CosmoCalc manual

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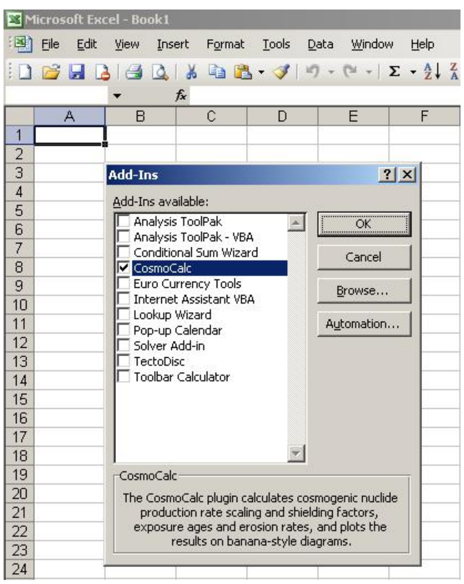
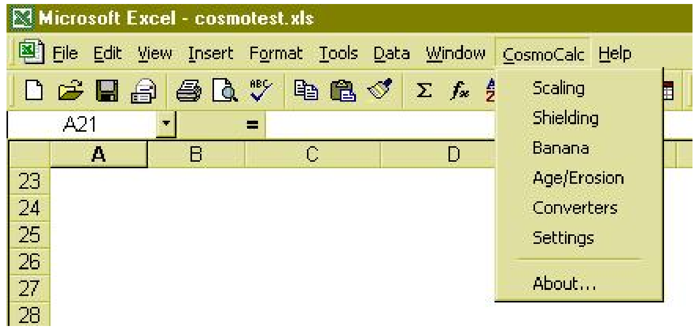
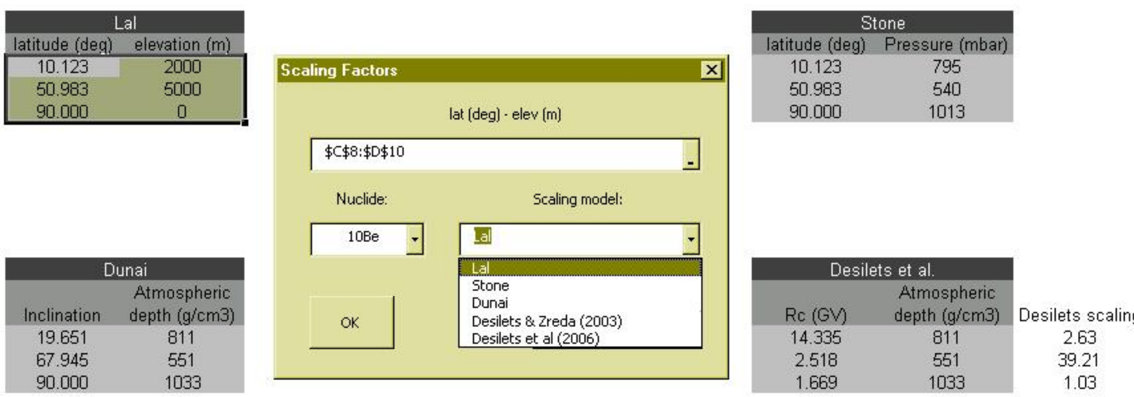
CosmoCalc.xla is an Excel add-in designed with the intention to implement the increasingly sophisticated tools of terrestrial cosmogenic nuclide geochronology in a user-friendly way, while enforcing the good practice of using a consistent set of production rate scaling factors for both the calibration sites and the unknown samples. The add-in as well as the CosmoTest.xls spreadsheet with test data can be downloaded from the CosmoCalc website http://cosmocalc.london-geochron.com. Full details about the calculations are provided in the G-Cubed article [1].



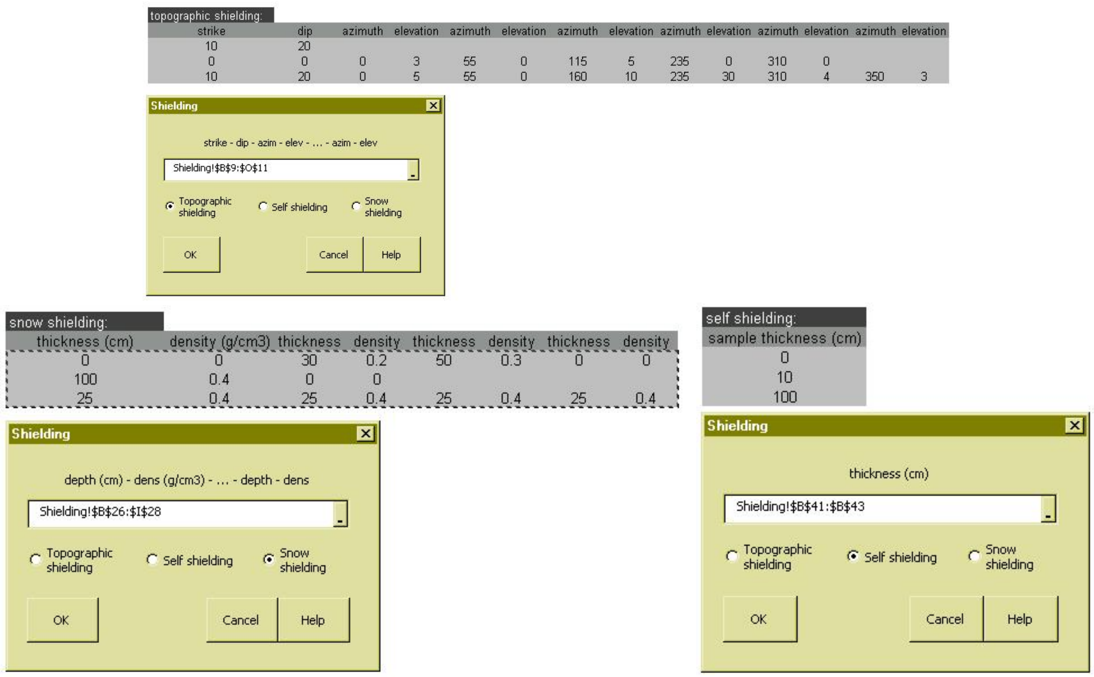
CosmoCalc can be installed by downloading CosmoCalc.xla to the Excel Add-Ins folder. Start Excel and select Tools → Add-Ins, or More Commands → Add-Ins in Excel2010 and above. An Add-In is enabled when its checkbox is marked. The Add-In is disabled by unmarking the CosmoCalc checkbox. To remove the program, simply remove the .xla file from the Add-In folder.



After installing the add-in (see downloadable instructions), a toolbar menu appears that guides the user through the data reduction and closely follows the outline of this manual. The following pages will show how to scale production rates for latitude and elevation, how to calculate topographic, snow and self-shielding factors, generate banana-plots, calculate exposure ages, burial ages and erosion rates, and calculate geomagnetic cutoff rigidities, atmospheric depths and so forth.



Cosmogenic nuclide production rates are a sensitive function of latitude and elevation, and a lively debate is going on in the community as to how to best calculate these scaling factors. CosmoCalc presently implements four scaling models: Lal [2], Stone [3], Dunai [4] and Desilets [5][6]. Although the more recent models such as those by Dunai and Desilets are significantly more sophisticated than the early scaling model by Lal, they are just as easy to use in CosmoCalc: just select two columns with a measure of the sample's latitude and elevation, select the nuclide and scaling model of interest and click "OK".



It is equally simple to compute topographic, snow and self-shielding factors. The nuclide concentrations and the product of the scaling and shielding factors are the only input required for all further calculations.

CosmoCalc uses the ingrowth equation of Granger and Smith [7], which is a summation of four exponentials: one for neutrons, two for slow muons and one for fast muons.

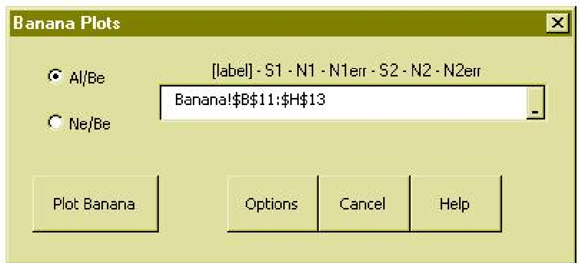
$$N(t,\epsilon,\tau) = Pe^{-\lambda\tau}\sum_{i=0}^{3}\frac{S_iF_i}{\lambda+\epsilon\rho/\Lambda_i}\left(1-e^{-(\lambda+\epsilon\rho/\Lambda_i)t}\right)$$

with:

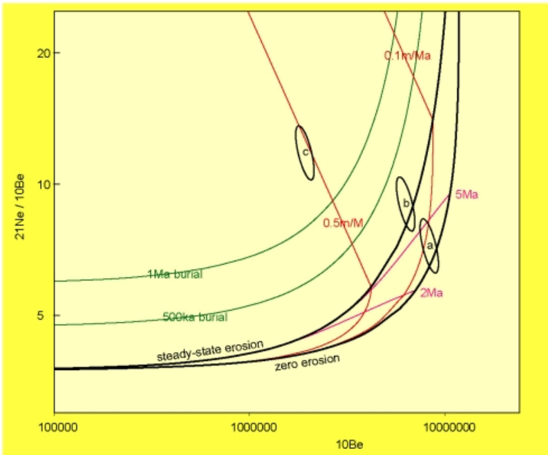
N = nuclide concentration	t = age
ϵ = erosion rate	τ = burial age
P = SLHL production rate	ρ = rock density
λ = decay constant	Λ_i = attenuation length
S_i = scaling factor	F_i = relative production
i = 0: neutrons	i = 1, 2: slow muons
i = 3: fast muons	

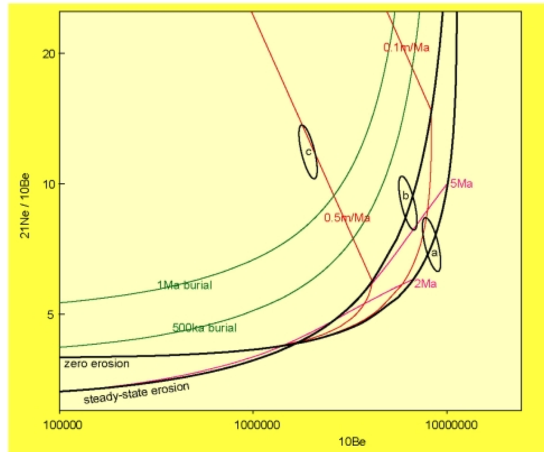
Default values for the various parameters in this equation are those advocated by [7], but alternative values can also be set. In a simple exposure history, the cosmogenic nuclide concentration is a function of the exposure age, the erosion rate and the burial age. Those are three parameters, so if only one nuclide was measured, we need two assumptions, whereas if two nuclides were analysed, of which at least one radionuclide, only one assumption is needed.

Label	Sc	26Al	26Al err	Sc	10Be	10Be err
a	1.0	4.595E+06	2.297E+05	1.0	1.720E+06	8.599E+04
b	4.0	1.047E+06	5.234E+04	4.0	5.388E+05	2.694E+04
c	2.0	2.888E+07	1.444E+06	2.0	6.143E+06	3.072E+05



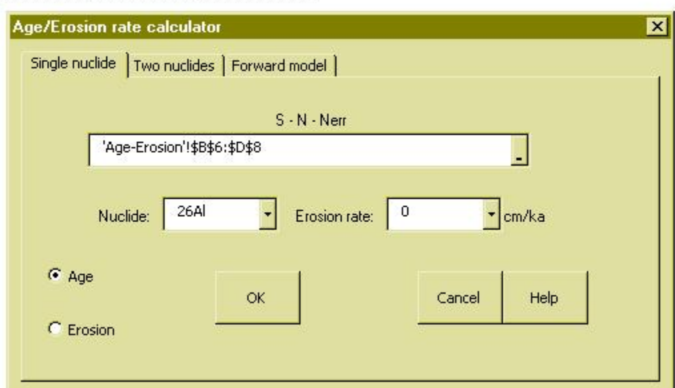
Measuring two nuclides also allows the generation of banana-plots. These are sophisticated devices which depend on a large number of parameters, such as the production rates at sea level and high latitude, the scaling model, and the relative proportions of the various production mechanisms. Prior to CosmoCalc, banana plots were often generated in graphics applications such as Grapher$^{©}$. The advantage of CosmoCalc is once again its flexibility. Different kinds of Al-Be and Ne-Be plots can be generated on the fly.





These two Ne-Be plots, for example, show how the contribution of muons causes a characteristic cross-over between the steady-state and zero erosion lines, which is absent when muons are neglected.

1 nuclide dating		
S	26Al	26Al err
5.0	3.225E+07	1.61E+06
14.0	6.714E+06	3.36E+05
1.0	2.412E+05	1.21E+04



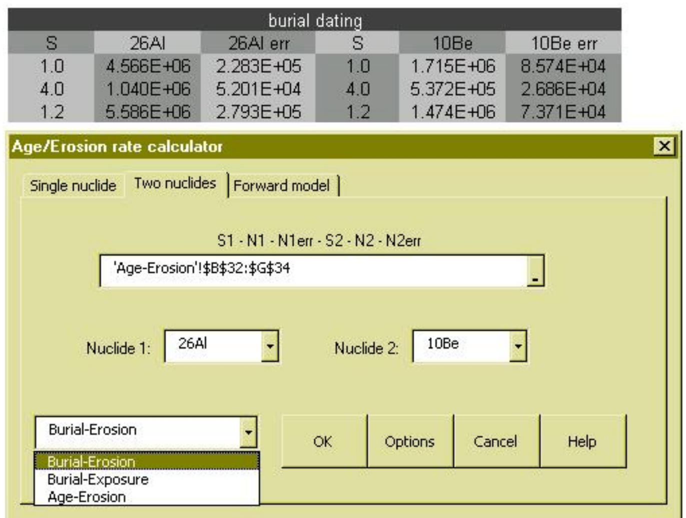
Given a scaling factor and the concentration of a single nuclide, and assuming zero burial, CosmoCalc can either calculate a steady state erosion rate, or a finite exposure age under the assumption of a particular erosion rate.

Only one assumption is needed if two nuclides were measured. For example, by assuming an erosional steady state and setting an infinite exposure age, CosmoCalc simultaneously computes the erosion rate and burial age:

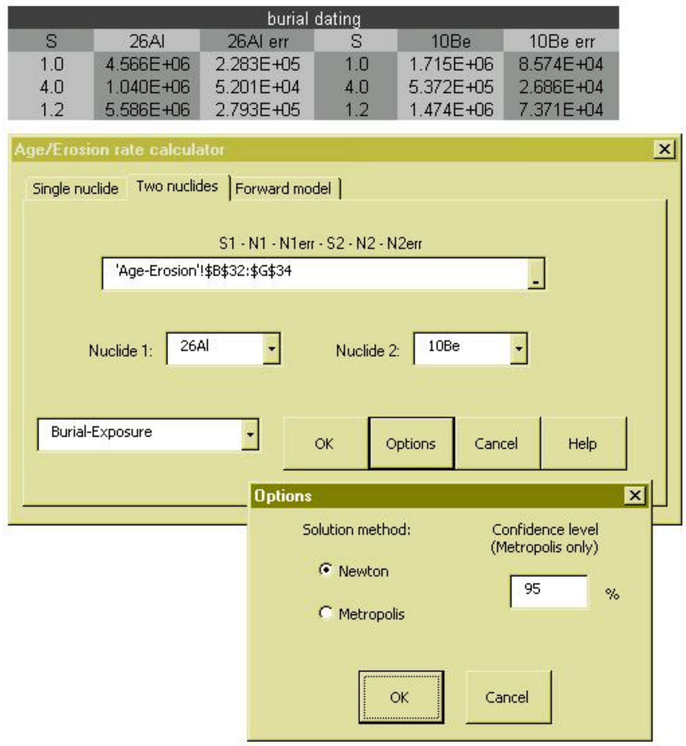
$$\begin{cases} f_1(\epsilon,\tau) : N_1 = P_1 e^{-\lambda_1 \tau} \sum_{i=0}^{3} \frac{S_{i,1}F_{i,1}}{\lambda_1+\epsilon\rho/\Lambda_{i,1}} \\ f_2(\epsilon,\tau) : N_2 = P_2 e^{-\lambda_2 \tau} \sum_{i=0}^{3} \frac{S_{i,2}F_{i,2}}{\lambda_2+\epsilon\rho/\Lambda_{i,2}} \end{cases}$$

Alternatively, if a sample plots inside the erosion island of the banana plot, we can safely assume zero burial, and simultaneously compute the exposure age and erosion rate:

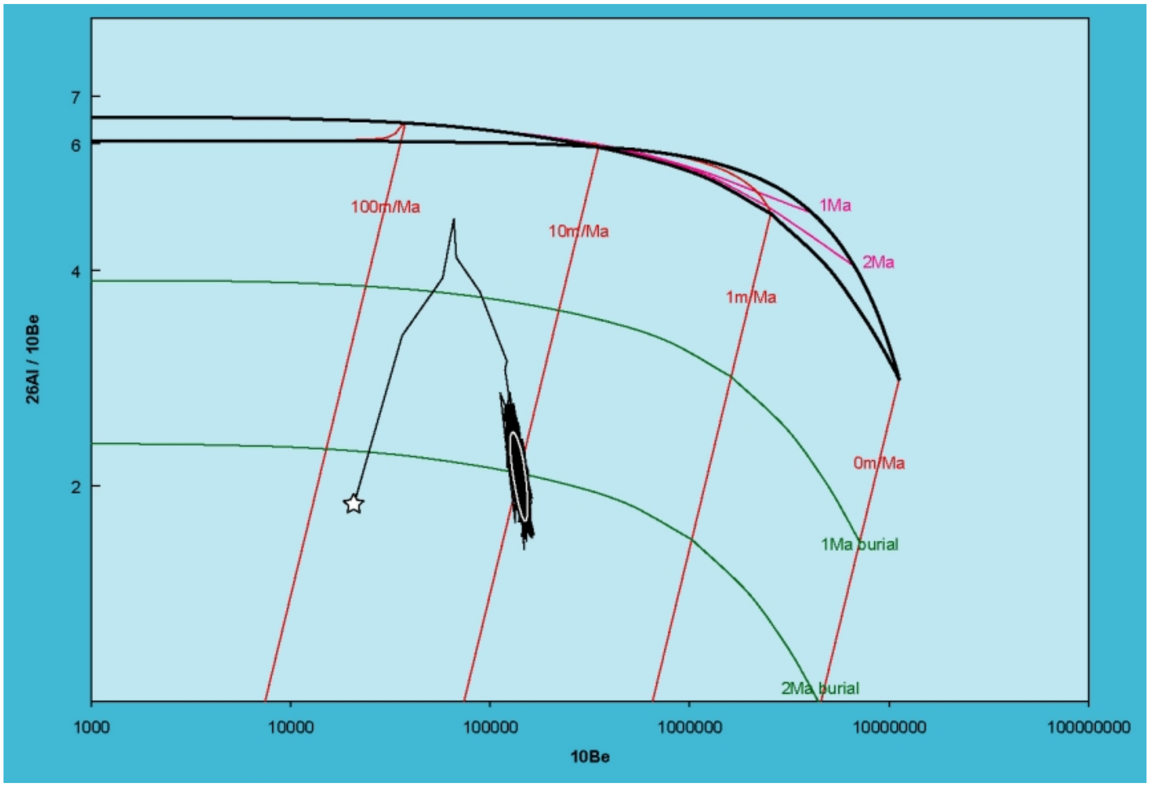
$$\begin{cases} f_1(\epsilon,t) : N_1 = P_1 \sum_{i=0}^{3} \frac{S_{i,1}F_{i,1}}{\lambda_1+\epsilon\rho/\Lambda_{i,1}} \left(1-e^{-(\lambda_1+\epsilon\rho/\Lambda_{i,1})t}\right) \\ f_2(\epsilon,t) : N_2 = P_2 \sum_{i=0}^{3} \frac{S_{i,2}F_{i,2}}{\lambda_2+\epsilon\rho/\Lambda_{i,2}} \left(1-e^{-(\lambda_2+\epsilon\rho/\Lambda_{i,2})t}\right) \end{cases}$$



All these calculations are equally simple in CosmoCalc. Simply select the desired calculation and the two nuclides from pull-down menus, select two times three columns of the spreadsheet with the correction factors, the nuclide concentrations and their 1-σ uncertainties, and click “OK”.



CosmoCalc implements two numerical techniques to solve the non-linear systems of equations. The default is Newton's method, which is a very fast and exact algorithm. The Metropolis algorithm is offered as an alternative.



The Metropolis algorithm is a Monte Carlo method that is computationally considerably more intensive than Newton's method. Over a thousand iterations, it first converges from an initial guess to the correct solution and then continues to sample the entire solution space. The Metropolis algorithm has two advantages of Newton's method. First, it will always find a solution, even if the sample plots just into the so-called "forbidden zone" of the banana plot. Newton's method would diverge in this case.

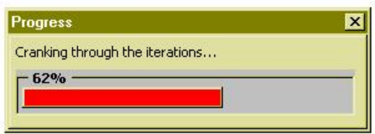
Second, the Metropolis algorithm will yield asymmetric and therefore more meaningful confidence intervals than the symmetric confidence bounds given by Newton's method, which are calculated by standard error propagation.

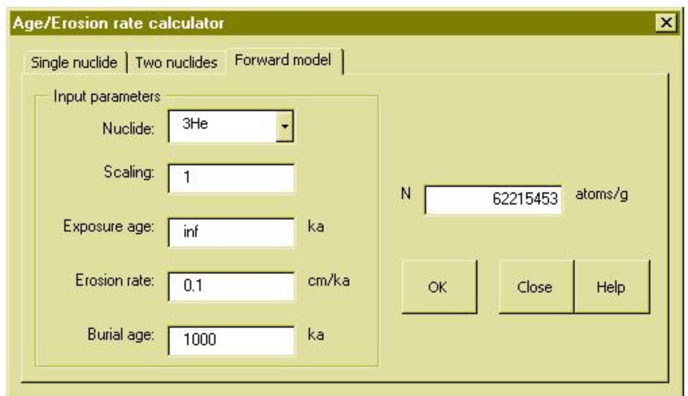
Newton:

burial dating									
S	26Al	26Al err	S	10Be	10Be err	Burial Age (ka)	1 sigma	Exposure Age	1 sigma
1.0	4.566E+06	2.283E+05	1.0	1.715E+06	8.574E+04	1217.5	212.9	680.5	183.7
4.0	1.040E+06	5.201E+04	4.0	5.372E+05	2.686E+04	2103.5	227.1	69.7	14.2
1.2	5.586E+06	2.793E+05	1.2	1.474E+06	7.371E+04	686.1	326.8	356.4	131.0

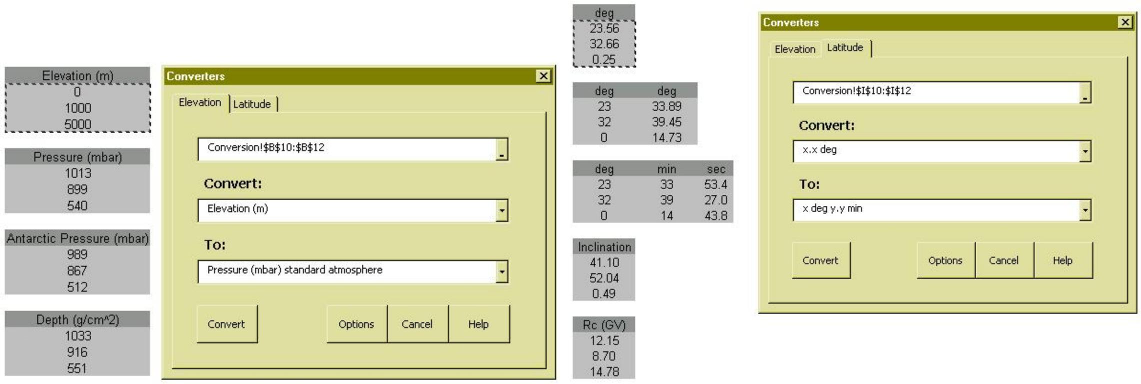
Metropolis:

burial dating											
S	26Al	26Al err	S	10Be	10Be err	Burial age (ka)	2.5 pctile	97.5 pctile	Exposure age (ka)	2.5 pctile	97.5 pctile
1.0	4.566E+06	2.283E+05	1.0	1.715E+06	8.574E+04	1209.6	901.2	1531.1	676.8	491.1	896.0
4.0	1.040E+06	5.201E+04	4.0	5.372E+05	2.686E+04	2099.6	1753.9	2448.1	69.4	52.6	91.4
1.2	5.586E+06	2.793E+05	1.2	1.474E+06	7.371E+04						

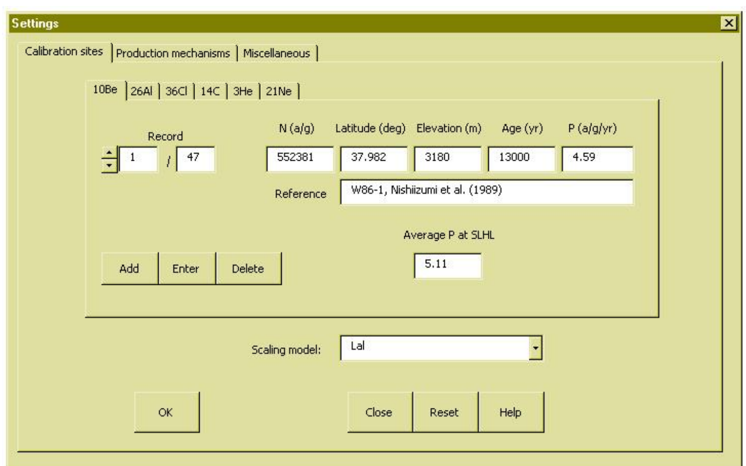




CosmoCalc also provides a useful forward modeling function. This function was used to generate the synthetic data of the CosmoTest worksheet.

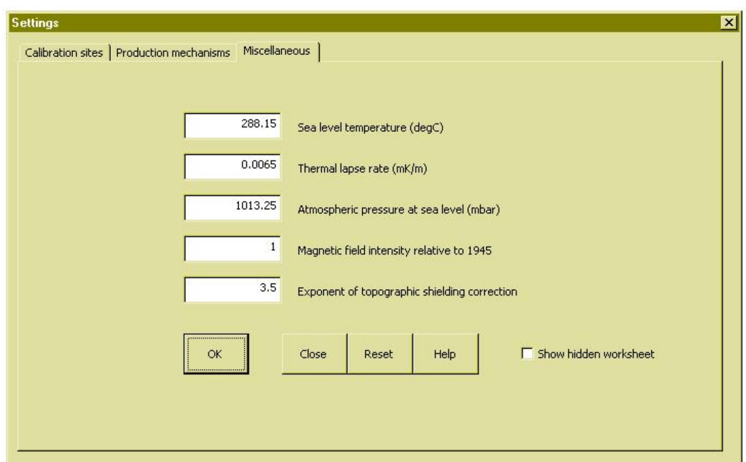


Different scaling models use different kinds of geographic input. For example, Lal's scaling model uses elevation whereas Stone uses atmospheric pressure and Dunai and Desilets atmospheric depth. Furthermore, Lal and Stone use geomagnetic latitude whereas Dunai uses geomagnetic inclination and Desilets cutoff rigidity. To facilitate the comparison of the various scaling models, CosmoCalc provides some easy-to-use conversion tools.



Scaling factors are the subject of much debate, and are definitely an important issue, but they all have one thing in common, namely the crucial importance of using the same scaling model for the unknown sample and the calibration sites. For this reason, CosmoCalc defines the production rates not explicitly but *implicitly*, by specifying the raw measurements of the calibration sites. The program comes with a set of default calibration sites, but this list can be modified by removing and adding new sites.

It was shown earlier that the ingrowth equation is made up of 4 exponentials, all parameters of which can be customized in this menu, where the relative contribution of neutrons and muons as well as their respective attenuation lengths can be set. The default values are those recommended by Granger and Smith [7], but alternative options are also given, or custom values can be set by the user. For example, the ingrowth equation of Schaller et al. [8], which contains not 4 but 8 exponentials, is implemented in CosmoCalc by a least squares approximation of four exponentials.



Finally, some leftover parameters important for the scaling and shielding factors can be set on the last tab of the shielding menu.

References

[1] Vermeesch, P., 2007, CosmoCalc: an Excel add-in for cosmogenic nuclide calculations: Geochemistry, Geophysics, and Geosystems (in press)

[2] Lal, D., Cosmic ray labeling of erosion surfaces: in situ nuclide production rates and erosion models, *Earth and Planetary Science Letters, 104*, 424-439, 1991.

[3] Stone, J., Air pressure and cosmogenic isotope production, *Journal of Geophysical Research, 105*, 23753-23759, 2000.

[4] Dunai, T.J., Scaling factors for production rates of in situ produced cosmogenic nuclides: a critical reevaluation, *Earth and Planetary Science Letters, 176*, 157-169, 2000.

[5] Desilets, D., and M. Zreda, Spatial and temporal distribution of secondary cosmic-ray nucleon intensities and applications to in situ cosmogenic dating, *Earth and Planetary Science Letters, 206*, 21-42, 2003.

[6] Desilets, D., M. Zreda, and T. Prabu, Extended scaling factors for in situ cosmogenic nuclides: New measurements at low latitude, *Earth and Planetary Science Letters, 246*, 265-276, 2006.

[7] Granger, D.E., and A.L. Smith, Dating buried sediments using radioactive decay and muogenic production of ^{26}Al and ^{10}Be, *Nuclear Instruments and Methods in Physics Research B, 172*, 822-826, 2000.

[8] Schaller, M., F. von Blanckenburg, A. Veldkamp, L.A. Tebbens, N. Hovius, and P.W. Kubik, A 30000yr record of erosion rates from cosmogenic ^{10}Be in Middle Europe river terraces, *Earth and Planetary Science Letters, 204*, 307-320, 2002.