Clinker, Pumice, Scoria, or Paralava? Vesicular Artifacts of the Lower Missouri Basin

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Abrading artifacts made of vesicular (porous) rock are not uncommon at archaeological sites along the Missouri River and adjacent areas. Various terms have been used to describe this material including pumice, scoria, clinker, and floatstone. Each of these terms implies different geologic origins (volcanic vs. non-volcanic) and affects interpretation of the potential modes of transport. Identification of the source area of these materials may provide significant information regarding past human movements and activities. This study focuses on vesicular artifacts in the central Plains and in particular from the Leary site (25RH1) in the southeastern corner of Nebraska. Scanning Electron Microscopy (SEM) was used to identify the chemical compositions of a subset of the Leary artifacts and comparative geologic samples of volcanic and metasedimentary origin. The results imply that the Leary (and likely many other) vesicular artifacts from the central Plains are non-volcanic in origin. The raw material from which these artifacts were made is more properly termed "paralava" and derives from outcrops in the northern Plains. Historical documents suggest that this buoyant material was transported naturally by the Missouri River as "floatstone".

Keywords: paralava, clinker, Scanning Electron Microscope, semiquantitative analysis, abrading artifacts

It is not unusual to find abrading artifacts at archaeological sites along the Missouri River and in neighboring areas that are made of a vesicular rock (having open pores) (Wedel 1961:89, 188). This material has been variously identified in artifact catalogs and archaeological site reports as clinker, pumice, scoria, pseudoscoria, and floatstone (e.g., Beck and Begeman 1998; Bell 1936; Bray 1991; Flenniken and Ozbun 1988; Hill and Wedel 1936; Porter 1962; Strong 1935; Wedel 1943, 1959, 1961). These terms carry different meanings, which are rarely defined in the archaeological literature, and imply different geologic origins, namely non-volcanic vs. volcanic. These origins influence the interpretations of modes of transport for the raw material, namely natural vs. anthropogenic. Identification of the source area of these materials and their mode of transport may provide significant information regarding past human movements and activities. The goals of this study are to clarify the different meanings of these terms, to identify the rock type of a sample of artifacts, and to discuss the archaeological implications of the geologic material. This study focuses on vesicular materials recovered from archaeological sites in the central Plains and specifically on the identification of a subset of vesicular materials from the Leary site (25RH1) in southeastern Nebraska.

Vesicular artifacts from this site (as well as

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many others in the region [Table 1]) have been referred to as "pumice" (Hill and Wedel 1936:47), suggesting a rock of volcanic origin. Given the lack of suitable volcanic deposits in the central Plains, the presence of "pumice" at Leary and other sites in this region implies human transport over great distances from western sources such as Yellowstone or the Rio Grande Rift. Many Plains archaeologists, however, suggest that this material derived from sediments melted by natural underground coal fires in the northern Plains. The vesicular stone subsequently eroded into tributary rivers and naturally drifted down the Missouri River as "floatstone" (Blakeslee and Caldwell 1979:35, 66; Blakeslee et al. 2001:96–97; Henning and Shermer 2004:508; Hill and Wedel 1936:47; Porter 1962:267–268; Wedel 1943:194). If correct, the term "pumice" is incorrectly applied and creates contradictions between the implied and actual mode of transport.

TERMINOLOGY

Vesicular lithic material is highly porous stone whose visible air pockets significantly decrease its density. Surfaces are often rough and abrasive. Many vesicular artifacts found at archaeological sites exhibit smoothed surfaces and grooves suggesting their use as abraders, for example, for shaping wooden shafts or sharpening bone into piercing tools. The Omaha and other Plains Indians reportedly used "pumice-stone" to scrape hides during the tanning process (James 1823:221; Maximilian 1906:261). Natural sources of vesicular rock, which may be derived either from volcanoes or from melted sediments, do not occur as surface outcrops in the central Plains. This material, therefore, must have been transported to this region via humans or by natural processes.

"Pumice" and "scoria" are common terms used to refer to vesicular rock (Table 1). The geologic definitions of these words make it clear these rocks have a volcanic origin. Pumice is a light-colored, silica-rich volcanic rock that is vesicular and low in density. Essentially pumice is natural glass with trapped bubbles creating the vesicles. Scoria is a magnesium- and iron-rich, vesicular volcanic rock dark in color and denser than pumice because of its composition. Both result from explosive, gas-rich volcanic eruptions. Local residents of western North Dakota often use the term "scoria" colloquially and incorrectly when referring to naturally baked, red siltstone or claystone prevalent in that region (Biek and Gonzalez 2001:67, 71; Bluemle 1988:29, 2002; Sigsby 1966). Pseudoscoria is a non-genetic term that implies a non-volcanic material similar in appearance to scoria, but it is not widely used. Floatstone does not identify rock type but implies transport via water. This identification is based on the fact that the low density of highly vesicular rock, whether volcanic or non-volcanic in origin, allows it to float.

Another term used by archaeologists to refer to vesicular lithic material is "clinker" (e.g., Anderson 1980; Baerreis 1968; Blakeslee et al. 2001; Calabrese 1969; Porter 1962). This term is used broadly by geologists for naturally baked and fused sediments, although clinker also refers to culturally-produced slag from ore refining, coal burning, or brick making. The geologic term 'paralava' is most accurately applied to vesicular clinker because it refers specifically to naturally melted or fused rock formed by heating or baking of sedimentary rocks or unconsolidated sediments at high temperatures produced by adjacent burning coal seams (Clark and Peacor 1992:558; Coates 1984; Cosca et al. 1989:86, 87; Sokol et al. 1998). Paralava is also an appropriate term for non-volcanic glass formed by the same process. Non-volcanic glass is more likely to form when, prior to the baking or melting event, the sedimentary rock has little water and a high amount of sand. Non-volcanic glass (i.e., glassy paralava) has a different texture than the artifacts and comparative samples here because it does not have abundant vesicles. Furthermore, glassy paralava may be knappable.

SOURCE AREAS

Paralava outcrops occur in areas where coal is prevalent and partially exposed at the surface where it is susceptible to ignition from lightning or prairie fire. This situation exists in the northwestern plains of western North Dakota, northeastern Wyoming, and eastern Montana (Figure 1). Although distant from the central Plains, this region is drained by the Missouri River and its

Table 1. Sites Discussed in the Text.

Site Name	Published Term	Affiliation	Reference
Cherokee (13CK405)	clinker	Archaic	Anderson 1980:225
DB (14LV1071)	scoria	Archaic	Beck & Begeman 1998:232–233, 236–238; Logan 1998:330–331
Signal Butte (25SF1)	pumice	Archaic	Strong 1935:230
Hamner Mounds (23SA115)	pumice	Woodland (& Archaic)	Graham 1978, KSU Archaeology Lab catalog
Leahy (25NH6)	scoria	Woodland	Hill & Kivett 1940:199
Utlaut (23SA162W)	pumice	Woodland (& early historic Oneota)	KSU Archaeology Lab catalog
Renner (23PL1)	pumice or scoria	Kansas City Hopewell	Roedl & Howard 1957:79; Wedel 1943:60–61
Renner Mound (23PL30)	pumice	Kansas City Hopewell	Wedel 1943:145
Trowbridge (14WY1)	pumice	Kansas City Hopewell	Wedel 1959: 545, 547
Williams (13PM50)	clinker	Great Oasis	Williams 1974:20–21
Larson (13PM61)	clinker, scoria, pumice	Great Oasis-Mill Creek	Henning 1996:11, 40, 42, 50, 53, 55, 92
Brewster (13CK15)	pumice	Mill Creek	Flenniken & Ozbun 1988:40
Broken Kettle (13PM1)	clinker	Mill Creek	Fugle 1962:44–45
Kimball (13PM4)	clinker	Mill Creek	Baerreis 1968:180–184; Fugle 1962:65
Phipps (13CK21)	clinker	Mill Creek	Baerreis 1968:180–181; Fugle 1962:29
14ML417	pumice	Central Plains tradition	Latham 2003:20; Latham 2004:44
Avondale Mounds (23CL23)	pumice	Central Plains tradition (& Woodland)	Wedel 1943:150
Gates (25SY5)	pumice-like material	Central Plains tradition	Strong 1935:152, 162
Glenwood site House X-11 (13ML237)	pumice or scoria	Central Plains tradition	Anderson 1961:34
Kullbom House I (13ML13)	pumice or scoria	Central Plains tradition	Anderson 1961:57
House III (13ML12)			Anderson 1961:63
Nuzum (14DP10)	clinker	Central Plains tradition	Calabrese 1969:77, 78
Rock Bluffs (25CC31)	pumice-like	Central Plains tradition	Strong 1935:141–142
Schulte (25CD1)	scoria	Central Plains tradition	Bell 1936:49, 74
Steed-Kisker (23PL13)	pumice	Central Plains tradition	Wedel 1943:86
Wiseman (25CD3)	scoria	Central Plains tradition	Bell 1936:49, 57, 74, 75
Leary (25RH1)	pumice	Late Prehistoric Oneota (& Central Plains tradition)	Hill & Wedel 1936:47
Bastian (13CK28)	(pumice)	Late Prehistoric Oneota	Dale R. Henning, personal communication, 2005
Dixon (13WD8)	scoria	Late Prehistoric Oneota	Link 1999:60
Glen Elder (14ML1)	clinker	Late Prehistoric Oneota (White Rock phase)	Blakeslee et al. 2001:96–97; Rusco 1960:59
Utz (23SA2)	scoria pumice	Late Prehistoric Oneota & Proto/Early Historic Oneota	Berry & Chapman 1942:303, 305; Bray 1991:121
Blood Run (13LO2)	clinker	Protohistoric Oneota	Henning & Shermer 2004:436, 508
Doniphan (14DP2)	pumice	Protohistoric Oneota	Wedel 1959:117, 124
Fanning (14DP1)	pumice	Protohistoric Oneota	Wedel 1959:158–159
Gumbo Point (23SA4)	pumice	Historic Missouria	Chapman 1959:48
Hayes (23VE4)	pumice	Historic Osage	Chapman 1965:576, 581
Plattner or Little Osage (23SA3)	pumice	Historic Osage	Chapman 1959:14

Note: (see Figure 1 for site locations).

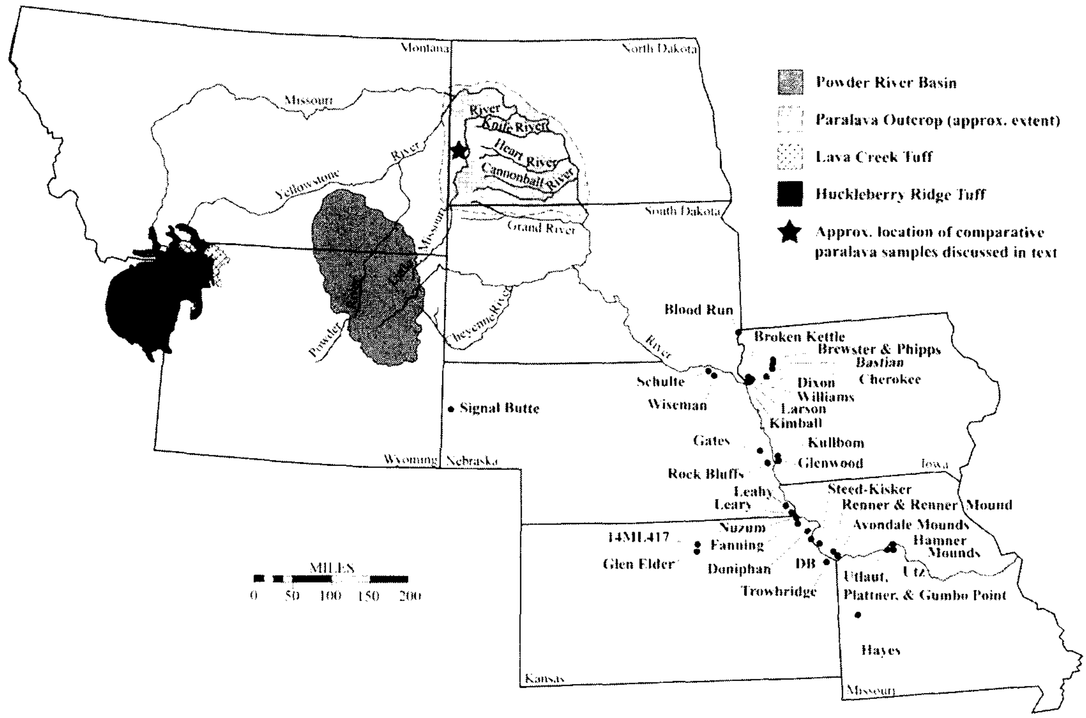

Figure 1. Map of the Missouri River basin showing possible source areas of vesicular rock as well as archaeological sites for which vesicular artifacts have been reported. The star marks the approximate location where comparative paralava samples were obtained. The artifacts analyzed for this study came from the Leary site (25RH1).

tributaries raising the possibility that eroded paralava has been naturally transported by these rivers. In this case, transport of paralava to the central Plains is a natural geologic process. Native Americans may have found this material deposited along the Missouri River and collected it for future use. It is also possible that this material was collected at the source area and carried or exchanged between individuals into the central Plains. Humans may also have transported vesicular volcanic materials.

The closest sources of exposed volcanic rock to the central Plains are in the Yellowstone region of northwestern Wyoming and the volcanic fields in northern New Mexico. Although ashes from the Yellowstone eruption do occur in the central Plains, these typically have a grain size of ~2 μm. Pumice as large as that observed at archaeological sites could have two transport mechanisms operating singly or in concert. Pumice from the Yellowstone caldera could have entered the headwaters of the Missouri River and been transported naturally downstream. Alternatively, this material would require human transport from Yellowstone. Volcanic scoria, which closely resembles the study samples in color, is typically too dense to float because of its high iron and magnesium contents. The closest scoria localities are cinder cones in the Clayton-Raton volcanic field of northern New Mexico. This material would have to be carried to the central Plains because of its density and lack of fluvial systems linking these two areas.

Although visually similar, one may distinguish pumice/scoria and paralava because their respective volcanic and metasedimentary origins create distinct mineralogical and chemical compositions (Coates 1984:201; Sokol et al. 1998). Pumice from the Yellowstone caldera contains high amounts of silica (SiO_2) and alumina (Al_2O_3) and low amounts of iron (Fe) and magnesium (Mg) (Perkins and Nash 2002:371). Scoria generally has lower amounts of SiO_2 and Al_2O_3 and alkali elements such as sodium (Na) and potassium (K). Like pumice, paralavas also tend to have high amounts of SiO_2 and Al_2O_3 but they have lower amounts of Fe compared to pumice and scoria (Clark and Peacor 1992:560; Cosca et al. 1989:96). These compositional differences also create mineralogical differences between the volcanic and metasedimentary rock types. Given these differences, it is relatively straightforward to test whether vesicular lithics are of volcanic or metasedimentary origin. In order to infer the area of origin and mode of transport of vesicular rocks to the central Plains, we analyzed the chemical composition of a subset of vesicular artifacts from the Leary site (25RH1) in extreme southeastern Nebraska (Figure 1).

VESICULAR ARTIFACTS IN THE PLAINS

Artifacts made of vesicular rock have been recovered from a number of archaeological sites in the Great Plains, especially along or near the Missouri River (Wedel 1961:89,188). This is especially true for sites in the middle reach of the Missouri River in North Dakota and South Dakota (e.g., Ahler 2003a:163, 2003b:251–252; Ahler and Badorek 2003:105; Caldwell 1966:63–64; Hoffman 1967:25; Johnston 1967:35; Lehmer 1966:40–41; Porter 1962:267–268; Smith 1977:86; Stephenson 1971:69, 137; Wedel 1961:188). Previous analysis and identification of the raw material from which these artifacts were made is restricted to a study completed by James W. Porter (1960, 1962) of lithic materials from three village sites near Mobridge, South Dakota. Macroscopic and petrographic analyses of these vesicular lithic materials led Porter to classify them as 'clinker,' which he described as "a porous, multi-colored baked sediment which resembles scoria or pumice" (Porter 1960:29). Although Porter noted an acid or silica matrix for this material that is similar to pumice, he stated that pumice and scoria showed "definite crystals enclosed in the glass. The clinker in only a few instances gave the faintest of outlines of some anisotropic mineral" (Porter 1960:29–30). Porter further noted that this material formed adjacent to burning coal veins west of his study area (e.g., northwestern South Dakota and adjacent areas of Wyoming, Montana, and North Dakota) and implied that it was carried to his study area via the Missouri River and its tributaries as floatstone (Porter 1960, 1962:267–268). Many Plains archaeologists who have encountered vesicular lithic artifacts in archaeological collections since Porter's study have likewise identified this material as clinker (Table 1).

Vesicular artifacts also have been reported from a number of sites in the central Plains, including parts of Iowa, Nebraska, Kansas, and Missouri. These sites range in age from the Archaic through the Protohistoric or Early Historic period (Table 1). The majority are located along or near the Missouri River valley, although several are found some distance from that valley (Figure 1).

Many of the vesicular objects found at archaeological sites exhibit modifications. For example, specimens from the Broken Kettle, Cherokee, DB, Hamner, Kimball, Leahy, Leary, Phipps, Schulte, Steed-Kisker, Trowbridge, Utz, Wiseman, and other sites have grooves, likely from shaping wooden shafts or for sharpening wood or bone for awls or other piercing implements (Anderson 1980:225; Beck and Begeman 1998:235–236; Bell 1936:49; Bray 1991:121; Fugle 1962:29, 44–45, 65; Hill and Wedel 1936:47; Wedel 1943:86, 1959:545, 547). Not all vesicular objects are grooved. Several recovered from Cherokee, Doniphan, Fanning, Glen Elder, Leary, Nuzum, Renner, Rock Bluffs, and other sites have flat, rounded, slightly depressed, or irregular surfaces that may have been used for preparing hides or other relatively soft materials (Anderson 1980:225; Bell 1936:49; Blakeslee et al. 2001:96; Calabrese 1969:77, 78; Hill and Wedel 1936:47; Strong 1935; Wedel 1943:61, 1959:545, 547). The most unique vesicular lithic object reported in the central Plains is a pipe recovered from the Wiseman site, a St. Helena phase (Late Prehistoric) site in northeastern Nebraska (Bell 1936:57, 132–133) (Table 1).

LEARY SITE VESICULAR ARTIFACTS

For our analysis, a set of artifacts was selected from the Leary site (25RH1). This Late Prehistoric village is located in the very southeastern corner of Nebraska on a low terrace along the Big

Nemaha River approximately 2.4 km above its confluence with the Missouri River (Figure 1). Early excavations indicated a major Oneota occupation (Hill and Wedel 1936) that may have coincided in part or immediately followed a Central Plains tradition occupation documented during subsequent investigations (Ritterbush 2002). A number of vesicular artifacts have been recovered from Leary, 13 of which were inspected for this study.

The Leary vesicular artifacts are generally irregular in shape with dimensions ranging from 3.00–9.81 cm long, 1.62–7.22 cm wide, 0.99–5.96 cm thick, and weighing 2.7–152.2 g. Colors exhibited on individual and between pieces is variable but includes bluish gray and black, very dark gray, to red and yellowish red. Most of the artifacts show wear or modification, commonly 'U'- and 'V'-shaped grooves. Four of the objects show no obvious cultural modification. Six have one or two grooves, while the remaining three have numerous grooves (n=5–12). V–shaped grooves (n=32) occur more commonly than those that are rounded or U-shaped (n=23). Classic loaf-shaped and other sandstone abraders have also been recovered from the Leary site (Hill and Wedel 1936:47). The vesicular abraders are less abundant and more irregularly shaped. Although most of the vesicular artifacts show evidence of use as abraders and would have been effective in smoothing bone or other materials, none are shaped like typical sandstone abraders found at this and other sites in the Plains (Flenniken and Ozbun 1988). Simple flotation tests revealed that 11 of the vesicular artifacts floated in water, while two did not (catalog #2338, 6034).

In the first published mention of these artifacts at Leary, Hill and Wedel (1936:47) referred to the material as 'pumice.' They stated that the source of these "pumice" lumps was unknown but that they probably floated down the Missouri River. When discussing the Fanning site in nearby Kansas, Wedel later (1959:158) noted that, "Pumice occurs as irregular slightly worked lumps that may have been gathered along the shore of the Missouri River, as it was by the Historic Indians of the Valley." The interpretation that vesicular materials arrived in the eastern central Plains via natural processes of the Missouri River was reiterated by Wedel in 1961 (89, 175). It is unclear whether Hill and Wedel believed this material was of volcanic origin as the term 'pumice' implies, but it is clear that they understood the potential role of the Missouri River in transporting this material to the eastern edge of the central Plains from distant sources.

METHODS

We conducted semi-quantitative geochemical analysis of four vesicular lithic objects from the Leary site (catalog #6034, 6614, 5338, 1806) and four comparative paralava samples from North Dakota using an Energy Dispersive Spectrometer (EDS) attached to a Scanning Electron Microscope (SEM). We chose this technique because it is non-destructive. We compared these analyses to published compositions for other possible source materials. The four objects analyzed from the Leary site are finely vesicular and dark gray to red in color. Three have multiple, straight grooves on one or more surfaces, while the fourth exhibits no clearly artificial grooves or modified surfaces. Unlike the others, the latter object (#6034) does not float in water. Although highest precision results are obtained by SEM on flat, highly-polished surfaces, we chose to analyze clean, unpolished surfaces of the artifacts in order to avoid possible destruction of cultural information. Each artifact was carefully examined and washed with distilled water. Comparative samples of paralava were obtained from outcrops near the Little Missouri River in the North Dakota Badlands (Figure 1). Polished thin sections were made of the comparative paralava samples.

The instrument used for our analysis was a Hitachi S-3500N with secondary electron and backscattered electron imaging capabilities owned and operated by the Department of Entomology at Kansas State University. This instrument also has an Oxford Instruments energy dispersive spectrometer (EDS) that determines the chemical compositions of reference and sample materials. Before we analyzed the comparative samples and artifacts, we calibrated the SEM beam current using a cobalt reference standard. Next we analyzed a multi-mineralic set of standards to obtain intensity information for elements of interest (Ca, Mg, Na, Ti, K, Si, Fe, Al, P, C). Following standardization, a homogeneous plagioclase of known composition was analyzed to check calibration and standardization. If the readings differed by more than ~2 percent, we re-standardized the SEM by individually analyzing different minerals for each element. We completed this procedure prior to every session of comparative or artifact sample analysis. During the analyses, the operating conditions included 20 kV voltage and working distances of 14.8–21 mm. A small spot size was obtained by magnification of 20,000x to analyze a homogeneous portion of the matrix, which approximates the bulk rock composition in that area. Using the SEM, we analyzed four points on each comparative sample and each artifact. Analyses that did not return a total sum of oxides between 98 and 101 percent were rejected. Readings were taken at four points on two different faces of one artifact (#1806-a, vesicular face; #1806-b, smooth face).

RESULTS

Viewing the artifacts with the SEM revealed that the matrix of each artifact consisted of numerous tiny, round vesicles that created a very rough texture. Geochemically, the artifact samples showed moderately high amounts of SiO_2 (57.29–70.93 percent) and relatively high amounts of Al_2O_3 (16.84–26.47 percent). K_2O (1.55–3.57 percent) and Fe (FeO_t 0.78–6.99 percent and Fe_2O_{3t} 0.866–7.759 percent, where Fe_2O_{3t} is total iron calculated from the reported FeO_t analysis) appear in relatively low quantities (Table 2). Geochemical data from individual loci on mineral inclusions or heterogeneous areas were not included in the comparison with potential source

Table 2. Chemical Compositions in Weight Percent Oxide of Artifact Samples by Semi-quantitative Energy Dispersive Spectrometry (EDS) Capabilities of the Scanning Electron Microscope (SEM)

Artifact Number	SiO_2	TiO_2	Al_2O_3	FeO_t	MgO	CaO	Na_2O	K_2O	P_2O_5	Total
6034-1*	64.63	0.67	21.92	3.52	3.66	1.16	1.18	2.65	0.47	99.86
6034-2	69.69	0.48	18.78	2.27	0.93	1.89	3.09	2.87		100.00
6034-3	66.57	0.78	21.09	3.40	2.94	1.42	1.13	2.68		100.01
6034-4	70.18		19.82	2.49	2.87	1.12	1.40	1.94		99.82
1806-a1	65.90		22.35	2.56	3.30	0.62	2.17	3.10		100.00
1806-a2	64.53	0.56	22.03	3.35	3.58	0.78	1.94	3.13		99.90
1806-a3	64.28	0.45	22.94	3.70	3.00		2.06	3.57		100.00
1806-a4	66.66		21.99	2.12	3.08	0.71	2.34	3.09		99.99
1806-b1	69.89		19.28	0.78	1.61	1.36	4.40	2.35		99.67
1806-b2	62.06		24.95	3.39	4.18		2.47	2.95		100.00
1806-b3	61.62	0.47	24.05	3.09	3.30	1.66	3.78	2.03		100.00
1806-b4	63.11	0.46	21.50	4.48	3.04	1.71	3.01	2.70		100.01
5338-2	57.29	0.51	24.75	6.99	5.22	2.45	1.23	1.55		99.99
5338-3	65.89	0.67	24.00	1.57	3.68		1.66	2.53		100.00
5338-4	62.07	0.44	26.47	2.82	4.53		1.52	2.16		100.01
6614-1	70.93	1.06	16.84	5.05	2.00	1.15	0.62	2.36		100.01
6614-3	65.84	0.30	21.04	3.68	3.48	0.82	1.31	2.81	0.54	99.82
6614-4	62.93		22.16	3.78	2.88	2.07	1.61	3.21	1.01	99.65

**The format for the sample number is ####-1 where the last number refers to the individual SEM analysis and the previous numbers refer to catalog numbers assigned by the Nebraska State Historical Society to the individual Leary site artifacts.*

materials.

The paralava comparative samples included four samples from the North Dakota Badlands. The SEM analysis for the four paralava samples revealed high amounts of SiO_2 (62.94–75.97 percent) and relatively high amounts of Al_2O_3 (14.11–27.93 percent). Low amounts of K_2O (0.84–4.30 percent) and Fe (FeO_t 0.34–1.47 percent and Fe_2O_{3t} 0.377–1.632 percent) were present in these samples (Table 3).

Although the high temperature processes associated with the formation of paralava changes the protolith or parent rock (Bauer 1972; Clark and Peacor 1992; Coates 1980:38; Cosca et al. 1989; Herring 1979, 1980:42–43), Sokol and others (1998) note that bulk chemical composition of the protolith is the dominant control on the final mineralogy and composition of the paralava. Some variation may be induced by the maximum annealing temperature and the volatile content and composition (Sokol et al. 1998), but the oxide compositions of low volatility elements (Si, Al, Fe, Mg) should change the least. A diagram that classifies sedimentary rock type according to chemical composition provides a useful aid to summarize the compositions of the comparative samples. Figure 2 displays the composition of paralava samples analyzed in this study along with paralava samples analyzed by Cosca and others (1989) and Clark and Peacor (1992) from the Powder River basin of Wyoming and Yellowstone volcanic tuff (pumice) samples analyzed by Perkins and Nash (2002). The compositions of the majority of the paralavas suggest their protolith or pre-metamorphic lithology was shale or shale with minor amounts of quartz (wacke and arkose fields) (Figure 2). A few samples from the Powder River basin have high Fe_2O_3/K_2O plotting in the iron-rich shale region. This may reflect pyrometamorphic loss of K with steam, carbon, and sulfur gas species because of its relatively low boiling temperature (759° C; Lide 1996:4,122) and high mobility in fluids. The compositional distribution shown in Figure 2 reflects the heterogeneity of paralava. This is expected as the formations that produce paralava are compositionally varied. Likewise, temperatures, compositions, and amounts of gases created by pyrometamorphism vary widely at small scale (cm to dm).

INTERPRETATION

The sedimentary rock classification illustrated in Figure 2 is useful in showing similarities and variation among paralavas and in identifying some geochemical similarities and differences between paralavas and pumice. The Perkins and

Table 3. Chemical Compositions in Weight Percent Oxide of Comparative Paralava Samples by Semi-quantitative Energy Dispersive Spectrometry (EDS) Capabilities of the Scanning Electron Microscope (SEM).

Paralava Sample	SiO_2	TiO_2	Al_2O_3	FeO_t	MgO	CaO	Na_2O	K_2O	P_2O_5	Total
5002A–1*	69.36		17.12	1.47	3.96	2.12	4.22	1.48		99.73
5002A-2	73.01		18.50		0.32	1.45	5.25	1.47		100.00
5002A-3	75.97		14.76	0.35	2.37	0.73	4.17	1.65		100.00
5002A-4	67.87	0.38	18.74	0.93	3.49	2.51	4.60	1.47		99.99
5002B-1	69.78		18.35	0.34	4.17	1.21	4.90	1.25		100.00
5002B-3	67.83		20.83	0.47	2.50	1.93	5.25	1.19		100.00
5003A-2	62.94		25.16		5.91		5.14	0.84		99.99
5003A-3	67.83		22.51		1.81		6.56	1.29		100.00
5007C-3	63.14	0.38	27.93		6.15		1.27	1.14		100.01
5007C-4	67.51		22.01	0.91	6.36		1.58	1.63		100.00

**The format for the sample number is ####-1 where the last number refers to the individual SEM analysis and the previous four numbers refer to the catalogued specimen.*

Nash (2002) study of the Yellowstone eruptions concluded that the Lava Creek Tuff (0.60 Ma) and Huckleberry Ridge Tuff (2.06 Ma) had relatively high percentages of SiO_2 (73.3–74.2 percent) and Al_2O_3 (11.7 percent) and low amounts of K_2O (4.9–5.1 percent) and iron (Fe_2O_{3t}=1.65–1.70 percent). Note there are two tuffs from the Lava Creek episode. Perkins and Nash (2002) provide analyses for member B of the Lava Creek Tuff. These readings are comparable with the highest percentages of SiO_2 in the paralava samples, but higher than those of the artifacts; lower in Al_2O_3 than the paralava and artifact samples; and higher in potassium oxide (K_2O) than the paralava and artifacts. If these data are plotted on the same sediment rock type diagram, it is clear that the pumice from these volcanic eruptions would have compositions more similar to arkose than shale (Figure 2). Arkose is sandstone with a high proportion of aluminous feldspar minerals and iron oxide or calcite cement.

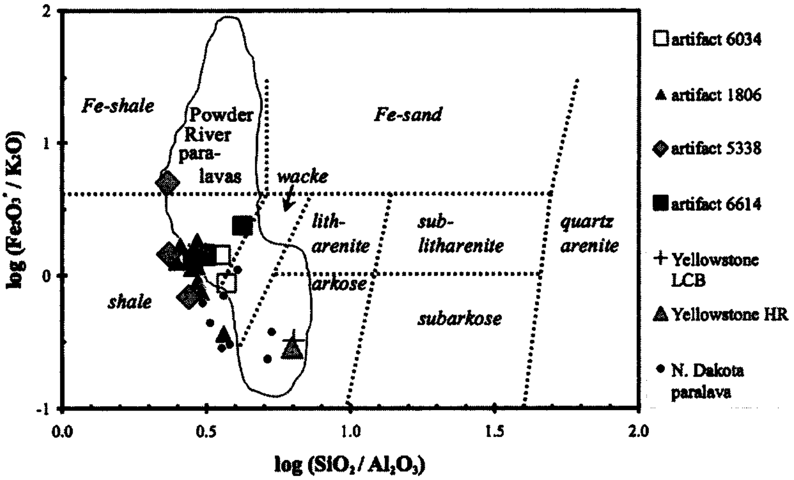

Figure 2. Logarithmic plot of Fe_2O_3/K_2O vs. SiO_2/Al_2O_3 comparing possible paralava source compositions and compositions of volcanic pumice from Yellowstone with compositions of Leary vesicular artifacts. A field is drawn around the set of published Powder River basin paralava compositions (Clark & Peacor 1992:560; Cosca et al. 1989:95–96). Yellowstone pumice compositions include those from the Huckleberry Ridge (HR) eruption and the Lava Creek Tuff, B unit (LCB) eruption (Perkins & Nash 2002:371). Leary site artifacts (larger symbols) nearly all plot in the shale compositional field, as do the comparative paralava samples from North Dakota. (Fe_2O_3* is total iron calculated by multiplying measured total iron as FeO by 1.11 [Kilinc et al. 1983]. Quartz arenite is a sandstone. Arkose consists mainly of quartz and aluminous feldspar minerals. Shale has the highest alumina contents due to its abundance of clay minerals).

The Leary artifacts group largely together within the range of shale (Figure 2). The composition of these artifacts overlaps in part with the North Dakota paralava comparative samples and is least similar, among the potential source materials, to the volcanic pumice compositions. The composition of the latter also overlaps that of some of the paralava samples, but not the artifacts. The majority of the paralava and all the artifact samples have higher levels of alumina (Al_2O_3) than the Yellowstone tuffs. Figure 3 defines additional similarities and differences between the paralava, artifact, and Yellowstone tuff samples in that the pumice has much lower amounts of MgO than the comparative paralavas and the Leary artifacts. In sum, the sample artifacts from the Leary site are almost certainly derived from paralava based on their physical appearance, density, and chemical compositions. They are not derived from either volcanic pumice or scoria.

From our analysis of comparative paralava samples from western North Dakota, the artifacts, and published data pertaining to Powder River basin paralava and Yellowstone tuffs (pumice), it is clear that the Leary artifacts are of metasedimentary origin, and, therefore, should be termed 'paralava'. It is impossible to determine the exact point of origin of the materials from which these artifacts were made, although their compositions resemble the tested samples from the Badlands of western North Dakota.

It is possible that native inhabitants of the central Plains obtained paralava for abrading tools by traveling to source areas, through exchange with other groups, or by finding material in the alluvial deposits of the Missouri River. Histori-

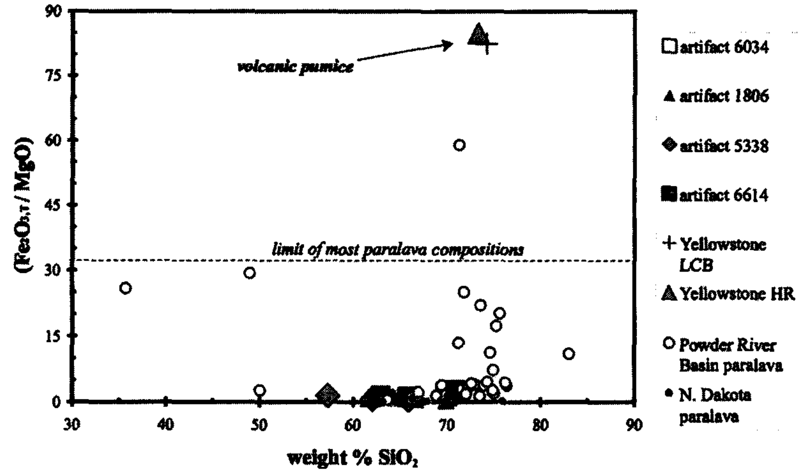

Figure 3. Fe_2O_3/MgO vs. weight percent SiO_2 distinguishes the Leary artifacts and most paralava compositions from those of Yellowstone pumices. Although the silica range is similar, the volcanic pumice has very little MgO (0.02 weight percent) relative to the paralavas. (Published data are from *the sources cited in Figure 2*).

cal documents note the association of vesicular material with the Missouri River, particularly the erosion and transport of paralava by water. The earliest mention of "pumice" along the Missouri River appears to be by William Clark in his journal entry of June 8, 1804. Here, he refers to finding a hunter's cache in the ground along the river in what is now central Missouri (Moulton 1986:286–287). This cache included kegs, hides, and "an Pummey stone," which was likely used by native and Euroamerican hunters for preparing hides. Although this entry does not indicate the origin of the "pumice," other entries indicate its availability along the Missouri River as floatstone or in natural outcrops in the northern Plains. On August 4, 1804, north of present-day Omaha, Nebraska, Clark noted "great ma[n]y *Pamey* Stones on the Shore of various Sises" and "Pumey [pumice] Stone is found on the Sides of the river of various Sizes" (Moulton 1986:445). No doubt these had floated downstream from outcrops along the Missouri River and its tributaries in the northern Plains. On March 21, 1805, while wintering at Fort Mandan in present-day North Dakota, Clark described original outcrops of this material and an experiment he conducted in order to interpret the process causing its formation,

> on my return to day to the Fort I came on the points of the high hills, Saw an emence quantity of Pumice Stone on the Sides & foot of the hills and emence beds of Pumice Stone near the Tops of the [hills] with evident marks of the hill haveing once been on fire, I collected Some the different i e Stone Pumice Stone & a hard earth and put them into a furnace the hard earth melted and glazed the others two and the hard Clay became a pumice Stone Glazed (Moulton 1987a:318, cf. 317).

Meriwether Lewis sent several samples of clinker and paralava back east as mineralogical specimens in April 1805 before continuing upriver from Fort Mandan. The Donation Book of the American Philosophical Society, where these items were eventually curated, records interesting information about these materials,

> 62 Specimen of the pumice Stone found amongst the piles of drift wood on the Missouri. Sometimes found as low down as the mouth of the osage river *[present-day central Missouri]*. I can hear of no burning mountain in the neighborhood of the Missouri or its Branches, but the bluffs of the River are now on fire at Several places, particularly that part named in our chart of the Missouri *The Burning Bluffs*. The plains in many places, throughout this great extent of open country, exhibit abundant proofs of having been once on fire—Witness the Specimens of Lava and Pummicestone found in the Hills near fort mandon ...
>
> 67 A Specimen of Lava & pumice Stone found in great abundance on the Sides of the hills in the Neighborhood of Fort Mandan 1609 miles above the mouth of the Missouri—exposed by the washing of the Hills from the rains & melting Snow— ... The tract of Country which furnishes the Pummice Stone seen floating down the Misouri, is rather burning or burnt plains than burning mountains (Moulton 1987a:478)

Lewis and Clark documented similar material farther upstream and along tributaries of the

Missouri River in journal entries that mentioned the "birnt hills & pumice stone" (Moulton 1987a, 1987b) in western North Dakota and eastern Montana. Lewis made special mention April 14, 1805, of this material drifting down the Little Missouri River:

> while we remained at the entrance of the little Missouri, we saw several pieces of pumice stone floating down that stream, a considerable quantity of which had lodged <and collected> against a point of drift wood a little above it's entrance (Moulton 1987b:34).

No doubt these early references have contributed in part to the casual and inappropriate use of the term pumice compared to its modern, specific geologic context.

Other early European and American travelers (e.g., Bradbury, Brackenridge, Maximilian) made similar comments about the presence of "pumice" along the shores or banks of the Missouri River, its similarity to volcanic material yet lack of volcanic deposits in the region, and its ability to float. George Catlin, an artist who traveled along the Missouri River and nearby Badlands in 1832, painted the outcrops of clinker or "pumice" as he called it (see Catlin's painting entitled "Brink Kilns; Clay Bluffs 1900 Miles Above St. Louis" in Troccoli [2002:149]). In his writings, he, like Lewis and Clark, explained the process by which paralava eroded from natural outcrops and was then carried on the current of the Missouri River,

> ...and the...masses of pumice and basalt [paralava] are crumbling off...by the force of the gorges of water [and] carried into the river...and wafted for thousands of miles...floating as light as a cork upon its surface, and lodging in every pile of drift-wood from this place to the ocean (Catlin 1848:70).

Catlin and others were mistaken in naming this material "pumice," but his description of the erosion of this naturally baked material in western North Dakota and its transport downriver explains how natural movement of paralava occurred before the Missouri River was modified by dams and reservoirs in the twentieth century.

The authors of these historical sources did not provide detailed descriptions of individual pieces of vesicular stone. Nonetheless, it is difficult to imagine materials much different than those found in archaeological sites along the Missouri River. These pieces are generally small, irregular in shape, and have rounded or smoothed surfaces. Due to the vesicular nature of paralava, it is easily broken and abraded. Although large masses of paralava can be found intact at their sources, only relatively small pieces would have survived the long trip from those outcrops to the central Plains. Wedel (1943:60–61, 86) noted that the maximum dimension of vesicular artifacts at the Renner and Steed-Kisker sites (near present-day Kansas City, Missouri) was 9.5 cm. The maximum measurement of the 13 artifacts we inspected from the Leary assemblage was only slightly larger at 9.8 cm. Comparable sized vesicular artifacts were recovered from the DB site in northeastern Kansas, as well as sites in northwestern Iowa (e.g., Broken Kettle, Kimball, Williams) (Beck and Begeman 1998:236–237; Fugle 1962:44, 65; Williams 1974:21). This suggests that erosion, transport as drift, and subsequent use by prehistoric peoples reduced pieces of this material to sizes easily held in one hand. It is possible that the use of the material would have broken off areas of greater vesicularity, perhaps explaining why two of the Leary site samples did not float in water. Small stones, especially lightweight vesicular stone, easily could be transported by water, and by humans after collecting it along the river.

The transport of paralava down the Missouri River and subsequent use by prehistoric peoples has been underway for thousands of years as suggested by the presence of vesicular artifacts at Archaic sites, such as Cherokee and DB in northwestern Iowa and northeastern Kansas, respectively. Most of the sites with vesicular lithic artifacts in the central Plains are along or near the Missouri River (Figure 1). Blakeslee and Caldwell (1979:79) note that vesicular artifacts are less common at sites located some distance from the Missouri River. Their presence away from this valley may be explained by occasional travel, exchange, or migration from or through that region (e.g., Henning 1996:11, 92; Henning and Toom 2003:203). The vesicular lithic objects at 14ML417 and Glen Elder in north-central Kansas, roughly 165 miles west of the Missouri River

(Blakeslee et al. 2001; Latham 2003, 2004; Rusco 1960:59), may have been carried there by visitors or obtained through exchange. Diagnostic artifacts at Glen Elder indicate that it was occupied by Oneota peoples, who also lived near (e.g., Leary site) or east of the Missouri Valley. Thus, it would be plausible to interpret transport of this material from the Missouri River region by Oneota peoples traveling westward into the Plains. The abrasive quality of the paralava would be useful for tanning hides or sharpening awls for preparing and sewing hides obtained while hunting bison on the western prairies. A similar relationship between Oneota peoples might explain the presence of this material at late prehistoric Oneota sites in the Midwest including OT in southwestern Wisconsin (Hollinger 1993:86) and Wever in southeastern Iowa (Dale R. Henning, personal communication 2005). These sites are located along the Mississippi River well above its confluence with the Missouri. It is unlikely that the Oneota people who lived along the Mississippi obtained paralava directly from the Missouri River unless they traveled long-distances to the west or south. Travel and exchange between Oneota peoples may explain the presence of paralava artifacts in the Midwest. The abrader included with a burial at the later Oneota Flynn site in northeastern Iowa (Bray 1961:16) might reflect continued relationships between Oneota peoples in the Midwest with those living along the eastern edge of the central Plains. Other people living along the Mississippi River but below its confluence with the Missouri River may have had access to paralava that floated down both the Missouri and the lower reach of the Mississippi River. "Pumice abraders" are occasionally reported at Woodland period sites in the Cairo Lowlands of southeastern Missouri (e.g., Williams 1974:16–17, 81).

Vesicular material is also reported at Signal Butte in western Nebraska (Strong 1935:230). Instead of being obtained from the Missouri River, this material may have been carried here from the Powder River basin, which is located nearby in Wyoming. Rather than suggesting natural river transport, this material may reflect early human movements through this region and the direct collection of vesicular material from its source. Comparative compositional analyses similar to those used in this study might be used to test this hypothesis.

CONCLUSION

Based on our comparative analysis of the composition of vesicular materials potentially available in the central Plains, we conclude that the vesicular artifacts at the Leary site are metasedimentary, rather than volcanic in origin. Their chemical compositions are similar to paralava samples from the northern Plains. Their physical and chemical characteristics suggest origin as a shale or similar material (e.g., siltstone, claystone) that was naturally heated to very high temperatures (i.e., paralava). The exact point of origin of the vesicular material represented at Leary and other sites in the central Plains has not been identified due to the limited size of our comparative database. The heterogeneity of paralavas observed in outcrop suggests chemical heterogeneity at small scale. This may prevent identification of a single outcrop source. Early historic documents, however, suggest that this material most likely derived from the middle reaches of the Missouri River or its tributaries in Montana, North Dakota, South Dakota, or Wyoming. No doubt pieces of paralava entered the Missouri River from multiple sources in this region. The important point is that this material is not volcanic in origin (thus is not true "scoria" or "pumice") and does not necessarily represent transport by humans through long-distance travel or exchange. Given the metasedimentary origin of the tested vesicular artifacts from Leary and, most likely, similar artifacts from other sites in the central Plains, especially those near the Missouri River, the term "paralava" is most correctly applied to this material. Although the term "clinker" also refers to heated sediments, it includes baked stones that are not vesicular and slag or mining refuse. We encourage adoption of the term "paralava" because it clarifies both the geologic origin and implications for the transport of this material in the central Plains. The presence of paralava in this region, especially along or near the Missouri River, can be explained by natural processes. In essence, the source of paralava, although in actuality a secondary source, can be considered local to archaeological sites in the eastern central Plains.

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