Determining continental crust sources using zircons from Proterozoic Piedmont rocks of central Virginia

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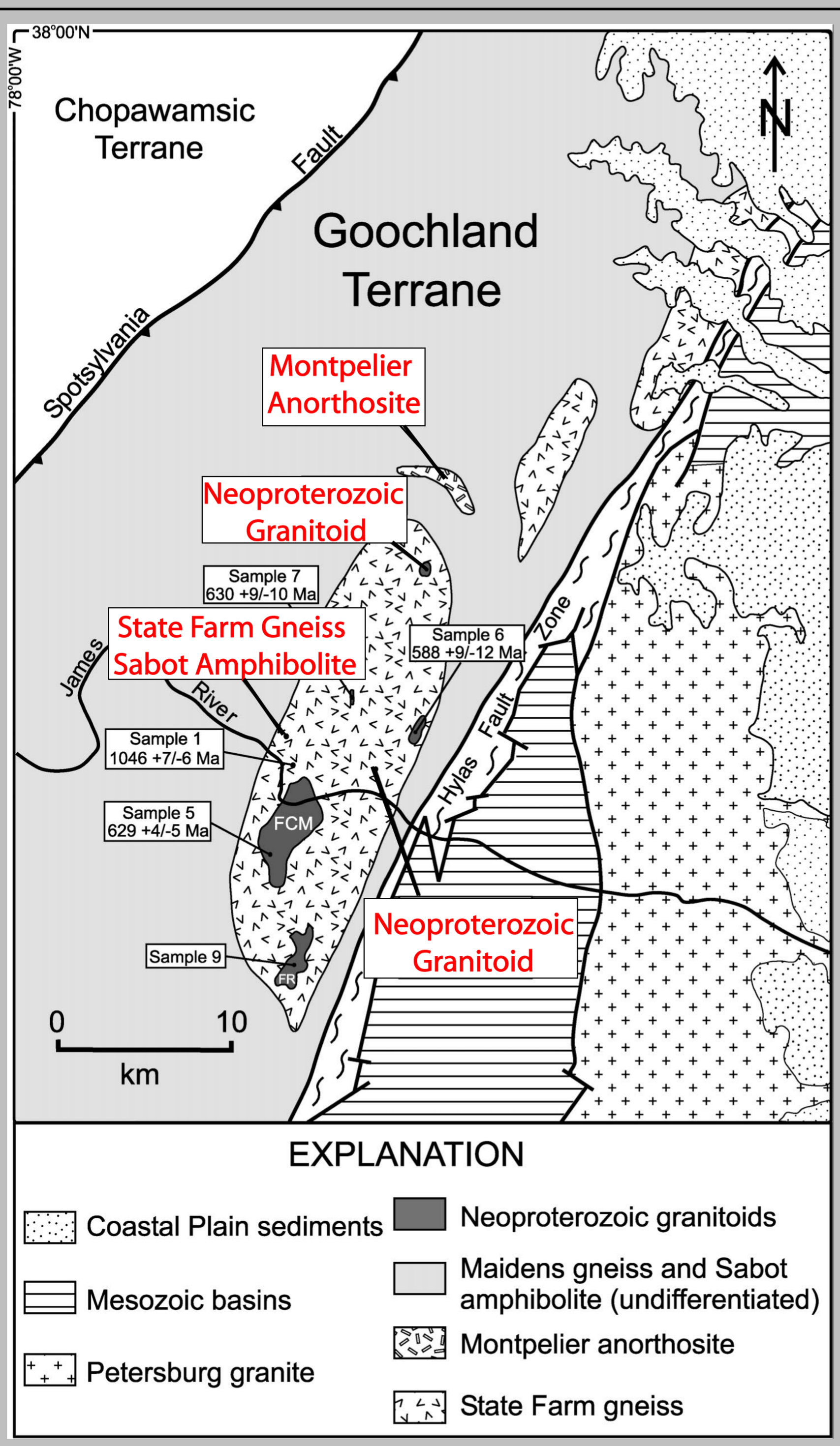

I. Introduction

The Goochland terrane is interpreted to be a section of continental crust and is situated within the Piedmont Province of central Virginia (Fig. 1). It is bordered on the east by the Hylas fault zone and on the west by the Spotsylvania fault.

The rocks within the terrane underwent granulite facies metamorphism during the Mesoproterozoic, as evidenced by relict granulite assemblages, and amphibolite facies metamorphism during the late Paleozoic.

The crystallization dates reflect a complex history of orogenic and rifting events starting during the Grenville orogeny and extending through the rifting of Rodinia. This study examines the sources of the igneous rocks during those events in terms of mantle, crustal, or mixed sources. The five rocks investigated are listed below with their crystallization ages.

- **State Farm gneiss** 1057-1013Ma
- **Montpelier anorthosite** 1045±10 Ma
- **Neoproterozoic granitoid A** &
- **Neoproterozoic granitoid B**
  - Inherited cores ca. 1Ga
  - Neoproterozoic rims 654-588 Ma
- **Sabot amphibolite** 552±11 Ma

Figure 1. Geologic map of the Goochland terrane. Sample sites are in red type. The Neoproterozoic granitoids intrude the State Farm gneiss dome. The Montpelier anorthosite may also intrude the State Farm gneiss at depth.

Figure 2. Photograph of the Sabot amphibolite with a blue rock hammer for scale. Dark mafic layers are interlayered with light felsic layers; all slope from the upper left to lower right corner of the image. Image courtesy of Brent Owens.

II. Hypothesis

The magmas that formed the five igneous rocks came only from crustal sources. I performed isotope analyses for oxygen, Lu-Hf, and U-Pb on separated zircons to test the hypothesis regarding the sources of the magmas.

III. Methods of Analysis

Table 1

Technique	Purpose	Location
Standard mineral separation	Separate zircons from rocks	University of Maryland
CL and BSE imaging	Create images of the zircon grains	University of Maryland
Secondary Ionization Mass Spectrometry	Analyze oxygen isotope ratios	University of Wisconsin - Madison
Split stream LA-ICP-MS	Simultaneously analyze U-Pb ratios and Lu-Hf ratios	Washington State University

IV. Results

- $^{18}O/^{16}O$, $^{176}Hf/^{177}Hf$, and $^{207}Pb/^{206}Pb$ ratios were used to calculate $\delta^{18}O$, εHf, and crystallization age values
- Analysis spots that had crystallization ages outside of the previously published age ranges were excluded
- $\delta^{18}O$ and εHf values for the Neoproterozoic granitoids are different than the $\delta^{18}O$ and εHf values of the State Farm gneiss
- Some inherited cores from the granitoids have $\delta^{18}O$ and εHf values similar to the gneiss
- Montpelier anorthosite has $\delta^{18}O$ values similar to the gneiss
- Sabot amphibolite has positive εHf values and one point that has mantle-like $\delta^{18}O$ values

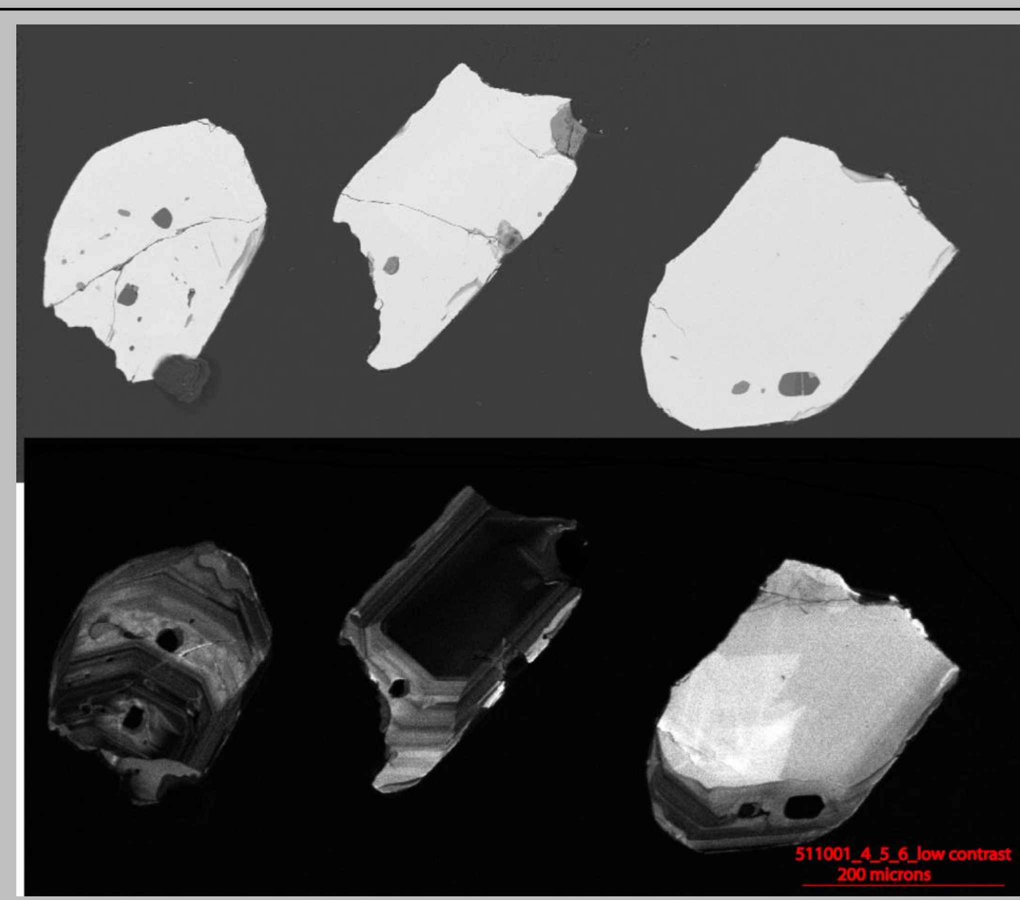

Figure 2. Backscatter electron (above) and cathodoluminescence (below) images of zircons from Neoproterozoic granitoid A. Zones and inclusions are visible in all three grains. Darker cores are recognizable in the left and center grains.

V. Discussion

Figure 4

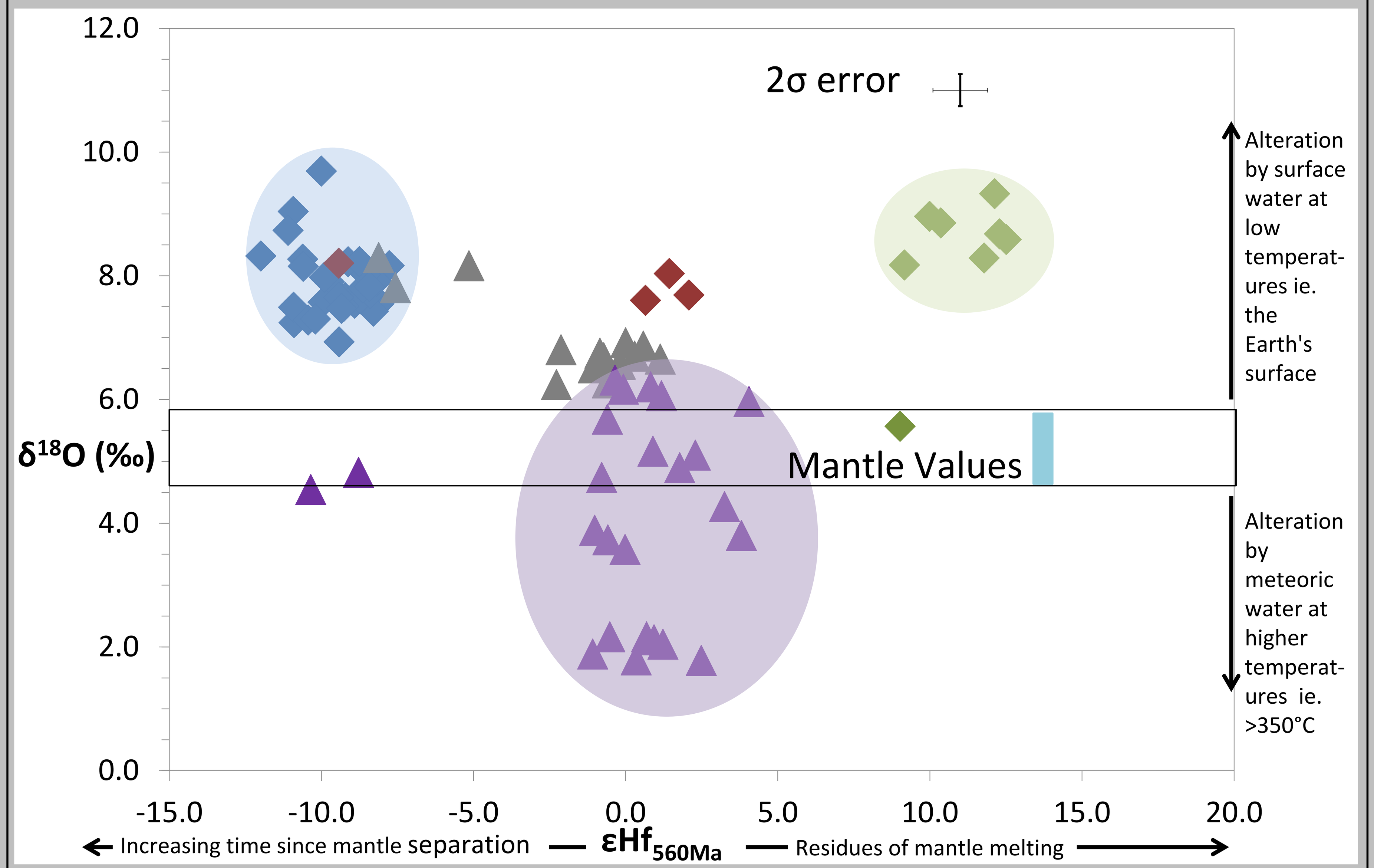

Figure 4. Graph of $\delta^{18}O$ values compared to εHf of all five rocks calculated at 560Ma. The $\delta^{18}O$ range for the mantle is outlined in black and is from Kemp and Hawkesworth. The pale blue box represents the εHf values of the depleted mantle.

V. Discussion

Figure 5

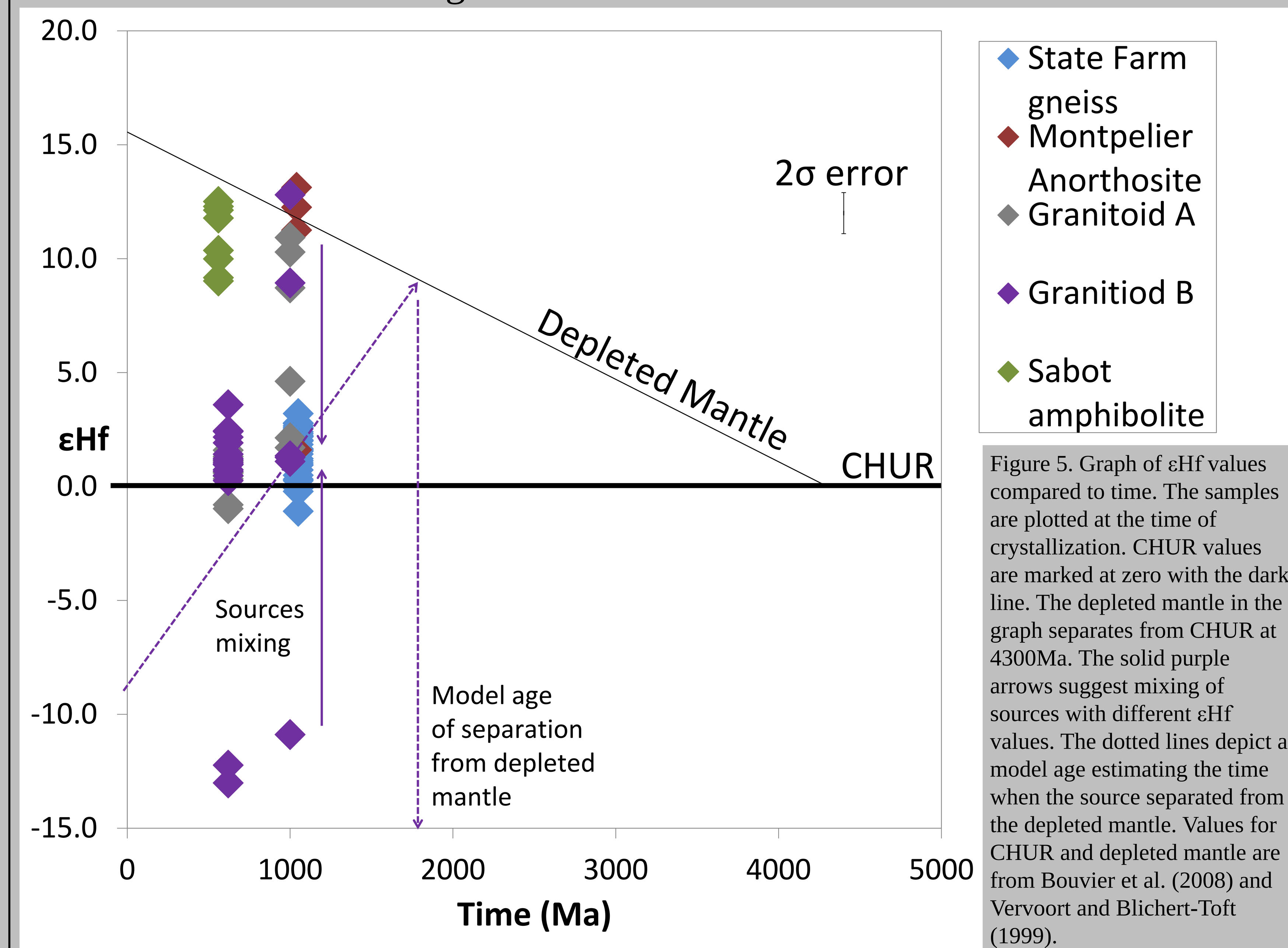

Figure 5. Graph of εHf values compared to time. The samples are plotted at the time of crystallization. CHUR values are marked at zero with the dark line. The depleted mantle in the graph separates from CHUR at 4300Ma. The solid purple arrows suggest mixing of sources with different εHf values. The dotted lines depict a model age estimating the time when the source separated from the depleted mantle. Values for CHUR and depleted mantle are from Bouvier et al. (2008) and Vervoort and Blichert-Toft (1999).

- Inherited cores in one Neoproterozoic granitoid have εHf and $\delta^{18}O$ values similar to the State Farm gneiss, suggesting the gneiss was the source of these zircons
- Gneiss and granitoids have different εHf and $\delta^{18}O$ values at 560Ma, which suggests:
  - they separated from the mantle at different times
  - gneiss was not the sole source of the granitoids
  - granitoids had a juvenile component in the source of melt
  - gneiss' $\delta^{18}O$ values suggest a supracrustal component in the melt
  - granitoids' range of lower $\delta^{18}O$ values suggest hydrothermal alteration at higher temperatures, mixing of a supracrustal component with a hydrothermally altered component
- Montpelier anorthosite has few data points, but:
  - one point has εHf and $\delta^{18}O$ signature of gneiss
  - three points have more juvenile εHf values like the granitoids
  - melt may have included zircon xenocrysts from the gneiss
  - more data is necessary to investigate the source of melt
- Sabot amphibolite suggests two sources of magma:
  - both sources had εHf values similar to depleted mantle
  - one source had supracrustal $\delta^{18}O$ values
  - the other source had mantle like $\delta^{18}O$ values
- Sabot amphibolite has interlayered mafic and felsic layers in the field (Figure 2), which is consistent with two different sources

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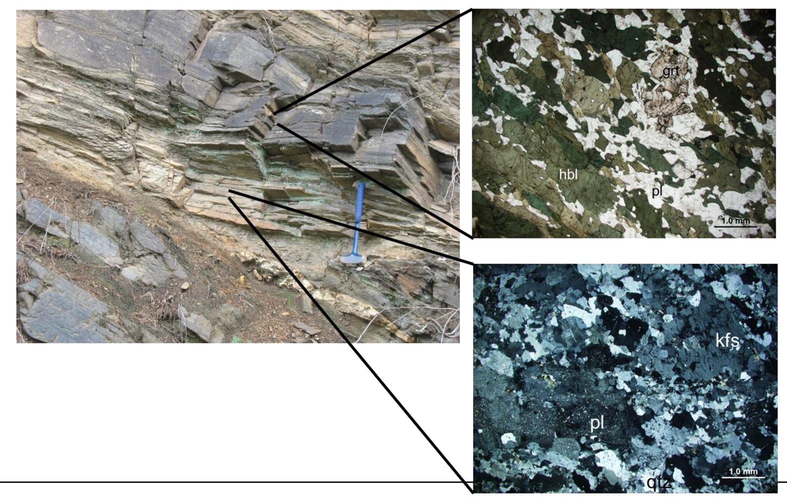
VI. Conclusions

- Neoproterozoic granitoids are not derived from only crustal sources
- Some inherited cores came from the State Farm gneiss, likely during granitoid intrusion of the gneiss
- Granitoids show strong evidence for a more juvenile component likely associated with rifting events
- Montpelier anorthosite has supracrustal $\delta^{18}O$ values and more juvenile εHf values
- Sabot amphibolite data support two different melt sources for mafic and felsic layers
- More research should investigate the anorthosite and the amphibolite layers



Technique	Purpose	Location
Standard mineral separation	Separate zircons from rocks	University of Maryland facilities
Cathodoluminescence and back scatter electron imaging	Create images of the surfaces and interiors of zircon grains	University of Maryland Electron Probe Microanalyzer
Secondary Ionization Mass Spectrometry	Analyze the oxygen isotope ratios within zircon grains	University of Wisconsin - Madison
Split stream Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry	Simultaneously analyze the U-Pb ratios and Lu-Hf ratios within zircon grains	Washington State University