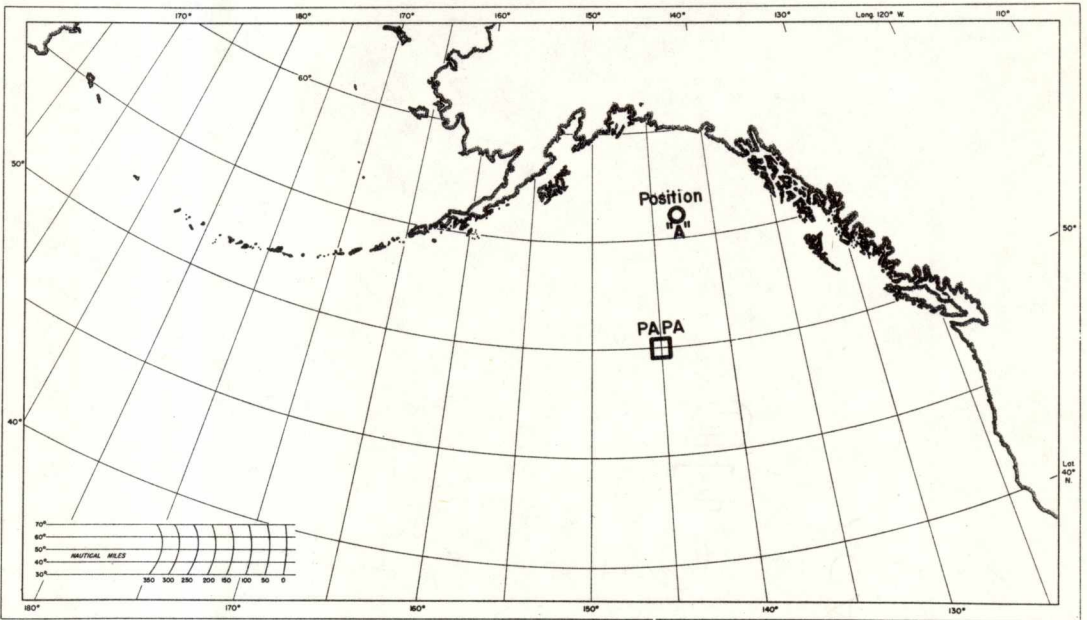
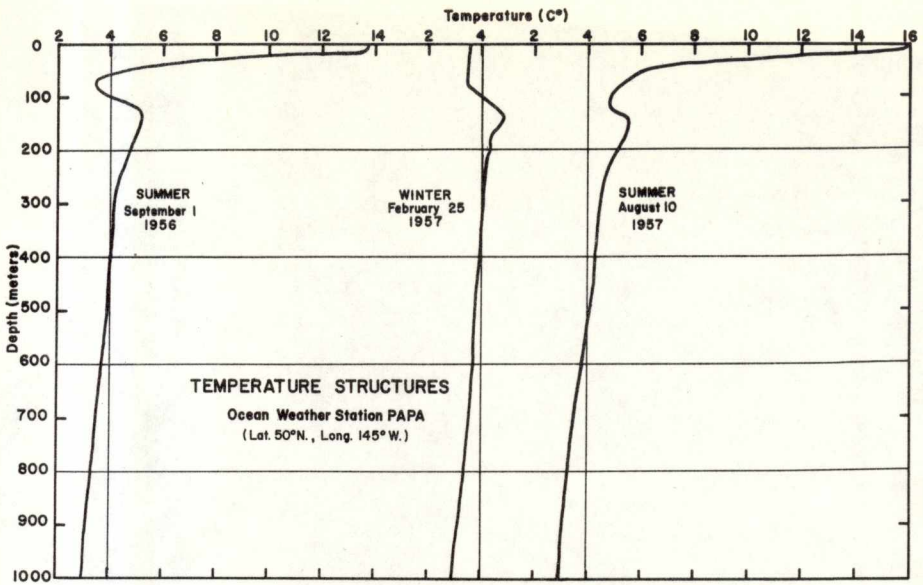


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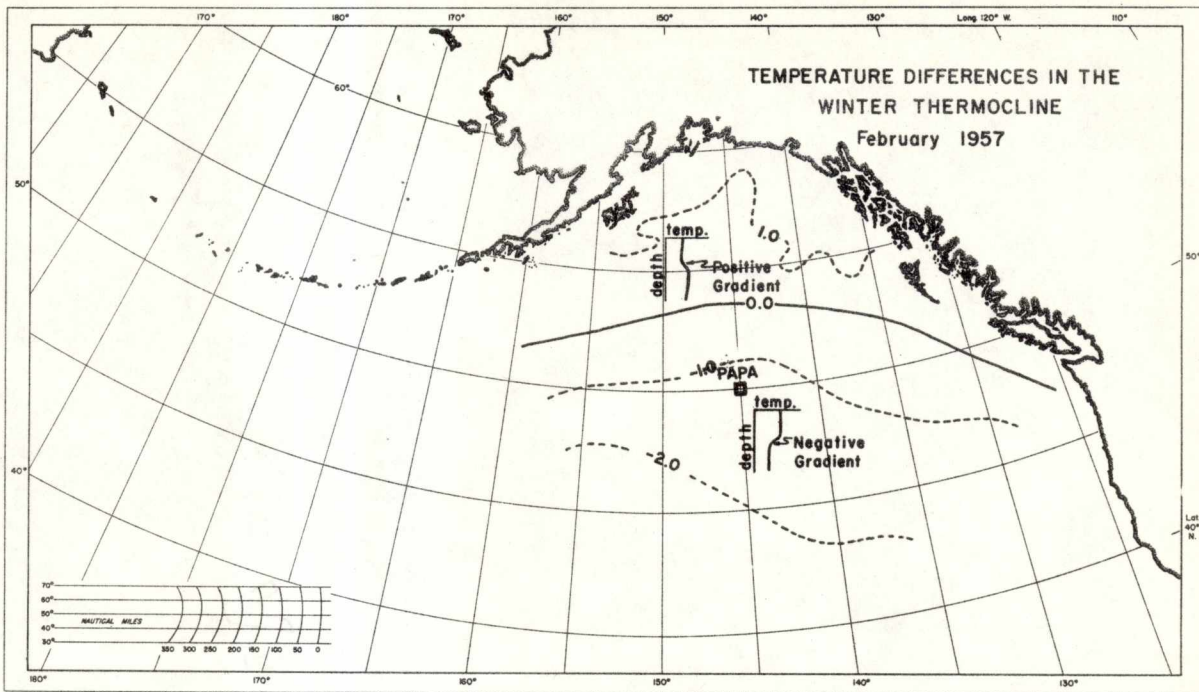


FIGURE 13

SEA WATER TEMPERATURES (°C) STATION PAPA, 1954-55

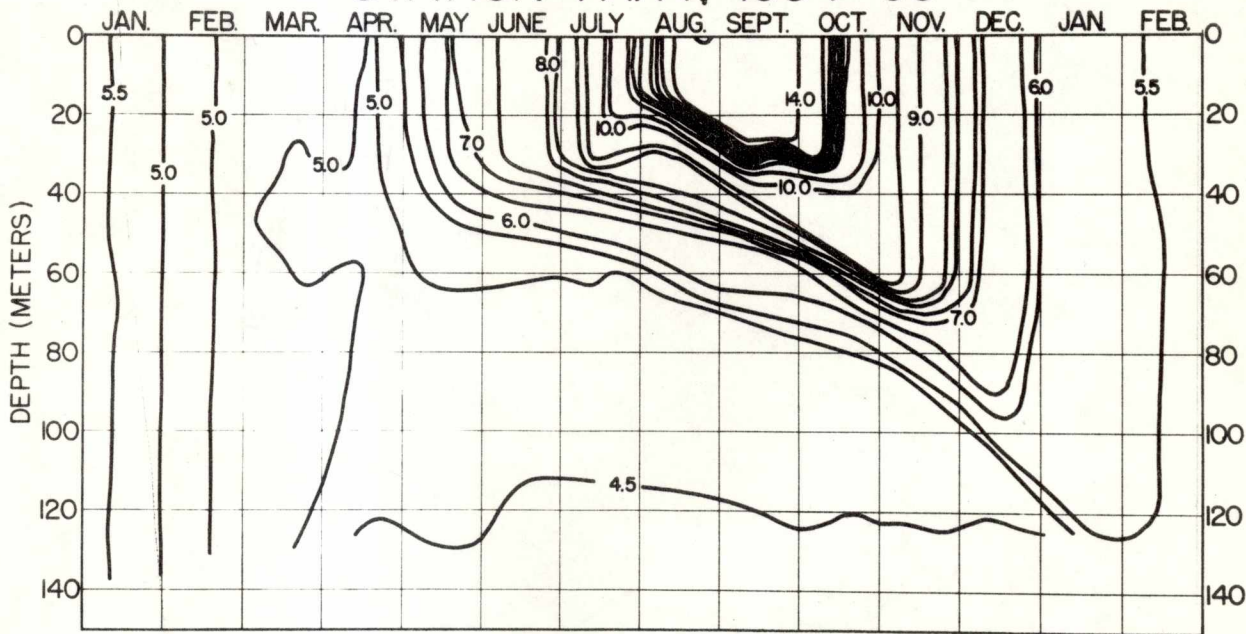


FIGURE 14

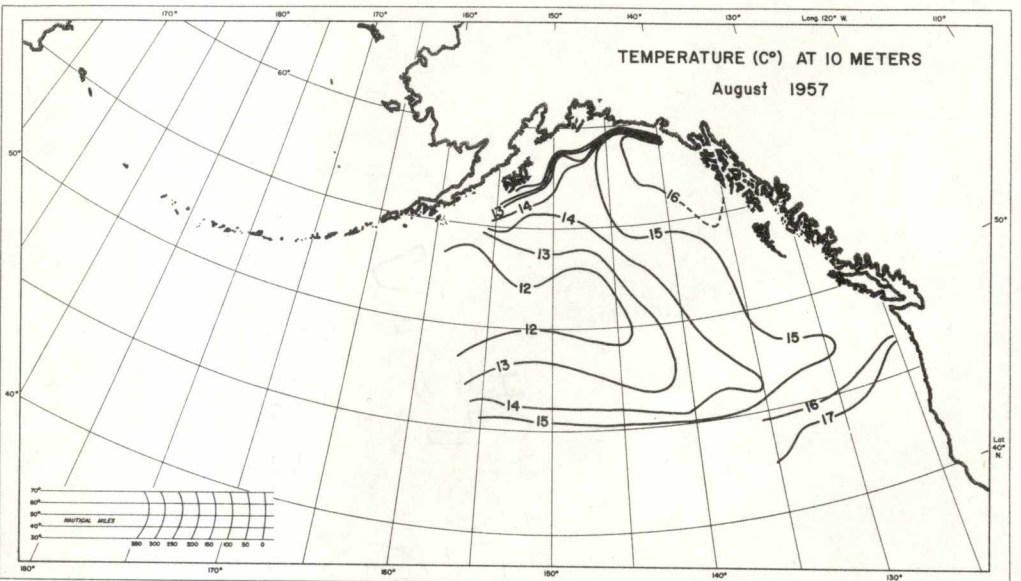
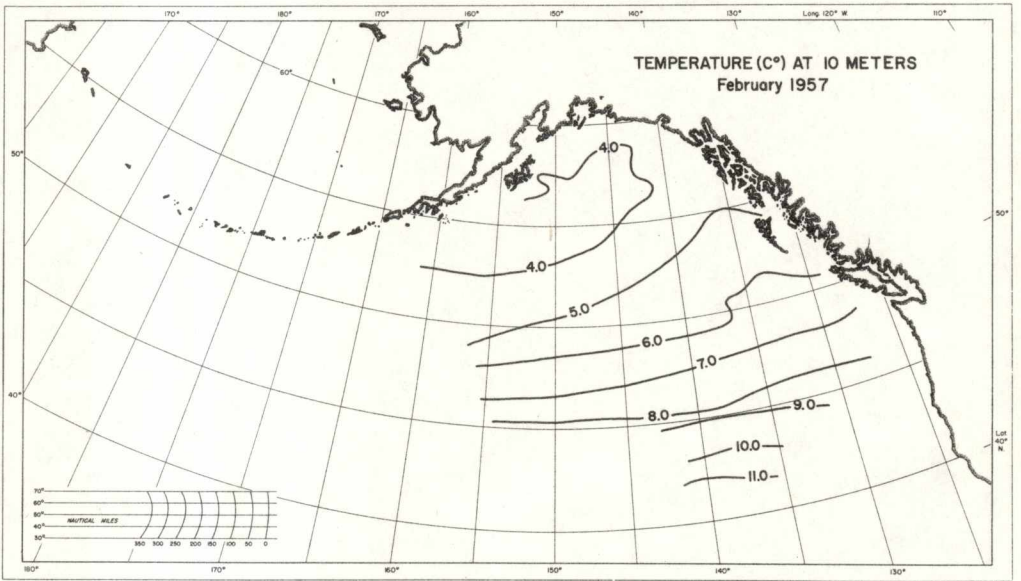
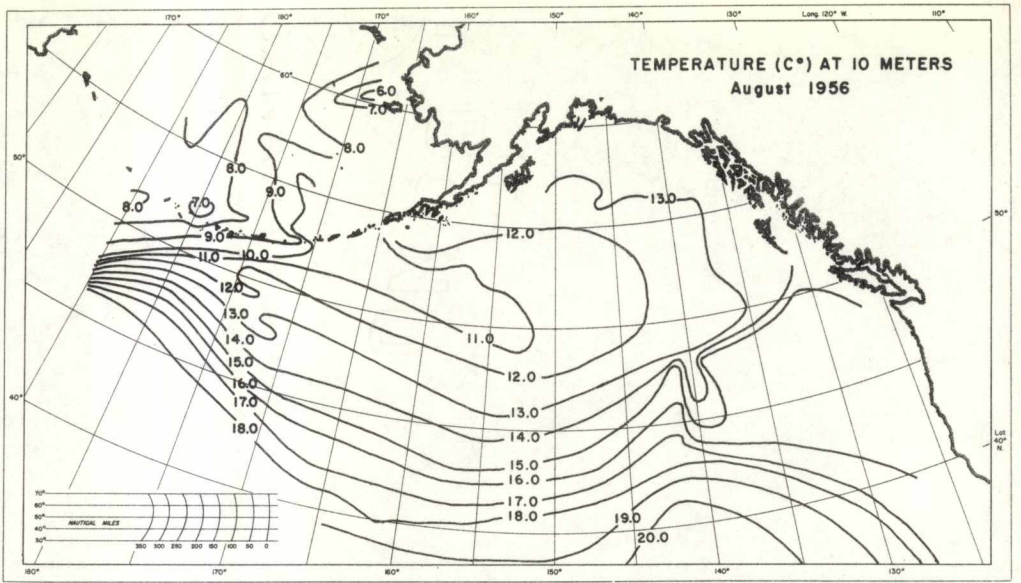


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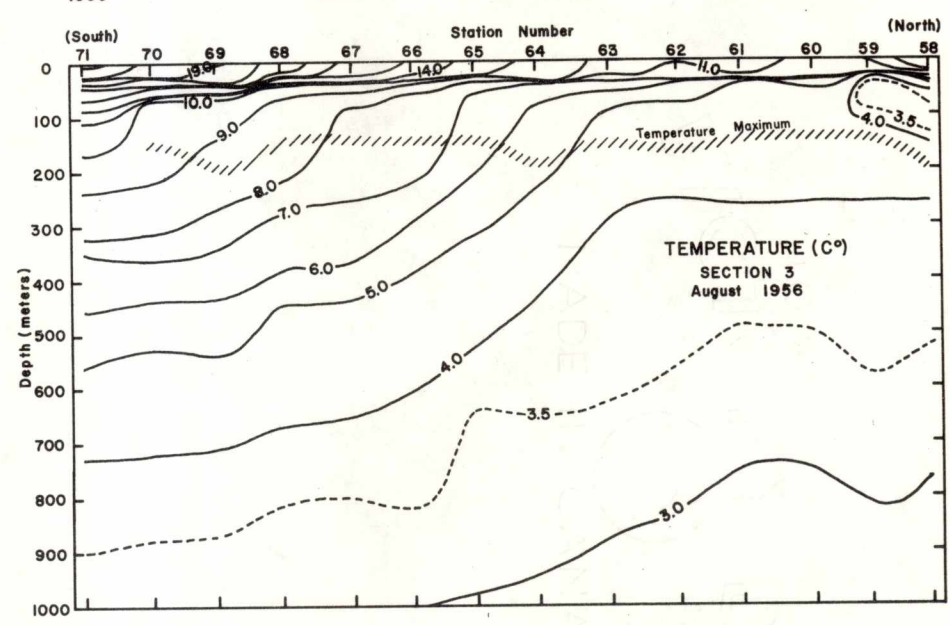
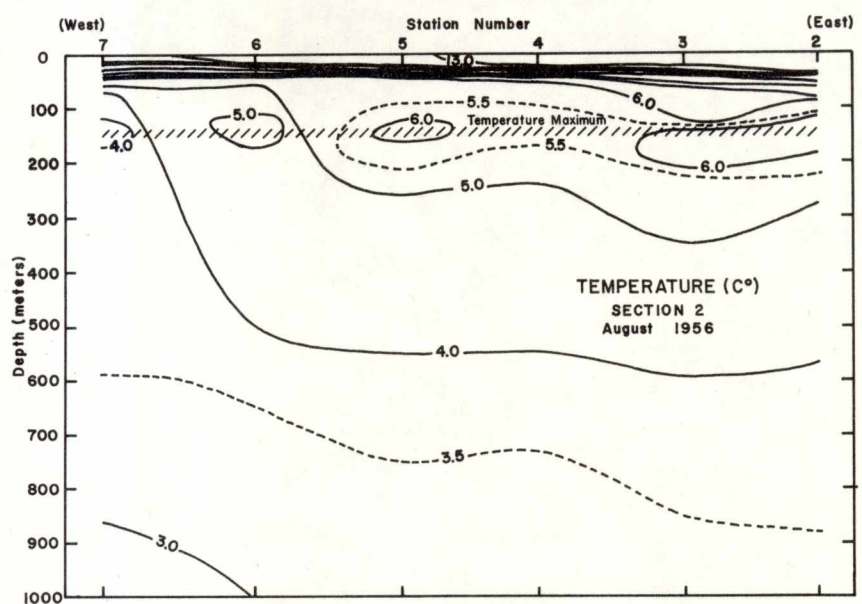
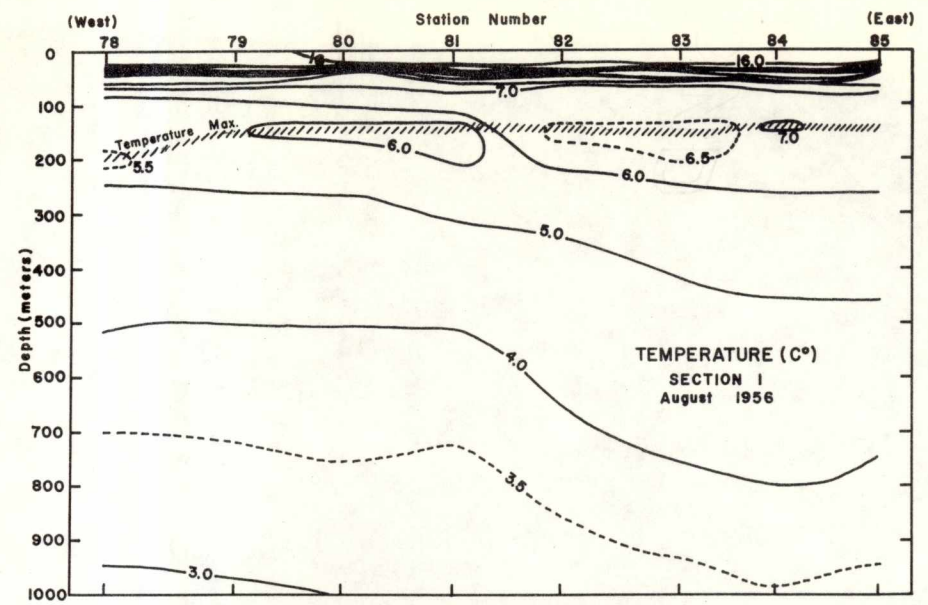


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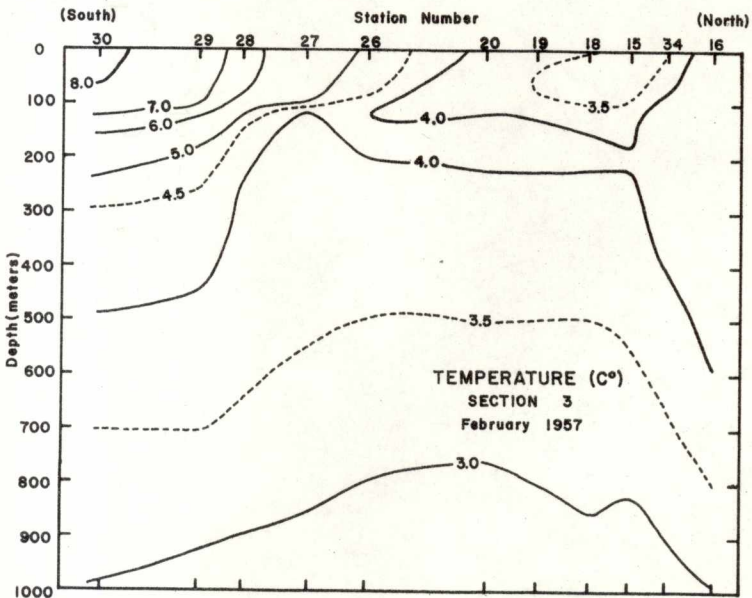
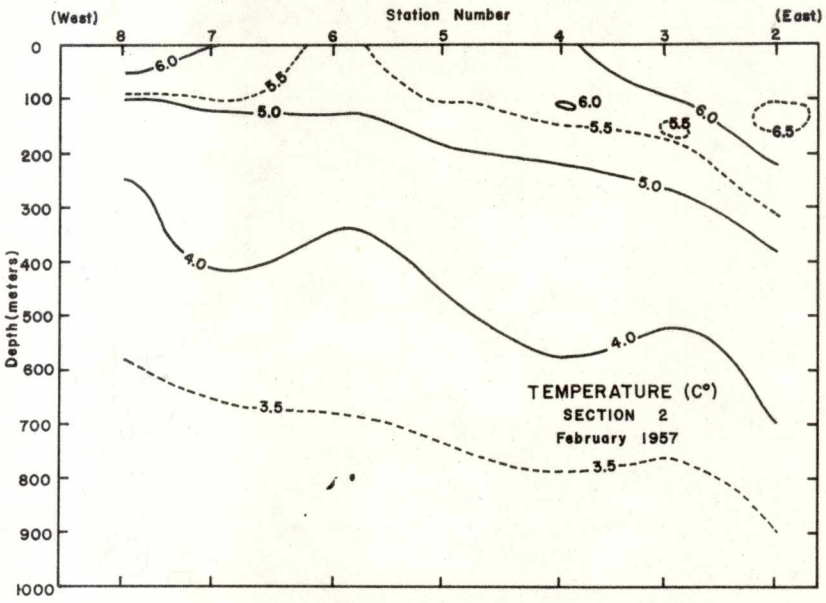
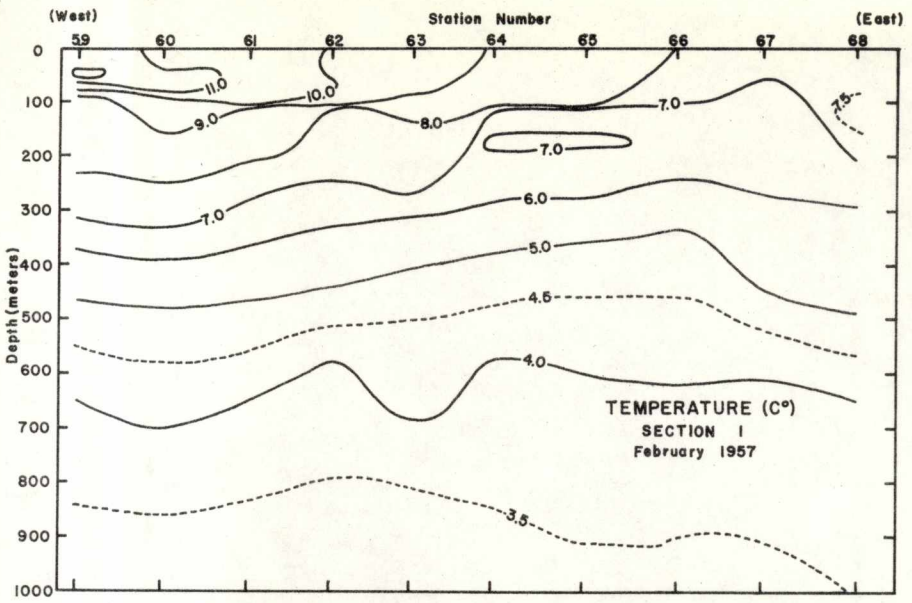


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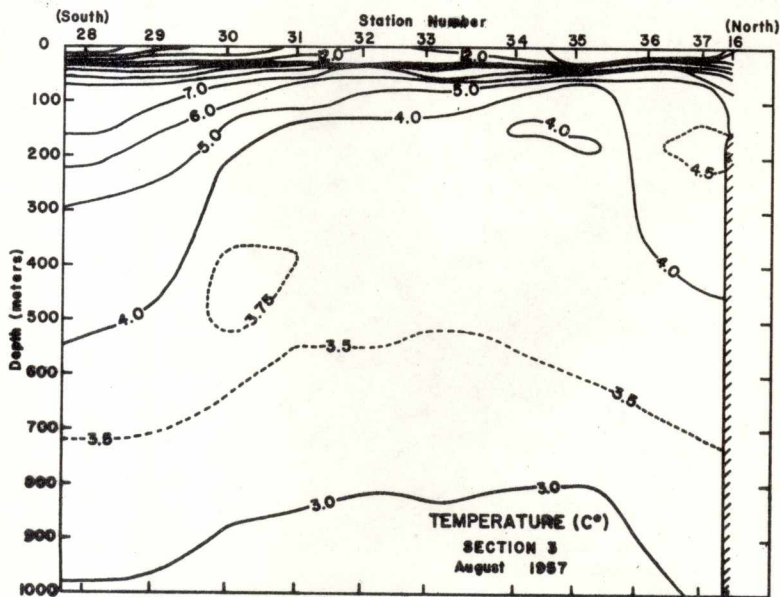
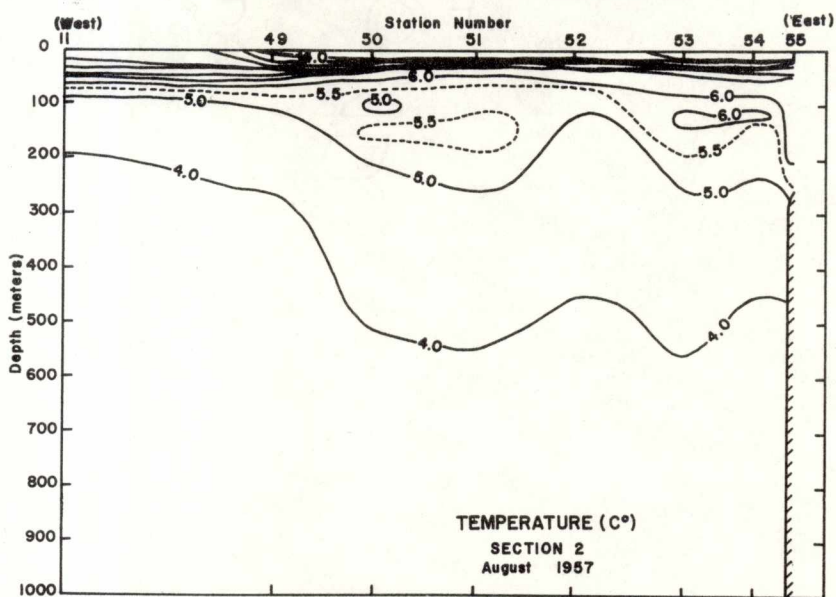
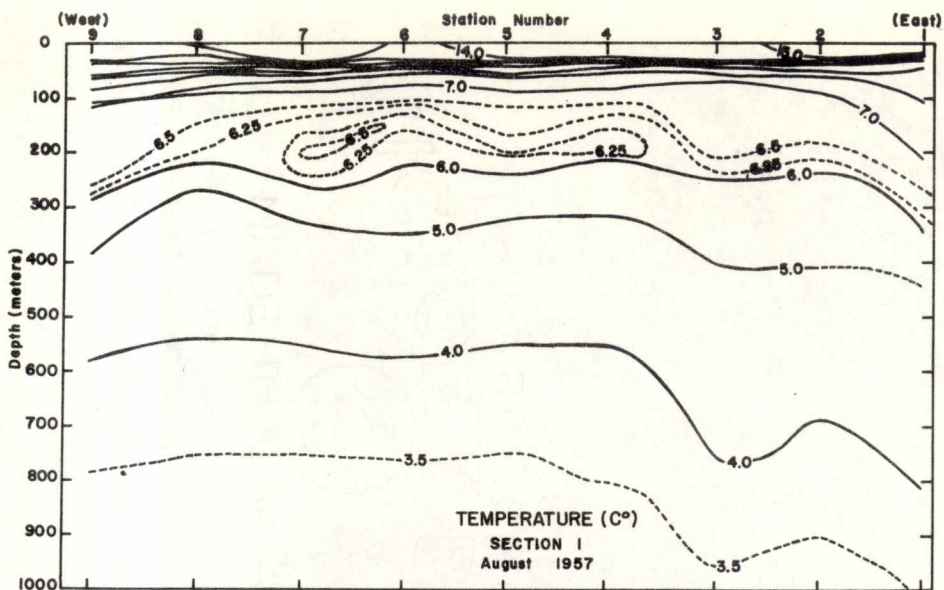


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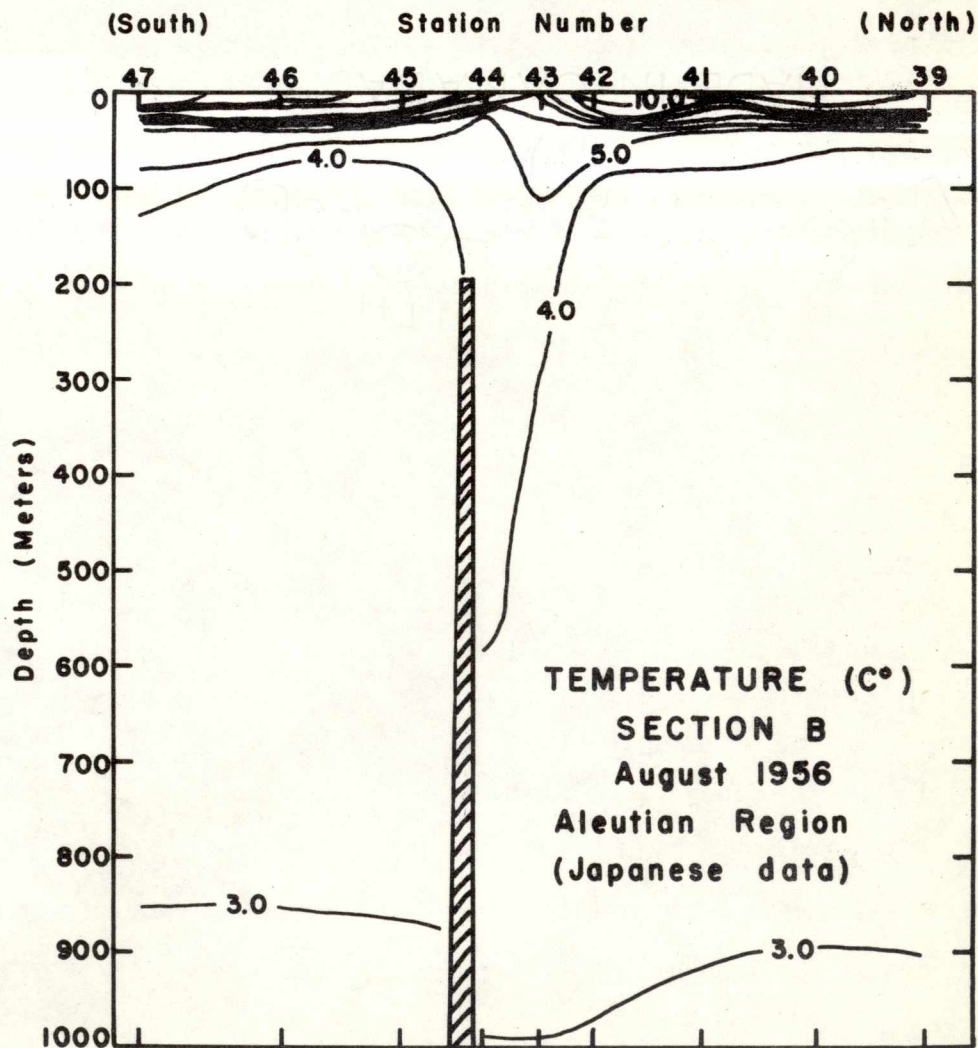
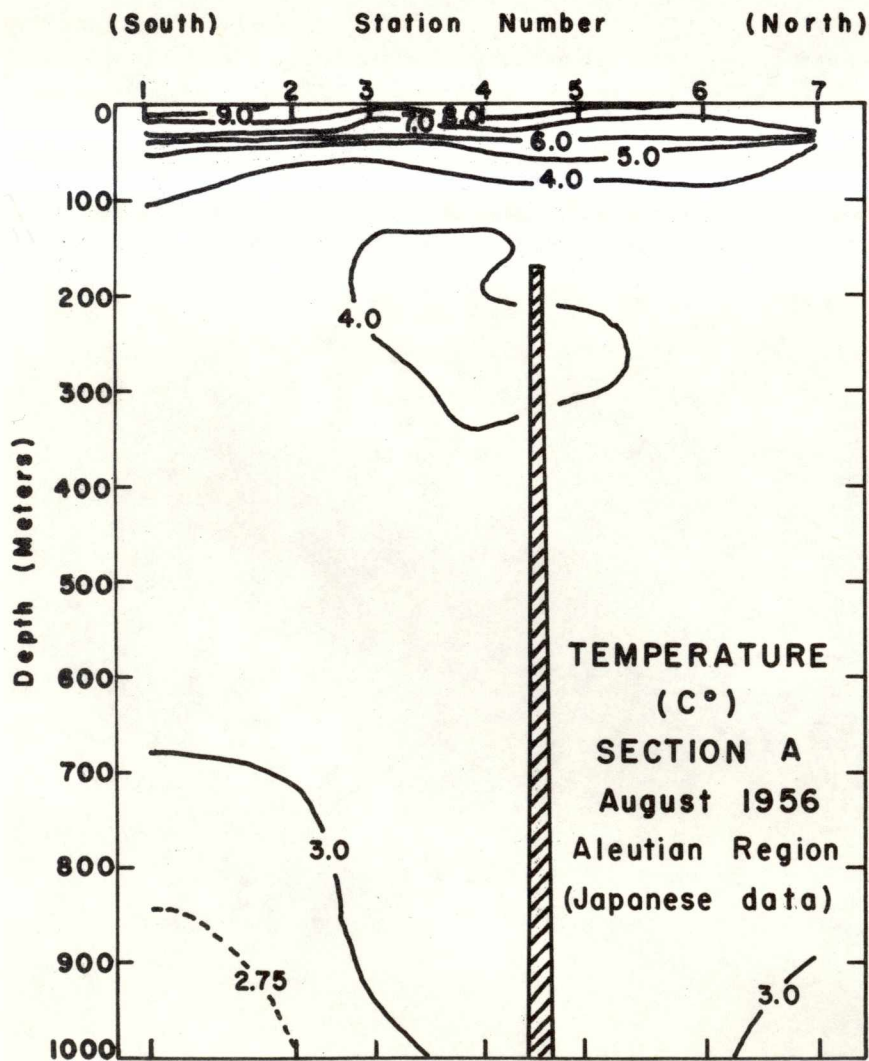


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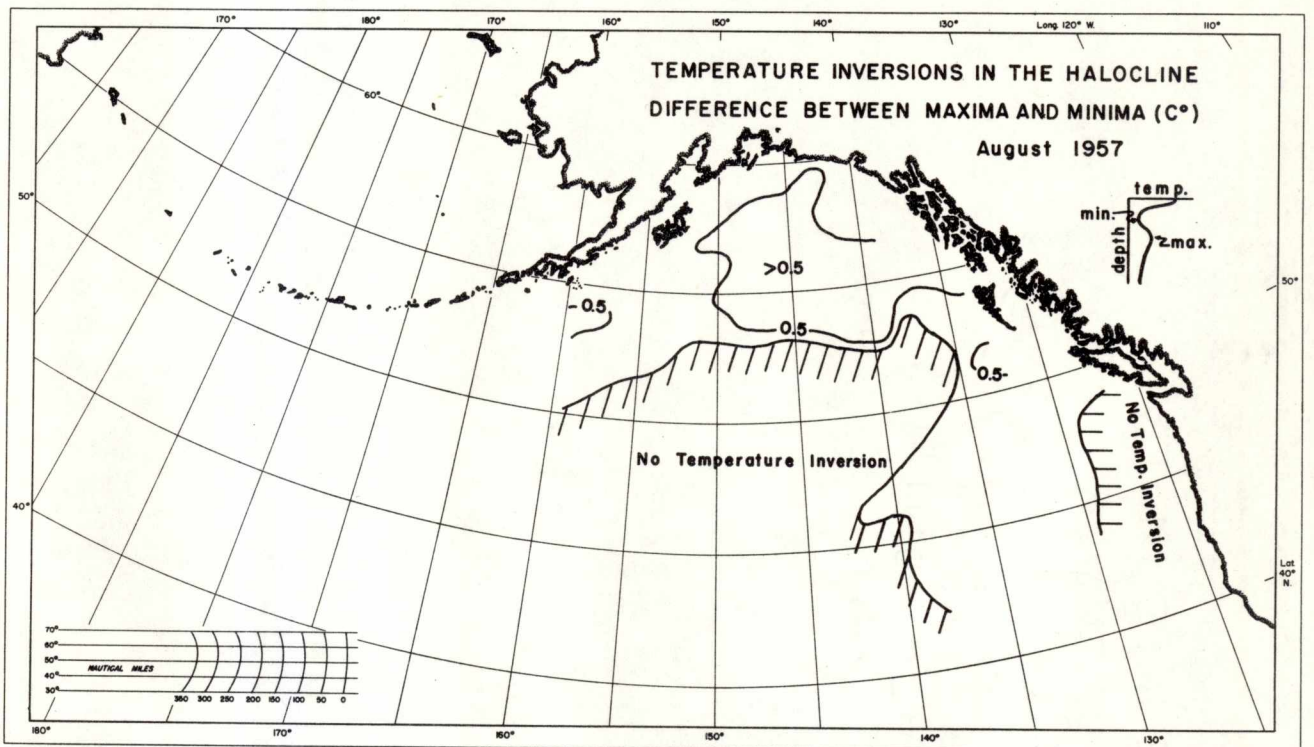
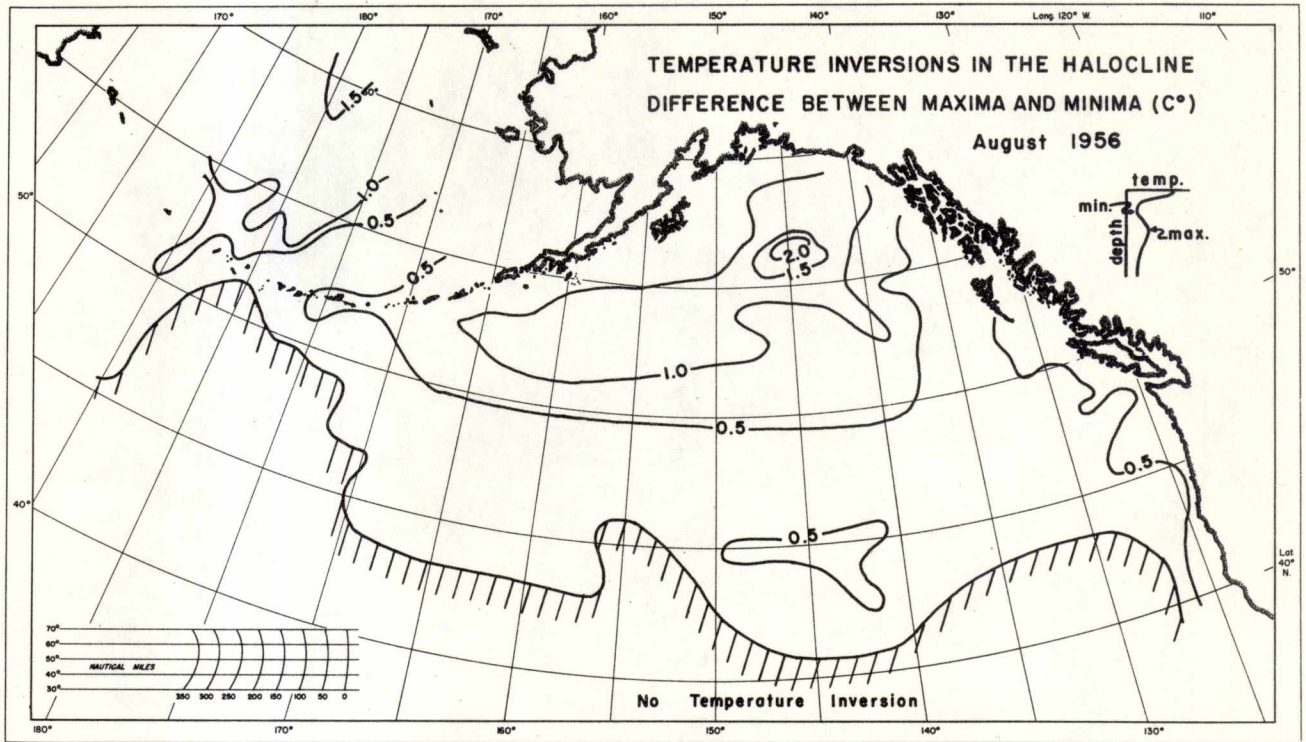


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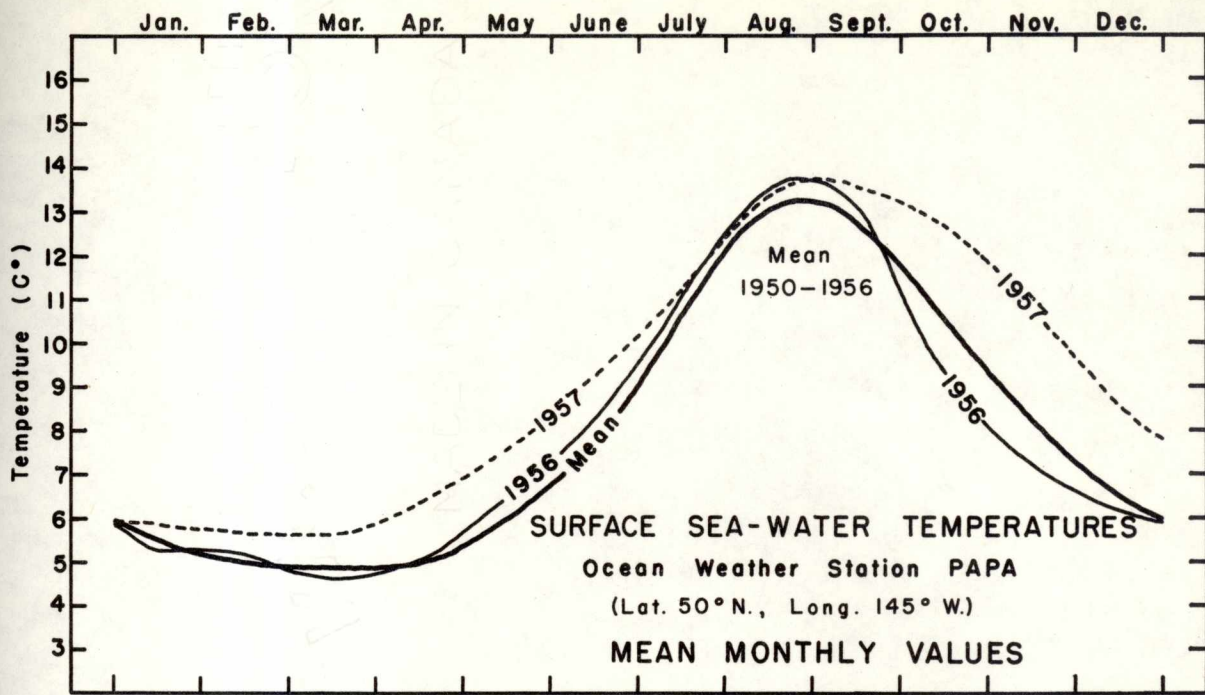


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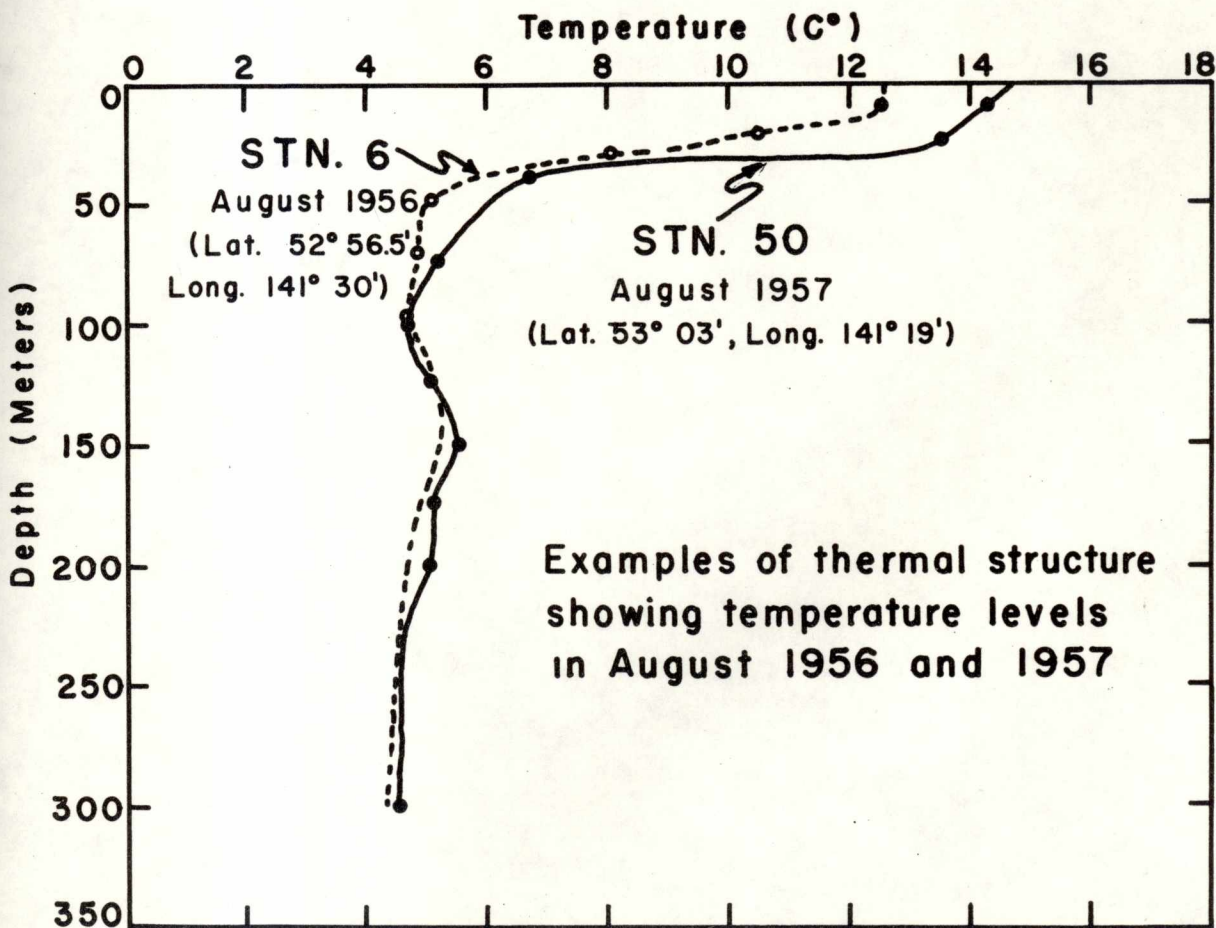
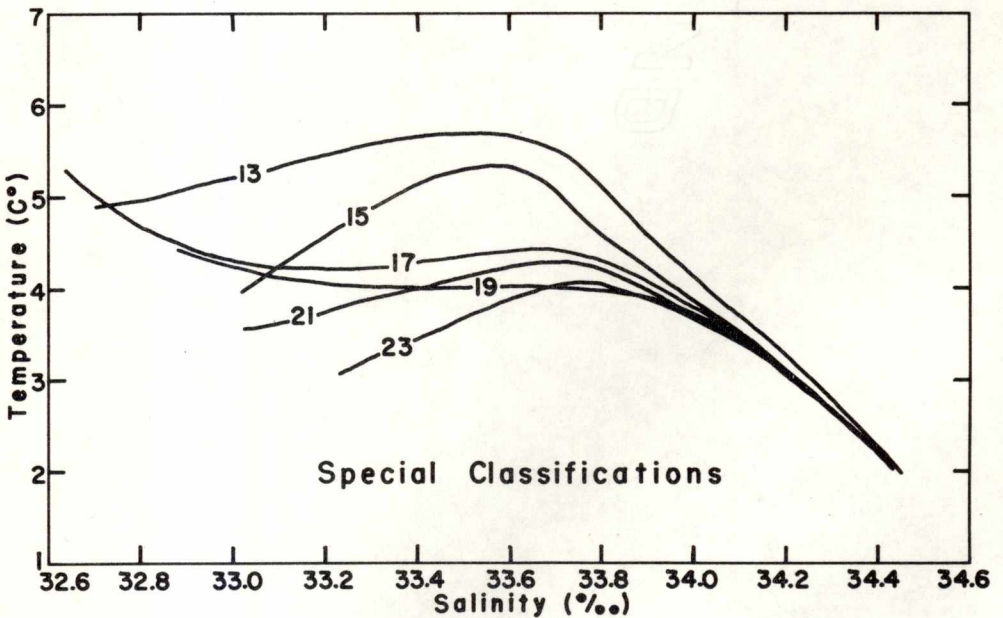
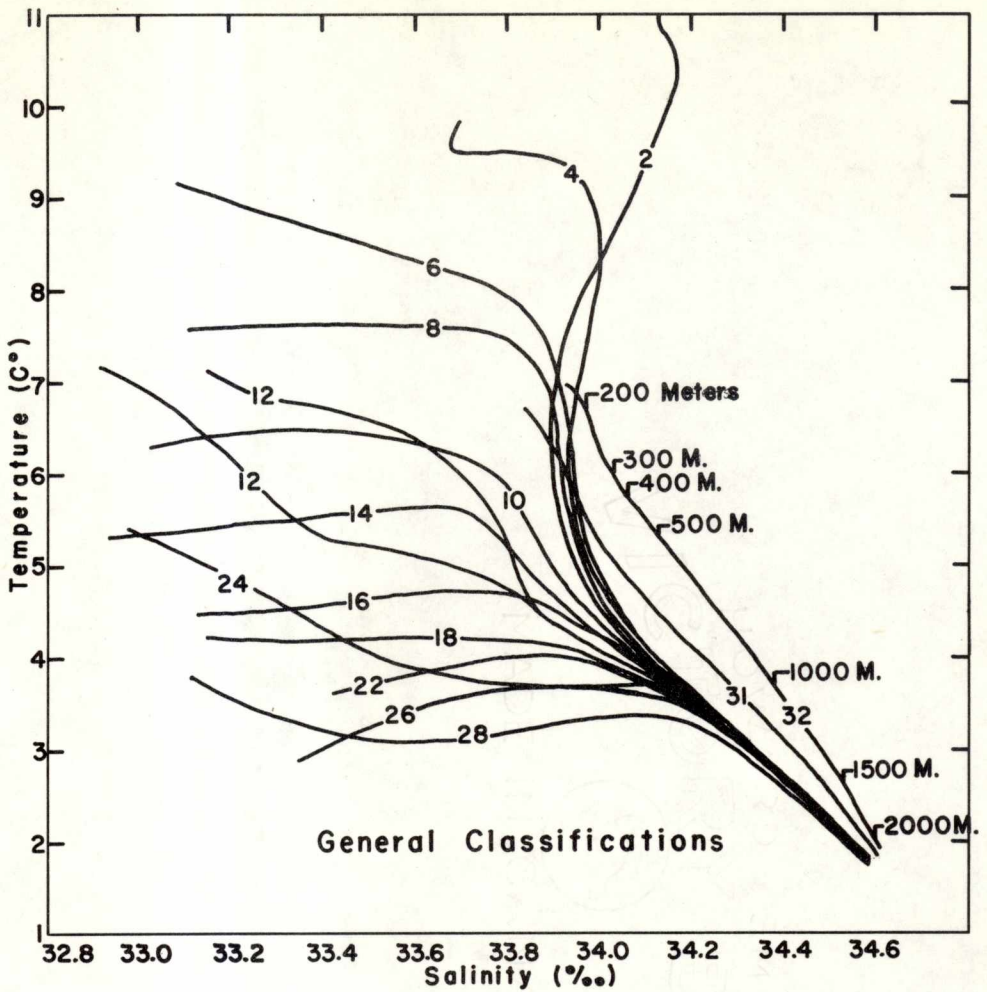


Figure 22



Classification of Water Masses
 Temperature-Salinity Diagram
 Figure 23

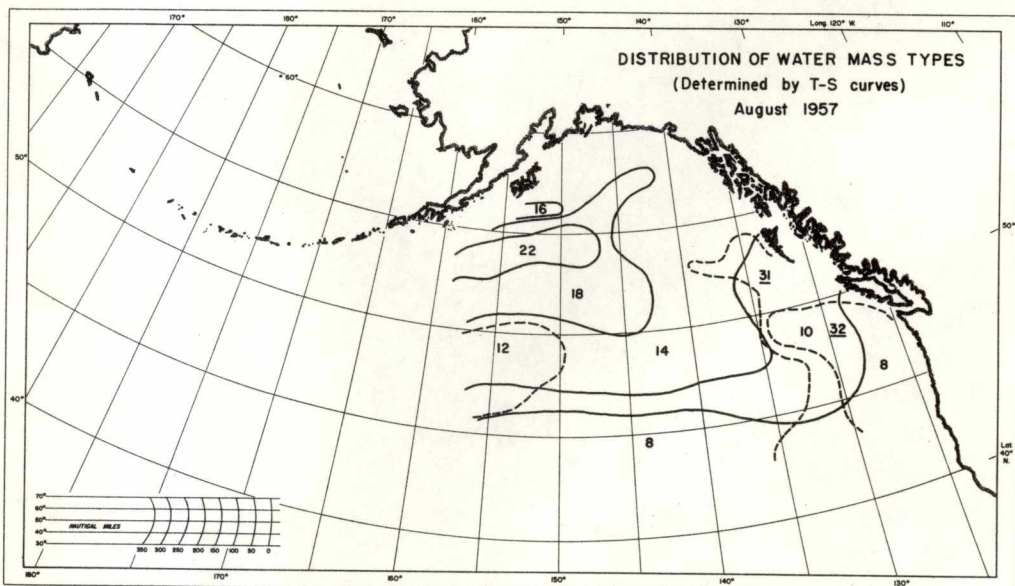
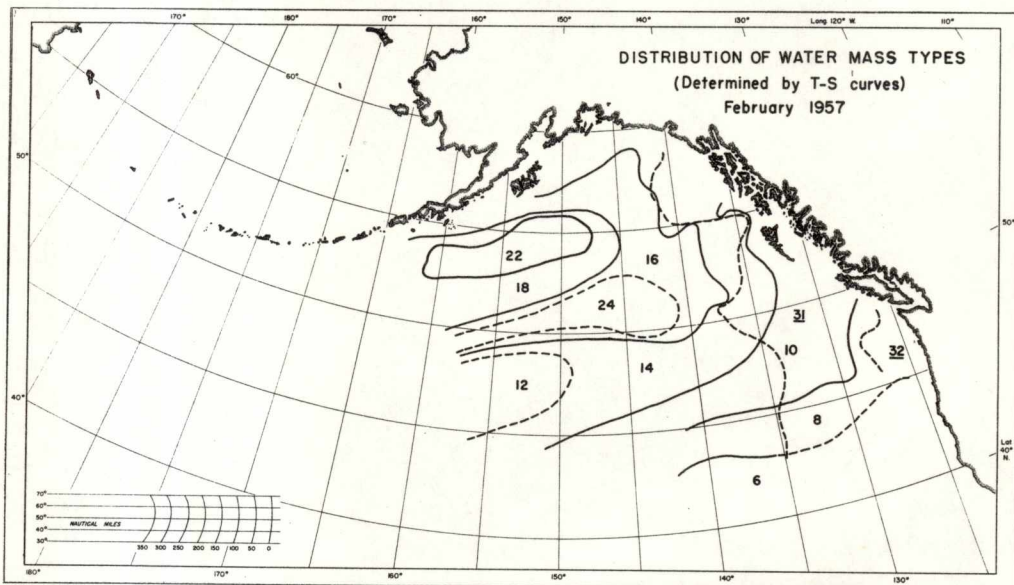
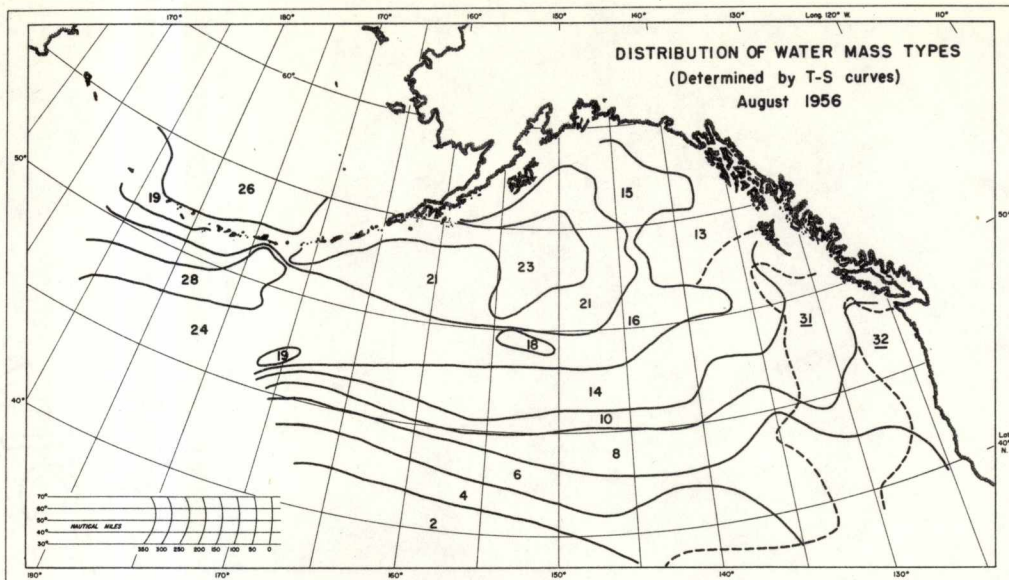


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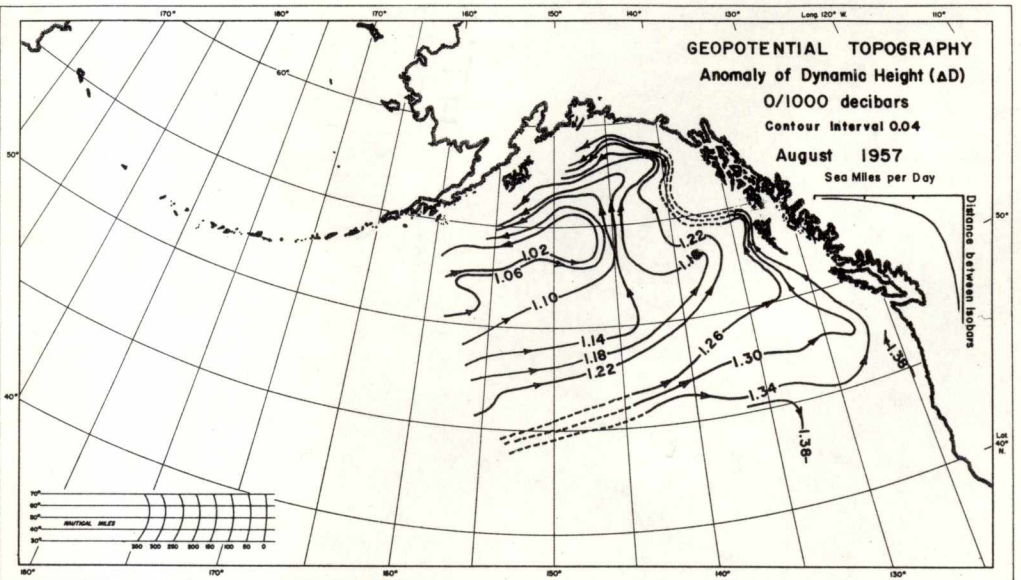
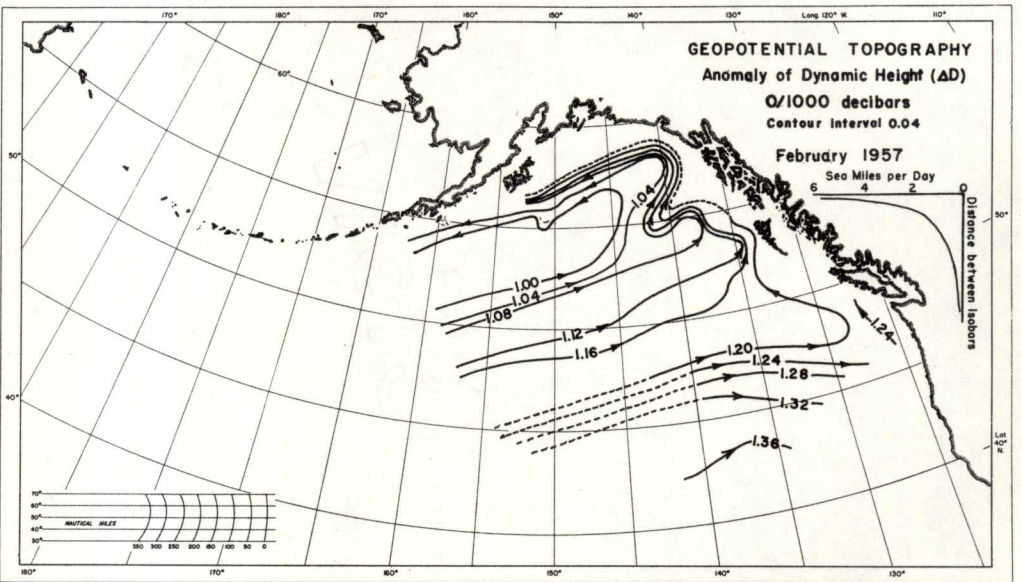
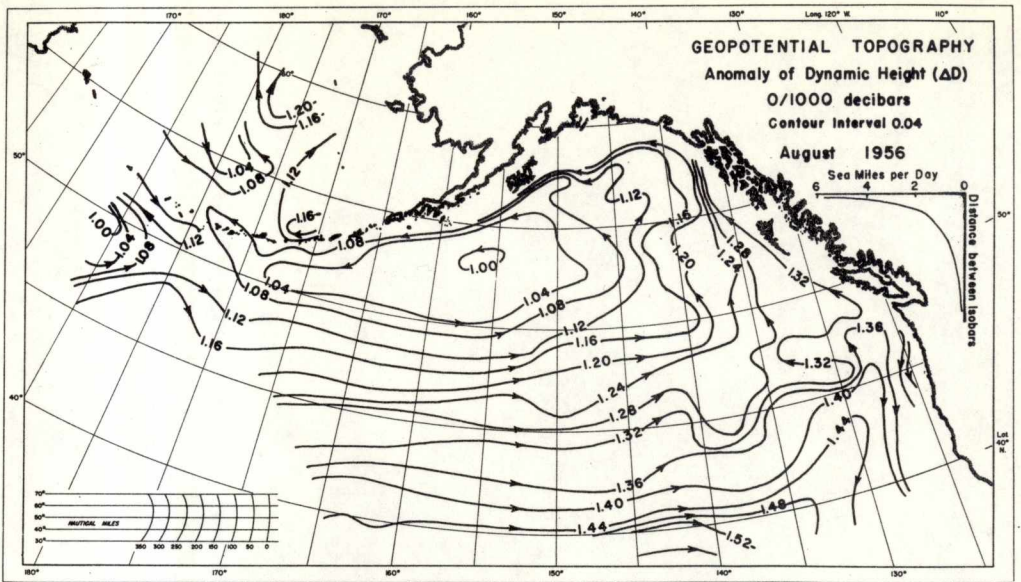


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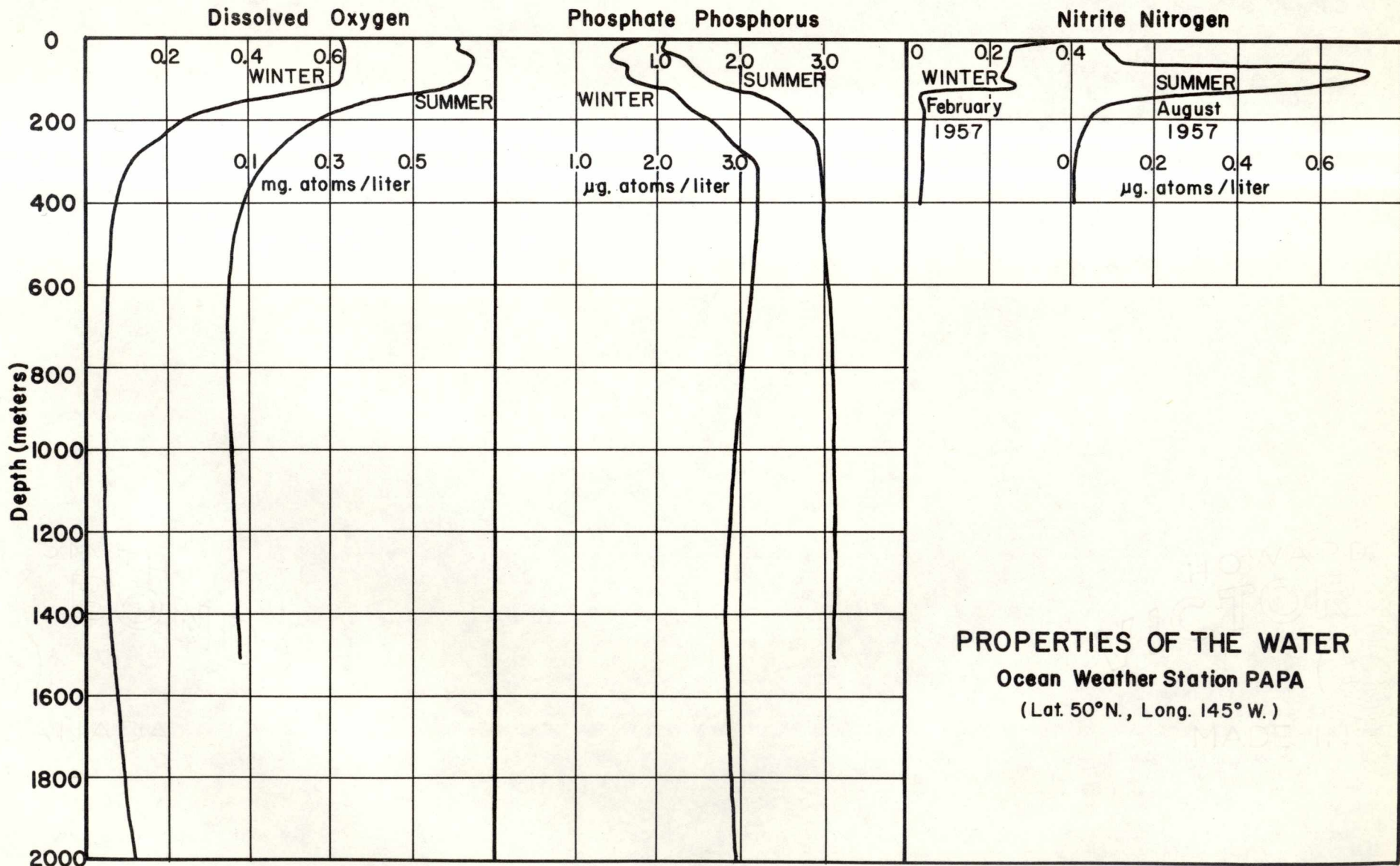


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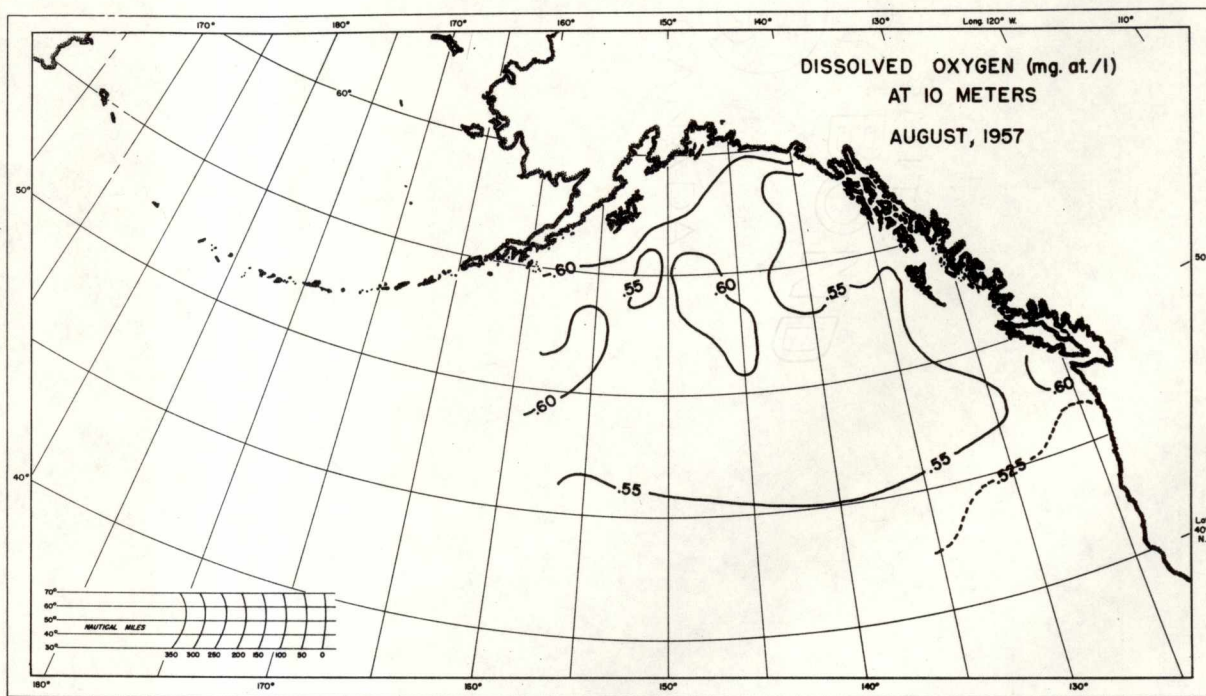
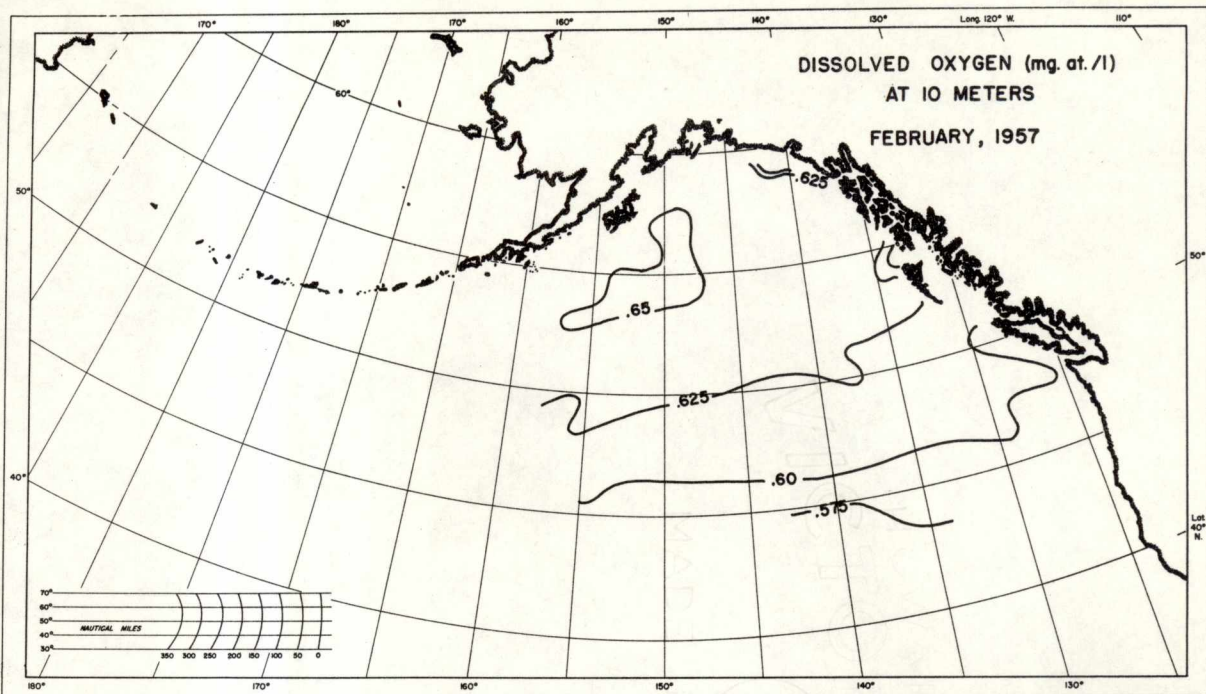


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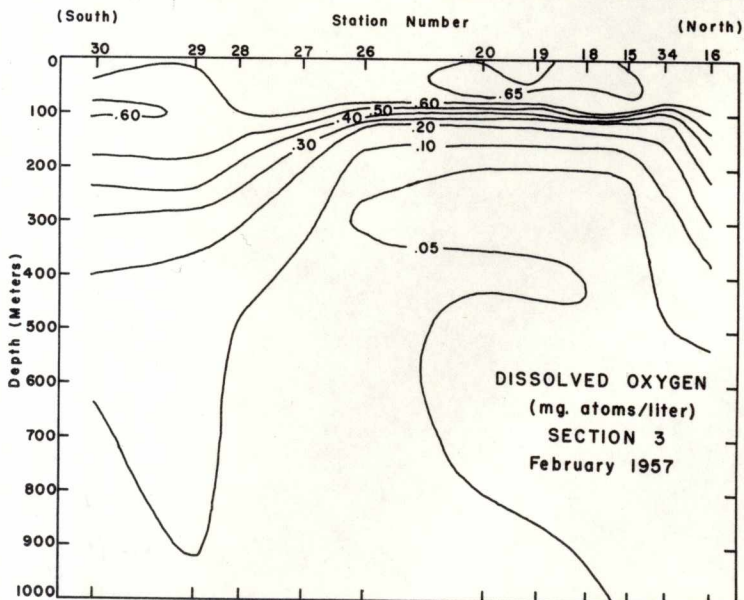
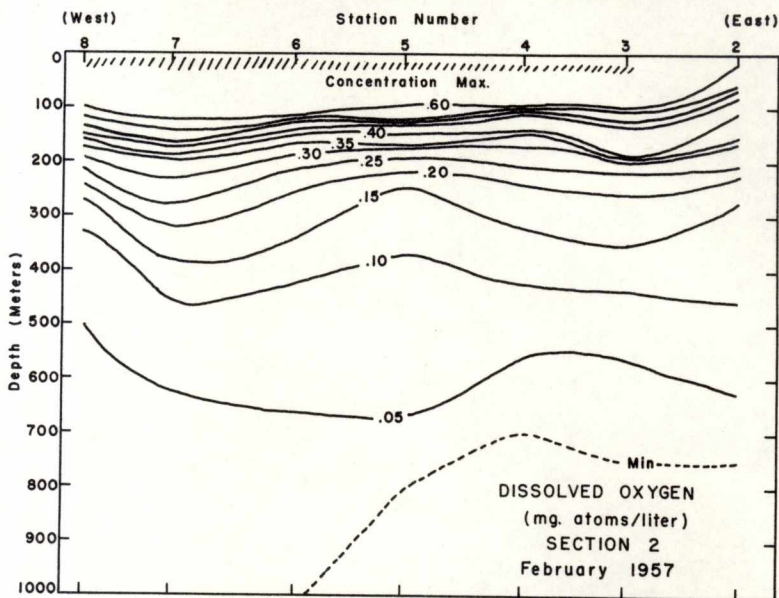
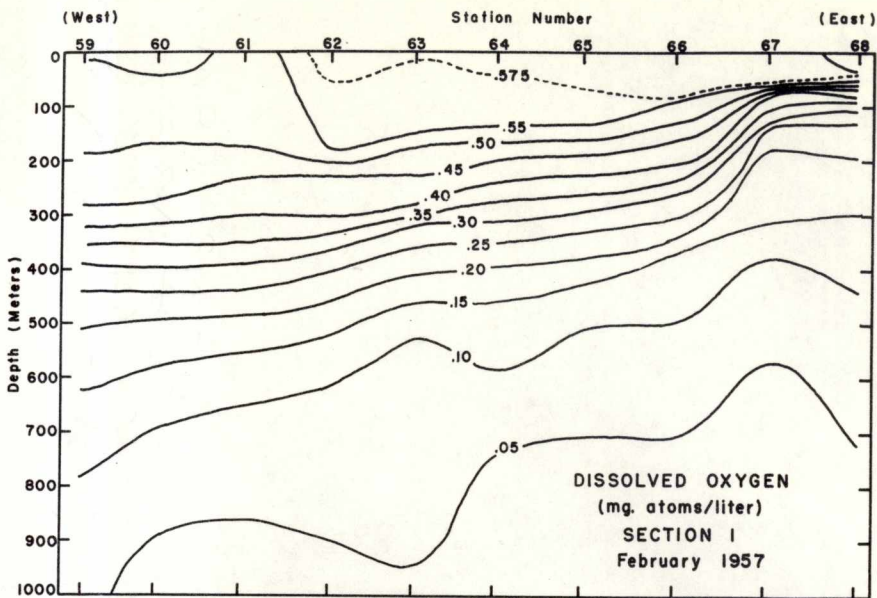


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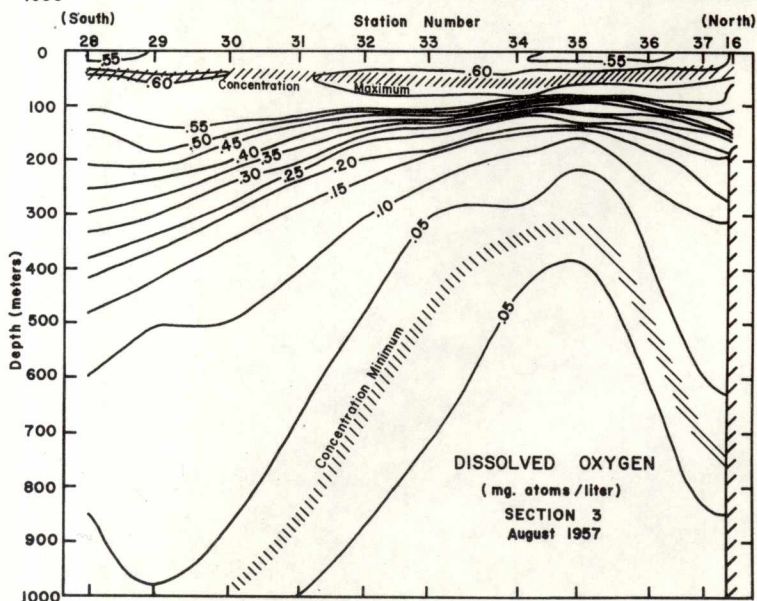
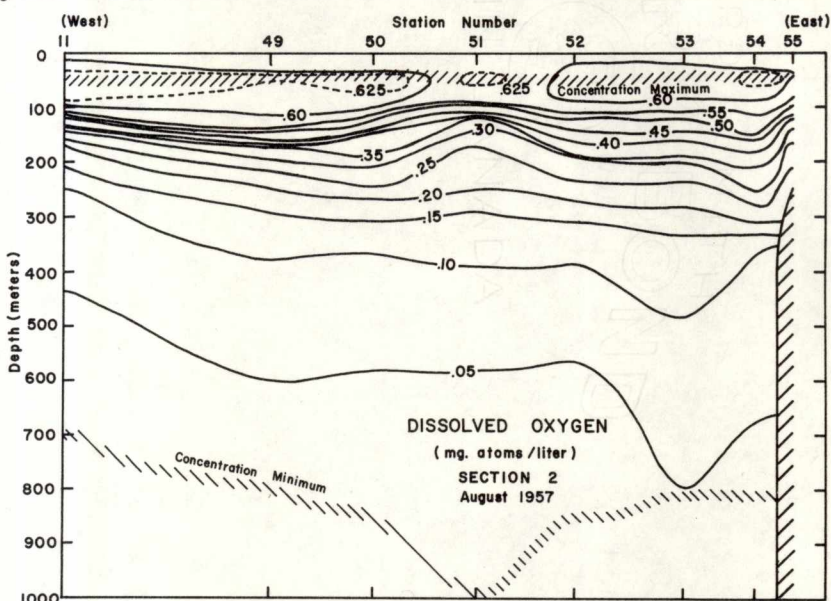
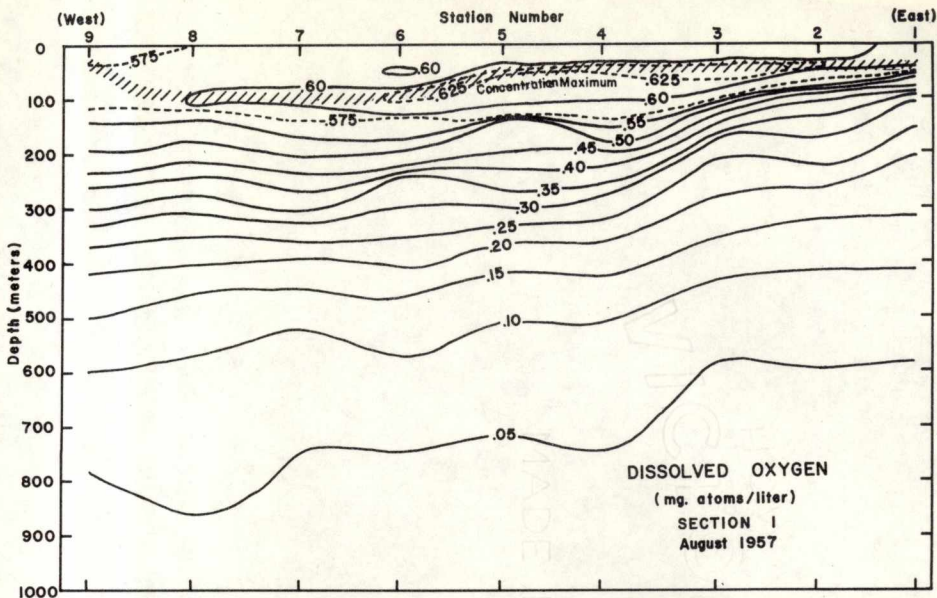


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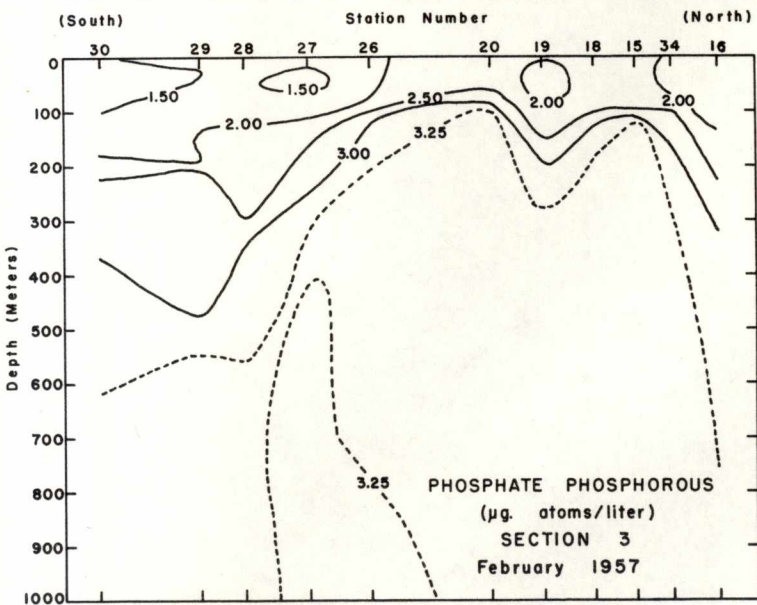
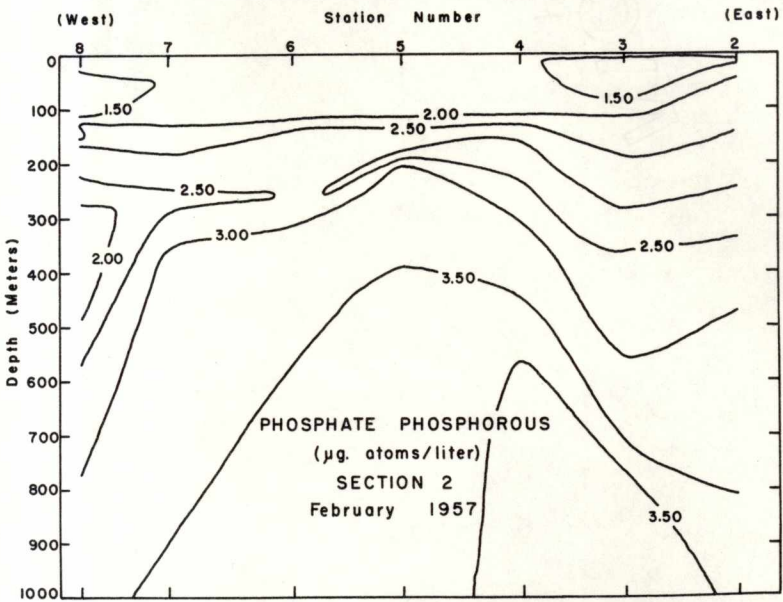
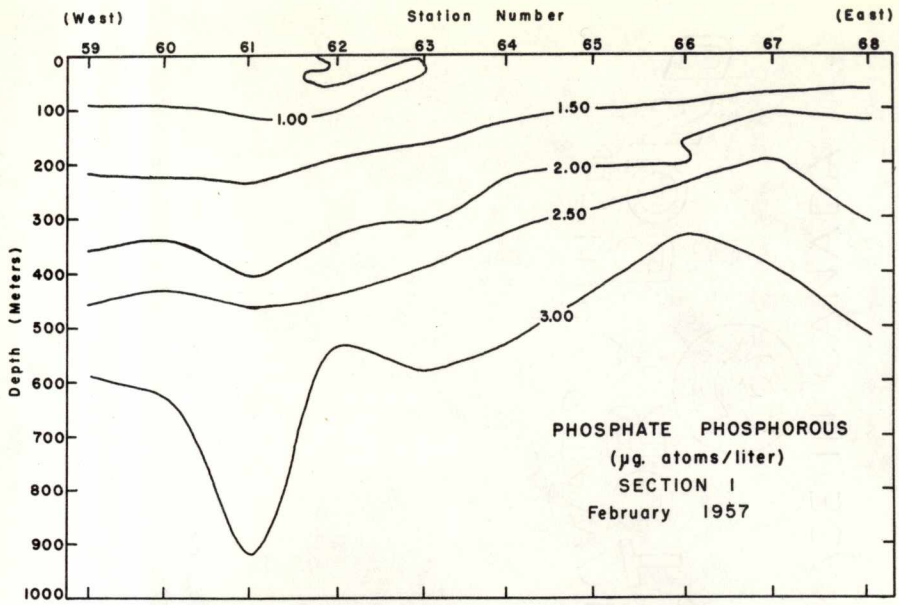


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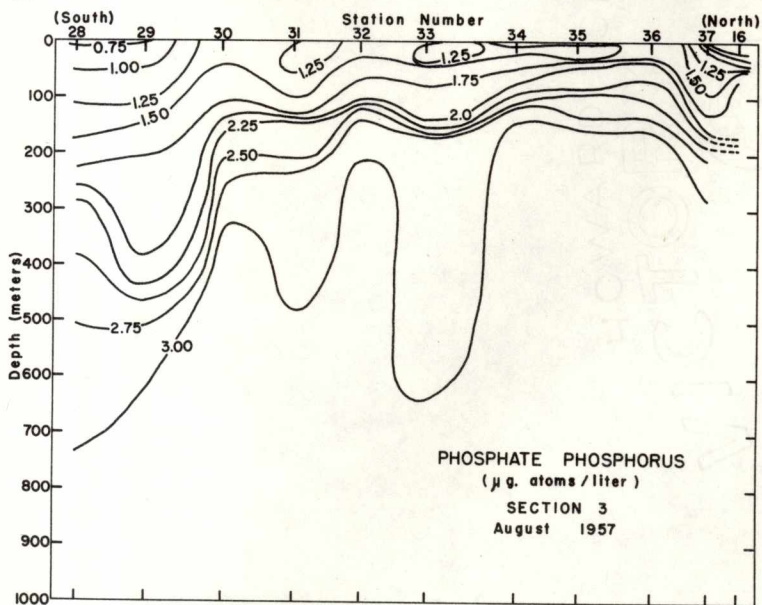
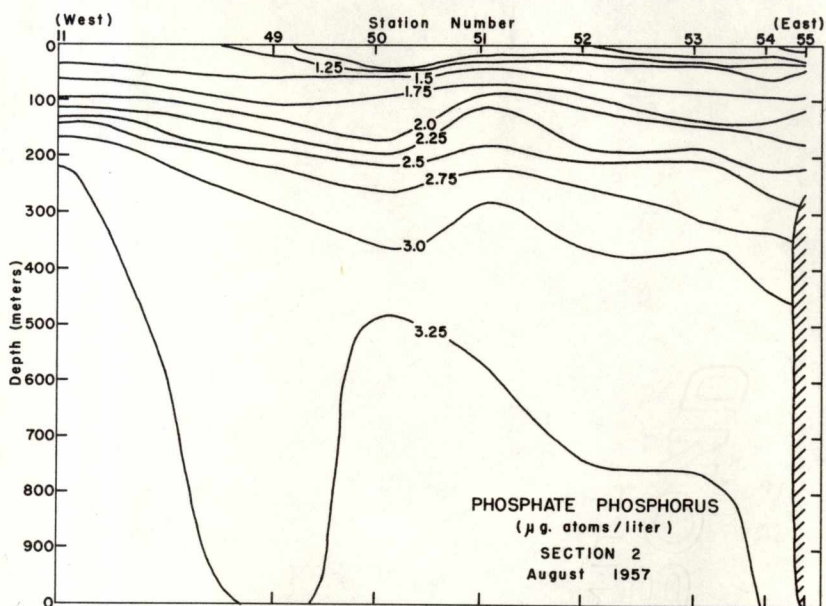
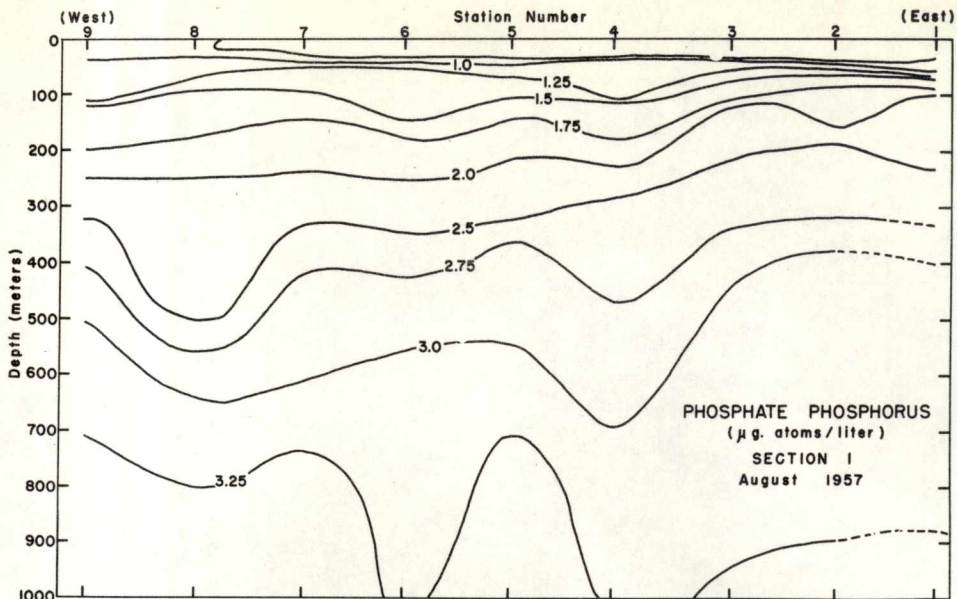


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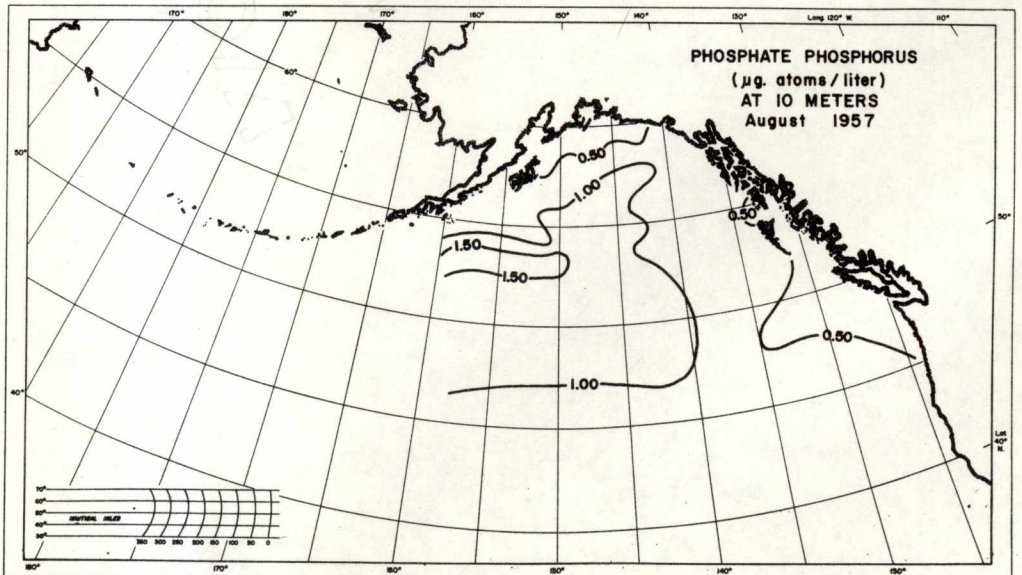
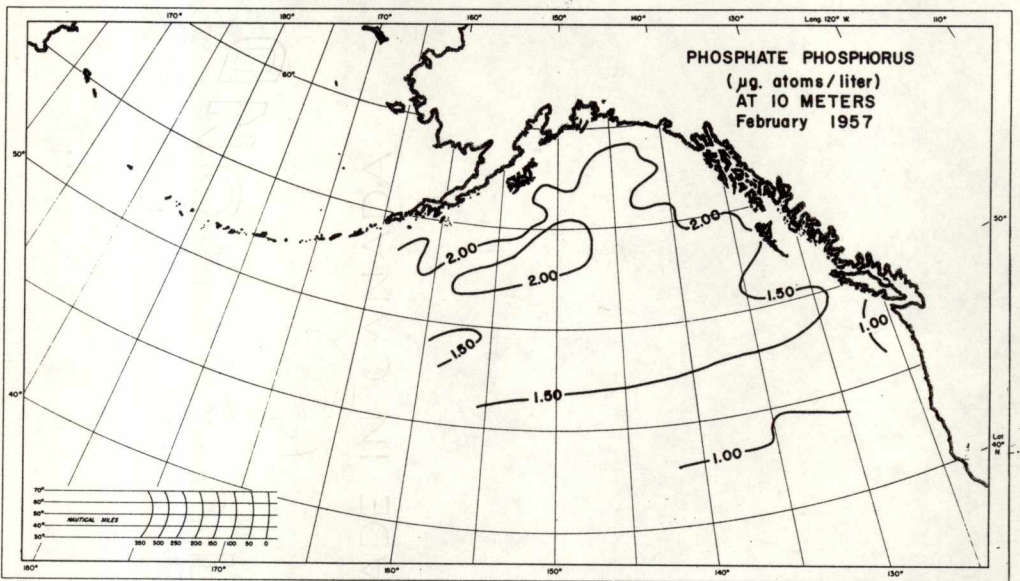
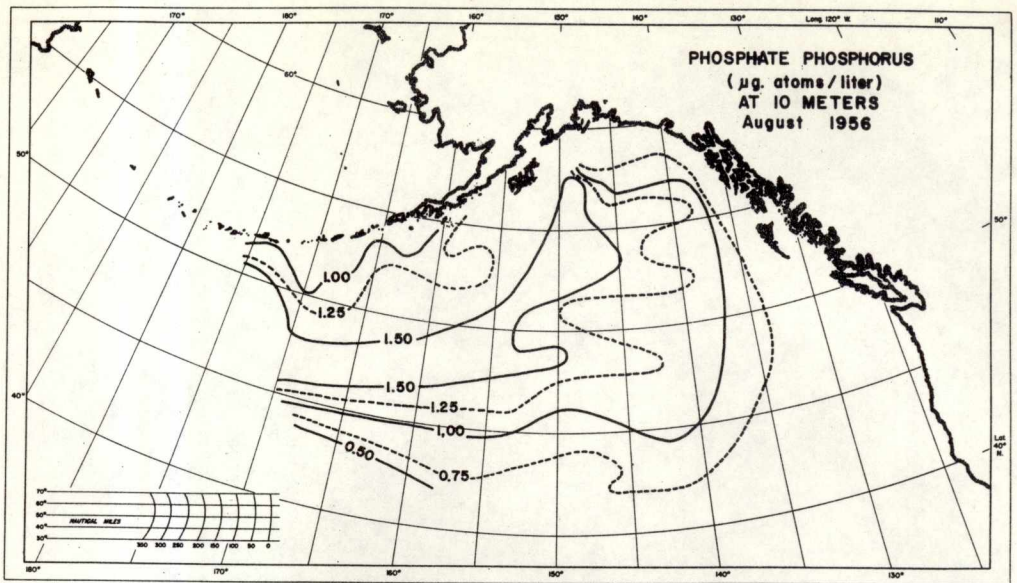


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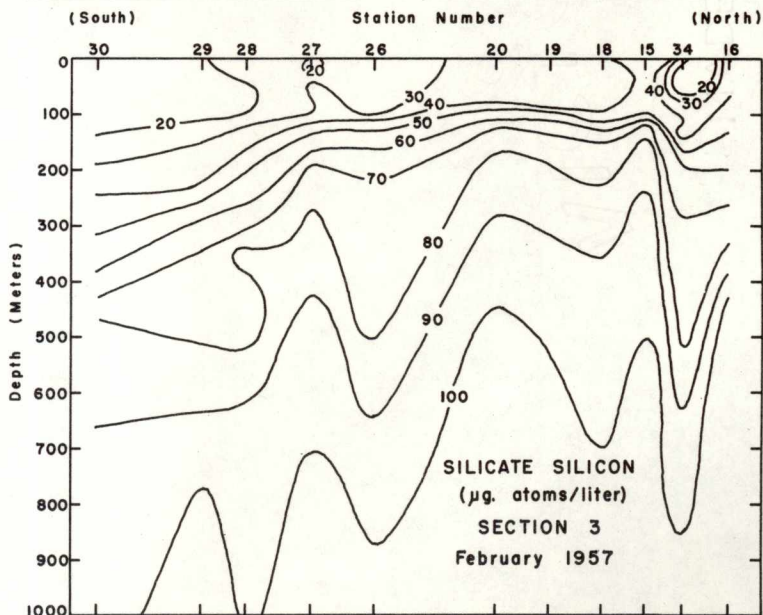
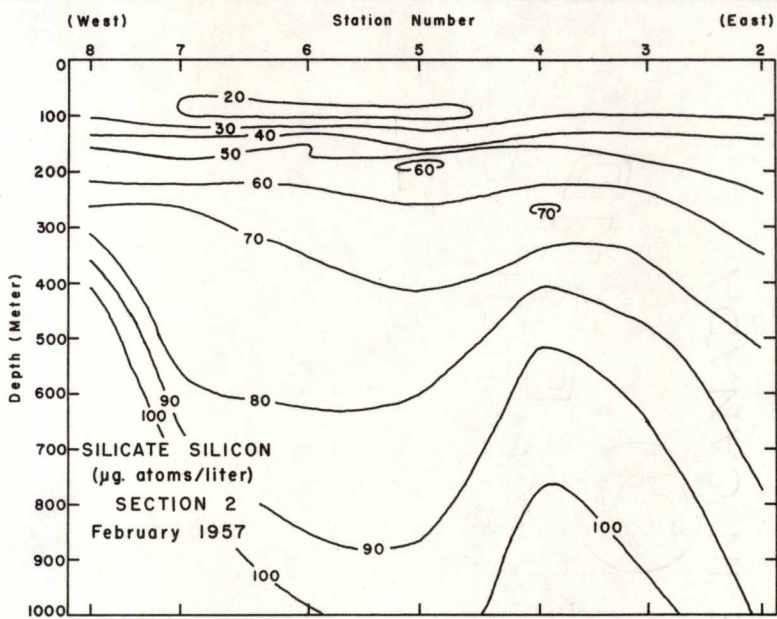
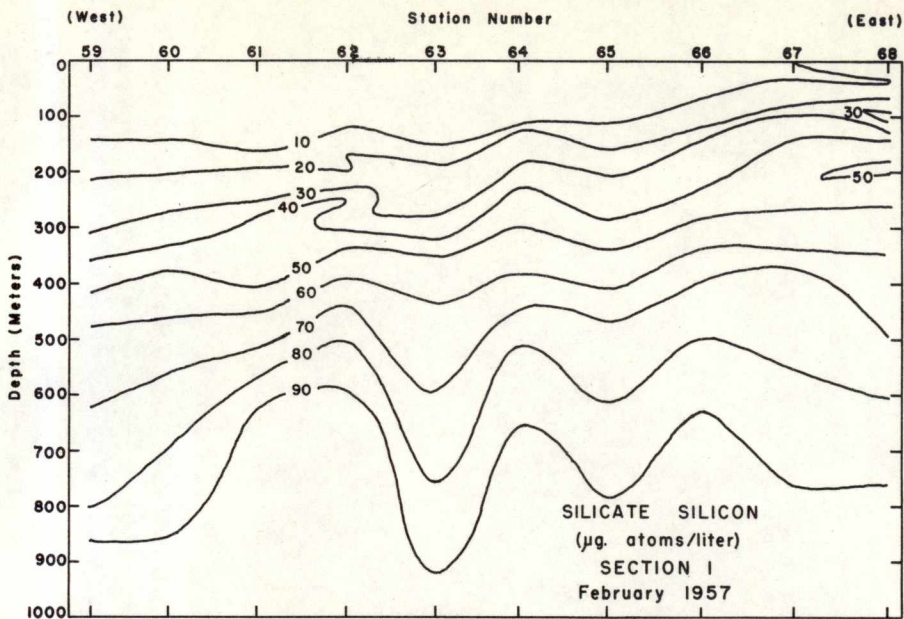


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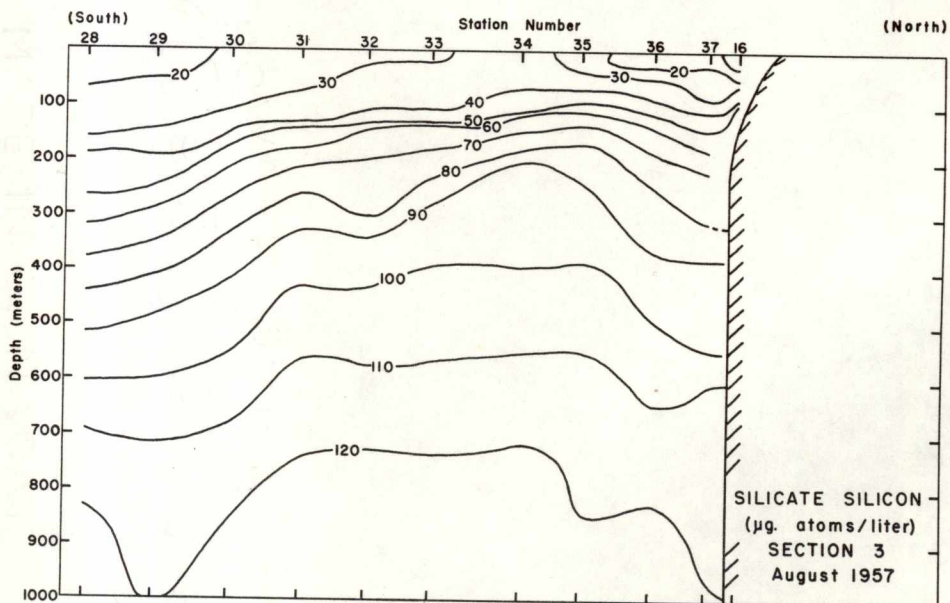
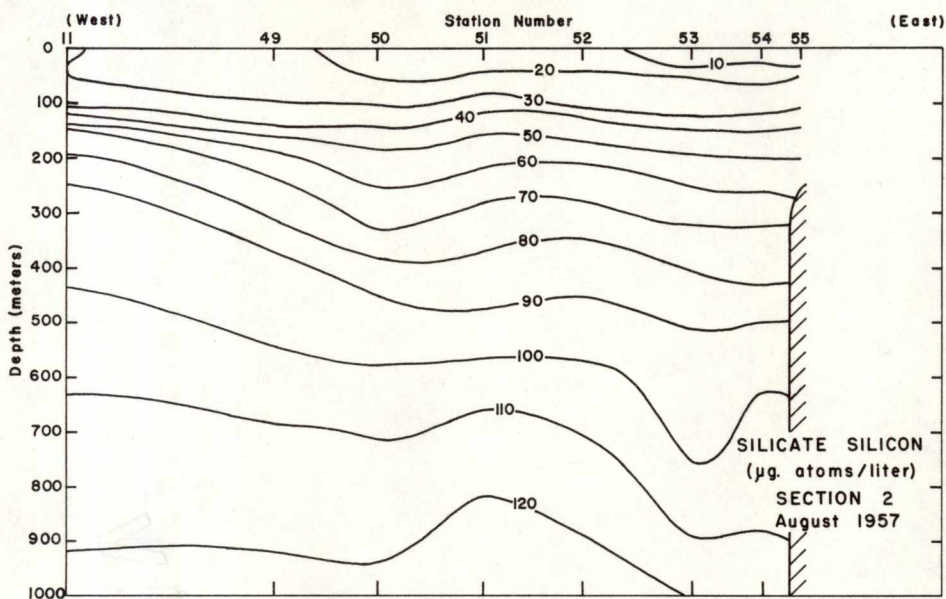
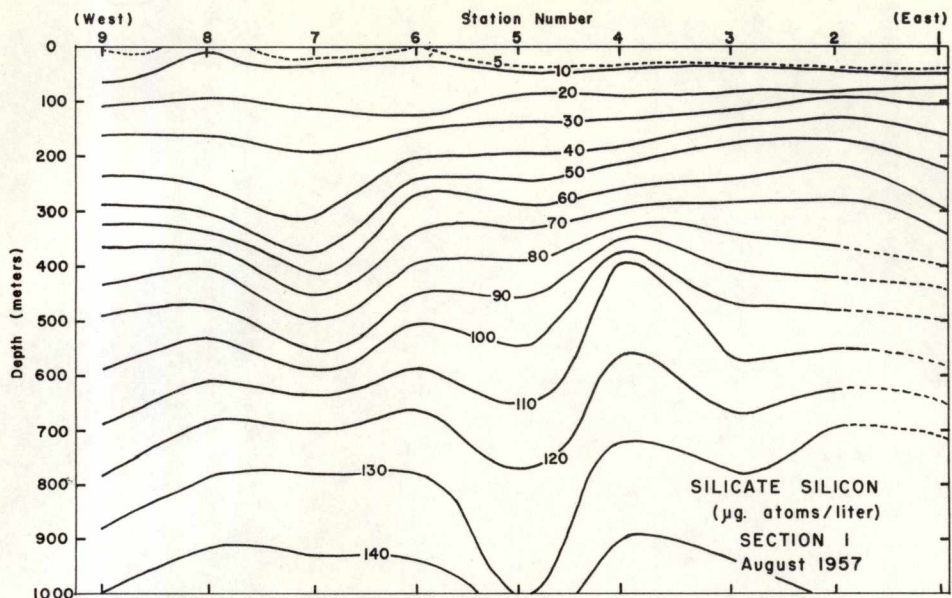


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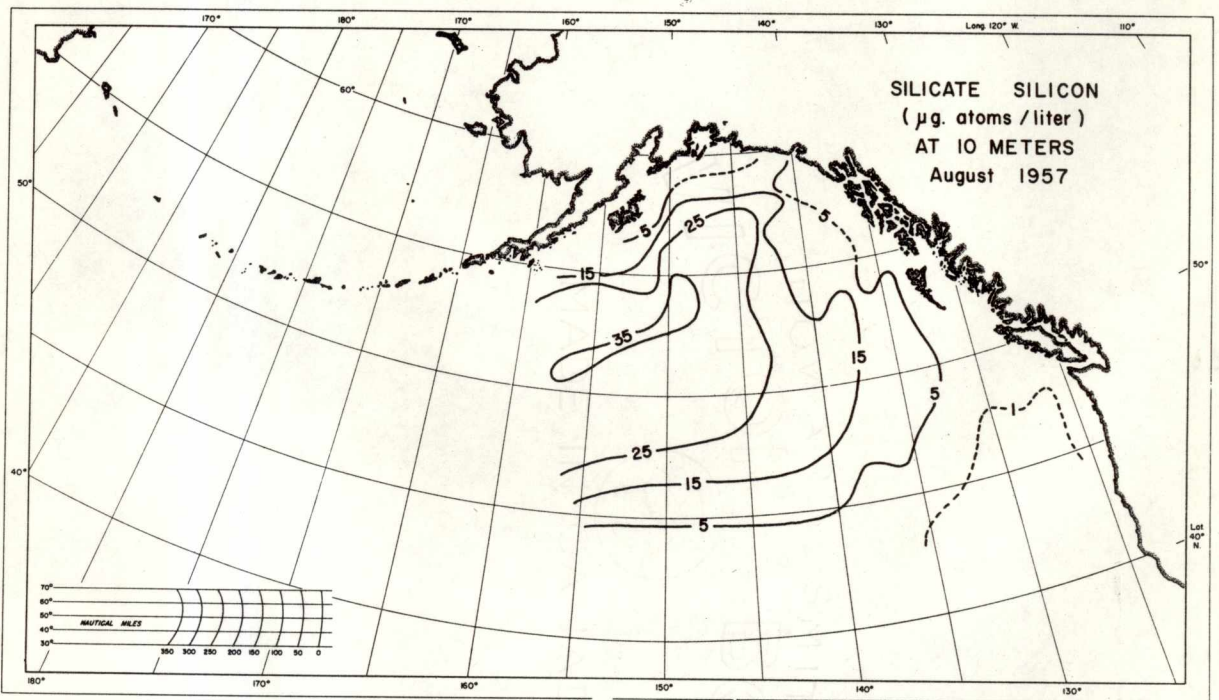
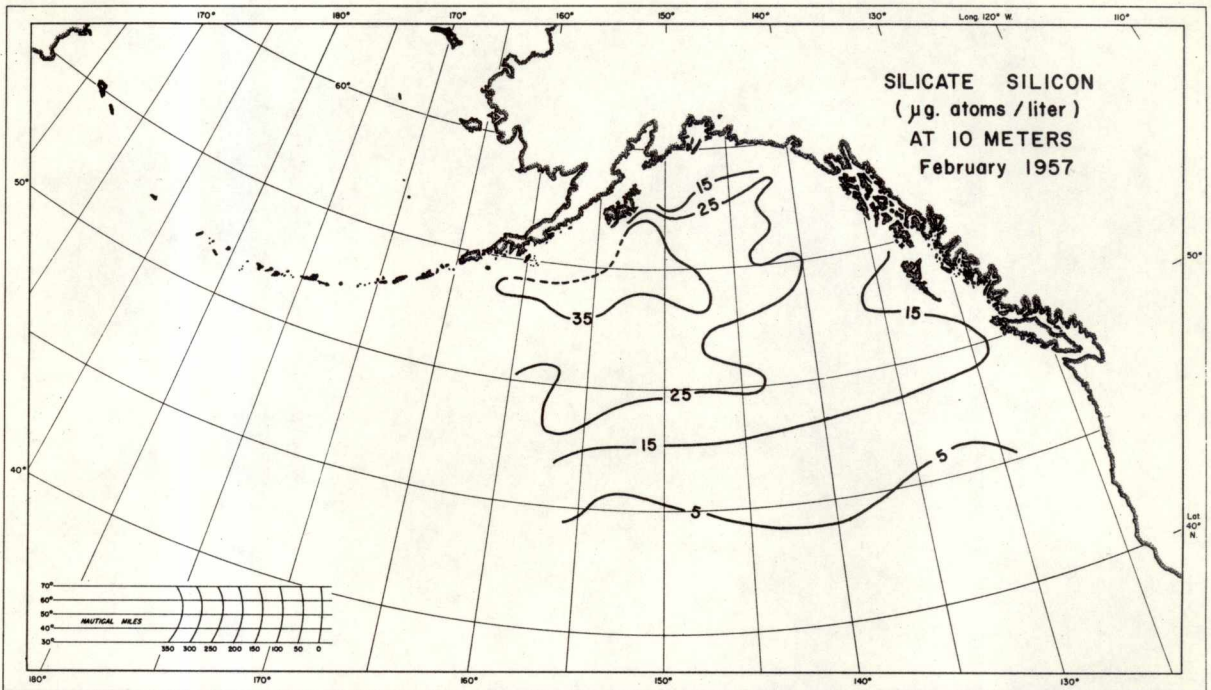


Figure 35