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Preliminary study on the erratic exposure ages of Grove Mountains, East Antarctica

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Abstract The first study of erratic boulder exposure ages in the Grove Mountains, interior Antarctica, indicates the two erratic boulders (060131-1 and 060131-2, collected from a typical nunataks, Zakharoff Ridge in the Grove Mountains) have ^{10}Be minimum exposure ages of 1.24 ±0.11 Ma, 1.37 ±0.12 Ma, and ^{26}Al ages of 0.90 ±0.12 Ma, 0.44 ±0.04 Ma, respectively. Meanwhile, another erratic boulder sample 060131-4, coming from vicinal ice surface, has ^{10}Be and ^{26}Al minimum exposure ages of 0.47 ±0.3 Ma and 0.44 ±0.04 Ma, respectively. The exposure ages of the three erratic boulders are nearly similar to the bedrocks with the similar elevation. Thus, using the technique of *in situ* produced terrestrial cosmogenic nuclides, the ice sheet evolution histories in the Grove Mountains reflected by erratic boulder and bedrock exposure ages are basically consistent

Key words East Antarctica, Grove Mountains, Zakharoff Ridge, ^{10}Be and ^{26}Al exposure age, erratic boulders

1 Introduction

In last two decades, the technique of in situ produced terrestrial cosmogenic nuclides (such as ^{3}He, ^{10}Be, ^{21}Ne, ^{26}Al, ^{36}Cl, etc.) has been widely applied in geosciences, as an important and useful tool to study the surface processes[1-6]. Especially, dating the minimum exposure age of the surface rock (usually the time of deglaciation) and calculating the maximal surface erosion rate have been becoming the most extensive and typical application fields, by measuring the *in situ* produced cosmogenic nuclides concentrations of the surface rocks (bedrocks or erratic boulders).

Recently, study of the Cenozoic and Pliocene evolution of the Antarctic Ice Sheet behavior is becoming one of the considerable scientific hot spots, which is important for reconstructing global paleo-climate evolution[7]. Dating surface exposures of bedrocks or moraine deposits using *in situ* produced cosmogenic nuclides provides a direct method to indicate the exposure time of the surface after deglaciation, and it is generally applied in the areas of Antarctica[8-13]. The study of the exposure ages in the interior Grove Mountains (GM) has been just beginning. Based on the previous work, this paper will discuss the exposure ages of the erratic boulders in this region. Considering the different reversion-zero mechanisms of the exposure ages of the bedrock and erratic boulder, we will compare the bedrock and erratic exposure ages, in order to further discuss the glacier evolution history of this region.

2 Geological setting

The GM lie in Princess Elizabeth Land (72°20′-73°10′S, 73°50′-75°40′E), in the interior of East Antarctica, on the east coast of Lambert Rift, between the Zhongshan Station and Dome A, 450 km away from the Zhongshan Station, cover an area of ~3200 km^2 and include 64 nunataks[12,14]. Bedrocks of the GM are mainly composed of high-grade late Proterozoic metamorphic rocks including felsic granulite, granitic gneiss, mafic granulite lenses and charnockite, ranging in grade from upper amphibolite to granulite facies[14-16]. The Zakharoff Ridge (72°54′S, 75°11′E), one of the typical nunataks in this region, lies in the southern part, near the Mount Harding (72°53′S, 75°01′E) (Fig 1). The elevation of the glacial surface on the dorsal side is 1800-1900 m, and 2000-2100 m on the stoss side. Ice striations and moraines were commonly found up to ~100 m above the present ice surface. This perhaps suggests a limited increase of the ice sheet surface elevation after initial decrease from the crest.

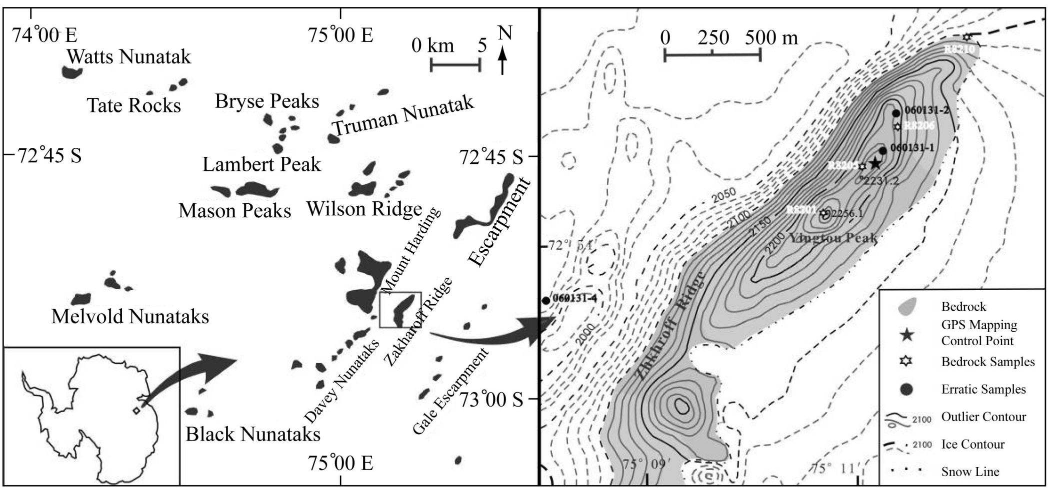

Fig 1 Map of the Zakharoff Ridge showing the sampling positions

During the 1998, 1999, and 2005 summers, the 15th, 16th, and 22nd Chinese Antarctic Research Expedition (CHINARE) worked in the GM and found potential indicators of the past surface elevations of the interior EAIS, such as soils and moraines, containing the Tertiary sporopollen[17-19]. They also found the Cenozoic conglomerate, which has undergone preliminary analysis[20]. Huang *et al.* (2008)[13] reported the bedrock exposure age of the Zakharoff Ridge and Mount Harding, the two typical nunataks in GM. The highest bedrock has minimum exposure age of 2 Ma, indicating the minimum age of deglaciation in this region. Previous work unveils the research of the glacier evolution from Pliocene in interior Antarctica, and still it calls for more detailed work on it.

3 Sampling and Laboratory Treatment

The previously studied six bedrock samples R8201, R8203, R8205, R8206, R8207, and R8210 were collected from top to bottom of the stoss slope with gradient slop of Zakharroff Ridge (peak altitude is 2256 m) by Huang *et al.* (2008)[13]. And we will focus in the following analyses on three erratic boulder samples 060131-1, 060131-2 and 060131-4 coming from the same profile, which are almost located with the equal elevations as the bedrock samples R8205 (about 2225 m), R8206 (about 2204 m) and R8210 (about 2100 m), respectively (Fig. 1). We determined the locations and elevations of all sample sites with the topographic map drawn by Antarctic Center of Surveying and Mapping of the Wuhan University, State Bureau of Surveying and Mapping, and Chinese Arctic and Antarctic Administration (2001). Elevation uncertainties are less than 20 m.

The erratic boulder sample 060131-1 was collected below the crest of the Zakharroff Ridge and near one of the Chinese surveying marks, at about 2225 m. It is nearly triangular in shape, with side length of 2.5 m and thickness of approximately 1 m; the sample 060131-2 (about 2208 m) partially has side length of 1m and thickness of approximately 0.5 m. Because the erratic boulders near the ice surface in this profile are all fragmental, and small size (with diameter < 0.5 m), we sampled the erratic boulder sample 060131-4 (about 2083 m) at the modern ice surface of the dorsal site in the west of Zakharroff Ridge, to compare with the lowest bedrock sample R8210 (nearly 2100 m) (Fig. 2). Table 1 shows the details of all samples. The samples analyzed were taken from flat slopes, and sampling depths were < 5 cm. We avoided those sites sheltered by high landforms or erratic boulders during sampling. Thus, shielding and depth corrections were not considered in this work.

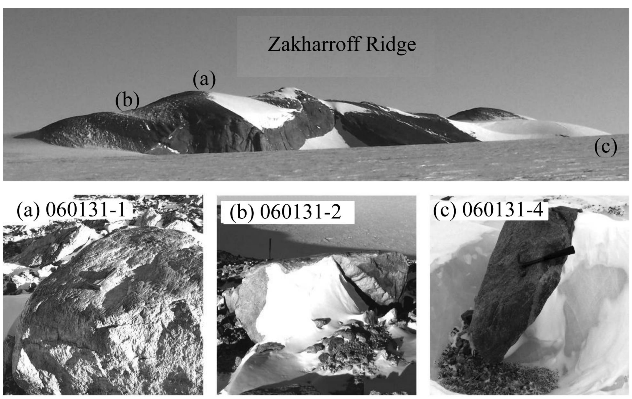

Fig. 2 The pictures of the Zakharrof Ridge and the erratic boulder samples

Chemical preparations of the samples were carried out in the cosmogenic nuclide laboratory at the Institute of Geology and Geophysics, Chinese Academy of Sciences. The ^{10}Be and ^{26}Al concentrations were measured by the accelerator mass spectrometry (AMS) at the Australian Nuclear Science and Technology Organization (ANSTO), Australia. Details of the ^{10}Be and ^{26}Al measurement procedures, calibration and background corrections can be found in the literatures of Huang *et al.* (2008)[13], Kong *et al.* (2007)[21] and Fink *et al.* (2004, 2006)[22, 23].

4 Results and Discussion

Table 1 shows both the measured values and calculated ages. The calculation results show that the ^{26}Al and ^{10}Be minimum exposure ages of the erratic boulder samples 060131-1 and 060131-4 are basically in accordance considering their errors, respectively. However, the ^{26}Al and ^{10}Be minimum exposure ages of the sample 060131-2 show certain deviation. Generally, it rarely appears in erratic boulder sample testing, so the detail reasons are not clear. Figure 3 plots the $^{26}Al/^{10}Be$ ratios Vs ^{10}Be concentrations normalized to sea level and high latitude for all samples. The samples 060131-1 and 060131-4 are both projected within the erosion island, which is usually considered to only have simple exposure histories because erosion occurred for erratic boulder samples[13, 23, 24]. Nevertheless, 060131-2 is projected outside of the erosion island because of deviation of its ^{26}Al and ^{10}Be concentrations (Fig. 3). Due to the better precision of ^{10}Be exposure age than that of ^{26}Al, we will discuss with ^{10}Be exposure age below.

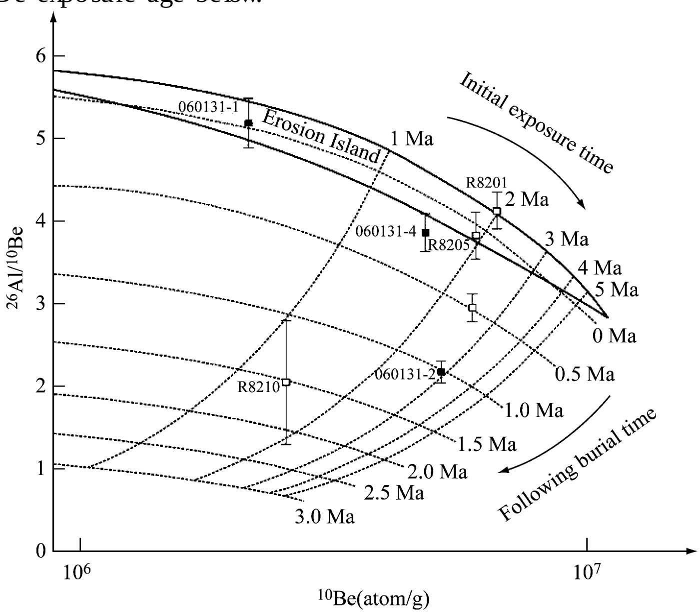

Fig. 3 Plot of $^{26}Al/^{10}Be$ vs ^{10}Be concentrations. ^{10}Be concentrations have been normalized to sea level and high latitude according to scaling method of Lal (1991)[1], modified by Stone (2000)[25].

In table 1, the bedrock sample R8201 (about 2256 m), located on the crest of the Zakharoff Ridge, has ^{10}Be and ^{26}Al minimum exposure age of 2.00 ±0.22 Ma and 2.13 ±0.56 Ma, limiting the minimum age of deglaciation in this region[13]. Meanwhile, the ^{10}Be minimum exposure age of the erratic boulder samples 060131-1 (1.24 ±0.11 Ma), 060131-2 (1.37 ±0.12 Ma) and 060131-4 (0.47 ±0.03 Ma) are basically identical with that of the bedrock samples R8205 (1.72 ±0.18 Ma), R8206 (1.68 ±0.17 Ma) and

R8210 (0.57 ±0.04 Ma), respectively, which are almost located in the same elevations as the erratic boulders, respectively. Hence, the exposure ages of the bedrock and erratic boulder in the GM are essentially consistent with each other.

Table 1. Elevations and exposure ages of the erratic samples exposure ages in Zakharoff Ridge

Sample	type	Ele (m)	Quartz (g)	^{10}Be conc (10^6 atom/g)	^{26}Al conc (10^6 atom/g)	^{26}Al/^{10}Be	Min ^{10}Be age (Ma)*	Min ^{26}Al age (Ma)*
060131-1	erratic boulder	2225	72.19	40.2 ±1.0	154.6 ±8.0	3.85 ±0.23	1.24 ±0.11	0.90 ±0.12
060131-2	erratic boulder	2208	25.92	42.6 ±1.0	92.0 ±3.6	2.16 ±0.13	1.37 ±0.12	0.44 ±0.04
060131-4	erratic boulder	2083	121.16	15.6 ±0.4	80.7 ±2.5	5.18 ±0.30	0.47 ±0.3	0.44 ±0.04
R8201	bedrock	2256	12.4	56.7 ±1.5	234 ±11	4.14 ±0.22	2.00 ±0.22	2.13 ±0.56
R8205	bedrock	2230	11.0	50.6 ±1.8	194 ±13	3.82 ±0.29	1.72 ±0.18	1.35 ±0.25
R8206	bedrock	2204	12.7	48.9 ±1.2	144 ±4.6	2.94 ±0.17	1.68 ±0.17	0.83 ±0.10
R8210	bedrock	2100	15.2	19.5 ±0.5	40 ±12	2.03 ±0.75	0.57 ±0.04	0.18 ±0.07

Note: The four bedrock samples (R8201、R8205、R8206、R8210) data cited by Huang FX, *et al* (2008)
* The minimum ^{10}Be and ^{26}Al exposure ages are calculated by using scaling method for Antarctica from Lal (1991)[1], modified by Stone (2000)[25].
* The errors of minimum ^{10}Be and ^{26}Al exposure ages (1δ) include 2% from AMS, 6% from production rate, 1% from Be carrier and 4% from ICP-AES for Al

Generally speaking, the *in situ* produced cosmogenic nuclides exposure ages of the bedrock and erratic boulder have certain difference. The glacier evolution reflected by the bedrock is as follows: the bedrock to the depth of over 1.2 m will be eroded, while the glacier is moving forward, then the accumulation of the cosmogenic nuclides returns back to zero. When the glacier recedes, the cosmogenic nuclides will begin to increase again. Furthermore, the surface bedrock still has remnant cosmogenic nuclides, even if the insufficient thickness of the surface bedrock is eroded. So the amount of the cosmogenic nulides will accumulate as the glacier fades away. At the same time the bedrock exposure age indicates the multiple cumulative exposures age[26]. However, as to the erratic boulder, the meaning of exposure age is relatively complicated. Generally, the erratic boulder is transported by the erosion of the glacier from allopatry. Though the course is probably complex, the accumulation of the cosmogenic nulides concentration could be neglected because of the strong erosion in the course of transportation, according to the previous research. After the glacier recedes, the moraine debris of the glacier terminus are unloaded, locating above the bedrock, and it starts timing the exposure, namely, initial accumulation of the cosmogenic nuclides concentration. The erratic boulders probably have been eroded or overturned, if they had experienced a glaciation once again, to the effect they begin to time again with the deglaciation. As the erratic boulders are always subjected to intense erosion of the glaciation, they hardly preserve the previous cosmogenic nuclides concentration. Hence the minimum exposure age difference between the bedrock and the erratic is common, while the bedrock preserves the previous cosmogenic nuclides concentration[27]. But the result of our present study indicates the *in situ* producted cosmogenic nuclides exposure ages of the bedrock and erratic boulder are consistent with each other within the errors, meaning the cosmogenic nuclides concentration of the bedrock has little evident previous accumulation. Hence, the *in situ* producted cosmogenic nuclides ^{26}Al and ^{10}Be exposure ages of the bedrock and erratic boulder indicate the identical history of deglaciation in the GM, interior Antarctica.

5 Conclusions

The study on the *in situ* producted cosmogenic nuclides ^{10}Be and ^{26}Al exposure ages of the erratic boulders collected from the nunatak Zakharroff Ridge in the Grove Mountains, indicates that they are consistent with the bedrock exposure ages in this region. Hence, the erratic boulders and bedrock exposure ages both probably reflect the evolution history of glacier in Grove Mountains, interior land of Antarctica.

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