論文内容の要旨

論文題目

Cosmogenic nuclides analysis of the Laschamp geomagnetic excursion in the Dome Fuji ice core, Antarctica

ラシャンプ地磁気エクスカーション時における南極ドームふじ氷床コア中の複数の宇宙線生成核種の分析

氏　名　阿瀬　貴博

The cosmogenic long-lived radionuclides tell us the history of the past cosmic rays. The production rate of cosmogenic nuclides varies because the change in geomagnetic field intensity and the solar activity strongly influences galactic cosmic rays especially at lower part of energy that reach on the Earth's surface. The most promising cosmogenic nuclides having long half-life are ^{14}C ($T_{1/2}$ = 5730 yr), ^{10}Be ($T_{1/2}$ = 1.5 Myr), ^{26}Al ($T_{1/2}$ = 710 kyr) and ^{36}Cl ($T_{1/2}$ = 301 kyr). In the atmosphere, ^{14}C and ^{10}Be are produced from nitrogen and oxygen, and ^{26}Al and ^{36}Cl are produced from argon. Among these nuclides, only ^{14}C and ^{36}Cl can be produced by low energy neutrons with reactions of $^{14}N(n, p)^{14}C$, $^{35}Cl(n, \gamma)^{36}Cl$ and $^{36}Ar(n, p)^{36}Cl$, although ^{35}Cl and ^{36}Ar are minor component in the atmosphere. The dependencies of production rates on solar modulation and geomagnetic field intensity were estimated using pure physical model (Masarik and Beer, 1999).

The galactic cosmic rays consist of proton (87%), alpha-particles (12%) and heavier nuclei (1%). The proton differential energy spectrum at the Earth can be written in the form (Castagnoli and Lal, 1980):

$$f(T,\Phi) = A\frac{T(T+2E_0)(T+m)^{-\gamma}}{(T+\Phi)(T+2E_0+\Phi)} \qquad (1)$$

where T (MeV) is the proton kinetic energy, E_o its rest energy of the proton in MeV, Φ is the solar modulation parameter (MeV), which varies from ~ 300 MeV during the minimal solar activity up to

~ 1000 MeV during the maximum, $A = 9.9 \times 10^8$, m = 780 exp(-2.5×10^{-4} E_0), $\gamma = 2.65$.

The curves for different Φ values are shown in Figure 1. The solar activity influences low energy cosmic rays efficient more. However, these curves cannot be shown correctly at the energy below 100 MeV, because it is necessary to consider about the influence of solar cosmic rays and anomalous cosmic rays in this energy range. This part of the energy spectrum does not contribute significantly to the production of the cosmogenic nuclides under present geomagnetic field because of the geomagnetic cut-off in the upper atmosphere, and the threshold of the spallation reaction. On the other hand, during the lower geomagnetic field intensities, there is a possibility that energy in this part contributes to the production rates especially the low energy products of ^{14}C and ^{36}Cl because the cut-off effect becomes lower.

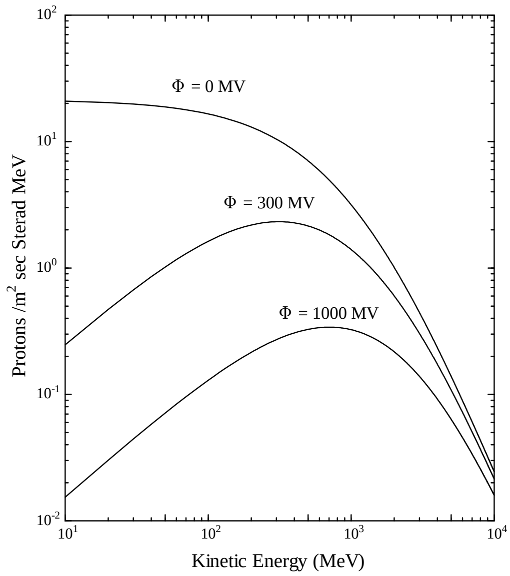

Fig. 1. Differential cosmic ray proton energy spectra. The Φ is a solar modulation parameter (Castagnoli and Lal, 1980). The larger Φ indicates the more activities of the sun.

One of the most valuable records of cosmogenic nuclides is polar ice sheet. The ice cores taken from both polar regions provide us the long time history of the cosmogenic nuclides fluxes as well as the many climatic information. Previous investigations show that the evidence of the correlation of the ^{14}C in tree ring and the ^{10}Be in the ice core (e.g. Finkel and Nishiizumi, 1997, Yiou *et al*, 1997, Beer *et al*, 2002, Muscheler *et al*, 2005, Horiuchi *et al*, 2008), and the 205-yr DeVries cycles of the sun are also confirmed in the ^{10}Be during MIS 3 (Beer *et al*, 2002).

In this thesis, we have tried to detect the peaks of three cosmogenic nuclides (^{10}Be, ^{26}Al, ^{36}Cl) concentration during the geomagnetic field excursion in the Antarctic ice core. Especially, ^{26}Al and ^{36}Cl without reports are clarified. This study focuses on the estimation of changing the energy spectrum of cosmic ray during the Laschamp geomagnetic excursion using the difference of the change in three cosmogenic radionuclides concentration peaks and/or the change in the amplitude according to the solar modulation cycles reconstructed from the Dome Fuji ice core, Antarctica.

In this study, the first deep ice core drilled at the Dome Fuji station during 1995-1996 was used. A part of this ice core samples are preserved the Institute of Low Temperature Science, Hokkaido University. The samples from 700 – 850 m depth corresponding to 34 -45 kyr BP of DFGT-2006 age (Parrenin *et al*, 2007) were cut out from this ice core and the surface was thinly cut down with a ceramic knife. The resolution of samples are about 1 m for AMS which corresponding approximately about 75 years of this depth.

As the results, the distinct ^{10}Be peaks are found that can be attributed as the Laschamp excursion (Fig. 2). The two ^{10}Be profiles of the Dome Fuji and the Dome C (Raisbeck *et al.*, 2007) are very similar each other. The linear relationship to the core depth was found from corresponding ^{10}Be sub-peaks (Fig. 3). This relation can be allows any data from both cores directly compared during this period.

The ^{26}Al peak was also found at same depth of the ^{10}Be and the shape of the peaks very similar (Fig. 2). This is the first data of the continuous record of the cosmogenic ^{26}Al during the geomagnetic excursions.

The $^{26}Al/^{10}Be$ ratios are nearly constant during this period and the almost same the present value (Fig. 4). It is suggested that the shape of the energy spectrum of the high energy part of the cosmic rays are also same in present day.

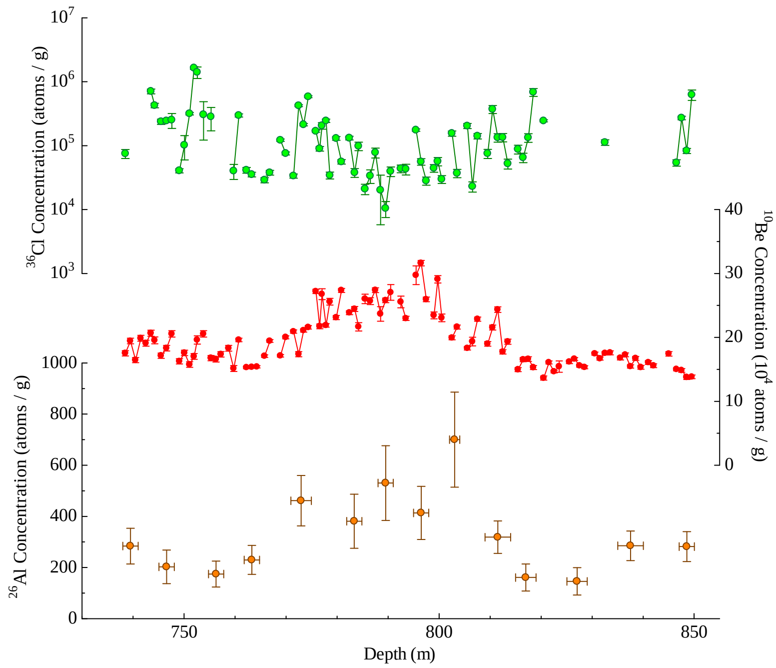

Fig. 2. The depth profiles of each nuclide. This depth corresponding to 38 - 45 kyr BP from the DFGT-2006 age (Parrenin *et al*, 2007)

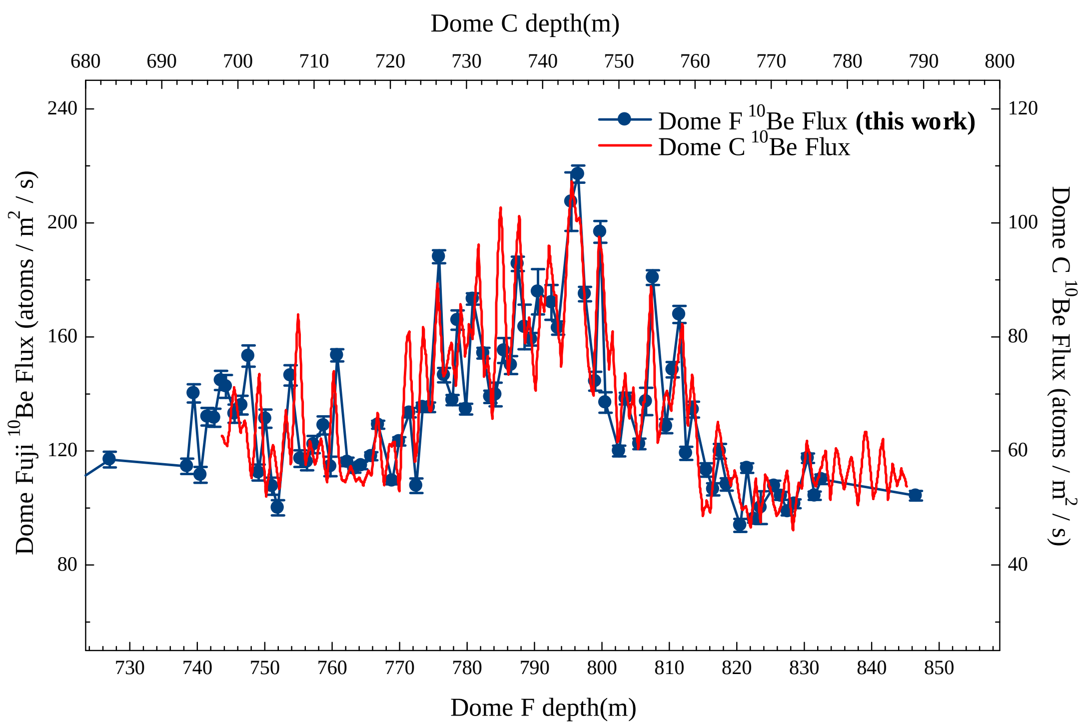

Fig. 3. Comparing with ^{10}Be fluxes from Dome Fuji and Dome C. The Dome C data were taken from Raisbeck *et al.*, 2007.

In the ^{36}Cl results, large discrepancy was found in this period (Fig. 2). Moreover, in the some of depths, concentrations of ^{36}Cl were higher than the ^{10}Be results. The $^{36}Cl/^{10}Be$ ratios also scattered from 0.04 to 9.6 (Fig. 4). It is not observed in the results of shallow section of this study. It is not possible to explain by the production process of spallogenic ^{36}Cl from ^{40}Ar in the atmosphere. In addition, it is also hard to assume the change of the transportation process, because no comparable evidences of other climate records had been observed of this period.

Therefore it may suggest that the possibility of the low energy product such as the neutron capture reaction from the ^{36}Ar (and also ^{35}Cl possibly) was higher than the spallation product from ^{40}Ar.

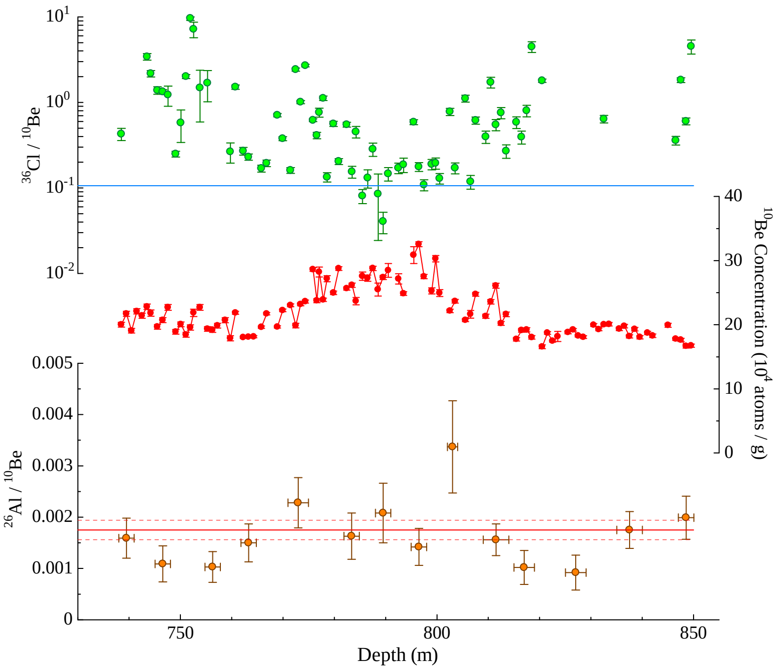

Fig. 4. The ratios of $^{36}Cl/^{10}Be$ and $^{26}Al/^{10}Be$ compared with ^{10}Be. The blue line indicates the present production ratio calculated by Masarik and Beer, 1999. The red line also indicates the present value reported by Horiuchi et al., 2007.

The quantitative evaluation of the energy spectrum of cosmic rays is not yet performed because of the lack of the nuclear data of ^{36}Cl from Argon. More measurements both upper and deeper part of this core are needed to understand between the ^{36}Cl anomaly and geomagnetic excursion.

References

Beer J., R. Muscheler, G. Wagner, C. Laj, C. Kissel, P.W. Kubik and H.A. Synal, Quatern. Sci. Rev. 21 (2002), pp. 1129-1139.

Castagnoli G. and D. Lal, Radiocarbon 22 (1980), pp. 133-158.

Finkel, R.C. and Nishiizumi, K., Journal of Geophysical Research 102, (1997), pp. 26699-26706.

Horiuchi K., H. Matsuzaki, A. Ohta, Y. Shibata and H. Motoyama, Nucl. Instr. and Meth. B 259 (2007), pp. 625-628.

Horiuchi K., T. Uchida, Y. Sakamoto, A. Ohta, H. Matsuzaki, Y. Shibata and H. Motoyama, Quaternary Geochronology 3 (2008), pp. 253-261.

Masarik J. and J. Beer, Journal of Geophysical Research 104 (1999), pp. 12099-12111.

Muscheler R., J. Beer, P.W. Kubik and H.-A. Synal, Quatern. Sci. Rev. 24 (2005), pp. 1849-1860.

Parrenin F., G. Dreyfus, G. Durand, S. Fujita, O. Gagliardini, F. Gillet, J. Jouzel, K. Kawamura, N. Lhomme, V. Masson-Delmotte, C. Ritz, J. Schwander, H. Shoji, R. Uemura, O. Watanabe and N. Yoshida, Clim. Past 3 (2007), pp. 243-259.

Raisbeck G.M., F. Yiou, J. Jouzel and T.F. Stocker, Clim. Past 3 (2007), pp. 541-547.

Yiou, F., Raisbeck, G.M., Baumgartner, S., Beer, J., Hammer, C., Johnsen, S. *et al*, J. Geophys. Res. 102, pp. 26783-26794. 1997.