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**Subject:** **Fossil regoliths**  
**Date:** April 25, 2007 12:20:43 PM EDT  
**To:** "Mckay, David S. (JSC-KA)" <david.s.mckay@nasa.gov>  
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 1 Attachment, 1.5 MB

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David,

I read your text on fossil regoliths recently posted on the lunar list server. You and several others have emphasized what important information may be learned about solar history from future studies of the lunar regolith, especially fossil regoliths. In your own words: "*The implications of decoding this information would be immense and might change our basic concepts of the evolution of ...the sun..... Documentation of this record preserved in the lunar regolith may turn out to be the single most useful scientific task for human*

*visits to the moon, and could justify the entire program in the eyes of the public, Congress, and the Administration"*

Although fossil regoliths MAY give new information about ancient solar particle fluxes and compositions and the history of the Sun, I would make four cautioning points.

1) Solar physicists do not expect the composition of most solar elements to have significantly evolved over time. (The D/H ratio is one clear exception, but most of its evolution occurred very early.) Attempts to explain the variable 15N/14N ratio in the lunar regolith as solar variability over time were resisted by solar physicists, and today many believe this variability is not in the solar wind. So, differences in solar wind compositions between old versus young regoliths are probably quite small.

2) Isotopic fractionation of solar wind species implanted into lunar regolith is significant, ubiquitous, and not always easy to correct for. An example is solar wind Xe. Xe is a large and heavy species which has a relatively low diffusion rate compared to other noble gases. Several labs working with lunar soils from several Apollo missions used grain-size separates to determine the isotopic composition of solar wind Xe. The figure below plots the results of these various studies, along with some related data. Although this scanned graph (from a 1974 GCA paper of mine) is of poor quality, you can see that all of these trapped Xe compositions vary by about 4% in each of these isotopic ratios. Further, the variability in these ratios fall along the theoretical mass fractionation trends, demonstrating that these variable trapped solar compositions were generated by diffusion loss and related processes within the regolith. This amount of isotopic variability is greater than any expected solar variability and probably also exists in fossil regoliths. So, how does one resolve any variation in old and recent solar wind from these lunar regolith effects? Where along these fractionation trends is the "true" solar wind Xe composition?

<<Xe\_Fractionation.bmp>>

3) Effects of heating of a fossil regolith by a later, overlying lava flow may further produce species fractionation. This effect would be more serious on thin regoliths, as Ian Crawford discusses in his lunar list server text.

4) Due to significant loss processes of many solar wind species by diffusion and sputtering in the lunar regolith, the absolute and relative abundance of elements is also difficult to determine. These regolith effects are also likely larger than any natural solar variations. Considering higher energy solar particles, e.g. solar flare proton fluxes, whose variability over time is an important question, one can analyze the products of nuclear interactions of these solar particles with the regolith. However, such studies rely, not on fine-grained regolith, but on surfaces of cm-size thickness, which have been exposed sufficiently long to accumulate measurable products, but not so long so as to establish erosional equilibrium over the whole nuclear interaction depth. A favorable time is of the order of a million years. In the Apollo collection, relatively few samples have met these criteria and have yielded relevant data. (See Rao et al., GCA 58, p.4231). Thus, although scientifically valuable, such special samples may be hard to identify in fossil regoliths.

Donald Bogard, ARES, Code KR, NASA/JSC

*Human history becomes more and more a race between education and catastrophe.*

*H.G. Wells*

*A man's mind once stretched by a new idea can never return to its original dimension.*

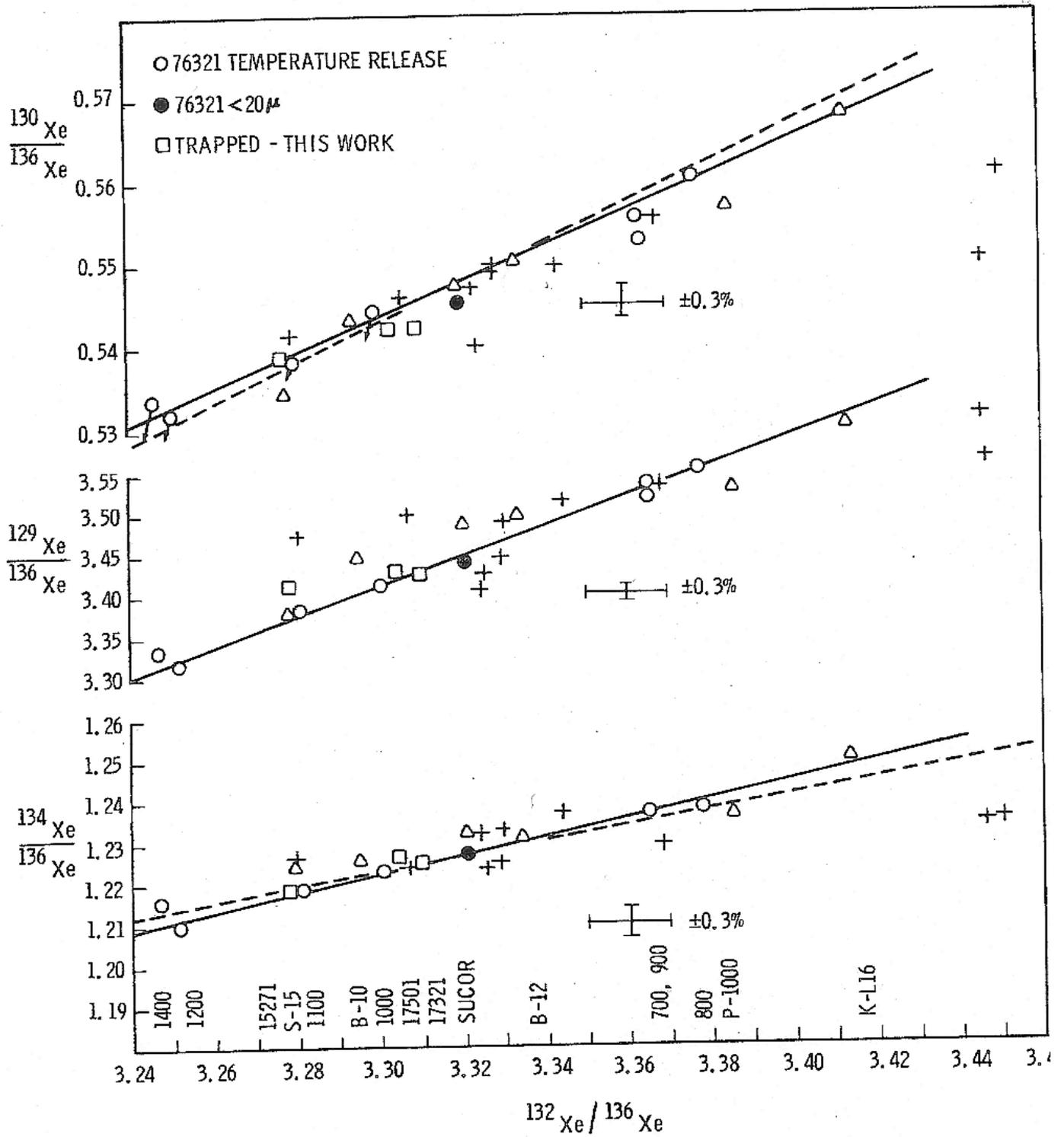


Fig. 5. Isotope correlation plots for five isotopes of Xe from the stepwise temperature release of 76321,  $<20 \mu$ . Temperatures are indicated in  $^{\circ}\text{C}$ . The solid lines represent linear mass fractionation trends normalized to  $^{132}\text{Xe}/^{136}\text{Xe} = 3.321$  as measured in the  $<20 \mu$  size fraction. (The mass fractionation trend for  $^{129}\text{Xe}/^{136}\text{Xe}$  is graphically indistinguishable from the solid line.) Corrections to the 1000–1400 $^{\circ}\text{C}$  data for cosmogenic Xe are shown in the  $^{130}\text{Xe}/^{136}\text{Xe}$  plot as short arrows. A number of trapped Xe compositions (including those in Table 5) are also shown and are identified as follows: crosses (+), various soils from five lunar sites, Basford *et al.* (1973); triangles: SUCOR, Podosek *et al.* (1971); B-10 = BEOC 10084, Eberhardt *et al.* (1970); B-12 = BEOC 12001, Eberhardt *et al.* (1972); P-1000, the 1000 $^{\circ}\text{C}$  extraction of Pesyanoe, Marti (1969); K-L16 = Luna 16 fines, Kaiser (1972); S-15 = 15601, Srinivasan *et al.* (1972). A typical uncertainty in trapped isotopic ratios of  $\pm 0.3\%$  is shown; some reported uncertainties are