The exposure age dating of the mountain-top detritus employing in-situ produced cosmogenic 10Be and 26Al

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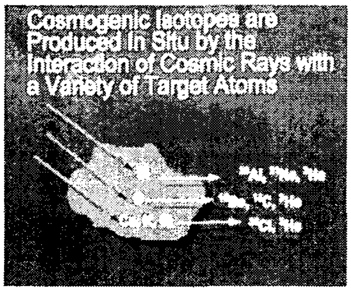
1. Introduction



The Earth is exposed to cosmic rays that originate from our Sun and from the Galactic system. Cosmogenic isotopes are produced by spallation reactions induced by high energy nucleons, secondary thermal neutron capture reactions, and by muon-induced reactions. As the cascade of reactions propagated down through the atmosphere and eventually the upper few meters of the Earth"s crust, the composition of the nuclear particle flux tends to become dominated by neutrons. Considering the reactions mentioned above, cosmogenic isotopes, which can be found in terrestrial environments, are either of extraterrestrial origin, produced in the atmosphere (so called 'Garden Effect'), in situ, of primodial radiogenic, or anthropogenic origin. Over the past decade, the cosmogenic exposure dating method has been undergoing major developments in the wide range of geomorphic areas. Recent advances in analytical chemistry and unclear physics have provided geomorphologists with the opportunity to constrain rates of landscape evolution directly. Use of high-sensitivity noble gas and accelerator mass spectrometry (AMS) now allows quanititive abundances measurement of extremely rare isotopes including those produced by the interaction of cosmic rays with rock and soil (Elmore and Phillips, 1987). The different physical and chemical properties of the six most widely used nuclides makes it possible to apply the surface exposure dating methods on rock surfaces of virtually any lithology at any latitude and altitude, for exposures ranging from 102 to 107years (Gosse and Phillips, 2001).

2. Terrestrial Cosmogenic Isotope production

Cosmic-ray-derived nucleons decrease exponentially with depth through the atmosphere, hydrosphere, and lithosphere. The principal nucleons of the cosmic-ray flux are protons, alpha particles, secondary neutrons, and muons. A prerequisite for the application of the in-situ produced cosmogenic nuclides for the study of erosional histories of surfaces is a knowledge of their production rates under different irradiation conditions: altitude, latitude, irradition geometry and shielding, and erosion rate (Lal, 1991).

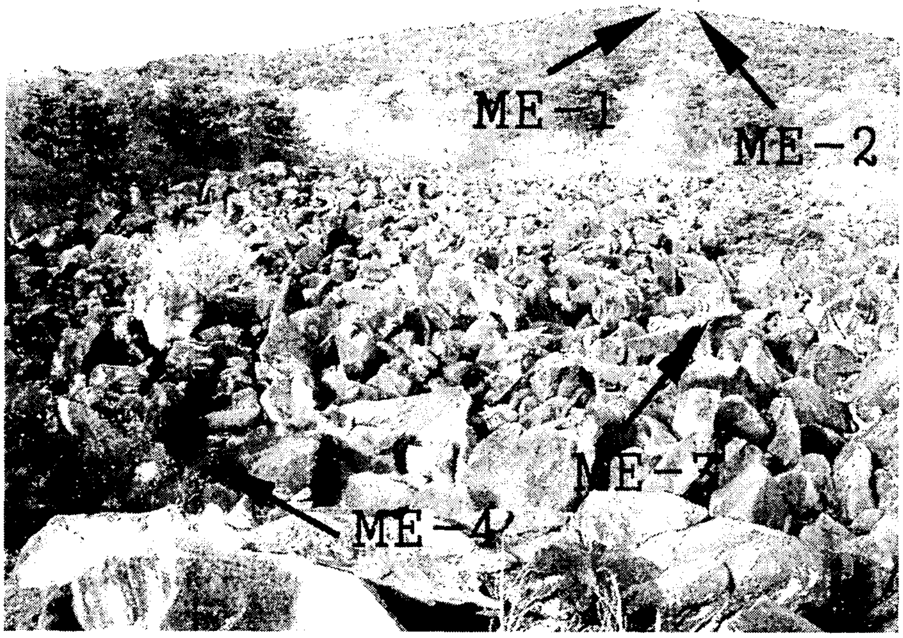
In rock (=2.7g/cm-3), roughly half the fast cosmic ray neutrons are absorbed above a depth of 45cm (attenuation length = 150-170g/cm-2). The number of atoms of the in-situ produced cosmogenic isotope within the rock at any depth, x, is given by the following equation(Equation 1)

$$N(x,t) \equiv N(x,0)e^{-\lambda t} + \frac{P(0)}{\lambda + \mu\varepsilon} e^{-\mu x}(1 - e^{-(\lambda+\mu\varepsilon)t})$$

Where N(x,0) is the initial number of atoms/g in the rock surface now at depth, x, after an irradiation for a time period, t. μ is absorption coefficient (ρ/Λ), ε = erosion rate, and λ = disintegration constant. P(0) is production rate depending on altitude and geomagnetic latitude.

Figure 1 (Cerling and Craig, 1994) shows the concentrations of in-situ cosmogenic isotopes for the case where there is no erosion. Radioactive isotopes approach a steady-state concentration after 4 to 5 half-lives, which limits the application of those isotopes to cases where the exposure age is within 3 to 4 half-lives.

3. Study Area



This research area is situated on the Mt. Maneo, South Korea and its summit is 670.4m in height above mean sea level. The slope of this mountain dips downward over 25 in steepness from the summit to the point of 500m a.m.s.l but from this knickpoint (about 500m a.m.s.l.) becomes more gentle and comes to be less than 5 in steepness until the altitude of 300m. Lithology includes andesite, volcanic tuff, granite, and rhyolite and some faults are found east of the research area.

Sample collection can be time consuming. Samples are frequently collected using hammers and chisels to exploit preexisting weaknesses in the surface. Interpretation of isotope concentration is simplest if samples are collected from large, flat-lying surfaces. It is known that the neutron-induced production rate of 10Be or 26Al is constant within the top of 5cm of an exposed surface and then decreases exponentially (Masarik and Reedy, 1995). It may therefore seem reasonable to only use the top 5cm of rcok surface for surface exposure dating. In this research, two categories of materials are sampled and the top 1 to 1.5 cm of rock is only used. Two samples (ME-1 and ME-2) is collected from tors in the summit and the other two (ME-3 and ME-4) is collected from blocks to be guessed from source rock (tor).

4. Result and Discussion

From the geomorphic perspective, all the landform evolves with time. Thus erosion rate is one of most important parameters in determining the feasibility of surface exposure dating with a particular isotope. Figure 2 shows the in situ build-up curve for 10Be concentrations (in units of atom/g of quartz per year) as a function of exposure age for different erosion rates. Thus, for constant erosion and prolonged exposure, the in situ equilibrium concentration to an overall effective decay constant of (+ /), which represents an effective mean surface age of 1/((+) (Tuniz et al., 1998).

$$T_{eff} = -\ln[1-(\lambda+\varepsilon\rho/\Lambda)(C/P)]/\ (\lambda+\varepsilon\rho/\Lambda)\text{----------------------}(2).$$

Where P is the production rate in atom g-1y-1, C is the concentration in atom g-1, ε is the erosion rate in cm y-1, ρ is the density in g cm-3, λ is decay constant in y-1, and Λ is the macroscopic attenuation length (150-170g cm-2) for spallogenic production. In this model, the effective surface exposure age (Teff) is the time during which erosion removes a rock depth equivalent to one absorption mean free path ($\Lambda/\rho \approx 50$ cm in common rocks). Figure 3 shows the relationship between erosion rate and effective surface exposure age for radionuclides of different half-life and stable isotopes (Lal, 1991). It is inferred that the equilibrium concentration is achieved much earlier when the erosion rate of a sample increases. Thus, the erosion rate of a sample and the half-life of an applicable isotope are important factors when used in surface exposure dating.

Sample No.	Latitude (°N)	Longitude (°E)	Altitude (km)	Mass (g)	^{10}Be/^{9}Be (10^{-13}atoms)	^{10}Be 10^{5}atoms/g	P(0) atoms/g/yr	$T_{eff(yr)}$ (ε = 0)
ME-1	35 ° 27 ′ 20 ″	128 ° 57 ′ 20 ″	0.6704	21.225	2.54	4.003	8.1775	49517
ME-2	35 ° 27 ′ 20 ″	128 ° 57 ′ 23 ″	0.6704	27.749	4.77	5.797	8.1775	72077
ME-3	35 ° 27 ′ 12 ″	128 ° 57 ′ 10 ″	0.431	21.456	1.83	2.86	6.8917	41905
ME-4	35 ° 27 ′ 10 ″	128 ° 57 ′ 8 ″	0.429	22.896	1.80	2.654	6.8817	38924

<Table 1> Cosmogenic Isotope data

Table 1 lists the cosmogenic radionuclides 10Be and 26Al data and ages. The ages presented in Tabel 1 are derived as discussed above. From a frost weathering point of view, detritus are chipped off from the source bedrock due to the pressure of differential expansion between minerals consisting of bedrock. The angularity of the block get stronger with increase of difference in freeze-thaw condition. The chipped block accumulate in situ in the flat surface whereas get moved down in the slope. Under periglacial environment, the top surface of soil horizon get mobilized in wet season. This process are termed as solifluction (gelifluction). Bearing the process discussed above in mind, the blocks in the gentle slope were chipped off form the bedrock (tor) and moved down. The exposure ages of rock outcrops in this table-1 indicate only minimum exposure ages.

From the table above, it can be inferred that blocks on the slope (ME-3 and ME-4) were stabilized earlier than 38,924yrs and the formation of block stream and production of the blocks were made in the periods of between about 70,000 and 40,000yrs, which was drier and colder than today.

The age suggested above is available only during the steady-state erosion condition. Therefore multiple cosmogenic isotopes have to be measured to confirm this erosion condition and in the future study, data on multiple measurements from the same landform will be proposed in more detail.

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