LATE QUATERNARY ENVIRONMENTAL CHANGES IN THE ANTARCTIC AND THEIR CORRELATION WITH GLOBAL CHANGE

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Abstract: Records from Antarctic ice free areas and ice cores testify that environmental and climatic changes in the Antarctic region are coordinated with global changes since late Pleistocene. Either expansion or retreat of the Ice Sheet will significantly affect changes of sea level. The greenhouse effect has disturbed the worldwide cooling tendency which started 3 Ka. However, the course of such a limited temperature increase was very slow, and in the next 50 years, the temperature probably will not be able to reach as high as it was in the mid-Holocene. Even in that time the Antarctic Ice Sheet was still stable. According to available tidal monitoring data recorded in past decades, the rise in sea level caused by melt water from the Antarctic ice may be less than 0.2 m in the coming 50 years.

Key words: Antarctic environmental changes, greenhouse effect, sea level rise

Introduction

The Antarctic is the most important cold source on the Earth with about 24.5×10^6 km^3 of ice (Lovering and Prescott, 1979) which accounts for 90% of total ice volume of the globe. Retreat or advance of the Antarctic Ice Sheet will effect the fluctuation of sea level. It is calculated that if the Antarctic Ice Sheet should completely melt, global sea level rise would be about 60 m (Lovering and Prescott, 1979).

Scientists now are concerned the question of whether or not the global warming caused by the increase of air CO_2 concentration will lead to a significant melt or even collapse of the Antarctic Ice Sheet, followed by a large rise of sea level. According to the literature (Wang and Zeng, 1988), CO_2 concentration in 1986 reached 345 ppm an increase of 23% over the 280 ppm of 1860. Some meteorologists predict that, before 2040–2100, CO_2 concentration will be twice of that in 1860, which will cause the global temperature increase by 1.5–4.5°C (Wang and Zeng, 1988) and sea level will rise 5 m mainly due to melting of west Antarctic Ice Sheet (Mercer, 1978).

However, it is inferred from many sources (Denton and Hughes, 1981) that the Antarctic environmental changes were coordinated with global changes since late Pleistocene (Zhang, 1988, 1990) and the Antarctic Ice Sheet has long been stable, although recording many changes (Hughes *et al.*, 1981).

Based on the records both from Antarctic ice free areas and ice cores, this paper discusses briefly assumed disaster in the coming 50–100 years.

Records from Antarctic Ice Free Areas

Although the Antarctic ice free areas are limited in extent and their records are not very accurate and systematic, they all reveal that the main climatic events in the Antarctic correspond to other events in other parts of the world (Zhang *et al.*, 1983; Zhang, 1988).

During the last glaciation the Antarctic Ice Sheet expanded greatly. During the last glacial maximum period (GMP) (18 Ka), it was 500–1000 m thicker (Hughes *et al.*, 1981; Denton, 1979; Clark and Lingle, 1979) and the area covered was much larger than that of today, and Antarctic continental shelves were almost covered by grounded ice (Zhang, 1985a). The areas of summer and winter sea ice were 10 times and twice those of today (Cook and Hays, 1982).

During the last glacial interstadial period (50–25 Ka), transgression took place onto the Antarctic coastal zone according to reports from the Vestfold Hills (Zhang and Peterson, 1984; Zhang, 1985a, 1985b), Ross Island (Ward and Webb, 1979; Stuiver and Denton, 1977) and King George Island (Xie, 1987; Zhang and Xie, 1990), from which dates of 31 Ka (Jin, 1985), 36 Ka and 49 Ka (Stuiver and Denton, 1977) and 43 Ka (Zhang and Xie, 1990) have been respectively obtained from marine organic deposits. Therefore, this transgression can be correlated with the same event which is recorded widely at North America (Mayewski *et al.*, 1981), Europe (Anderson, 1981) and Asia (Shi and Wang, 1981; Shi and Fan, 1990). However, Quilty (1986), Adamson and Pickard (1986) realized that the marine deposits in Marine Plain in the Vestfold Hills is probable early Pliocene age, as Quilty discovered skull fragments of marine mammal in the sediments (Quoted in Adamson and Pickard, 1986) and Tertiary marine diatoms *Thalassiosira torokina* Brady, *Nitzshia praeinterfrigidaria* McCollum and *Eucampia antarctica* have been found from the sediments (Adamson and Pickard, 1986). But the author considers that these Tertiary skull fragments of mammal and diatom fossils could be reworked during the last glacial interstadial period. A notable feature of the marine deposits is unconsolidated and soft, but there are some semi-consolidated fragments or blocks of marine deposits contained in them (Zhang, 1985a). These Tertiary marine diatoms mentioned above have been also recorded by Li, J. (1985), but their presence is rare and always in fragmental manner.

A drastic drop of the sea level during GMP has been reported on the worldwide (Flint, 1971; Shi and Wang, 1981; Yang, 1985; Zhang, 1985a, 1988). The Antarctic ice volume of 23.45×10^6 km^3 which was used by Flint as a parameter to calculate the figures of sea level drop is about

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Table 1. Comparison of Late Pleistocene and Holocene Strata in the World.

Region / Time	Vestfold Hills Antarctica (1)	McMurdo Sound Antarctica (2) (3)	East China (4)	Europe and Greenland (5)	North America (6) (7)
Holocene	Present Neoglaciation (3200 yBP)	Present Neoglaciation	Present Neoglaciation (3000-2000 yBP)	Present Neoglaciation (2500-2000 yBP)	Present Neoglaciation (2500-2000 yBP)
	Post Glaciation optimum Climatic Period (7500-5000 yBP)	Post Glaciation (9490 yBP) optimum Climatic Period (6600-5650 yBP)	Post Glaciation (10000 yBP) optimum Climatic Period (6000-5000 yBP)	Post Glaciation (8000-4500 yBP) High Temperature Period (7000-6000 yBP)	Post Glaciation High Temperature Period (7500-6000 yBP)
Late Pleistocene	Late Vestfold (last) Glaciation (25000-10000 yBP)	Late Ross Glaciation (25000-10000 yBP) GMP (21200-17000 yBP)	Late Dali Glaciation (25000-10000 yBP) GMP (14700 yBP)	Late Weichselian Glaciation (25000-10000 yBP)	Late Wisconsin Glaciation (24000-10000 yBP)
	Glacial Interstadial (50000-25000 yBP)	Glacial Interstadial (50000-25000 yBP)	Glacial Interstadial (40000-25000 yBP)	Mid-Weichselian Interstadial (50000-25000 yBP)	Mid-Wisconsin Interstadial (50000-24000 yBP)
	Early Vestfold Glaciation (>50000 yBP)	Early Ross Glaciation (>50000 yBP)	Early Dali Glaciation (>40000 yBP)	Early Weichselian Glaciation (> 50000 yBP)	Early Wisconsin Glaciation (>50000 yBP)

(1) Zhang, 1988; (2) Denton, et al. 1975; (3) Hughes, 1981; (4) Shi and Wang, 1981; (5) Anderson, 1981; (6) Mayewski, 1981; (7) Grove, 1979.

4.5% less than more accurate figure of 24.50×10^6 km^3 (Lovering and Prescott, 1979), but the idea suggested by Flint, that sea level in GMP was 130 m lower than that of today, has become generally accepted.

After the last glaciation, a more extensive transgression again occurred in the Antarctic coasts during the mid-Holocene period. In the Vestfold Hills marine deposits on terraces at 15 m, 10 m and 6 m (Zhang, 1985b) above sea level, have yielded ^{14}C dates of 7500 years B.P., 6100 years B.P. and 5500 years B.P. (Jin, 1985; Adamson and Pickard, 1983, 1986). Marine fossils are very abundant in the marine deposits and include bivalves, diatoms, foraminiferas and ostracods etc. (Crespin, 1960; Lan, 1985; Gou and Li, 1985; Li and He, 1985; Quilty, 1986). Assembladges of marine fossils and depositional features show that the Antarctic coastal sea was much warmer during the Mid-Holocene than that at present. At 7500–6000 years B.P., mean annual temperature might be 2°C higher than that of today (Li and He, 1985; Zhang, 1985a).

Marine deposits of the same age are also widely distributed along the east Antarctic coast, Antarctic Peninsula and sub-Antarctic Islands at different elevations (Cameron and Goldthwait, 1961; Denton *et al.*, 1970; Stuiver and Denton, 1977; Yoshida, 1983; Carrara, 1979; Xie, 1987). It is inferred that transgression of mid-Holocene represents a climatic optimum stage (7500 years B.P.–5000 years B.P.) in Antarctic region and coincides with global event (Grove, 1979; Hope and Peterson, 1975; Hughes *et al.*, 1981; Zhu, 1973; Zhang, 1985a, 1990). Those raised marine beaches of mid-Holocene are certainly the marks of ancient shore lines, but their present elevation could not represent the height of sea level in that period since the rising of Antarctic beaches are mainly caused by glacio-isostatic rebound (Zhang and Peterson, 1984). In general, the warm period coincides with high sea level, but we still do not know how high the Antarctic sea level was in mid-Holocene.

In recent 3000 years 3 alternate stages of cold and warm periods were apparently occurred around the world (Zhu, 1973; Shi and Wang, 1981; Karlen, 1973; Denton, 1974; Hope and Peterson, 1975). Three cold periods appeared at 3000 years B.P., 2000 years B.P. and from 15th century to mid period of 19th century when mean annual temperature was 1–2°C lower than at present. Same events also appeared in the Antarctic region (Zhang, 1985a, 1990) and the last cold period began 3325 ± 103 years B.P. (Jin, 1985; Zhang, 1985a).

The climatic events that coordinately appeared on the Antarctic and the rest of the world since late Pleistocene can be summarized in Table 1.

Records from Antarctic Ice Core

Since the 1960's a great progress has been made on the study of Antarctic ice core. Vostok ice core provides a continuous record of climatic changes in the past 160,000 years (Jouzel *et al.*, 1987; Barnola *et al.*, 1987). And Dome C core provides 30,000 years record of climatic changes (Lorius *et al.*, 1981; Thompson *et al.*, 1981). Some important results can be summarized as follows:

1)Since the last interglacial stage (12.5 Ka), there were three cold periods (i.e. B, D, and F) and three warm periods intervals (i.e. A, C, and E) (Lorius *et al.*, 1985). Temperature curves both at the penultimate glacial stage (H) and last GMP (B) are almost the same. The present stage is in the progress of temperature dropping course of the post climatic optimum.

2) CO_2 concentration apparently varied from glacial period to the interglacial period. For instance, CO_2 concentration in the last glaciation was 200 ppm and in Holocene period it increased to 280 ppm (Barnola *et al.*, 1987). While in the past 100 years CO_2 concentration rapidly increased to 345 ppm in 1986 from 280 ppm of 1860 (Wang and Zeng, 1988). It shows that before 1860 industrial revolution CO_2 concentration was 23% lower than that at present, but 46% higher than that in last glaciation (Barnola *et al.*, 1987). So, there probably is a positive correspondence relationship between CO_2 concentration and temperature, i.e., raising of temperature is followed by increase of CO_2 concentration and the increase of CO_2 concentration contrarily resulted in the raising of temperature. It has been estimated that 50% of CO_2 concentration increased (from 200 ppm to 300 ppm) will cause a temperature rise of 1.2°C worldwide (Genthon *et al.*, 1987).

3) Due to rapid increase of CO_2 concentration since industrial revolution of 1860, the greenhouse effect has already influenced the Antarctic region which is evidenced by the increase of temperature on Antarctic inland (0.3°C of mean annual temperature higher than that of 1910 at Dome C) (Bolgan *et al.*, 1979) and retreat of ice edge (Denton *et al.*, 1970; Voronov, 1964; Yoshida, 1983; Zhang, 1988, 1990). The north edge of Ross Ice Sheet at McMurdo Sound retreated 6–8 Km in distance between 1910 and 1973 (Hughes *et al.*, 1981). On the other hand, precipitation also increased following the increase of temperature. For instance, mean annual precipitation in 1960 at Dome C area reaches 48 mm/y against 37 mm/y of 1910 (Bolgan *et al.*, 1979) and on the Antarctic Peninsula it reached 385 mm/y from 246 mm/y at the same time (Gonfiantine, 1965).

Discussion

Now the sensitive question to the world is: if CO_2 concentration reaches 2 times of that before industrial revolution (1860) in the next 50–100 years, whether the temperature might intensively increase by 2–4°C which will cause a great bulk of Antarctic ice to be melted away following 5 m of sea level rising (Mercer, 1978)?

This is a very complicated question. Although some senior scientists believe that double increase of CO_2 concentration in next 50 years may result in an increase of 1.5–4.5°C of surface temperature on the globe (WMO/UNEP/ICSU-SCOPE, 1985), it is difficult to estimate the amount of industrial CO_2. Therefore, the difference of estimated temperature increase for next 50–100 years is quite big (Wang and Zeng, 1988).

It is interesting to note that a recent simulation with a coupled ocean-atmosphere model (Stouffer *et al.*, 1989) of the atmospheric response to a doubling of the global CO_2 level over a century shows an interhemispheric asymmetric in the warming of surface in temperatures, with the Antarctic increasing very slowly and the Arctic faster. This may coincide with a new finding of the variations of the Arctic and Antarctic sea-ice extent which have behaved asymmetrically over nearly a decade (1978–1986): significant decreases in ice extent in the Arctic and no significant trends in the Antarctic (Gloerson and Campbell, 1991).

Here the author emphasizes that the man made effect on CO_2 concentration increasing which resulted in the warming up of the world happens under the background of cooling tendency of post climatic optimum.

Records from Antarctic ice cores (Barnola *et al.*, 1987; Genthon *et al.*, 1987; Lorius, 1981) show that CO_2 concentration is in direct proportion to the temperature in past 160,000 years. By estimation in general, the temperature in climatic optimum period of mid-Holocene was about 2°C higher than that at present (Zhu, 1973; Shi and Wang, 1981). The global cooling tendency began from about 3000 years B.P. (Jin, 1985; Zhang, 1985a; Shi and Wang, 1981; Yang and Yang, 1985). However, CO_2 concentration rapidly increased by 23% from 280 ppm of 1860 to 345 ppm of 1986 under the background of climatic cooling tendency. Industrial CO_2 has changed the natural variation of CO_2 concentration, therefore, more or less disturbed the global cooling course which is indicated by 0.3°C of mean annual temperature increase from 1910 to 1973 in Antarctic inland (Bolgan *et al.*, 1979) and 0.5°C of average temperature increase in the earth surface since 1900 (Gloerson and Campbell, 1991). From these figures, a conclusion may be derived that the temperature increase course in past 60–70 years is slow. It must be considered for estimating the degrees of temperature increase in the coming 50–100 years.

In fact, advance and retreat of ice sheet occurred on the Antarctic coasts during the climatic optimum period of mid-Holocene. But even at that stage, the Antarctic Ice Sheet including ice shelves in Ross and Weddell seas were stable. Melt on the front of the Antarctic Ice Sheet caused by slight increase of temperature in past decades was very slow and limited. Increase of snow accumulation in the same time in Antarctic inland infers that a little warm up is not only unable to destroy the stability of the Antarctic Ice Sheet but also favorable to the accumulation of the Ice Sheet.

In general, the east Antarctic Ice Sheet grounded on the land is stable, and the west Antarctic Ice Sheet is unstable as its considerable part floating on the sea. But surrounding the west Antarctic Ice Sheet, there are many ice shelves to protect it. Only if those ice shelves were completely melt away the crisis of destroy of west Antarctic Ice Sheet may occur. Results from Ross Ice Sheet Project (RISP) (Thomas and MacAyeal, 1979; Clausen *et al.*, 1979; Zotikov *et al.*, 1979) show that the ice shelf has been becoming thicker both on the surface and at its bottom in recent time. Surface snow accumulation reaches 200–300 mm/y (Thomas and MacAyeal, 1979) and the thickness of bottom ice which was frozen from sea water in the past 600 years reaches 6 m, at an accumulation rate of about 10 mm/y (Zotikov *et al.*, 1979) which indicates that the Ross Ice Shelf in past hundreds of years is always under a stable and extremely cold condition.

Why the Antarctic seas are not or very little warming up corresponding to the air temperature increase? Basic reason is that the southern ocean is contained in a closed cold hydrologic system which protects the ingression of warm currents from north. Meanwhile, melt of large number of icebergs and sea ice take a great quantity of heat energy out from the sea water. Therefore, the Antarctic seas always keep in a low temperature condition. Water temperature of

Antarctic seas (south of 66°S) even in summer season is below −1°C. It is considered that even if the air temperature increased by 1–2°C caused by greenhouse effect in coming 50–100 years, the west Antarctic ice sheet including ice shelves could not be disintegrated.

Tide-gauge records for past nearly one hundred of years offer a valuable basement to measure the figures of sea level rise in the coming 50–100 years. According to the original data of 162 tide-gauge stations around world (Xie, 1990), an average rate is accounted to be of 0.7–1.2 mm/y for the sea level rise from 1900 to 1978 which is comparable to that of 1.3 mm/y (Ren, 1990; Hicks, 1981), but much smaller than that of 2.5 mm/y suggested by Emery and You (1981).

Tide-gauge records also contain a relative subsidence and/or uplift of coastal land, and only those stations situated at tectonically stable coasts, the records may actually reveal the fluctuations of average sea level (Ren, 1990). However, based on those figures the amplitude of sea level rise for the next 50 years also can be roughly estimated to be 0.035–0.06 m, or 0.065 m, or 0.125 m. Even if the rate increased by 50%, a total amplitude of sea level rise in the coming 50 years will be less than 0.2 m.

Conclusion

Some preliminary conclusions may be given as follows:

1) Climatic and environmental changes in Antarctic region since Late Pleistocene are correlated with those in the rest of world. They all respond to the global changes.

2) The Antarctic Ice Sheet (including ice shelves) has been prolonged stable even in the last interglacial stage and in the period of Holocene climatic optimum.

3) Temperature in coming 50–100 years effected by increase of CO_2 concentration may not reach as high as it was in mid-Holocene. Therefore, no destroy crisis of the Antarctic Ice Sheet will appear. On the background of global cooling course, such man made affection had already reached the Antarctic region. A slowly slight rise of air temperature results in two opposite phenomena: slight retreat of the margin of the Antarctic Ice Sheet and increase of precipitation in the Antarctic inland.

4) According to the tide-gauge records in past decades, an average rate of sea level rise is 0.7–1.2 mm/y (Xie, 1990), 1.3 mm/y (Hicks, 1981) or 2.5 mm/y (Emery and You, 1981). Counting based on these figures, a total amplitude of the sea level rise in the coming 50 years will be from 35 mm to 125 mm and even if 50% of positive error was added for the increase of sea level rise in the future, it will be still less than 0.2 m in next 50 years.

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