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Climate Signals from ^{10}Be Records of Marine Sediments Surrounded with Nearby a Continent

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1. Introduction

Climate signals from ^{10}Be records in marine environments have been studied for last two decades (Aldahan et al., 1997, Bourlès et al., 1989, Christl et al., 2003, Eisenhauer et al., 1994, Horiuchi et al., 2000, 2001, Kim and Nam, 2010, Knudsen et al., 2008, McHargue et al., 2010, McHargue and Donahue, 2005). Understanding of regional climate signals is feasible through not only ^{10}Be but also ^9Be from the sediment. This is because ^9Be is terrigenous origin while ^{10}Be signal is affected by climatic condition and production at the top of atmosphere. Recent study from the East Sea of Korea (05-GCRP-21) indicated that climate signals from ^{10}Be records of Korean marine sediment are generally representing global climate variations during warm and cold periods from Last Glacial Maximum to Holocene and also MIS (marine isotope stage) 6 to Eemian. The ^{10}Be records of the East Sea are well compared with those from the oxygen isotopic record of this marginal sea (Kim and Nam, 2010). During the warm interglacial periods the ^{10}Be concentrations per sediment mass have significantly increased while during the cold glacial periods those have decreased (Aldahan et al., 1997, Eisenhauer et al., 1994). This result also shows that a vivid record of $^{10}\text{Be}/^9\text{Be}$ indicates a significant increase of ^{10}Be at a time of 120 kyr, which might be an indication of the paleomagnetic excursion.

Interestingly, it was found that the ^{10}Be concentrations per 1g sediment of this region were about 30% lower than other ^{10}Be records of largely open marine environment. We also found that ^{10}Be concentrations of the Blake Outer Ridge were similar to those from Korean marine sediments (McHargue et al., 2000). Two study areas are located nearby large continents: the East Asia (the East Sea) vs North America (the Atlantic). This could be caused by sediment inflow to the marine environment which is close enough to the continent. Therefore, local marine environmental influence is revealed through the beryllium isotopes. Both cases would have similar climatic signals due to their geographical locations nearby continent. The lower ^{10}Be concentrations for these regions could be also involved in ocean current and circulation. Relatively deep sea water of these regions may not be well mixed rapidly with the surface water and old sea water with relatively lower ^{10}Be concentration remains in the sediment records. For this chapter, we investigated climatic signals from Be isotope records of the East Sea of Korea and the Mendeleev Ridge of the Arctic Ocean and compared with the records from the Blake Outer Ridge studied by McHargue et al., 2000. In addition, global ^{10}Be records of marine sediments for various regions will be briefly discussed. This chapter

would provide a new insight guide into understanding climate signals through ^{10}Be records of various marine environments.

2. Beryllium isotopes in terrestrial environments

2.1 Cosmic ray induced ^{10}Be production rate

Production rates of cosmogenic isotopes depend on geomagnetic latitude, altitude, and flux of incoming cosmic rays to the earth (Lal, 1988). The Earth's geomagnetic field deflects incoming cosmic rays and has an effect on the production rate of *in situ* cosmogenic isotopes. This deflection affects the incident angle and the rigidity of cosmic rays. The rigidity is defined as $r = pc/q$, where p is the momentum, q is the charge of the particle, and c is the velocity of light (O'Brien, 1979). The vertical cutoff rigidity is the lowest at the geomagnetic poles and highest at the equator. Therefore, greater cosmic rays reach to the poles and attenuation length at low latitude is greater than at high latitude (Simpson and Uretz, 1953). Since geomagnetic latitude affects the production rate of cosmogenic isotopes, understanding of the secular variation of the Earth's geomagnetic field is important. It is known that variations of geomagnetic field intensity cause changes in the flux of cosmic rays, in solar activity, and in shielding by the Earth's magnetosphere. Laj et al., 1996 describes geomagnetic intensity and ^{14}C abundance in the atmosphere and ocean during the past 50 kyr. This paper shows geomagnetic change effects on the ^{14}C production, which is increased by the decrease of the Earth's dipole moment. Similarly, the relationship between ^{10}Be production rate and geomagnetic field intensity was studied using deep-sea sediments. These results also demonstrate the importance of the relationship between cosmogenic nuclide production and intensity of geomagnetic dipole moment variation (Frank et al., 1997). Thus, production of cosmogenic isotope should be corrected with the variation of geomagnetic dipole moment variation. It has been found that the Earth's geomagnetic pole is essentially the geographic pole for periods greater than about 2 kyr (Champion, 1980, Ohno and Hamano, 1992). Therefore, a correction from geographic reading to geomagnetic reading is required. For most cases of ^{10}Be or ^{26}Al surface exposure dating samples, the working range of age is from several thousand years to a few million years. Thus, in this case, the correction for geomagnetic reading may not be required, but the correction of production related to secular variation of geomagnetic dipole moment intensity is required. Masarik et al., 2001 demonstrated the correction of *in situ* cosmogenic nuclide production rates for geomagnetic field intensity variations during the past 800 kyr. This paper indicated that at the equator integrated production rates for exposure ages between ~40 and 800 kyr are 10 to 12% higher than the present day value, whereas at latitudes greater than 40 degree, geomagnetic field intensity variations have hardly influenced *in situ* cosmogenic nuclide production.

Production rates as a function of both latitude and altitude have been studied in the past. For a few decades, models from Lal and Peters, 1967 and Lal, 1988, have been widely used for the scaling factors for production rates of *in situ* produced cosmogenic nuclides. A third degree polynomial equation found in Lal, 1991, enables one to calculate the production rate of ^{10}Be and ^{26}Al with respect to geomagnetic latitude and altitude. A reevaluation of scaling factors for these production rates has been attempted recently using non-dipole contributions of the geomagnetic field to the cosmic ray flux and observed attenuation lengths (Dunai, 2000). The scaling factors for the nuclear disintegration with respect to geomagnetic latitude and altitude from Lal's work are

involved in the geocentric axial dipole hypothesis and this is appropriate for time scales exceeding 200 kyr. The non-dipole components of the Earth's magnetic field contribute up to 20% to the total field; therefore, they must be considered for short-term effects of cosmic rays. It is known that the new scaling factors and those of Lal are significantly different, by up to about 30%, especially at high altitude and at low latitude. Currently, a few other research groups have been involved in studying production rates of cosmogenic nuclide or measurement of neutron flux as a function of geomagnetic latitude and altitude. This additional research on this field may provide a confirmation of these scaling factors for the production of *in situ* cosmogenic isotopes. (Stone, 2000, Graham et al., 2005a,b,c, 2000, Lifton et al., 2001, Desilets et al., 2006).

2.1.1 Production rate in the atmosphere

^{10}Be is produced in the atmosphere by nuclear interactions with oxygen and nitrogen (Peters, 1955, Goess and Phillips, 2001). The intensity of the cosmic ray flux depends on galactic and solar sources, and modulation by the heliomagnetic and geomagnetic fields. Both ^{10}Be is produced by spallation reactions in the atmosphere, and then ^{10}Be is well mixed up (Ueikkila et al., 2009) and removed from the atmosphere by precipitation scavenging of aerosol particles to land and sea. Eventually, these nuclides are deposited within ocean sediment. The ^{10}Be concentration at 10.7 km of stratosphere and at 19.2 km in the tropospheric concentration are known to be 7×10^6 atoms/ m^3 , and 1.3×10^7 atoms/ m^3 , respectively. The global average ^{10}Be production rate is found to be $(1.21 \pm 70) \times 10^6$ atoms/ cm^2/yr (Monaghan et al., 1985). Estimates of the ^{10}Be production rate derived from measurements on ice cores, lake sediments, and deep-sea sediments range from 0.35×10^6 atoms/ cm^2/yr to 1.89×10^6 atoms/ cm^2/yr . (Monaghan et al., 1985). Castagnolie et al., 2003 demonstrated reconstruction of the modulation parameter M from the open solar magnetic flux proposed by Solanki et al., 2000, and experimental values calculated from the GCR spectra measured with balloons and spacecraft are compared well with ^{10}Be concentration measured at the Dye3 ice core, assuming constant accumulation rate during the period of 1810-1997. The production rate of ^{10}Be ranged from 0.015 to 0.025 atoms/ cm^2/s (Castagnolie et al., 2003).

The precipitation onto the surface of the Earth and the deposition of ^{10}Be in soils is influenced by climate. In turn, the production of ^{10}Be in the atmosphere is influenced by the magnetic dipole field of the Earth to which it is inversely related. This relationship between the production of ^{10}Be and the geomagnetic field has been shown by the correlation between the variations of ^{10}Be and those of the measured paleo-inclination data of the dipole field in sediments (Frank et al., 1997, Frank, 2000, Masarik et al., 2001, Laj et al., 2000), and the concentrations of ^{10}Be in marine sediments and the measured paleointensity (Carcaillet et al., 2004, McHargue and Donahue, 2005).

The influence of climate on the deposition of ^{10}Be , otherwise is problematic for interpretations of the cosmic-ray flux, in itself is a worthy subject for study. For example, variations in the deposition rates of ^{10}Be and sediments affect the $^{10}\text{Be}/^9\text{Be}$ ratio due to the uneven mixing of the two isotopes in the hydrological cycle. That, ^{10}Be , produced largely in the atmosphere, is transported to the surface of the earth by rain and dry precipitation to the sea. In contrast, ^9Be , derived from terrigenous materials, is transported to the sea largely by rivers, and to a lesser extent by atmospheric deposition.

Location	^{10}Be	Source	Reference
USA continent	$(1.38 \pm 0.36) \sim (3.96 \pm 0.35) \times 10^6$ atoms/cm ² /yr	rain	Monaghan et al., 1985
USA Hawaii	$1.9 \times 10^3 \sim 8.94 \times 10^4$ atoms/g	rain	Monaghan et al., 1985
Tropical region	Avg. 1.53×10^4 atoms/g	rain	Monaghan et al., 1985
Illinois, USA	$2 \sim 7 \times 10^7$ atoms/g	soil	Brown et al., 1989
Japan, Kikari Is	$(0.80 \sim 7.17) \times 10^9$ atoms/g	soil	Maejima et al., 2005
Japan, Kikari Is	$(2.0 \sim 3.5) \times 10^6$ atoms/cm/yr	rain	Maejima et al., 2005
New Zealand	$(2.1 \sim 2.9) \times 10^4$ atoms/g	rain	Graham et al., 2003
Korea, Masanri	$(0.67 \sim 1.47) \times 10^8$ atom/g	soil	Kim et al., 2011a
India	$(0.43 \sim 3.34) \times 10^7$ atoms/l	rain	Somayajulu et al., 1984
Global	$(1.21 \pm 0.70) \times 10^6$ atoms/cm ² /yr	rain	Monaghan et al., 1985

Table 1. Production rate and concentration of ^{10}Be in the rain and soil.

2.1.2 ^{10}Be in land surface

Precipitation was collected for approximately one year during 1980 at seven localities in the continental U.S.A. (Monaghan et al., 1985). The ^{10}Be flux ranged from $(1.38 \pm 0.36) \times 10^6$ to $(3.96 \pm 0.35) \times 10^6$ atoms/cm²/yr (Monaghan et al., 1985). In the case of Hawaii, ^{10}Be concentration ranges from 1.9×10^3 to 8.94×10^4 atoms/g in rain water. The mean ^{10}Be deposition rate in temperate latitude is determined to be 1.53×10^4 atoms/g in rain water (20% error). Monaghan et al., 1985 indicated that the concentration of ^{10}Be in surface soils and river sediments varies between 10^7 and 10^9 ^{10}Be atoms/g soil with the modal concentration of ^{10}Be lying between 4×10^8 and 6×10^8 atom/g. The relationship between annual rainfall and ^{10}Be deposition rate is plotted to be linearly proportional to each other (Maejima et al., 2005). This study shows that ^{10}Be fluxes (cm/day) for the two rain collection sites are relatively higher during a collection period of January 22 to April 22 than other collection period (Maejima et al., 2005).

Seasonal variations for ^7Be and ^{10}Be concentration in Tokyo and Hachijo-Island during a period of 2002 to 2003 were similar to each other. The peak value for ^7Be and ^{10}Be concentration appeared in April and October, respectively. Especially, in April when stratosphere-troposphere exchange occurs, peak values for the atomic ratio $^{10}\text{Be}/^7\text{Be}$ appeared. Low ^7Be and ^{10}Be concentrations and the atomic ratio of $^{10}\text{Be}/^7\text{Be}$ appeared in summer, July to August. Because the composition of the aerosol of Tokyo was almost same to the nearby soil, it is considered that Tokyo was strongly influenced by re-suspended soil contamination. Yamagata et al., 2005 indicated that using Al concentration in the aerosols, the enrichment of ^{10}Be concentration by re-suspended soil contamination was estimated to be about 30%.

In the case of Southern Hemisphere, Graham et al., 2003 demonstrated ^7Be and ^{10}Be fluxes at 36 to 45°S were determined to be $(1.2 \sim 14) \times 10^7$ atoms/kg and $(2.1 \sim 2.9) \times 10^7$ atoms/kg, respectively. These results are similar to those for rain sampled at mid-latitude sites across the USA from 1986 to 1994. The annual ^7Be and ^{10}Be flux rates are ~ 15 and $\sim 27 \times 10^9$

atoms/ m^2 , respectively, at the northern sites of Leigh and Gracefield, and are significantly lower at ~ 9 and $\sim 19 \times 10^9$ atoms/ m^2 , respectively, at the southern site of Denidin, because of the lower average rainfall there. Graham et al., 2003 indicated that $^7\text{Be}/^{10}\text{Be}$ in New Zealand ranged 0.47 to 0.61 and this is significantly lower than the ratio in USA (0.69~0.78). This is due to re-suspended dust to the primary atmospheric ^{10}Be in the rain sample in New Zealand. Interestingly, the ratio of $^7\text{Be}/^{10}\text{Be}$ at three sites are 0.70 (Leigh), 0.65 (Gracefield) and 0.50 (Dunedin). These results suggest an overall reduction in the $^7\text{Be}/^{10}\text{Be}$ ratio from north to south, due to increasing residence time for Be isotopes in the atmosphere above New Zealand. The mean residence time for ^7Be and ^{10}Be in the atmosphere above New Zealand range from 77 to 109 days and are lower in the summer than the winter due to transfer of older stratospheric air to the tropopause in late spring-early summer (Graham et al., 2003).

Maejiam et al., 2005 demonstrated that ^{10}Be concentrations of six soil samples on the raised coral reef terraces of Kikari Island, southwest Japan ranged from 0.80 to 7.17×10^9 atoms/g. The annual deposition rate of ^{10}Be from the atmosphere to Kikari Island from 2000 and 2002 ranged from 2.0 to 3.5 atoms/ cm^2/y . The minimum absolute age was calculated from the inventory of meteoric ^{10}Be in the soil, and the annual deposition rates of ^{10}Be are ranged from 8 to 136 kyr (Maejima et al., 2005). A 36 cm of soil depth profile from the Roberts Massif, Antarctica was studied to obtain the age of soil by Graham et al., 1997. The sampling site is located in the edge of the nearby East Antarctic Ice Sheet at an altitude of 2700 m. This site is considered to have been ice-free for an extremely long period of time, of the order of several million years. The results of Graham et al., 1997 determined its minimum soil age of 12 million years which is much older than other $^{40}\text{Ar}/^{38}\text{Ar}$ dating result of 8 million years for volcanic deposit, Scoria associated with soils on the tills laid down by the Meserve Glacier, Antarctica.

2.1.3 ^{10}Be in the ocean

Using radiocarbon, the sedimentation rates during glacial periods and deglacial periods for the western Arctic Ocean were found to be 0.5 cm/kyr and 1-2 cm/kyr, respectively (Darby et al., 1997). A recent study shows that the concentration of ^{10}Be in the authigenic fraction of the sediment normalized to the total sediment mass is indirectly correlated to the oxygen isotope curve (McHargue and Donahue, 2005). For example, a low $^{10}\text{Be}/^9\text{Be}$ ratio in sediments would imply that terrestrial source of ^9Be has increased compared to the more oceanic ^{10}Be . Correlation of ^{10}Be with $\delta^{18}\text{O}$ recorded in marine sediment from the Blake Outer Ridge (DSDP site 72) shows a climatic effect on the ^{10}Be record in addition to cosmogenic effects. Age-corrected ^{10}Be variability in the sediment cores studied in Aldahan et al., 1997 and the oxygen isotope stratigraphy with the climatic stages numbered from 1 to 10, is generated from Aldahan et al., 1997. ^{10}Be from sediments of the Arctic Ocean covering the past 350 kyr shows well defined trends of Be isotopes coincident with interglacial/glacial climatic cycles and demonstrates that the sedimentation rates are higher during glacial periods and lower generally due to low sedimentation/accumulation rate during interglacial periods (Aldahan et al., 1997).

The ^{10}Be records of four sediment cores, taken along a transect from the Norwegian Sea via the Fram Strait to the Arctic Ocean, demonstrate that high ^{10}Be concentration are related to interglacial stages and that sediment sequences with low ^{10}Be concentration are related to glacial stages. This study confirms that the sharp contrast of high and low ^{10}Be concentrations at climatic stage boundaries are an independent proxy for climatic and

sedimentary change, and can be applied for ^{10}Be stratigraphic dating of sediment cores (Eisenhauer, 1994).

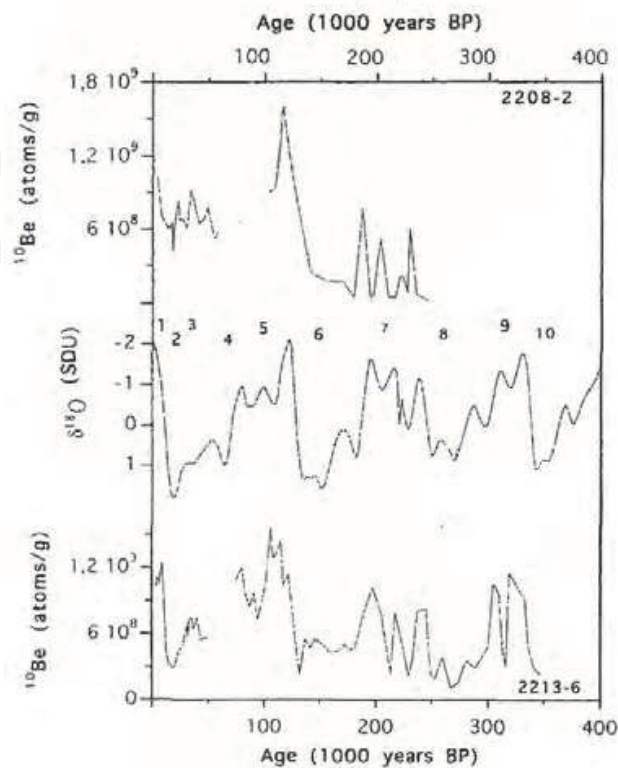


Fig. 1. Age corrected ^{10}Be as a function of age (Aldahan et al., 1997).

Also, Carcaillet et al., 2004 produced high resolution authigenic $^{10}\text{Be}/^9\text{Be}$ records over the last 300 kyr from sedimentary cores off the Portuguese coast. Comparison of $^{10}\text{Be}/^9\text{Be}$ and benthic $\delta^{18}\text{O}$ records from the two cores suggested that dipole moment lows may be associated with the end of interglacial episodes, and have a quasi-period of 100 kyr (Carcaillet et al., 2004). In a recent study, McHargue and Donahue, 2005 showed a strong correlation between ^{10}Be and oxygen isotope stages from the Blake Outer Ridge in the Atlantic Ocean. This relationship between climate and ^{10}Be deposition suggest that ^{10}Be could be used, in addition to, or as proxy for $\delta^{18}\text{O}$ in the studies of the climatic influences on marine sedimentation.

Other considerations are the carbonate flux in sediment which is strongly correlated to ^{10}Be flux, and carbonate-free sediments from which $\delta^{18}\text{O}$ is difficult to obtain from foraminifera. In addition, the two isotopes of beryllium, as stated above, are source dependent, thus the relationship of ^{10}Be to ^9Be in the sediments is a function of the relative contributions from atmospheric and terrestrial sources, and their mixing time in the sea.

Paleomagnetic intensity obtained from deep sea cores is well described in recent publications (Valet, 2001, Guyodo et al., 2000, Guyodo and Richter, 1999). However, it was found that climatic influence on ^{10}Be deposition can be significant, obscuring those variations from its production in the atmosphere, and thus must be addressed (Frank et al, 1997, Kok, 1999). Scavenging corrected ^{10}Be records compared to calculated variation of the global ^{10}Be production based on paleomagnetic intensity records (Christl et al., 2003) (Figure

2) show the variation of ^{10}Be flux in each location with general agreement of inversely proposal to the paleomagnetic intensity from Mazaud et al., 1994, Yamazaki and Iokyr et al., 1994, and Guyodo and Valet, 1999.

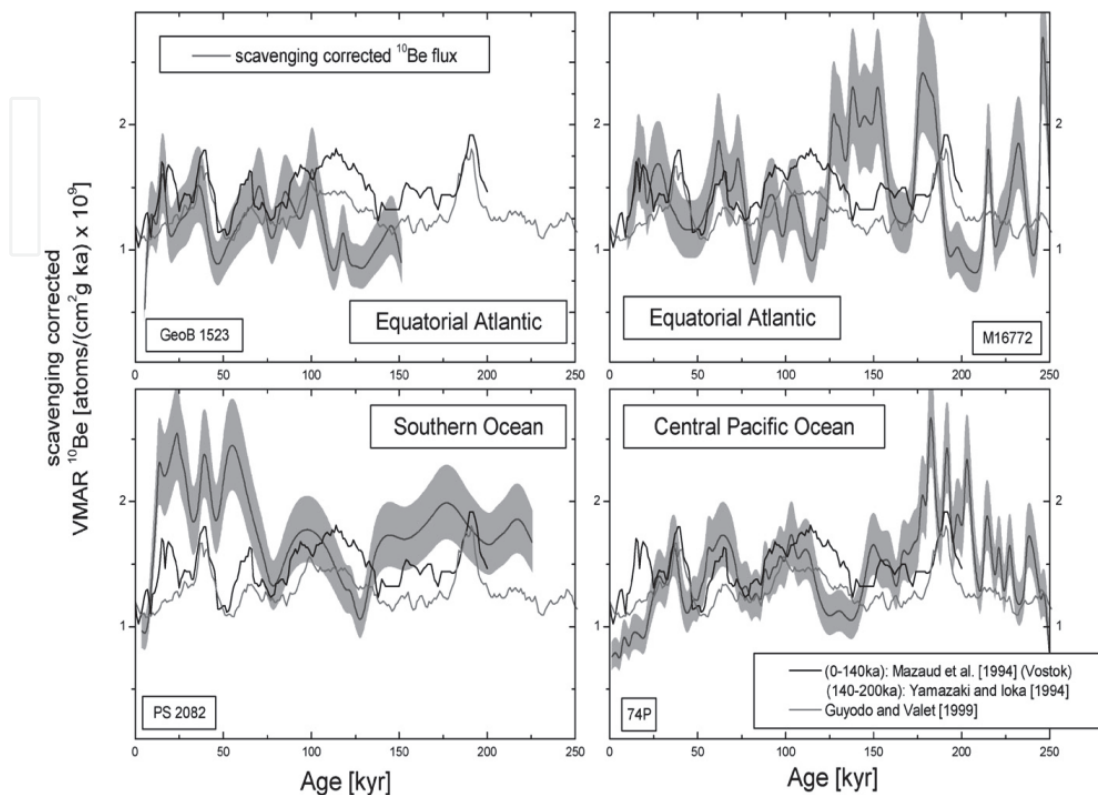


Fig. 2. Scavenging corrected ^{10}Be records compared to calculated variation of the global ^{10}Be production based on paleomagnetic intensity records (Christl et al., 2003).

2.2 ^{10}Be chemistry

Generally, to extract authigenic beryllium isotopes from sediments, the procedure of Bourles et al., 1989 is used. About one gram of sediment is leached in a solution of 25% acetic acid and hydroxylamine-HCl to separate the “authigenic” fraction of the sediment from the “terrigenous” fraction. Most samples had more than 1 g of dry sediment; however, in the case of less than 1 g, two or three neighbouring samples were combined for the analysis. When ^{10}Be is normalized to the mass of the authigenic fraction, it should more accurately reflect its concentration in ocean water than ^{10}Be normalized to the total mass of the sediment (McHargue and Donahue, 2005, McHargue et al., 2010). This fraction is mostly composed of exchangeable ions, carbonates, and Fe-Mn hydroxides. Two aliquots of the leachate are prepared, one for the elemental analysis with ICP-MS/ICP-AES, and one for the preparation of AMS samples.

Figure 3 shows the flow chart of ^{10}Be chemistry to extract authigenic beryllium from sediment. This chemistry includes two steps of purification procedures using perchloric acid and nitric/hydrochloric acid. These steps are important to extract authigenic beryllium isotopes. Sometimes, this step is repeated to remove unwanted organic materials. When the unwanted organic materials are not completely removed, the residue sample is often difficult to dissolve in weak acidic solution for ICP analysis. This also causes a further

problem in the step of Be separation using Na-EDTA. The concentration level for Be is mostly in ppb range; therefore, Be analysis was performed using ICP-MS. For AMS, the Be fraction is precipitated as $\text{Be}(\text{OH})_2$ and combusted to BeO. $^{10}\text{Be}/^{9}\text{Be}$ ratios for chemical blank are found to be less than $\sim 1 \times 10^{-14}$ with 2 mg of ^9Be carrier. ^9Be and other elements can be measured by ICP-MS and ICP-AES.

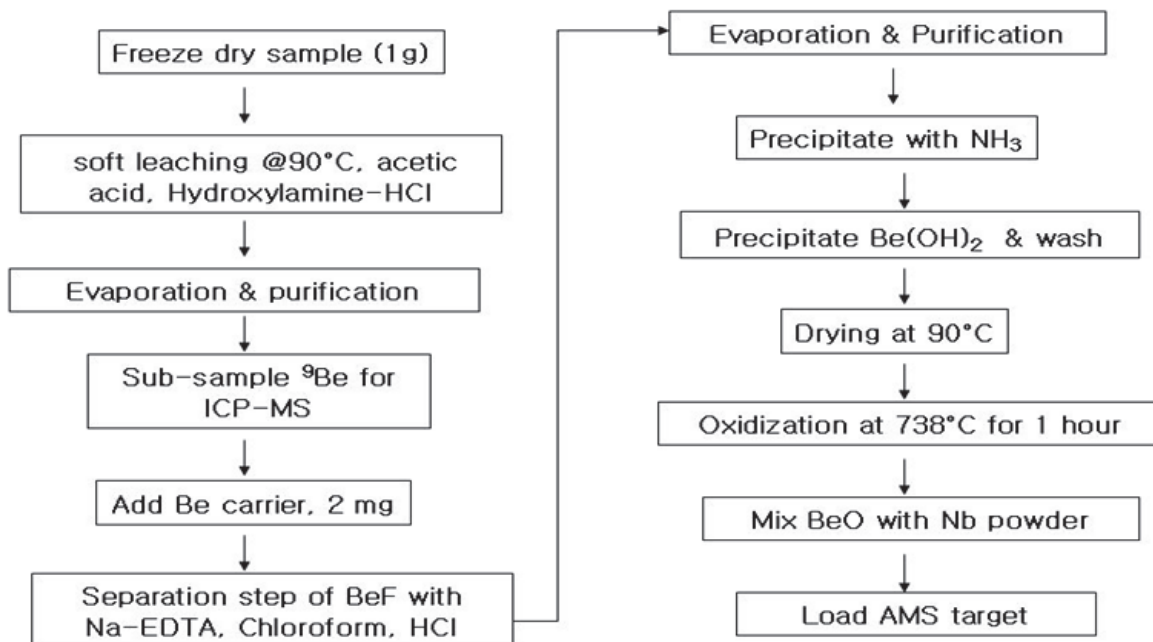


Fig. 3. Description of authigenic Be isotope extraction method.

2.3 The climate signal of ^{10}Be from nearby a continent

The signal of ^{10}Be from the East Sea in the Pacific Ocean and the Blake Outer Ridge in the North Atlantic Ocean may give similar climatic influence because of its proximity to continents (Kim and Nam, 2010, McHargue et al., 2000). The depths of basins where sediment core collected were about 3,700 m and 3,818 m in the East Sea and Blake Outer Ridge, respectively. Because both cores were collected in the basin of the ocean, we might expect water circulation could be weaker. This could allow rather older waters can remain at the bottom of the basin. In this case, we may expect lower concentration of ^{10}Be in sediment compared to samples collected from other open seas (Bourlès et al., 1989, Knudsen et al., 2008). Also, the influence from the continent would be similar in both regions. The terrestrial origin of ^{10}Be over glacial/deglacial time period may similarly appear.

As shown in Figure 4, three locations were examined with respect to ^{10}Be concentration as a function of time and any related proxies for each site. Mostly, maximum ^{10}Be concentrations in various marine sediment samples appear to be above 1×10^9 atoms/g sediment (Bourlès et al., 1989, Knudsen et al., 2008). Both the East Sea and Blake Outer Ridge, ^{10}Be concentrations are reached at 8×10^8 atoms/g. This value is at least 30 percent lower than the most maximum value of ^{10}Be in each marine sediment core. Also, when ^9Be is investigated with ^{10}Be , ^9Be signal may be another indicator as a signal of sediment input from the land to the offshore. In the case of the study of the East Sea, the ^9Be values also show similar trend to those of ^{10}Be . This shows that both warmer periods of the Holocene and the Eemian,

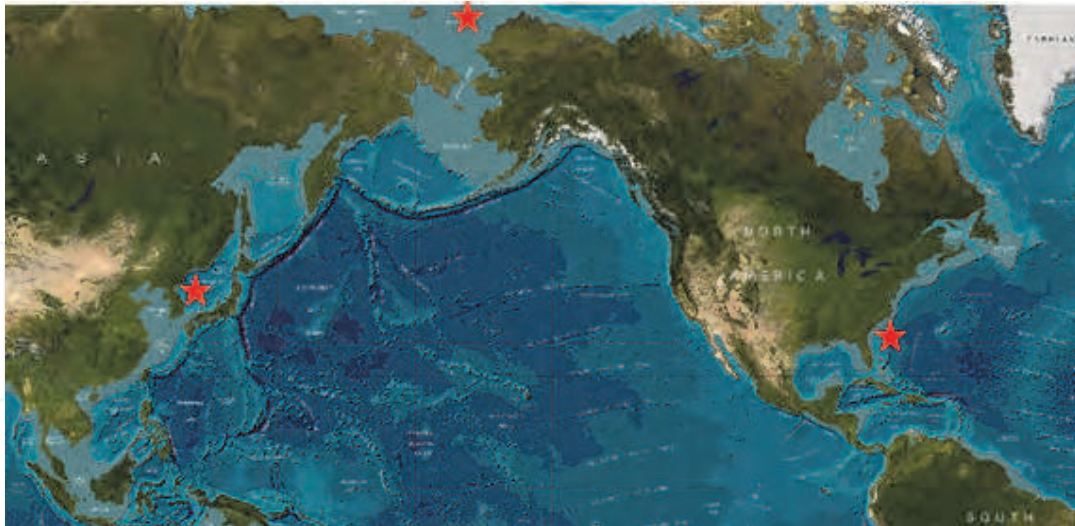


Fig. 4. Locations of the coring sites of the East Sea, Black Outer Ridge, and Mendeleev Ridge in the western Arctic Ocean.

wetter and warmer climate influenced ^9Be to be transported from the land to the ocean. ^{10}Be is transported from the both land and atmosphere. The signal of $^{10}\text{Be}/^9\text{Be}$ especially stands for lack of either lack of ^9Be transport or higher production rate of ^{10}Be , possibly associated with paleomagnetic intensity. In Figure 5, A, B, and C are associated with relatively higher $^{10}\text{Be}/^9\text{Be}$ compared to neighbouring $^{10}\text{Be}/^9\text{Be}$ values. A could be partially due to lowered value of ^9Be ; B and C could be due to production rate of ^{10}Be . This study shows high production rate of Be at 15.5 and near 120 kyr. Also, lower ^{10}Be production rate is shown at 130.6 kyr during MIS 6 (Figure 5) (Kim and Nam, 2010). These three points can be identified easily with $^{10}\text{Be}/^9\text{Be}$ ratios. In the Figure 5, the regions associated with climatic influence are clearly shown as the $^{10}\text{Be}/^9\text{Be}$ ratios to be within the value between 2 and 3. This observation could be useful in future analysis. Based on Wagner et al., 2000, lower paleomagnetic intensities are associated with the ages at 1.5, 2.5, 4.0, and 6.5 kyr (Christl et al., 2003). Therefore, B could be likely involved in higher production rate of ^{10}Be at 1.5 kyr (Kim and Nam, 2010) (Figure 5).

Figure 6 shows the ^{10}Be concentration and M/Mo as determined from measured NRM/ARM of core CH88-10P with respect to depth and time. This figure shows that ^{10}Be concentration is inversely proportional to the relative paleomagnetic intensity. The production rate of ^{10}Be occurred at about 40 and 65 kyr. The peak values of $^{10}\text{Be}/^9\text{Be}$ reached at maximum at about 40 kyr. This time period is named as Laschamp paleomagnetic excursion where the expected ^{10}Be reaches at a maximum value. These paleomagnetic excursions are well compared with GRIP records.

A recent investigation on ^{10}Be and ^9Be from the Mendeleev ridge in the Arctic Ocean shows that ^{10}Be record at 75 kyr reveals production rate decrease evidently for at least 35 kyr of duration (Kim et al., 2011b). At this time the paleomagnetic intensity is found to be at maximum (Figure 2) (Christl et al., 2003; Flank et al., 1997). Interestingly, the values of magnetic susceptibility (Guyodo and Valet, 1996) obtained from a lake (Lac du Bouchet, France) are high as well as $\delta^{18}\text{O}$. Also, ^9Be is relatively high which stands for a warm climate. The results of this study confirm that ^{10}Be reveals predominantly paleomagnetic features over the $\delta^{18}\text{O}$ at the extreme point of paleomagnetic intensity. This situation brings us to have precaution in a misuse of ^{10}Be as a climatic tracer. This study confirms the fact that the ^{10}Be record for climatic tracer, comparison with ^9Be is essential. When both

beryllium isotopes behaves similarly, the pattern of Be can be used to determine whether the record of Beryllium isotopes is associated with colder or warmer climate based on their consistent concentration trend. The total authigenic ^{10}Be and ^9Be ($^9\text{Be} \gg ^{10}\text{Be}$) can be referred as ^9Be because of their amount ratio in terrestrial environment. The ^9Be can be used as another climatic indicator like Sr, Ca, opal, TOC. The study at The Mendeleev Ridge confirms that ^9Be generally has a positive correlation with opal, TOC, $\delta^{13}\text{C}_{\text{org}}$ and negative correlation with CaCO_3 (Nam unpublished) (Figure 7). General trend of ^9Be clearly show the anti-correlation between ^9Be and Ca or Sr (Boulrès et al., 1989, Kim et al., 2011b). Therefore, we can conclude that ^{10}Be has a positive correlation with $\delta^{18}\text{O}$ which gives ^{10}Be to be used as a climate indicator, however, this is only true when ^9Be reveals similar climatic pattern with ^{10}Be . Both ^{10}Be and ^9Be show lower concentration at a cold/dry climate and higher concentration at a warm/wet climate period (Kim and Nam, 2010).

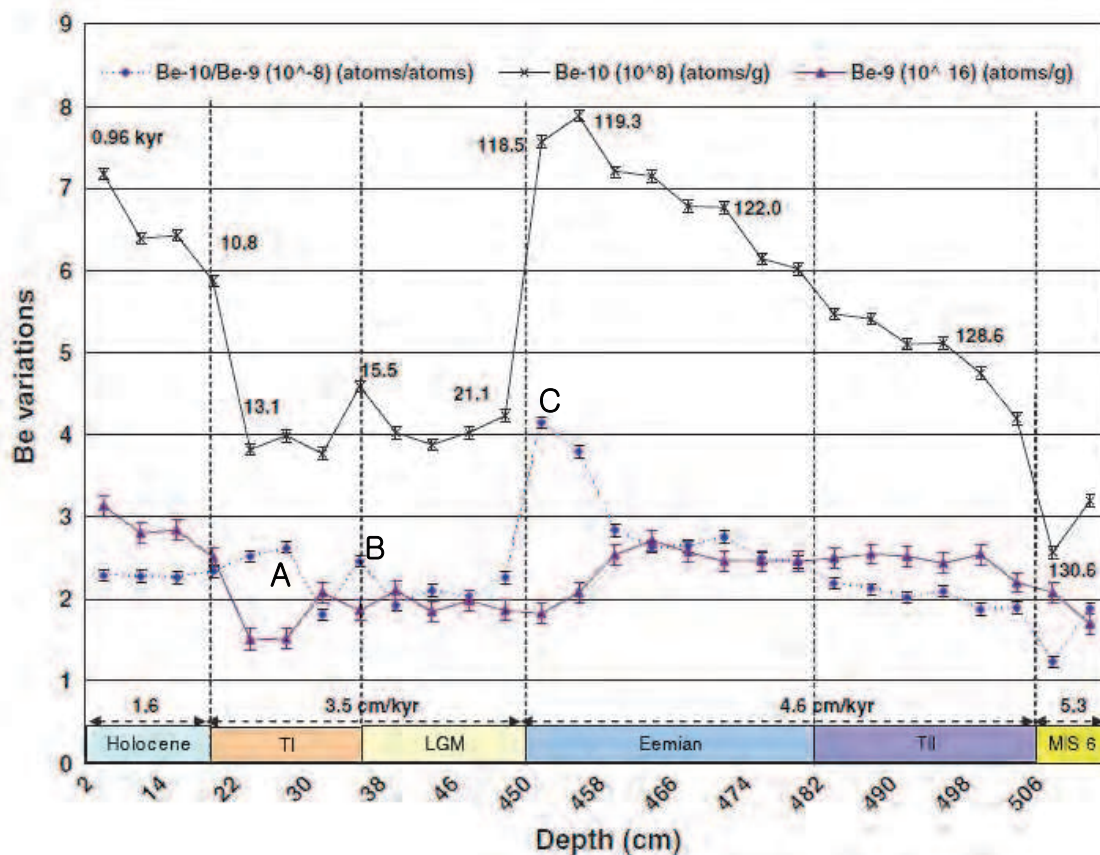


Fig. 5. Authigenic beryllium isotope records from the East Sea, Korea (Kim and Nam, 2010).

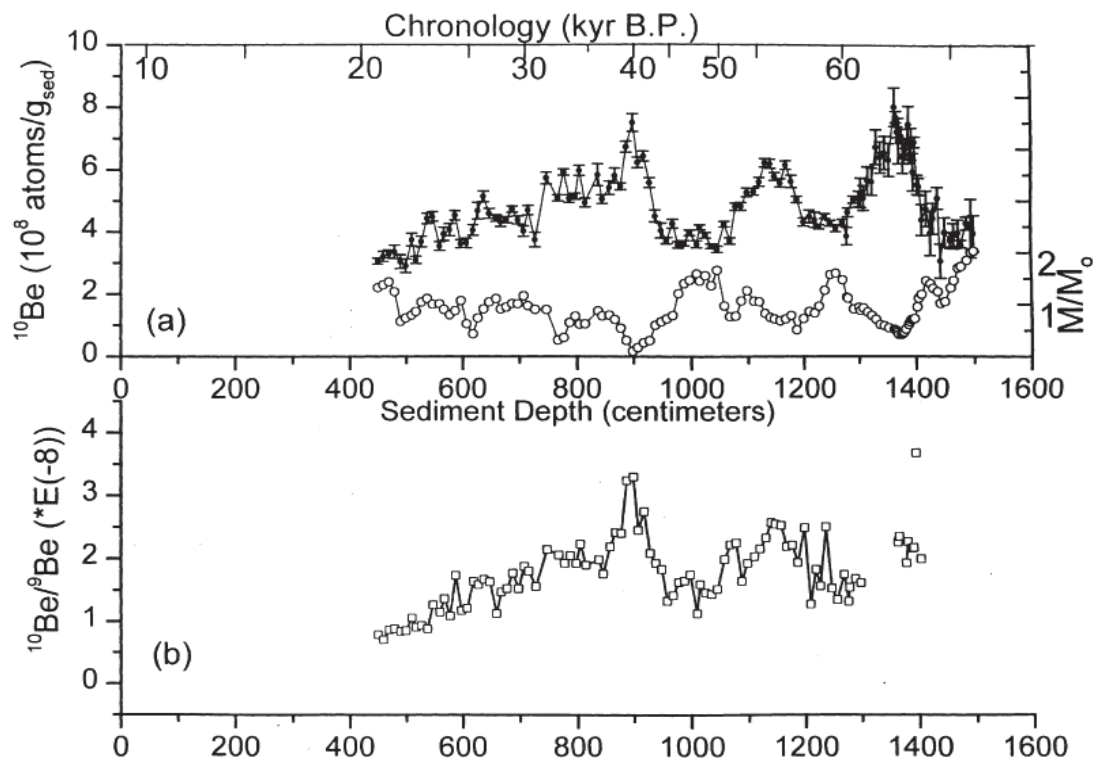


Fig. 6. The ^{10}Be concentration and M/Mo as determined from measured NRM/ARM (Schwartz et al., 1998) of core CH88-10P versus depth and time (McHargue et al., 2000).

2.4 Current problem and future research

A number of investigations show that there has been positive correlation between oxygen isotope and ^{10}Be concentration (Aldahan et al., 1997). Also, a positive correlation between oxygen isotopes and paleomagnetic intensity and also magnetic susceptibility is investigated (Carcaillet et al., 2004). During the Holocene, paleomagnetic intensity was gradually increased since the time of Laschamp excursion. This confirmed that production rate of ^{10}Be at present is the lowest value since Laschamp excursion. However, the ^{10}Be values recent years are higher than the ^{10}Be concentration and the trend of ^{10}Be is similar to that of $\delta^{18}\text{O}$ value. This implies that ^{10}Be is closely related to climatic and temperature variation. Because of this contradictory fact, confining the cause of climate change using nuclides which sun's activity related became important.

Although there have been a number of investigation on climate study using above parameters, obscurity in finding the cause of climate change is still remain. The relationship among production rate of ^{10}Be , paleomagnetic intensity, and Sun-climate connection was studied (Sharma, 2002). This study estimated changes in ^{10}Be production rate and the geomagnetic field intensity, variations in solar activity were calculated for the last 200 kyr., and confirms that the production of ^{10}Be in the Earth's atmosphere depends on the galactic cosmic ray influx that is affected by the solar surface magnetic activity and the geomagnetic dipole strength. However, large variations in the solar activity are evident. The marine $\delta^{18}\text{O}$ record and solar modulation are strongly correlated at the 100 kyr timescale. This proposes that variation in solar activity control the 100 kyr glacial-interglacial cycles. Sharma, 2002 suggested that the ^{10}Be production rate variations may have been under-estimated during the interval between 115 kyr and 125 kyr, and may have biased the results (Sharma, 2002).

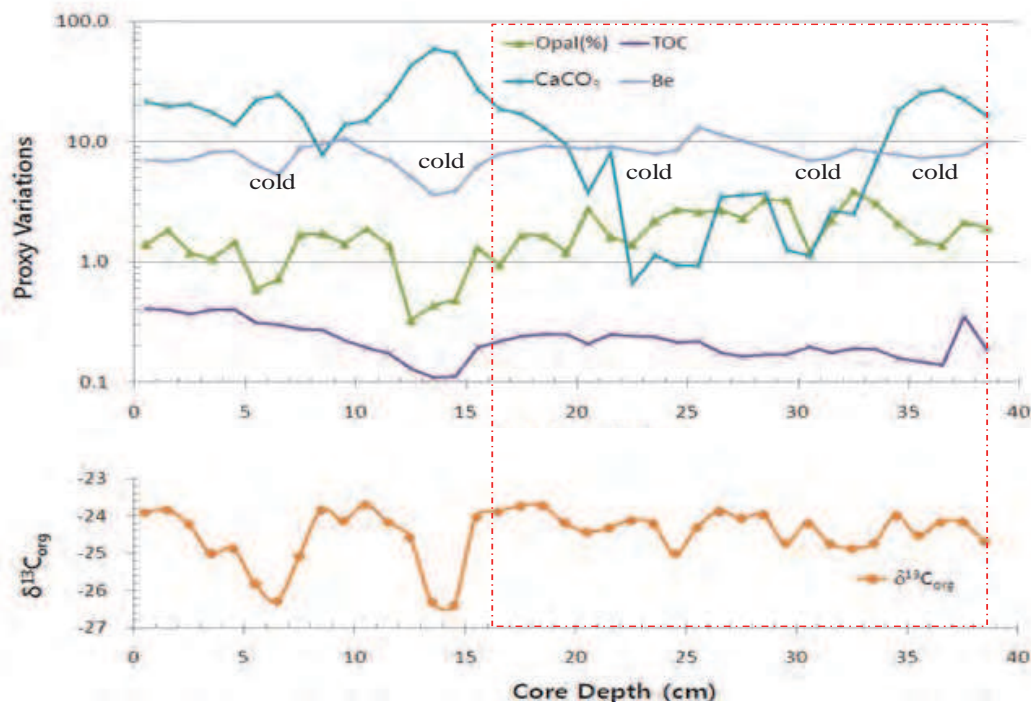


Fig. 7. Multi-proxy record from the core (PS72/396-3) from Mendeleev Ridge, the Arctic Ocean (Kim et al., 2011b).

Usoskin et al., 2004 indicated that the reconstructed sunspot record exhibits a prominent period of about 600 years, in agreement with earlier observations based on cosmogenic isotopes. Also, there is evidence for the century scale Gleissberg cycle and a number of shorter quasi-periodicities whose periods seem to fluctuate on millennium time scale. This invalidates the earlier extrapolation of multi-harmonic representation of sunspot activity over extended time intervals and the present high level of sunspot activity is unprecedented on the millennium time scale (Usoskin et al., 2004). Accepting solar forcing of Holocene and glacial climatic shift implies that the climate system is far more sensitive to small variation in solar activity than generally believed. In order to fully understand how sensitive climate really is for variations in solar activity, we need to look for additional evidence and to quantify such evidence, both in paleorecords and in observations of present climate with models to estimate climate change in the future (Geel et al., 1999).

3. Conclusions

As a climate indicator, ^{10}Be has been frequently investigated because of its property associated with rainfall, dust fallout and its production mechanism in the atmosphere by cosmic-rays. Similar patterns of ^{10}Be and $\delta^{18}\text{O}$, magnetic susceptibility records show climatic influence, however, ^{10}Be is incorporated with the production rate which is inversely proportional to the paleomagnetic intensity. The cyclic orbital forcing effect toward ^{10}Be , $\delta^{18}\text{O}$, and paleomagnetic intensity are connected, ^{10}Be signal is clearly mixed with climatic component and earth's paleo magnetic strength. Scrutinizing authigenic ^{10}Be with ^9Be , a region either climatic or production related zone can be evidently identified by looking at the $^{10}\text{Be}/^9\text{Be}$ ratios. Investigation of ^9Be is another useful tracer to examine climatic influence

of marine environments with other multi-proxies which have positive or anti-correlated with ^9Be . Marine environments like the East Sea of Korea, Blake Outer Ridge, and Mendeleev Ridge are associated with significant terrigenous input during deglacial periods. Examining both beryllium isotopes together with other multi-proxy stratigraphy will provide understanding the pattern of environmental change at various glacial/interglacial events much more evidently.

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This book offers an interdisciplinary view of the biophysical issues related to climate change. Climate change is a phenomenon by which the long-term averages of weather events (i.e. temperature, precipitation, wind speed, etc.) that define the climate of a region are not constant but change over time. There have been a series of past periods of climatic change, registered in historical or paleoecological records. In the first section of this book, a series of state-of-the-art research projects explore the biophysical causes for climate change and the techniques currently being used and developed for its detection in several regions of the world. The second section of the book explores the effects that have been reported already on the flora and fauna in different ecosystems around the globe. Among them, the ecosystems and landscapes in arctic and alpine regions are expected to be among the most affected by the change in climate, as they will suffer the more intense changes. The final section of this book explores in detail those issues.

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