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Chemical Oceanography of the Bransfield Strait: Micronutrient Compounds (SIBEX-Phase II Cruise. Chile)

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ABSTRACT

As a contribution to the international project Biological Investigations of Marine Antarctic Systems and Stocks (BIOMASS), the participating countries have been performing several biological-oceanographic cruises in the Bransfield Strait and adjacent areas. From January 24th to February 12th 1985, the Instituto Antártico Chileno (INACH) carried on a third biological-oceanographic cruise in the Bransfield area. This cruise was named SIBEX-Phase II (Second International BIOMASS Expedition Phase II). Such expedition was accomplished with the M/N Capitan Alcazar, performing 31 oceanographic stations in the Bransfield Strait, Gerlache Strait and Weddell Sea.

The Escuela de Ciencias del Mar, Universidad Católica de Valparaíso, took part in this SIBEX-Phase II cruise, carrying out research on the chemical characteristics of the water masses present in that area. Water samples were collected, in the upper 700 meters, to analyze their micronutrient contents (phosphate, nitrate and silicate). A Nutrient-Autoanalizer System, built at the Universidad Católica de Valparaíso, was used to run the chemical analysis.

The observed SIBEX-Phase II (austral summer 1985) cruise micronutrient contents, was compared with micronutrient concentrations observed during (summer 1982) FIBEX cruise and (summer 1984) SIBEX-Phase I cruise, carried on by INACH. The larger 1985 summer concentrations were statistically different ($\alpha = 0.05$), to the ones observed in the same area, during 1981 summer and similar to the ones observed in the summer 1984.

In this area, two water masses were detected: a) Bellingshausen Antarctic Surface Water and b) Weddell Sea Surface Water. Beside these water masses, four water bodies were also observed and they correspond to: a) Bransfield Strait Surface Water, b) Gerlache Strait Surface Water, c) Antarctic Peninsula Continental Shelf Surface Water and d) Bransfield Strait Deep Water.

From the point of view of the micronutrient contents, the water masses are characterized by: a) Antarctic Surface Water: low silicate (< 60 µM), compared to the Bransfield waters; Weddell Sea Surface Water: High phosphate, nitrate and silicate (> 1.8 µM, > 18 µM and > 60 µM).

In relation to the water bodies, they are characterized by: a) Bransfield Strait Surface Water: High phosphate, nitrate and silicate (> 1.8 µM, > 18 µM and > 70 µM); b) Gerlache Strait Surface Water: Low phosphate, nitrate and silicate (< 1.0 µM, < 10 µM and < 70 µM); c) Antarctic Peninsula Continental Shelf Water: High phosphate, nitrate and silicate (> 2.0 µM, > 26 µM and > 80 µM); Bransfield Strait Deep Water: High phosphate, nitrate and silicate (> 2.4 µM, > 30 µM and > 90 µM).

From the point of view of the T-S structures, six different T-S diagrams were identified. A zonation map was prepared to show where these structures were present. In relation to the temperature-micronutrient diagrams (T-Phosphate, T-Nitrate and T-Silicate), they were used as a complement to the T-S diagrams in the water masses structure characterization of the area.

RESUMEN

Como una contribución al Proyecto Internacional Biological Investigations of Marine Antarctic Systems and Stocks (BIOMASS), los diferentes países participantes en dicho proyecto han venido realizando, desde 1981, una serie de cruceros biológico-oceanográficos en el área del estrecho Bransfield y zonas adyacentes. Entre los días 24 de enero y 12 de febrero de 1985, el Instituto Antártico Chileno (INACH) realizó un tercer crucero biológico-oceanográfico en el área del Bransfield, al cual se le denominó SIBEX-Fase II (Second International BIOMASS Expedition Fase II). Dicha expedición se realizó con la M/N Capitán Alcázar, efectuando 31 estaciones oceanográficas en el área del estrecho Bransfield, estrecho Gerlache, y mar de Weddell.

Como participante en el crucero SIBEX-Fase II, la Escuela de Ciencias del Mar de la Universidad Católica de Valparaíso realizó una investigación sobre las características químicas de las aguas de la zona muestreada.

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Para ello se colectaron muestras de agua para el análisis de compuestos micronutrientes (fosfatos, nitratos y silicatos), en la capa comprendida entre 0 y 700 metros de profundidad, utilizándose en el análisis químico un Autoanalizador de Nutrientes construido por dicha universidad.

El contenido de micronutrientes observado durante el crucero SIBEX-Fase II (verano 1985) fue comparado con aquellos de los cruceros FIBEX (verano 1982) y SIBEX-Fase I (verano 1984), también realizados por INACH. En general, las concentraciones presentes durante el verano de 1985 fueron significativamente mayores (α = 0,05) a las observadas en la misma zona en el verano de 1981, no ocurriendo lo mismo respecto al verano de 1984.

En la zona se observaron dos masas de agua las cuales corresponden a: a) Agua Superficial Antártica del Mar de Bellingshausen y b) Agua Superficial del Mar de Weddell. Además de estas masas de agua, también se observaron cuatro cuerpos de agua que corresponden a: a) Agua Superficial del Estrecho Bransfield, b) Agua Superficial del Estrecho Gerlache, c) Agua Superficial de la Plataforma Continental de la Península Antártica y d) Agua Profunda del Bransfield.

Desde el punto de vista del contenido de micronutrientes estas masas de agua se caracterizaron de la siguiente forma: a) Agua Superficial Antártica del Mar de Bellingshausen, por un comparativamente bajo contenido de silicato (<60 μM), respecto al Bransfield y b) Agua Superficial del Weddell, por un alto contenido de fosfato, nitrato y silicato (> 1,8 μM, > 18 μM y > 60 μM).

En cuanto a los cuerpos de agua presentes, éstos se caracterizaron por: a) Agua Superficial del Bransfield, por alto contenido de fosfato, nitraro y silicato (> 1,8 μM, > 18 μM y > 70 μM); b) Agua Superficial del Gerlache, por bajo contenido de fosfato, nitrato y silicato (< 1,0 μM, < 10 μM y < 70 μM); c) Agua Superficial de la Plataforma Continental de la Península Antártica, por alto contenido de fosfato, nitrato y silicato (> 2,0 μM, > 26 μM y > 80 μM); d) Agua profunda del Bransfield, por alto contenido de fosfato, nitrato y silicato (> 2,4 μM, > 30 μM y > 90 μM).

Desde el punto de vista de las estructuras T-S, se pudo identificar seis clases o tipos distintos de diagramas T-S, preparándose un mapa de las zonas en que estas estructuras fueron observadas. En cuanto a los diagramas Temperatura-Micronutriente (T-Fosfato, T-Nitrato y T-Silicato), éstos fueron utilizados como complemento a los diagramas T-S en la caracterización de la estructura de masas o cuerpos de agua del sector.

INTRODUCTION

The oceanographic characteristics of the Bransfield Strait are very particular, being its behaviour as a water body, different from the surrounding seas. These particular characteristics are fundamentally the result of its geographic isolation.

The South Shetland Islands are located in its northern limit and the Antarctic Peninsula is located in its southern limit. The strait is placed between them and it is formed by three separated basins with a maximum depth of about 2200 meters. Those basins are not only separated between them, but also from their adjacent seas, connecting with them through some shallow passages.

In addition to their particular characteristics of lower temperature and salinity, this isolation of the waters below 1000 meters depth, made Clowes (1934) conclude that the strait bottom waters should have been formed inside the strait itself. This author also indicated that the possible mechanism of formation of this water should be the winter thermohaline convection over the Antarctic Peninsula Continental Shelf which would contribute to the renovation of the strait bottom waters.

Clowes (1934) also concluded that the relatively warmer and less saline waters, as well as the subsurface temperature and salinity maximum, found during summer in the western limit and in the north of the strait, come from the Bellingshausen Sea entering the strait by advection.

In relation to the southeastern portion of the Bransfield Strait, this is under the influence of the colder and more saline waters of the Weddell Sea which enter the strait flowing over the Continental Shelf near D'Urville and Joinville Islands. This author proposed that these waters are spread along the coast of the Antarctic Peninsula as far as Trinidad Island, where they meet the waters coming from the Gerlache Strait.

After Clowes' (1934) work, the research on the Bransfield Strait had a considerable decay until the Gordon and Nowlin's paper (1978). These authors carried out a new analysis of the physical and chemical oceanographic conditions of the strait, based on data collected by the R/V Conrad and the R/V Melville, obtained during the International Studies of the Southern Ocean (ISOS) project. The paper of Gordon and Nowlin (1978) contributed with new evidences which tended to confirm the thermohaline convection as a mechanism of formation of the Bransfield Strait bottom waters.

During 1981 summer, new research studies were carried out in the Bransfield Strait as a part of the International BIOMASS project (Biological Investigations of Marine Antarctic Systems and Stocks). As a first phase of this project, the participating countries performed a series of Biological Oceanographic Expeditions in the area of the strait and adjacent zones. On this phase, known as FIBEX (First International Biomass Expedition) the Instituto Antártico Chileno (INACH) organized a cruise from January 26th to February 22nd 1981 on board of B/I Itzumi. The results of this cruise were published as a series of papers in the INACH Scientific Series N° 28 (1982). Among these papers, the work of Sievers (1982) and Salamanca and Acuña (1982) are relevant contributions, which are referred to physical and chemical characteristics of the strait found during the performance of such cruise.

After FIBEX and after a series of international meetings about the informations collected by the several participating countries, a second phase of BIOMASS project was programmed under the name of SIBEX.

For this second phase INACH organized two expeditions which would be performed during the 1984 and 1985 summers. The first one should be a complement to the main SIBEX cruise programmed fo 1985 summer. This expedition named SIBEX-Phase I was organized with the objective of studying the oceanographic characteristics of the Bransfield Strait and adjacent zones, in connection with water masses and water bodies of the zone, temperature, salinity, dissolved oxygen and micronutrient characteristics.

The results of the SIBEX-Phase I, performed from January 27th to February 10th 1984, were published in the INACH Scientific Series N° 33 (1985). Among these papers the work of Kelly *et al.* (1985), Rojas (1985) and Silva (1985) are relevant contributions which are referred to the physical and chemical characteristics of the strait found during the performance of such cruise.

The main cruise named SIBEX-Phase II was performed from January to February 1985 with similar objectives to the 1984 cruise, with a higher emphasis on the fishery-biological area.

The objective of this paper is the description of the chemical oceanographic conditions, regarding the micronutrient contents (phosphate, nitrate and silicate) and the relation of these micronutrients with the water masses and water bodies of the Bransfield Strait and adjacent zones. It is also the objective of this paper to analyze the interannual variability observed during the three cruises performed by INACH, as a contribution to the International BIOMASS Project.

MATERIALS AND METHODS

The studied area corresponds to the Bransfield Strait interior waters and the Weddell Sea northeastern portion (Figure 1). Such zone was sampled from January 24th to February 12th on board of the M/N Capitan Alcazar, which was conditioned for oceanographic studies.

34 hydrographic stations were sampled with Niskin bottles up to a maximum depth of 700 meters. For the analysis of phosphate, nitrate and silicate a sample of 60 cc of sea water was taken from each Niskin bottle. Such sample was filtered through a Wathman FC glass fiber filter, throwing the first 20 cc and keeping the remaining 40 cc. The filtered sample was preserved with 2 drops of a mercuric chloride solution and frozen to -30° C in poliethylene bottles. These bottles were previously washed with a 5% hydrochloric acid, rinsed with deionized water and dried with acetone. The frozen samples were analyzed one month later in the Chemical Oceanographic Laboratory at the Universidad Católica de Valparaíso.

Phosphate, silicates and nitrates samples were analyzed in a Micronutrient Analyzer System built by the Universidad Católica de Valparaíso. The chemical analytical technics used by this system corrrespond to those described by Atlas *et al.* (1971).

Micronutrient concentrations were expressed in micromoles per liter or micromolar (μM) and the nitrate values correspond to nitrate + nitrite concentrations. Corrections for the refraction indexes were also included in the computations.

All the concentrations of the samples were corrected by a 1.035 factor for phosphate, 0.971 factor for nitrate and 1.082 factor for silicate. These factors were used to correct changes that happen during the freezing. They were empirically obtained by the author in previous sample freezing preservation experiments at Valparaíso.

There was no need to use factors to correct changes due to the use of glass fiber filters. Experiments on this showed almost no alterations.

The micronutrient horizontal distribution was analyzed based on horizontal levels at 0, 25, 50, 100, 200 and 300 meters. The vertical distribution was analyzed based on 7 vertical sections with a north south general direction and one section with east west direction (along the axis of the strait) (Figure 1).

T-S diagrams were used for the analysis of water masses and water bodies present in the area. They were prepared based on the data obtained by the Instituto de Fomento Pesquero (IFOP), during the same cruise. T-phosphate, T-nitrate and T-silicate plots were used as a complement to the study of the respective water masses and water bodies characteristics.

In order to make a statistic comparison between the micronutrients mean concentrations that were present in the water during the performance of FIBEX, SIBEX-Phase I and SIBEX-Phase II, a Student-Newman-Keuls test was applied. This test consists of using the range as the statistic to compare the differences between means (Sokal and Rohlf, 1969). Therefore, the mean nutrient concentrations were compared at 0, 50, 100 and 200 meters levels based on the data collected from the stations, contained in the common area to the three cruises.

RESULTS

Phosphate

The phosphate surface concentration fluctuated from 0.50 μM to 2.23 μM (Figure 2). In general the phosphate surface distribution presented a series of high and low concentration nucleus. The most outstanding nucleus were the ones of low concentrations located in the northern mouth of the Gerlache Strait (< 0.60 μM) and the ones located to the south of Livingston Island (< 1.0 μM) and to the southeast of Deception Island (< 1.4 μM). Another outstanding nucleus is the one of high concentration (> 2.0 μM), located to the west of the Antarctic Peninsula and covering almost all the area between Clarence and Joinville Islands (Figure 2).

In relation to higher depths (25 to 300 meters) the phosphate presented a similar distribution to the one of the surface only in the 25 m level. In the 50 m level the only nucleus that remained were the ones of low concentration of the Gerlache Strait and Deception Island. To deeper levels, these nucleus practically disappeared and the phosphate distribution tended to be more uniform (Figures 3 to 7).

Regarding phosphate vertical distribution, it showed the lowest concentrations in the surface waters, increasing with depth and generally reaching a maximum at the deepest analyzed level (Figures 8 to 15). The vertical concentration gradient was more noticeable at the surface layer (0 - 100 meters), than at the deepest one (100 - 600 meters), where the concentration was more uniform. This high vertical gradient was more noticeable in sections 6 and 7 (Figures 13 and 14).

Nitrate

The nitrate surface concentration ranged from 5.3 to 26.8 μM. Its distribution presented a series of high and low concentration nucleus similar to the phosphate surface distribution (Figure 2).

The most outstanding nucleus are those of low concentration in the Gerlache Strait (< 6 μM) and the ones to the south of Livingston (< 12 μM) and southeast of Deception Island (< 20 μM) (Figure 2). Another outstanding nucleus is the one of high concentration (> 24 μM) located to the north of the Antarctic Peninsula, near Trinidad and Torre Islands. This nucleus extends towards the east and covers all the area between Clarence and Joinville Islands (Figure 2).

At deeper horizontal levels, the distribution of maximum and minimum concentration nucleus was similar to that of surface, maintaining the outstanding nucleus only to the 25 meters level (Figure 3). In the 50 meters level the low concentration nucleus present to the South of Livingston Island disappeared (Figure 4). At the 100 to 300 meters levels the nitrate concentration tended to be more uniform.

The nitrate vertical distribution presented the lowest concentrations on the surface waters showing an increase towards the bottom and reaching a maximum at the deepest analyzed level.

In a similar way to the phosphate distribution the nitrate showed a maximum vertical concentration gradient in the upper 100 meters. Below this depth the nitrate concentration is more uniform, decreasing the vertical gradient towards the bottom (Figures 8 to 15). The maximum vertical nitrate concentration gradient is located in the coastal portion of sections 6 and 7. This is the result of comparatively lower nitrate surface concentrations.

Silicate

The silicate surface concentration ranged from 48 μM to 91 μM (Figure 2). Its distribution shows two well defined areas in the Bransfield Strait, one with concentrations lower than 70 μM towards the west and one with concentrations higher than 80 μM towards the east (Figure 2).

Two high concentration nucleus (> 90 μM), were observed near by Torre Island and south of Clarence Island. A nucleus of low concentration (< 50 μM) was also observed to the south of Snow Island (Figure 2).

At the levels of 25 to 100 meters, the silicate horizontal distribution is similar to the one in the surface (Figures 3 to 7). At deeper levels (200 to 300 meters), the silicate concentration tends to be more uniform.

The silicate vertical distribution as well as the phosphate and nitrate vertical distribution, showed the lowest concentrations on the surface layer, increasing with depth to reach a maximum at the deepest analyzed level. The silicate vertical concentration gradient is higher in the surface layer (0 - 100 meters) than in the deeper layer (100 - 600 meters). This is more noticeable in the coastal part of sections 6 and 7 (Figures 8 to 15).

DISCUSSION

Chemical Oceanographic Conditions

The silicate surface distribution shows a simple general distribution pattern, with concentrations that decrease gradually from the Antarctic Peninsula to the South Shetland Islands (Figure 2). This pattern is very similar to the one described by Salamanca and Acuña (1982) for FIBEX cruise (summer 1981). This similarity is referred only to the isolines distribution and not to the concentrations themselves, which are higher in the SIBEX-Phase II than in the SIBEX-Phase I cruise.

Regarding the surface distribution of phosphate and nitrate concentrations, they show a relatively complex distribution pattern in relation to the silicate one. The complexity of these patterns is due to the presence of high and low concentration nucleus, located near Livingston and Deception Islands. These nucleus alter the gradual north-south variation shown by the silicate pattern (Figure 2).

In the analysis of the data of SIBEX-Phase I cruise (summer 1984), Silva (1985) shows a very similar distribution pattern to the one presented here for SIBEX-Phase II cruise (summer 1985). However, there are some differences between these cruises, as well as the nucleus positions and their extreme concentrations. Nevertheless, they are definitely lower than the ones observed when comparing the SIBEX-Phase I and the FIBEX cruises.

When statistically comparing the micronutrients concentrations for the common area to the three cruises (FIBEX, SIBEX-Phase I and SIBEX-Phase II), it was possible to infer that at the level $\alpha = 0.05$ there are significant differences between the mean micronutrient concentrations at the levels of 0, 50, 100 and 200 meters. In this way, the Student-Newman-Keuls test (Sokal and Rohlf, 1969), shows that the phosphate, nitrate and silicate concentration means of the FIBEX cruise are different from the micronutrients concentration means of the SIBEX-Phase I and SIBEX-Phase II cruises, being the exception the nitrate at the 100 and 200 meters level (Table I). This test also shows that there are no statistically significant differences between the phosphate and silicate concentrations means of the SIBEX-Phase I and SIBEX-Phase II cruises, being the exception the silicate at the 200 meters level.

In order to obtain a graphic view of the concentration differences between micronutrients from the three cruises and like Silva (1985) did, a figure with mean nutrient distribution at the different compared depth levels was prepared. In this figure it is also indicated their respective standard deviations and the minimum and maximum concentrations observed in the common sampling area (Figure 16). In such figure, it can be seen that the micronutrient concentrations during 1984 and 1985 summers were higher than during 1981 summer.

According to this, the 1981 summer can be considered as a significatively different period, regarding 1984 and 1985 summers. Based on temperature data of the area, Rojas (1985) intends to consider 1981 summer as an anomalous one. Nevertheless, it must be clear that it is premature to say definitely that 1981 summer is an "abnormal" summer, because the data is scarce.

Up to now, there are no long time series to establish a statistically valid "normal" pattern of the area. Besides this, having no information on the natural variability of the area, it is still more difficult to establish "abnormality", since the observed interannual differences may be within such range. In this latter situation this "abnormality" would be only a non significant deviation relative to the interannual mean.

Independently of the knowledge of the natural variability of the area, it is posible to say that due to their high nutrient concentration, these waters are potentialy very nutritive. Their concentrations are above the minimum requirements for the phytoplankton growth such as those indicated by Margalef (1980).

In general, it is estimated that the waters south of the Circumpolar Front have very high nutrient concentrations for them to become a limitant factor to the phytoplankton growth (Jacobs *et al.*, 1979). Is is possible to think that in this area the light availability could be more important as a limiting growth factor, than the nutrient availability.

Regarding the differences in the nutrient concentrations between the Bransfield Strait and the adjacent seas and water bodies, a similar situation to the one observed by Silva (1985), can be described for SIBEX-Phase II. The main differences are present between the Bransfield Strait and the Bellingshausen Sea in the surroundings of Smith and Low Islands. In the area near Brabant Island, the Bransfield also shows differences in the nutrient concentration with the Gerlache Strait.

In the first case, the differences are present in the silicate concentration in the upper 100 meters. In this layer, the Bransfield shows higher silicate concentrations than the Bellingshausen Sea. These differences oscilate between 20 μM in the surface to 10 μM in the 100 meters level (Figures 2 to 5 and 14).

Besides these differences in the silicate concentration, Silva (1985) also found differences in the nitrate and phosphate contents in the 100 to 400 meters level. In this layer both nutrients show a subsuperficial maximum in the Bellingshausen Sea. These last differences were not observed in the SIBEX-Phase II cruise due to the lack of deep stations in the Bellingshausen area.

In relation to the differences between the Bransfield and the Gerlache Strait waters, these are also referred to the surface layer (0 to 100 meters). The Gerlache waters are comparatively very low in the nutrient contents, therefore a surface minimum is observed. (Figures 2 to 5 and 14). This minimum is very noticeable in the phosphate and nitrate concentrations. The silicate concentration shows almost no difference.

In the SIBEX-Phase I cruise, the low silicate concentrations were more noticeable than in the SIBEX-Phase II. This is due to the fact that in the first cruise the sampling covered the Gerlache interior waters. Nevertheless, the silicate concentrations are similar for both cruises in the stations near the mouth of the strait.

In the horizontal distribution of the micronutrients within the Bransfield Strait, it was previously stated that there are clearly two definite nucleus of low concentration in the first 50 meters (Figures 2 to 4). Of both nucleus, only the one near Deception Island has its counterpart in the FIBEX-

Phase I cruise, because in this 1984 summer cruise, a similar nucleus to the south of King George Island was present.

In relation to the low concentration nucleus near Trinidad Island (Figures 2 to 4), this doesn't have a counterpart in 1984 summer. On the contrary, a high nitrate concentration nucleus was present in the area in that opportunity. This situation brings about differences in this micronutrient of about 12 μM between cruises.

The explanation to these differences seems to be in the high biomass present in the area during the SIBEX-Phase II cruise, which was over the 60 mg chlorophile "a"/l (Uribe, personal communication). Since this process is not seen in the salinity isolines distribution of the same cruise (Kelly and Blanco, 1986; Rojas, 1986), it should be put aside the possibility of being an advective process, as it could be thought based on the micronutrients isolines distribution. Therefore, there is not an advection of waters with low nutrient concentration from the Gerlache to the Bransfield (Figures 2 to 4).

Regarding the micronutrients vertical distribution below the 200 meters, this is very homogeneus and it only shows sudden ups and downs of some isolines. These changes in depth are only present in the interior areas of the Bransfield Strait (Sections 3, 4 and 5), and they usually do not compromise the almost homogeneus interior waters.

These changes in the micronutrients isolines depth were also observed in the SIBEX-Phase II in the temperature, salinity and solved oxygen (Kelly *et al.*, 1985; Rojas, 1985) and in the micronutrients (Silva, 1985). Therefore, this seems to be a characteristic of this area.

Water Masses Structure: T-S Diagrams.

The analysis of the T-S diagrams observed during the SIBEX-Phase II cruise, prepared on the basis of the data obtained by the Instituto de Fomento Pesquero in such cruise, makes possible to discriminate between the six T-S structures defined by Silva (1985) for this area. To identify the different T-S structures, this author considered, besides his own data, the work of Clowes (1934), Sievers (1982), Stein (1983) and Uribe *et al* (1983), which gave information from the area not studied by SIBEX-Phase I cruise.

When analyzing the data of the SIBEX-Phase II cruise, the same as in FIBEX and SIBEX-Phase I, it is possible to observe the concurrence to the Bransfield of the main sources of water types, which, by advection towards the interior, originate the central water of the strait. These sources are the Bellingshausen to the west, the Weddell Sea to the east, the Gerlache Strait and the Antarctic Continental Shelf to the south. It was not observed a contribution of the Drake Passage to the north, due to the barrier formed by the South Shetland Islands.

Having as a basis the distribution proposed by Silva (1985), six different T-S types correspond to: Bellingshausen Sea type, Bransfield-Bellingshausen mixture type, Gerlache Strait type, Antarctic Peninsula Continental Shelf type, Weddell Sea type and Bransfield Strait central mixture type. Regarding these type structures, the stations of SIBEX-Phase II were distributed according to its T-S, making a zonation map (Figure 17). Such map shows the different T-S structures types from the stations considered as more characteristic, as well as the zone where such type of T-S structure was observed.

In the case of the Bellingshausen Sea the corresponding T-S to this type of structure would rather correspond to a remaining T-S characteristic of this zone, because they are just in the limit of influence of this sea and therefore they are very much like the Bransfield-Bellingshausen mixture type T/S (Figure 17).

In general, it is possible to say the Bransfield zone has "pure" T-S types or T-S structures only in the areas adjacent to it. Such areas provide by advection different water masses and water bodies which are mixed in different proportions, according to their location, generating the Bransfield central water. Due to this characteristic of the area, it is easy to find a whole "family" of T-S diagrams in a relative short distance. This situation is not common in the oceans.

Water Masses Structure: Micronutrients

The water masses observed during SIBEX-Phase II cruise were: Bellingshausen Antarctic Surface Water, Weddell Surface Water and Upper Circumpolar Deep Water. In relation to water bodies these were: Bransfield Surface Water, Gerlache Surface Water, Antarctic Peninsula Shelf Surface Water and Bransfield Deep Water.

From the standpoint of micronutrient concentration and in a similar way to Silva (1985), these water masses and water bodies can be characterized by their comparatively different contents. Nevertheless, one must keep in mind that the water masses and water bodies chemical characteristic correspond to non-conservative characteristics. Therefore, one must be careful in one's interpretation.

In some opportunities the chemical characteristics could become important complements, contributing with definitive evidences to solve some situations that conservative parameters only suggest. Gordon and Nowlin (1978) used the Tritium distribution in order to confirm the presence of convective processes in the Bransfield. They are also useful complements in the identification of water masses. For example, Sievers and Nowlin (1984) used the deep nitrate and phosphate maximum to characterize the Upper Circumpolar Deep Water in the Drake Passage area.

From the standpoint of the micronutrient contents, only remnants of the Bellingshausen Antarctic Surface Water in the area near Low and Smith Islands. This water mass has high nitrate and phosphate contents, similar to those of the Bransfield Surface Water, without taking into account the low concentration nucleus produced by biological activity (Figures 2 to 5).

Nevertheless, the silicate concentrations show different contents for both water masses. The Bellingshausen Surface Water has a lower silicate contents than the Bransfield Surface Water (Figures 2 to 5 and 14). This is why Silva (1985) indicates that the Bellingshausen Antarctic Surface Waters should be characterized, from the chemical standpoint, as "low" silicate concentration ($<$ 60 μM) and the Bransfield waters and adjacent areas, as high silicate concentration ($>$ 60 μM).

On the other hand, the nutrient concentration of the Weddell Surface Water and the interior Bransfield Surface Waters do not differ much (Figures 2 to 5). Nevertheless, there is a definitive increase in the nutrient concentration towards the Weddell and the Antarctic Peninsula.

The Antarctic Peninsula Shelf Surface Water body is characterized by the highest surface nutrient concentrations in the area (Figure 2 to 5). In SIBEX-Phase II cruise these concentrations were higher than 2.0 μM for phosphate, higher than 26 μM for nitrate and higher than 80 μM for silicate. In relation to SIBEX-Phase I (Silva, 1985), these were similar for silicate and phosphate. Nitrate was around 2 μM higher.

The Gerlache Surface Water is quite different from the Bransfield Surface Water due to the comparatively low nutrient concentrations of the former (Figures 2 to 5 and 13 to 14). The Gerlache Strait shows the lowest concentrations of the studied area and therefore it is characterized by a minimum in the concentration of nitrate (< 10 μM), phosphate (< 1.0 μM) and silicate (< 70 μM).

It is important to indicate that the low concentrations observed near Trinidad Island are not associated with the low nutrient concentration of the Gerlache Surface Water. (Figures 2 to 5). These low concentrations have a biochemical explanation based on a high nutrient consumption due to a high phytoplankton biomass (Uribe, personal communication).

Therefore, it is not the result of an advective process as it can be thought from the nitrate and phosphate isolines configuration.

In relation to the use of temperature-nutrient diagrams to identify water masses and water bodies, Gordon and Nowlin (1978) used T-Silicate diagrams to show differences between Bransfield and Weddell deep and bottom waters. Duncombe-Rae (1985), in a preliminar analysis of the SIBEX I Sud-African cruise to Prydz Bay area (about 64° S, 59° E), used salinity-nutrient diagrams for this water masses analysis. Based on these diagrams, this author indicates the possibility of identify three water types in the region.

Silva (1985) also made an analysis of T-Nutrient diagrams structures of all the SIBEX-Phase I oceanographic stations. This author indicates that these diagrams give information similar to that of the T-S diagrams, except those from the Bellingshausen Sea.

The T-nitrate and T-phosphate diagrams from the Bellingshausen Sea give a characteristic shape different to the respective T-S diagram. Therefore, they can be used in the identification of the Upper Circumpolar Deep Water.

According to Silva (1985), the differences between the T-nutrient and the T-S diagrams are due to the presence of a maximum in the subsurface concentration in phosphate and nitrate, inherent to the Upper Circumpolar Deep Water. This maximum in the nutrient vertical distribution gives as a result a characteristic T-phosphate and T-nitrate shape, which is different from the T-S shape and therefore useful for the identification of this water mass.

In the case of SIBEX-Phase II T-phosphate, T-nitrate and T-silicate diagrams (Figure 18), they show a similar information to that of SIBEX-Phase I cruise. They also show that the Upper Circumpolar Deep Water was not present in the studied area.

The Upper Circumpolar Deep Water observed by Silva (1985), in the SIBEX-Phase I cruise, was not observed during the SIBEX-Phase II cruise due to the lack of deep stations in the Bellingshausen Sea.

CONCLUSIONS

The analysis of the results obtained during the SIBEX-Phase II cruise and its comparison with the available information, specially that one of the SIBEX-Phase I cruise, performed in the same area, gave the following conclusions:

1.—During 1985 summer, the Bransfield Surface Water mean phosphate, nitrate and silicate concentrations were statistically different (higher) from those observed in the same area during 1981 summer ($\alpha = 0.05$), except by the nitrate in the 100 and 200 meters level.

2.—The Bransfield water phosphate, nitrate and silicate mean concentrations present during 1985 summer were statistically similar in relation to those ones present during 1984 summer ($\alpha = 0.05$). Silicate mean concentrations in the 100 and 200 meters level were significatively different.

3.—Two water masses were observed in the zone: a) Bellingshausen Antarctic Surface Water and b) Weddell Surface Water. Besides those water masses, four water bodies were observed: a) Bransfield Surface Water, b) Gerlache Surface Water, c) Antarctic Peninsula Continental Shelf Surface Water and d) Bransfield Deep Water.

4.—From the point of view of the micronutrient contents (phosphate, nitrate and silicate) these masses were characterized in the zone by: a) Bellingshausen Antarctic Surface Water, a comparatively low silicate (in relation to Bransfield) (< 60 μM); b) Weddell Surface Water, high nitrate, phosphate and silicate (> 1.8 μM, > 18 μM and > 60 μM); c) Upper Circumpolar Deep Water relative maximum of phosphate and nitrate (> 2.4 μM and > 28 μM).

In relation to water bodies present, they were characterized by: a) Bransfield Surface Water, high phosphate, nitrate and silicate (> 1.8 μM, > 18 μM and > 70 μM); b) Gerlache Surface Water, low phosphate, nitrate and silicate (< 1.0 μM, < 10 μM and < 70 μM); c) Antarctic Peninsula Continental Shelf Surface Water, high phosphate, nitrate and silicate (> 2.0 μM, > 26 μM and > 80 μM); d) Bransfield Deep Water, high phosphate, nitrate and silicate (> 2.4 μM, > 30 μM and > 90 μM).

5.—Six water masses and water bodies were observed in the zone, which correspond to the following types or classes of T-S diagrams: a) Weddell Sea, b) Bransfield central zone, c) Gerlache Strait, d) Antarctic Peninsula Continental Shelf, e) Mixture Bransfield and Bellingshausen and f) Bellingshausen Sea.

6.—The typical T-S and T-nitrate and T-phosphate structures from the Bellingshausen Sea were identified only as residuals in the oceanographic stations near the Bellingshausen Sea. This residual presence of the typical Bellingshausen structure was due to the fact that the Upper Circumpolar Deep Water mass, characteristic of this zone, was not observed in the sampling area of the SIBEX-Phase II cruise.

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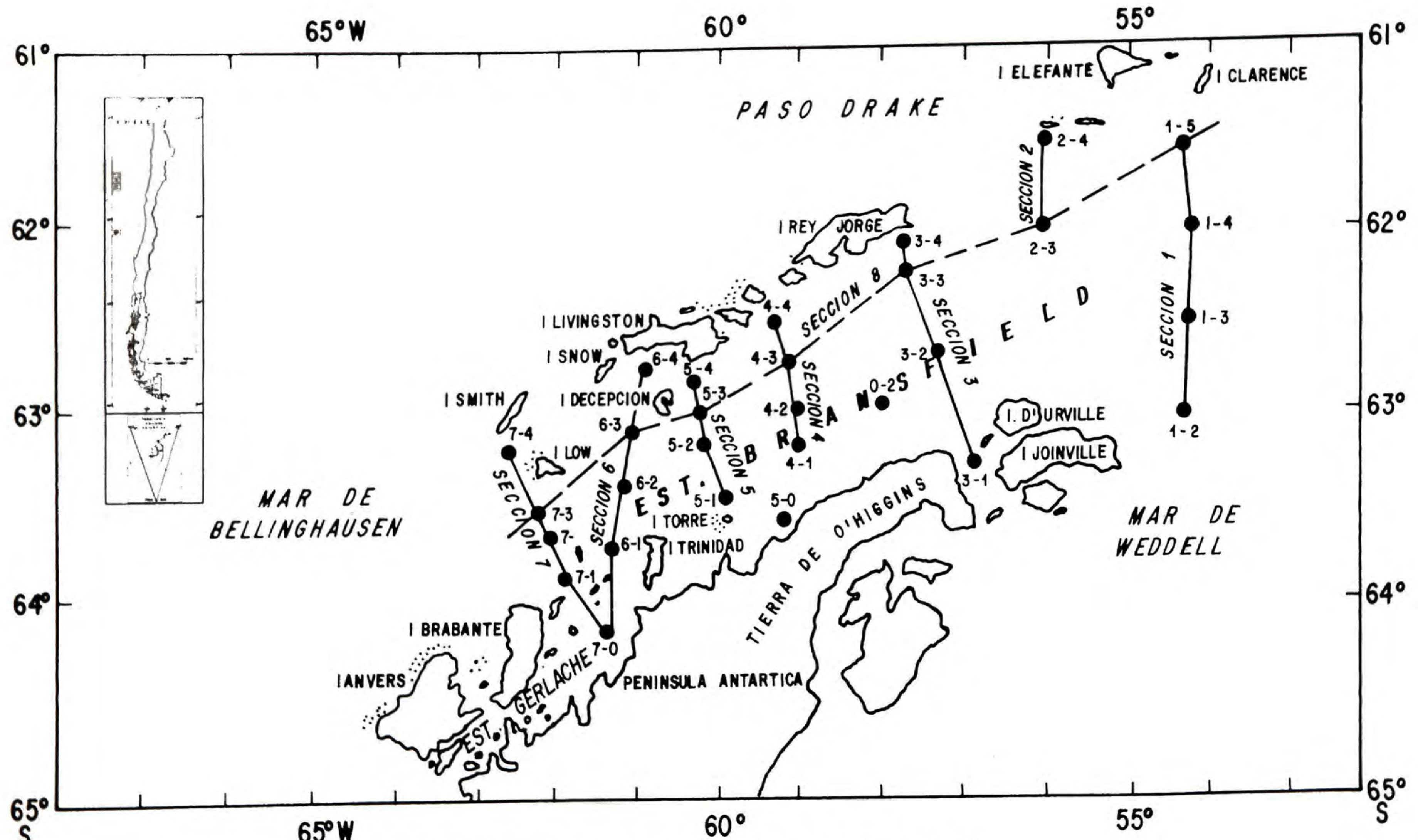

Figure 1.—Oceanographic station position and section distribution.

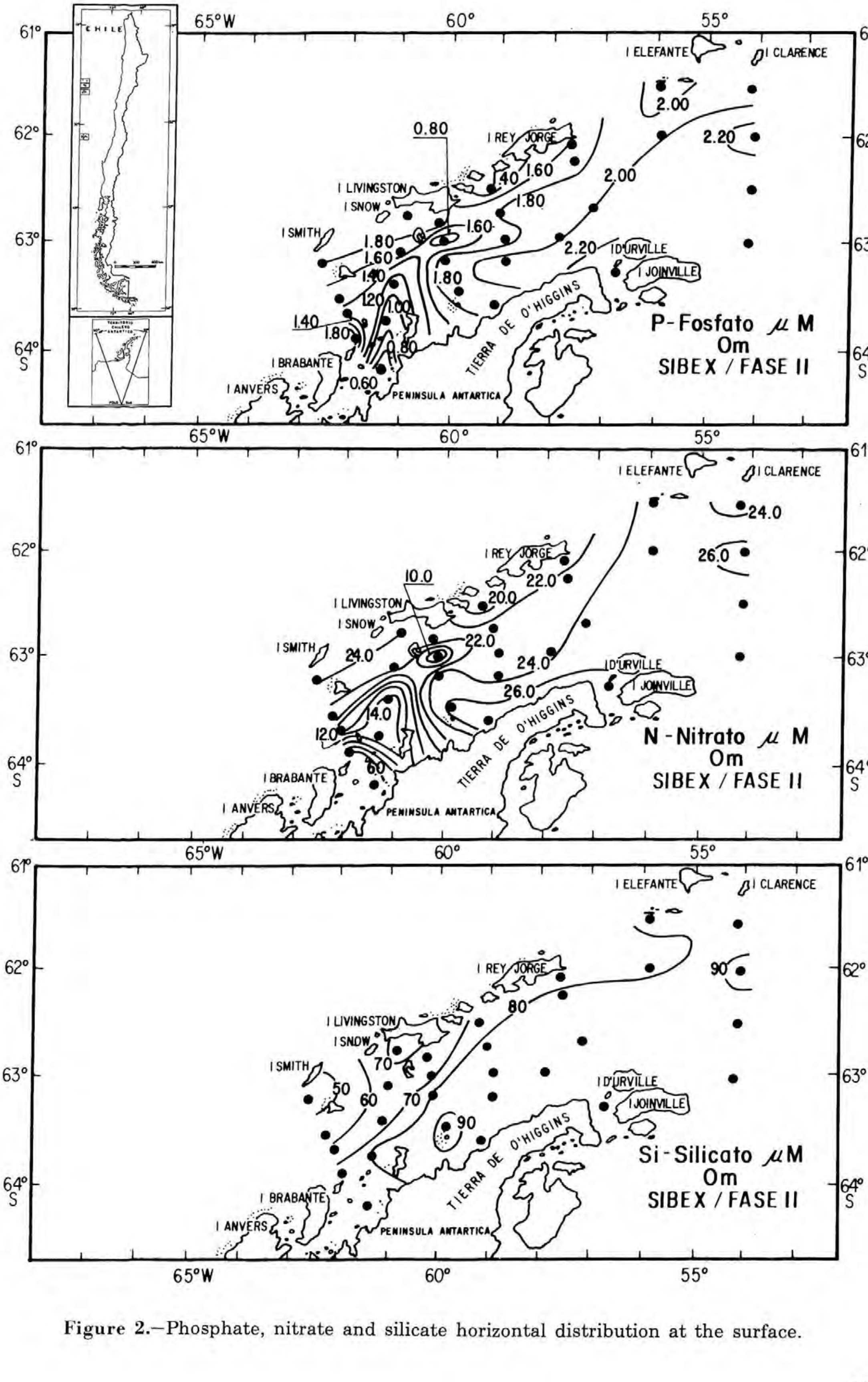

Figure 2.—Phosphate, nitrate and silicate horizontal distribution at the surface.

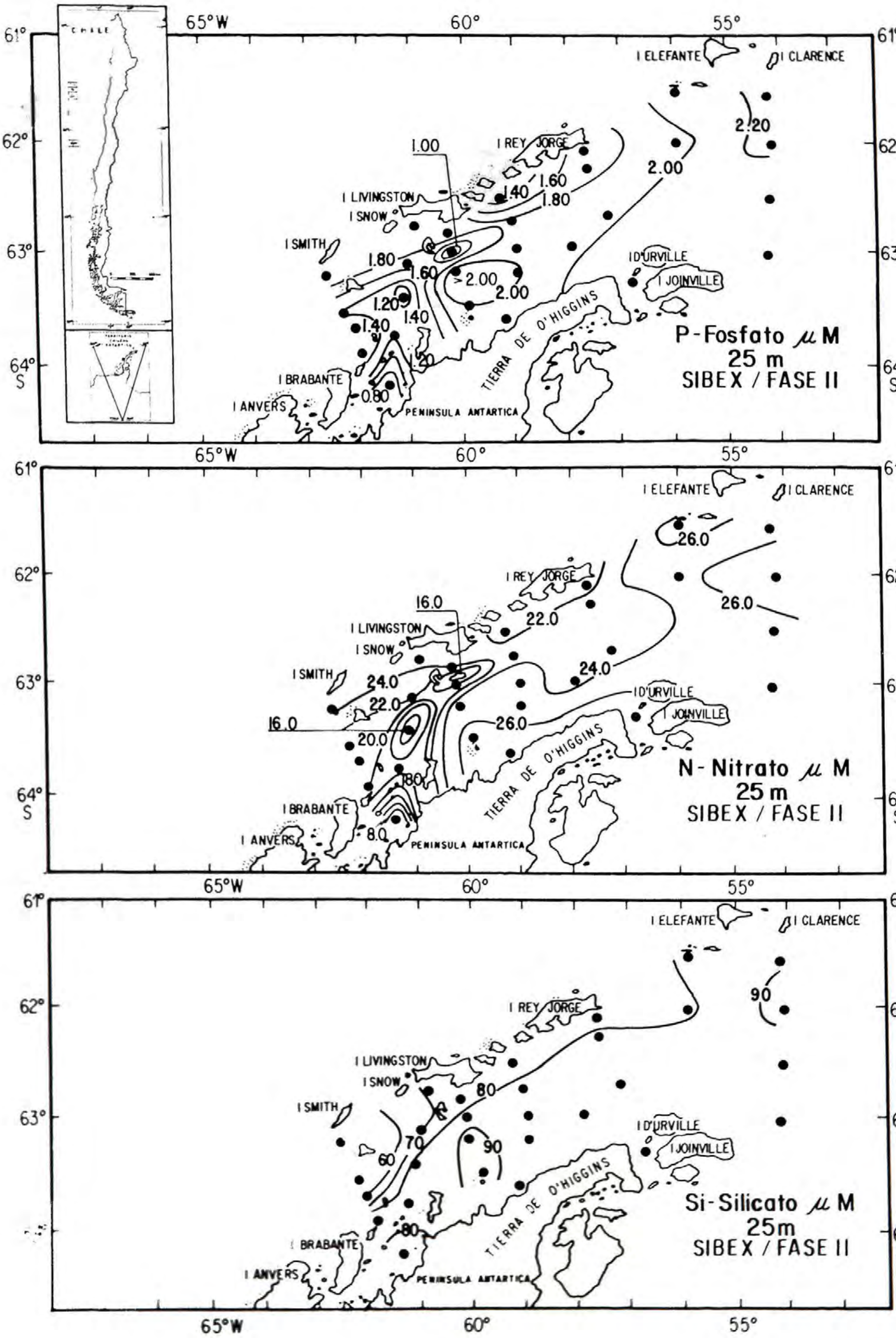

Figure 3.–Phosphate, nitrate and silicate horizontal distribution at the 25 m level.

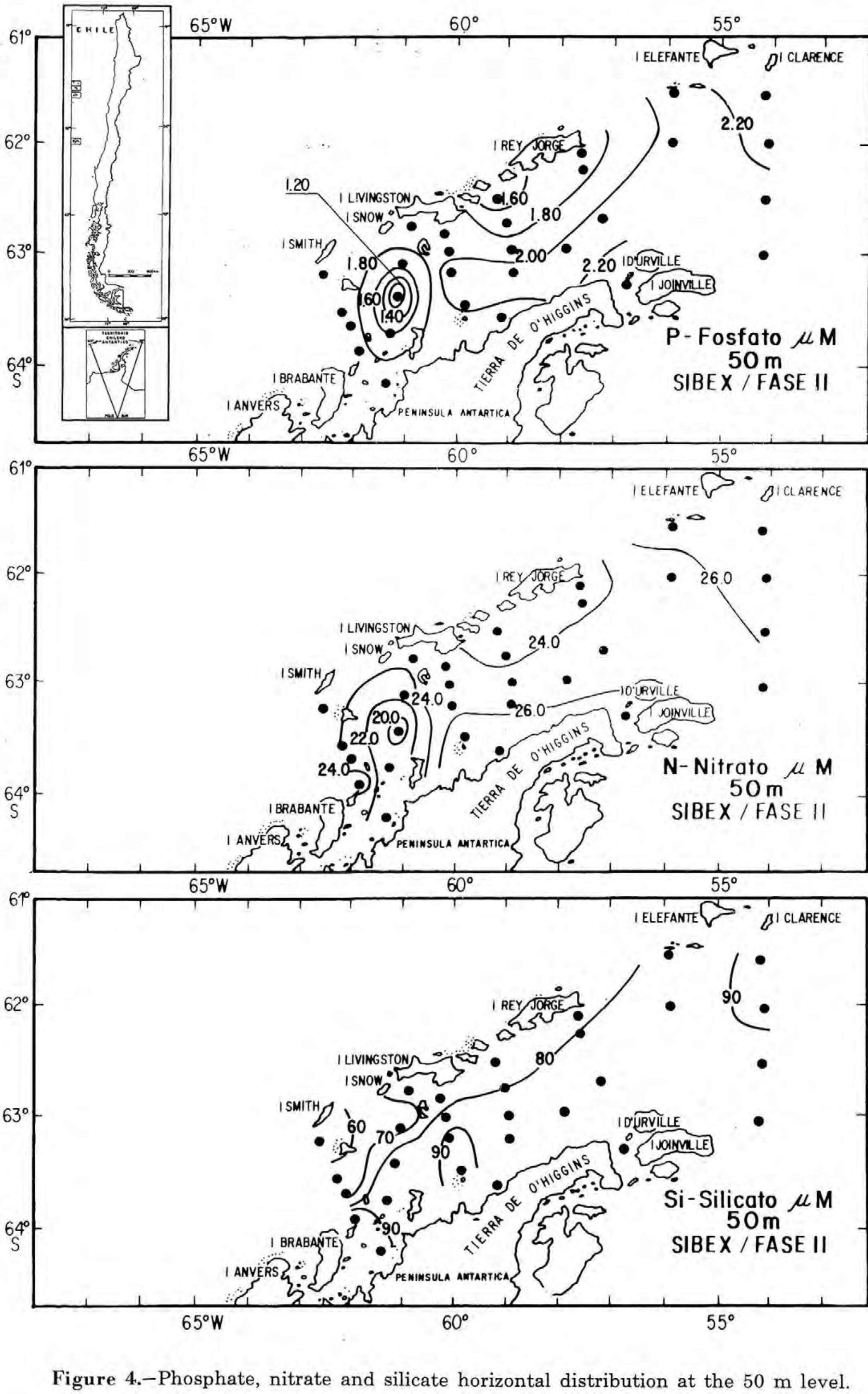

Figure 4.—Phosphate, nitrate and silicate horizontal distribution at the 50 m level.

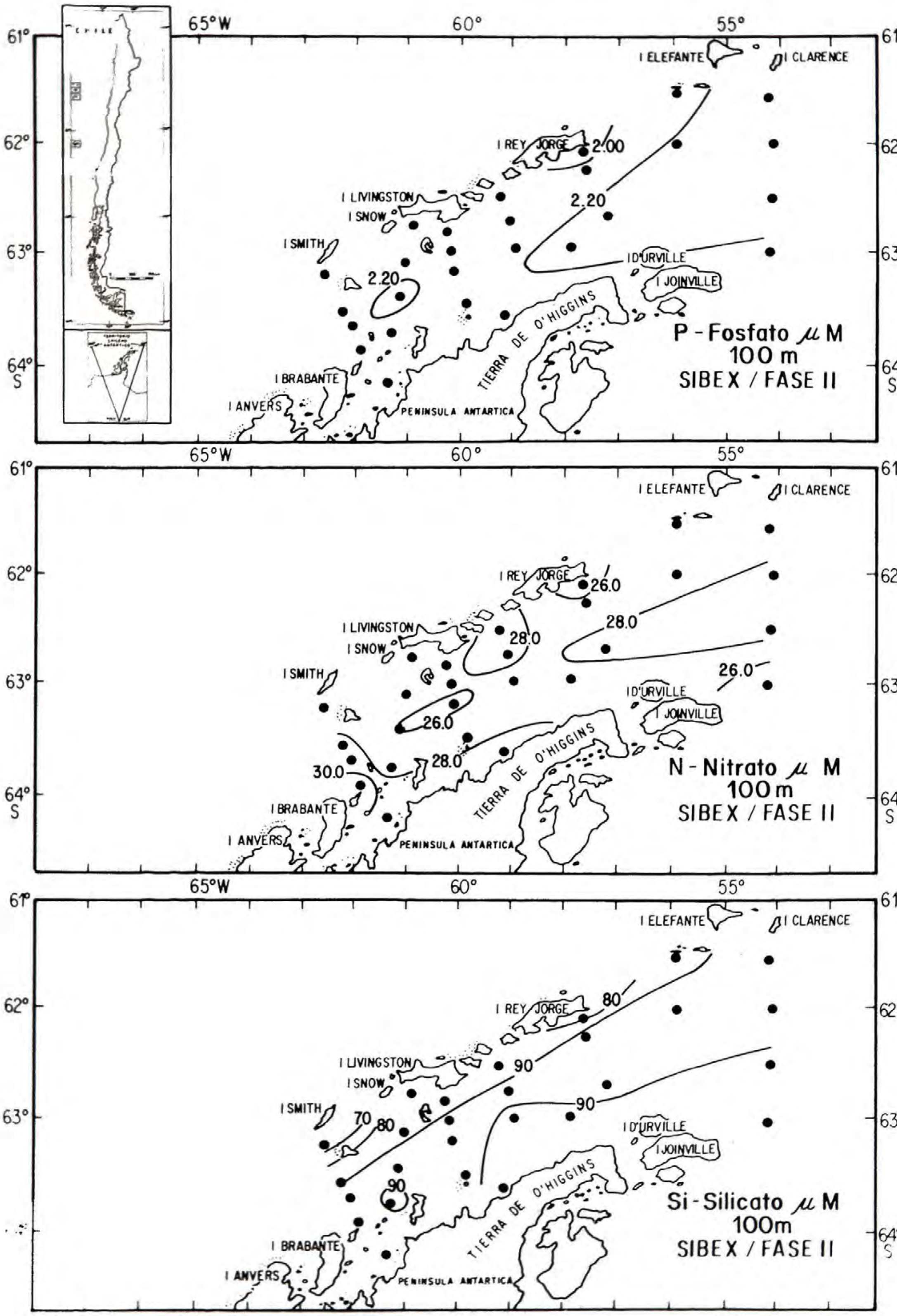

Figure 5.–Phosphate, nitrate and silicate horizontal distribution at the 100 m level.

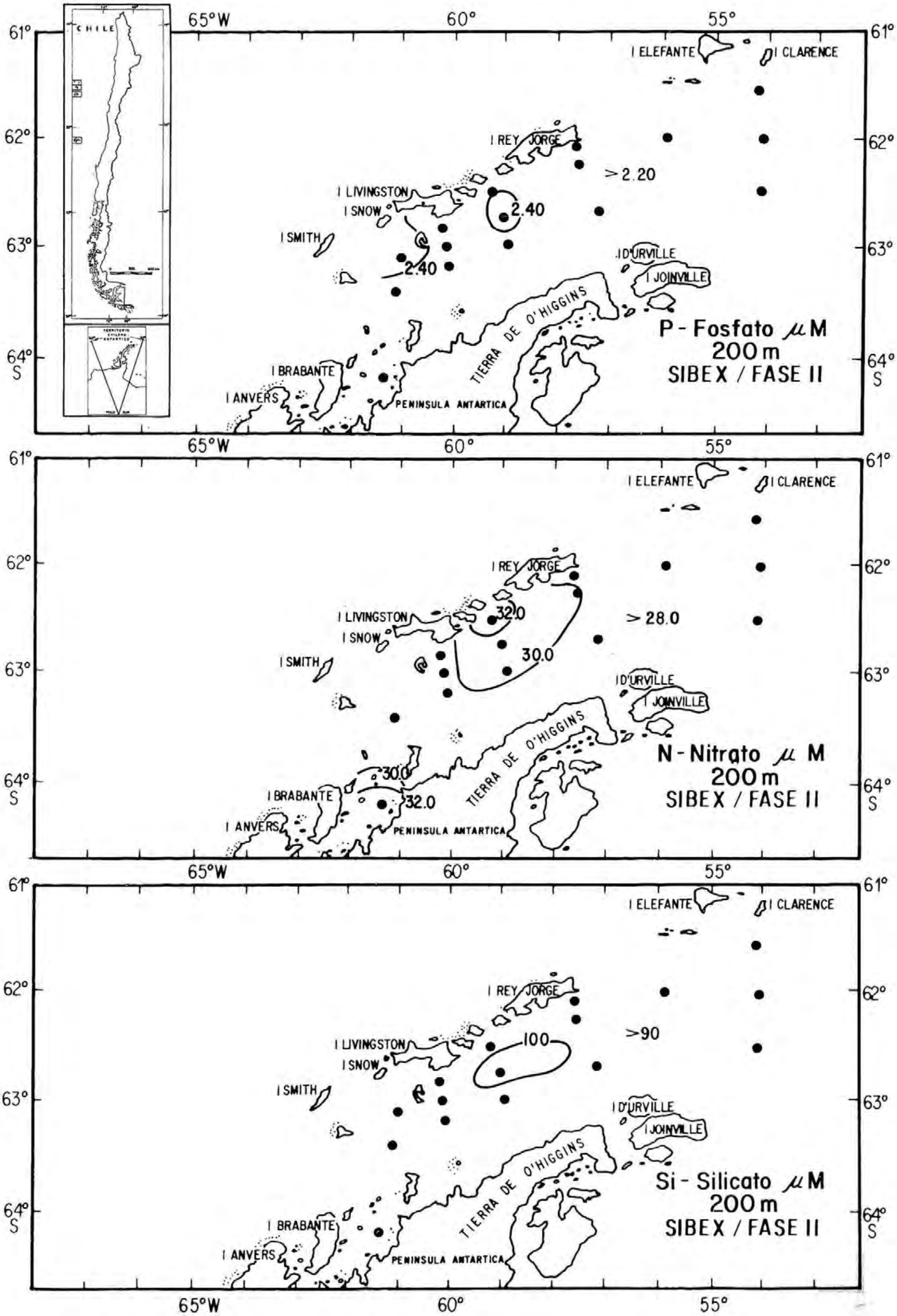

Figure 6.—Phosphate, nitrate and silicate horizontal distribution at the 200 m level.

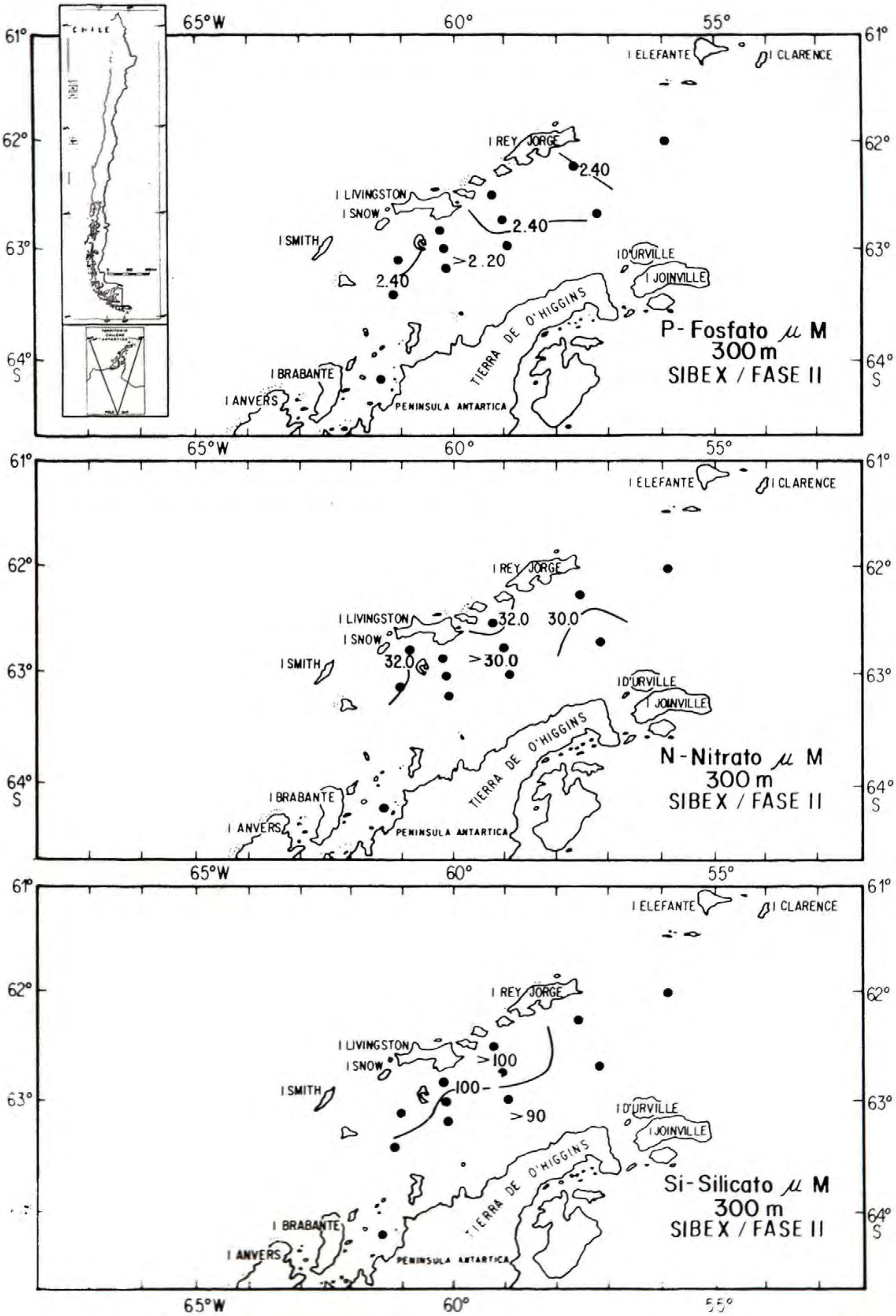

Figure 7.—Phosphate, nitrate and silicate horizontal distribution at the 300 m level.

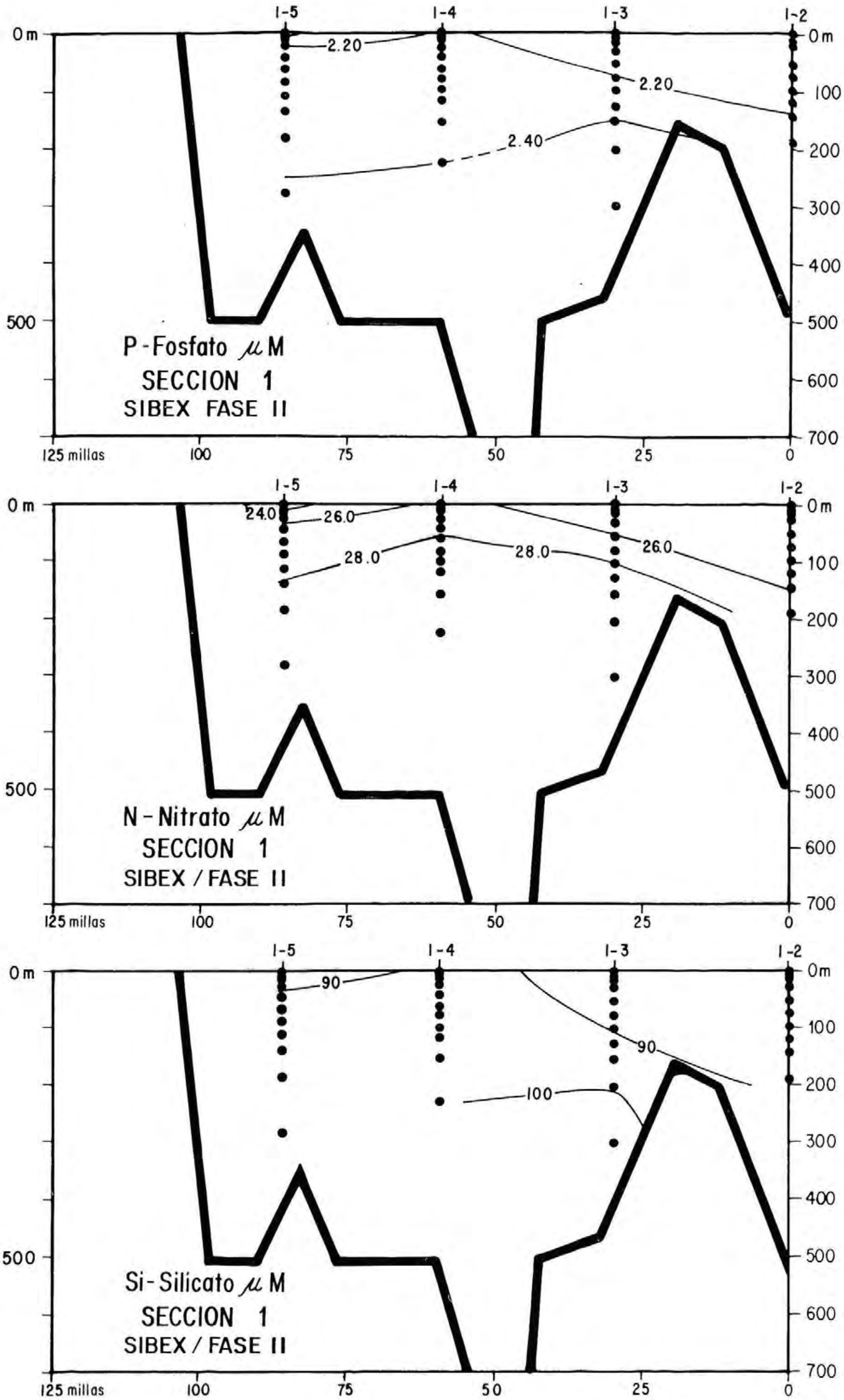

Figure 8.—Vertical distribution of phosphate, nitrate and silicate in the section 1.

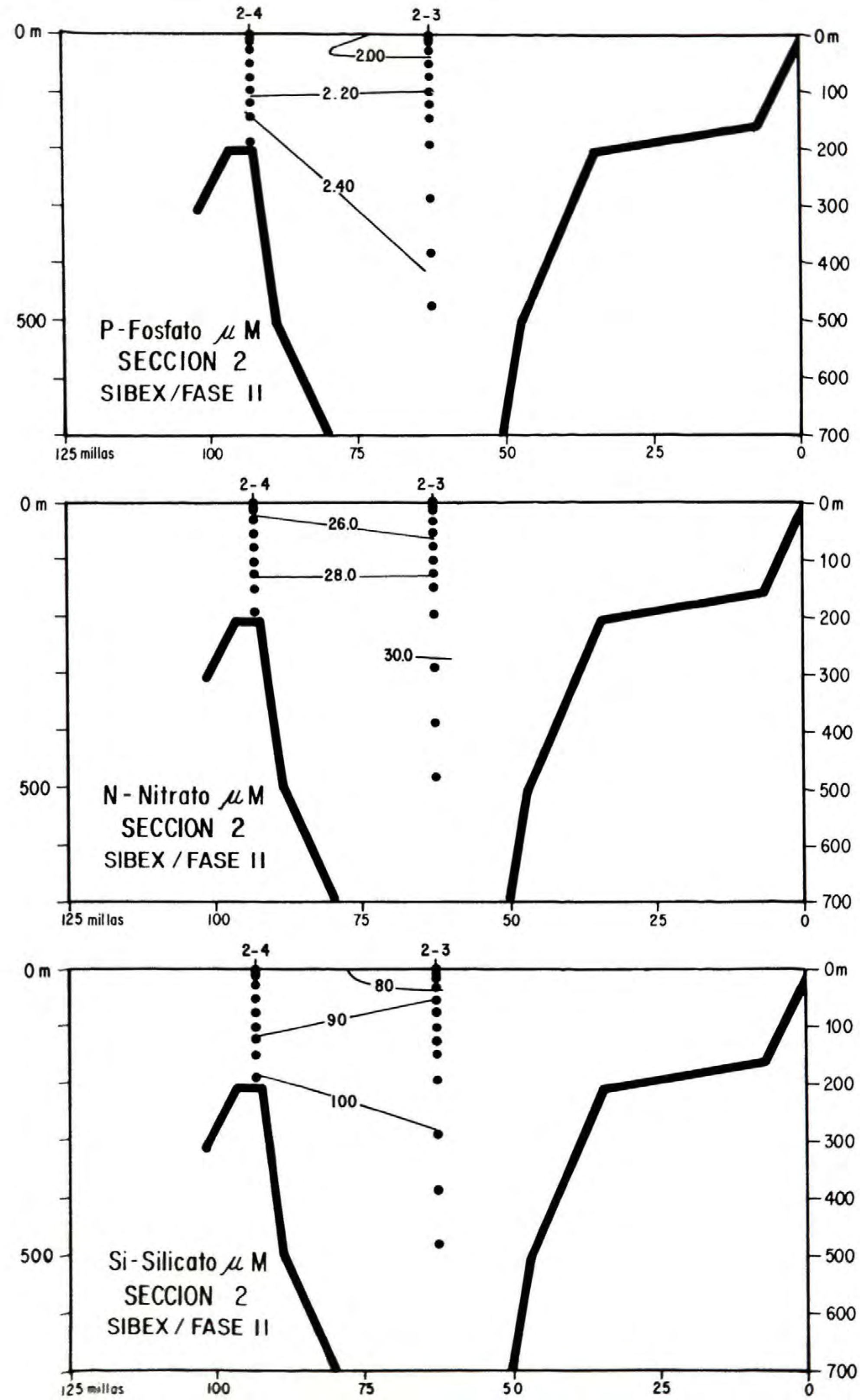

Figure 9.—Vertical distribution of phosphate, nitrate and silicate in the section 2.

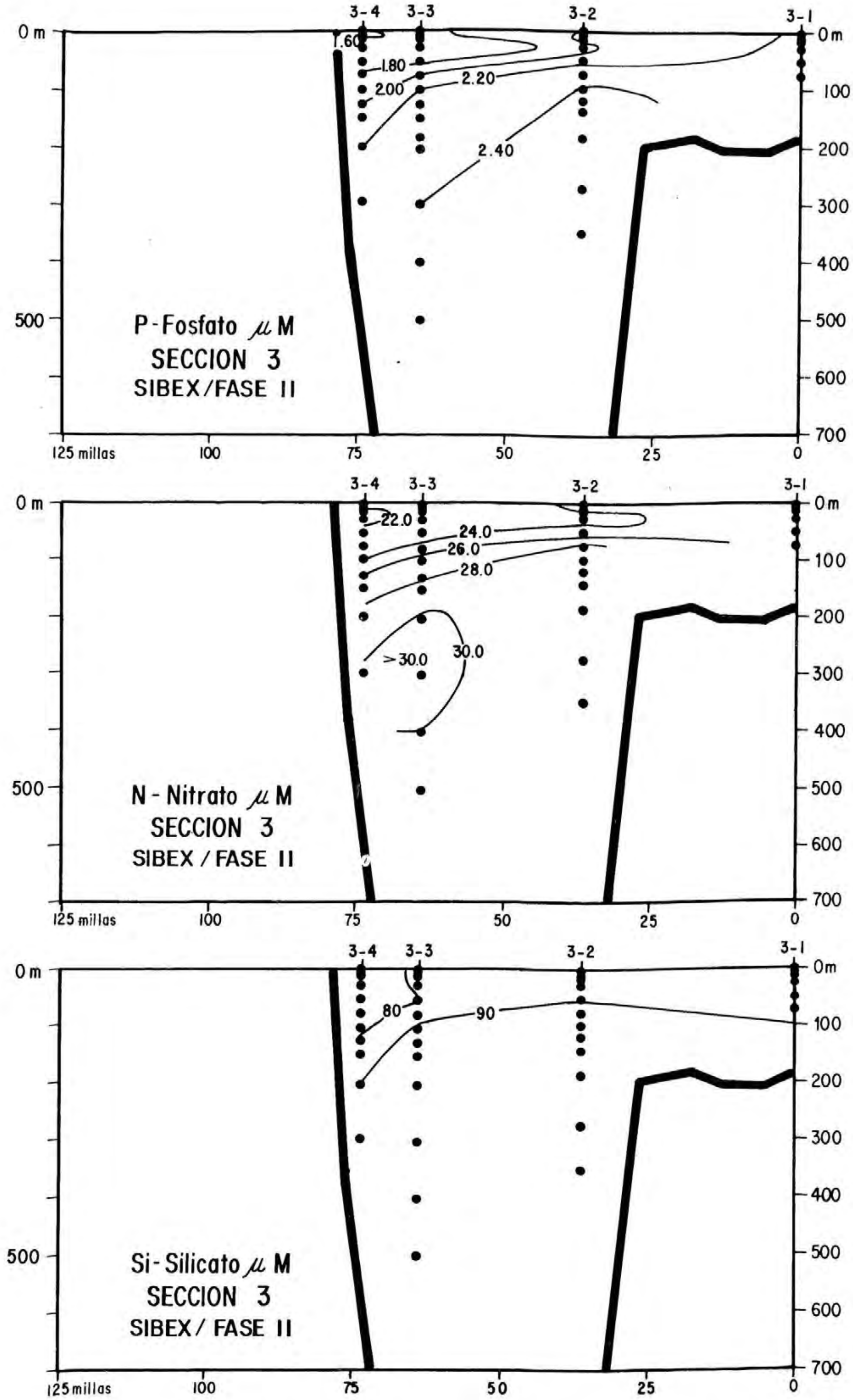

Figure 10.—Vertical distribution of phosphate, nitrate and silicate in the section 3.

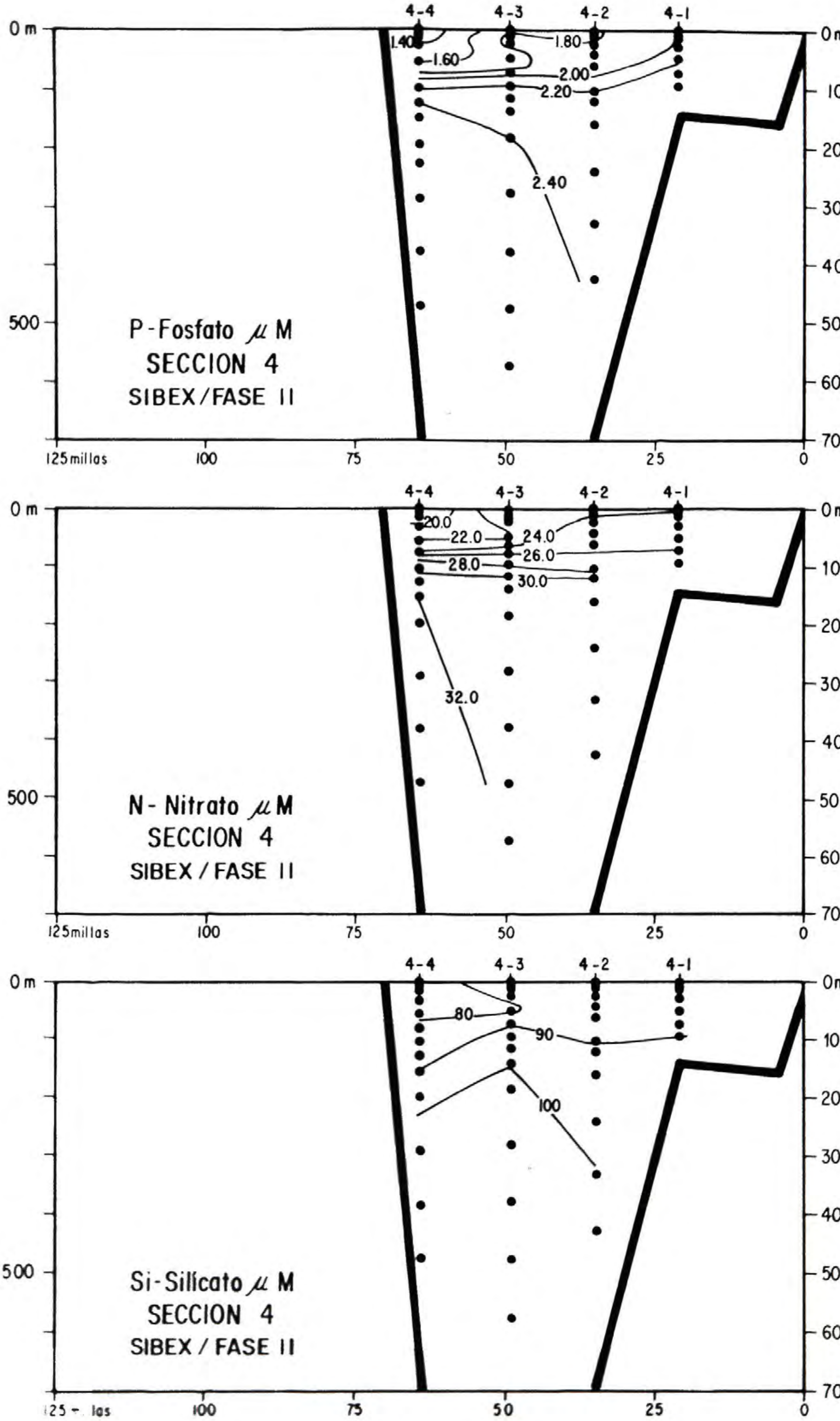

Figure 11.—Vertical distribution of phosphate, nitrate and silicate in the section 4.

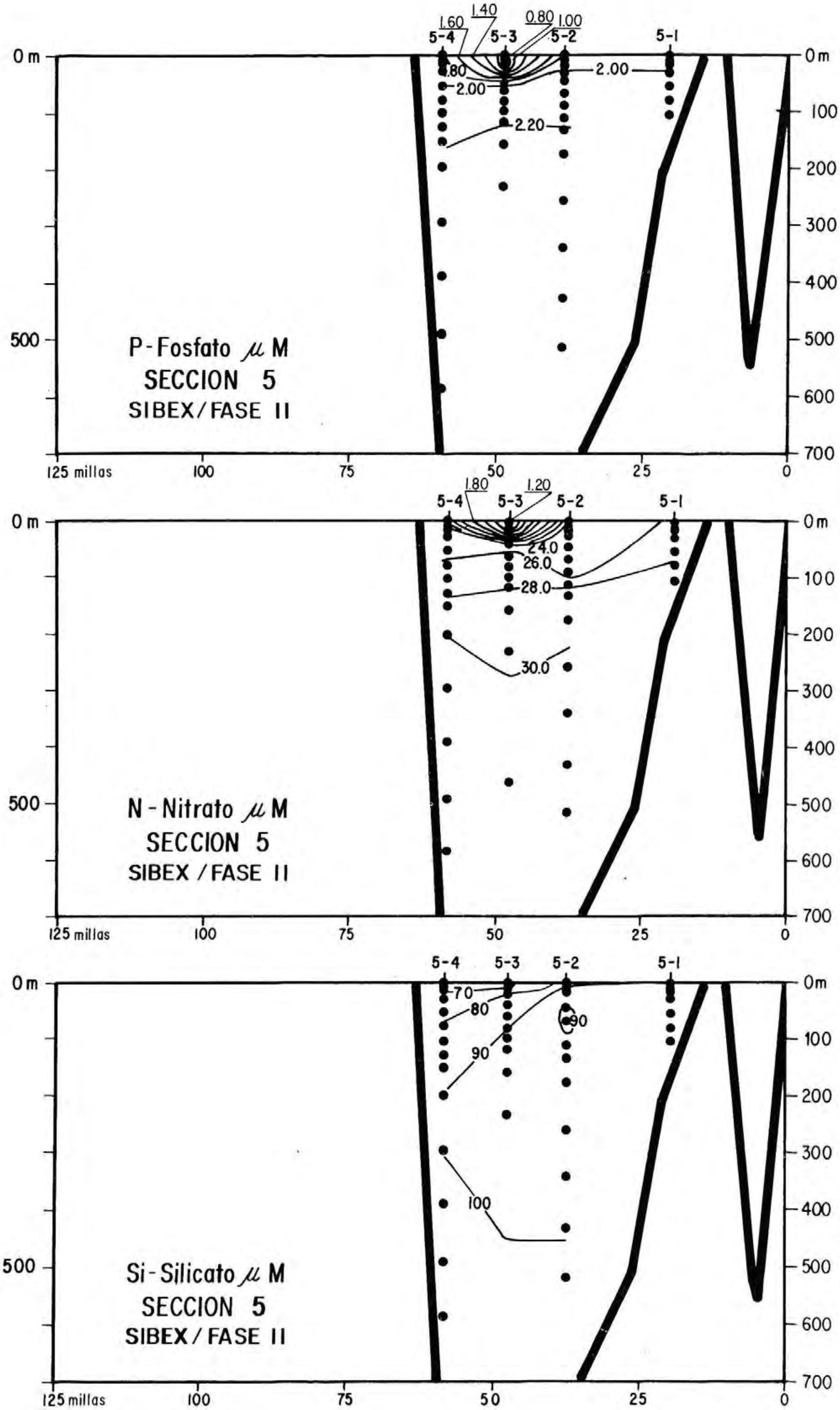

Figure 12.—Vertical distribution of phosphate, nitrate and silicate in the section 5.

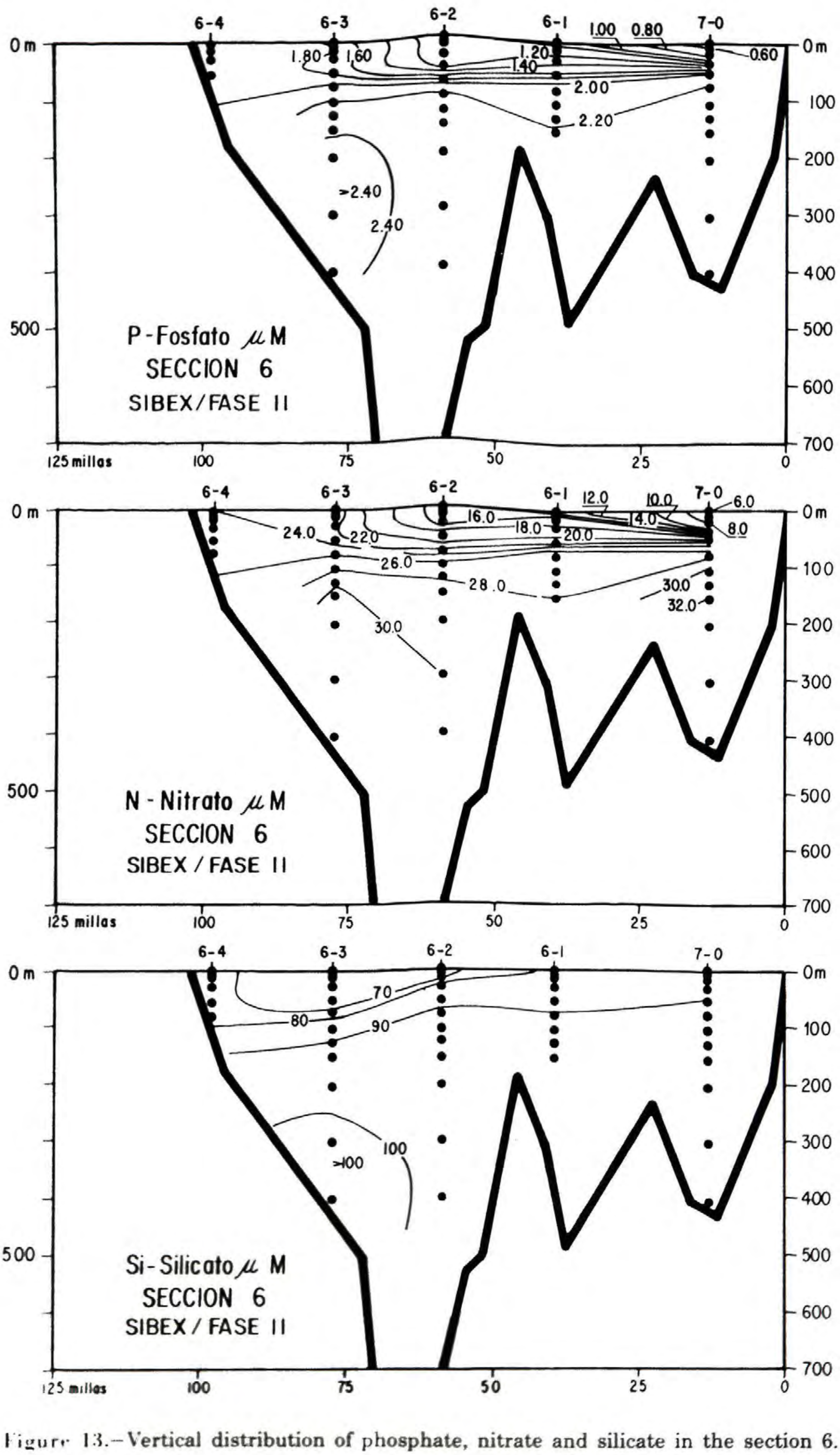

Figure 13.—Vertical distribution of phosphate, nitrate and silicate in the section 6.

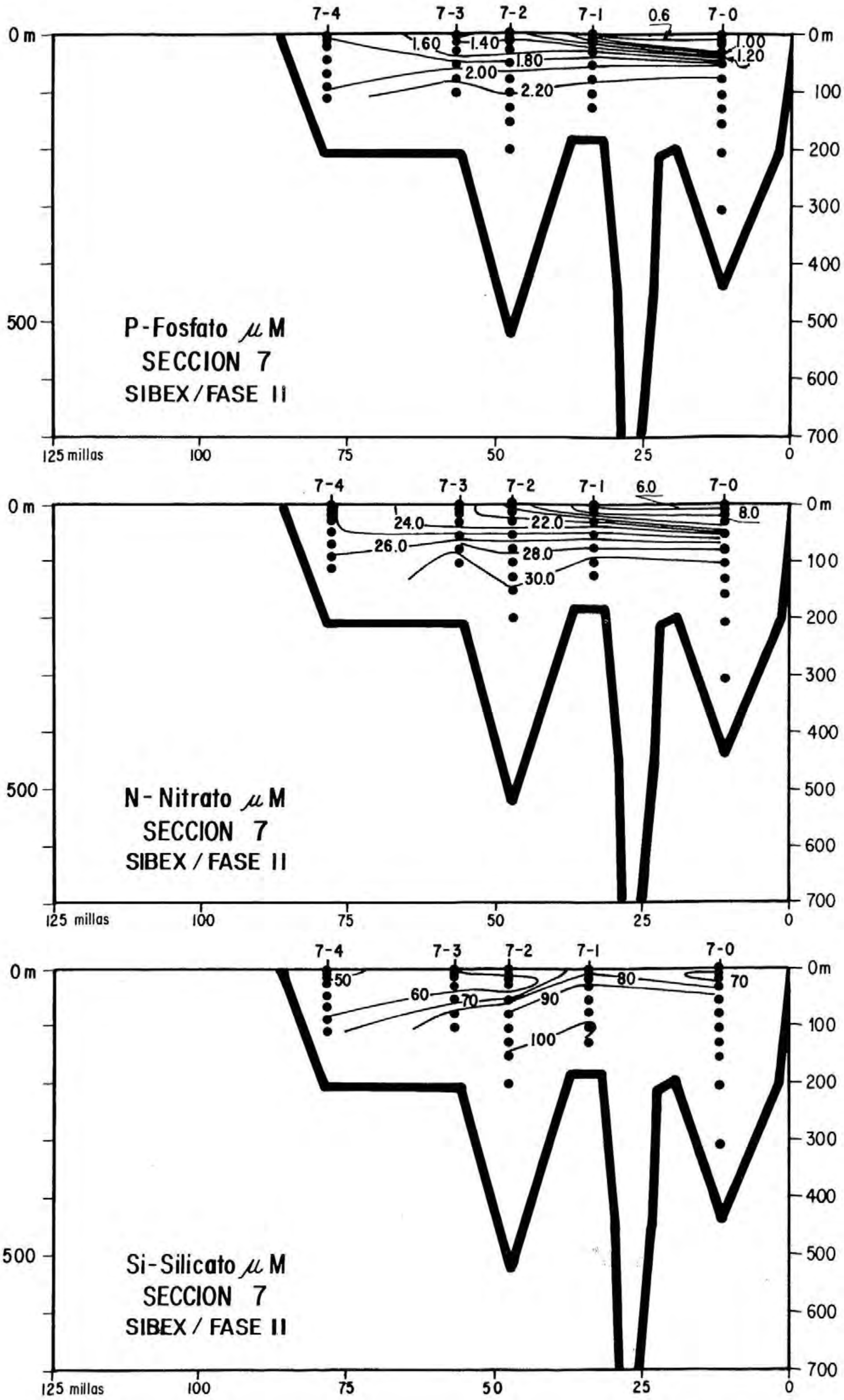

Figure 14.—Vertical distribution of phosphate, nitrate and silicate in the section 7.

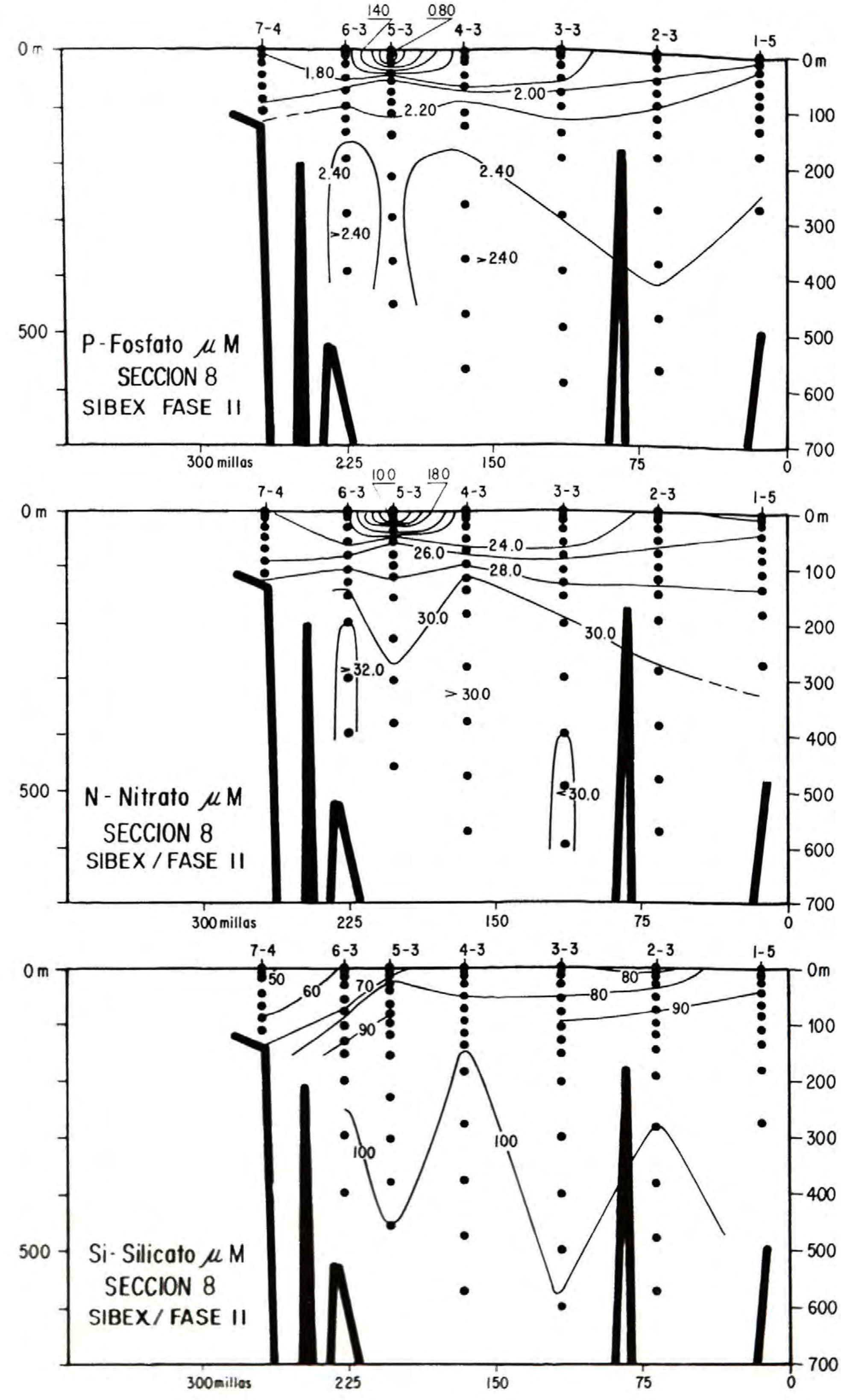

Figure 15.—Vertical distribution of phosphate, nitrate and silicate in the section 8.

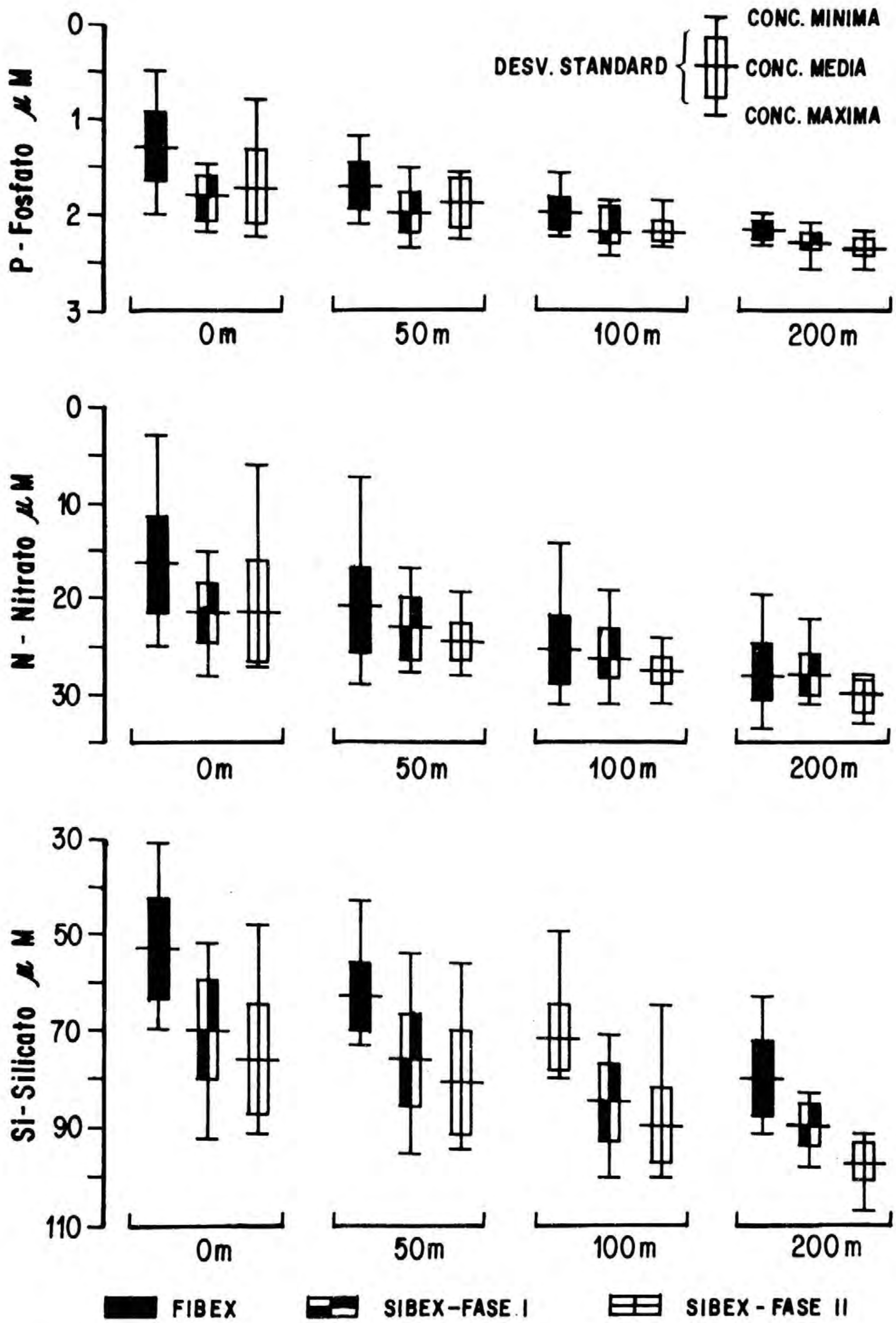

Figure 16.—Graphical comparison of the mean concentration, standard deviation of the mean and maximum and minimum values observed at the 0 m, 50 m, 100 m and 200 m levels for the different stations comprised between the common area for FIBEX-CHILE (January-February, 1981), SIBEX-Phase I (January-February, 1984) and SIBEX-Phase II (January-February, 1985) cruises.

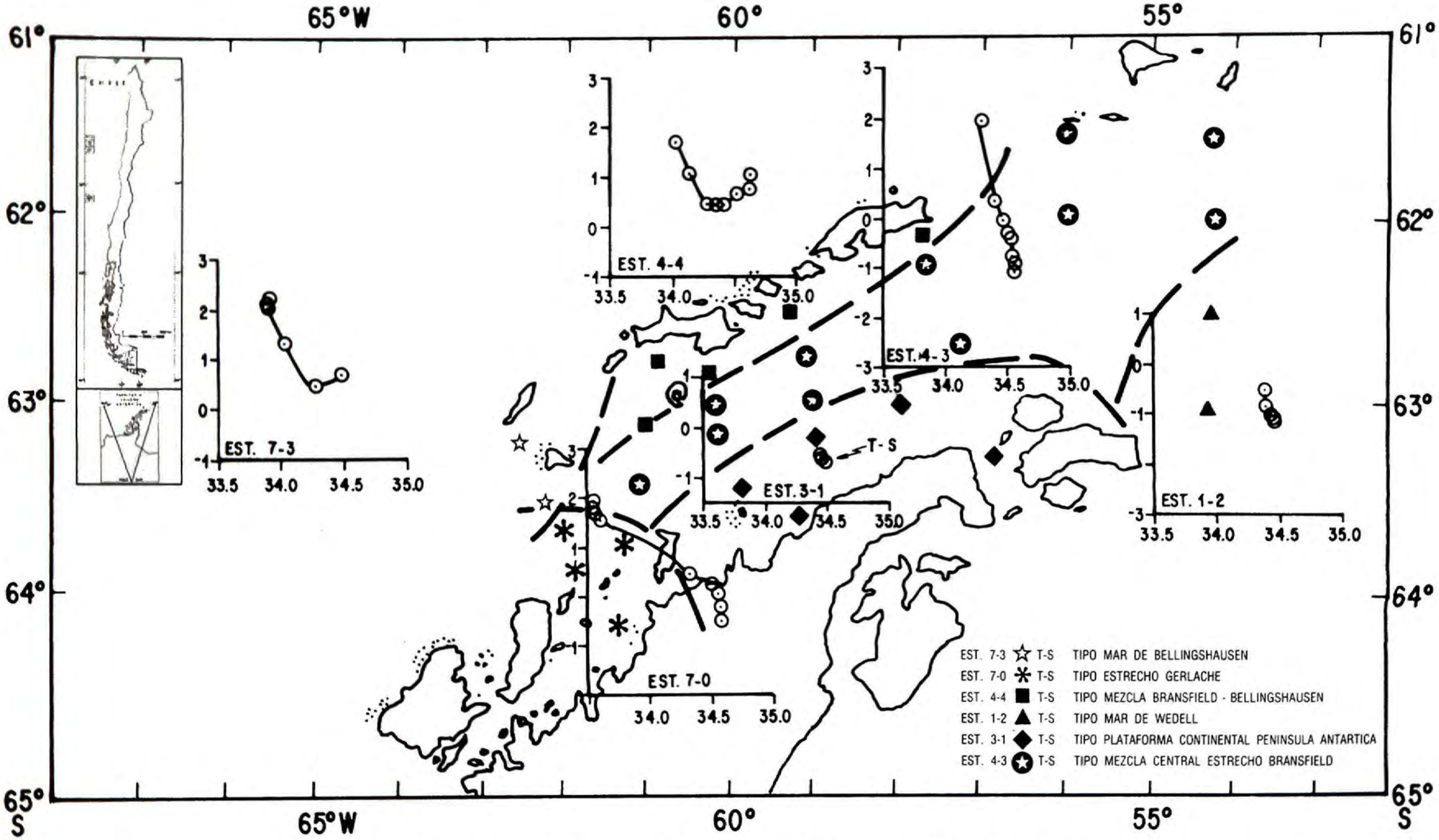

Figure 17.—T-S type distribution map. Characteristic T-S diagrams and the different oceanographic stations associated to them are shown.

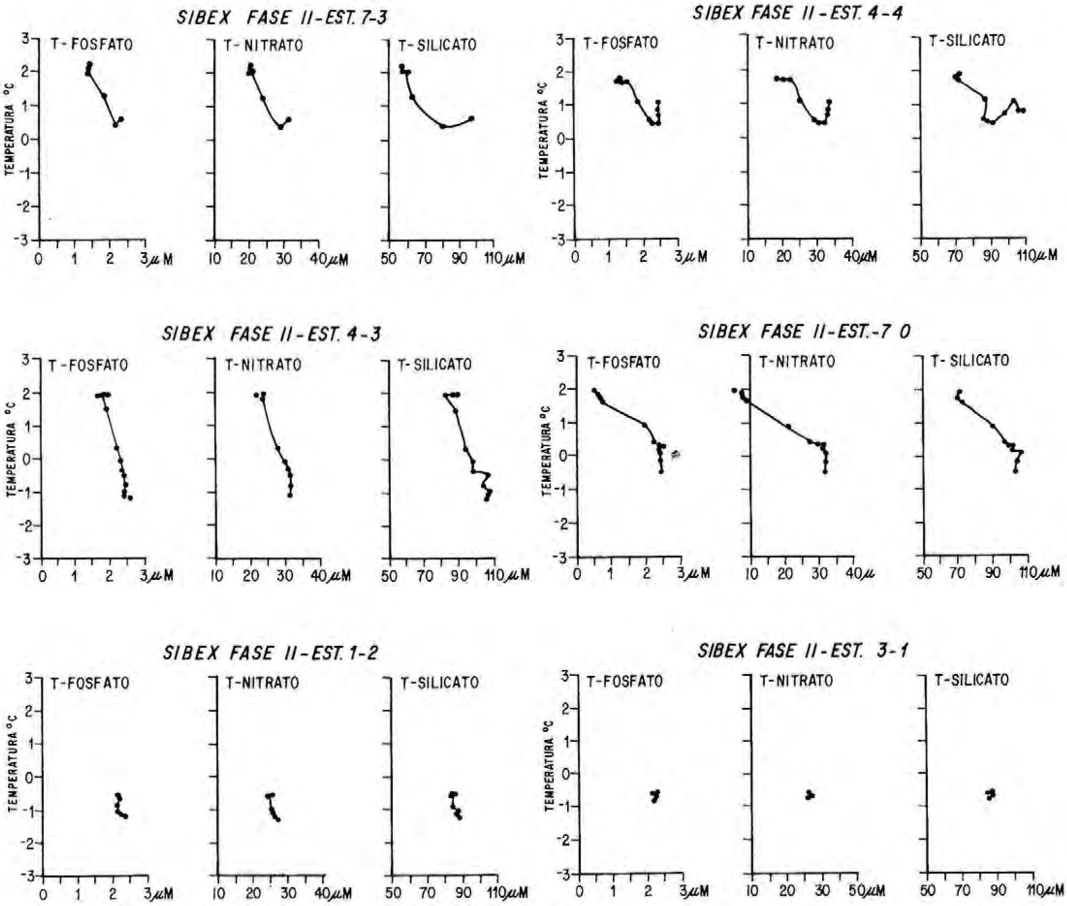

Figure 18.—Temperature-Phosphate, Temperature-Nitrate and Temperature-Silicate diagrams for the different characteristic stations used as station types in the T-S diagram identification (see Figure 17).

Table I

MULTIPLE COMPARISON OF THE MEAN MICRONUTRIENT CONCENTRATIONS OF FIBEX, SIBEX-PHASE I AND SIBEX-PHASE II CRUISES ACCORDING TO THE STUDENT-NEWMAN-KEULS PROCEDURE

		FIBEX-SIBEX I		FIBEX-SIBEX II		SIBEX I-SIBEX II	
		LSR Crit	LSR Obs	LSR Crit	LSR Obs	LSR Crit	LSR Obs
0 m	Phosphate	2.19	5.21(*)	1.87	4.25(*)	1.75	0.96
	Nitrate	3.08	5.20(*)	2.63	5.01(*)	2.45	0.19
	Silicate	6.16	16.96(*)	7.59	22.86(*)	5.87	5.90
50 m	Phosphate	1.58	2.90(*)	1.35	1.90(*)	1.26	1.00
	Nitrate	1.87	2.17(*)	2.31	3.34(*)	1.78	1.17
	Silicate	5.47	13.14(*)	6.73	17.75(*)	5.60	4.61
100 m	Phosphate	0.84	1.83(*)	1.04	2.08(*)	0.83	0.25
	Nitrate	19.87	9.10	17.44	0.90	16.12	10.00
	Silicate	4.55	12.99(*)	5.63	17.75(*)	4.44	4.76(*)
200 m	Phosphate	0.91	1.66(*)	0.74	1.36(*)	0.72	0.30
	Nitrate	17.99	0.50	21.94	18.20	17.66	17.60
	Silicate	3.90	9.63(*)	4.76	17.00(*)	3.83	7.37(*)

(*) Significative difference between cruises ($\alpha = 0.05$).

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