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New evidence for enhanced cosmogenic isotope production rate in the atmosphere ~37 ka BP

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ABSTRACT. A ^{36}Cl peak has been found at about 37 ka BP in the Guliya ice core, drilled from the Qinghai–Tibetan Plateau. This peak is indicative of enhanced cosmogenic isotope production in the atmosphere, rather than a change in accumulation rate. Comparison with the records of ^{10}Be and ^{36}Cl in ice cores from Antarctica and Greenland indicates that peaks of the cosmogenic isotopes are global, and that they can be used as time markers for dating ice cores. Interestingly, the 37 ka BP global event coincided with a cold period.

INTRODUCTION

Ice-core records can provide information not only on climatic and environmental changes on Earth, but also on events that have occurred elsewhere in the universe. ^{10}Be is produced in the atmosphere by the interaction of high-energy cosmic-ray primaries and secondaries with nitrogen and oxygen, and usually adheres to aerosols, settling to the surface of the Earth mainly by means of wet deposition. The half-life of ^{10}Be is about 1.5×10^6 years. Solar activity has thus been detected from the records of ^{10}Be in polar ice cores (Beer and others, 1988, 1990, 1991; Raisbeck and Yiou, 1988; Stuiver and others, 1995). The discovery of ^{10}Be peaks in Antarctic ice cores at about 35 ka BP (Yiou and others, 1985; Raisbeck and others, 1987) has aroused special interest in the studies of environmental science, climatology and cosmology (Sonett and others, 1987; Kocharov, 1990). Records of ^{10}Be in the Byrd (West Antarctica) ice core and in the Camp Century (Greenland) ice core further aroused interest in the possibility of using ^{10}Be as a time marker (Beer and others, 1992). If the ^{10}Be peaks are caused by an increase in flux of cosmic rays into the Earth's atmosphere, then simultaneous concentrations of other cosmogenic isotopes would also show peak values in various deposition media such as snow (thus records in ice cores) and deep-sea sediments in the middle and low latitudes. Here we report on cosmogenic ^{36}Cl recorded in the Guliya ice core, Qinghai–Tibetan Plateau (QTP). ^{36}Cl is produced in the atmosphere by the interaction of cosmic rays with argon. The half-life of ^{36}Cl is about 3.0×10^5 years.

GULIYA ICE CORE

Information recorded in ice cores from the middle and low latitudes can establish a bridge for the interpretation of the mechanisms of climatic and environmental changes recorded in ice cores from bipolar regions. The QTP, located in the subtropical areas of the Northern Hemisphere, with a large amount of glaciers, provides an area for ice-core drilling. So far, many shallow and deep ice cores have been recovered in the plateau, such as Dunde ice cores from the Qilian mountains, Dongkemadi ice cores from the Tanggula mountains, Guliya ice cores from the west Kunlun mountains, Dasuopu ice cores from the Xixiabangma peak in the middle of the Himalaya, and Rongbuk ice cores from Mount Everest. Guliya ice cores are the longest of these.

The Guliya ice cap (35°17′ N, 81°29′ E) is the highest (summit 6710 m a.s.l), largest (about 376 km^2) and thickest (average > 200 m) subtropical ice cap yet investigated. During 1990–92, a Chinese–American expedition carried out glaciological study and ice-core drilling during three visits to the ice cap. Ice temperatures measured at 10 m depth in the boreholes at 6200 and 6710 m a.s.l in 1991 were about −15.5° and −18.1°C respectively. In this respect, the Guliya ice cap resembles a polar glacier (Yao and others, 1992). Annual accumulation rate varied from 140 to 260 mm w.e. in the elevation zone 6040–6710 m a.s.l. (Thompson and others, 1995). Six shallow ice cores and two deep ice cores were recovered from the ice cap during the three field seasons. The longest core, 308.6 m long, was drilled at about 6200 m in 1992. The estimated age for the bottom ice of this core is about 760 ka, based on the ^{36}Cl concentration data (Thompson and others, 1997; Yao and others, 1997). This is consistent with the age at which the QTP was first glacierized (Shi and others, 1995).

CONCENTRATION OF ^{36}Cl IN THE GULIYA ICE CORE

The basic purpose of measurements of ^{36}Cl in the Guliya 308.6 m ice core was to date the lower part of the core (Thompson and others, 1997; Yao and others, 1997) since substantial thinning precludes counting annual layers below 120 m. However, in order to detect whether there is a ^{36}Cl concentration peak in the Guliya ice core at about 35 ka BP, continuous sampling was carried out along a section of this core from 178 to 187 m which represents ice deposited around

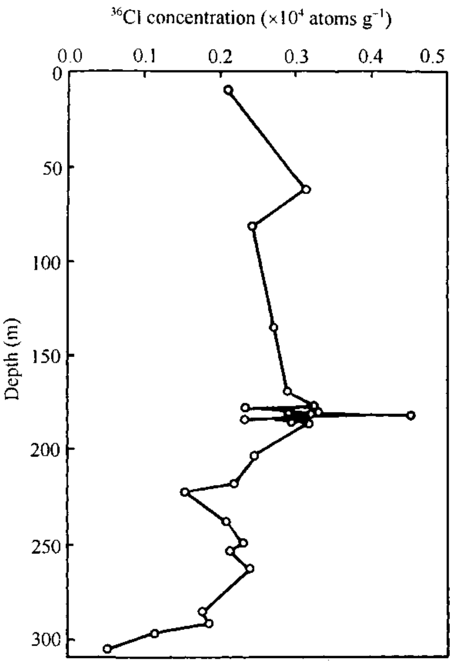

Fig. 1. Variations with depth of ^{36}Cl concentration in the Guliya ice core.

33–40 ka BP. This dating estimate is according to a CH_4-match time-scale (Thompson and others, 1997) and a time-scale developed by means of an ice-dynamics model and reference horizons (Yao and others, 1997). The sampling interval along this core section was about 1 m, equivalent to about an 800 year period. Measurement of ^{36}Cl in all 27 Guliya ice-core samples was done on an accelerator by J. Beer in Switzerland. An anomalously high (roughly twice the average concentration of all other samples from the upper 275 m section of the core (Fig. 1)) concentration of ^{36}Cl was found in the ice sample from 183–184 m. According to the established time-scale, the peak value of ^{36}Cl appears about 37–38 ka BP (Fig. 2).

For interpretation of the peak value, it is necessary to consider the climatic information. We can extract an accumulation record spanning only the past 2 ka from the Guliya ice cap (Yao and others, 1996). Thus climatic conditions 37 ka BP may be derived only from the other paleoclimatic proxy indices, such as lake evolution and pollen records. Recently a pioneer study on pollen record in Dunde ice cores suggested that the vegetation in the QTP region is sensitive to abrupt, century-scale climatic changes (K.-B. Liu and others, 1998). Therefore, in a high-resolution lacustrine sediment core, century-scale climatic changes can be inspected. Studies of a lacustrine sediment core from lake Tianshuihai, west Kunlun mountains (near the Guliya ice cap), have found that climatic conditions were very humid around 37 ka BP (Liu Guangxiu and others, 1998). These studies have used the ratio of *Artemisia* (typical of steppes) to *Chenopodiaceae* (typical of deserts) as a humidity index in arid and semi-arid regions. It has also been found that lake levels in the west Kunlun mountains and in the north Tibetan Plateau were very high in the period 30–40 ka BP (Li and Shi, 1992; Li, 1995). This supports the view derived from the pollen record of a high-precipitation regime, indicating that the peak ^{36}Cl concentration around 37 ka BP can be attributed only to an increase in deposition rate of the cosmogenic isotope and not to a change in accumulation rate.

COMPARISON WITH THE RECORDS OF COSMOGENIC ISOTOPES IN POLAR ICE

Changes in both atmospheric circulation pattern (including

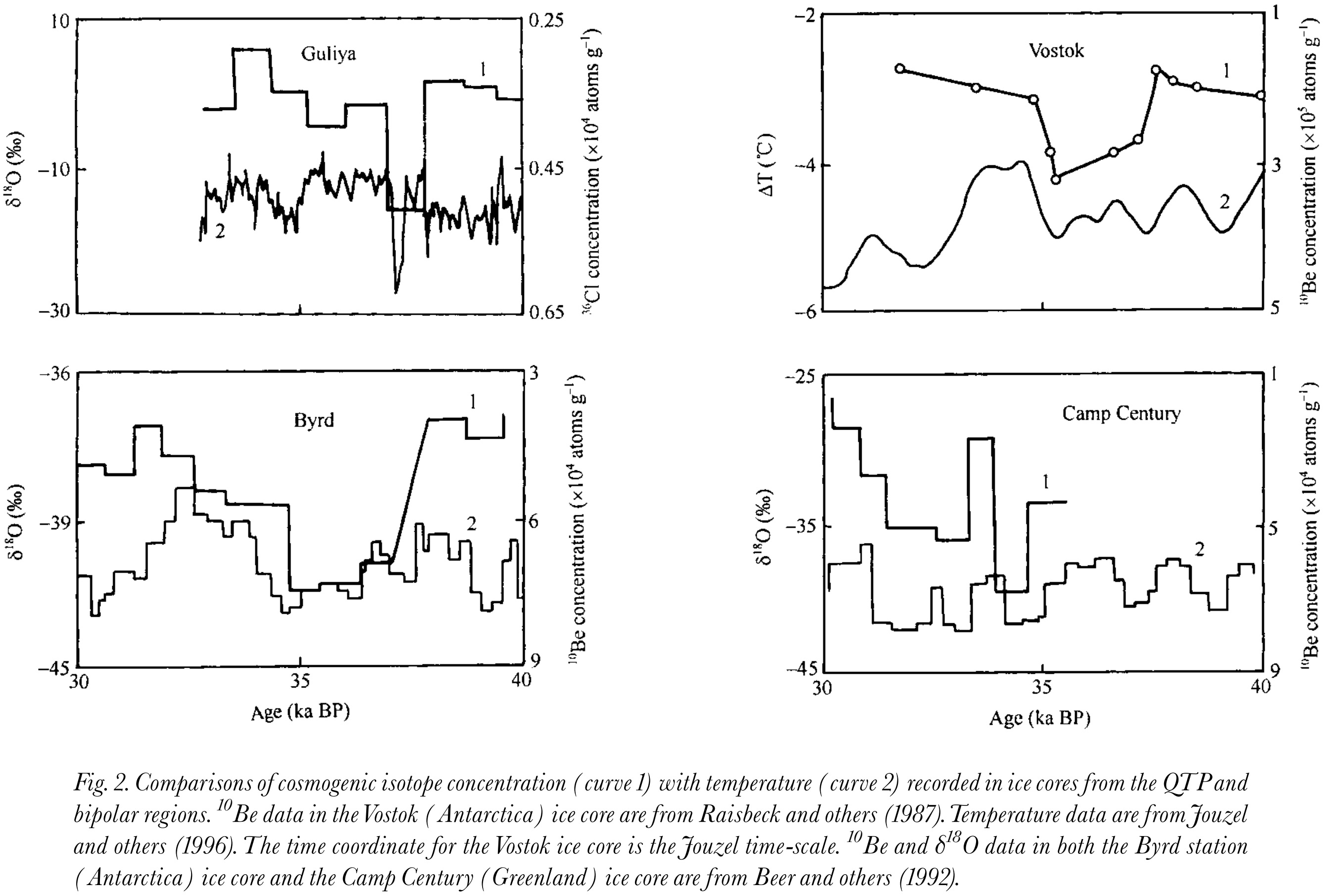

Fig. 2. Comparisons of cosmogenic isotope concentration (curve 1) with temperature (curve 2) recorded in ice cores from the QTP and bipolar regions. ^{10}Be data in the Vostok (Antarctica) ice core are from Raisbeck and others (1987). Temperature data are from Jouzel and others (1996). The time coordinate for the Vostok ice core is the Jouzel time-scale. ^{10}Be and δ^{18}O data in both the Byrd station (Antarctica) ice core and the Camp Century (Greenland) ice core are from Beer and others (1992).

the intensity of air exchange between the troposphere and the stratosphere) and cosmogenic isotope production rate can result in apparent variations of cosmogenic isotope deposition rate at one site. If we assume a given global production rate of cosmogenic isotopes in the atmosphere, it seems improbable that the same trend would be found in concentration variations recorded in different sediment materials in different areas of the Earth. This is especially so when the trend lasts for longer time-scales ~ 1 ka). Thus, by comparison of the records from different sites on the global scale, it is easy to ascertain whether meteorological effects should be eliminated as a factor influencing the cosmogenic isotope deposition rate. Figure 2 shows the record of cosmogenic isotopes in ice cores from the QTP, the Antarctic ice sheet and the Greenland ice sheet. It is emphasized that the ^{10}Be peak at about 36 ka BP in the polar ice has not yet been interpreted in terms of accumulation changes (Raisbeck and others, 1987, 1992; Beer and others, 1992). Considering the time-scale uncertainty for each core, it is fair to surmise that the cosmogenic isotope peaks in Figure 2 occurred at about the same time. Recent studies on ^{36}Cl and ^{10}Be in the Greenland Ice Core Project (GRIP) ice core have exhibited concentration spikes at about 37 ka BP (Baumgartner and others, 1997; Yiou and others, 1997). In addition, peak ^{10}Be concentrations in deep sea cores from the Gulf of California (McHargue and others, 1995) and the Mediterranean Sea (Castagnoli and others, 1995) have been found at about the same time. The above indicates that the increase in concentrations of cosmogenic isotopes at about 37 ka BP was a global event. This can be explained only by enhanced cosmogenic isotope production rate, and may be used as a time marker for dating of sediments.

From Figure 2, it can also be seen that the cosmogenic isotope event at about 37 ka BP coincided with a cold period (δ^{18}O as a proxy of temperature) both in the bipolar ice cores and in the QTP ice core. Of these the temperature decrease on the QTP was the most remarkable among the records, which may indicate that the QTP is a region sensitive to global climate change. However, this cold event does not reach the magnitude of the Last Glacial Maximum in any of the ice cores studied. It is difficult to find moraine evidence for this cold event in these regions, but end-moraine debris formed about 34 ka BP was found in the Ecuadorian Andes, and the glaciers there extended to their furthest limits in that period during the Last Glacial Stage (Clapperton, 1987). It is evident therefore that the global cosmogenic isotope event coincided with a global cold event about 37 ka BP. This phenomenon suggests the occurrences of these two events may have a common cause.

DISCUSSION

Enhanced cosmogenic isotope is related directly to an increase in cosmic ray into the Earth's atmosphere, which in turn is caused by an intensified cosmic-ray source (especially explosions of supernovae near the solar system), low solar activity and/or weak geomagnetic field.

Cosmic rays have been measured on the surface of the Earth for over half a century. It has been found that when cosmic ray incident to the surface increases greatly, especially when a nova explodes, the global air temperature may rise within 1 or 2 years (Yu, 1990). On the other hand, comparison of the supernovae observed in 1572 and 1604 with the ^{10}Be records in polar ice cores (Beer and others, 1991) reveals no ^{10}Be peak around these times. This may be because the two supernovae, Tycho and Kepler, were too far from the Earth. Moreover, there is no direct evidence for a supernova occurring near the solar system at about 37 ka BP. Thus it is premature to conclude that supernovae are related to the peak cosmogenic isotope or cold events at about 37 ka BP.

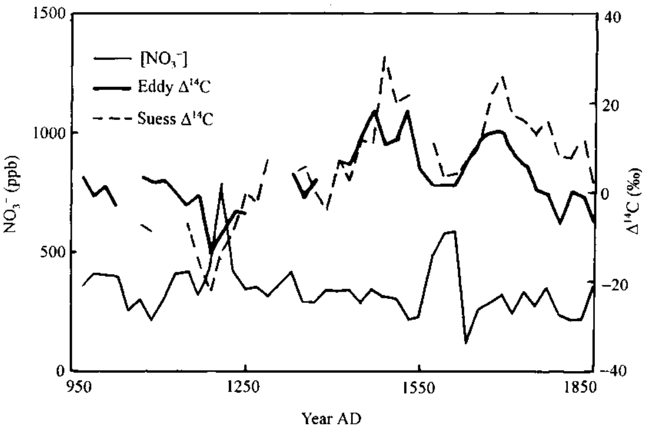

Fig. 3. The secular variations of NO_3^- in the Guliya ice core and $\Delta^{14}C$ in tree rings. All data are shown as 20 year means.

The well-known indicators of solar activity such as sunspots and δ^{14}C in tree rings, are usually available only for the past few centuries or several thousand years. It is important to look for proxy indicators that can extend far enough into the past to detect solar activity at about 37 ka BP. We have investigated NO_3^- concentration in the Guliya ice core in the past 1000 years, and found that there are some significant periodicities in NO_3^- variations, e.g. 22.9, 88.1, 31.3, 5.5 and 10.3 years (periodicities listed from high to low spectral density), most of which coincide with periodicities of solar activity (Wang and others, 1998). Figure 3 shows the secular variations of NO_3^- in the Guliya ice core and δ^{14}C in tree rings. A remarkable negative correlation can clearly be seen. Because human consumption of fossil fuel has rendered δ^{14}C in tree rings unusable for indicating the intensity of solar activity since industrialization (Suess, 1965; Eddy, 1977), only the data before industrialization are chosen here. This indicates that there is a positive correla-

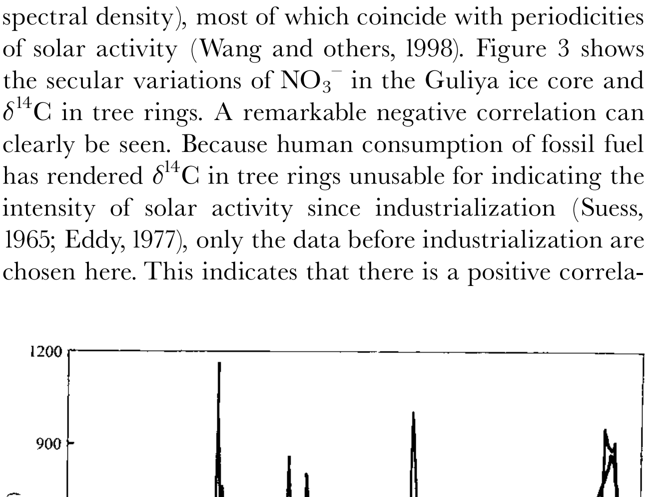

Fig. 4. Variations of NO_3^- concentration (thin solid line) in the Guliya ice core around 37 ka BP. The thick solid line is the smooth curve through the concentrations. The dashed line is the average concentration.

tion between the concentration of NO_3^- in the Guliya ice core and solar activity. Supposing this correlation also existed in the past, lower NO_3^- concentrations in 37–38 ka BP (Fig. 4) suggest that solar activity was low then. Also a decrease in solar radiation when solar activity was low (Friis-Christensen and Lassen, 1991) may have led to a cold climate on Earth. Thus, low solar activity is a possible cause of the events at 37 ka BP.

O'Brien's (1979) study pointed out that, for an almost zero dipole field, as may occur during a geomagnetic reversal, the mean global production rate of cosmogenic isotopes is enhanced by a factor of about 2. Moreover, it has been found that the climate warms when the geomagnetic field is strong, and cools when it is weak (Tang, 1996). Therefore investigation of the geomagnetic field condition is important for understanding the events at 37 ka BP. Reconstruction of paleointensity of the geomagnetic field in the past 80 ka from sea cores indicates that the intensity of the geomagnetic field reached a minimum at about 39 ka BP (Tric and others, 1992) when the Laschamp geomagnetic reversal event occurred. Recently, a study of the ^{36}Cl flux in the GRIP ice core has also shown that the peak at 37 ka BP is most likely the effect of the Laschamp event (Baumgartner and others, 1998). Thus a weak geomagnetic field could also be responsible for the peak cosmogenic isotope and cold events at about that time.

CONCLUSIONS

The peak ^{36}Cl concentration in the Guliya ice core at about 37 ka BP supports the previous view that the peak ^{10}Be in polar ice at about that time can be used as a time marker (Beer and others, 1992). The peak cosmogenic isotope concentrations in ice cores from the QTP, the Antarctic ice sheet and the Greenland ice sheet suggest that global production rate was enhanced then. It is noted that this enhanced production rate event coincided with a global cold period. The causes of the phenomenon were possibly low solar activity and a weak geomagnetic field. Whether there was a supernova explosion, and if so its climatic effects, needs to be studied further.

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