

Metarhyolite use during the Transitional Archaic in Eastern North America

Gregory H. Bondar

Doctoral Candidate
Department of Anthropology
Penn State University
University Park, PA 16802-3404

Paper presented at the 66th Annual Meeting of the Society for American Archaeology in New Orleans, Louisiana, April 2001.

Paper should not be cited without the permission of the author.

Office: 814-865-1231
FAX: 814-863-1474

<http://www.personal.psu.edu/ghb1/>

Abstract: Throughout the prehistory of eastern North America, metarhyolite served as an important lithic material. The use of this material increased dramatically with the intensification of trade relationships during the Late and Transitional Archaic periods. This paper will report the current results of an extensive inter-regional research project studying metarhyolite sources and the archaeological distribution from the Southeast and Mid-Atlantic regions. In particular, geochemical characterization by neutron activation analysis will be used to trace metarhyolite artifacts from the Transitional Archaic period to their geologic sources to identify long-distance routes of exchange and social interaction.

Metarhyolite, often called “rhyolite” or “felsite” by eastern archaeologists, is just one of the many kinds of lithic raw materials available in eastern North America. Occurring in massive bedded deposits from Maine to South Carolina (see Figure 1), it was continuously exploited for the manufacture of chipped-stone tools from the Paleoindian through European contact. However, unlike other more widely used materials like chert, jasper, quartz, or quartzite, metarhyolite is of volcanic origin. From the perspective of geochemical sourcing, this is of great significance in that each individual volcanic flow can be of relatively homogenous chemical composition. For example, artifacts made from obsidian, a glassy form of rhyolite, are routinely traced to the specific quarry site of their origin (e.g. Hurtado de Mendoza and Jester 1978; Glascock et al. 1988). Here in the east, however, this potentially useful property has been complicated by the fact that the material was then metamorphosed and, likely, chemically altered in the process.

To archaeologists, one of the most obvious and distinctive characteristics of metarhyolite is the fact that it is prone to substantial weathering in a short period of time (Stewart 1984, 1987). This complicates the sourcing of artifacts because most of the artifacts are weathered and may have a very different chemical composition from the geologic outcrops (cf. Luedtke 1978:418-20; 1979:751). In particular, the Alkali metals (sodium, potassium, rubidium, cesium, etc.), Alkali Earth metals (magnesium, calcium, strontium, barium, etc.), and many of the Transition metals (chromium, manganese, copper, lead, etc.) tend to be very mobile and easily go into solution, and may be, thus, removed from the material by leaching.

Because of this, only those elements that are not prone to being leached out by this weathering process should be considered in any kind of sourcing assay. Typically non-mobile elements include:

- Insoluble oxides of aluminum (Al), iron (Fe), and titanium (Ti)
- High field strength elements (HFSE), such as yttrium (Y), niobium (Nb), zirconium (Zr), tantalum (Ta), and hafnium (Hf)
- Elements in the lanthanide series, or Rare Earth elements (REE), such as lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), erbium (Er), dysprosium (Dy), thulium (Tm), ytterbium (Yb), and lutetium (Lu) that, as a group, behave similar to the HFSE’s.
- Elements in the actinide series, such as thorium (Th) and uranium (U), that, similarly, tend to behave as HFSE’s.

With these characteristics in mind, and because the rare earth elements (REE) are typically used to characterize volcanic and metavolcanic materials (e.g. Dudás 1990; Teixeira 1994; Bunker et al. 1986), this research will measure the amounts of the REE’s La, Ce, Nd, Sm, Eu, Tb, Yb, and Lu, and the HFSE’s Zr, Hf, Ta, Th, and U (see Table 1). However, following the methodology of Bedard and Barnes (1990) described below, the measurements for protactinium (Pa) and neptunium (Np) were used as a proxy to extrapolate the amounts of Th and U, respectively.

As neutron activation analysis (NAA) is a precise method for examining the REE series (e.g. Dudás 1990; Teixeira 1994; Bunker et al. 1986), and is one of the definitive techniques for characterizing rhyolitic materials (e.g. Hurtado de Mendoza and Jester 1978; Glascock et al. 1988), it was the method of characterization selected for this research. These analyses were performed at Penn State’s University Park Campus using their Breazeale Nuclear Reactor facility, following the procedure of Bedard and Barnes (1990), mentioned above. Due to the lack of an automatic sample changing system, this methodology was considered to provide the optimal balance between obtaining accurate measurements, while limiting both irradiation and counting times for elements with relatively long half-lives. For each run, sixteen samples, each weighing about one gram, were crushed, sealed in polyethylene vials, and mounted in an aluminum sample-holder, along with two vials each of U.S.G.S. STM-1 (syenite) and QLO-1 (quartz latite) standard reference materials. The sample holder was then mounted in a tube adjacent to the core face of the TRIGA reactor at the Breazeale Reactor facility. The reactor operated for 60 minutes at a power-level of 100 kW, thus bombarding the samples with neutrons at a flux of 10^{13} $n/cm^2 \cdot s$ and making the samples radioactive. The samples were allowed to decay for 7 to 10 days before being removed from the sample-mount and placed in the high-purity germanium detector, where their spectra were counted for 3 hours each.

Variation within a Sample

The first concern of this research was to evaluate the ability of this analytical method to compensate for differential weathering between samples from the same geologic specimen. In Figure 2, we see two samples taken from the same specimen of porphyritic metarhyolite from the Catoctin formation in Maryland: one from the white, chalky primary geologic cortex, while the other came from well within the specimen, and was much less weathered, if at all. Despite the fact that the cortex has been weathering for at least several thousand years, and is likely to have experienced more chemical alteration than most artifacts, there is excellent agreement between the compositions of the cortex and interior samples with the total variation being less than 10% (see Table 2).

Another test of geochemical consistency was performed on a biface from the Tuscarora Rockshelter site (18FR9) in Maryland. One heavily-weathered piece of this artifact, found outside the rockshelter, refit with a less weathered section found inside the rockshelter. This enabled the comparison of two samples, known to have similar chemical compositions, after they had weathered under different climatic conditions. Note from Figure 3 and Table 2 that the chemical compositions are fairly consistent, especially for

the heavier elements. Thus, despite the effects of differential weathering, the two sections of this artifact still have similar compositions of these elements. As a result of these two, and six other comparisons, it appears to be possible to reliably match artifacts with modest to heavy amounts of weathering back to their geologic sources.

The resistance of these elements to waterborn transport was inadvertently confirmed by the analysis of specimens from the deposit of “Colchester Jasper” in Colchester, Vermont. Despite the name, this material was actually thought to be either a metarhyolite or a very fine-grained quartzite. The assay by NAA showed that this material contained amounts of these elements that were too small to be detected. These results not only suggest that the Colchester deposit is, in fact, a quartzite, but that the characterization methodology used for this study would be inappropriate for the study of materials precipitated from aqueous solutions, like chert, flint, jasper, quartz, and quartzite.

Variation within a Formation

The potentially extreme geologic variation present on many quarry sites presents another potential complication in sourcing metarhyolite. Multiple macroscopic types can occur in the vicinity of a single quarry (e.g. Fauth 1978; Stewart 1984, 1987). However, the variation in the geochemistry is much lower than the macroscopic examination of hand specimens suggests: several macroscopically distinct varieties are geochemically indistinguishable. In Figure 4, we see several very different varieties of metarhyolite from across the Caladonia State Park/Snaggy Ridge quarry complex in the Catoctin formation of South Mountain in the Pennsylvania Blue Ridge. Despite the major morphological and macroscopic variation in this material, ranging from purple and blue porphyry, to red, blue, and gray aphanitic, and flow-banded varieties, the chemical composition follows remarkably similar trends and has an average variation of 21%. However, there are also some significant patterns within the geochemistry of this quarry area. The variation in the Hf/Ta and Ta/Th ratios exposes two distinctive clusters, as we see in Figure 5. These clusters could be the result of two completely different geologic events, one of which produced porphyritic material, the other aphanitic and flow-banded metarhyolite. In addition, all of the porphyritic samples are from the northern end of the quarry area, while the other samples are from the southern end. This demonstrates that, while there appears to be less chemical variation than the number of macroscopic types suggests, there is still significant patterned variation within a distance of less than one mile from north to south across that quarry area.

Comparing this area with metarhyolite from Maryland highlights the variation present in the Catoctin formation as a whole. In Figure 6, we see a clear dichotomy in the amounts of Eu and Ta between the northern and southern sources, with Pennsylvania metarhyolite containing less. Thus, based on the results of the limited number of samples run so far, there appear to be at least three different chemical signatures, correlating to discrete locales, present in the metarhyolites of the Catoctin formation of Pennsylvania and Maryland, as seen in Figure 5. Yet, despite the apparent ease with which local deposits within the Catoctin formation of Maryland and Pennsylvania are shown to be chemically distinctive, such local chemical subdivisions are not yet discernible in the data from the Carolina Slate Belt.

Fortunately, there is noticeable chemical distinctiveness at a regional level. When all specimens from Pennsylvania to North Carolina are considered, certain regional trends become apparent: the material from Pennsylvania and Maryland routinely contains significantly higher amounts of most of these thirteen elements than the material from the Carolina Slate Belt, with the notable exception being Tantalum. Thus, the Hf/Ta ratio provides a useful variable with which to distinguish between material originating in these two source regions, as we see in Figure 7. Similarly, metarhyolite from Mt. Rogers, Virginia can be identified because it has generally lower values of Eu.

To apply these data towards examining the use and exchange of metarhyolite across the prehistoric landscape of the eastern seaboard, I have, so far, accessed the site files of eight east coast states so as to both identify sites containing metarhyolitic materials, as well as sites containing material from the Archaic-Woodland Transition. From this list of more than 28,000 sites, I have been able to generate state-wide and inter-regional maps showing the distribution of this material.

In Figure 8, Notice the three major source areas: around Boston, Massachusetts, the Maryland and Pennsylvania Blue Ridge, and the Slate Belt of the North Carolina Piedmont. As Barber and Tolley (1999) observed, the prehistoric distribution of material from Mt. Rogers in southwestern Virginia was fairly local. Note the low, but persistent, presence of metarhyolite along the entire Delmarva Peninsula of Maryland and Virginia, and across the Virginia Piedmont. In both of these areas, I am particularly interested in examining the cultural distribution of metarhyolite artifacts attributed to the so-called “Broadspear Horizon” of the Archaic-Woodland Transition, particularly the Savannah River phase. By tracing these artifacts to their source, I hope to be able to clarify the patterns of exchange that are so characteristic of this time period.

Materials from three collections of probable Savannah River association have been analyzed so far. First, the data from three artifacts, provided by Joel Gunn of UNC, from the Neuse River III site in the northern North Carolina piedmont clearly places their origin as one of the sources in the Carolina Slate Belt, as seen in Figure 10. Similarly, five broadspears, provided by Dennis Blanton,

from the Dismal Swamp of the southeastern Virginia coastal plain show that they, too, originated from Slate Belt sources, as seen in Figure 11. Finally, artifacts from the Virginia Department of Historic Resources from several sites across the Virginia Piedmont, Delmarva Peninsula, and into the Shenandoah Valley were also examined. Of these, broadspear sites from Mechlinburg, Louisa, and Hanover counties in the Piedmont could all be traced to sources in the Carolina Slate Belt. The assemblages of one site in Louisa county (44LS173) and two in Hanover county (44HN5, 44HN77) in the central to lower piedmont of Virginia, are of particular interest in that they are approximately equidistant, and 150 kilometers, from the nearest known prehistoric metarhyolite quarries. Yet, despite the long distance and apparently equal access, metarhyolite on these three sites was consistently from the Slate Belt sources. In contrast, a broadspear fragment from Caroline County of the Piedmont, and both artifacts from the Delmarva Peninsula, are not from the Slate Belt. While a Pennsylvania source appears to be likely for these three artifacts, the Mount Rogers source in southwestern Virginia cannot be ruled out at this time. However, a fragment of a Middle Archaic Morrow Mountain II biface from Augusta County in the Shenandoah Valley is very similar to material excavated from the Fairwood Livery site (44GY18), a Middle Archaic reduction site close to the Mount Rogers quarries.

These results are interesting for several reasons. First, the evidence from Augusta County suggests that metarhyolite from the Mount Rogers source was being transported over much greater distances during the Middle Archaic than previously believed. Similarly, the data from the Virginia Piedmont demonstrate not only that Late Archaic groups in central Virginia were able to obtain material from over great distances, but that they also maintained links to central North Carolina that enabled them to obtain this material. In contrast, the prehistoric residents of the Delmarva Peninsula not only obtained metarhyolite from northern rather than southern sources, but they also appear to have favored material coming down the peninsula from sources in Pennsylvania rather than across Chesapeake Bay from the sources in Maryland. While links to the north may have existed on the Delmarva Peninsula, the presence of a northern origin for three expanding-stem bifaces, resembling Susquehanna broadspears, from southern Virginia was not supported as all three clearly originated from sources in the Slate Belt.

While compelling,, I must once again stress that, until statically-significant levels of sampling from each quarry are achieved, these must be considered to be preliminary results. Depending on the variation present in each source, usually ranging from 20-30%, as seen in Table 3, the complete characterization of each quarry could require several hundred samples per quarry. Once collection and analysis of the source data is completed, the matching of artifacts to these sources will be confirmed through the use of discriminant analysis using the calculation of the Mahalanobis distances, a technique commonly used to match NAA spectra from obsidian artifacts with their sources (Luedtke 1978, 1979; Glascock et al. 1988, 1994). This technique makes quantified source assignments by calculating the non-Euclidian Mahalanobis distance between all thirteen elements, rather than simply focusing on a few individual elements as I have for the purpose of this talk. However, applying this technique to a total of 2-300 geologic and quarry source specimens should provide a reliable database upon which future analyses may build.

References Cited

Barber, M. B. and G. A. Tolley

1999 "The Fairwood Livery Site (44GY18), Grayson County, Virginia: Mount Rogers Formation Rhyolite Within a Settlement and Regional Perspective". Paper presented at the 29th Annual Meeting of the Middle Atlantic Archaeological Congress, Harrisburg, Pennsylvania.

2000 "Beyond Quarrying: Lithic Quarry Activities in Quartzite, Jasper, and Rhyolite". Paper presented at the 65th Annual meeting of the Society for American Archaeology, Philadelphia, Pennsylvania.

Bedard, L. Paul and Sarah-Jane Barnes

1990 Instrumental Neutron Activation Analysis by Collecting Only One Spectrum: Results for International Geochemical Reference Samples. *Geostandards Newsletter* 14(3):479-84.

Bunker, M. E., M. M. Minor, and S. R. Garcia

1986 Neutron Activation Analysis. In *Materials Characterization*, edited by ASM Handbook Committee, Ruth E. Whan, Coordinator, pp. 233-242. ASM Handbook, Volume 10. American Society for Metals.

Dudás, Francis Örs

1990 *Petrogenesis and Mantle Source of Igneous Rocks in the Crazy Mountains, Montana*. Unpublished Ph. D. Dissertation. Department of Geosciences, The Pennsylvania State University, University Park.

Fauth, John L.

1978 Geology and Mineral Resources of the Iron Springs Area, Adams and Franklin Counties, Pennsylvania. *Atlas 129c, Fourth Series*. Pennsylvania Geological Survey, Harrisburg.

Glascock, Michael D., J. Michael Elam, and Robert H. Cobean

1988 Differentiation of Obsidian Sources in Mesoamerica. In *Proceedings of the 26th. International Archaeometry Symposium*, R. M. Farquhar, R. G. V. Hancock, and L. A. Pavlish eds., pp. 245-51. University of Toronto Press, Toronto.

Glascock, Michael, Hector Neff, K. S. Stryker, and T. N. Johnson

1994 Sourcing Archaeological Obsidian by an Abbreviated NAA Procedure. *Journal of Radioanalytical and Nuclear Chemistry* 180(1):29-35.

Hurtado de Mendoza, Luis and William A. Jester

1978 Obsidian Sources in Guatemala: A Regional Approach. *American Antiquity* 43(3): 424-435.

Luedtke, Barbara E.

1978 Chert Sources and Trace-element Analysis. *American Antiquity* 43(3):413-23.

1979 The Identification of Sources of Chert Artifacts. *American Antiquity* 44(4):744-57.

Stewart, R. Michael

1984 Archaeologically Significant Characteristics of Maryland and Pennsylvania Metarhyolites. In *Prehistoric Lithic Exchange Systems in the Middle Atlantic Region*, edited by Jay F. Custer, pp. 1-13. Center for Archaeological Research Monograph No. 3. University of Delaware, Newark.

1987 Rhyolite Quarry and Quarry-Related Sites in Maryland and Pennsylvania. *Archaeology of Eastern North America* 15: 47-57.

Teixeira, João Batista G.

1994 *Geochemistry, Petrology, and Tectonic Setting of Archean Basaltic and Dioritic Rocks from the N4 Iron Deposit, Serra Dos Carajás, Pará, Brazil*. Unpublished Ph. D. Dissertation. Department of Geosciences, The Pennsylvania State University, University Park.

Variation within a Specimen

#	Overall Variation of Eu-Th	Zr			La			Ce			Nd			Sm									
		N	Σ	Var	Avg	N	Σ	Var	Avg	N	Σ	Var	Avg	N	Σ	Var							
																	Var	Var	Var	Var	Var	Var	
1	25%	3	542.3	3	166.9	25%	97.8	3	27.3	24%	213.1	3	60.4	24%	99.5	3	31.4	26%	18.7	3	5.9	26%	
2	30%	2	392.6	2	37.7	9%	69.1	2	60.1	54%	72.2	2	32.0	34%	82.5	2	71.0	53%	19.3	2	14.9	50%	
3	8%	2	935.3	2	87.3	9%	131.5	2	19.1	13%	205.8	2	112.9	40%	160.1	2	7.2	4%	29.6	2	0.3	1%	
4	35%	2	357.9	2	84.4	20%	55.8	2	73.1	68%	151.6	2	182.0	65%	55.4	2	47.3	53%	13.3	2	6.6	37%	
5	24%	2	556.7	2	225.3	31%	12.3	2	3.9	28%	27.6	2	9.1	27%	18.8	2	6.7	28%	8.8	2	1.2	13%	
6	16%	2	-	0	-	-	22.3	2	5.4	21%	62.3	2	13.7	19%	23.8	1	-	-	7.8	2	2.6	27%	
7	23%	3	173.8	3	69.1	29%	9.0	3	7.0	41%	20.0	3	13.5	38%	7.8	3	7.8	47%	1.9	3	1.5	42%	
8	15%	2	-	0	-	-	19.3	2	2.2	11%	45.0	2	8.9	17%	19.3	1	-	-	4.9	2	1.0	17%	
	Eu	Tb			Yb			Lu			Hf			Ta									
		Avg	N	Σ	Var	Avg	N	Σ	Var	Avg	N	Σ	Var	Avg	N	Σ	Var						
																		Var	Var	Var	Var	Var	Var
1	3	0.2	19%	1.6	3	0.5	25%	7.9	3	2.3	24%	1.2	3	0.3	24%	19.5	3	5.7	24%	5.6	3	1.8	27%
2	2	1.3	34%	2.3	2	1.0	34%	7.7	2	2.0	22%	1.1	2	0.2	20%	19.0	2	3.8	17%	10.1	2	2.7	22%
3	2	0.2	7%	2.3	2	0.1	6%	12.0	2	0.1	1%	1.4	2	0.1	4%	35.9	2	2.0	5%	25.5	2	1.6	6%
4	0	-	-	2.5	2	0.6	20%	11.0	2	3.6	27%	1.6	2	0.5	25%	16.9	2	3.5	18%	5.1	2	2.1	32%
5	1	-	-	2.6	2	0.5	17%	11.2	2	2.9	22%	1.6	2	0.5	24%	21.0	2	6.8	26%	4.5	2	1.7	30%
6	2	0.0	2%	2.0	2	0.4	19%	9.5	2	2.2	20%	1.9	2	0.3	16%	5.3	2	1.2	19%	22.9	2	0.9	4%
7	2	0.3	44%	0.5	1	-	-	2.5	3	0.2	9%	0.5	3	0.1	17%	5.5	3	2.0	28%	28.0	3	3.6	11%
8	1	-	-	0.9	2	0.2	14%	3.2	2	0.4	12%	0.6	2	0.1	12%	3.2	2	0.2	7%	50.3	2	6.4	12%
	Th	U			Eu/Tb			Lu/Hf			Hf/Ta			Ta/U									
		Avg	N	Σ	Var	Avg	N	Σ	Var	Avg	N	Σ	Var	Avg	N	Σ	Var						
																		Var	Var	Var	Var	Var	Var
1	3	2.8	26%	1.4	3	0.5	27%	0.6	3	0.06	9%	0.1	3	0.00	2%	3.5	3	0.20	5%	4.0	3	0.18	4%
2	2	3.4	25%	3.2	2	0.6	17%	1.2	2	0.00	0%	0.1	2	0.00	3%	1.9	2	0.13	7%	3.1	2	0.24	7%
3	2	1.2	8%	6.3	2	0.1	2%	1.2	2	0.01	0%	0.0	2	0.00	1%	1.4	2	0.17	11%	4.1	2	0.16	4%
4	2	6.6	24%	4.0	2	1.3	26%	-	0	-	-	0.1	2	0.01	9%	3.5	2	0.76	19%	1.3	2	0.14	10%
5	2	4.7	23%	2.6	2	0.8	27%	0.2	1	-	-	0.1	2	0.00	3%	4.7	2	0.26	5%	1.8	2	0.08	5%
6	2	2.8	19%	3.0	2	1.3	32%	0.5	2	0.12	21%	0.4	2	0.02	4%	0.2	2	0.04	17%	8.2	2	3.13	30%
7	3	2.8	26%	1.8	3	0.6	23%	1.4	1	-	-	0.1	3	0.02	19%	0.2	3	0.06	27%	16.5	3	3.89	19%
8	2	0.6	11%	1.5	2	0.6	33%	1.4	1	-	-	0.2	2	0.01	5%	0.1	2	0.00	5%	36.7	2	11.58	26%

Table 2. Trace element variation present within a single specimen.

#		Variation within a Type																							
		Overall		Zr		La		Ce		Nd		Sm													
		N	Var	Avg	Var	Avg	Var	Avg	Var	Avg	Var	Avg	Var												
1	Pennsylvania	5	22%	542.3	5	171.8	23%	73.1	5	27.0	23%	145.7	5	40.9	20%	82.3	5	30.6	23%	15.8	5	4.8	20%		
2	Pennsylvania	5	23%	651.4	5	190.4	23%	120.9	4	51.2	27%	214.2	5	54.9	21%	118.0	5	39.5	23%	21.0	5	6.8	22%		
3	Virginia	4	32%	346.8	4	50.7	12%	40.1	3	58.4	54%	83.7	4	131.1	47%	32.3	4	38.3	43%	8.5	4	6.8	38%		
4	North Carolina	11	23%	237.1	6	96.6	25%	24.0	11	7.0	18%	59.3	11	17.3	20%	26.2	10	12.3	24%	7.1	11	2.4	21%		
5	North Carolina	10	25%	173.8	3	69.1	29%	13.9	10	5.8	28%	32.0	10	13.2	26%	12.1	7	6.4	33%	3.5	10	1.7	31%		
		Eu		Tb		Yb		Lu		Hf		Ta													
		Avg	N	Σ	Var	Avg	N	Σ	Var	Avg	N	Σ	Var	Avg	N	Σ	Var	Avg	N	Σ	Var	Avg	N	Σ	Var
1	Pennsylvania	1.1	5	0.2	16%	1.5	5	0.3	17%	8.3	5	1.9	19%	1.1	5	0.2	14%	22.2	5	8.7	27%	3.2	5	1.3	28%
2	Pennsylvania	1.1	4	0.2	18%	1.7	5	0.5	21%	9.0	5	2.2	20%	1.2	5	0.2	17%	25.0	5	8.6	25%	6.9	4	3.0	28%
3	Virginia	0.4	1	-	-	1.8	4	1.0	34%	8.9	4	3.3	24%	1.3	4	0.5	25%	16.4	4	2.4	12%	3.3	4	2.4	37%
4	North Carolina	1.0	10	0.3	18%	1.4	11	0.6	28%	6.3	11	2.5	22%	1.1	11	0.5	25%	5.7	11	2.4	20%	36.7	11	18.9	27%
5	North Carolina	0.8	6	0.3	27%	0.8	8	0.3	27%	2.7	10	0.6	17%	0.5	10	0.1	19%	3.6	10	1.7	23%	40.5	10	21.1	24%
		Th		U		Eu/Tb		Lu/Hf		Hf/Ta		Ta/U													
		Avg	N	Σ	Var	Avg	N	Σ	Var	Avg	N	Σ	Var	Avg	N	Σ	Var	Avg	N	Σ	Var	Avg	N	Σ	Var
1	Pennsylvania	9.0	5	2.8	23%	2.2	5	1.1	28%	0.7	5	0.08	9%	0.1	5	0.02	23%	7.1	5	0.41	5%	1.5	5	0.37	20%
2	Pennsylvania	10.5	5	2.8	22%	2.1	5	1.0	31%	0.6	4	0.07	10%	0.1	5	0.01	23%	3.4	4	0.24	6%	3.8	4	0.30	7%
3	Virginia	17.3	4	8.5	31%	3.2	4	1.5	30%	0.6	1	-	-	0.1	4	0.02	23%	7.2	4	4.41	38%	1.0	4	0.40	30%
4	North Carolina	9.4	11	3.3	22%	2.4	11	1.0	24%	0.9	10	0.41	29%	0.2	11	0.11	30%	0.2	11	0.05	18%	16.8	11	10.30	24%
5	North Carolina	5.3	10	2.5	23%	1.5	10	0.5	20%	1.4	5	0.41	21%	0.2	10	0.05	24%	0.1	10	0.07	30%	29.1	10	15.69	25%

Table 3. Trace element variation present within several general geologic types.

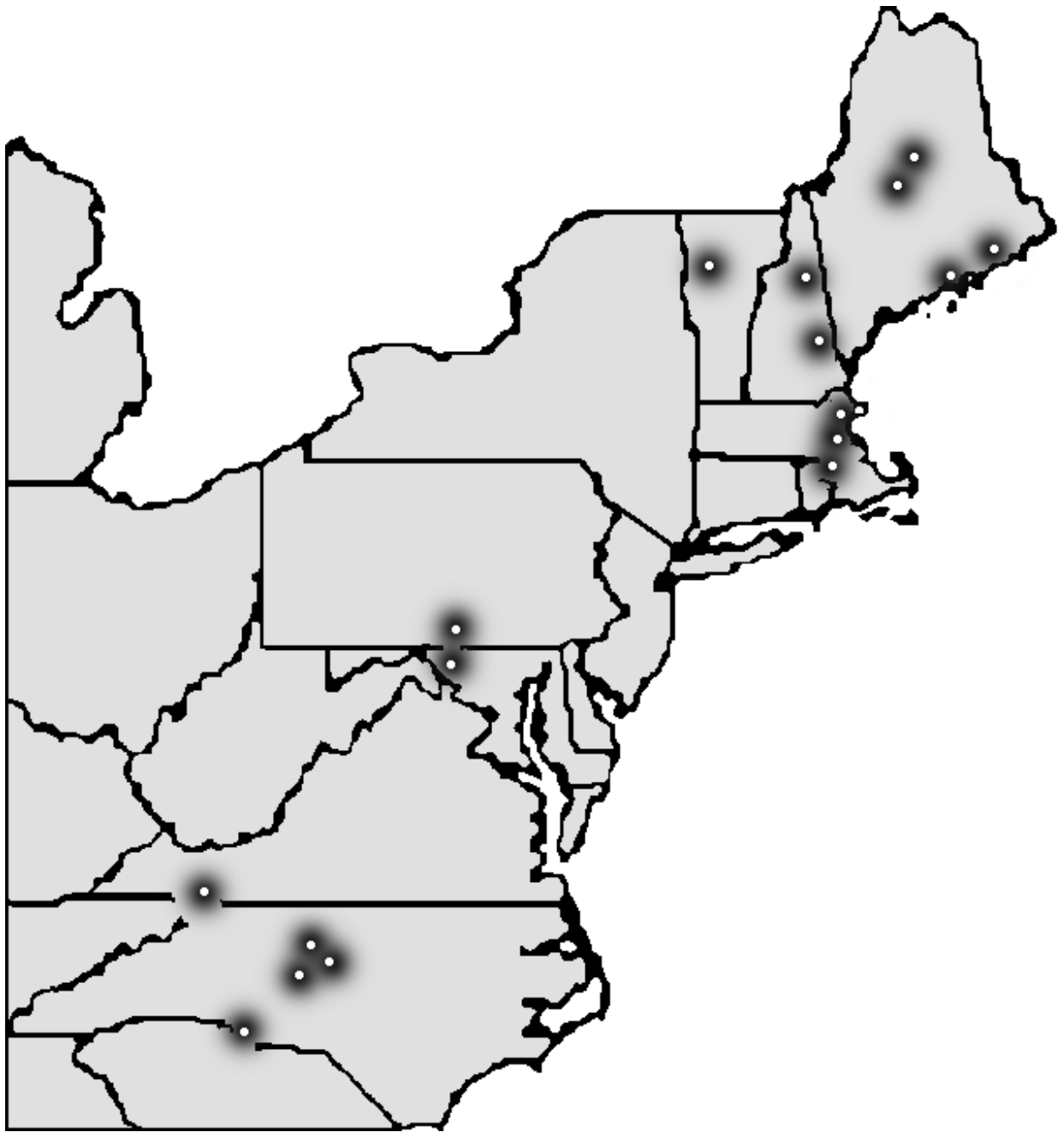


Figure 1. Metarhyolite Sources in the eastern United States

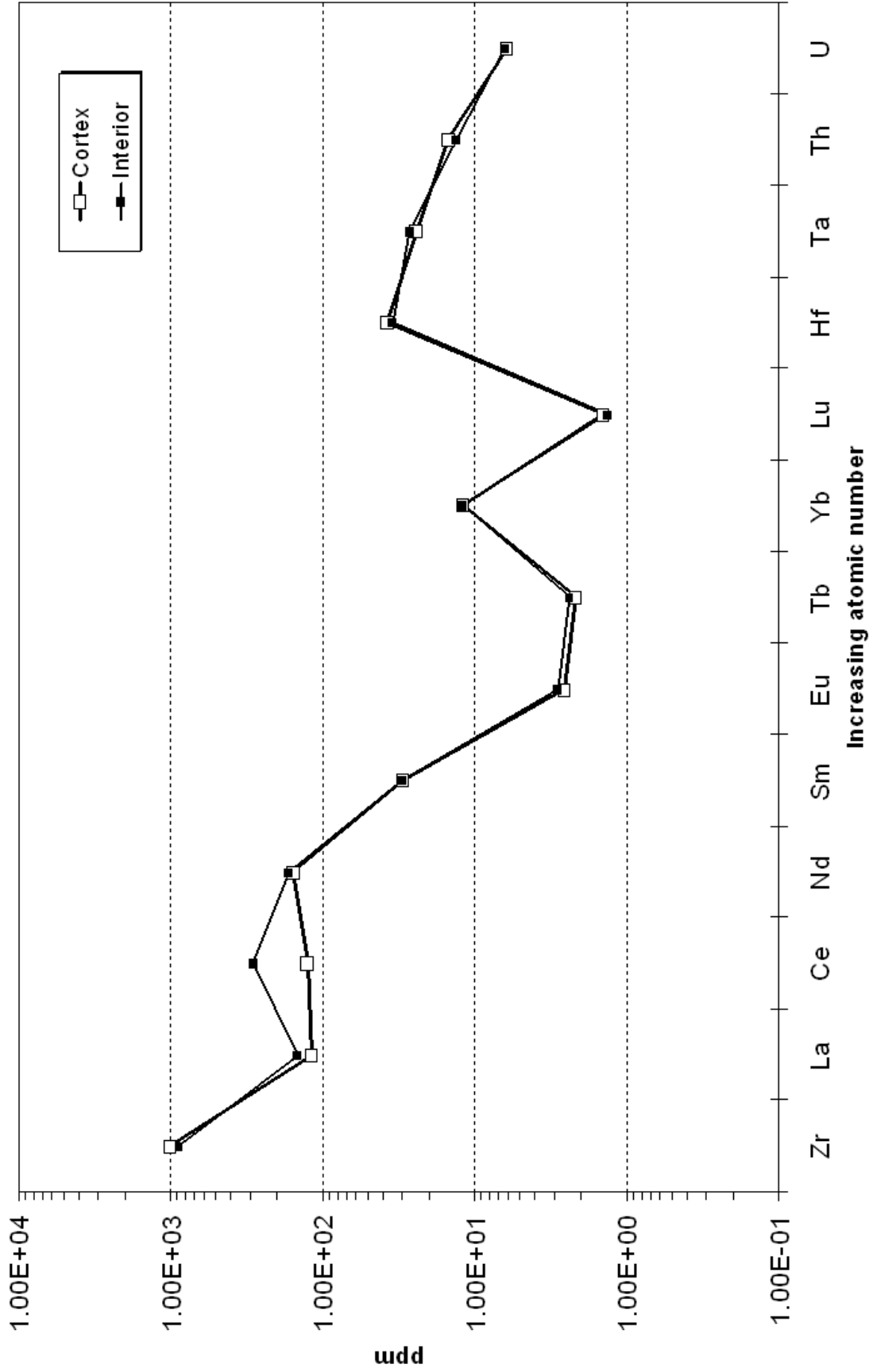


Figure 2. Comparison between the chemical composition of weathered and unweathered samples from the same specimen of porphyritic metarhyolite from the Catoctin Formation of Maryland.

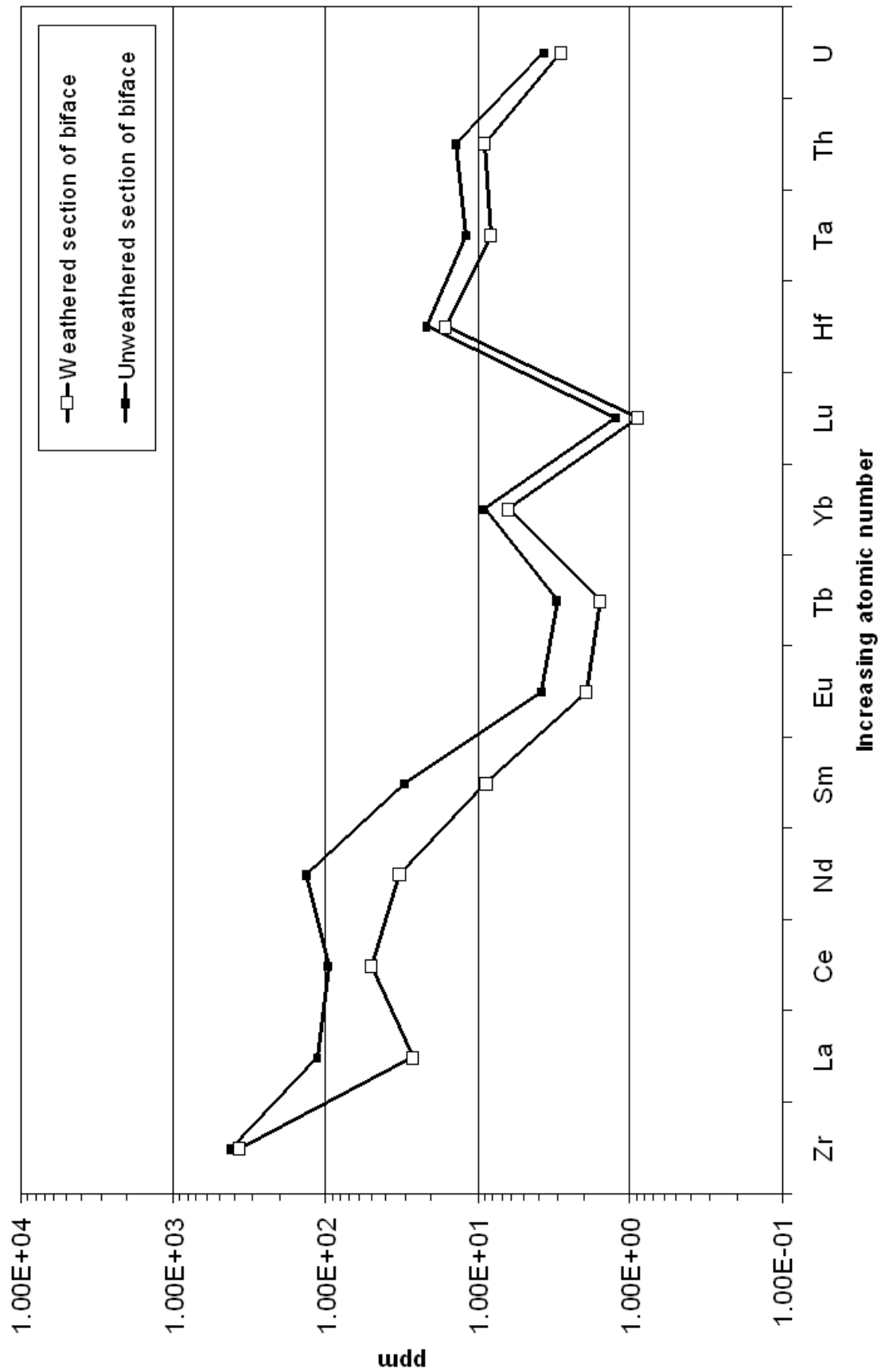


Figure 3. Comparison between two samples from a refit biface displaying differential weathering.

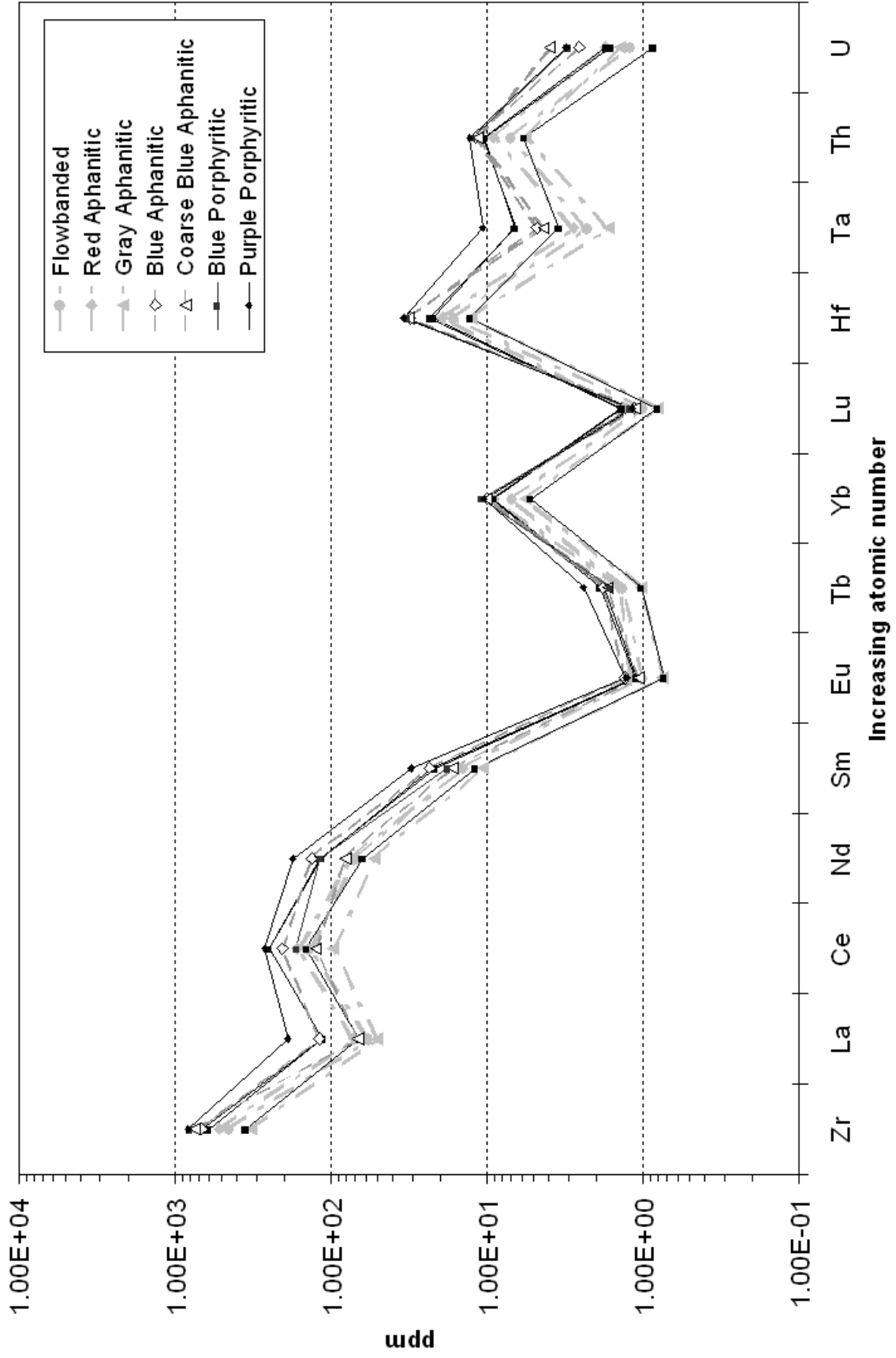


Figure 4. Comparison of several varieties of metarhyolite from Snaggy Ridge near Caladonia State Park, Pennsylvania.

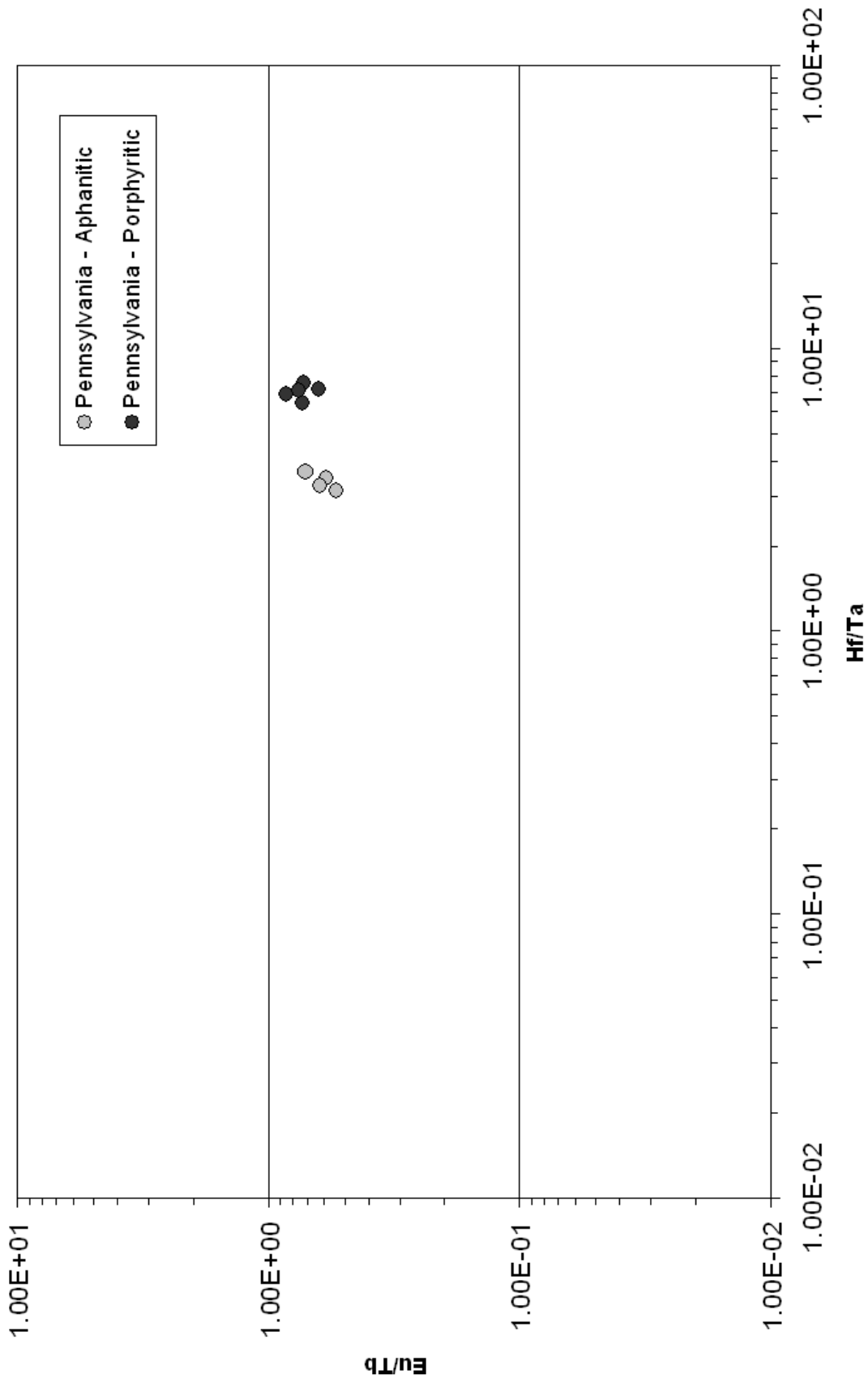


Figure 5. Plot of Eu/Tb ratios against Hf/Ta ratios demonstrating the associations between source regions.

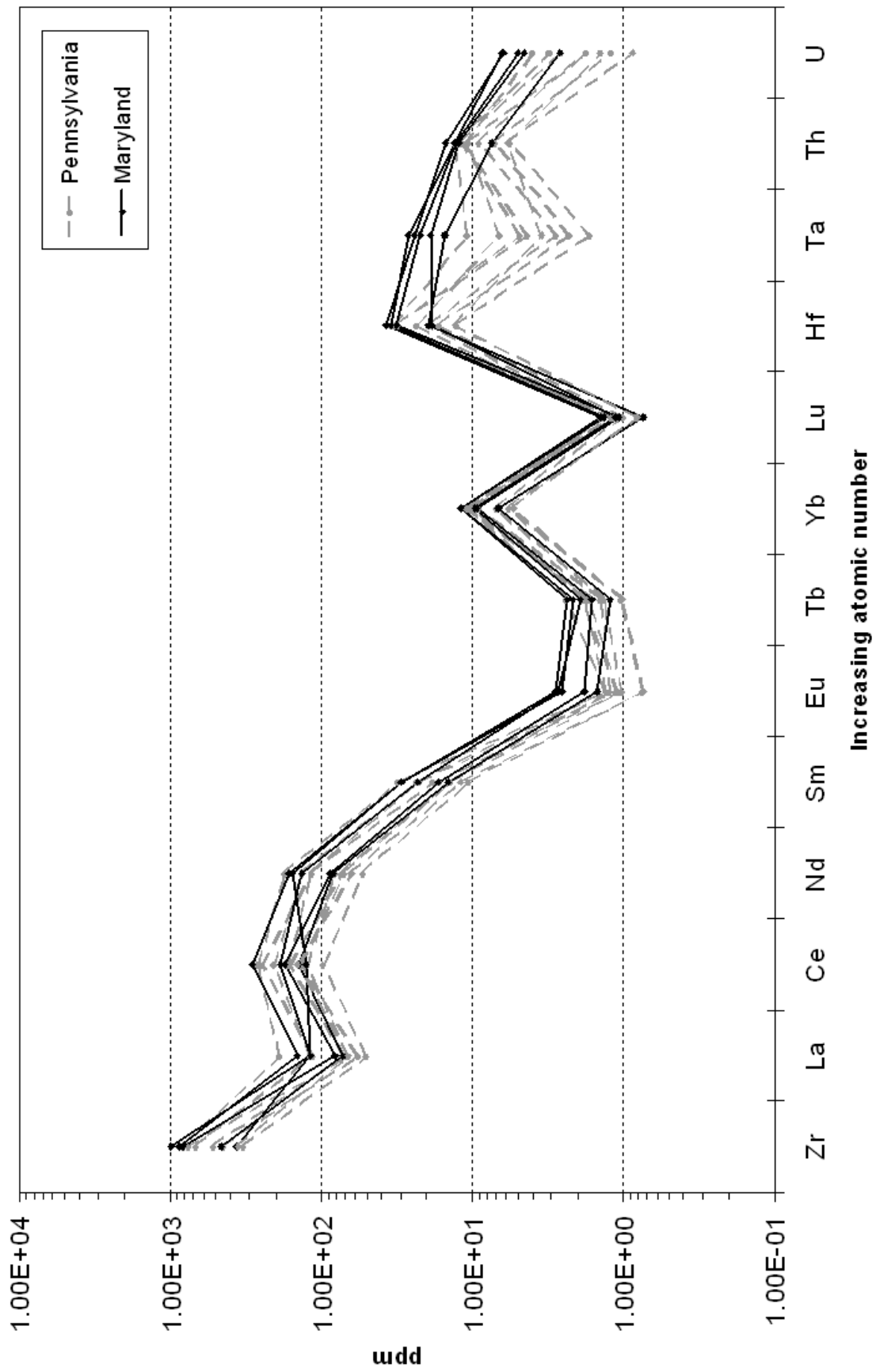


Figure 6. Comparison of Pennsylvania and Maryland metarhyolites.

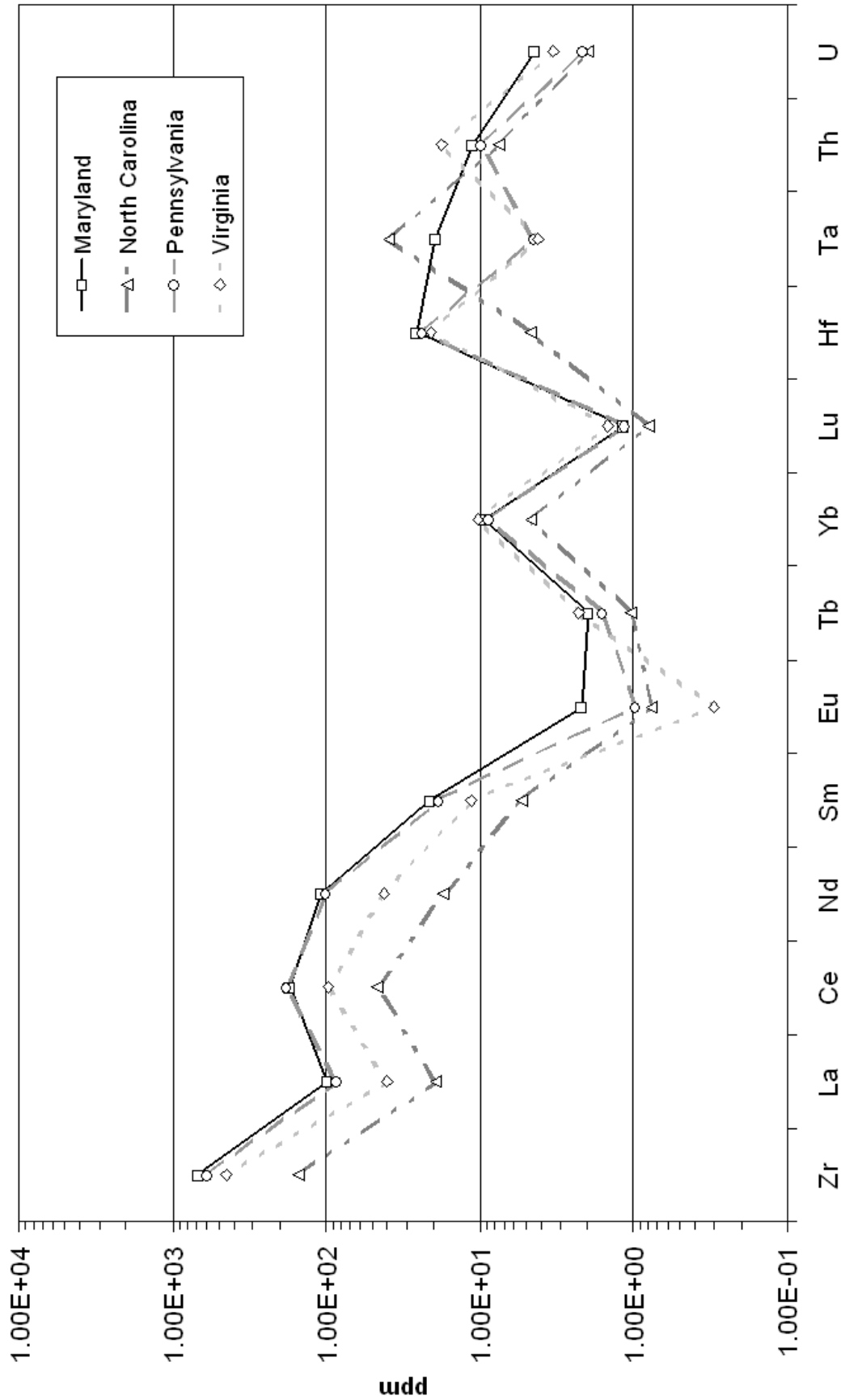


Figure 7. Average trace element values for forty-nine samples across four regions.

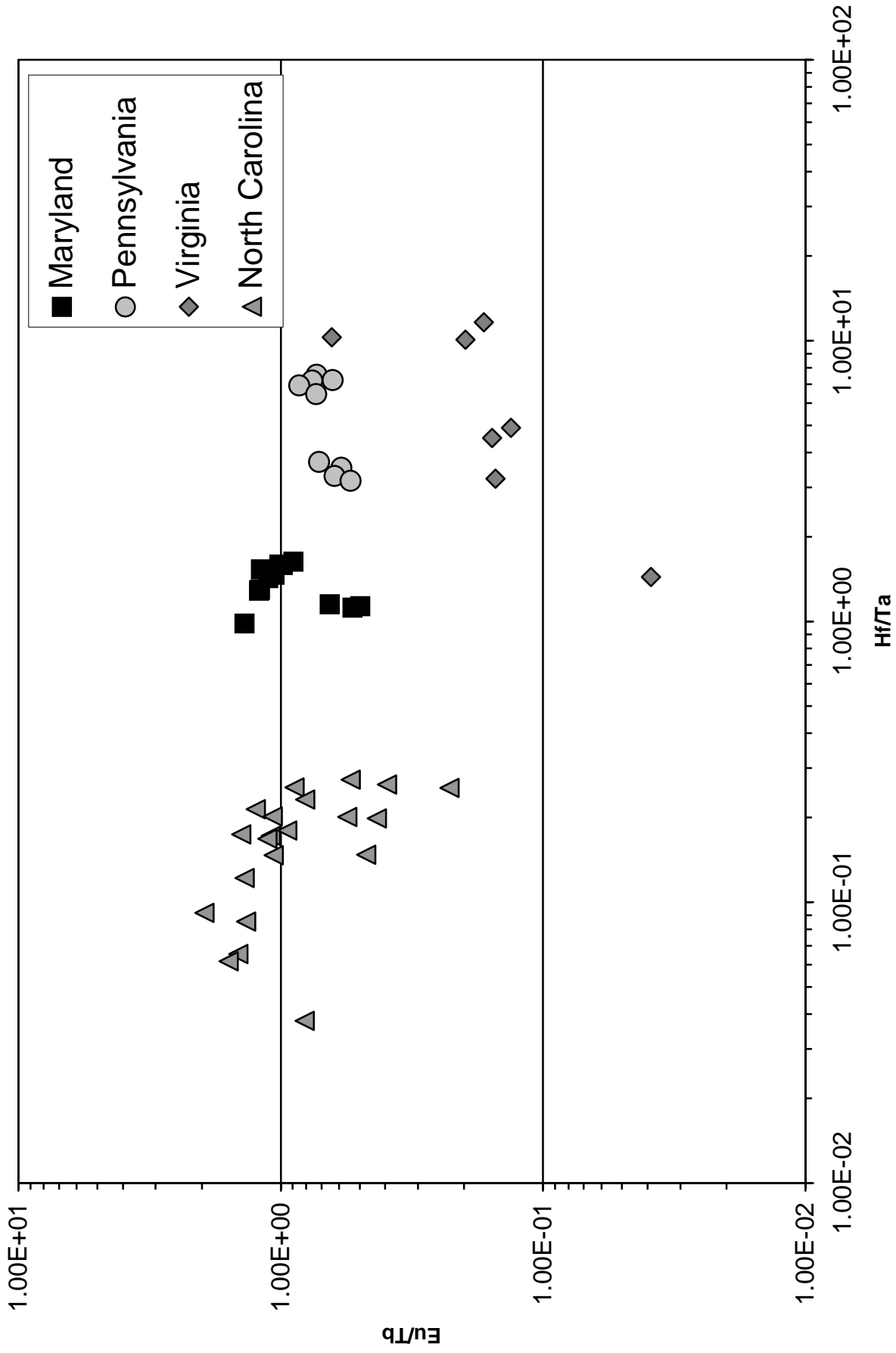


Figure 8. Plot of Eu/Tb ratios against Hf/Ta ratios demonstrating the associations between source regions.

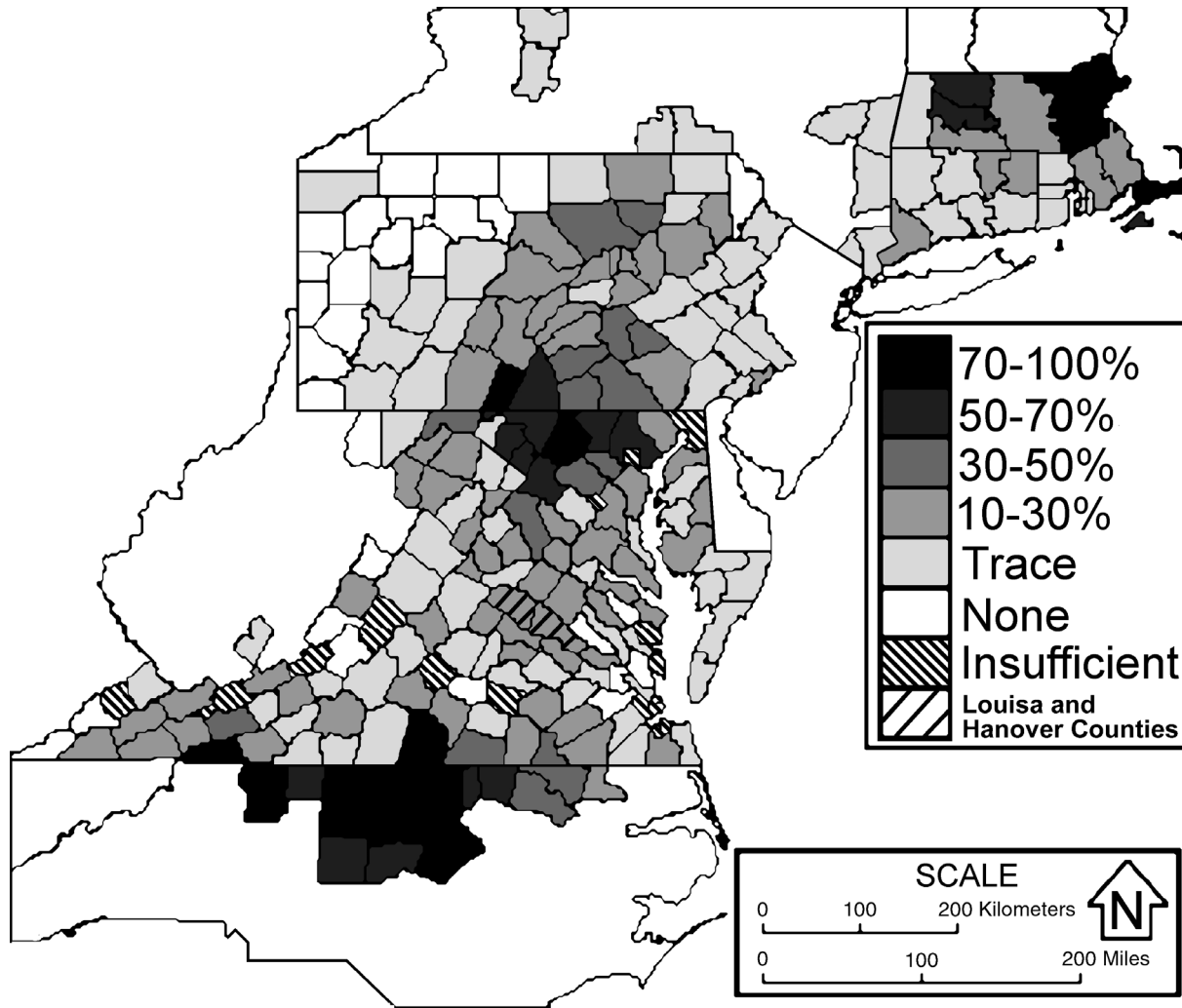


Figure 9. Percentage of prehistoric sites per county containing metarhyolite/metadacite.

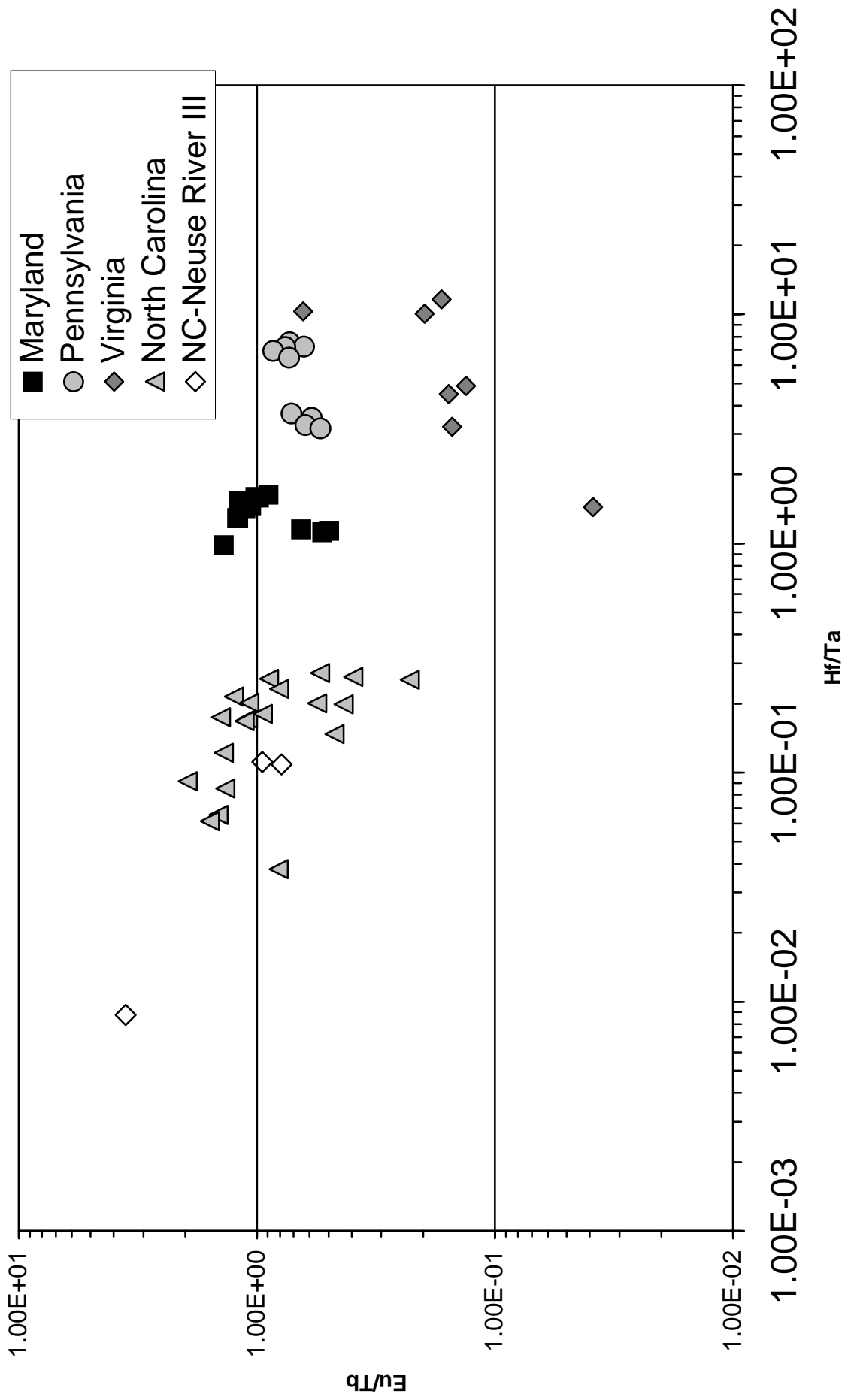


Figure 10. Plot of Eu/Tb ratios against Hf/Ta ratios demonstrating the association between source material and artifacts from the Neuse River III site in North Carolina.

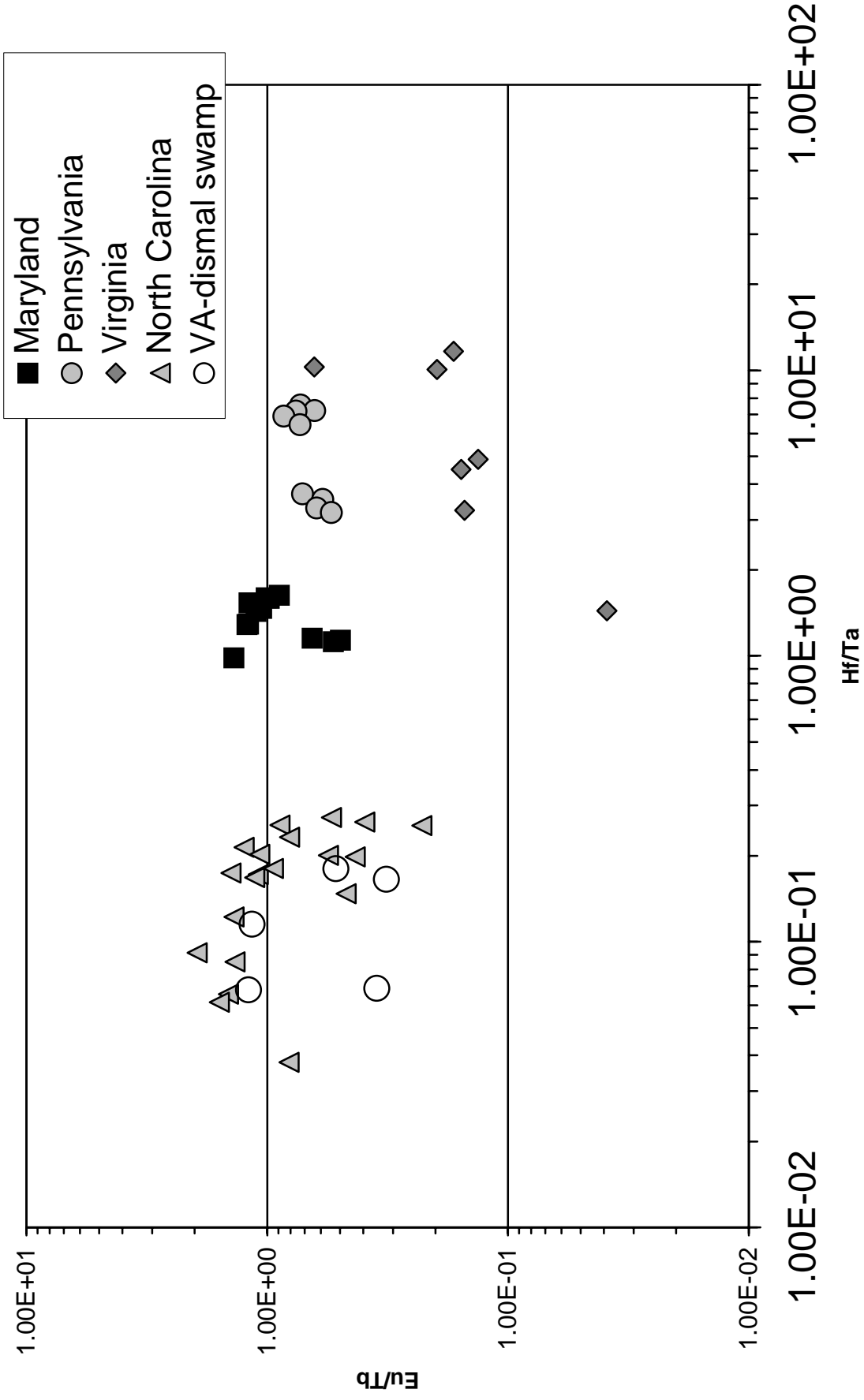


Figure 11. Plot of Eu/Tb ratios against Hf/Ta ratios demonstrating the association between source material and artifacts from the Dismal Swamp in Virginia.

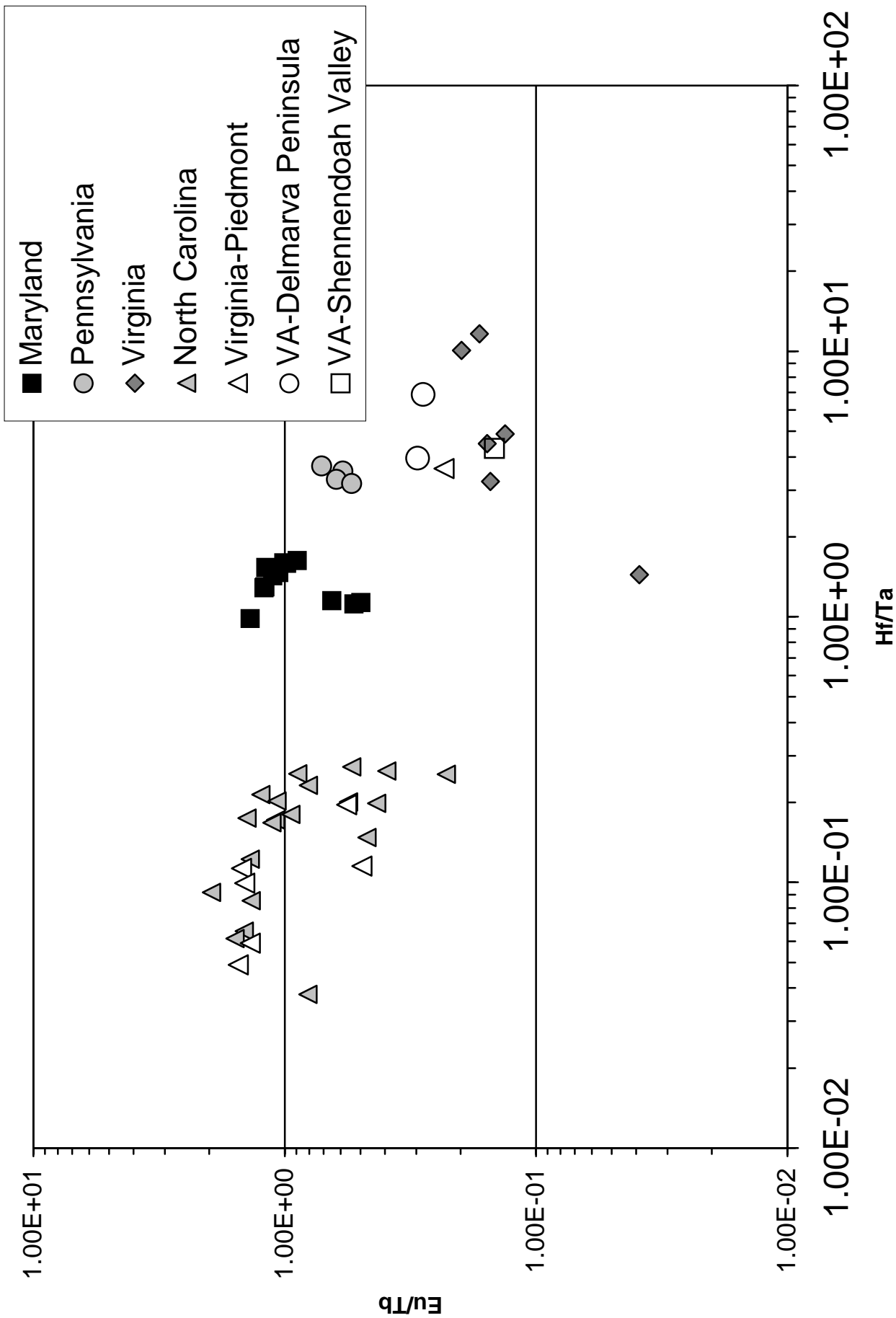


Figure 12. Plot of Eu/Tb ratios against Hf/Ta ratios demonstrating the association between source material and artifacts from the Piedmont, Delmarva Peninsula, and Shenandoah Valley of Virginia.