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Holocene glacial-marine sedimentation in the Prydz Bay, Antarctica*

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Abstract The typical glacial-marine sedimentation has been recorded from core NP93-2 in the Prydz Bay, Antarctica. The sedimentation processes, sedimentary environment and paleoclimate variations since 12937 a B. P. have been discussed, based on grain size, mineral composition and micropaleontological data, etc.. The climate variation occurred at 10 ka, which expressed that there were increased inputs of terrigenous clastics. The climate change once again but temporarily took place at late Holocene.

Key words Prydz Bay, Antarctica, glacial-marine sedimentation, paleoclimate.

1 Introduction

The Prydz Bay is located at seaward extension of Lambert sag, which is mostly covered by Lambert ice sheet and Amery ice shelf. A broad sag exists on the shelf, which is considered as resulting from glacial erosion (Anderson and Smith, 1989) and has smooth seafloor. The continental slope lies in the outer side of the sag, gently dipping and smooth, of which the isobath is slightly bent outward. But the continental slope on the both ends becomes narrow and steep. Several channels extend in NNE and NNW directions.

There are two kinds of regional circulating currents as follows: (1) current on the bank of Antarctica flows eastward along the edge of the continental shelf; (2) current on the periphery of Antarctica flows between 40°～60°S, formed by wind to the west. The circumfluence at 3000～4000 m depth in the Prydz Bay is complex and still not clear, because of effection of the Kerguelen Plateau under water (Le, 1995).

Glacial-marine sedimentation has been discussed by seismic data analysis (Kuvaas and Leitchenkov, 1992) and drill data during cruise ODP119. It is defined as "glacial-marine sediments" which include both glacial clastics and marine sediments (Borns and Matsch, 1988). Following the development of investigation in the sea area around Antarctica, the situation is advantage for the study of paleoenvironment evolution of

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Antarctica continent.

Core NP93-2 has been sampled by the 9th Chinese National Antarctic Research Expedition which is collected by SM-2 type gravity piston. The sample site is located at the Prydz Bay (67°59′S, 73°08′E)(Wang *et al.*, 1996). Water depth is 550 m. Core length is 85 cm. To study the features and marks of glacial-marine sediments are valuable for knowing the melting of ice sheet, paleoceanography and paleoclimate evolution, therefore, the sedimentary features from core NP93-2 are discussed in the article.

2 Grain-size of sediments

According to naked eyes, the sediments from core NP93-2 can be divided into 6 layers from top to bottom as follows:

(1) 0～8.5 cm, tawny clayey silts or sands;
(2) 8.5～22.5 cm, grayish green clayey silts;
(3) 22.5～37 cm, grayish green sandy clays, bearing some conglomerates;
(4) 37～71 cm, grayish green clayey silts or sands, bearing conglomerates;
(5) 71～75.5 cm, deep grayish black silty clays;
(6) 75.5～85 cm, grayish green silty clays.

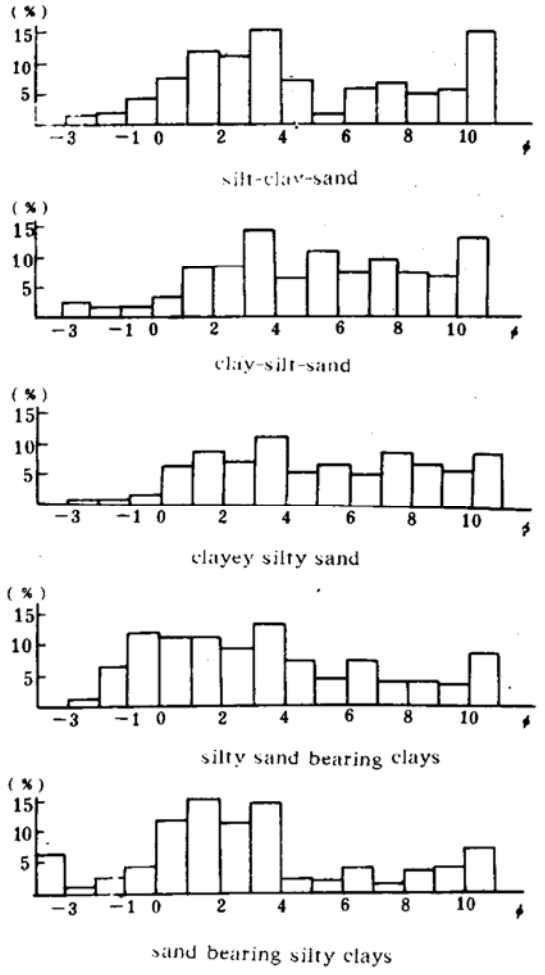

Fig. 1. Histogram of grain-size from core NP93-2.

Sample-taking from core NP93-2 begins at 3 cm depth and at an interval of 5 cm. Every sample is 2 cm in thickness. 17 samples have been gained in all. If the diameter of gravel is more than 20 mm, no samples have been analyzed. The results are shown on the histogram of grain-size (Fig. 1) and the accumulation frequency curve of grain-size (Fig. 2).

Clearly, on the basis of colour of sediments and grain-size composition, five types of sediment have been divided in the following: (1) silt-clay-sand; (2) clay-silt-sand; (3) clayey silty sand; (4) silty sand bearing silty clays; (5) sand bearing silty clays. The sediment features of core NP93-2 are not abruptly changed from bottom to top, but very slowly.

By the analysis results of grain-size of sediment from core NP93-2, the sediments consist of 0.3%～10.7% gravels (usually less than 5%), 35%～60.7% sands (usually 40%～50%), 15.2%～33.65% silts (usually 20%) and 13.2%

~27.7% clays (usually 20%). In the histogram of grain-size of sediments (Fig. 1), the curve of sand bearing clay and silt has one weak single peak, but the other four types sediments have no apparent peaks. On the accumulation frequency curves of grain-size of sediments from core NP93-2 (Fig. 2), the five curves are extending similarly and gently, or not steeply dipping.

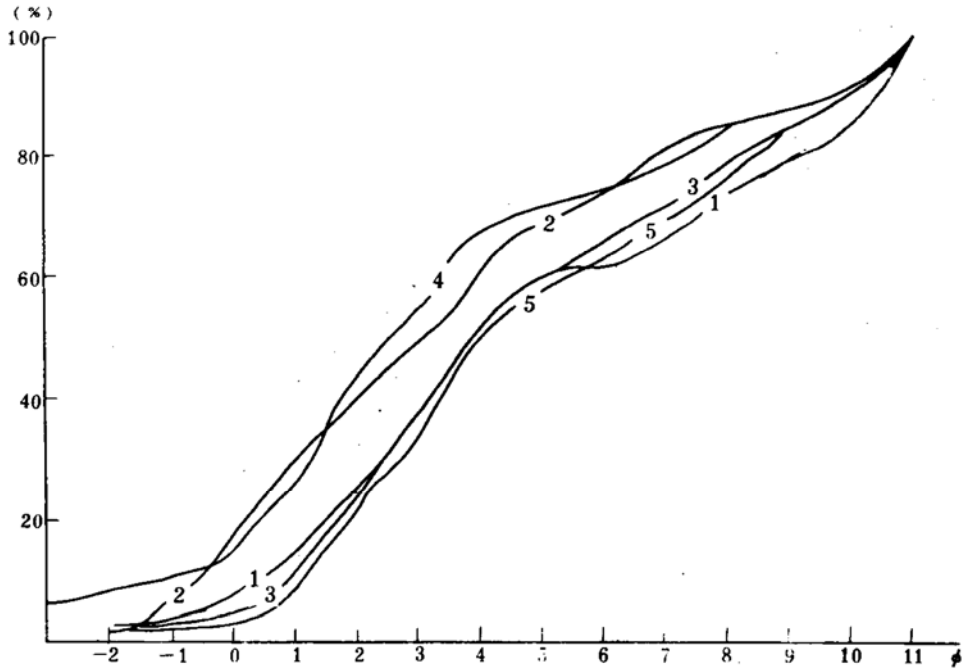

Fig. 2. Accumulation frequency curve of grain-size from core NP93-2.

For quartering coefficient of grain-size, there are 13 samples with 2.28~2.87; 4 samples with 3.12~3.12. The former is thought to be poor sorting, the latter is regarded as the poorest sorting, based on the standards of quartering sorting coefficient.

The sand contents of the sediments in the core NP93-2 greatly change at 78~79 cm depth. The sand content over the depth is 59.6%, that bellow the depth is 35%. Moreover, the sand contents from 0 to 79 cm depth are higher than 43.6% and have four peaks, which occurred at 23~24 cm, 43~44 cm, 58~59 cm and 79 cm respectively. The upper sediments of the four peaks are always coarse. It is probable that glacial-derived clastics increased when climate got warm, but more data are needed for supporting. The sediments from core NP93-2 are typical glacial-marine sediments which have high contents of gravels and clays, sorting is poor to poorest. The sediment compositions are greatly different from those of outer continental shelf and upper continental slope in tropical or subtropical area, which are usually coarse shore sediments formed during lower sea-level (Wu and Luo, 1994).

3 Mineral compositions

The results of X-ray diffraction analysis of core NP93-2 (Table 1) indicate that sediments are composed of terrigenous clastic minerals, such as plagioclase, K-feldspar, quartz, amphibole and some clay minerals. They usually contain number of siliceous oozes. There occur a lot of gravels in some sediment layers, which are mica schist and granogiorite. The kinds of heavy minerals are relativeless but content is higher, which are consist of amphibole and glauconite. Amphibole content is as high as 19.45%. The sediments contain not only such altered minerals as plagioclase, K-feldspar, but also stable quartz. The content of altered minerals are greater than contents of stable minerals. This indicates that the sediments in glacial-marine environments have experienced quite slow weathering, decomposition and secondary changes.

Table 1. X-ray diffraction analysis of core NP93-2

Sample number	Montori llonite	Illite	Kaolinite	Chlorite	Amphibole	Quartz	K-feldspar	Plagioclase
1	2.09	5.11	1.02	1.48	5.82	12.89	29.52	42.04
2		4.55	0.92	1.09	5.44	10.42	22.76	54.84
3		5.37	0.74	1.01	7.91	12.88	26.52	45.58
4		3.69	0.72	0.99	4.38	9.85	38.78	41.59
5		2.96	0.68	0.97	2.94	8.30	55.18	28.94
6		3.89	0.80	1.31	4.10	19.22	41.92	28.75
7		5.41	0.85	1.53	8.24	21.56	32.63	29.77
8		2.98	0.71	0.91	4.66	27.05	16.82	46.58
9		3.94	0.79	1.23	19.45	11.79	39.37	23.42
10		7.77	1.14	1.97	6.25	29.45	18.11	35.28
11		3.58	0.87	1.02	7.08	20.42	16.23	50.78
12		4.94	0.75	1.01	5.43	13.70	42.23	31.93
13		5.56	0.55	0.76	9.47	18.65	25.16	39.83
14		4.35	0.63	1.79	7.16	19.82	32.45	33.79
15		4.73	1.05	1.92	5.38	23.39	30.68	32.83
16		4.12	1.06	1.48	7.88	14.09	35.14	36.22
17	3.37	3.92	0.76	1.76	3.98	15.64	22.15	48.40

Clay minerals have a lot of features, although they take up a little contents of the sediments. Illite is the most important clay mineral accounting for 2.96%～7.77%, which is the intermediate mineral between kaolinite and montmorillonite. It is formed in lower temperature and ill-drainage environment. Kaolinite comes from the diamictons, which consist of feldspar and feldpatfoid and other aluminum-silicate minerals. There is less montmorillonite, which can only be seen on both top and bottom.

4 Microbiogenic sedimentation

There have been found number of diatoms, radiolarians and sponge-spicules, together with a few foraminifera and ostrocades.

The diatoms are rich both in quantity and in kinds(Fig. 3). *T. antarctica* amounts to 40%, reflecting an open ocean water, *N. Kerguelensis* accounts for 10%. These dis-

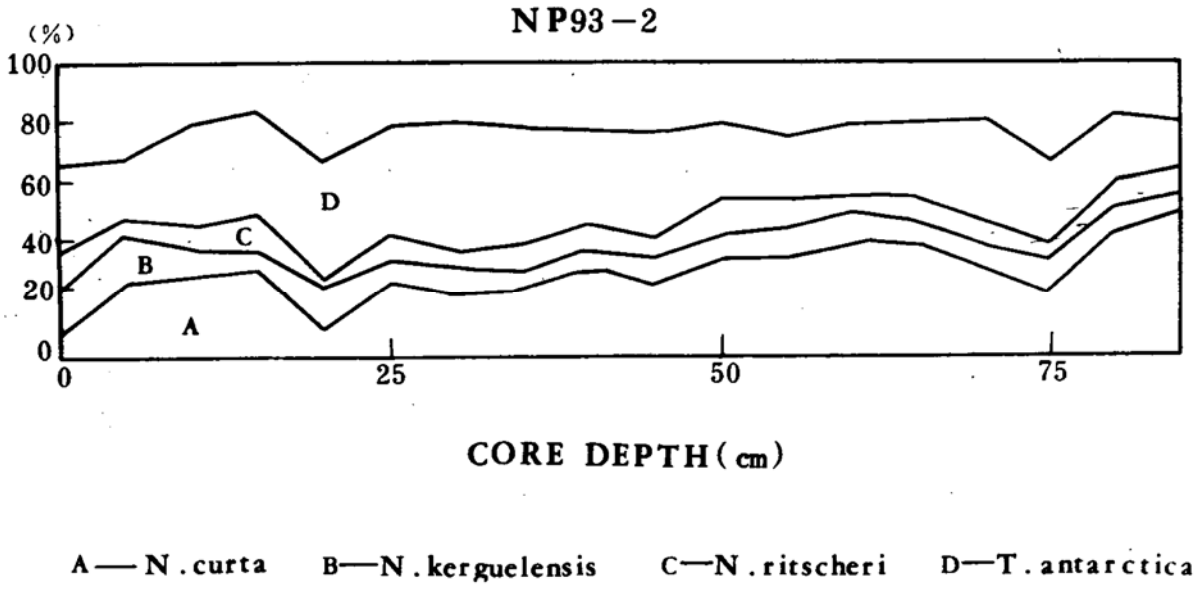

Fig. 3. Distribution of dominate diatom species from core NP93-2.

tribution of diatoms indicate that the sediments were formed far from seashore, showing a relative deep water environment. On the basis of numbers and types of diatoms, there are two climate events: the first apparent climate change happened at 75 cm depth, below which there are high contents of the cold species *A. antinochilus* and ice-edge species *N. curta*, and there are low contents of Thalassiosira. These reflect the cold climate and lower sea-level during late Pleistocene. The another climate variation took place during Holocene. *E. antarctica*, which reflects cold climate, change in number from more to less and then to more during Holocene (Fig. 5). It means that there existed a cold climate period during Holocene warm stage.

Foraminifera are few in core NP93-2 about 200 tests have seen in 50 g dry samples. Most of foraminifera are benthic ones, which include: *Miliammina arenacea*, *Trifarina carinata* and *Globigerina pachyderma*. The abundance of foraminifera in the middle of the core NP93-2 is lest than that on both ends (Fig. 4). The siliceous foraminiferal fauna, especially *Miliammina arenacea* is most abundant in core NP93-2. The highest content is up to 96.5%. Three foraminiferal assemblages can divided from upper to lower in the following: (1) 1～8 cm, *Cibicides-Miliammina* assemblage, it contains abundant kinds of species; (2) 9～66 cm, *Miliammina* assemblage, the kinds of species are less than those of *Cibicides-Miliammina* assemblage. Most of them are *Miliammina arenacea* with siliceous tests, associated with radiolarians, diatoms and sponge-spicules, and (3) 66～78 cm, *Globigerina pachyderma-Trifarina carinata* assemblage. It is characterized by occurrence of a lot of *Globigerina pachyderma* and *Trifarina carinata*, while *Miliammina* decrease to $<60\%$ in content. Data mentioned above show that the water depth of the sedimentary environment on both ends is deeper than that in the middle depth. The coldest climate stage occurred below 76 cm depth, which has a lot of cold species, such as *Globigerina pachyderma*, which occupies 100% of planktonic foraminifera.

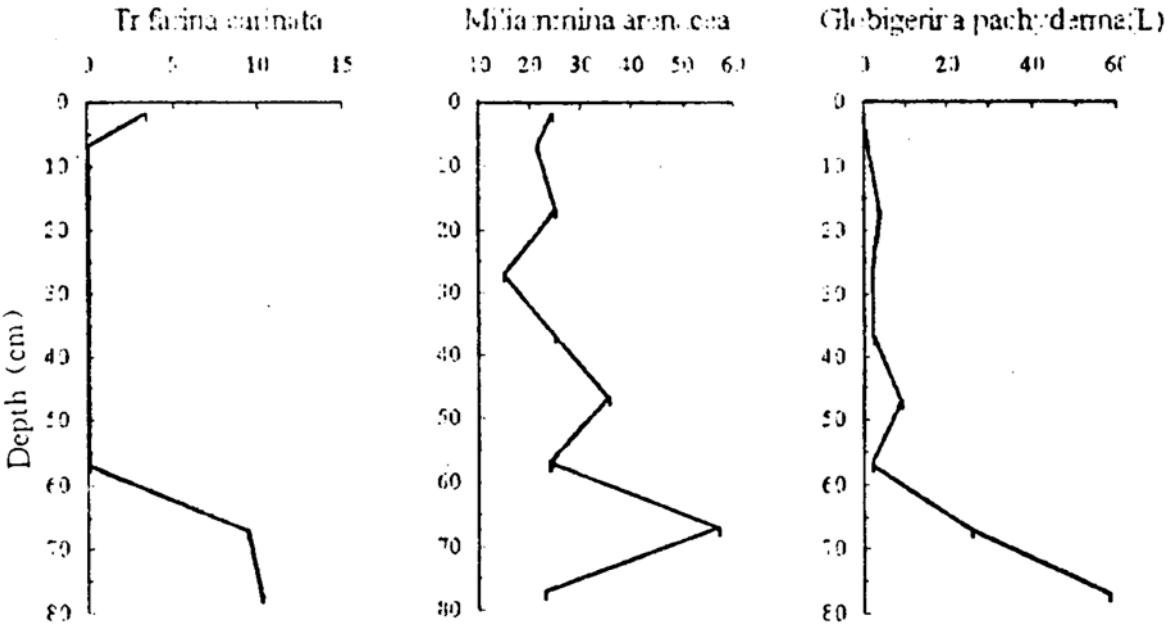

Fig. 4. Distribution of dominate Foraminifera species from core NP93-2.

A few of bryowhytes algae and some Anthophyta have been seen in the Antarctic continent. The palynomorphs found in core NP93-2 are not the modern ones. Three assemblages can be divided from top to bottom.

Zone 1, *Podocarpidites-Gleichenidites*

Zone 2, *Schizaeoisporites-Podocarpidites-Nothofagidites*

Zone 3, *Lygodiumporites-Classopollis*

Zones 2 and 3 in the lower part of the core NP93-2 mainly contain Cretaceous pollen such as : *Nothofagidites*, *Podocarpidites*, *Phyllocladites*, *Araucariacites*, *Proteacidites*, *Lygodiumporites*, *Schizaeoisporites*, *Gleichenidites*, *Osmundacidites*, *Classopollis* and *Cyathidites*. Zone 1 in the upper part of the core NP93-2 contains Neogene pollen such as: *Polypodiaceoisporites*, *Ulmipollenites*, *Engelhardtioidites*, *Myrtaceidites* and *Taxodiaceaspollenites*, etc.. The pollen fossils are mainly distributed in tropical and subtropical region, so it is suggested that Antarctic continent was located in middle-low latitude region during Cretaceous-Neogene. The pollen assemblages in core NP93-2 should represent the paleoclimate features in source areas.

5 Stratigraphic chronology and paleoclimate evolution

Four ^{14}C ages have been determined in core NP93-2 (Table 2). It is worthy to indicate that stratigraphic chronology at the top of the core NP93-2 is (3100±800) a B. P.. We considered that mistake originated from two factors: one is "Ocean carbon reservoir effect" which led to ^{14}C ages older. The study of ^{14}C ages of the northwest sea area in Antarctic Peninsula (Yue, 1989) have conformed that there are 456 a older but generally less than 1000 a. Another factor is lack of modern sediment by current erosions, which

occurred in the other sediment core in the Prydz Bay (Wu and Lu*; Hambrey *et al.*, 1991). We have gained (8303±800) a B. P. and (10315±800) a B. P. ages at the depth 55～60 cm and 70～72. 5 cm, respectively. The Godenburg reverse polar drift occurred at 60～67. 5 cm depth, whose age should be generally considered to be about 8000 ～10000 a B. P. (Wang *et al.*, 1996). If we calculated its exact age with the average rate between 60～72. 5 cm depth, the event of Goldenburg reverse polar drift occurred at 9982～8880 a B. P..

The ^{14}C ages and sedimentation rates of core NP93-2 have been listed in the Table 2. All data and the age-dating of paleoclimate zone discussed in the following have not been corrected. Although we are lack of the ^{14}C age of the bottom of core NP93-2, we can infer from average rates. The average sedimentation rate is 5. 72 cm/ka between 60cm to 72. 5 cm depth, and 15 cm thickness of sedimentary layer from 70 cm to 85 cm depth should represent 2622 a, therefore, the age of its bottom would be about (12937±800) a B. P.. That is that sediments from core NP93-2 represent Holocene and part of Late Pleistocene, the boundary of Holocene and Pleistocene is divided at 70～75 cm depth. Based on diatom biostratigraphy, the boundary is drawn at 75 cm depth.

Table 2. ^{14}C age* and sedimentation rate of core NP93-2

Depth (cm)	^{14}C ages (a B. P.)	Layer(cm)	Sedimentation rates (cm/ka)	Average sedimentation rates (cm/ka)
0～2. 5	3100±800	0～32. 5	6. 03	6. 57
27. 5～32. 5	5390±800			
55～60	8303±800	32. 5～60	9. 44	
67. 5～72. 5	10315±800	60～72. 5	5. 72	

* The radiocarbon measuring was taken by Prof. Shen Chengde.

6 Stages of paleoclimate evolution

Stages of paleoclimate evolution is shown in Fig. 5.

1. Paleoclimate zone 1, 85～75 cm depth, corresponding age is 12937～11189 a B. P.. The content of *A. antinochilus* reflecting cold climate is high, while the *Thalassiosira* content is lower. These also indicated that ice melting water flows weakly and little terrigenous clastic matters input during this stage, which represents Late Pleistocene.

2. Paleoclimate zone 2, 75～50 cm depth, corresponding age is 11189～7508 a B. P.. It contained a few *A. antinochilus* and a lot of terrigenous clastic matters, as well as high foraminiferal contents during this period. These indicated that climate was warm period. By comparing with world ice variation curve (Beget, 1983), it belongs to interglacial stage.

3. Paleoclimate zone 3, 50～41 cm depth, corresponding age is 7508～6661 a B. P. It contained less terrigenous clastics and low foraminiferal contents. These reflected the cold climate stage during Holocene warm stage.

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* Wu Shiguo and Lu Jun (in press): Sedimentary record of paleoclimate changes since 15000 a in the Prydz Bay, Antarctica. Chinese Acta Sinica.

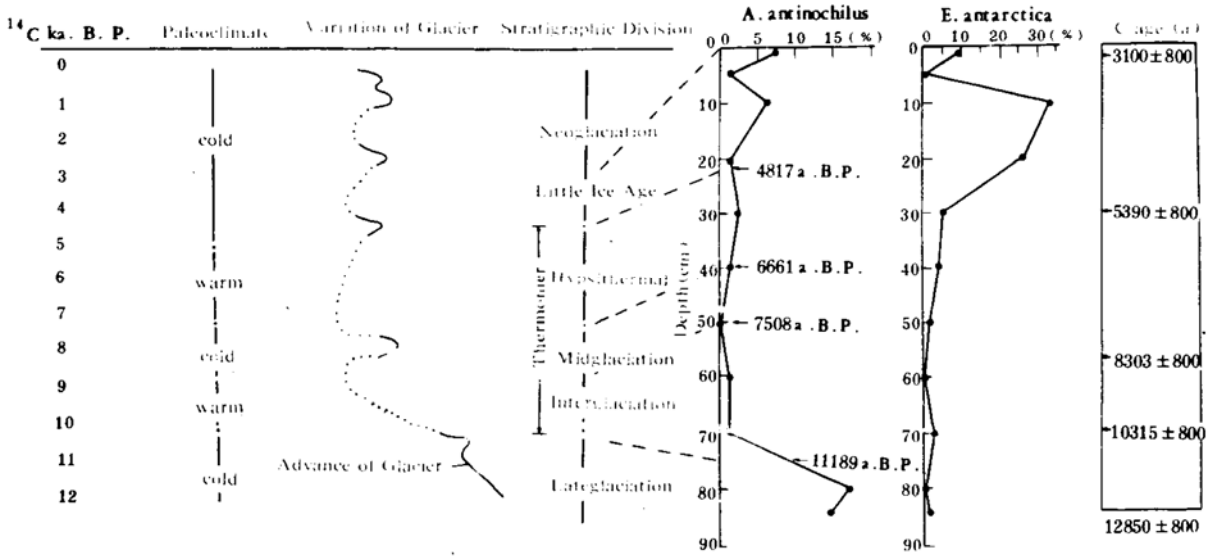

Fig. 5. World glacial variation curve (Beget, 1983) and paleoclimate stages of core NP93-2.

4. Paleoclimate zone 4, 41～22. 5cm depth, corresponding age is 6661～4817 a B. P.. It contained less species of diatom living in ice-edge environment and it contained highest foraminiferal contents at 36～38 cm layer. These reflected the most warm stage.

5. Paleoclimate zone 5, 22. 5～0 cm depth, corresponding age is 4817～3100 a B. P.. Total cold species such as: *A. antarctica* and *A. antinochilus* increased apparently. Foraminiferal fauna in the 9～22. 5 cm layer decreased. These reflected cold climate, which represented the cool stage during Holocene.

To sum up, the sediments of core NP93-2 have apparent characteristics of glacial-marine sedimentation. Although the core NP93-2 is only 85 cm depth, it represents Holocene and part of Late Pleistocene deposits, which consist mainly of terrigenous clastics. Part of the sediments come from Cretaceous-Paleocene strata which were formed in tropical and subtropical regions. It also records environment at that time and climate variations since 12937 a B. P.. The important climate variation took place at 10698 a B. P. (here we have used 500 a correction values), since then the climate got warm. According to diatom assemblage features, the climate variation during Holocene warm stage occurred at 60 cm depth of the core. To study of the detailed paleoclimate variation, more research works should be done.

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