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A preliminary study on oxygen isotope of ice cores of Collins Ice Cap, King George Island, Antarctica*

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Abstract Glacier-forming material shows no difference of oxygen isotope for different heights above sea level on Big Dome of Collins Ice Cap. $\delta^{18}O$ variations of surface firn with depth(time) are extremely similar. Owing to the material and energy exchange between different annual layers, homogeneity of oxygen isotope arises and leads to no avail of $\delta^{18}O$ ice-core dating on Big Dome Summit of Collins Ice Cap. Affected by seasonal variations of temperature, oxygen isotope composition of winter layer is distinctly different from that of summer layer whose $\delta^{18}O$ value is higher and variation coefficient is smaller. By means of direct comparison oxygen isotope/temperature gradient of Collins Ice Cap is defined as 0.74‰/℃ in use of annual mean temperature and $\delta^{18}O$ value on Big Dome Summit and Small Dome Top of Collins Ice Cap.

Key words Collins Ice Cap, oxygen isotope, climate, temperature.

1 Introduction

As a climate index, stable isotope provides a powerful research method for palaeoclimatic reconstruction of the Antarctic ice-cores(Jouzel and Lorius 1987; Yao and Qin 1995). Stable isotope distribution pattern of ice-cores is an important aspect in comprehensive and thorough-going studies of ice-cores. During 1991～1992 glacier workers from P. R. C. carried out ice-core drilling in considerable scale on Collins Ice Cap, King George Island, Antarctica, obtained a series of shallow ice-cores at different elevations including the Big Dome and Small Dome and offered a precious opportunity to understand stable isotope distribution characteristics of ice-cores of King George Island area in an all-round way. Ice-core drilling position, mass balance, temperature distribution and general characteristics in stratigraphy and density variation of Collins Ice Cap have been carefully described(Xie *et al.* 1994; Han *et al.* 1994, 1995), in this paper it is unnecessary to go into details again. But this paper is only to analyse oxygen isotope space distribution characteristics of Collins Ice Cap and to discuss the relationship between oxygen isotope and climate and temperature.

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2 Sampling and analysing

Ice-cores of Collins Ice Cap were all gained through the BZXJ-model ice-core drilling machine newly-made by Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Sciences. During drilling and collecting ice-cores, strict protection measures against the pollution and melt were taken so that it's as good as possible to satisfy the demands of physical and chemical analyses of ice-cores (Han *et al.* 1994). Collected ice-cores were transported under frozen condition from the Antarctica to the low temperature laboratory of Polar Research Institute of China, partly to University of New Hampshire, U. S. A. and are preserved under −25℃. Ice-cores were taken out before analyses, cut apart with band saw on clean low-temperature working table. We scraped a few millimetres of surface ice, choosed the insides of ice-cores not contaminated and caused them to melt under normal air temperature. Oxygen isotope analyses of 0～13. 96 m depth ice-cores from Big Dome Summit of Collins Ice Cap were completed in glacier research group, Institute for the Study of Earth, Ocean and Space, University of New Hampshire, U. S. A. Their sampling interval is 15～20 cm, total is 87 samples. Oxygen isotope analyses of 13. 96～20. 02 m depth and 27. 78～30. 52 m depth ice-cores from Big Dome Summit of Collins Ice Cap and firn samples drawn from BDA, BDB, BDC and Small Dome Top (SDT) were completed in state key laboratory of mineralization in Nanjing University. Sampling interval of BDS ice-cores is 15～20 cm (total of 50 samples), sampling interval of firn from BDA (total of 10 samples), BDB (total of 10 samples) and BDC (total of 10 samples) is between 30 cm and 130 cm, sampling interval of SDT (total of 20 samples) is 10～20 cm. All measured results were demarcated and rectified by GBW, SLAP and SMOW. Analytical precision of $\delta^{18}O$ is ±0. 2 ‰. On the basis of field obeservation and indoor stratigraphic description, firn samples of BDA, BDB and BDC respectively span two annual layers with SDT one annual layer.

3 Results and discussion

3. 1 Spacial distribution characteristics

$\delta^{18}O$ variation of BDS ice-cores of Collins Ice Cap with depth is shown in Fig. 1. The elevation of BDS is 702 m. It can be seen from Fig. 1 that basic variation trend of $\delta^{18}O$ is that as depth goes on $\delta^{18}O$ variation range is gradually getting small. Taking 8 m depth as the boundary, above it $\delta^{18}O$ average value of firn samples of about two annual layers is −10. 78 ‰, variation coefficient is 16% and summer layer's $\delta^{18}O$ value is higher than winter layer's; below it $\delta^{18}O$ average value of ice-core samples of about four annual layers is −9. 34 ‰, variation coefficient is 11. 7% and seasonal and annual variations of $\delta^{18}O$ have become not obvious.

$\delta^{18}O$ variations of BDA, BDB and BDC surface firn with depth are expressed in Fig. 2. The elevations of BDA, BDB and BDC are 610 m, 510 m and 380 m respectively. It can be seen from Fig. 2 that the general $\delta^{18}O$ variations of firn samples of

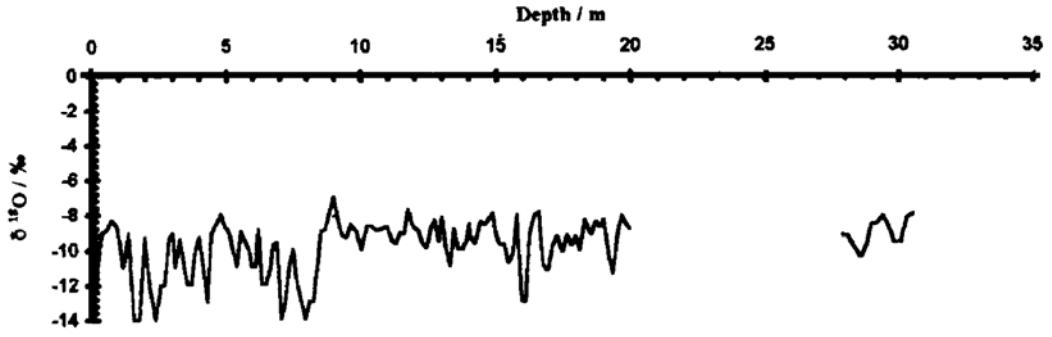

Fig. 1. $\delta^{18}O$ – depth section of ice-cores from Big Dome Summit, Collins Ice Cap.

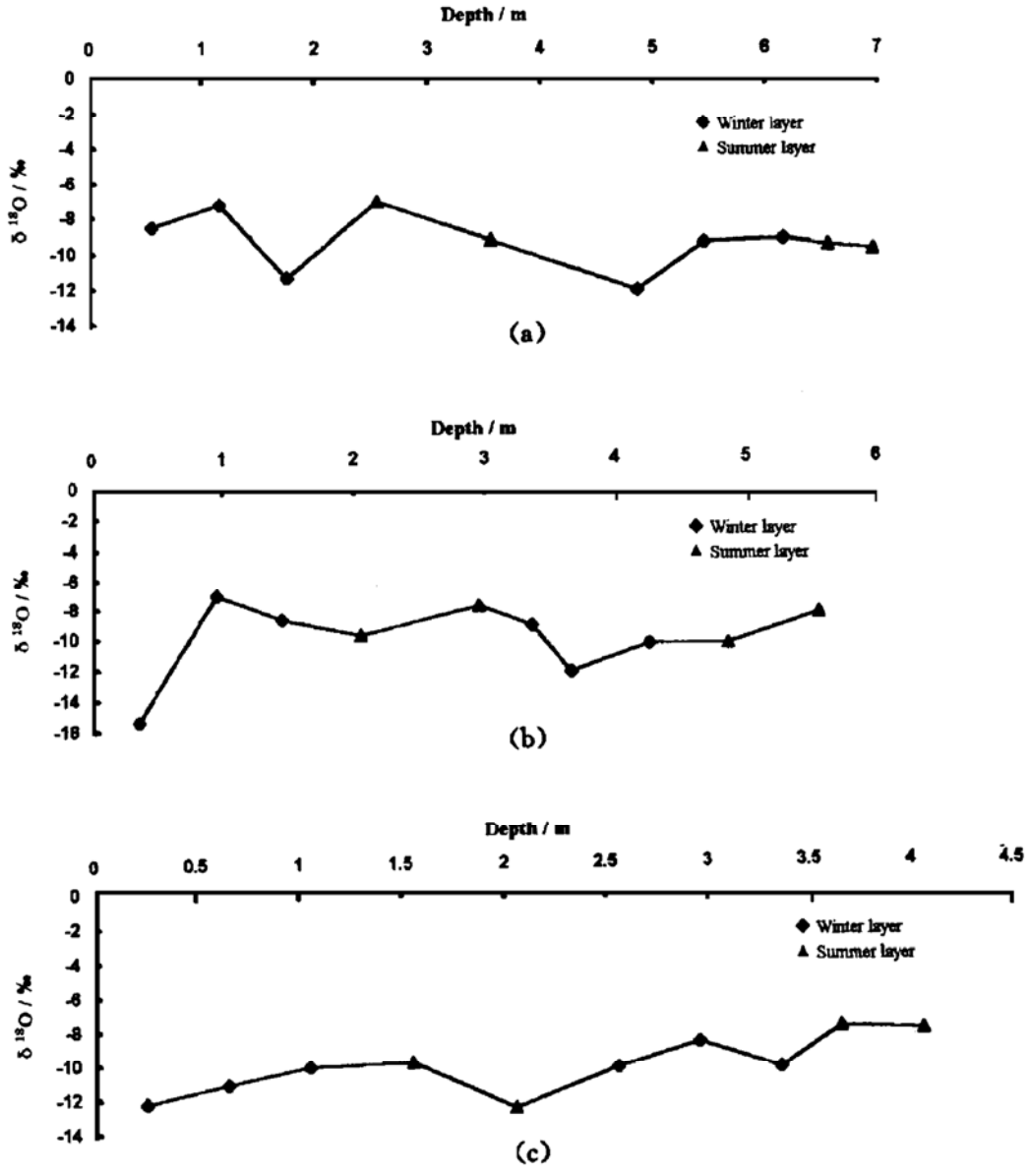

Fig. 2. $\delta^{18}O$ – depth section of surface firn from BDA(a), BDB(b) and BDC(c) of Big Dome, Collins Ice Cap.

different elevations on Big Dome of Collins Ice Cap are identical basically, show no difference of oxygen isotope composition for different altitudes. This reflects that glacier-forming material derived from the same source on Big Dome of Collins Ice Cap. It seems that $\delta^{18}O$ fluctuations of surface firn displayed in Fig. 2 appear to be

rhythmical variation. Each section of Fig. 2 consists of ten $\delta^{18}O$ values, in which every five continous samples were collected from single annual layer (the first three samples from winter layer, the last two samples from summer layer) and therefore what each section shows is $\delta^{18}O$ variations of surface firn of two annual layers. Winter layers' $\delta^{18}O$ average values of BDA, BDB and BDC are -9.62 ‰, -10.5 ‰ and -10.51 ‰ respectively; summer layers' $\delta^{18}O$ average values of BDA, BDB and BDC are -8.9 ‰, -9.18 ‰, -9.68 ‰ respectively. Differing from the general pattern in which $\delta^{18}O$ value tends to become low along with the increase of elevation and the decrease of temperature, whether in the winter layer or in the summer layer, $\delta^{18}O$ variations with elevations on Big Dome of Collins Ice Cap are not clear, even $\delta^{18}O$ value yet slightly increases along with the increase of elevation. For this phenomenon one possible explanation is that the elevation of Big Dome, Collins Ice Cap is not high, among BDA, BDB and BDC elevation difference is little and it's not enough to form obvious $\delta^{18}O$ variation with elevation. Another possible interpretation is that Big Dome of Collins Ice Cap is affected by north-western airflow, temperature inversion is very frequent and melting phenomenon is also fairly intensive.

$\delta^{18}O$ variation of 2.53 m shallow ice-cores from SDT, Collins Ice Cap with depth is shown in Fig. 3. The elevation of SDT is 252 m. The upper eight samples in section are from winter layer, their $\delta^{18}O$ average value is -9.44 ‰, variation coefficient is relatively high and is 11.7%; the lower twelve samples in section actually come from two annual layers which were fully changed into ice as a result of strong melting events and may be regarded as one summer layer, their $\delta^{18}O$ average value is -7.22 ‰, variation coefficient is relatively small and is only 8%. Thus it can be observed that affected by seasonal variation of temperature oxygen isotope composition of winter layer is distinctly different from one of summer layer. $\delta^{18}O$ value of summer layer is obviously high and variation coefficient is small.

3.2 Relations between $\delta^{18}O$ and temperature

Light isotope molecule ($H_2{}^{16}O$) of water is faster in evaporation and slower in coagulation than heavy isotope molecule ($H_2{}^{18}O$), so air mass moving to polar inland has a quantitative reduction of heavy isotope molecule and a drop of $\delta^{18}O$ by degrees be-

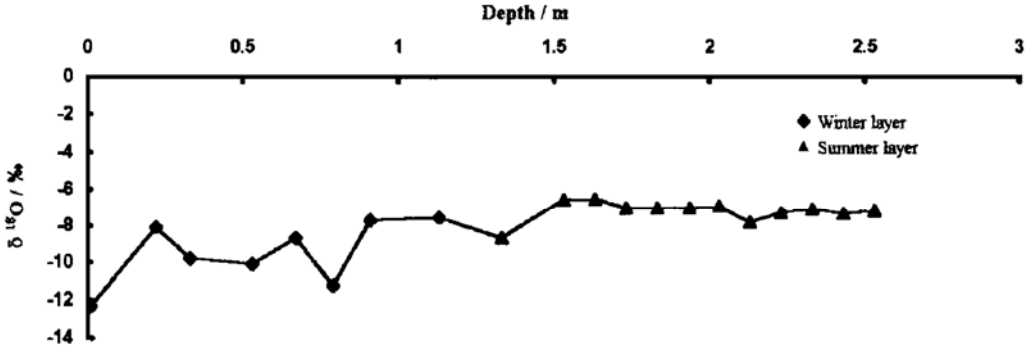

Fig. 3. $\delta^{18}O$ – depth section of ice-cores from Small Dome Top, Collins Ice Cap.

cause of fractional action and it leads to the emergence of land effect. $\delta^{18}O$ of atmospheric precipitation is closely related to isotopic fractionating coefficient which is controlled by temperature and its action on saturation vapour pressure, therefore $\delta^{18}O$ of atmospheric precipitation has close relationship with temperature. Seasonal $\delta^{18}O$ variation emerged in polar precipitation is due to the dual effect of temperature and land-latitude. For this reason in terms of theory if we carry out the continuous sampling and analysing for shallow ice-cores on polar ice-sheet, we can acquire the past climatic records of ice-sheet surface when each layer initially deposits (Qin and Wang 1989).

Indoor stratigraphic analyses show that the Big Dome and the Small Dome of Collins Ice Cap go through a series of melting events and have a wide-ranging existence of infiltration-freezing thin pieces, lenticles and layers of ice, which gives the fact that in the past the temperature is often 0℃ or above 0℃ over there. It was proven by the stratigraphy of two ice-cores from Collins Ice Cap that Big Dome Summit belongs to warm infiltration zone, while Small Dome Top to infiltration zone (Han *et al.* 1994). All around the King George Island is sea and the King George Island is situated in a condition of typical marine climate. On BDS winter snow layer is very thick and prevents cold front from moving to the inside. In summer the temperature is generally above 0℃, which lasts for a long time, a great quantity of melted water infiltrates into thick winter snow layer, the temperature of which changes owing to freeze and latent energy release which cause the temperature of whole annual layer to go up to melting point, even some of melted water may pass through whole annual layer and go into the firn layer of last year. During this process occurs material and energy exchange between different annual layers and arises homogeneity of oxygen isotope. Probably this is the main reason which leads to no avail of dating ice-core and regainning multi-year climatic variation trendence in use of $\delta^{18}O$ on Big Dome Summit of Collins Ice Cap.

BDA, BDB and BDC of Collins Ice Cap respectively arch across two annual layers from bottom to top, i.e., from the summer of 1991 to the winter of 1992. $\delta^{18}O$ variation with depth essentially represents its variation with time —— provided depth coordinate is changed into time coordinate, practically measured $\delta^{18}O$ profile of ice-core can be regarded as time sequence profile. Though data are limited, it still can be seen from actually measured results of $\delta^{18}O$ that on Big Dome of Collins Ice Cap exist seasonal cycles and climatic variation of one cyclic year (Fig. 2): average temperature of the winter is low and temperature variation is big, while average temperature of the summer is high and temperature variation is relatively small. With the gradual variation of the summer, 1991→the winter, 1991→the summer, 1992→the winter, 1992, $\delta^{18}O$ shows clearly related synchronous variation with temperature. In many places mean isotopic compositions of snow are mainly determined by mean temperatures of precipitation sites, assuming unchanged source of the moisture, at intermediate and high latitudes temperature variation plays a important role in $\delta^{18}O$ seasonal variation (Rozanski *et al.* 1982). It looks as if there is no exception either for Collins Ice Cap of King George Island.

In the polar regions, the isotope composition of the fallen snow is dependent mainly on the temperature at the site of precipitation, although it is also influenced by other factors. The Rayleigh simple isotopic model suggests (Jouzel *et al.* 1989) that, at intermediate and high latitudes, $\delta^{18}O$ should vary linearly with temperature. This relationship is well supported by observations of present-day and past sediments in Antarctica and Greenland (Jouzel *et al.* 1993; Jones *et al.* 1993; Johnsen *et al.* 1995). A drop in stable isotope ratio along with an increase of elevation actually also reflect the relationship between isotopic composition and temperature. It is impossible for us to know exactly the temperature at which the fallen snow forms, so we often establish the approximate relation between δ measurement and surface annual mean temperature during the practical work. Annual mean temperature of BDS is about -9.3℃ and annual mean temperature of SDT is about -5.7℃, there is 3.6℃ difference between the two sites. $\delta^{18}O$ average value of 8 m shallow ice-cores from BDS is -10.78 ‰ and $\delta^{18}O$ average value of 2.53 m shallow ice-cores from SDT is -8.11 ‰, there is 2.67 ‰ difference between the two values. Therefore, owing to the limited data, the method of direct comparison is adopted and oxygen isotope/temperature gradient of Collins Ice Cap area can be defined as 0.74 ‰/℃, which is similar to oxygen isotope/temperature gradient of Antarctic Peninsula's Dolman Island and Palmer Land Plateau ——0.5～0.6 ‰/℃, which Peel *et al.* (1988) obtained by means of comparing the long-term trends or materials of neighbouring sites.

4 Conclusion

To sum up the above-mentioned, the following conclusions could be reached: (1) Big Dome Summit of Collins Ice Cap belongs to warm infiltration zone, as a result of material and energy exchange between different annual layers, homogeneity of oxygen isotope arises and leads to no avail of dating ice-cores on Big Dome Summit and recovering climatic multi-year variation trend of Collins Ice Cap area in use of $\delta^{18}O$. (2) $\delta^{18}O$ variation trends of surface layer firn from BDA, BDB and BDC of Collins Ice Cap with depth (time) are identical, show no difference of oxygen isotope composition for different elevations. This reflects that glacier-forming material derived from the same source. (3) Affected by seasonal variation of temperature, oxygen isotope composition of winter layer is distinctly different from that of summer layer, whose $\delta^{18}O$ value is high and variation coefficient is small. (4) By means of direct comparison oxygen isotope/temperature gradient of Collins Ice Cap area is defined as 0.74 ‰/℃ in use of annual mean temperatures and $\delta^{18}O$ mean values of Big Dome Summit and Small Dome Top, which is similar to oxygen isotope/temperature gradient of adjacent ice-cores from Dolman Island and Palmer Land Plateau, Antarctic Peninsula.

It should be pointed out that though climatic variation studies of Collins Ice Cap have obtained some positive results, there still exist many provocative questions. For instance, along with the increase of elevation and the decrease of temperature, $\delta^{18}O$ of surface layer firn from Big Dome of Collins Ice Cap unusually rise to some extent,

what exactly is the cause of forming this perverse phenomenon? What are spacial variation of oxygen isotope of ice-cores from different elevations on Collins Ice Cap and its primary influence factors? And is it possible to establish correlation between oxygen isotope and temperature as well as elevation on Collins Ice Cap? For the purpose to answer these questions, it is pending further arduous, deepgoing and painstaking studies.

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