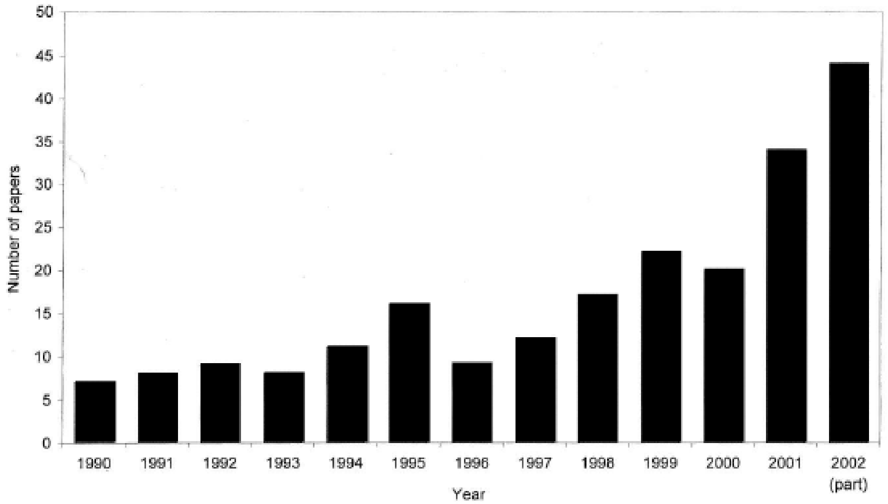
Terrestrial cosmogenic isotopes

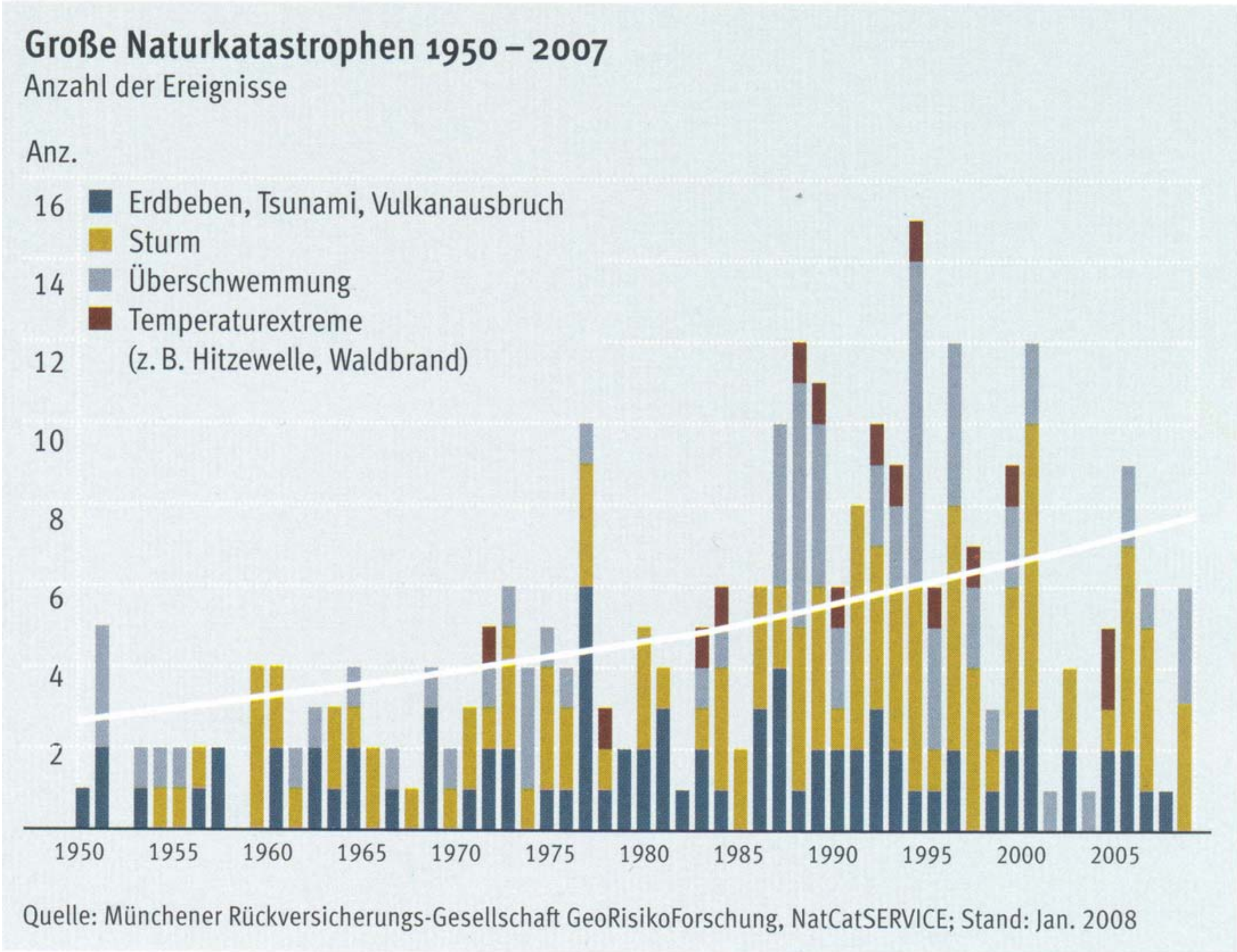
Great impact on environmental and earth sciences over the last decade

Methodological process is accelerating

Many novel tools

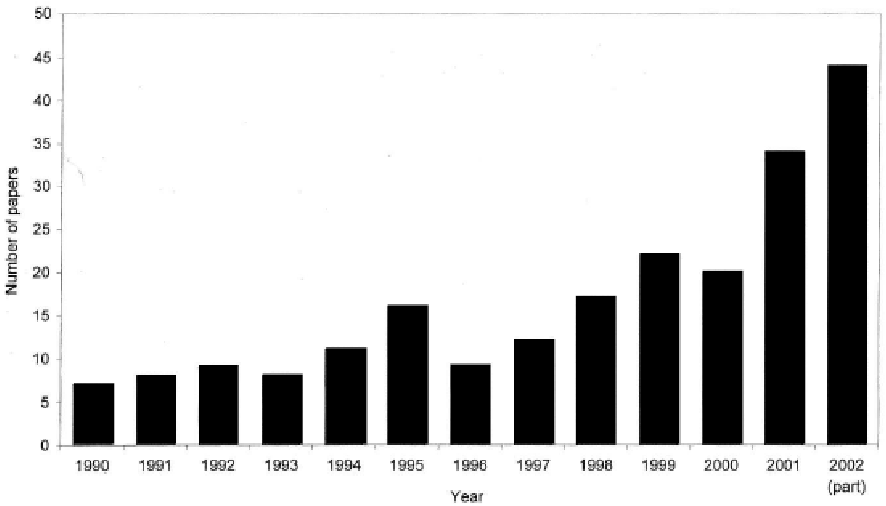


Cockburn & Summerfield 2004

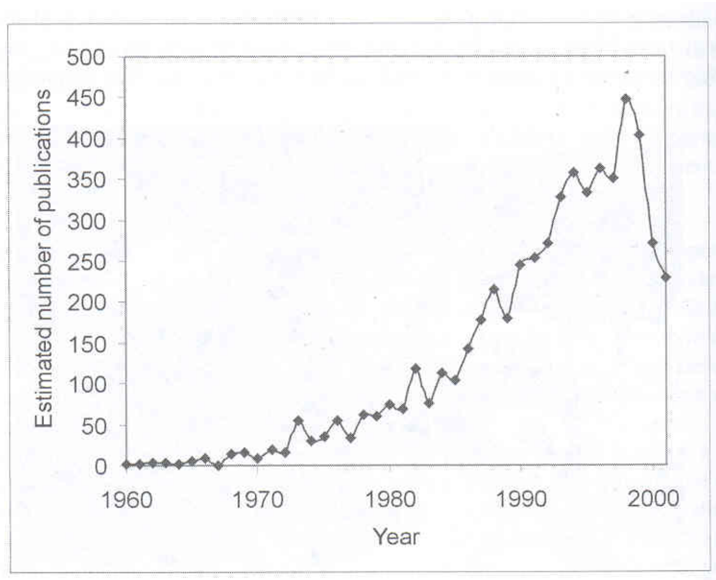

Große Naturkatastrophen 1950 – 2007
Anzahl der Ereignisse
Anz.
16
14
12
10
8
6
4
2
Erdbeben, Tsunami, Vulkanausbruch
Sturm
Überschwemmung
Temperaturextreme
(z. B. Hitzewelle, Waldbrand)
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
Quelle: Münchener Rückversicherungs-Gesellschaft GeoRisikoForschung, NatCatSERVICE; Stand: Jan. 2008

Terrestrial cosmogenic isotopes

The "centre of mass" of many geoscience departments has shifted from solid Earth subfields towards surface processes (Bruce Watson, Elements 2009)



Cockburn & Summerfield 2004



Davis et al. 2003: papers containing "U-Pb" and "zircon" as key words

Improvements: particle accelerators instead of counting

Accelerator mass spectrometer

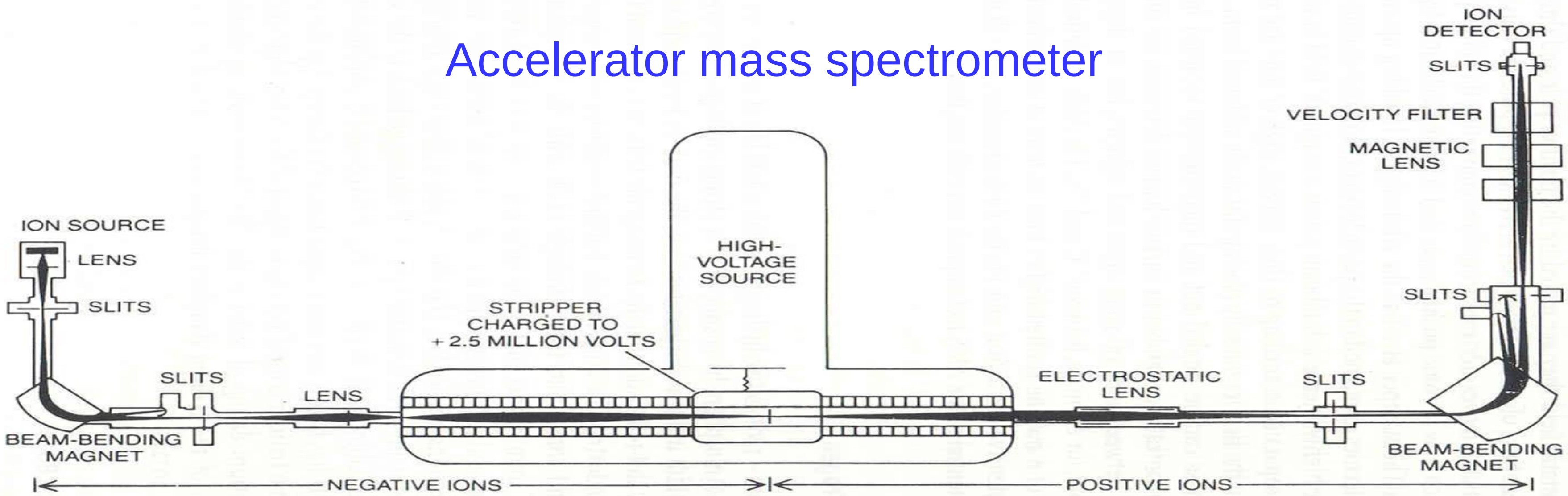
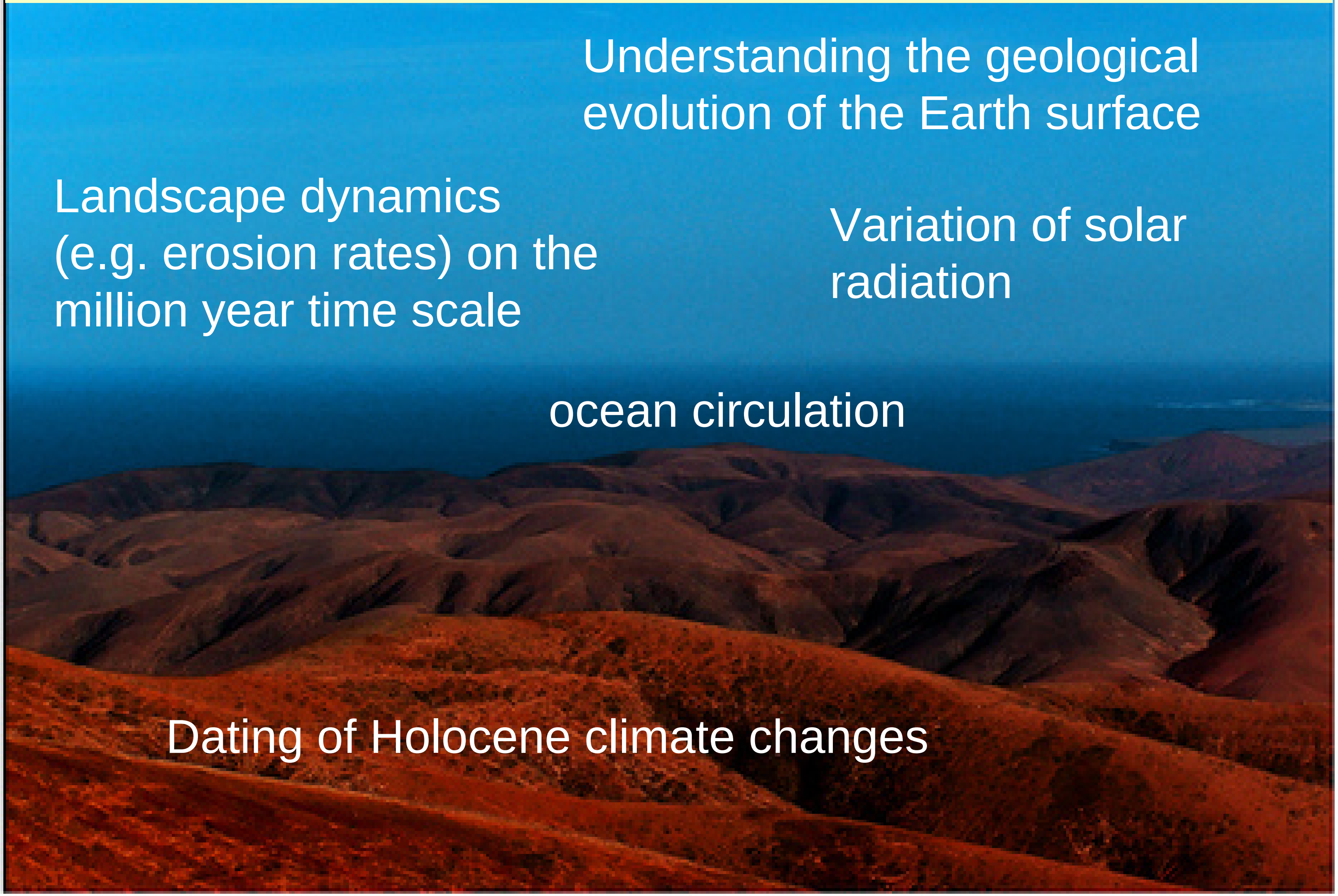


Fig. 37. Principal components of an accelerator mass spectrometer. (After Hedges and Gowlett 1986)

AMS has a factor of a millon lower detection limit for ^{14}C, ^{36}Cl, ^{10}Be, ^{26}Al compared to counting methods

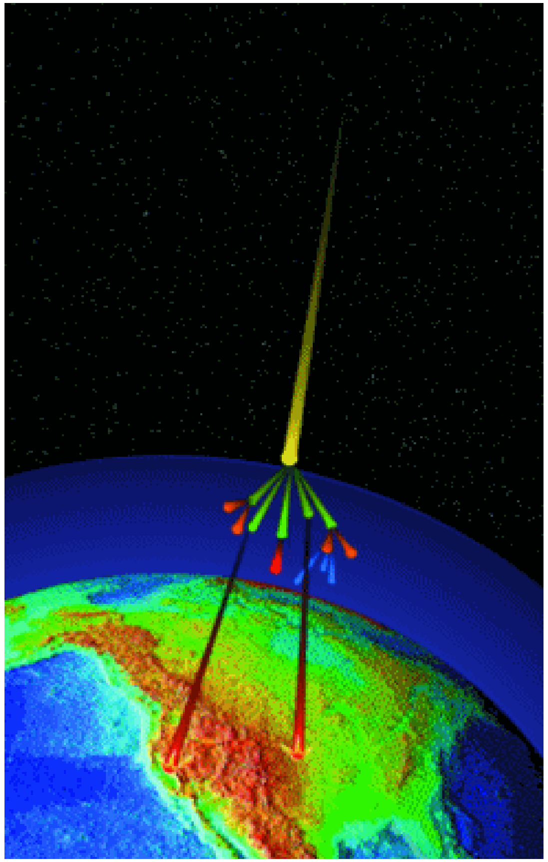
Why studying cosmogenic isotopes?



Discovery of cosmic-rays

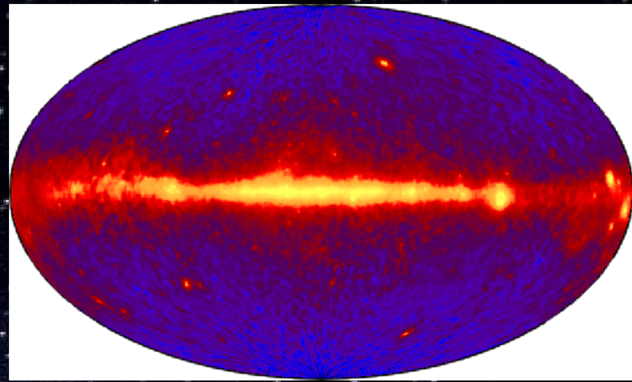
Libby introduced radiocarbon dating (^{14}C) in 1947 (received Nobel Prize in chemistry in 1960)

Discovery of ^{10}Be, ^{7}Be (1956-1957)
Arnold (Chicago)
Peters, Devendra Lal (Bombay)



Victor Hess discovered the „cosmic rays“ in his balloon flights of 1911-1912 (received Nobel Prize in physics in 1936)

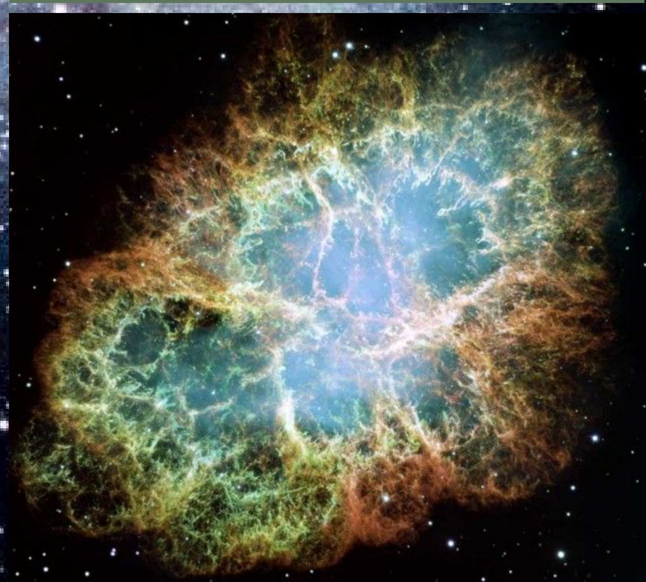
Cosmic-rays



http://heasarc.gsfc.nasa.gov/docs/objects/heapow/archive/large_scale_structure/egret_allsky.html

Galactic cosmic rays derive their energy from supernova explosions

Crab nebula (Krebsnebel)



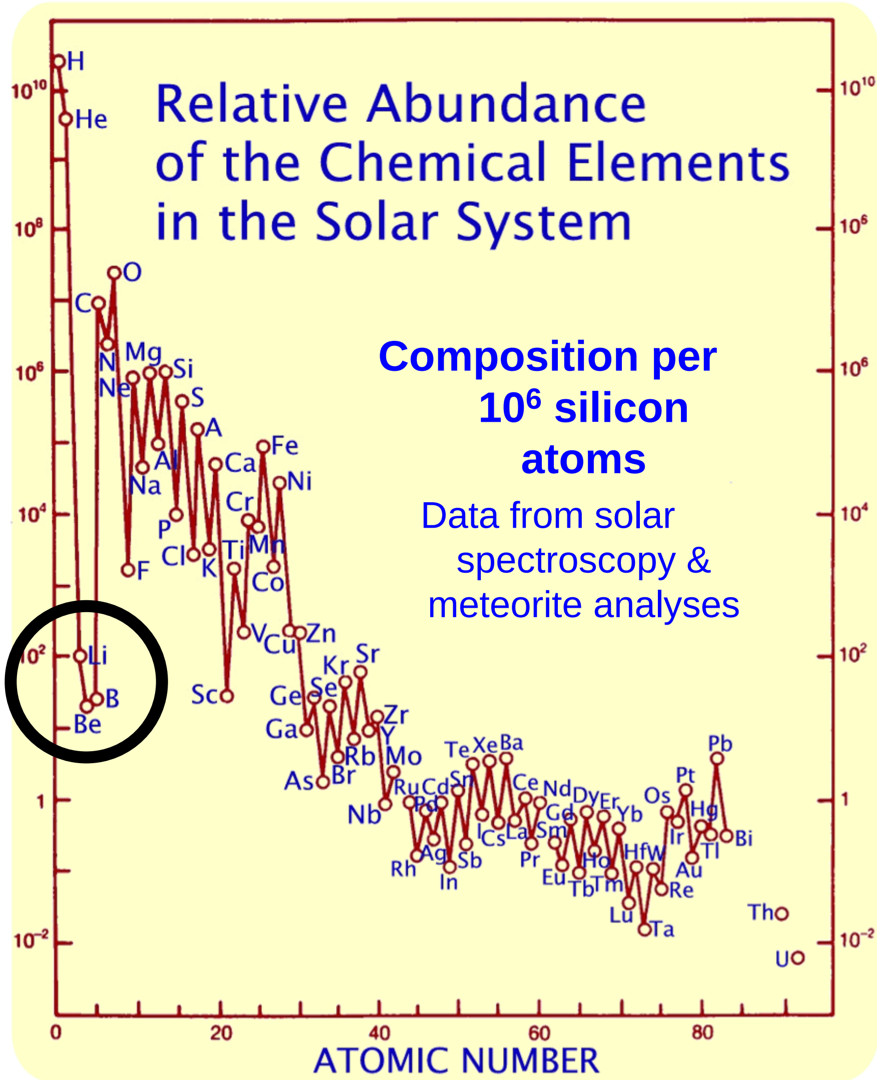
http://www.spacetelescope.org/images/html/heic0515a.html

Galactic cosmic rays: originate in sources outside the solar system, throughout our Milky Way galaxy.

Solar energetic particles: nuclei and electrons accelerated in association with energetic events on the Sun

Cosmic-rays

The light elements
Li, Be and Bor (skipped by nucleosynthesis) are produced by cosmic rays *(Walker et al. 1985)*

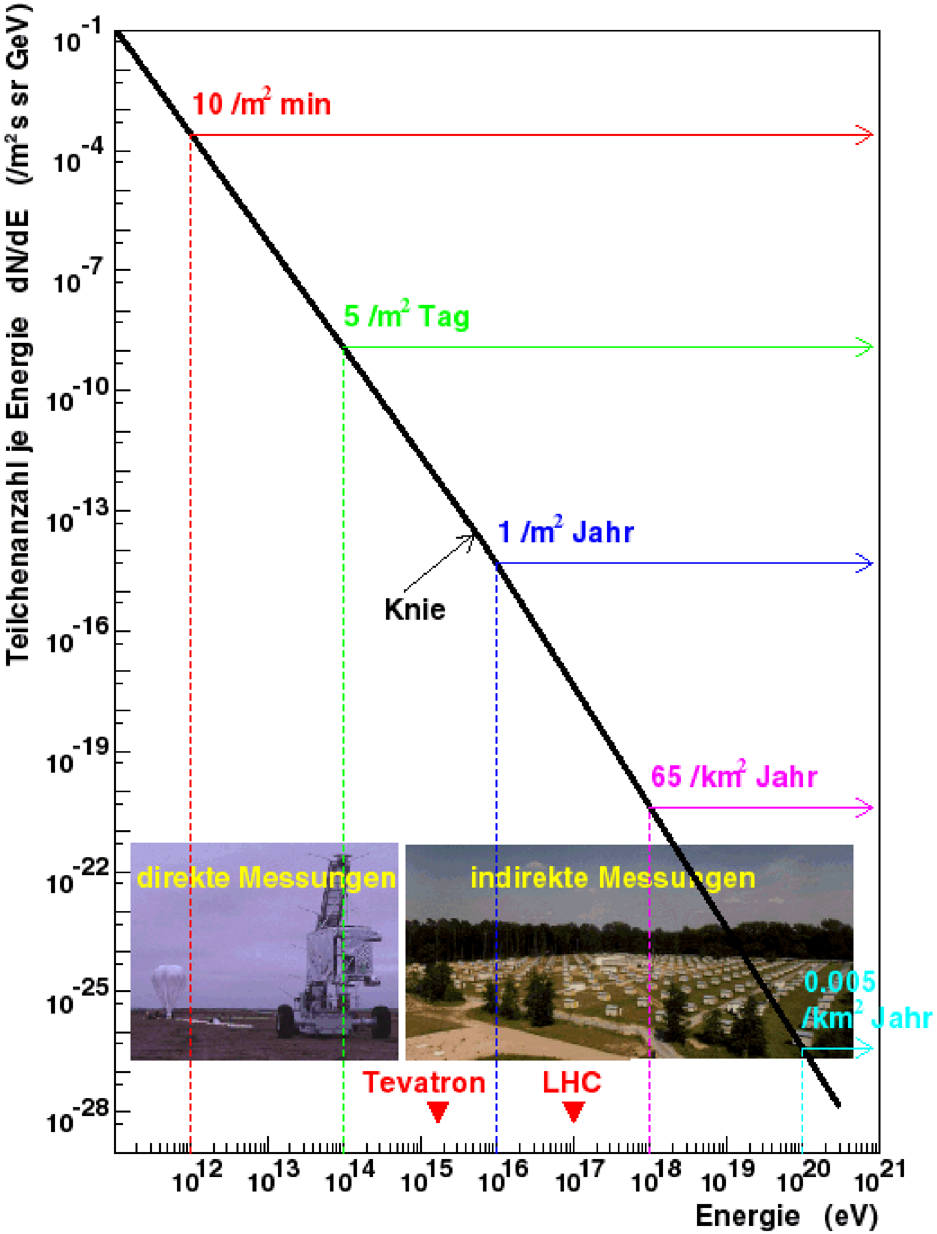


3-alpha process

$$^{4}_{2}He + ^{4}_{2}He \rightarrow ^{8}_{4}Be$$

$$^{8}_{4}Be + ^{4}_{2}He \rightarrow ^{12}_{6}C + \gamma$$

Energy of cosmic-rays



Components of galactic cosmic-rays

87-89% protons

10-12% α-particles

1-2% electrons

1% heavier elements

Secondary cosmic-rays

Pions → muons, neutrinos, γ-rays

electrons

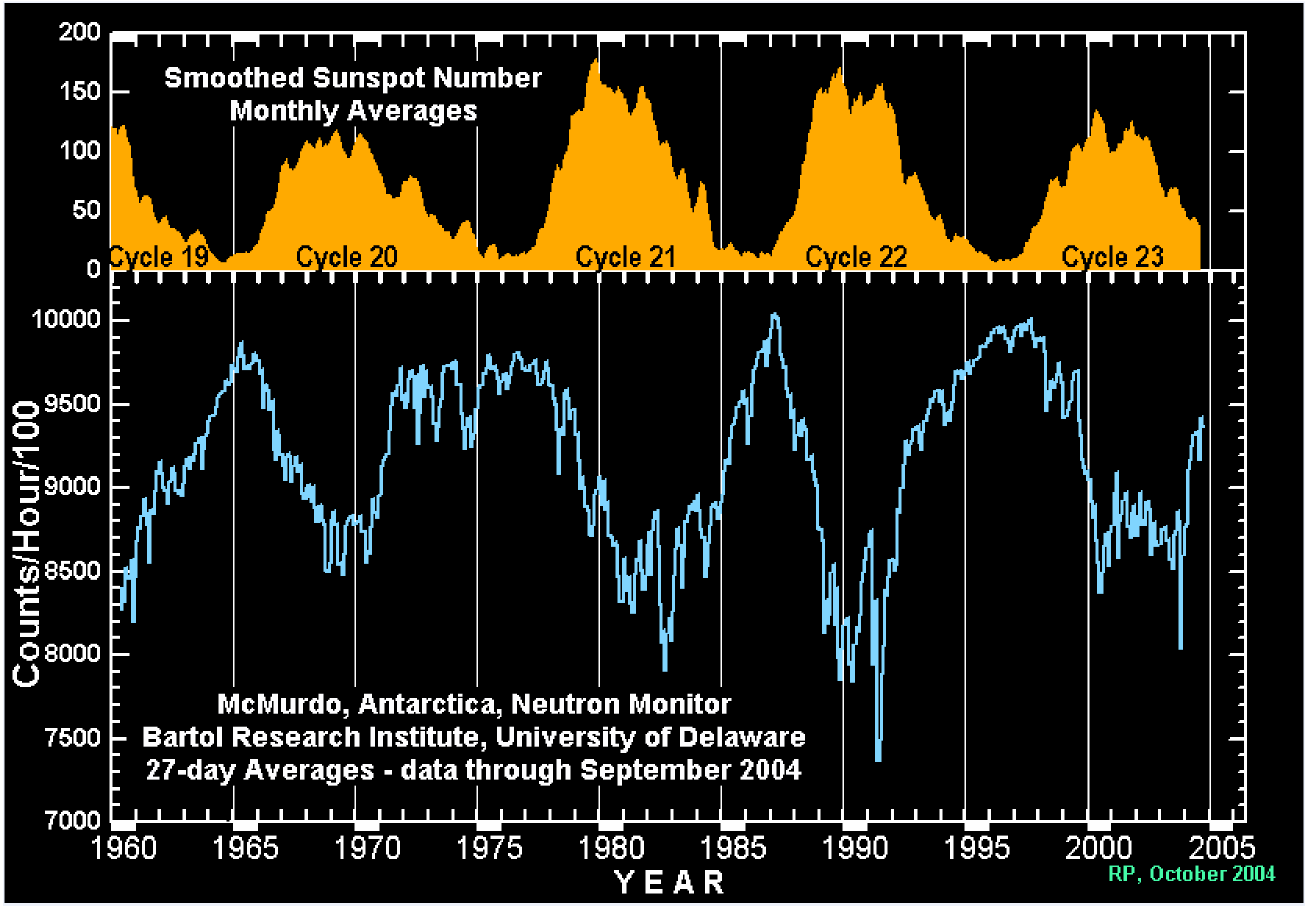
positrons

Particle colliders

Tevatron, Fermilab, USA

LHC, CERN, Geneva

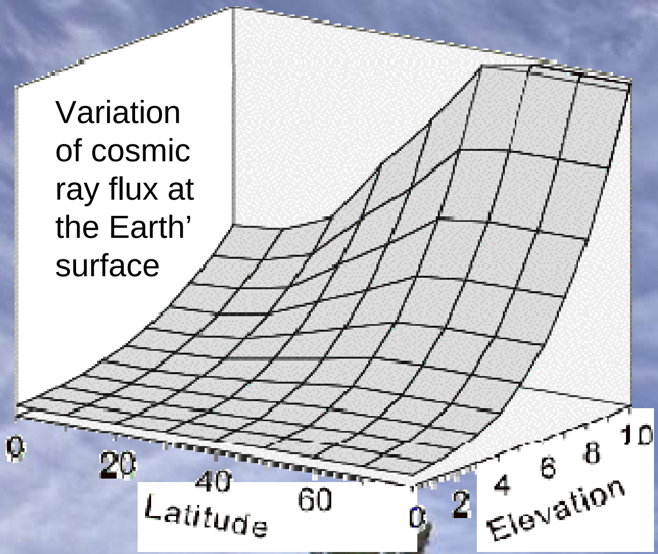
Variation of production rate



When the sun is active, we get fewer cosmic rays here

What about long-term averaged intensity variation in the Earth's magnetic field?

Variation of production rate



The **rate of production** of cosmogenic isotopes depends on the concentrations of the target elements (O, K, Ca, Mg), elevation, surface orientation, and geomagnetic latitude

<u>Comparison with redness of a person's skin (suntan)</u>

Gosse and Phillips (2001)

Suntan – wears away

Cosmogenic nuclide – decays

Suntan lotion shields skin from radiation

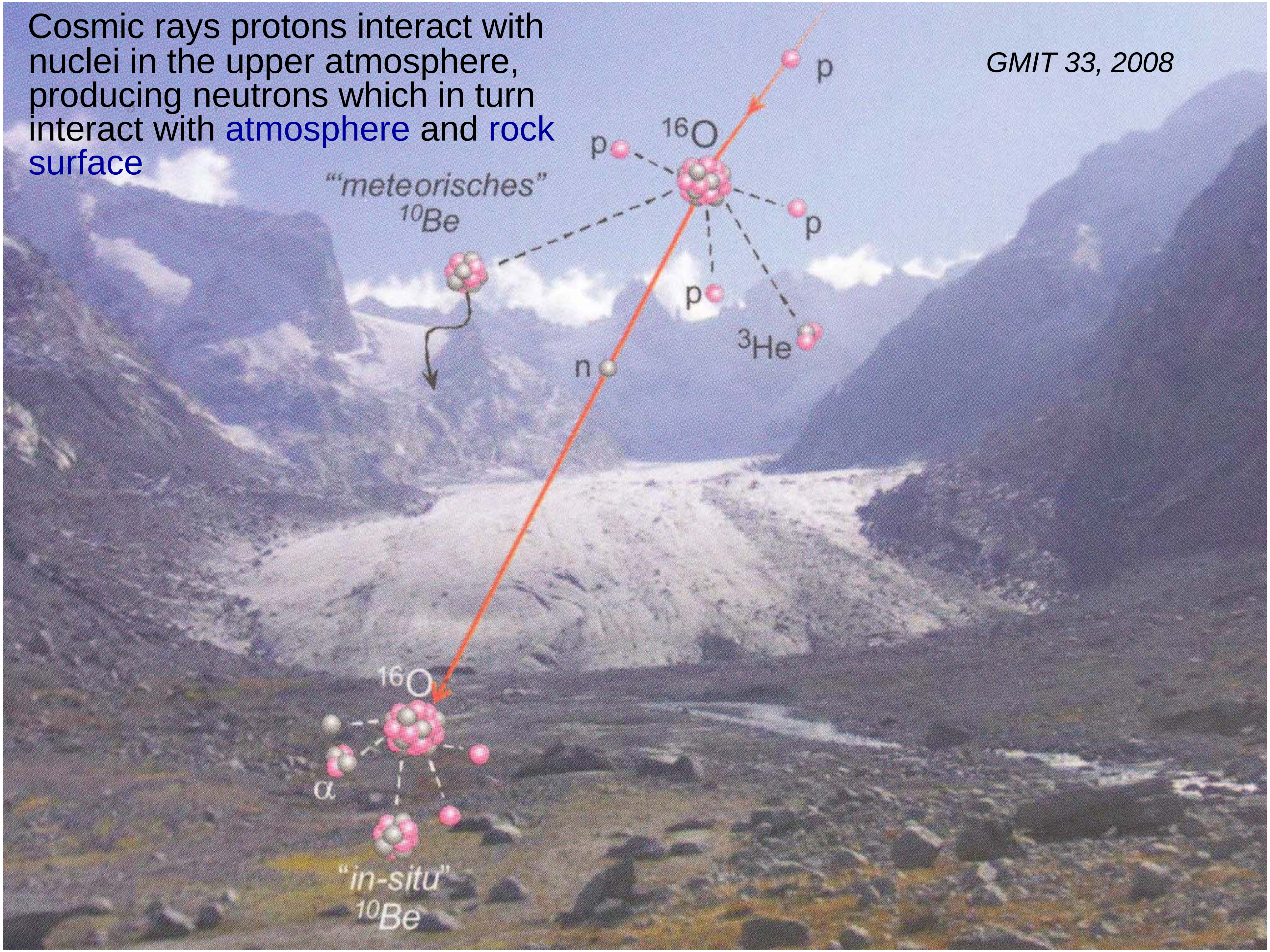
Atmosphere and snow shields a landform from radiation

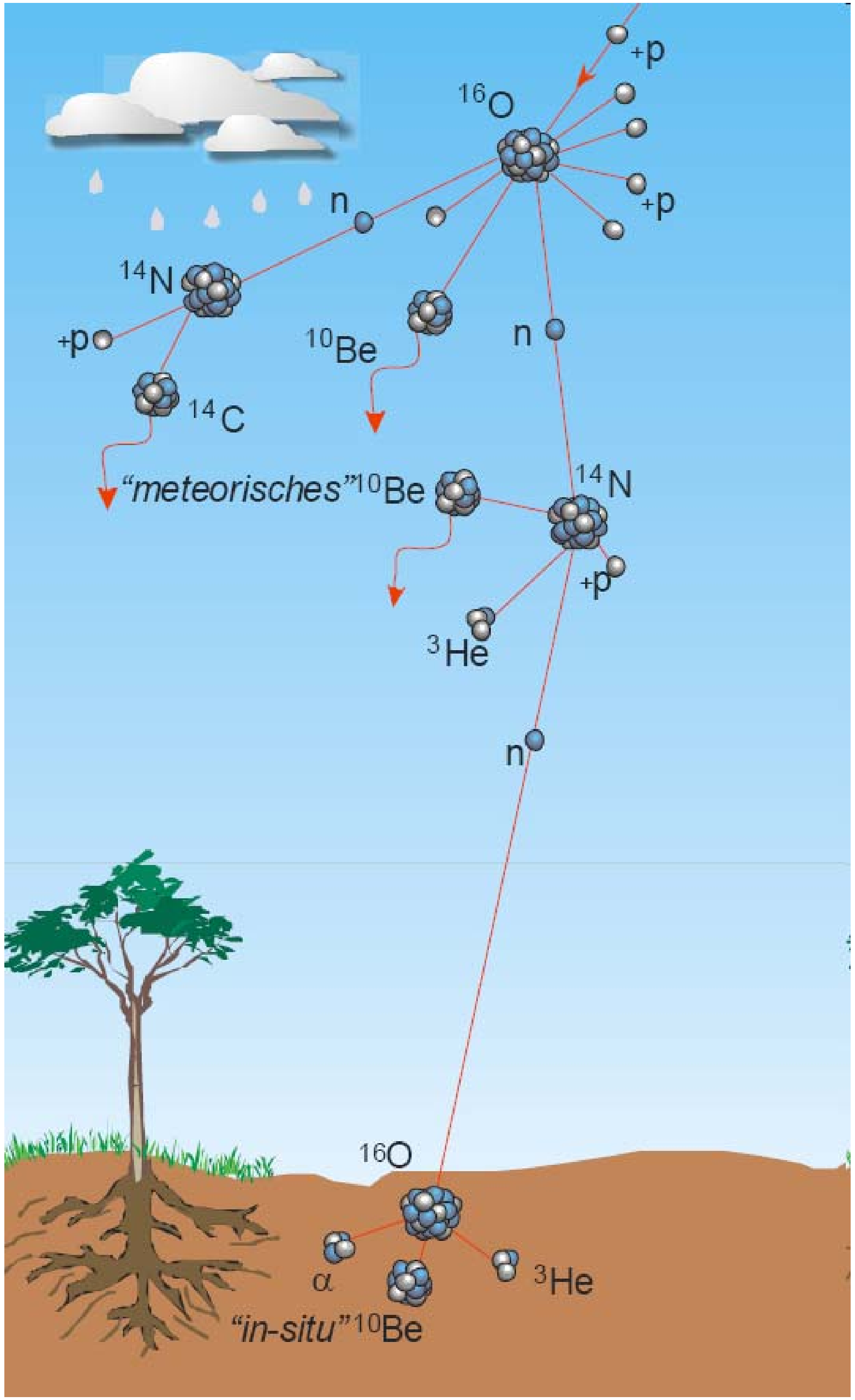
Not everybody tans to the same degree of redness

Nuclide production varies in different minerals

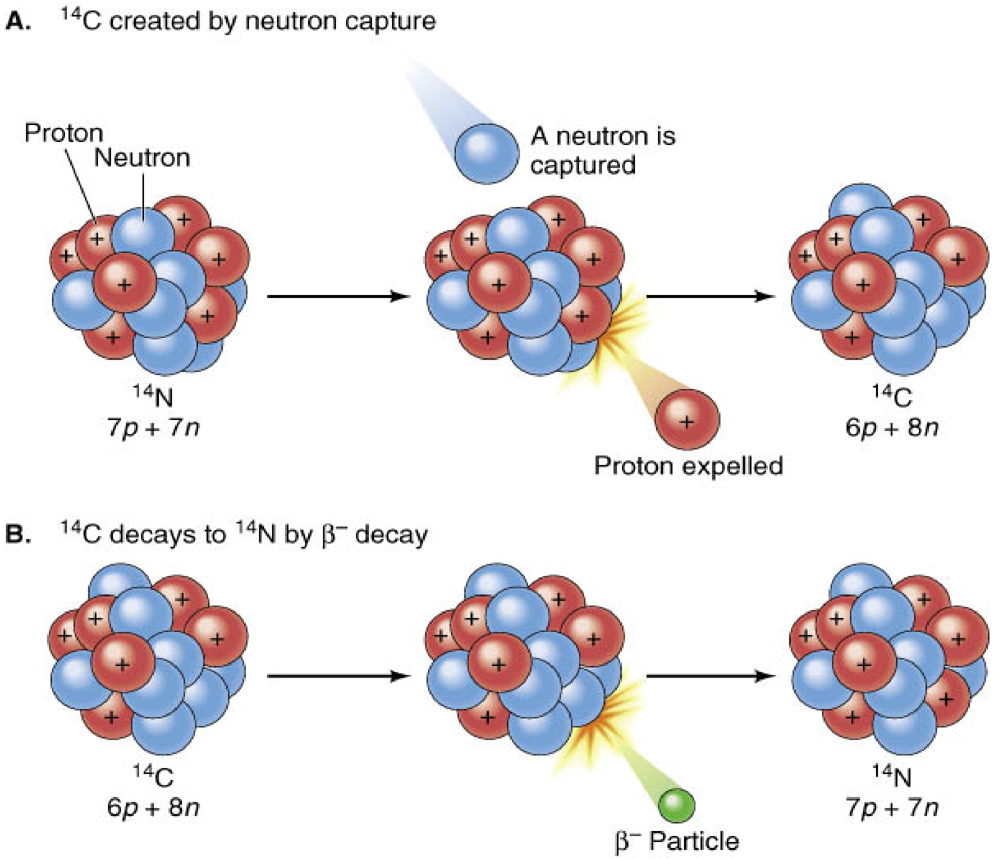
Cosmic rays protons interact with nuclei in the upper atmosphere, producing neutrons which in turn interact with atmosphere and rock surface

GMIT 33, 2008





+p
^{16}O
+p
n
^{14}N
+p
^{10}Be
n
^{14}C
"meteorisches" ^{10}Be
^{14}N
+p
^{3}He
n
^{16}O
α
^{3}He
"in-situ" ^{10}Be



A. ^{14}C created by neutron capture
Proton
Neutron
A neutron is captured
^{14}N
$7p + 7n$
Proton expelled
^{14}C
$6p + 8n$
B. ^{14}C decays to ^{14}N by β^- decay
^{14}C
$6p + 8n$
β^- Particle
^{14}N
$7p + 7n$

Terrestrial cosmogenic isotopes

Basic applications

1. Dating via radioactive decay
2. Dating via nuclide accumulation
3. Exchange rate quantification via nuclide accumulation and extraction
4. Nuclide concentrations as function of paleomagnetic and solar intensity

Production of cosmogenic isotopes

Major *in-situ* produced cosmogenic nuclides in terrestrial materials

Isotope	**Production rate (atoms / g / year)**	**Half-life (years)**	**Target elements in terrestrial rocks**
^{3}He	75 – 100 (olivine)	stable	O, Si, Al, Mg
^{10}Be	5 – 7 (quartz)	1.5×10^{6}	O, Si, Al, C
^{14}C	18 – 20	5730	C, O
^{21}Ne	18 – 21 (quartz)	stable	Mg, Na, Si, Al
^{26}Al	30 – 36 (quartz)	0.71×10^{6}	Si, Al
^{36}Cl	8 – 10 (basalt)	0.30×10^{6}	Cl, K, Ca
^{53}Mn	?	3.7×10^{6}	Fe

Cerling & Craig (1994) Annu. Rev. Earth Planet. Sci. 22

Major target minerals:
^{3}He: olivine, pyroxene hornblende
^{10}Be, ^{14}C, ^{21}Ne, ^{26}Al: quartz
^{36}Cl: calcite, K-feldspar

Cosmogenic isotopes are produced in near surface rock by collisions of high energy neutrons and muons with specific target elements in rocks and minerals. All production rates scaled to sea-level high latidude (>60°)

Table 23.1 Principal long-lived cosmogenic radionuclides and their uses in isotope geoscience

Nuclide	$T_{1/2}$ *y*	λ y^{-1}	*Principal Uses*
^{10}Be	1.5×10^{6}	0.462×10^{-6}	Dating marine sediment, Mn-nodules, glacial ice, quartz in rock exposures, terrestrial age of meteorites, and petrogenesis of island-arc volcanics
^{14}C	5730 ± 40	0.1209×10^{-3}	Dating of biogenic carbon, calcium carbonate, terrestrial age of meteorites
^{26}Al	0.716×10^{6}	0.968×10^{-6}	Dating marine sediment, Mn-nodules, glacial ice, quartz in rock exposures, terrestrial age of meteorites
^{32}Si	276 ± 32	0.251×10^{-2}	Dating biogenic silica, glacial ice
^{36}Cl	0.308×10^{6}	2.25×10^{-6}	Dating glacial ice, exposures of volcanic rocks, groundwater, terrestrial age of meteorites
^{39}Ar	269	0.257×10^{-2}	Dating glacial ice, groundwater
^{53}Mn	3.7×10^{6}	0.187×10^{-6}	Terrestrial age of meteorites, abundance of extraterrestrial dust in ice and sediment
^{59}Ni	8×10^{4}	0.086×10^{-4}	Terrestrial age of meteorites, abundance of extraterrestrial dust in ice and sediment
^{81}Kr	0.213×10^{6}	3.25×10^{-6}	Dating glacial ice, cosmic-ray exposure age of meteorites