EXPANDING THE GEOCHEMICAL DATABASE FOR VIRGINIA JASPER SOURCES

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ABSTRACT

Instrumental neutron activation analysis (INAA) has been performed on 101 samples of jasper from Virginia. The study includes geological samples from five localities and artifacts from six different archaeological sites. Geological samples available for this study came from Brook Run (15), Flint Run (20), Bonifant (16), Rockbridge (20), and Virginia Beach (20). Ten artifacts were obtained from multiple sites located on Fort Pickett and from Maycock's Point (44PG40). The source data were examined to identify elemental differences that could be used to differentiate between individual sources. The artifact data were then projected against the source groups to determine the most probable sources. Assignments of the artifacts to geological sources were successfully made for 80% of the archaeological samples.

INTRODUCTION

Throughout prehistory in the Eastern United States the extraction and distribution of resources varied in response to population consumption levels, political agendas, and to changes in the ecological structure of the resource base. The trade and exchange of resources is one strategy that responds to the need for commodities and esoteric items that help keep communities intact. In a much-reference paper, Stewart (1989) recognizes two broad forms of exchange. The first is characterized as a *broad-based* exchange network where exchange between people or communities occurs in a down-the-line manner through an interconnected web of relationships. The second form is referred to as *focused* network exchange and categorizes communities that acquire objects from broad-based networks outside of their territory, or home range, and hoard the objects for their own use or consumption. Focused exchange can play a significant role in more complex chiefdom societies where exotics are used to legitimize social position and political office (Helms 1979; Earle 1997). However, it is also found in less complex organizations such as the Hopewell core area where the gift giving of exotic items was used to bind together dispersed and segmented tribal societies after long periods of separation (Yerkes 2002). Through the study of jasper distributions we hope to gain additional insights into the various forms of the prehistoric exchange process.

The focus of this paper is to develop a statistical solution for source provenience investigations of jasper artifacts recovered from archaeological sites in the southern part of the middle Atlantic region. Once this baseline information has been established, it will be possible to address the forms and temporal variation in prehistoric exchange within Virginia. Here, we present new results on the chemical analysis of five Virginia sources by instrumental neutron activation analysis (INAA) and show how the unique composition of geological sources in different regions can be used to establish characteristic chemical signatures.

PREVIOUS RESEARCH

The chemical characterization of jasper sources has continued for more than a quarter century and has become increasingly broad in scope and sophisticated in the treatment of analytical data. This has been paralleled by the discovery of new jasper deposits that brings the total documented number to 27 sources that extend from New Brunswick to North Carolina (Table 1; Figure 1). Most of the jasper deposits can be characterized as point sources that consist of discreet surface exposures made accessible by geological uplift and surface erosion. In three instances, the closely spaced deposits have been grouped into the regional source areas of the Reading Prong (Anthony and Roberts 1988; Hatch 1994), the Hatch/Branch Road quarries, and the Iron Hill/Chestnut Hill complex (Cunningham 2005). A second source type consists of terrain sources characterized by secondarily deposited water-worn nodules in river sediments. The deposits in the vicinity of Virginia Beach along the shores of the Chesapeake Bay are one such example.

In the earliest provenance investigation of eastern U.S. jaspers, Blackman (1974) contrasted the chemistry of the Reading Prong sources with that of Iron Hill as determined by atomic absorption and flame emission spectrophotometry. He found that the two regions were easily differentiated as a result of the non-overlapping concentration ranges of Na, K, Cr, Ni, Co, Fe, and Rb. This initial effort was followed by the pioneering work of Miller (1982) who conducted INAA analysis of seven jasper sources that included the newly recognized Hatch jasper quarry (formerly called Houserville) in Central Pennsylvania. Discriminant analysis of the data set indicated that all jasper bearing regions could be successful partitioned. However, within the Reading Prong mis-classifications were present among the Lyons, Macungie, and Vera Cruz quarries. A follow-up study to this research indicated that twenty archaeological unknowns from the Kinport site (Miller 1987) could be confidently assigned to the Hatch, Vera Cruz, Flint Run, and Iron Hill sources. Also during this period, Luedtke (1987) contrasted the chemistry of the Lime Rock, Rhode Island, and Reading Prong jaspers and was able to successfully partition the two source areas using a simple bivariate plot of cobalt versus lanthanum. The assignment of archaeological unknowns from sites in Massachusetts using the same approach prompted her to hypothesize that many artifacts originated from the Reading Prong had made their way to New England during the late Middle Woodland Period.

A few years later, an additional project involved the analysis of 20 jasper locations (n=266) from the Reading Prong region, the Hatch/Branch Road source area, Iron Hill, and Flint Run using X-ray fluorescence (XRF) analysis (Stevenson et al. 1992). The results were complementary to the work of Miller (1982) in that the regional source areas could be statistically discriminated, but that individual sources within the Reading Prong did not have discreet chemical signatures. This led to a significant number of misclassifications in the discriminant analysis that was improved upon by grouping the quarries in the Reading Prong into four subgroups based upon spatial proximity.

A subsequent study by King and Hatch (1997) used a portion of the XRF data set of Stevenson *et al.* (1992) representing 12 quarries (n=158) in the Middle Atlantic region. They also processed an additional 80 archaeological samples derived from sites located from southern Virginia to Maine. The intent of study was to document the geographic range of Pennsylvania jaspers and to evaluate the initial observations of Luedtke (1987) that Pennsylvania jaspers were represented in New England

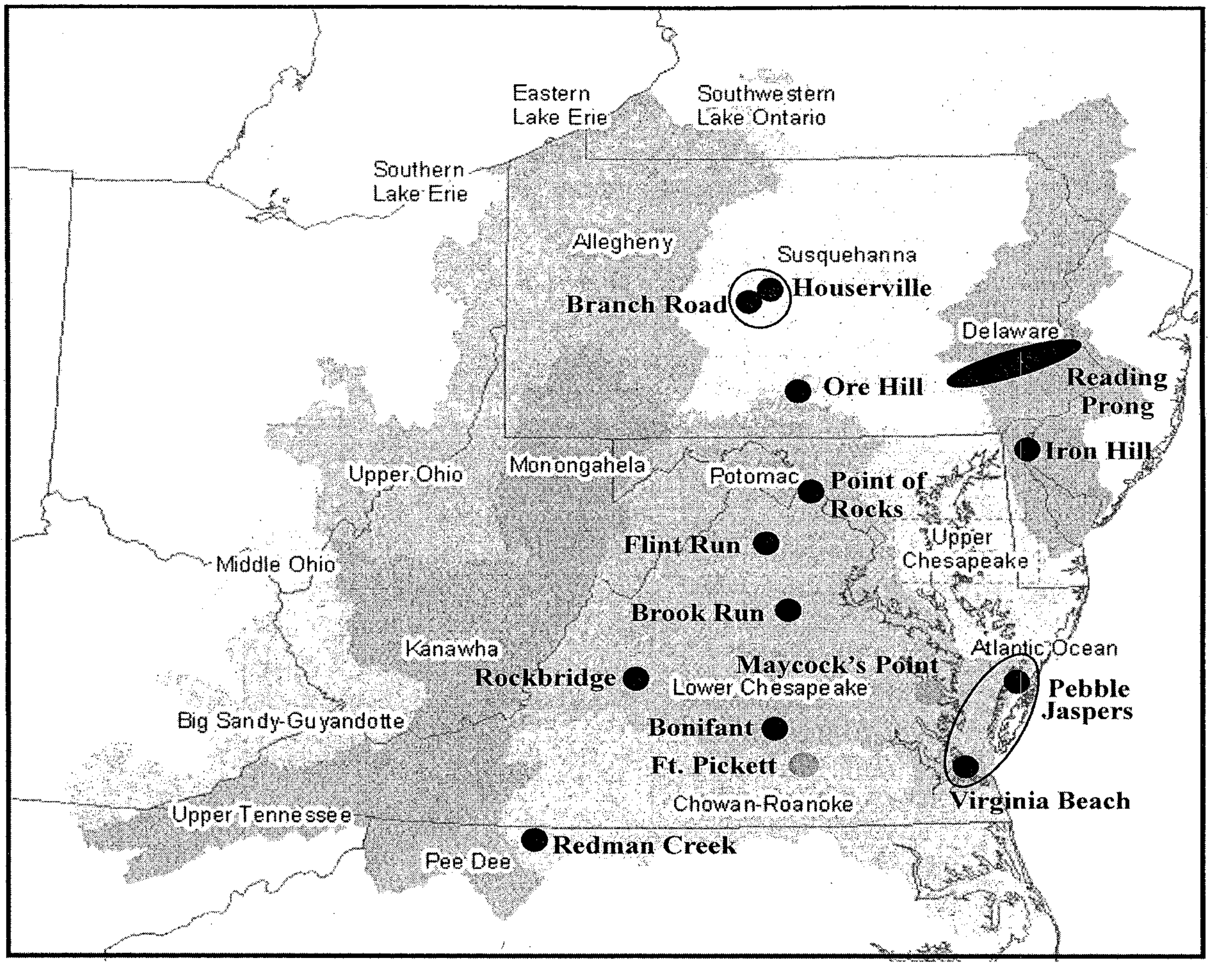

Figure 1. Distribution of jasper sources (black) and locations of archaeological unknowns (gray) in the Middle Atlantic region.

archaeological assemblages. The researchers were able to improve upon the discriminant solution of Stevenson *et al.* (1992) by transforming the raw data so that is more closely met the assumption of normality required by the statistical procedure. The observed versus predicted classifications could distinguish each of the regional source groupings within Pennsylvania and Delaware. However, a significant number of mis-classifications (10 of 29) were made between the Flint Run source and the Reading Prong source area.

The 80 archaeological specimens were assigned to three of the source groups: Reading Prong (n=20), Hatch/Branch Road (n=7) and Flint Run (n=54). No artifacts were assigned to Iron Hill. In their consideration of the results King and Hatch (1997) explain the absence of Iron Hill assignments from the small number of source samples that did not represent the full source chemical variability and thus hindered the ability of the algorithm to make a classification. The assignment of a large number of artifacts to the Flint Run source was also problematic and was interpreted to be a result of undocumented sources within the archaeological assemblage.

The conclusions of King and Hatch (1997) appear to be correct. Since their work was published five new jasper sources have been discovered within Virginia (Table 1). All of them are located to the south of Flint Run and are found in the Coastal Plain, Piedmont, or foothills of the Blue Ridge (Figure 1). Only one of the quarries has been systematically investigated. Extensive excavations at the Brook Run site (44CU122) revealed high-quality jasper that was heavily exploited during the Early Archaic period (10,000-8500 BP). INAA analysis of a sample of the artifacts (n=15) was also completed under the same

TABLE 1: DOCUMENTED JASPER SOURCES IN THE EASTERN UNITED STATES

Source Name	State/Province	Site Number	Source Type
Heath Farm	Delaware	18CE8	Point
Iron Hill Cut	Delaware	18CE65	Point
Iron Hill School	Delaware	7NC-D-34	Point
Cooch Complex	Delaware	7NC-D-108	Point
Choptank River	Maryland	--	Terrain
Point of Rocks	Maryland	18FR31	Point
Cape May	New Jersey	--	Terrain
Stokes Co.	North Carolina	--	Point
Washademaok	New Brunswick	BkDm3	Point
Branch Road	Pennsylvania	36CE258	Point
Durham	Pennsylvania	36BU26	Point
Hatch Quarry	Pennsylvania	36CE238	Point
King's	Pennsylvania	36LH2	Point
Longswamp	Pennsylvania	36BK479	Point
Lyons	Pennsylvania	36BK15	Point
Macungie	Pennsylvania	36LH11	Point
Mast Farm	Pennsylvania	36LH37	Point
Ore Hill	Pennsylvania	36LS13	Point
Urffer's Farm	Pennsylvania	36LH57	Point
Vera Cruz	Pennsylvania	36LH12	Point
Lime Rock	Rhode Island	--	Point
Monkton	Vermont	--	Point
Rockbridge	Virginia	44RB323	Point
Beasley Bay	Virginia	44AC136	Terrain
Bonifant	Virginia	44PO132	Point
Brook Run	Virginia	44CU122	Point
Flint Run	Virginia	44WR12	Point
Virginia Beach	Virginia	44VB5	Terrain

* The Hatch quarry was formerly known as the Houserville jasper quarry

study (Monaghan *et al.* 2004). The remaining four sources have not been systematically investigated or chemically characterized until now. Intriguing is the possibility that if the Virginia sources account for a sizable proportion of the Flint Run source assignments of King and Hatch (1997), it suggests that Virginia was an area from which jasper was carried into the northern Middle Atlantic region.

For this paper, we conduct INAA on geologic samples obtained from four jasper quarries (Bonifant, Flint Run, Rockbridge, Virginia Beach) and incorporate the previously reported data from Brook Run

(Monaghan *et al.* 2004) to develop a regional data set for Virginia sources. Also included in this analysis are ten archaeological unknowns from southern Virginia archaeological sites that will be used to evaluate the potential for source group assignments. Based upon the distributional analysis of jaspers by Hatch and Maxham (1995) in Pennsylvania, it is likely that the vast majority, 80%, of artifacts within a region are discarded less than 160 km from the source. Therefore, if our discriminant solution is successful, we can expect that eight of our ten unknowns will be assigned to a geological source within Virginia.

GEOLOGICAL AND ARCHAEOLOGICAL CONTEXTS

Geological

The jasper deposits used in this analysis have the following geological contexts (USGS 1993):

Bonifant: Located near Macon, Virginia, in the eastern Piedmont, this is a point source associated with a formation of porphyoblastic garnet-biotite gneiss.

Brook Run: This point source is found in the subsided intrusive volcanic and metamorphic rocks of the Triassic Culpeper Basin. Multiple north-south trending faults are contained within the basin and the quarry is associated with one of these faults where siltstone and sandstone deposits interface (Monaghan *et al.* 2004).

Flint Run: A point source in the northern Shenandoah Valley located at a zone of contact between the Beekmantown carbonates and Blue Ridge formations.

Rockbridge: Located in Arnold's Valley within the Blue Ridge Mountains, this point source is found within the Chilhower Group of the Blue Ridge Anticlinorium; a formation of conglomerate, quartzite, and metasiltstone-phyllite.

Virginia Beach: This terrain source, located near the entrance to the Chesapeake Bay, is associated with the Tabb formation; a pebbly sand that grades up to muddy, fine grained sand and sandy silt.

A sixth source known as Beasley Bay has been reported (Lowrey 2003), but no samples were available for analysis. This is a terrain source of small pebbles contained within the Kent Island Formation on the eastern shore of Chesapeake Bay. This is a medium to coarse-grained sand and sandy gravel with well-sorted finely grained sand.

Archaeological

Ten jasper samples were obtained from six archaeological sites within two distinct regions. Four artifacts were from Maycock's Point (44PG40) and six jasper samples were collected from the Fort Pickett Maneuver Training Center (MTC) (Table 2). These specimens were collected from five sites and one survey location within Nottoway and Dinwiddie counties. The provenience information for each of these samples is described below.

Maycock's Point (44PG40): Four jasper flakes (DHR-431 to DHR-434) were selected from the shell midden deposits at Maycock's Point (44PG40), a Middle Woodland site located along the shore of the James River in Prince George County, eastern Virginia (Figure 1). Previous research at this site by C.G. Holland (Holland n.d.), The College of William and Mary (Barka and McCary 1977; Opperman 1980), and Anthony Opperman (Opperman 1992), has documented the presence of an extensive shell midden that is up to 90 cm deep. This prehistoric occupation dates to between AD 245±90 and AD 875±90. Excavations have revealed nine distinct strata of shell, burned shell, and soil that contain high densities of cultural material and perishable faunal and botanical remains. The earlier analyses of the Maycock's ceramic assemblage indicate that Middle Woodland Mockley Ware predominates and that only very small

TABLE 2: ARCHAEOLOGICAL JASPER ARTIFACTS ANALYZED BY INAA

Lab Number	Site Number	Provenience	Artifact	Cultural Context
DHR-330	44DW308	ST. CE23	Flake	Unknown
DHR-331	44NT62	Surface	Endscraper	Middle-Late Archaic
DHR-333	44DW305	402.4NE, S1, L.2	Flake	Late Archaic- Middle Woodland
DHR-334	44NT78	805.3, NE, Quad, L.2	Flake	Transitional-Middle Woodland
DHR-335	44DW305	410.2, SW Quad	Flake	Late Archaic-Middle Woodland
DHR-336	2004.2	Bag 15, 455N 500W	Palmer Point	Early Archaic
DHR-431	44PG40	Unit A3, L. B1	Flake	Middle Woodland
DHR-432	44PG40	Unit A3, L. B1	Flake	Middle Woodland
DHR-433	44PG40	Unit A3, L. B1	Flake	Middle Woodland
DHR-434	44PG40	Unit A4, L. G1	Flake	Middle Woodland

percentages of Early Woodland and Late Woodland materials are present. The jasper artifacts came from Units A3, Level B1 (10-15 cm bgs) and A4, Level G1 (45-50 cm bgs).

44DW305: Two jasper artifacts were recovered from site 44DW305 (DHR-333, DHR-335). The site is a Late Archaic and Early-Middle Woodland procurement site located on a small knoll at an elevation of 77 m (250 feet) AMSL, 70 m (230 feet) northeast of a small, unnamed intermittent creek. No jasper artifacts were recovered during the Phase I survey of site 44DW305, and only two were collected during Phase II evaluation. Both artifacts came from Test Unit 4, with the first specimen (specimen #402.4) provenienced to the upper Ap-horizon at 11-13.5 cm below datum while the second (specimen #410.2) was recovered from the lower Ap-horizon at 22-30 cm below datum. These samples were in association with quartz-tempered pottery of cordmarked surface treatment and flakes of rhyolite, diabase, and quartz. Both of the jasper specimens were tertiary reduction flakes.

44DW308: The jasper specimen from site 44DW308 (DHR-330) was collected from Shovel Test CE23. The site is located on a slight northeast-facing ridge at an elevation of 97 m (315 feet) AMSL, and 46 m (150 feet) east of an unnamed intermittent creek. The single jasper artifact was recovered from the Ap-horizon and was the only artifact recovered from within Shovel Test CE23. Other shovel tests excavated within this site yielded quartzite, quartz, and crystal quartz flakes. Like the specimens described above, the jasper artifact from site 44DW308 is a tertiary reduction flake. As no diagnostic artifacts were recovered from this site, the temporal affiliation is not known.

***44NT62*:** Site 44NT62 was identified from visible artifacts on the ground surface as a result of plowing. The site is located on the crest of a small northeast-southwest-trending ridge nose at an elevation of 131 m (435 feet) AMSL and overlooks a small, unnamed tributary of Tommeheton Creek located at a distance of 450 m to the southeast. All artifacts were surface collected and included, in addition to a jasper endscraper (DHR-331), a metavolcanic Morrow Mountain projectile point, two unidentified quartz bifaces, and several pieces of quartz debitage. The presence of the Morrow Mountain point type suggests a Middle to Late Archaic period occupation at site 44NT62.

44NT78: One jasper artifact (DHR-334) was collected during a Phase II evaluation of 44NT78 conducted in the summer of 2004. This Transitional-Late Archaic-Early Woodland site is located on a knoll at an elevation of 74 m (235 feet) AMSL overlooking a small, unnamed intermittent creek 24 m (80 feet) to the south. The age assignment is based on the presence of both steatite vessels and sand/grit tempered, predominantly fabric impressed (73% of identified sherds) ceramics. The jasper specimen was a tertiary reduction flake, recovered from the B-horizon in Test Unit 8, at a depth of 10-20 cm below datum. Also recovered from the same stratum, level, and quadrant of this unit was a chert projectile point provisionally identified as Merom (800 B.C. to A.D. 1), flakes of diabase, quartz, quartzite, rhyolite, and three steatite bowl fragments.

Site 2004.2: Site 2004.2 is located on a broad ridge top at an elevation of 105 m (333 feet). Small drainages descend from the landform and feed Birchin Creek. Archaeological debris occurs within a 200 x 300 m area and consists of a continuous low-to-moderate density distribution of artifacts within the plowzone. Diagnostics from the site reveal occupations during the Early and Late Archaic. An Early Archaic Palmer point with a missing base was recovered through shovel testing. The point was manufactured from light yellow-brown jasper.

ANALYTICAL METHODS

The source samples and artifacts were washed in de-ionized water to remove all possible dirt and other loose materials from the surface. Samples for INAA were prepared by placing the source specimens between two tool steel plates and crushing them with a Carver Press to obtain a number of small 50-100 mg fragments. The fragments were examined under a magnifier to eliminate any with metallic streaks or crush fractures that could possibly contain contamination. Several grams of clean fragments were obtained from each sample and stored temporarily in plastic bags.

Two separate analytical samples were prepared from each source and artifact specimen. The first sample used for short irradiations was made by placing about 200 mg of fragments into clean high-density polyethylene vials. A second sample used for long irradiation and weighing about 800 mg was placed in clean high-purity quartz vials. Individual sample weights were recorded to the nearest 0.01 mg using an analytical balance. Both irradiation vials were sealed prior to irradiation. Standards made from the National Institute of Standards and Technology (NIST) certified standard reference materials SRM-1633a (Coal Fly Ash), SRM-278 (Obsidian Rock), and SRM-688 (Basalt Rock) were similarly prepared.

IRRADIATION AND GAMMA-RAY SPECTROSCOPY

Instrumental neutron activation analysis (INAA) of archaeological materials at MURR, which consists of two irradiations and a total of three measurements of emitted gamma rays, constitutes a superset of the procedures employed at most other INAA laboratories. As discussed in detail in Glascock (1992), a short irradiation is carried out through the pneumatic-tube irradiation system. Samples and standards in polyethylene vials are sequentially irradiated, in pairs, for five seconds by a thermal neutron flux of 8×10^{13} n cm^{-2} s^{-1}. Following irradiation, the samples undergo decay for 25 minutes so that radioactivity from the short-lived radioisotope ^{28}Al (half-life = 2.24 min) is reduced to an acceptable level for sample handling. The sample vials are mounted in sample holders at a distance of 10 cm from the face of separate high-purity germanium (HPGe) detectors. The sample holders are designed to continuously rotate the samples during a 12-min counting period in order to compensate for slight differences between individual sample shapes. The short-count, gamma-ray spectra are stored and subsequently analyzed in batches to determine the concentrations of elements in the unknown archaeological samples relative to the known concentrations in the standard reference materials. The short-lived elements measured are aluminum (Al), calcium (Ca), dysprosium (Dy), potassium (K), manganese (Mn), sodium (Na), titanium (Ti), and vanadium (V). A few of the elements are below detection limits in some of the samples.

The long irradiation samples and standards in high-purity quartz vials are wrapped in bundles of approximately 32 unknowns and six standards each. Two sample bundles are placed inside an aluminum can and irradiated for 70 hours by a thermal neutron flux of 5×10^{13} n cm^{-2} s^{-1}. Following irradiation, the sample bundles are unwrapped and the quartz vials are washed in aqua regia to remove possible surface contamination. Two separate gamma measurements are performed on the individual samples from each bundle using a pair of HPGe detectors coupled to automatic sample changers with rotating sample holders. The first measurement for 2,000 seconds (i.e., the "middle count") is usually made about one week after the end of irradiation after allowing ^{24}Na (half-life = 15 hr) to decay to a safe handling level. The middle count yields data for the determination of several medium half-life elements, including arsenic (As), barium (Ba), lanthanum (La), lutetium (Lu), neodymium (Nd), samarium (Sm), uranium (U), and ytterbium (Yb). After an additional three- or four-weeks of decay, a final measurement on each sample for three hours (i.e., the "long count") is carried out. The latter measurement yields the data for several long-lived elements, including cerium (Ce), cobalt (Co), chromium (Cr), cesium (Cs), europium (Eu), iron (Fe), hafnium (Hf), nickel (Ni), rubidium (Rb), antimony (Sb), scandium (Sc), strontium (Sr), tantalum (Ta), terbium (Tb), thorium (Th), and zinc (Zn). Additional details about gamma-ray spectroscopy, neutron activation analysis, and standardization can be found in Glascock (1998).

The element concentration data from the three measurements were tabulated in parts per million using the EXCEL spreadsheet program. Descriptive data for the archaeological samples were appended to the concentration spreadsheet and the data were stored in a dBASE/FOXPRO database file useful for organizing, sorting, and extracting sample information.

INTERPRETING THE COMPOSITIONAL DATA

Interpretation of compositional data obtained from the analysis of archaeological materials is discussed in detail elsewhere (e.g., Baxter and Buck 2000; Bieber *et al.* 1976; Bishop and Neff 1989; Glascock 1998; Harbottle 1976; Neff 2000) and is only summarized here. The main goal of data analysis is to identify distinct homogeneous groups within the analytical database. Based on the provenance postulate of Weigand *et al.* (1977), different chemical groups may be assumed to represent geographically restricted sources. For lithic materials such as obsidian, basalt, and cryptocrystalline silicates (e.g., chert, flint, and jasper), raw material samples are frequently collected from known outcrops or secondary deposits and the compositional data obtained are used to define the source localities or boundaries. In contrast, the locations of ceramic raw materials are often inferred by comparing unknown specimens (i.e., ceramic artifacts) to knowns (i.e., clay samples) or by indirect methods such as the "criterion of abundance" (Bishop *et al.* 1992) or by arguments based on geological and sedimentological characteristics (e.g., Steponaitis *et al.* 1996). The ubiquity of ceramic raw materials usually makes it impossible to sample all potential "sources" intensively enough to create groups of knowns to which unknowns can be compared. Lithic sources tend to be more localized and compositionally homogeneous in the case of obsidian or compositionally heterogeneous as is the case for most cryptocrystalline silicates (e.g., chert, flint, and jasper).

Compositional groups are viewed as "centers of mass" in the compositional hyperspace described by the measured elemental data. Groups are characterized by the locations of their centroids and the unique relationships between the elements (i.e., correlations). Decisions about whether to assign a specimen to a particular compositional group are based on the overall probability that the measured concentrations for the specimen could have been obtained from that group.

Potential compositional groups can be hypothesized initially by using non-compositional information (e.g., archaeological context, visual attributes) or by application of one or more different pattern recognition techniques to the multivariate chemical data. Some of the pattern recognition techniques that have been used to investigate archaeological data sets are cluster analysis (CA), principal components analysis (PCA), and canonical discriminant analysis (CDA). Each of the techniques has it own advantages and disadvantages for data interpretation that may depend upon the types and quantity of data available.

Whether a source group can be discriminated easily from other groups can be evaluated visually in two dimensions or statistically in multiple dimensions. A metric known as the Mahalanobis distance (or generalized distance) makes it possible to describe the separation between groups or between individual samples and groups on multiple dimensions. The Mahalanobis distance of a specimen from a group centroid (Bieber *et al.* 1976; Bishop and Neff 1989) is defined by the equation:

$$D^2_{y,X} = [y - \overline{X}]' I_x [y - \overline{X}]$$

where y is the 1 x m array of logged elemental concentrations for the specimen of interest, X is the n x m data matrix of logged concentrations for the group to which the point is being compared with $\overline{X}$ being it 1 x m centroid, and I_x is the inverse of the m x m variance-covariance matrix of group X. Because Mahalanobis distance takes into account variances and covariances in the multivariate group it is analogous to expressing distance from a univariate mean in standard deviation units. Like standard deviation units, Mahalanobis distances can be converted into probabilities of group membership for individual specimens. For relatively small sample sizes, it is appropriate to base probabilities on Hotelling's T^2, which is the multivariate extension of the univariate Student's t.

When group sizes are small, Mahalanobis distance-based probabilities can fluctuate dramatically depending upon whether or not each specimen is assumed to be a member of the group to which it is being compared. Harbottle (1976) calls this phenomenon "stretchability" in reference to the tendency of an included specimen to stretch the group in the direction of its own location in elemental concentration space. This problem can be circumvented by cross-validation, that is, by removing each specimen from its presumed group before calculating its own probability of membership (Baxter 1994; Leese and Main 1994). This is a conservative approach to group evaluation that sometimes excludes "true" group members.

RESULTS AND DISCUSSION

The INAA results were tabulated using the EXCEL spreadsheet program and combined with the descriptive data to create a database for sorting and extraction of subsets. In this study we determined that canonical discriminant analysis (CDA) was our best option for establishing differences between the known geological sources because it met the three rules for this statistical procedure. Our data set: 1) contained two or more groups, 2) contained more than two specimens per group, and 3) the number of variables (elements) is greater than zero and the number of variables (n=16) is less than the total number of cases (source samples) minus two (n=78) (Klecka 1980). Due to the large number of missing values for many of the elements, only 16 elements could be used satisfactorily: As, Ba, La, Sm, Yb, Ce, Co, Cr, Eu, Fe, Sb, Sc, Th, Zn, Mn, and Na (Appendix I). Any missing values or zero entries for the subset of elements that reflect concentrations below detection limits were automatically replaced by a calculated non-zero value that did not effect the minimum Mahalanobis distance from the group centroid or probability of group assignment (Sayre 1975). This approach helps prevent skewing of the CDA calculations that can occur from zero entries. Data for the specimens from the six sources were log-transformed prior to performing the CDA in order to reduce the possible "weighting effect" that occurs when high concentration elements such as Fe are compared to low concentration elements such as the REEs. A plot based on discriminant analysis of the geological specimens is shown in Figure 2 (CD function #1 versus CD function #2). The plot displays a reasonable degree of differentiation between the sources. The ellipses are calculated at the 90% confidence level for each source.

The discriminant functions determined from the source data were applied to the jaspers from Fort Pickett (44DW305, 44DW308, 44NT33, 44NT62, 44NT78) and Maycock's Point (44PG40) so that artifacts could be compared to the geological source groups. Figures 2 shows the artifacts projected against the source ellipses.

Mahalanobis distance based probabilities for membership of artifact specimens in the five geological source groups were calculated as shown in Table 3 using the cross-validation procedure discussed above. Using the information presented in Figure 2 and Table 3, it appears that we can be

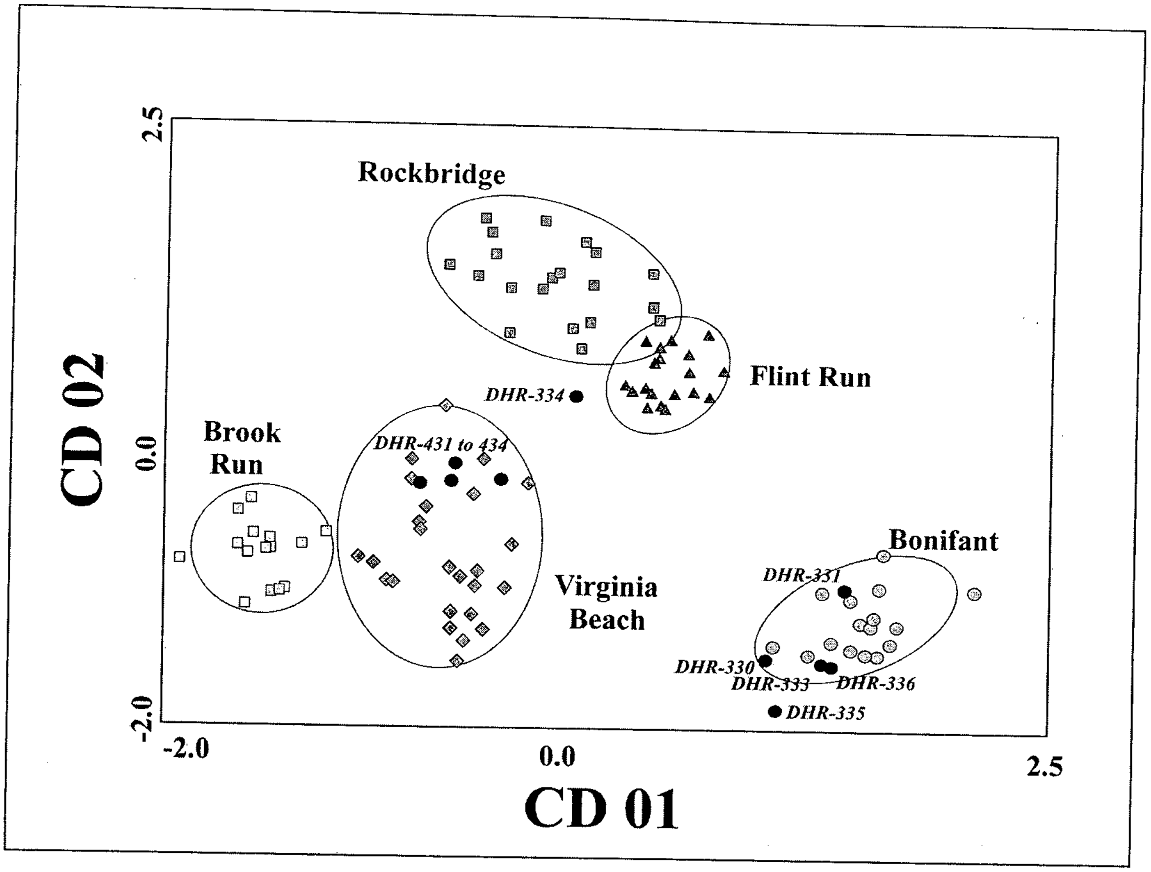

Figure 2: Plot of canonical discriminant functions 1 and 2 for Virginia jasper sources.

TABLE 3: MAHALANOBIS DISTANCE PROBABILITIES

ID No.	Bonifant	Brook Run	Flint Run	Rockbridge	Virginia Beach	Group
DHR-330	36.550	0.000	0.000	0.000	0.003	1
DHR-331	0.498	0.000	0.000	0.001	0.000	1
DHR-333	2.981	0.000	0.000	0.000	0.000	1
DHR-334	0.000	0.000	0.000	1.929	0.087	4
DHR-335	3.732	0.000	0.000	0.000	0.000	1
DHR-336	0.177	0.000	0.000	0.000	0.001	1
DHR-431	0.000	0.011	0.001	0.014	79.668	5
DHR-432	0.000	0.024	0.000	0.037	4.913	5
DHR-433	0.000	0.000	0.000	0.004	0.011	5
DHR-434	0.000	0.290	0.000	0.019	11.843	5

reasonably confident in stating that four of the six artifacts from Fort Pickett originated from the Bonifant source that is approximately 50 km distant. These are samples: DHR-330, DHR-331, DHR-333, and DHR-336. Sample DHR-335 fell just outside of the 90% confidence ellipse for the Bonifant source while artifact DHR-334 has the highest probability of belonging to the Rockbridge group. All of the artifacts (DHR-431 to DHR-434) from Maycock's Point are linked to the Virginia Beach source (90 km distant) although DHR-433 has a lower probability that could place it within the Rockbridge source. These classifications resulted in the assignment of 80% (8 of 10) of the unknowns to a geological source and left 2 (20%) samples without a provenance assignment. This result is comparable to the results of Hatch and Maxham (1995) who observed that up to 80% of jasper samples in Pennsylvania were discarded within 160 km of their geological source.

CONCLUSIONS

Our study suggests that the major sources of jasper in Virginia can be differentiated from one another using INAA elemental data analyzed by canonical discriminant analysis. This technique produced well-defined statistical clusters for each of the geological sources with only minimal overlap between the Rockbridge and Flint Run 90% confidence ellipses. This degree of spatial separation provides a solid foundation for provenance studies under the assumption that the source sampling conducted to date captures the full chemical variability of each outcropping used in the past. The strength of our solution is in part validated by the successful artifact attributions from a variety of archaeological contexts. Most artifacts from Fort Pickett, Virginia, appear to be from the Bonifant source, and artifacts from Maycock's Point are most probably from Virginia Beach terrain source.

It is our opinion, however, that several fundamental tasks are required before jasper provenance studies can be routinely applied in the Middle Atlantic region. First, there are a number of reported jasper occurrences throughout Virginia (Dietrich 1990) that need to be evaluated to determine if the localities were exploited in prehistory. The discovery of a large piece of float jasper in a stream in Montgomery County (Tom Klatka, Virginia Department of Historic Resources, Roanoke, personal communication) suggests this may be highly likely. The use of source material such as the Virginia Beach Pebble jaspers indicates that smaller materials from more limited deposits may not have been overlooked by Native American populations in prehistory. Secondly, INAA analysis of the Pennsylvania jasper sources will need to be repeated using the methods and standards described above. The original raw data from earlier INAA studies have not been published and/or are not available and as a result cannot complement the Virginia data set. Similarly, the large X-ray fluorescence studies of Stevenson *et al.* (1992) and King and Hatch (1997) cannot be integrated into the INAA data set because of differences in elemental detection limits and elements that are uniquely visible to each form of instrumentation. The earlier analyses suggest that sources such as Iron Hill will be statistically different because of their very high iron content and the sole occurrence of niobium, but the ability to develop a unique statistical solution for all of the Middle Atlantic sources remains to be demonstrated.

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REFERENCES CITED

Anthony, D.W. and D.G. Roberts
1988 *Stone Quarries and Human Occupations in the Hardyston Jasper Prehistoric District of Eastern Pennsylvania.* Report prepared for the Pennsylvania Department of Transportation, Engineering District 5-0, John Milner and Associates, West Chester, PA.

Barka, N.F. and B.C. McCary
1977 Early Shell Tempered Pottery in the James River, Virginia. *Eastern States Archaeological Federation Bulletin* 35,36:17.

Baxter, M.J.
1994 Archaeological Uses of the Biplot – a Neglected Technique? In *Computer Applications and Quantitative Methods in Archaeology*, edited by G. Lock and J. Moffett, pp. 141-148. BAR International Series S577. Tempvs Reparatvm, Archaeological and Historical Associates, Oxford.

Baxter, M.J. and C.E. Buck
2000 Data Handling and Statistical Analysis. In *Modern Analytical Methods in Art and Archaeology*, edited by E. Ciliberto and G. Spoto, pp. 681-746. Chemical Analysis Series, Volume 155. John Wiley & Sons, New York.

Bieber, A.M. Jr., D.W. Brooks, G. Harbottle and E.V. Sayre
1976 Application of Multivariate Techniques to Analytical Data on Aegean Ceramics. *Archaeometry* 18:59-74.

Bishop, R.L. and H. Neff
1989 Compositional Data Analysis in Archaeology. In *Archaeological Chemistry IV*, edited by R.O. Allen, pp. 576-586. Advances in Chemistry Series 220, American Chemical Society, Washington, DC.

Bishop, R.L., R.L. Rands, and G.R. Holley
1992 Ceramic Compositional Analysis in Archaeological Perspective. In *Advances in Archaeological Method and Theory*, Volume 5, edited by M. B. Schiffer, pp. 275-330. Academic Press, New York.

Blackman, M.J.
1974 The Geochemical Analysis of Jasper Artifacts and Source Material from Delaware and Pennsylvania. *Transactions of the Delaware Academy of Sciences 1974 and 1975.* Delaware Academy of Sciences, Newark, DE.

Cunningham, K.
2005 *The Prehistory of Lums Pond: The Formation of an Archeological Site in Delaware-Volume II.* Delaware Department of Transportation, Dover.

Dietrich, R.V.
1990 *Minerals of Virginia, 1990.* Department of Mines, Minerals and Energy, Richmond, VA.

Earle, T.
1997 *How Chiefs Come to Power: The Political Economy in Prehistory.* Stanford University Press, Stanford.

Glascock, M.D.
1992 Characterization of Archaeological Ceramics at MURR by Neutron Activation Analysis and Multivariate Statistics. In *Chemical Characterization of Ceramic Pastes in Archaeology*, edited by H. Neff, pp. 11-26. Prehistory Press, Madison, WI.
1998 Activation Analysis. In *Instrumental Multi-element Chemical Analysis*, edited by Z.B. Alfassi, pp. 93-150. Kluwer Academic Publishers, Dordrecht, the Netherlands.

Harbottle, G.
1976 Activation Analysis in Archaeology. *Radiochemistry* 3:33-72.

Hatch, J.W.
1994 The Structure and Antiquity of Prehistoric Jasper Quarries in the Reading Prong, Pennsylvania. *Journal of Middle Atlantic Archaeology* 10:23-46.

Hatch, J.W. and M.D. Maxham
1995 Jasper-bearing Assemblages in Pennsylvania: Implications for the Antiquity and Scale of Regional Exchange. *Archaeology of Eastern North America* 23:231-245.

Helms, M.
1979 *Ancient Panama: Chiefs in Search of Power.* University of Texas Press, Austin.

Holland, C.G.

n.d. The Tar Bay Study. Ms. On file, The Virginia Department of Historic Resources, Richmond.

King, A., J.W. Hatch and B.E. Scheetz

1997 The Chemical Composition of Jasper Artifacts from New England and the Middle Atlantic: Implications for the Prehistoric Exchange of "Pennsylvania Jasper." *Journal of Archaeological Science* 24:793-812.

Klecka, W.

1980 *Discriminant Analysis*. Sage Publications, Newbury Park.

Leese, M.N. and P.L. Main

1994 The Efficient Computation of Unbiased Mahalanobis Distances and Their Interpretation in Archaeometry. *Archaeometry* 36:307-316.

Lowrey, D.

2003 *Archaeological Survey of the Middle Atlantic Coast Shorelines Associated with Accomack County and Northhampton County, Virginia.* Survey and Planning Report Series No. 7. Virginia Department of Historic Resources, Richmond.

Luedtke, B.E.

1987 The Pennsylvania Connection; Jasper at Massachusetts Sites. *Bulletin of the Massachusetts Archaeological Society* 48:37-47.

Miller, P.E.

1982 *Prehistoric Lithic Procurement: A Chemical Analysis of Eastern U.S. Jasper Sources and Consideration of Archaeological Research Design*. M.A. Thesis, The Pennsylvania State University.

1987 *Functional and Chemical Analysis of Materials from the Kinport Site, Cambria County, Pennsylvania*. Report prepared for NPW Consultants, Inc., Uniontown, PA.

Monaghan, G.W., D.R. Hayes, S.I. Dworkin, and E. Voigt

2004 Geoarchaeology of the Brook Run Site (44CU122): An Early Archaic Jasper Quarry in Virginia, USA. *Journal of Archaeological Science* 31:1083-1092.

Neff, H.

2000 Neutron Activation Analysis for Provenance Determination in Archaeology. In *Modern Analytical Methods in Art and Archaeology*, edited by E. Ciliberto and G. Spoto, pp. 81-134. Chemical Analysis Series, Volume 155. John Wiley & Sons, New York.

Opperman, A.F.

1980 *An Analysis of Prehistoric Ceramics from Maycock's Point, Price George County, Virginia.* B.A. Thesis, Department of Anthropology, The College of William and Mary, Williamsburg, VA..

1992 *Middle Woodland Subsistence at Maycock's Point (44PG40), Prince George County, Virginia.* Master of Arts Thesis, The University of Tennessee, Knoxville.

Sayre, E.

1975 Brookhaven Procedures for Statistical Analyses of Multivariate Archaeometric Data. Internal Report. Brookhaven National Laboratory, Upton, NY.

Steponaitis, V., M.J. Blackman, and H. Neff

1996 Large-scale Compositional Patterns in the Chemical Composition of Mississippian Pottery. *American Antiquity* 61:555-572.

Stevenson, C.M., B.E. Scheetz, and M.C. Klimkiewicz

1992 *The Chemical Characterization of Pennsylvania Jasper Using X-ray Fluorescence Analysis*. Report submitted to the Pennsylvania Historical and Museum Commission, Harrisburg, PA.

Stewart, R.M.

1989 Trade and Exchange in the Middle Atlantic Region Prehistory. *Archaeology of Eastern North America* 17:47-78.

USGS

1993 Geological Map of Virginia. Williams and Heintz Map Corporation, Capitol Heights, MD.

Weigand, P.C., G. Harbottle and E.V. Sayre

1977 Turquoise Sources and Source Analysis: Mesoamerica and the Southwestern U.S.A. In *Exchange Systems in Prehistory*, edited by T.K. Earle and J.E. Ericson, pp. 15-34. Academic Press, New York.

Yerkes, R.W.

2002 Hopewell Tribes: A Study of Middle Woodland Social Organization in Ohio. In *The Archaeology of Tribal Societies,* edited by William A. Parkinson, pp. 227-245. International Monographs in Prehistory, Archaeological Series 15. Ann Arbor.

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APPENDIX I : ELEMENTAL DATA FOR VIRGINIA JASPER SOURCES IN PARTS PER MILLION

Source/ Site Name	Brook Run	Brook Run	Brook Run	Brook Run	Brook Run	Brook Run	Brook Run	Brook Run	Brook Run	Brook Run	Brook Run	Brook Run	Brook Run
Lab No.	CHR001	CHR002	CHR003	CHR004	CHR005	CHR006	CHR007	CHR008	CHR009	CHR010	CHR011	CHR012	CHR013
Na	234.0	237.8	150.4	192.5	187.1	259.4	191.7	198.4	198.5	257.6	231.8	183.6	278.9
Mn	377.4	140.3	232.0	410.6	101.4	318.1	136.7	126.8	66.1	324.2	256.7	72.6	613.6
Zn	8.75	8.27	7.14	5.80	6.13	9.48	5.22	6.98	11.17	10.81	7.19	7.96	5.64
Th	0.000	0.026	0.000	0.000	0.034	0.043	0.000	0.048	0.019	0.196	0.000	0.000	0.000
Sc	0.6	0.6	0.6	0.4	0.3	0.8	0.5	0.7	0.4	1.1	0.5	0.6	0.7
Sb	0.1	0.1	0.2	0.1	0.1	0.4	0.1	0.1	0.1	0.3	0.3	0.0	0.2
Fe	21004	18284	20425	17514	15403	24548	14441	15999	24505	24337	21795	15558	18830
Eu	0.142	0.197	0.082	0.212	0.140	0.178	0.041	0.041	0.157	0.185	0.129	0.049	0.145
Cr	0.295	1.422	0.303	0.686	0.819	1.966	0.193	0.565	0.777	1.629	0.477	0.359	0.908
Co	0.834	0.620	0.571	0.745	0.652	2.444	0.457	0.580	0.681	2.379	0.788	0.462	1.346
Ce	2.086	1.466	0.793	2.436	1.763	2.532	0.847	0.891	1.966	2.161	1.636	0.435	0.798
Yb	0.455	0.741	0.297	0.632	0.535	0.589	0.133	0.147	0.397	0.730	0.416	0.211	0.616
Sm	0.468	0.546	0.261	0.668	0.449	0.610	0.146	0.143	0.519	0.533	0.428	0.165	0.424
La	1.395	0.644	0.722	1.267	0.645	2.171	0.433	0.434	1.397	1.403	0.785	0.248	0.443
Ba	23.1	0.0	20.7	31.7	11.7	29.8	12.5	0.0	0.0	14.5	38.1	0.0	20.7
As	25.29	33.81	24.21	34.56	19.53	15.27	20.04	20.78	31.01	15.59	19.70	20.73	8.81

Brook Run	Bonifant #4	Bonifant #4	Bonifant #4	Bonifant #4	Bonifant #4	Bonifant #4	Bonifant #4	Bonifant #4	Bonifant #4	Bonifant #4	Bonifant #4	Bonifant #4	Bonifant #4
CHR015	DHR246	DHR247	DHR248	DHR249	DHR250	DHR251	DHR252	DHR253	DHR254	DHR255	DHR256	DHR257	DHR258
240.0	105.3	130.3	99.1	98.4	140.2	90.7	102.1	117.3	105.6	142.1	86.9	103.6	107.1
491.3	19.7	81.5	35.9	32.2	54.4	15.9	16.2	6.6	20.6	67.9	21.7	19.4	27.3
4.69	2.30	28.31	4.39	13.02	5.66	6.85	11.56	3.41	4.94	7.20	5.48	5.30	8.84
0.000	0.047	0.049	0.000	0.000	0.019	0.041	0.000	0.070	0.040	0.027	0.046	0.015	0.023
0.4	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17245	8638	59400	15534	29595	9974	15348	27326	12486	11337	10071	9703	10751	19903
0.153	0.095	0.047	0.086	0.087	0.027	0.030	0.033	0.032	0.034	0.024	0.027	0.014	0.063
0.871	0.933	1.386	0.000	0.378	0.667	0.807	0.338	0.923	0.668	0.812	0.422	0.804	0.685
0.872	0.620	9.344	1.843	4.714	1.817	2.030	4.505	1.813	1.761	1.606	1.466	1.452	2.672
1.001	1.112	0.000	0.000	0.972	0.555	0.605	0.000	1.154	1.197	0.700	0.847	0.480	1.300
0.639	0.129	0.227	0.254	0.221	0.107	0.102	0.102	0.096	0.128	0.080	0.089	0.078	0.171
0.459	0.495	0.220	0.465	0.395	0.136	0.151	0.164	0.192	0.180	0.158	0.144	0.090	0.335
0.476	2.860	0.992	1.331	1.751	0.630	0.732	0.649	0.806	0.829	0.623	0.761	0.297	1.122
6.9	19.1	0.0	0.0	0.0	0.0	33.3	14.3	0.0	0.0	39.7	8.1	29.9	11.1
12.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46	0.12	0.33	0.11	0.00

Bonifant #4	Bonifant #4	Bonifant #4	Flint Run	Flint Run	Flint Run	Flint Run	Flint Run	Flint Run	Flint Run	Flint Run	Flint Run	Flint Run	Flint Run	Flint Run
DHR259	DHR260	DHR261	DHR262	DHR263	DHR264	DHR265	DHR266	DHR267	DHR268	DHR269	DHR270	DHR271	DHR272	DHR273
86.1	120.6	106.7	73.4	72.5	114.0	94.5	94.3	79.9	82.8	112.5	86.3	93.1	93.1	64.8
20.9	128.2	25.2	135.9	104.7	15.4	19.8	17.7	12.2	10.8	19.9	28.6	48.0	93.8	22.7
4.85	8.79	11.95	19.17	16.00	3.23	4.62	4.94	5.81	16.84	9.53	7.58	20.88	34.27	8.51
0.068	0.062	0.026	0.025	0.000	0.005	0.000	0.000	0.054	0.056	0.089	0.073	0.024	0.335	0.043
0.1	0.1	0.1	0.2	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.3	0.3	0.6	0.2
0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12592	13724	21173	10576	8838	10977	15175	15894	1754	7196	2994	6665	10566	15914	6745
0.072	0.035	0.042	0.012	0.008	0.005	0.006	0.006	0.065	0.057	0.071	0.117	0.021	1.171	0.065
1.167	0.836	0.991	3.907	0.149	0.921	1.439	1.115	0.910	1.125	1.439	0.595	0.535	3.376	0.365
1.437	2.418	3.251	0.638	0.486	0.234	0.312	0.279	0.275	0.543	0.511	0.679	0.936	2.234	0.767
1.031	1.043	0.846	0.360	0.208	0.134	0.234	0.180	1.840	1.714	3.005	2.443	0.548	22.376	0.820
0.133	0.119	0.182	0.037	0.026	0.010	0.016	0.000	0.095	0.080	0.075	0.125	0.109	0.900	0.154
0.326	0.172	0.208	0.055	0.035	0.029	0.034	0.033	0.273	0.201	0.295	0.501	0.092	5.243	0.263
1.127	0.866	1.020	0.230	0.197	0.086	0.121	0.119	1.725	1.314	2.451	1.207	0.213	11.479	0.266
8.8	39.2	82.7	4.6	0.0	0.0	3.3	0.0	3.9	5.4	6.9	16.4	5.3	107.2	15.3
0.00	0.13	0.29	0.95	0.77	0.27	0.28	0.33	0.44	0.56	0.57	0.27	0.55	1.06	0.27

Flint Run	Flint Run	Flint Run	Flint Run	Flint Run	Flint Run	Flint Run	Flint Run	Rockbridge	Rockbridge	Rockbridge	Rockbridge	Rockbridge	Rockbridge
DHR274	DHR275	DHR276	DHR277	DHR278	DHR279	DHR280	DHR281	DHR339	DHR340	DHR341	DHR342	DHR343	DHR344
81.4	61.1	74.9	69.5	155.7	163.9	95.2	132.1	90.3	93.9	0.0	83.4	22.0	107.5
97.3	175.5	145.1	156.6	197.5	112.9	161.8	192.9	62.5	36.7	24096.5	396.0	5854.6	77.5
27.29	35.49	19.24	54.70	43.29	59.42	28.61	65.01	17.59	41.08	38.67	25.43	10.40	26.25
0.017	0.000	0.000	0.017	0.823	1.237	0.444	0.268	0.109	0.223	0.014	0.133	0.013	0.000
0.3	0.3	0.3	0.4	1.2	1.8	0.8	1.8	0.2	0.4	0.8	0.2	0.0	0.2
0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.2	0.2	0.3	0.2	0.0	0.3
19633	27778	13829	37489	28211	31767	20434	62638	27077	19307	30591	37116	16094	32152
0.028	0.018	0.015	0.024	7.229	12.549	2.858	4.795	0.025	0.066	0.123	0.068	0.009	0.028
0.524	0.624	0.371	1.218	9.134	14.461	4.434	8.364	1.223	2.472	0.560	1.489	0.587	1.245
2.755	4.269	2.034	6.589	7.181	5.245	3.172	9.153	1.003	0.595	10.772	0.714	1.348	1.144
0.440	0.391	0.179	0.449	98.370	166.850	38.013	66.653	0.920	2.575	12.809	2.000	0.501	1.174
0.428	0.362	0.297	0.276	1.904	3.369	0.837	1.126	0.071	0.205	0.261	0.202	0.034	0.112
0.106	0.064	0.048	0.084	28.398	45.097	11.985	19.620	0.172	0.359	0.752	0.355	0.086	0.235
0.197	0.116	0.081	0.157	38.054	60.504	15.674	27.895	0.651	1.829	2.745	1.190	0.389	0.582
6.6	5.5	8.2	13.8	878.9	1456.6	404.9	704.5	30.0	17.5	4210.2	7.3	445.2	11.3
0.76	1.03	0.53	1.56	1.22	1.65	1.26	2.83	3.63	4.45	17.23	12.61	13.90	1.72

Rockbridge	Rockbridge	Rockbridge	Rockbridge	Rockbridge	Rockbridge	Rockbridge	Rockbridge	Rockbridge	Rockbridge	Rockbridge	Rockbridge	Rockbridge
DHR345	DHR346	DHR347	DHR348	DHR349	DHR350	DHR351	DHR352	DHR353	DHR354	DHR355	DHR356	DHR357
96.1	83.7	97.1	94.9	99.5	151.6	234.7	89.5	113.2	83.4	100.1	76.5	102.8
40.3	23.6	106.9	45.0	36.9	458.9	249.6	44.4	2464.8	13.4	359.1	643.7	544.1
33.30	9.84	24.45	10.02	7.18	26.23	43.37	34.99	23.57	49.57	23.28	27.63	61.18
0.013	0.045	0.479	0.053	0.036	0.706	0.069	0.122	0.066	0.141	0.071	0.027	0.278
0.1	0.1	0.4	0.1	0.2	1.4	0.7	0.3	0.1	0.3	0.2	0.1	1.0
0.3	0.1	0.4	0.1	0.6	0.4	0.2	0.1	0.4	0.2	0.2	0.2	0.6
39144	7637	44227	4234	2744	49009	27756	13704	28100	15805	27450	51290	68365
0.025	0.022	0.076	0.043	0.143	2.510	1.612	0.081	0.042	0.033	0.092	0.064	0.156
1.335	0.692	3.777	0.481	0.353	7.280	2.337	4.814	1.456	1.359	3.290	1.226	13.123
1.107	0.335	1.634	0.226	0.263	0.703	0.876	0.439	0.874	0.392	0.632	1.875	2.808
0.652	0.786	2.125	2.008	2.847	133.842	76.036	2.629	2.121	1.411	7.020	1.401	6.830
0.101	0.044	0.254	0.164	0.344	1.470	0.569	0.124	0.098	0.091	0.140	0.186	0.256
0.212	0.154	0.395	0.277	0.817	11.584	8.615	0.449	0.381	0.162	0.494	0.332	0.894
0.434	1.027	1.225	1.106	2.314	68.498	94.481	2.545	1.274	0.758	3.889	0.816	4.049
13.5	8.7	10.1	15.5	16.3	256.6	106.9	75.4	36.7	32.1	30.0	15.3	43.5
3.51	0.89	10.59	1.24	0.84	10.35	9.90	2.57	29.25	4.79	9.64	6.64	11.03

Rockbridge	Virginia Beach	Virginia Beach	Virginia Beach	Virginia Beach	Virginia Beach	Virginia Beach	Virginia Beach	Virginia Beach	Virginia Beach	Virginia Beach	Virginia Beach	Virginia Beach	Virginia Beach
DHR358	DHR411	DHR412	DHR413	DHR414	DHR415	DHR416	DHR417	DHR418	DHR419	DHR420	DHR421	DHR422	DHR423
95.4	332.5	145.6	181.1	581.6	322.5	309.1	448.1	364.9	522.9	292.9	265.3	151.9	100.3
1858.9	6.3	28.8	141.6	45.3	22.2	108.8	10.3	61.6	122.0	21.6	13.1	20.8	306.1
16.68	2.87	9.42	7.86	10.62	3.22	6.80	9.12	4.47	21.13	12.92	1.99	1.58	14.79
0.035	0.120	0.051	0.025	0.317	0.138	0.131	1.283	0.342	0.952	0.361	0.083	0.309	0.411
0.1	0.2	0.1	0.4	0.4	0.3	0.9	2.4	0.7	3.3	0.8	0.5	0.6	2.2
0.2	0.0	0.1	0.3	0.0	0.1	0.2	0.1	0.1	0.3	0.0	0.0	0.1	0.2
31687	1415	5319	13384	10237	5598	18446	7790	10739	29668	6101	2768	3490	19041
0.013	0.808	0.017	0.031	0.218	0.486	0.135	0.656	0.100	0.320	0.045	0.029	0.034	0.876
1.029	2.567	0.214	1.369	3.320	4.085	1.428	8.608	6.848	31.548	13.696	0.432	1.178	4.532
0.678	0.237	0.349	2.732	1.942	1.473	5.335	0.681	1.465	8.295	1.498	0.364	0.654	11.672
0.539	11.067	1.186	1.099	8.693	8.671	3.833	40.500	4.897	12.911	2.342	0.629	1.800	34.009
0.037	0.867	0.074	0.060	0.279	0.527	0.283	0.603	0.146	0.677	0.114	0.064	0.116	1.130
0.091	2.936	0.208	0.150	0.917	1.975	0.550	3.080	0.418	1.461	0.226	0.122	0.162	3.550
0.320	7.979	0.256	0.584	3.753	5.157	1.567	22.645	3.252	8.712	1.778	0.307	1.073	14.925
41.7	6.9	20.7	279.9	206.7	104.9	72.0	189.3	362.2	176.9	835.4	20.9	790.2	366.8
16.09	0.44	3.10	4.93	2.21	3.30	6.26	4.25	8.80	20.49	4.97	0.57	1.27	11.43

Virginia Jasper Sources

Virginia Beach	Virginia Beach	Virginia Beach	Virginia Beach	Virginia Beach	Virginia Beach	Virginia Beach	Maycock's Point	Maycock's Point	Maycock's Point	Maycock's Point	44DW308	44NT62	44DW305
DHR424	DHR425	DHR426	DHR427	DHR428	DHR429	DHR430	DHR431	DHR432	DHR433	DHR434	DHR330	DHR331	DHR333
154.7	232.7	154.3	207.0	185.9	211.6	218.8	198.8	293.3	253.7	201.3	166.3	182.4	180.1
25.5	29.4	17.9	13.0	1.0	7.7	239.3	36.7	63.8	439.4	334.7	17.7	20.7	95.4
3.58	4.69	4.04	2.38	1.49	6.31	11.10	8.68	12.88	12.30	7.07	4.58	3.35	15.01
0.138	0.835	0.249	0.037	0.151	0.041	0.291	0.327	0.163	0.113	0.125	0.029	0.027	0.000
0.3	1.2	0.2	0.1	0.3	0.8	2.5	1.3	0.2	0.2	0.1	0.1	0.0	0.1
0.0	0.1	0.0	0.0	0.1	0.1	0.2	0.3	0.2	0.3	0.1	0.0	0.0	0.0
2659	5134	3800	550	566	3026	23920	5811	6077	21856	14407	16049	13997	22494
0.048	0.441	0.097	0.009	0.015	0.161	0.212	0.152	0.028	0.090	0.036	0.015	0.011	0.018
1.596	5.553	2.617	0.350	2.078	1.368	7.761	2.880	1.893	0.950	0.481	0.891	0.511	0.505
0.466	4.230	8.652	0.275	0.111	0.468	5.872	1.245	0.979	1.009	0.809	1.007	0.667	4.498
1.521	20.557	6.005	0.486	0.682	8.285	5.049	8.097	1.699	6.686	2.325	0.565	0.776	1.010
0.063	0.477	0.128	0.019	0.047	0.258	0.353	0.326	0.423	2.060	0.119	0.084	0.060	0.000
0.211	1.951	0.472	0.039	0.078	0.662	0.907	0.774	0.167	0.839	0.280	0.092	0.174	0.162
0.915	15.698	3.246	0.280	0.503	4.166	2.480	2.843	0.787	3.234	0.643	0.336	0.373	0.727
90.1	2091.2	68.7	106.2	219.2	17.4	42.2	723.0	34.9	85.5	53.9	0.0	8.3	0.0
1.25	3.80	3.48	0.54	0.50	0.66	9.97	0.00	2.12	18.69	11.13	0.39	0.26	0.00

44NT78	44DW305	2004.2
DHR334	DHR335	DHR336
106.5	205.2	144.8
24.0	171.4	642.1
0.97	5.04	3.92
0.042	0.038	0.027
0.0	0.1	0.5
0.2	0.0	0.0
1201	24397	8734
0.100	0.079	0.010
0.748	1.056	0.527
0.173	5.018	2.408
4.768	2.888	0.660
0.118	0.159	0.062
0.511	0.554	0.116
7.693	2.660	0.378
0.0	49.7	54.3
0.50	0.85	0.00