Appendix A. Expanded Analytical data of terrestrial cosmogenic nuclide ^{10}Be gecochronology.

Sample*	Sample type	Elevation (m)	Number of clasts analyzed	Average clast size (cm)	Standard deviation of clasts	Depth to top of sample (cm)	Thickness (cm)	Production Rate† (atoms/g*yr)		Shielding factor	Denudation Rate§ (cm/ka)	Quartz (g)	AMS values		10Be concentration (atoms/gram)		^{10}Be error (1σ)	Apparent age# (ka)	Apparent age error (2σ)	Location**
								Spallation	Muons				Be Carrier (mg)	^{10}Be/^{9}Be	^{10}Be/^{9}Be error (1σ)	^{10}Be concentration				
Qt5b-1L	depth profile	227	57	1.85	1.32	0	10	5.09	0.20	0.9994	0-0.1	36.7800	0.4153	5.26E-14	1.81E-15	3.73E+04	1.76E+03	na	na	3813529
Qt5b-2L	depth profile	227	77	1.83	1.13	30	10	5.09	0.20	0.9994	0-0.1	43.8300	0.4153	5.38E-14	1.50E-15	3.21E+04	1.02E+03	na	na	3813529
Qt5b-3L	depth profile	227	57	2.37	0.83	60	10	5.09	0.20	0.9994	0-0.1	38.6800	0.3866	5.16E-14	1.62E-15	3.22E+04	1.19E+03	na	na	3813529
Qt5b-4L	depth profile	227	45	2.61	0.79	90	10	5.09	0.20	0.9994	0-0.1	44.9907	0.3760	*6.03E-14*	*1.83E-15*	3.15E+04	1.24E+03	na	na	3813529
Qt5b-5L	depth profile	227	80	1.70	0.96	130	10	5.09	0.20	0.9994	0-0.1	46.0739	0.3760	3.42E-14	1.16E-15	1.65E+04	9.13E+02	na	na	3813529
6a-1a	boulder	231	na	na	na	0	2	4.66	0.19	0.9989	0-0.006	49.3600	0.4300	3.71E-13	3.50E-14	1.85E+05	2.62E+04	42431	15184	3813527
6a-2a	boulder	231	na	na	na	0	2	4.66	0.19	0.9989	0-0.006	41.6793	0.4400	3.70E-13	3.76E-14	2.61E+05	3.29E+04	67032	24642	3813527
6a-2L	boulder	231	na	na	na	0	2	4.66	0.19	0.9989	0-0.006	19.7800	0.4172	1.56E-13	3.65E-15	2.20E+05	1.70E+04	53011	11002	3813527
6a-3	boulder	231	na	na	na	0	2	4.66	0.19	0.9989	0-0.006	19.9700	0.4226	1.43E-13	4.25E-15	2.02E+05	1.67E+04	47430	10196	3813527
6a-5L	boulder	231	na	na	na	0	2	4.66	0.19	0.9989	0-0.006	39.9017	0.4140	2.44E-13	5.68E-15	1.69E+05	2.06E+04	39078	11810	3813527
6a-6a	boulder	231	na	na	na	0	2	4.66	0.19	0.9989	0-0.006	56.6335	0.3000	3.87E-13	6.05E-14	1.37E+05	2.57E+04	29545	13022	3813527
Qt1-01	depth profile	285	94	1.92	0.78	0	2	5.32	0.20	0.9995	0-0.1	37.8593	0.4379	5.44E-13	1.25E-14	4.18E+05	1.48E+04	na	na	3799362
Qt1-02	depth profile	370	60	2.00	1.06	35	10	5.32	0.20	0.9995	0-0.1	56.1900	0.2229	1.23E-12	2.79E-14	3.23E+05	1.13E+04	na	na	3799362
Qt1-03	depth profile	370	59	1.87	1.04	70	10	5.32	0.20	0.9995	0-0.1	40.4700	0.4364	2.86E-13	6.59E-15	2.04E+05	7.24E+03	na	na	3799362
Qt1-04	depth profile	370	101	1.84	0.96	170	10	5.32	0.20	0.9995	0-0.1	38.4900	0.4379	9.37E-14	2.54E-15	6.93E+04	2.71E+03	na	na	3799362
Qt1-05	depth profile	370	87	1.85	1.11	220	10	5.32	0.20	0.9995	0-0.1	44.6000	0.2231	1.56E-13	4.25E-15	4.98E+04	2.00E+03	na	na	3799362

*"L" or "A" at end of name indicates where the sample was run on the AMS; Arizona or Lawrence Livermore

†Production rates are from the CRONUS calculator and the script of Hidy et al. (2010).

§Denudation rates show the ranges used in models. Please see text for details.

#Apparent age is based on Cronus results for 0 erosion model. Depth profile ages are shown in Appendix Table 2

**Locations are given in Universal Transverse Mercator (UTM) coordinates system zone 11, using World Geodetic System 1984 (WGS84) datum.

DGC ^{10}Be depth profile simulator

version 1.0

Dalhousie Geochronology Centre

Site specific information:

location:

latitude (deg) xx.xxx	longitude (deg) xxx.xxx	altitude (m) xxxx
34.30972	-118.81027	285

topographic/geometric shielding:

The topographic shielding factor is 1 (no effect) as a default. If shielding has been measured, then an ascii text or Excel file can be loaded into the worksheet. To do this, right click on the disk icon below and select "Properties". From here you may specify your file type and path.This file should have two columns of data. Column 1 should contain a list of angular measurements of th horizon; column 2 should contain a list of azimuths associated with each horizon measurement. The program then makes a linear interpolation of the horizon based on these values and calculates a shielding factor. Additional shielding from samples collected on a dipping surface can be included if the strike and dip of the surface has been measured. If you already know your net topographic shielding factor, enter the value in the "define" field.

dipping surface?

strike (0 - 360): 0

dip (0-90; right hand rule): 0

horizon

- ○ user defined shielding
- ◉ File input

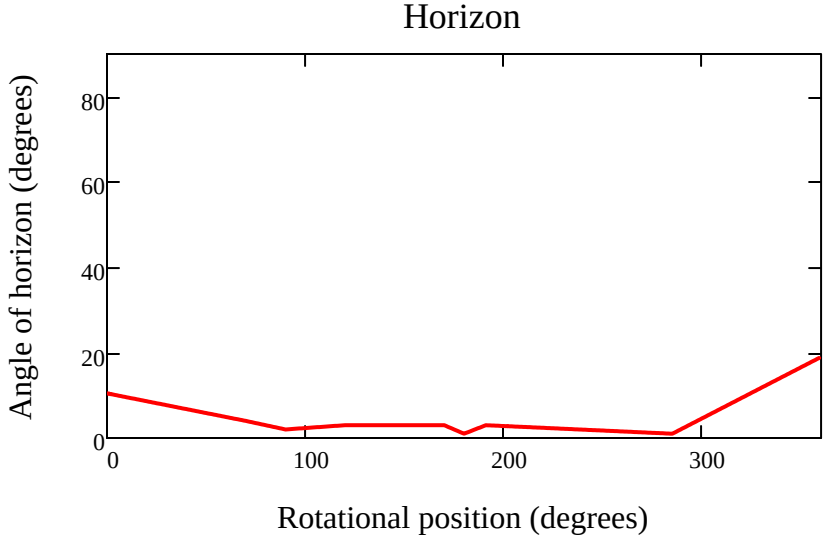
...\DDCN orizon.xls

or, define factor

0.979 (fraction)

shielding macro

Calculated or imputed shielding factor: $S_T = 0.9984626$



cover (e.g. snow, loess etc.):

This is your estimate of the percent change in production rate due to assumed periodic cover. Default is 1 (no effect).

cover factor (fraction) 1

Spallogenic production rate:

scaling scheme:

- (•) Stone 2000 after Lal 1991
- ( ) I know my spallogenic production rate _____ (atoms g^{-1} a^{-1})

Reference production rate: 4.76 (atoms g^{-1} a^{-1})

Isotope:

- (•) 10Be (1.387 Ma)
- ( ) 26Al

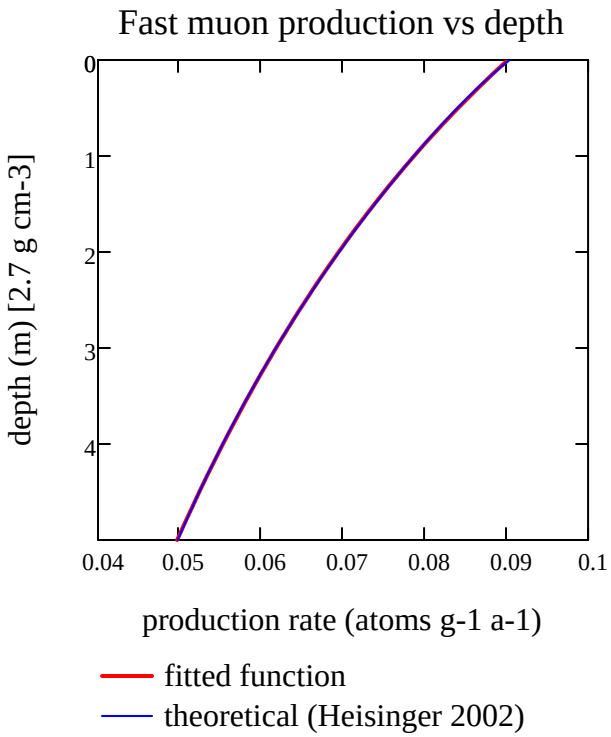
Production by muons:

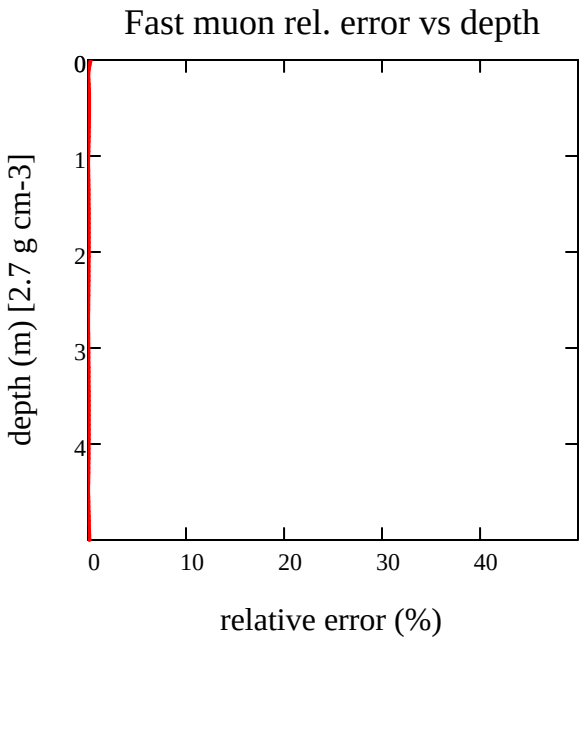
This scheme follows the theoretical equations of Heisinger et al. 2002a, 2002b for production of muons vs depth. The approach of Balco 2008 is adopted to generate production rates via negative muon capture and fast muons at any given depth and altitude. A two-term exponential best fit for fast muons and a three-term exponential best fit for negative muon capture is then determined over the depth range defined below and for the altitude of the sampling location. The displayed depth range is for rock with a conservative high density of 2.7g/cm^3, so in most cases the fitted depth will be deeper than indicated. The graphs below show the quality of each fit to the Heisinger equations over the specified mass-depth. A default depth range is set at 20 m. At a minimum, the depth range over which the muon terms are fit should be equal to the depth of your deepest sample plus the maximum net erosion of the surface.

depth of muon fit: 5 (m)

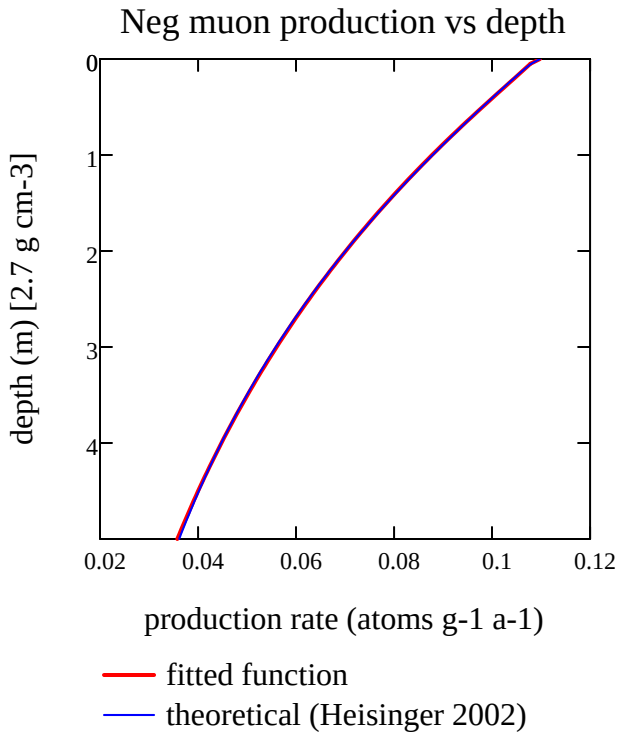
muon production

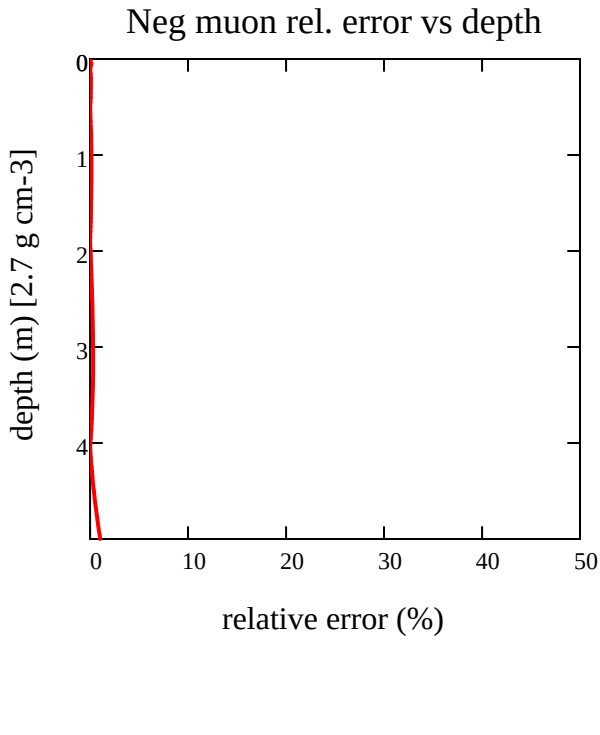
Mean relative error (%) of fit over depth range (fast muons): mean_muf_err = 0.0517967





Mean relative error (%) of fit over depth range (fast muons): mean_mun_err = 0.2065714





scaling macro

Calculated spallogenic production rate at surface (including shielding and cover): $P_r = 5.3237349$ (atoms g^{-1} a^{-1})

Calculated total muonic production rate at surface (muon shielding ignored): $M_r = 0.2001982$ (atoms g^{-1} a^{-1})

How would you like to treat error in the production rates?

To treat as constant, enter the same high and low value, and 0 for the error; to treat as stochastic between high and low end members, enter the high and low values, and 0 for the error; to treat as normally distributed about a mean value, ente the mean value in both the high and low fields, and your estimate for the relative error. Since the total muogenic production rate is approximated by five exponential terms, only a normally distributed percent error is currently allowed. The entered value is applied to each muon production term.

spallogenic production rate:

low 5.32 (atoms g^{-1} a^{-1})

high 5.32 (atoms g^{-1} a^{-1})

1σ error 0 (%)

muonic production rate:

1σ error 0 (%)

attenuation length for neutrons:

the recommended attenuation length for your latitude is: $\Lambda n = 160$ (g cm^{-2})

neutrons

low 160 (g cm^{-2})

high 160 (g cm^{-2})

1σ error 5 (g cm^{-2})

Uncertainty in half life?

Half life is normally distributed about the 1σ error specified (enter 0 to not include this error).

1σ error 5 (%)

Profile Data:

depth of each sample:

Enter depths to the **top** of each sample (from shallowest to deepest) in your profile. Separate each value with a space.

(cm)

thickness of each sample:

Enter thickness values for each sample in your profile. Separate each value with a space. Make sure the order of thicknesses matches those you entered in the "depth of samples" field

(cm)

concentration of each sample:

Enter concentration values for each sample in your profile. Separate each value with a space. Make sure the order of values matches those you entered in the "depth of samples" field

(atoms g^{-1})

1σ total measurement error for each sample concentration:

Enter 1 sigma errors in concentration for each sample in your profile. Separate each value with a space. Make sure the order of values matches those you entered in the "depth of samples" field.

(fraction)

Optional data input from file:

You may load your sample data from a text or Excel file rather than using the manual inputs above. To do this, first select the "file input" option below and then right click on the disk icon and select "Properties". From here you may specify your file type and path. Your data should be formatted as follows. Column order: sample depths, sample thicknesses, sample concentrations, 1σ measurement error. They should be in the same units as described above. The rows should should be ordered by sample depth (from shallowest to deepest).

Manual input ...\DDCNconc_1.xls
File input

data macro

depth (cm)	thickness (cm)	concentration (atoms g^{-1})	1σ concentration error (fraction)
35	10	322904.234447	0.035127
70	10	204151.347841	0.0354599
170	10	69266.305216	0.0391348
220	10	49804.055997	0.0400842

$$Z = \begin{pmatrix} 35 \\ 70 \\ 170 \\ 220 \end{pmatrix} \quad Th = \begin{pmatrix} 10 \\ 10 \\ 10 \\ 10 \end{pmatrix} \quad N = \begin{pmatrix} 322904.234447 \\ 204151.347841 \\ 69266.305216 \\ 49804.055997 \end{pmatrix} \quad Er = \begin{pmatrix} 0.035127 \\ 0.0354599 \\ 0.0391348 \\ 0.0400842 \end{pmatrix}$$

Bulk Density:

You may vary bulk density with depth by entering parameters for a step function describing measured or assumed changes in density with depth (e.g., if you measured density to be 2.1 +/- 0.2 g cm^{-3} between 0-30 cm, 2.3 +/- 0.1 g cm^{-3} between 30-60 cm, and 2.4 +/- 0.2 g cm^{-3} at depths greater than 60 cm, then you would enter the numbers 0 30 60--space delimited--in the "depths" field, the numbers 2.1 2.3 2.4 in the "densities" field, and the numbers 0.2 0.1 0.2 in the "density errors" field). You may also treat bulk density as a constant with depth; you can chose either a random or normal distribution for this constant value. As a check, your depth function is displayed in the plots below.

Constant density with depth; values varies randomly or normally:

low 2.2 (g cm^{-3})

high 2.5 (g cm^{-3})

1σ error 0 (g cm^{-3})

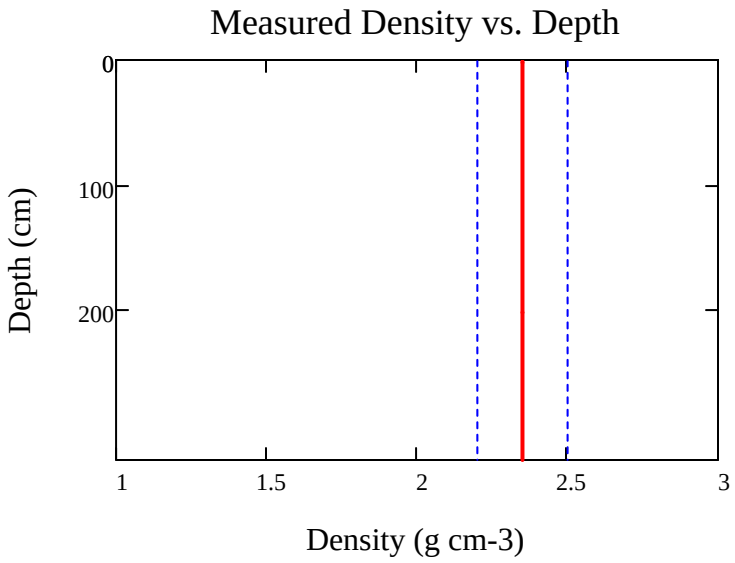
Measured values for densities at different depths; values are normally distributed (do not use for constant density with depth):

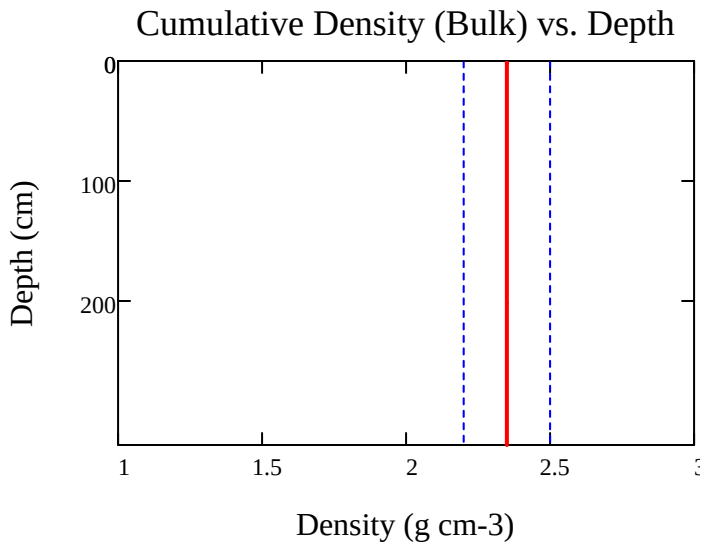
depths (cm)

densities (g cm^{-3})

1σ density errors (g cm^{-3})

density macro





Monte Carlo Simulator:

parameter values for simulation:

In the fields below, enter boundary conditions for the parameters you wish to stochastically simulate. To specify a known value for a parameter, enter the expected value in both the "low" and "high" fields; for this option you will have to enter 1σ relative error in the expected value as well. You may constrain the simulation by erosion rate, as well as erosion.

	age		net erosion		erosion rate		inheritance	
low	50000	(a)	-10	(cm)	0	(cm ka^{-1})	0	(atoms g^{-1})
high	150000	(a)	10	(cm)	0	(cm ka^{-1})	50000	(atoms g^{-1})
1σ error	0	(a)			.4	(cm ka^{-1})	0	(atoms g^{-1})

random permutations:

The simulation works by creating profiles from values sampled with the desired distribution from each of the above parameters. The total number of profiles needed to get a grood grasp of your solution space depends on how well you can constrain each of the parameters. Thus, it is more useful to specify a population of profiles that fit within a certain degree of confidence for your data, than to specify a number of total random profiles to create. This simulation will generate a profile, generate a reduced chi-squared value from that profile, and determine if that value is as good or better than the value generated from the data in your profile at the confidence window you specify; it will then continue until (n) profiles pass this chi-squared test. The total number of profiles needed to collect (n) "good" profiles is also displayed (m).

desired confidence (σ): 2

define chi-squared:

chi-squared cutoff macro

Max chi-squared value that will be collected*: chi = 4

*The simulation will only look for solutions with a lower reduced chi-squared value than that shown above. If your profile da is significantly scattered, then you may not be able to obtain low enough chi-squared values for certain confidence levels. I this case, it will be necessary to run the simulation at a higher cutoff for the chi-squared statistic. Although counter-intuitive, increasing your desired confidence level accomplishes this. This is easier to think of in terms of fitting curves to data points with error bars. A dataset may not allow any theoretical profile to fit the 1σ (68% confidence) data error, but allow profiles t fit the larger 2σ (95.4% confidence) error. Incidentally, a higher confidence results in a faster simulation as it is easier to fin possible solutions within the larger error window.

n

number of profiles within specified confidence: 100000

note: the best way to use this simulator is to start with low (n) values and do quick test simulations to tune the model to your data before running a very long high (n) value simulation. This allows you to do three things: 1) you can check the graphs below to see if the ranges you chose for your simulated parameters agree with the span of possible solutions for tha parameter and then increase or decrease those ranges accordingly, 2) you can get an estimate for how long your simulation will take at higher (n) values (simulation time is linear), and 3) in the unfortunate circumstance of highly scattere data, you can run a quick test to see if it is even possible to find solutions better than your chi-squared cutoff (if it takes the program more than minute to find just 1 solution, then it probably will not be very useful for you to continue at that level of confidence). An (n) value of at least 100,000 is recommended for any final estimate of a given parameter.

simulation macro

graph data

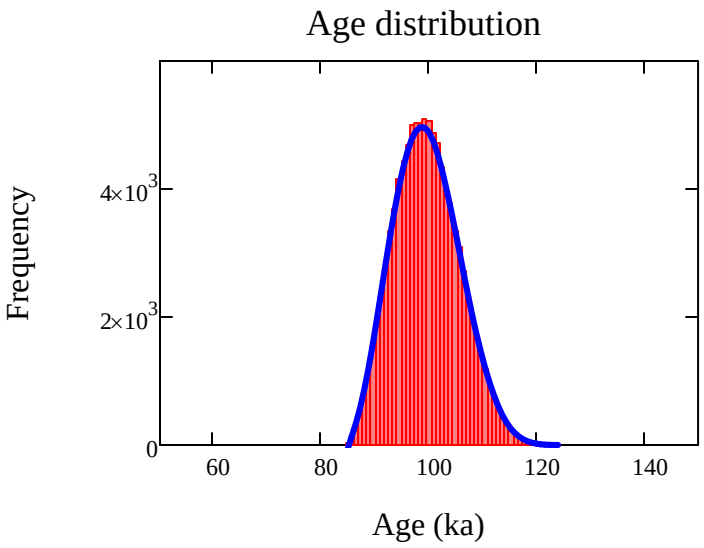
Results:

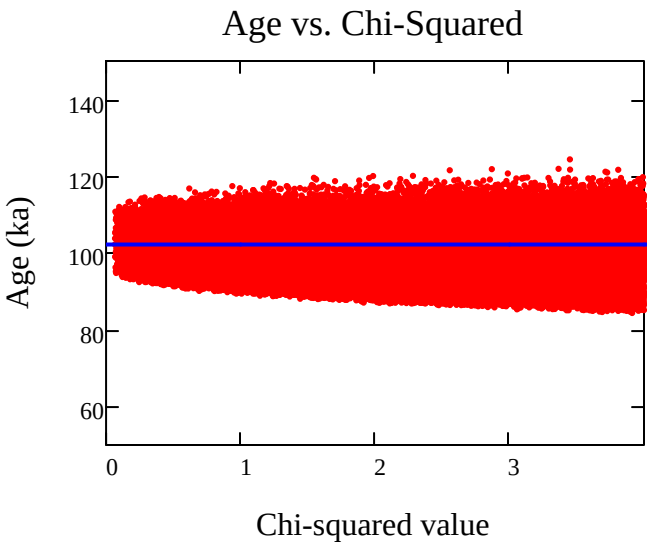
total number of simulated profiles: $m = 44716350$

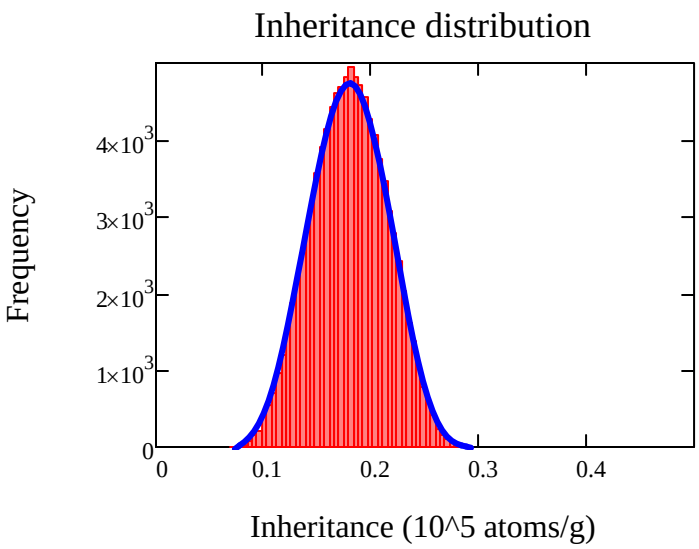
Mode, mean, and median values for age, inheritance, and erosion rate:

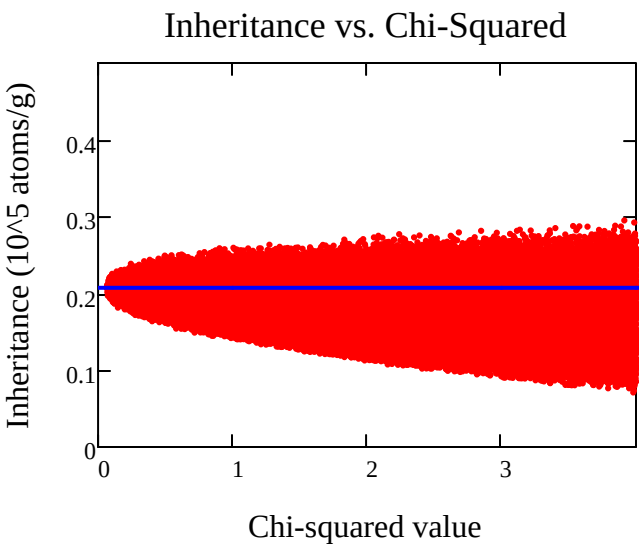
mean values:	$AGE_{mean} = 99.6 \cdot ka$	$INH_{mean} = 1.79 \cdot 10^4 \cdot \frac{atoms}{g}$	$Erate_{mean} = -0 \cdot \frac{cm}{ka}$
median values:	$AGE_{med} = 99.3 \cdot ka$	$INH_{med} = 1.80 \times 10^4 \cdot \frac{atoms}{g}$	$Erate_{med} = 0 \cdot \frac{cm}{ka}$
modal values:	$AGE_{mo} = 99.6 \cdot ka$	$INH_{mo} = 1.80 \times 10^4 \cdot \frac{atoms}{g}$	$Erate_{mo} = 0.08 \cdot \frac{cm}{ka}$
lowest χ^2 value:	$AGE_{\chi} = 102.2 \cdot ka$	$INH_{\chi} = 2.07 \times 10^4 \cdot \frac{atoms}{g}$	$Erate_{\chi} = -0 \cdot \frac{cm}{ka}$
maximum value:	$AGE_{max} = 124.4 \cdot ka$	$INH_{max} = 2.95 \times 10^4 \cdot \frac{atoms}{g}$	$Erate_{max} = 0.1 \cdot \frac{cm}{ka}$
minumum value:	$AGE_{min} = 84.4 \cdot ka$	$INH_{min} = 7.10 \times 10^3 \cdot \frac{atoms}{g}$	$Erate_{min} = -0.12 \cdot \frac{cm}{ka}$

The range in age, inheritance, and erosion values shown in these plots represent the range over your specified confidence

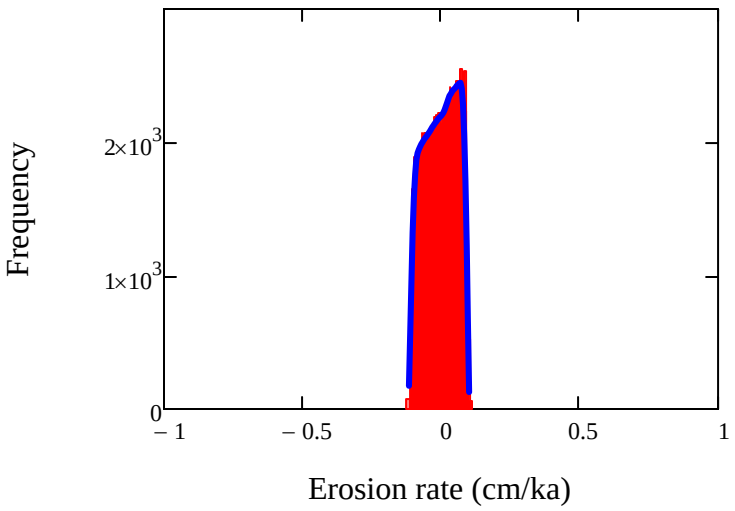




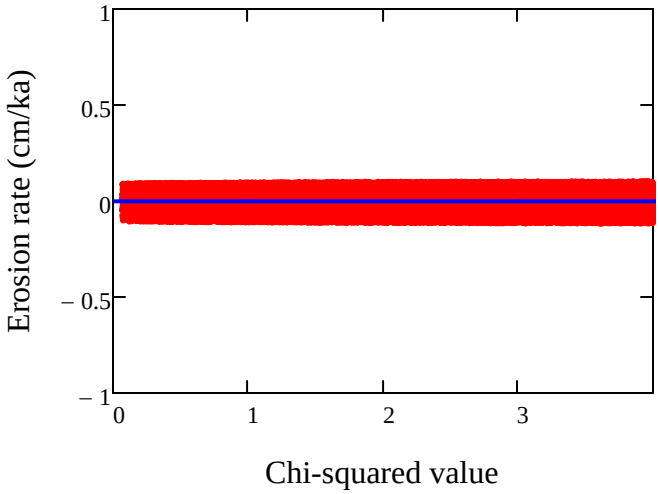




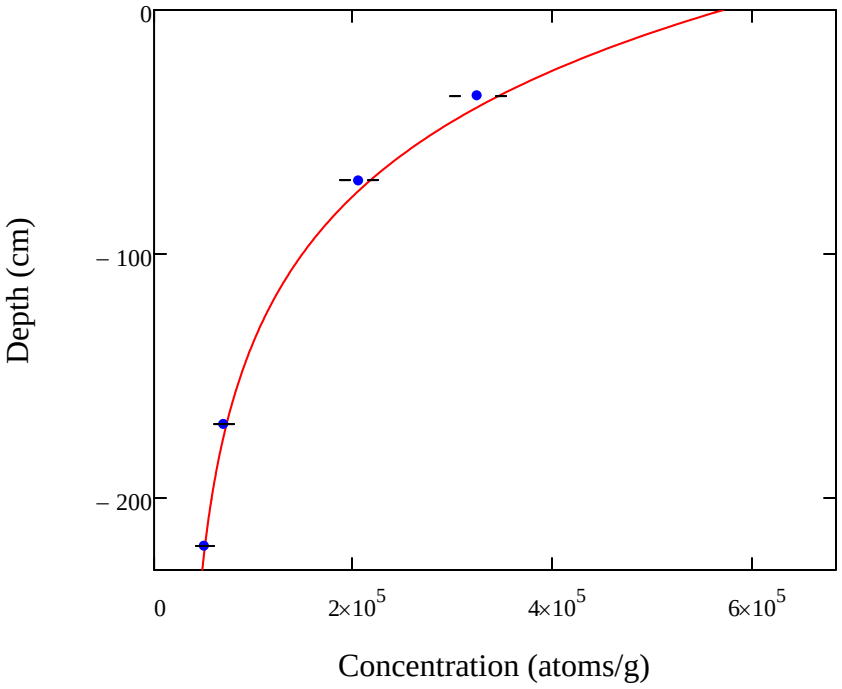
Erosion rate



Erosion rate vs. Chi-Squared value

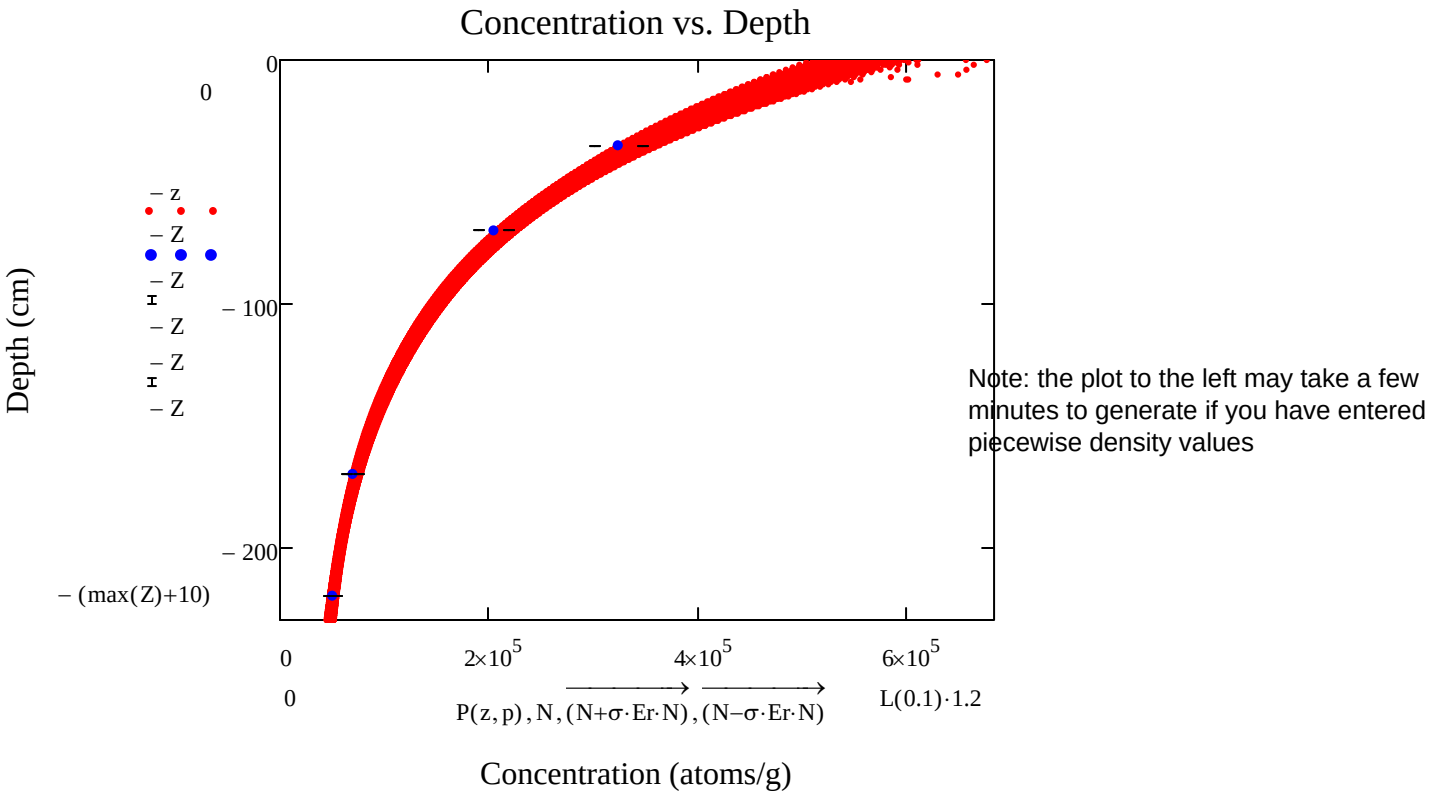


Concentration vs. Depth



parameters yielding best fit (lowest χ^2 value):

χ^2 value:	$chisqrs_0 = 0.0651586$
age:	$times_0 = 102.2 \cdot ka$
erosion rate:	$erosates_0 = -0.001 \cdot \frac{cm}{ka}$
inheritance:	$inhers_0 = 2.07 \times 10^4 \cdot \frac{atoms}{g}$
neutron atten. length:	$neut\_attens_0 = 158 \cdot \frac{g}{cm^2}$
spallogenic production rate:	$prates_0 = 5.32 \cdot \frac{atoms}{g \cdot a}$
muogenic production rate:	$murates_0 = 0.2 \cdot \frac{atoms}{g \cdot a}$
density:	$density = 2.45 \cdot \frac{g}{cm^3}$



Note: the plot to the left may take a few minutes to generate if you have entered piecewise density values

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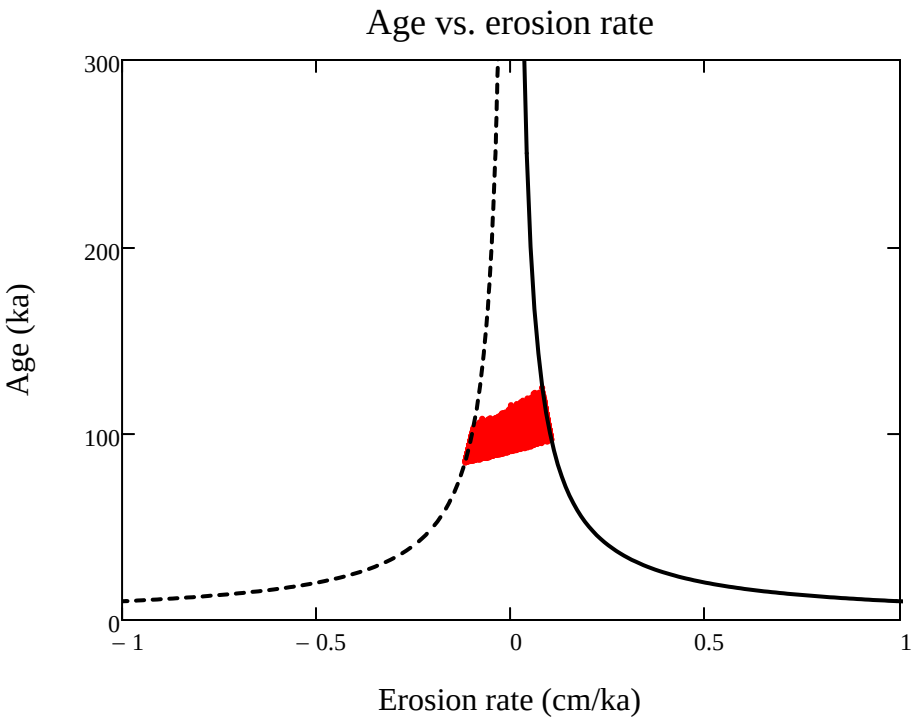

Age vs. erosion rate
300
200
100
0
Age (ka)
– 1
– 0.5
0
0.5
1
Erosion rate (cm/ka)
solution space
lower erosion constraint
upper erosion constraint

If you entered piecewise density data, the displayed values represent mean cumulative bulk densities at the depth of each sample

CRONUS-Earth ^{10}Be - ^{26}Al exposure age calculator -- results

Version information --	Component	Version
	Wrapper script:	2.2
	Main calculator:	2.1
	Constants:	2.2.1
	Muons:	1.1

Comments:

Production rate calibration information:	Using default calibration data set

^{10}Be results:

Results not dependent on spallogenic production rate model: *Exposure ages -- constant production*

Scaling scheme for spallation: Lal(1991) / Stone

Sample name	Thickness scaling factor	Shielding factor	Production rate (muons) (atoms/g/yr)	Internal uncertainty (yr)	Exposure age (yr)	External uncertainty (yr)
6a-1	0.9833	0.9989	0.194	4961	34730	5820
6a-2	0.9833	0.9989	0.194	6256	43080	7311
6a-3	0.9833	0.9989	0.194	3168	37952	4594
6a-5	0.9590	0.9989	0.194	3992	32485	4902
6a-6	0.9833	0.9989	0.194	4845	25661	5339

Exposure ages -- time-varying production models:

Scaling scheme for spallation:	Desilets and others (2003,2006)		Dunai (2001)		Lifton and others (2005)		I
Sample name	Exposure age (yr)	External uncertainty (yr)	Exposure age (yr)	External uncertainty (yr)	Exposure age (yr)	External uncertainty (yr)	Expo
6a-1	36968	6876	35962	6675	36171	6298	3
6a-2	44766	8414	43668	8191	43623	7684	4
6a-3	39926	5807	38916	5642	39011	5068	3
6a-5	34858	5964	33830	5774	34087	5389	3
6a-6	28064	6262	27195	6059	27473	5862	2

^{26}Al results:

Results not dependent on spallogenic production rate model:

Exposure ages -- constant production

Scaling scheme for spallation: Lal(1991) / Stone

Sample name	Thickness scaling factor	Shielding factor	Production rate (muons) (atoms/g/yr)	Internal uncertainty (yr)	Exposure age (yr)	External uncertainty (yr)
6a-1	--	--	--	--	--	--
6a-2	--	--	--	--	--	--
6a-3	--	--	--	--	--	--
6a-5	--	--	--	--	--	--
6a-6	--	--	--	--	--	--

Exposure ages -- time-varying production models:

Scaling scheme for spallation:	Desilets and others (2003,2006)		Dunai (2001)		Lifton and others (2005)		I
Sample name	Exposure age (yr)	External uncertainty (yr)	Exposure age (yr)	External uncertainty (yr)	Exposure age (yr)	External uncertainty (yr)	Expo
6a-1	--	--	--	--	--	--	
6a-2	--	--	--	--	--	--	
6a-3	--	--	--	--	--	--	
6a-5	--	--	--	--	--	--	
6a-6	--	--	--	--	--	--	

(No Al-26 / Be-10 plot)

$^{26}Al/^{10}Be$ ratios (relative to

Sample
6a-1
6a-2
6a-3
6a-5
6a-6

CRONUS-Earth ^{10}Be - ^{26}Al exposure age calculator -- results

Version information --	Component	Version
	Wrapper script:	2.2
	Main calculator:	2.1
	Constants:	2.2.1
	Muons:	1.1

Comments:

Production rate calibration information:	Using default calibration data set

^{10}Be results:

Results not dependent on spallogenic production rate model: *Exposure ages -- constant production*

Scaling scheme for spallation: Lal(1991) / Stone

Sample name	Thickness scaling factor	Shielding factor	Production rate (muons) (atoms/g/yr)	Internal uncertainty (yr)	Exposure age (yr)	External uncertainty (yr)
6a-1	0.9833	0.9989	0.194	7592	42431	8907
6a-2	0.9833	0.9989	0.194	10974	55925	12824
6a-3	0.9833	0.9989	0.194	5098	47430	7395
6a-5	0.9590	0.9989	0.194	5905	39078	7250
6a-6	0.9833	0.9989	0.194	6511	29545	7175

Exposure ages -- time-varying production models:

Scaling scheme for spallation:	Desilets and others (2003,2006)		Dunai (2001)		Lifton and others (2005)		I
Sample name	Exposure age (yr)	External uncertainty (yr)	Exposure age (yr)	External uncertainty (yr)	Exposure age (yr)	External uncertainty (yr)	Expo
6a-1	45018	10638	43615	10205	43654	9584	4
6a-2	60505	15777	58085	14905	58319	14073	5
6a-3	50472	9618	48614	9137	48665	8198	4
6a-5	41716	8902	40453	8552	40570	7950	3
6a-6	32488	8597	31348	8232	31672	7979	2

^{26}Al results:

Results not dependent on spallogenic production rate model:

Exposure ages -- constant production

Scaling scheme for spallation: Lal(1991) / Stone

Sample name	Thickness scaling factor	Shielding factor	Production rate (muons) (atoms/g/yr)	Internal uncertainty (yr)	Exposure age (yr)	External uncertainty (yr)
6a-1	--	--	--	--	--	--
6a-2	--	--	--	--	--	--
6a-3	--	--	--	--	--	--
6a-5	--	--	--	--	--	--
6a-6	--	--	--	--	--	--

Exposure ages -- time-varying production models:

Scaling scheme for spallation:	Desilets and others (2003,2006)		Dunai (2001)		Lifton and others (2005)		I
Sample name	Exposure age (yr)	External uncertainty (yr)	Exposure age (yr)	External uncertainty (yr)	Exposure age (yr)	External uncertainty (yr)	Expo
6a-1	--	--	--	--	--	--	
6a-2	--	--	--	--	--	--	
6a-3	--	--	--	--	--	--	
6a-5	--	--	--	--	--	--	
6a-6	--	--	--	--	--	--	

(No Al-26 / Be-10 plot)

$^{26}Al/^{10}Be$ ratios (relative to (

Sample
6a-1
6a-2
6a-3
6a-5
6a-6

DGC ^{10}Be depth profile simulator

version 1.0

Dalhousie Geochronology Centre

Site specific information:

location:

latitude (deg) xx.xxx	longitude (deg) xxx.xxx	altitude (m) xxxx
34.442	-119.2834	227

topographic/geometric shielding:

The topographic shielding factor is 1 (no effect) as a default. If shielding has been measured, then an ascii text or Excel file can be loaded into the worksheet. To do this, right click on the disk icon below and select "Properties". From here you may specify your file type and path.This file should have two columns of data. Column 1 should contain a list of angular measurements of th horizon; column 2 should contain a list of azimuths associated with each horizon measurement. The program then makes a linear interpolation of the horizon based on these values and calculates a shielding factor. Additional shielding from samples collected on a dipping surface can be included if the strike and dip of the surface has been measured. If you already know your net topographic shielding factor, enter the value in the "define" field.

dipping surface?

strike (0 - 360)	dip (0-90; right hand rule)
0	0

horizon

- (•) user defined shielding
- ( ) File input

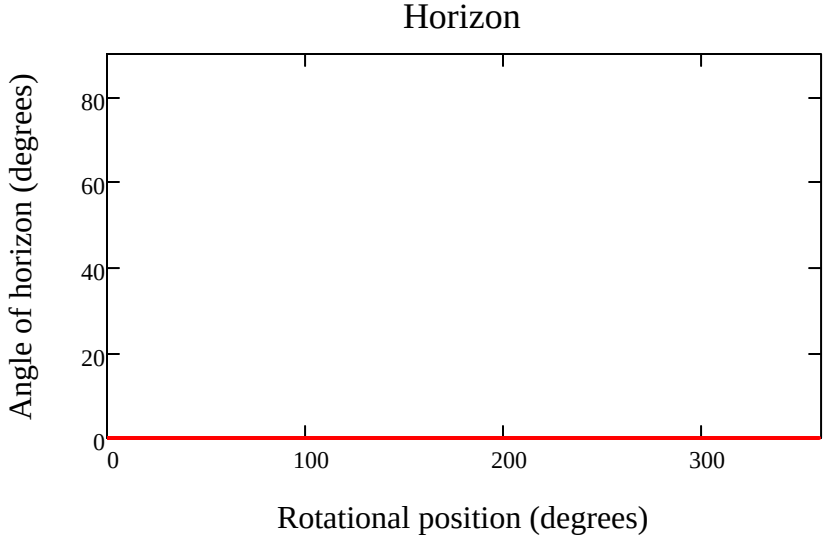
...\DDCN orizon.xls

or, define factor

0.9994 (fraction)

shielding macro

Calculated or imputed shielding factor: $S_T = 0.9994$



cover (e.g. snow, loess etc.):

This is your estimate of the percent change in production rate due to assumed periodic cover. Default is 1 (no effect).

cover factor (fraction) 1

Spallogenic production rate:

scaling scheme:

- (•) Stone 2000 after Lal 1991
- ( ) I know my spallogenic production rate [ ] (atoms g^{-1} a^{-1})

Reference production rate: [4.76] (atoms g^{-1} a^{-1})

Isotope:

- (•) 10Be (1.387 Ma)
- ( ) 26Al

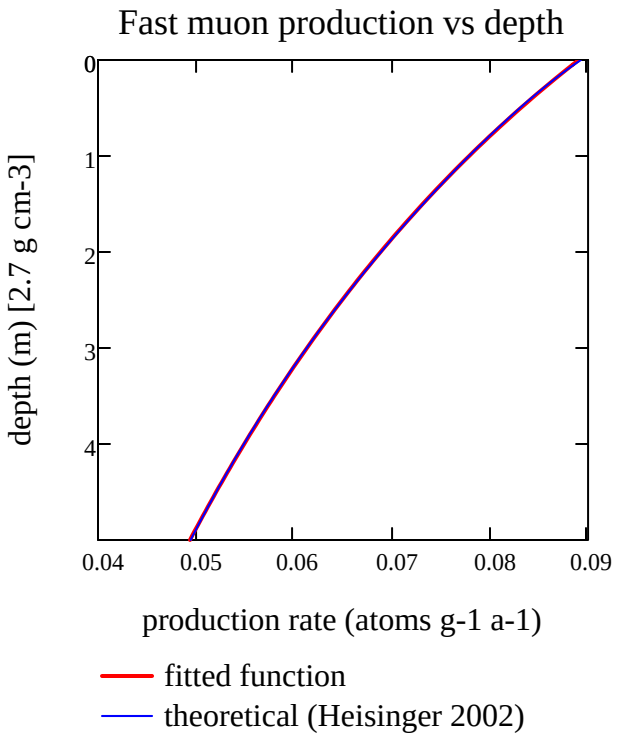
Production by muons:

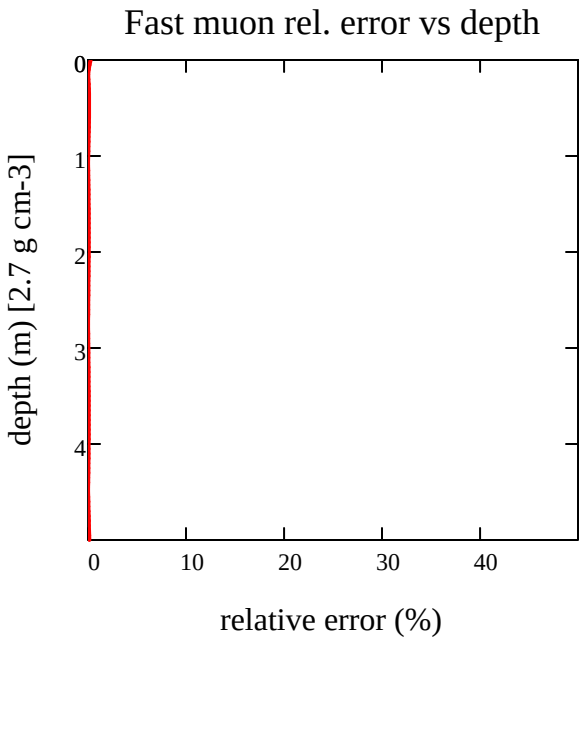
This scheme follows the theoretical equations of Heisinger et al. 2002a, 2002b for production of muons vs depth. The approach of Balco 2008 is adopted to generate production rates via negative muon capture and fast muons at any given depth and altitude. A two-term exponential best fit for fast muons and a three-term exponential best fit for negative muon capture is then determined over the depth range defined below and for the altitude of the sampling location. The displayed depth range is for rock with a conservative high density of 2.7g/cm^3, so in most cases the fitted depth will be deeper than indicated. The graphs below show the quality of each fit to the Heisinger equations over the specified mass-depth. A default depth range is set at 20 m. At a minimum, the depth range over which the muon terms are fit should be equal to the depth of your deepest sample plus the maximum net erosion of the surface.

depth of muon fit: [5] (m)

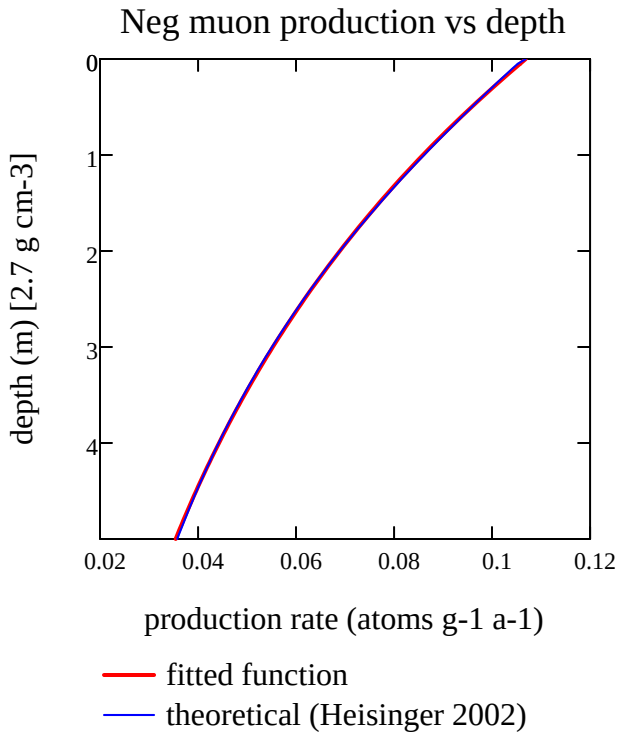
muon production

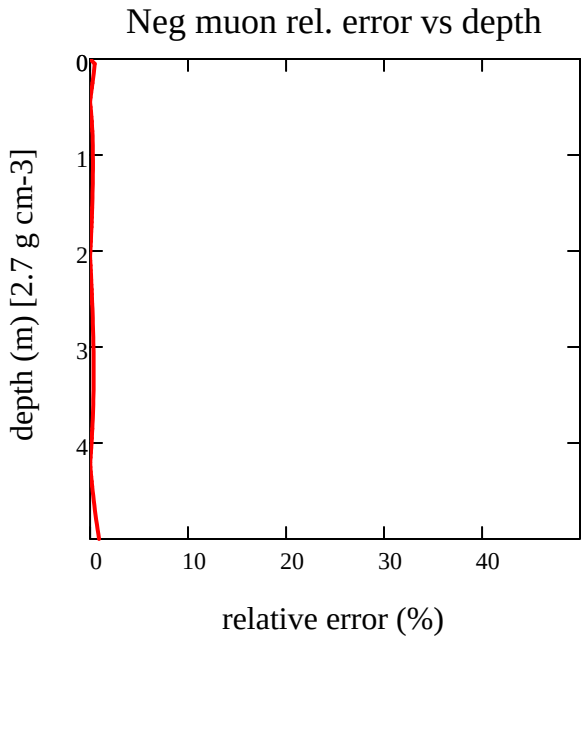
Mean relative error (%) of fit over depth range (fast muons): mean_muf_err = 0.0513573





Mean relative error (%) of fit over depth range (fast muons): mean_mun_err = 0.2530822





scaling macro

Calculated spallogenic production rate at surface (including shielding and cover): $P_r = 5.0872649$ (atoms g^{-1} a^{-1})

Calculated total muonic production rate at surface (muon shielding ignored): $M_r = 0.196143$ (atoms g^{-1} a^{-1})

How would you like to treat error in the production rates?

To treat as constant, enter the same high and low value, and 0 for the error; to treat as stochastic between high and low end members, enter the high and low values, and 0 for the error; to treat as normally distributed about a mean value, ente the mean value in both the high and low fields, and your estimate for the relative error. Since the total muogenic production rate is approximated by five exponential terms, only a normally distributed percent error is currently allowed. The entered value is applied to each muon production term.

spallogenic production rate:

low 5.09 (atoms g^{-1} a^{-1})

high 5.09 (atoms g^{-1} a^{-1})

1σ error 3 (%)

muonic production rate:

1σ error 3 (%)

attenuation length for neutrons:

the recommended attenuation length for your latitude is: $\Lambda n = 160$ (g cm^{-2})

neutrons

low 160 (g cm^{-2})

high 160 (g cm^{-2})

1σ error 5 (g cm^{-2})

Uncertainty in half life?

Half life is normally distributed about the 1σ error specified (enter 0 to not include this error).

1σ error 5 (%)

Profile Data:

depth of each sample:

Enter depths to the **top** of each sample (from shallowest to deepest) in your profile. Separate each value with a space.

(cm)

thickness of each sample:

Enter thickness values for each sample in your profile. Separate each value with a space. Make sure the order of thicknesses matches those you entered in the "depth of samples" field

(cm)

concentration of each sample:

Enter concentration values for each sample in your profile. Separate each value with a space. Make sure the order of values matches those you entered in the "depth of samples" field

(atoms g^{-1})

1σ total measurement error for each sample concentration:

Enter 1 sigma errors in concentration for each sample in your profile. Separate each value with a space. Make sure the order of values matches those you entered in the "depth of samples" field.

(fraction)

Optional data input from file:

You may load your sample data from a text or Excel file rather than using the manual inputs above. To do this, first select the "file input" option below and then right click on the disk icon and select "Properties". From here you may specify your file type and path. Your data should be formatted as follows. Column order: sample depths, sample thicknesses, sample concentrations, 1σ measurement error. They should be in the same units as described above. The rows should should be ordered by sample depth (from shallowest to deepest).

Manual input
File input
...\5bDFconc.xls

data macro

depth (cm)	thickness (cm)	concentration (atoms g^{-1})	1σ concentration error (fraction)
5	10	37310	0.0471723
35	10	32080	0.0317955
65	10	32180	0.0369795
95	10	31510	0.0393526
135	10	16540	0.0551995

$$Z = \begin{pmatrix} 5 \\ 35 \\ 65 \\ 95 \\ 135 \end{pmatrix} \quad Th = \begin{pmatrix} 10 \\ 10 \\ 10 \\ 10 \\ 10 \end{pmatrix} \quad N = \begin{pmatrix} 37310 \\ 32080 \\ 32180 \\ 31510 \\ 16540 \end{pmatrix} \quad Er = \begin{pmatrix} 0.0471723 \\ 0.0317955 \\ 0.0369795 \\ 0.0393526 \\ 0.0551995 \end{pmatrix}$$

Bulk Density:

You may vary bulk density with depth by entering parameters for a step function describing measured or assumed changes in density with depth (e.g., if you measured density to be 2.1 +/- 0.2 g cm^{-3} between 0-30 cm, 2.3 +/- 0.1 g cm^{-3} between 30-60 cm, and 2.4 +/- 0.2 g cm^{-3} at depths greater than 60 cm, then you would enter the numbers 0 30 60--space delimited--in the "depths" field, the numbers 2.1 2.3 2.4 in the "densities" field, and the numbers 0.2 0.1 0.2 in the "density errors" field). You may also treat bulk density as a constant with depth; you can chose either a random or normal distribution for this constant value. As a check, your depth function is displayed in the plots below.

Constant density with depth; values varies randomly or normally:

low 2.2 (g cm^{-3})

high 2.5 (g cm^{-3})

1σ error 0 (g cm^{-3})

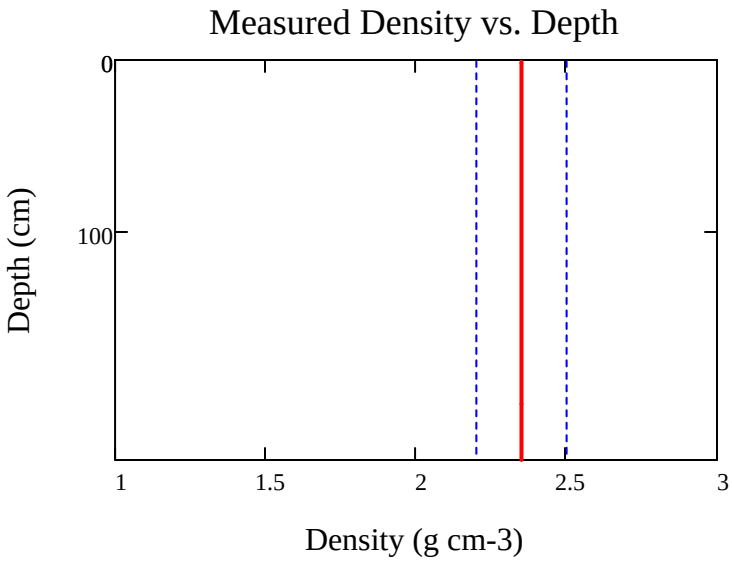
Measured values for densities at different depths; values are normally distributed (do not use for constant density with depth):

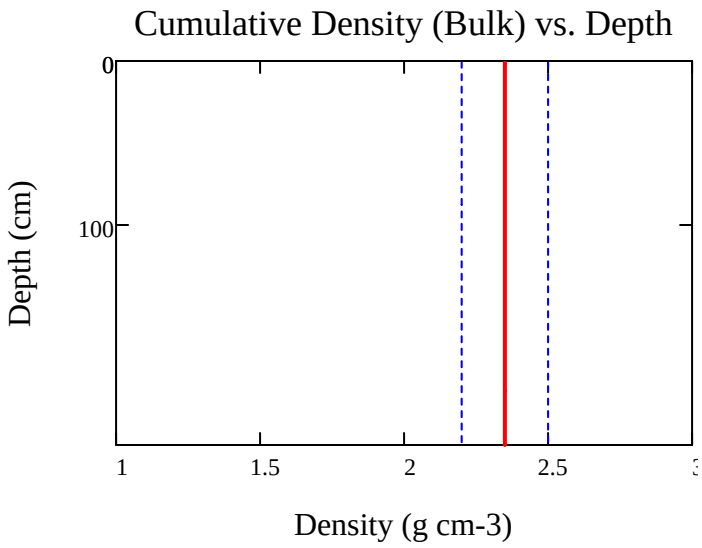
depths (cm)

densities (g cm^{-3})

1σ density errors (g cm^{-3})

density macro





Monte Carlo Simulator:

parameter values for simulation:

In the fields below, enter boundary conditions for the parameters you wish to stochastically simulate. To specify a known value for a parameter, enter the expected value in both the "low" and "high" fields; for this option you will have to enter 1 σ relative error in the expected value as well. You may constrain the simulation by erosion rate, as well as erosion.

	age		net erosion		erosion rate		inheritance	
low	1000	(a)	30	(cm)	0	(cm ka^{-1})	0	(atoms g^{-1})
high	25000	(a)	60	(cm)	20	(cm ka^{-1})	25000	(atoms g^{-1})
1σ error	0	(a)			0	(cm ka^{-1})	0	(atoms g^{-1})

random permutations:

The simulation works by creating profiles from values sampled with the desired distribution from each of the above parameters. The total number of profiles needed to get a grood grasp of your solution space depends on how well you can constrain each of the parameters. Thus, it is more useful to specify a population of profiles that fit within a certain degree of confidence for your data, than to specify a number of total random profiles to create. This simulation will generate a profile, generate a reduced chi-squared value from that profile, and determine if that value is as good or better than the value generated from the data in your profile at the confidence window you specify; it will then continue until (n) profiles pass this chi-squared test. The total number of profiles needed to collect (n) "good" profiles is also displayed (m).

desired confidence (σ): 2

define chi-squared: 60

chi-squared cutoff macro

Max chi-squared value that will be collected*: chi = 60

*The simulation will only look for solutions with a lower reduced chi-squared value than that shown above. If your profile da is significantly scattered, then you may not be able to obtain low enough chi-squared values for certain confidence levels. I this case, it will be necessary to run the simulation at a higher cutoff for the chi-squared statistic. Although counter-intuitive, increasing your desired confidence level accomplishes this. This is easier to think of in terms of fitting curves to data points with error bars. A dataset may not allow any theoretical profile to fit the 1σ (68% confidence) data error, but allow profiles t fit the larger 2σ (95.4% confidence) error. Incidentally, a higher confidence results in a faster simulation as it is easier to fin possible solutions within the larger error window.

n

number of profiles within specified confidence: 100000

note: the best way to use this simulator is to start with low (n) values and do quick test simulations to tune the model to your data before running a very long high (n) value simulation. This allows you to do three things: 1) you can check the graphs below to see if the ranges you chose for your simulated parameters agree with the span of possible solutions for tha parameter and then increase or decrease those ranges accordingly, 2) you can get an estimate for how long your simulation will take at higher (n) values (simulation time is linear), and 3) in the unfortunate circumstance of highly scattere data, you can run a quick test to see if it is even possible to find solutions better than your chi-squared cutoff (if it takes the program more than minute to find just 1 solution, then it probably will not be very useful for you to continue at that level of confidence). An (n) value of at least 100,000 is recommended for any final estimate of a given parameter.

simulation macro

graph data

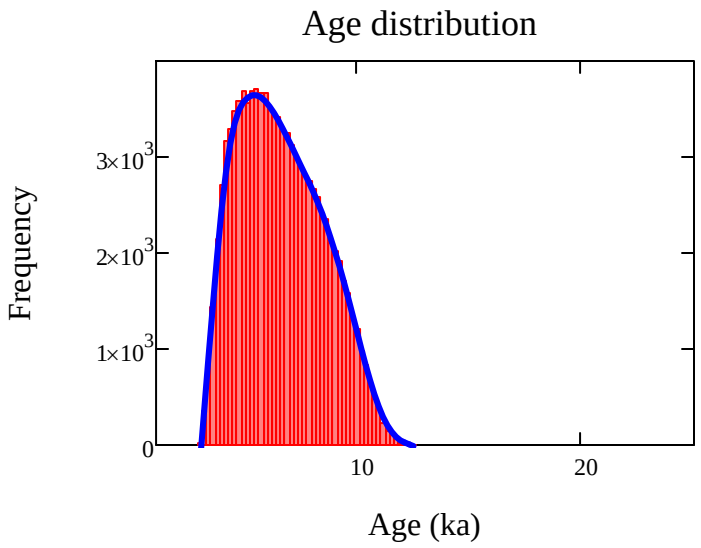
Results:

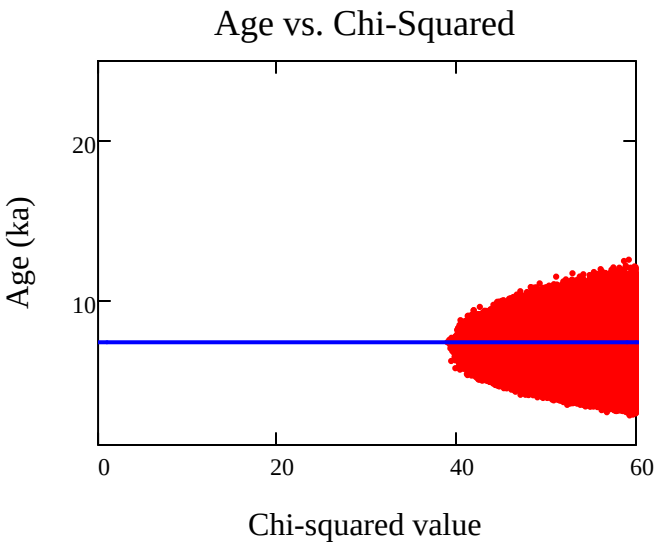
total number of simulated profiles: $m = 7422791$

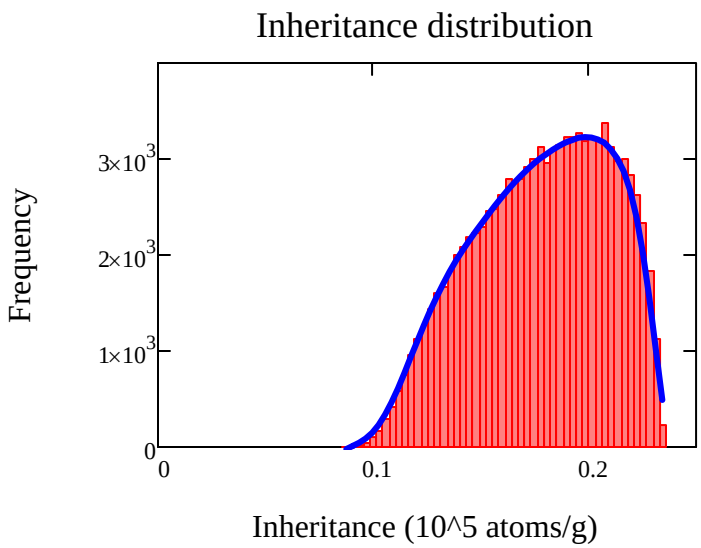
Mode, mean, and median values for age, inheritance, and erosion rate:

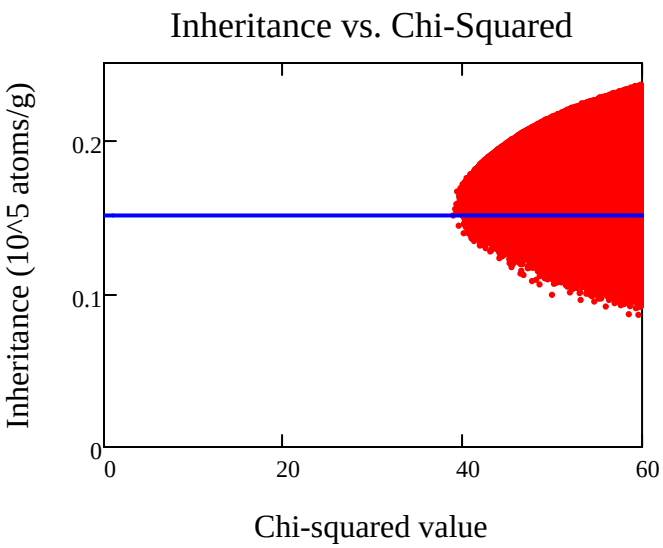
mean values:	$AGE_{mean} = 6.6 \cdot ka$	$INH_{mean} = 1.78 \cdot 10^4 \cdot \frac{atoms}{g}$	$Erate_{mean} = 7.37 \cdot \frac{cm}{ka}$
median values:	$AGE_{med} = 6.4 \cdot ka$	$INH_{med} = 1.81 \times 10^4 \cdot \frac{atoms}{g}$	$Erate_{med} = 6.94 \cdot \frac{cm}{ka}$
modal values:	$AGE_{mo} = 5.4 \cdot ka$	$INH_{mo} = 2.00 \times 10^4 \cdot \frac{atoms}{g}$	$Erate_{mo} = 5.6 \cdot \frac{cm}{ka}$
lowest χ^2 value:	$AGE_{\chi} = 7.4 \cdot ka$	$INH_{\chi} = 1.51 \times 10^4 \cdot \frac{atoms}{g}$	$Erate_{\chi} = 6.61 \cdot \frac{cm}{ka}$
maximum value:	$AGE_{max} = 12.6 \cdot ka$	$INH_{max} = 2.36 \times 10^4 \cdot \frac{atoms}{g}$	$Erate_{max} = 17.11 \cdot \frac{cm}{ka}$
minumum value:	$AGE_{min} = 2.9 \cdot ka$	$INH_{min} = 8.60 \times 10^3 \cdot \frac{atoms}{g}$	$Erate_{min} = 2.98 \cdot \frac{cm}{ka}$

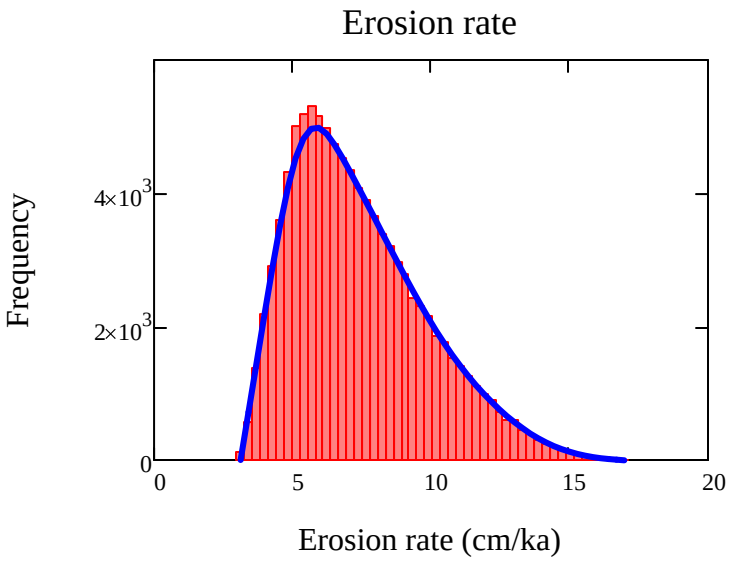
The range in age, inheritance, and erosion values shown in these plots represent the range over your specified confidence

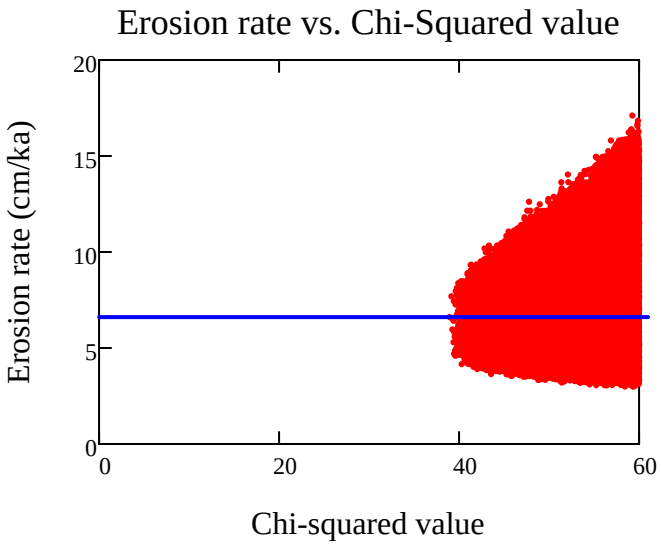


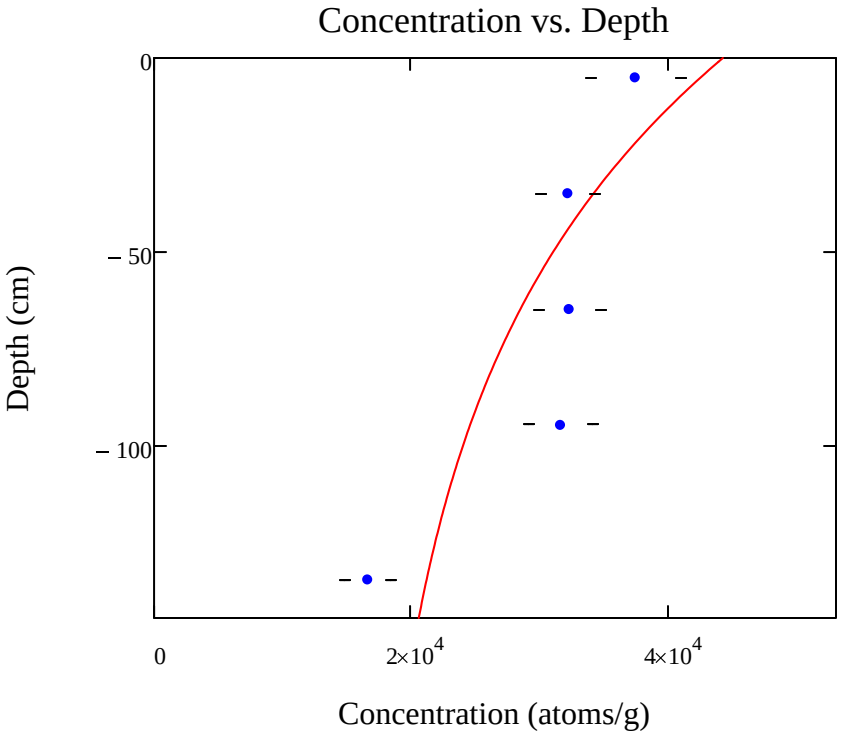












parameters yielding best fit (lowest χ^2 value):

χYJ(!245"3 $\text{chisqrs}_0 = 38.943481$

28"3 $\text{times}_0 = 7.4 \cdot \text{ka}$

"#&$%&'(#2-"3 $\text{erosates}_0 = 6.606 \cdot \frac{\text{cm}}{\text{ka}}$

%'<"#%-2'/"3 $\text{inhers}_0 = 1.51 \times 10^4 \cdot \frac{\text{atoms}}{\text{g}}$

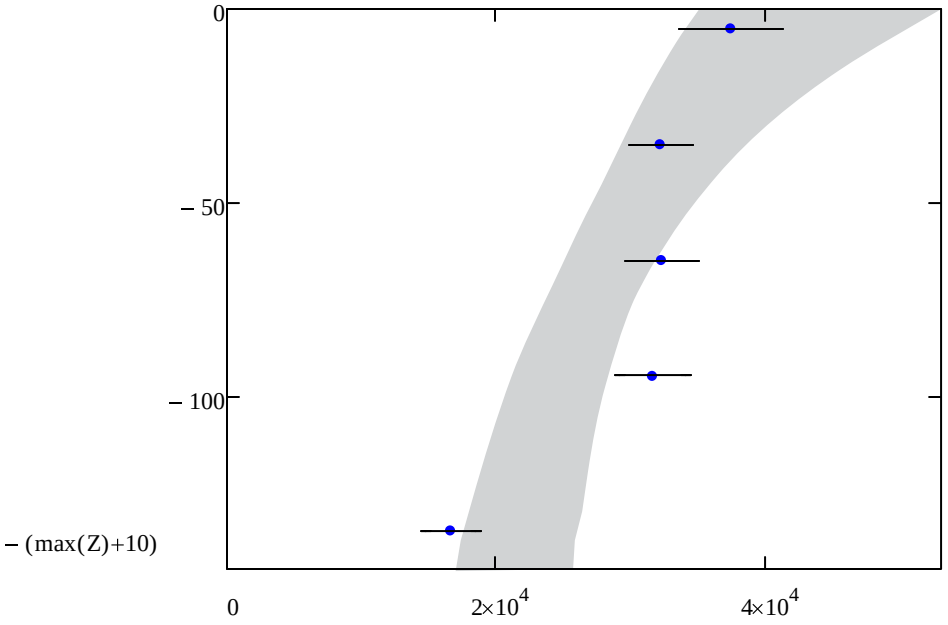
'"5-#&'(2--""*(4"'8-<3 $\text{neut\_attens}_0 = 174 \cdot \frac{\text{g}}{\text{cm}^2}$

$.244&8"'%/ .#&65/-%&'(#2-"3 $\text{prates}_0 = 5.03 \cdot \frac{\text{atoms}}{\text{g} \cdot \text{a}}$

15&8"'%/ .#&65/-%&'(#2-"3 $\text{murates}_0 = 0.2 \cdot \frac{\text{atoms}}{\text{g} \cdot \text{a}}$

6"'$%-F3 $\text{density} = 2.21 \cdot \frac{\text{g}}{\text{cm}^3}$

Concentration vs. Depth



Concentration (atoms/g)

er

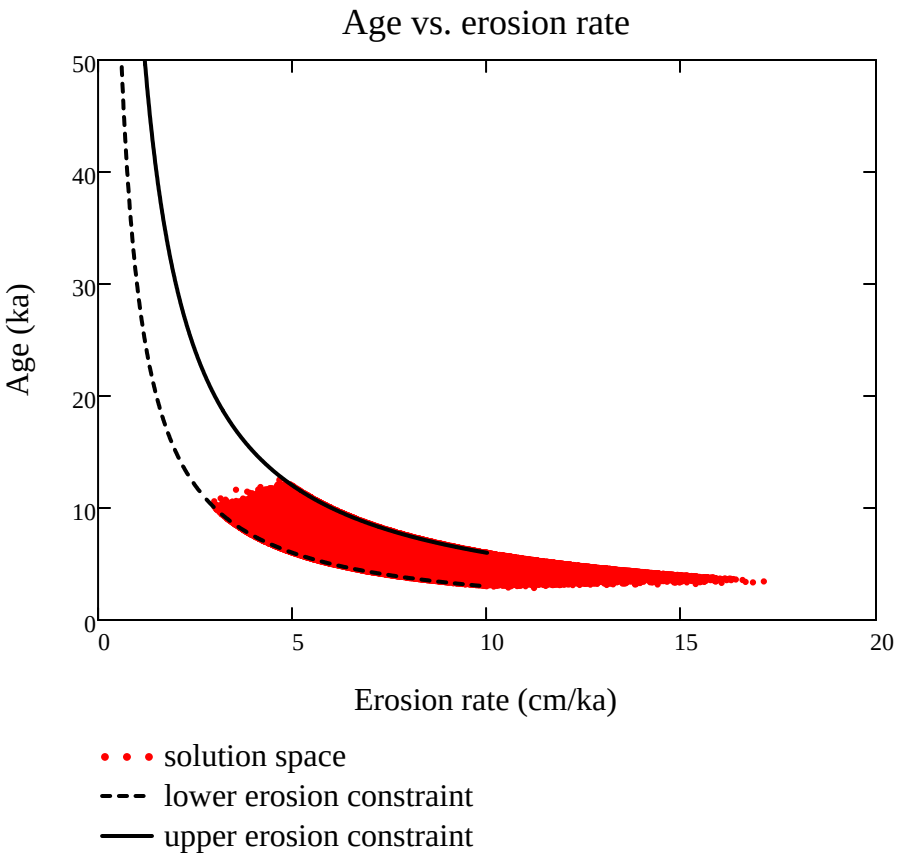
ta
n

o
d

at

d

.


Age vs. erosion rate
Age (ka)
Erosion rate (cm/ka)
0
10
20
30
40
50
0
5
10
15
20
solution space
lower erosion constraint
upper erosion constraint

If you entered piecewise density data, the displayed values represent mean cumulative bulk densities at the depth of each sample