Cosmogenic ^{21}Ne production systematics inferred from a 25-meter sandstone core

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***Summary**. We measured cosmic-ray-produced ^{21}Ne in quartz in a 25-meter sandstone core from an extremely low erosion rate site at high elevation in the Transantarctic Mountains. Fitting a ^{21}Ne production model to these data yields information about ^{21}Ne production systematics.*

Notable observations:

***Nucleogenic ^{21}Ne and Ne thermochronometry.** A significant fraction of ^{21}Ne in these samples is the result of U and Th decay and the reaction $^{18}O(\alpha,n)^{21}Ne$. Fitting a production model to these data requires parameterizing this part of the ^{21}Ne inventory as a function of the duration of nucleogenic Ne accumulation. Thus, the best-fit value of this parameter yields an Ne closure age. These rocks cooled through the Ne closure temperature (~90°C) at approx. 160 Ma.*

***Muon-produced ^{21}Ne.** These data require significant production of ^{21}Ne by muon interactions. Fitting a muon production model to these data implies that most of this production is by fast muon interactions, and negative muon capture is relatively unimportant. Existing estimates of muon interaction cross-sections do a decent job of fitting the data.*

What and why?

Measurements of cosmogenic ^{21}Ne in quartz from a 25-meter sandstone core. "Cosmogenic" ^{21}Ne is, in this case and in most others, measured by entirely degassing Ne from quartz samples under vacuum and then using the Ne isotope composition to deconvolve Ne produced by cosmic-ray bombardment from "trapped" Ne with atmospheric composition. This procedure, perhaps improperly, includes alpha-induced ^{21}Ne resulting from U and Th decay.

The point is to use the depth-dependence of cosmogenic ^{21}Ne concentrations to determine the relative importance of various ^{21}Ne production mechanisms. We do this by fitting a production model to the data.

^{21}Ne production mechanisms.

***Nucleogenic ^{21}Ne.** This is derived from the reaction $^{18}O(\alpha,n)^{21}Ne$. Nucleogenic ^{21}Ne production depends on the U and Th concentrations (which we have measured) and the duration of time the samples have resided below the Ne closure temperature (approx. 90° C). So the nucleogenic ^{21}Ne inventory can be parameterized by one free parameter - the Ne closure age.*

***Spallogenic ^{21}Ne.** The spallogenic ^{21}Ne inventory can be specified by the surface ^{21}Ne production rate (which we can estimate from independent calibration studies), the surface erosion rate, and an effective attenuation length Λ_{sp}. The exposure age and erosion rate at this site are such that spallogenic ^{21}Ne has most likely reached production-erosion equilibrium, so an exposure time is not required. We can't estimate both the erosion rate and the production rate simultaneously, so we specify the surface production rate.*

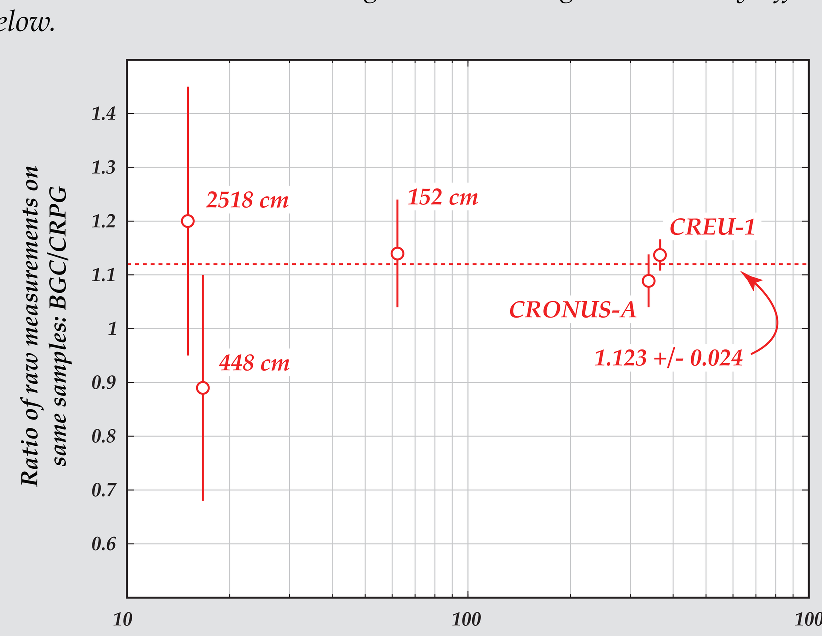
***Muon-produced ^{21}Ne.** We can compute the muon flux and energy distribution at our sample depths from the scheme of Heisinger and others, leaving three parameters that are necessary to specify the inventory of muon-produced ^{21}Ne: f^*, a yield factor for negative muon capture; σ_{190}, a cross-section for fast muon interactions, and an integration time for muon production. An integration time is required because the erosion rate at this site is such that the time required to attain production-erosion steady state for muon-produced ^{21}Ne is well in excess of the geological constraints on the Ne closure age.*

***Summary**. A forward model for these data requires seven parameters: Ne closure age, surface spallogenic production rate, erosion rate, Λ_{sp}, f^*, σ_{190} and an integration time for production by muons. Of these, two must be specified: neither the surface production rate and the erosion rate, or the muon integration time and cross-sections, can be found simultaneously. There are some geological limits on some of the parameters: the Ne closure age and the muon integration time can't exceed 177 Ma (the age of basaltic dikes whose emplacement would have caused heating and Ne loss) or be less than ca. 15 Ma (since which the topography has been essentially static).*

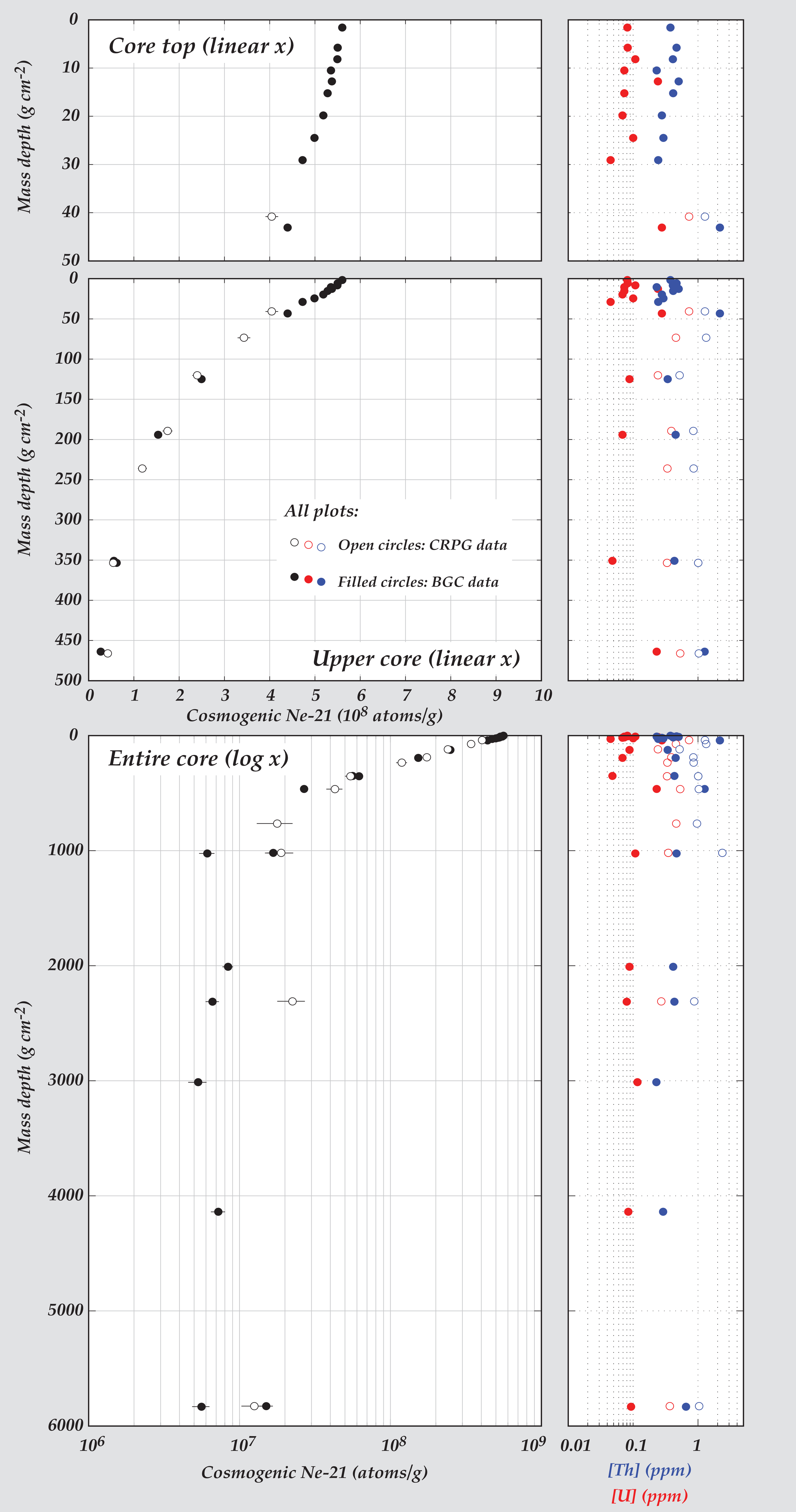
***Note:** We retract our statement from the abstract about the importance of alpha particle implantation. Differences in U and Th concentrations between etched and un-etched samples appear to fully account for the corresponding difference in ^{21}Ne concentrations. We did not have a complete set of U and Th measurements at the time of writing the abstract.*

Hidden in the small print at the bottom of the poster: interlaboratory standardization by exchange of samples

Both labs - CRPG and BGC - analysed (multiple) separate aliquots of five samples: two widely distributed intercomparison standards and three samples from the core itself. This exercise shows a systematic offset of ~10% between CRPG and BGC measurements of cosmogenic Ne-21. Obviously, we are investigating this. For purposes of this poster, the smaller data set (CRPG) has been normalized to the larger (BGC) using the summary offset shown below.



Results: total "cosmogenic" ^{21}Ne, [U], [Th]

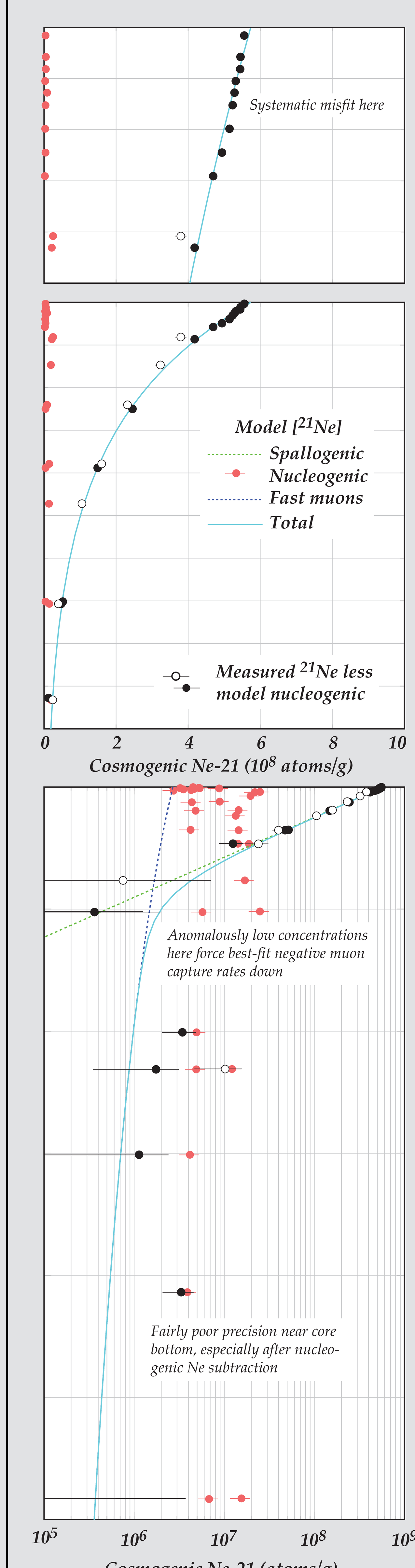


Notable observations:

- Scatter in cosmogenic ^{21}Ne concentrations appears correlated with [U] and [Th] -- in particular, comparison of samples from similar depths prepared at BGC (HF-etched) and those prepared at CRPG (not HF-etched) show that HF-etched samples have less U, Th, and cosmogenic ^{21}Ne.

"Cosmogenic" ^{21}Ne concentrations do not decrease below about 1000 g cm-2, which indicates that a significant fraction of "cosmogenic" ^{21}Ne in deep samples is in fact nucleogenic. These observations imply significant nucleogenic ^{21}Ne concentrations - more than 10 Matoms/g for some samples.

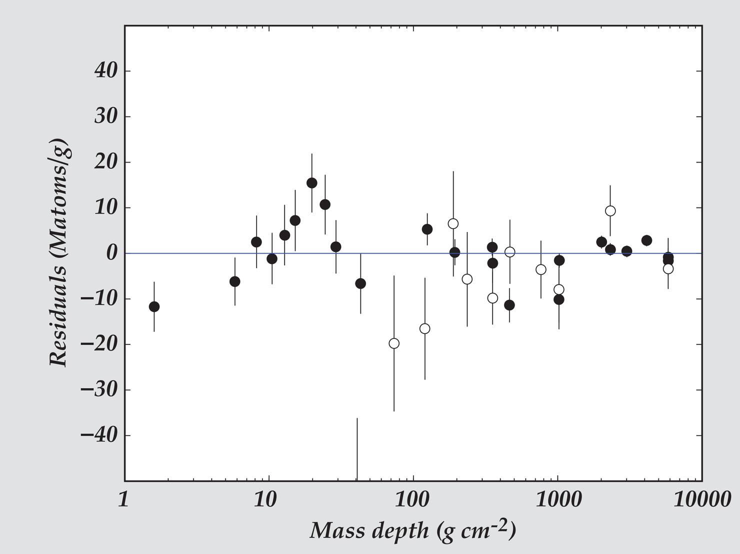
Data fitting and what we can learn from these data



One good fit (below and at left):

Specified: *Spallogenic ^{21}Ne production rate (150 atoms g^{-1} yr^{-1})*
Muon integration time (15 Ma)

Results: *Erosion rate 37 g cm^{-2} yr^{-1}*
Λ_{sp} 142.3 g cm^{-2}
Ne closure age 158 Ma
Negligible negative muon capture ($f^* = 0$)
$\sigma_{190} = 0.264$ mb ($P_{fast} = 0.13$ atoms g^{-1} yr^{-1} at SLHL)
$\chi^2/v = 2.3$



Other questions we might reasonably ask:

***Are existing estimates of muon interaction cross-sections consistent with these data?** Fernandez-Mosquera et al. (GRL, 2010) estimated f^* and σ_{190} from analogue reactions. If we specify these values, we can allow the integration time for muon production to be a free parameter.*

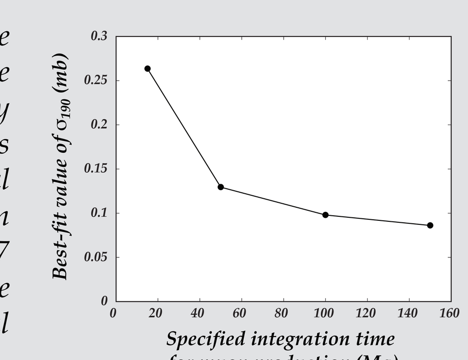
Specified: *Spallogenic ^{21}Ne production rate (150 atoms g^{-1} yr^{-1})*
$f^* = 0.29$ %; $\sigma_{190} = 0.79$ mb

Results: *Erosion rate 36 g cm^{-2} yr^{-1}*
Λ_{sp} 142.3 g cm^{-2}
Ne closure age 120 Ma
Muon integration time 15 Ma (see below)
$\chi^2/v = 2.7$

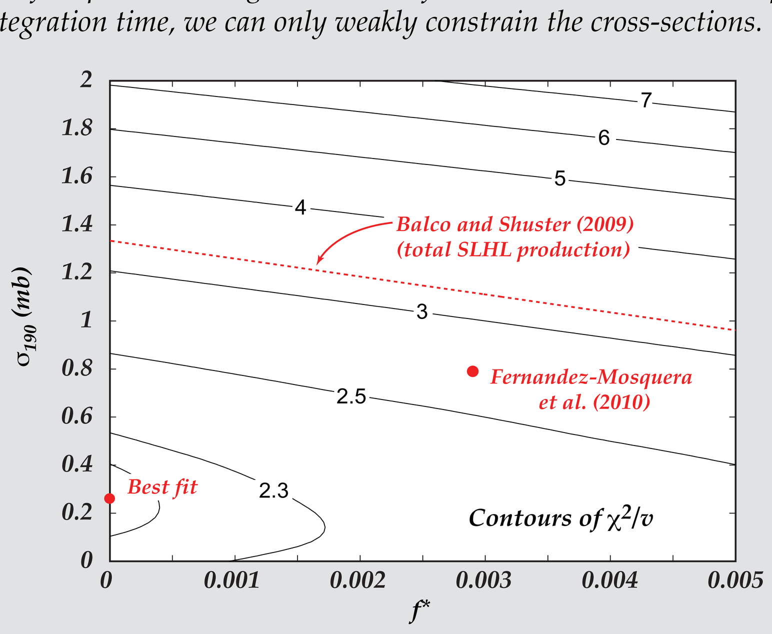
This results in a slightly poorer fit. The fit could be improved by reducing the integration time, but that would violate geologic constraints.

How accurately have we constrained muon interaction cross-sections?

First, there is a tradeoff between the integration time we use to compute the muon-produced Ne inventory and the interaction cross-sections that we infer. Because the geological limits on the integration time span an order of magnitude (15 Ma - 177 Ma), we can't uniquely determine the cross-sections absent additional information.



Second, reasonable fits can be obtained with a broad range of muon interaction cross-sections. Here we show the best fit values obtainable by specifying muon interaction parameters and allowing the integration time as a free parameter. Again, without further constraints on the appropriate integration time, we can only weakly constrain the cross-sections.



Notable observations:

- Systematic misfit near surface: "spallation nose?"

- Significant contribution implied from nucleogenic Ne

- Fast muon production strongly favored over negative muon capture

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