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Neutron activation analysis of 12,900-year-old stone artifacts confirms 450–510+ km Clovis tool-stone acquisition at Paleo Crossing (33ME274), northeast Ohio, U.S.A.

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ABSTRACT

The archaeologically sudden appearance of Clovis artifacts (13,500–12,500 calibrated years ago) across Pleistocene North America documents one of the broadest and most rapid expansions of any culture known from prehistory. One long-asserted hallmark of the Clovis culture and its rapid expansion is the long-distance acquisition of “exotic” stone used for tool manufacture, given that this behavior would be consistent with geographically widespread social contact and territorial permeability among mobile hunter–gatherer populations. Here we present geochemical evidence acquired from neutron activation analysis (NAA) of stone flaking debris from the Paleo Crossing site, a 12,900-year-old Clovis camp in northeastern Ohio. These data indicate that the majority stone raw material at Paleo Crossing originates from the Wyandotte chert source area in Harrison County, Indiana, a straight-line distance of 450–510 km. Our analyses thus geochemically confirm an extreme stone-source-to-camp-site distance of a Clovis site in eastern North America and thus provide strong inferential material evidence that the fast expansion of the Clovis culture across the continent occurred as a result of a geographically widespread hunter–gatherer social network.

1. Introduction

The archaeologically sudden appearance of Clovis artifacts across North America documents one of the broadest and most rapid expansions of any culture known from prehistory (Goebel et al., 2008; Hamilton and Buchanan, 2007; Meltzer, 2009; O'Brien et al., 2014; Prasciunas and Surovell, in press; Smallwood and Jennings, in press; Waters and Stafford, 2007). Current estimates suggest that the appearance of the Clovis culture occurred in the American West ca. 13,500–12,800 calibrated years before present (calBP) and in the East ca. 12,800–12,500 calBP (Ferring, 2001; Gingerich, 2011; Haynes et al., 1984, 2007; Holliday, 2000; Levine, 1990; Sanchez et al., 2014). Based on these dates, Clovis tools, including fluted lanceolate projectile points, spurred and notched endscrapers, prismatic blades, and bone and ivory rods, are among the earliest artifacts in North America.

One long-asserted hallmark of the Clovis culture and its rapid expansion is the long-distance acquisition of “exotic” stone used for tool manufacture (Meltzer, 2009; Bradley et al., 2010; Ellis, 2008; Frison and Bradley, 1999; Goodyear, 1989; Haynes, 2002; Kelly and Todd, 1988; Kilby, 2008; MacDonald, 1968; Speth et al., 2013; Stanford and Jodry, 1988; Witthoft, 1952). The question remains as to whether this acquisition occurred “directly,” that is, by Clovis foragers obtaining stone from a source themselves (Ellis, 2011), or “indirectly,” meaning the stone went through one or more intermediaries or groups between source and users (Hayden, 1982; Speth et al., 2013). With respect to direct acquisition, there is also debate as to whether stone procurement was “embedded” within a band's annual mobility round or whether specialized task groups made long-distance treks to the sources (Seeman, 1994; Speth et al., 2013).

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Whereas there exists archaeological equifinality for all the material correlates of these distinct possibilities (Bamforth, 2009; Burke, 2006; Meltzer, 1989; Speth et al., 2013), empirically validating the long-distance acquisition of stone by Clovis foragers—-whatever the acquisition procedure—has implications for the rapid expansion of Clovis culture. Given the low density of Clovis sites across North America, and thus presumably low population densities, empirical validation of long-distance acquisition of stone provides a unique opportunity for inferring geographically widespread social contact and territorial permeability among mobile hunter–gatherer populations (Bamforth, 2009; Burke, 2006; Ellis, 1989; Kelly and Todd, 1988; Pearce, 2014; Pearce and Moutsiou, 2014; Speth et al., 2013). For example, in terms of tool flaking patterns, there appears to have been a continent-wide standardization of Clovis technology, perhaps reflecting Clovis knappers sharing their technical knowledge through direct transmission (Sholts et al., 2012). Sholts et al. (2012) suggest this transmission could have occurred at quarries as foragers came together from wide-ranging areas to directly acquire stone before dispersing again. Alternatively, long-distance acquisition of stone via individual or group intermediaries clearly implies a widespread social network in which the exchange of physical resources occurred between mobile hunter–gatherer bands (Nash et al., 2013; Speth et al., 2013). Territories were "permeable" in that high-quality resources were available to all, and groups likely did not restrict resources in one area from groups originating from another area (Speth et al., 2013).

A significant obstacle to demonstrating Clovis long-distance acquisition of stone, however, is being able to empirically *and* objectively link the stone found at an archaeological site to a particular outcrop (Burke, 2006; Burke et al., 2014; Haynes, 2002; Nash et al., 2013; Speer, 2014). Virtually all raw-material identifications of Clovis tools continue to be based on qualitative descriptions of megascopic and macroscopic properties. The problem with this approach is that such properties alone are insufficient for discriminating among similar materials or for assigning specific provenance to materials if they occur in geographically widespread outcrops (Hoard et al., 1992; Huckell et al., 2011; Luedtke, 1979, 1992; Speer, 2014). Further, the identification of a stone raw material based solely on the appearance of a specimen in hand is subjective and oftentimes difficult to verify. As Luedtke (1993: 56–57) put it, "we all learn to recognize lithic types through an unsystematic learning process that does not include any tests to verify the accuracy of our learning…[T]he relationship between our typologies and geological reality is completely untested and unknown." When mega- and macroscopic identifications are tested for accuracy, the results are often surprisingly poor (Calogero, 1992; Ives, 1984, 1986; Luedtke, 1992, 1993; Nance, 1984). The problem is not the use of qualitative traits—systematic studies of qualitative traits such as fluorescence under ultraviolet light, color, texture, and presence of inclusions may provide reasonably confident provenance assignments (e.g., Hofman et al., 1991; Luedtke 1992; Lyons et al., 2003; Malyk-Selivanova et al., 1998)—but few such systematic studies have been undertaken. Rather, the problem arises from a conflation of extensionally derived descriptional ideational units, i.e., "types" of stone within a folk geological taxonomy, with empirical units, i.e., stone available from a specific location—a problem not unique to lithic-sourcing studies in archaeology (O'Brien and Lyman, 2002).

One alternative is trace-element analysis, a method commonly used on obsidian artifacts because of the chemical homogeneity of obsidian and the nearly unique chemistry of individual obsidian sources (Amick, 1997; Boulanger et al., 2014; Cannon and Hughes, 1997; Hester, 1988; Janetski and Nelson, 1999; Johnson et al., 1985; Kunselman, 1991; Smith and Kielhofer, 2012). However, in nearly all these instances obsidian has been either minority components of assemblages or isolated finds (e.g., Mockingbird Gap, New Mexico (Hamilton et al., 2009, 2013) and Murray Springs, Arizona (Shackley, 2007)), although one important exception to this pattern is the Dietz site in Oregon, where nearly all the Clovis artifacts are made from obsidian that has been geochemically sourced to outcrops no more than 120 km away (Beck and Jones, 2013; Pinson, 2011).

Determining the source of tools made from chert and other cryptocrystalline silicates—the preferred raw materials of Clovis knappers—is more challenging because of the tendency of chert to be heterogeneous within sources and, at times, to overlap in chemical composition among sources. Until the study reported here, the majority chert toolstone from only one unequivocal Clovis site in western North America had received chemical characterization: the Eckles site, a Clovis residential occupation in north-central Kansas. There, stone tools were shown to be made predominately (75–80%) from White River Group silicate, the source of which is in northeast Colorado, 450 km west of Eckles (Hoard et al., 1992, 1993; Holen, 2010). Despite this lone empirical datum point, the assumption of frequent Clovis long-distance acquisition of stone is widely held (e.g., Bradley et al., 2010; Gramly, 1999; Meltzer, 2009; Speth et al., 2013; Tankersley, 2004). Here we assess the assumption using geochemical data acquired through neutron activation analysis (NAA) of stone flaking debris from a Clovis site in eastern North America, Paleo Crossing (33ME274), located in Medina County, Ohio. (Fig. 1).

Paleo Crossing provides a unique opportunity to assess long-distance acquisition because the majority of the site's Clovis artifacts (>50%) have been proposed to be made from Wyandotte chert, based solely on visual examination of the entire assemblage (Brose, 1994; Tankersley and Holland, 1994). The closest sources of Wyandotte chert are in Harrison and Crawford counties, Indiana—a straight-line distance from Paleo Crossing of some 450–510 km (Brose, 1994; Eren, 2006, 2010; Eren and Redmond, 2011; Eren et al., 2004, 2005; Miller, 2013, 2014; Tankersley and Holland, 1994). It is important to note that we are not questioning previous macroscopic analyses suggesting that there is a majority stone raw material at Paleo Crossing visually consistent with Wyandotte chert. By employing NAA we are testing whether that majority raw material *is in fact* Wyandotte chert, rather than a "look alike."

This 450–510 km is an extreme source-to-site distance proposed for a Clovis "exotic" assemblage in eastern North America (Ellis, 2011). In fact, it is a minimum estimate of acquisition distance because foragers do not travel in straight lines (Meltzer, 2009). A least-cost path based on slope indicates the distance between Wyandotte chert sources and Paleo Crossing is 825 km (Fig. 1, route A), whereas different river routes are over 1000 km (Fig. 1, routes B & C). The assemblage from Paleo Crossing also includes material visually consistent with sources located less than 200 km from the site, such as Flint Ridge and Upper Mercer (Fig. 1) (Brose, 1994; Tankersley and Holland, 1994).

Between 1990 and 1993, staff from the Department of Archaeology at the Cleveland Museum of Natural History (CMNH), along with associated researchers, carried out survey and test excavations at the site. The project was stimulated by the 1989 discovery of Clovis projectile points and other stone tools by a local collector, who contacted the CMNH. Radiocarbon dating of charcoal from a subsurface feature provided a date of 10,980 ± 75 ^{14}C YBP[1] (Brose,

[1] This date is an average of several selected AMS dates. The dated subsurface feature (B XVII F#1) yielded dates of 10,800 ± 185 ^{14}C YBP, 10,980 ± 110 ^{14}C YBP, 11,060 ± 120 ^{14}C YBP, 12,000 ± 110 ^{14}C YBP, and 12,175 ± 115 ^{14}C YBP. These dates "define two cohesive but statistically distinct groups of radiocarbon ages; at 12,150 ± 75 B.P. and 10,980 ± 75 B.P." (Brose, 1994:65). Given that the older group of dates seems too old for a Clovis site in the Great Lakes region (Brose, 1994), and the younger group is consistent with Clovis dates elsewhere, Brose (1994:65) suggested the "most likely age of the [Clovis] occupation is reflected in the averaged date of the younger statistically distinct cluster of dates."

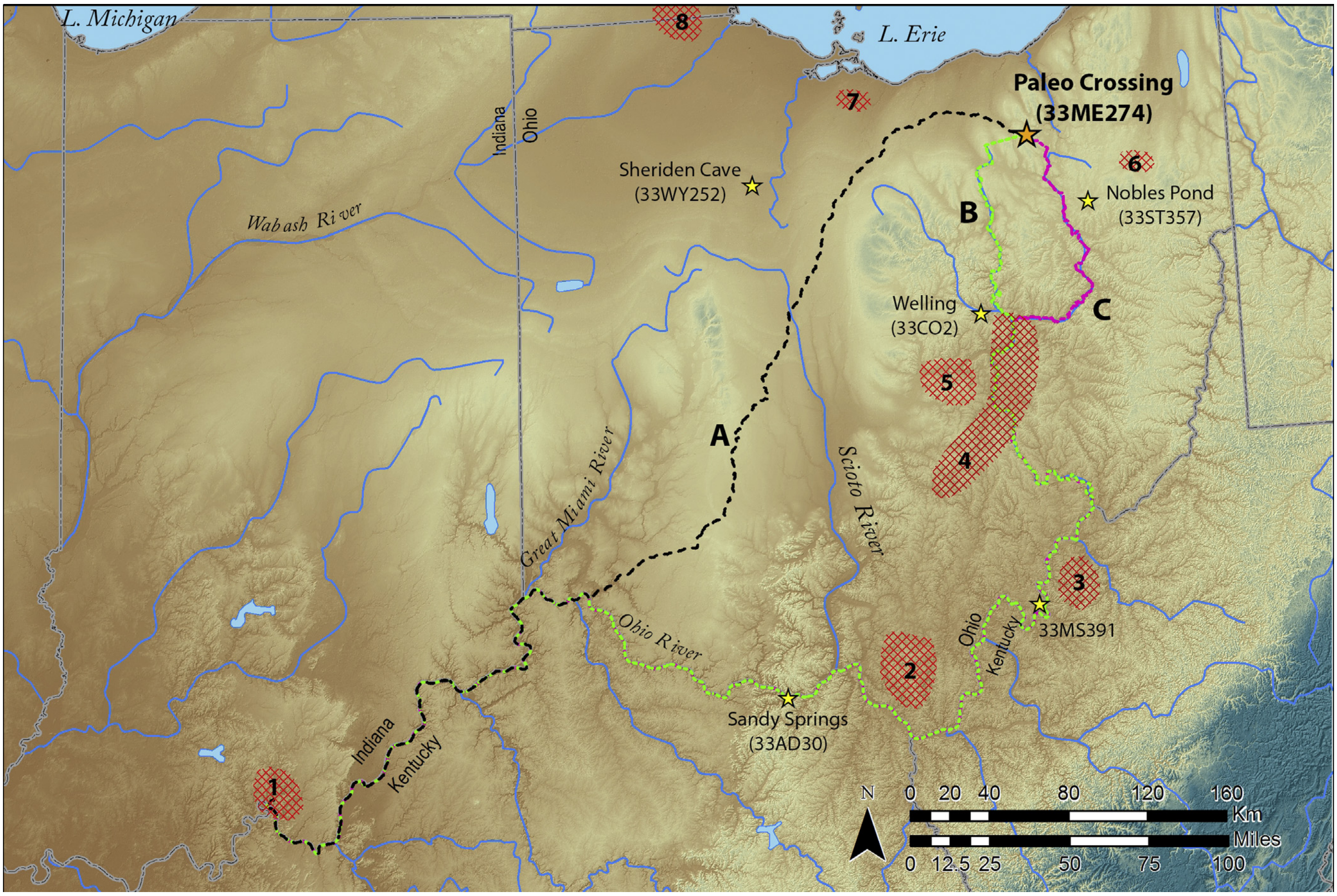

Fig. 1. Location of the Paleo Crossing Clovis site relative to the broader North American Midwest and Great Lakes regions, other Ohio Clovis sites, and the Wyandotte chert source area in south-central Indiana (1). Note that there are several toolstone sources closer to Paleo Crossing than the Wyandotte source, including Vanport and Brush Creek (2), Brush Creek (3), Upper Mercer (4), Flint Ridge (5), Plum Run (6), Pipe Creek (7), and Ten Mile Creek (8). Although the straight-line distance between Paleo Crossing and the Wyandotte chert source is 450–510 km, this linear distance should be considered a minimum estimate. A least-cost path derived from slope is 825 km (A), while an Ohio River–Muskingum River–Killibuck River route is 1275 km (B) and an Ohio River–Muskingum River–Tuscarawas River route is 1240 km (C).

1994) (calibrated at 2-sigma to 13,023–12,717 calBP using OxCal 4.2 (Bronk Ramsey, 2009) and IntCal13 (Reimer et al., 2013)). The earliest Paleoindian fluted projectile points in the Northeast have been often argued to be a post-Clovis cultural manifestation called "Gainey," although geometric morphometric analyses of points from Paleo Crossing (Fig. 2a–d) and "classic" Clovis points from the Southern Plains and Southwest show that Paleo Crossing points are indistinguishable from points typed as Clovis (Buchanan et al., 2014; see also Smith et al., in press) (see Supplementary Online Materials). The site has yielded other characteristic Clovis artifacts, including endscrapers, some with spurs and notches (Fig. 2e–g); graver spurs (Fig. 2h); evidence for prismatic blade production (Fig. 2i); overshot flakes[2] (Fig. 2j); and overshot mistakes on early stage fluted bifacial preforms (Fig. 2k).

[2] Although recent archaeological and experimental analyses have suggested overshot flakes to be mistakes, i.e., there was not an "intentional" or "controlled overshot flaking strategy" (Eren et al., 2013), it is possible that the presence of overshot flakes, or an increased frequency of overshot flakes, is still diagnostic of Clovis (Eren et al., 2014). That is why we believe it is important to mention the presence of overshot flakes at Paleo Crossing. However, the reader should note that Muñiz (2014) recently showed that there were no significant differences in overshot flaking between bifaces from Clovis caches and bifaces from Late Prehistoric caches. If further analyses support this result, then the presence of overshot flakes or overshot flake scars, even as mistakes, may not be diagnostic of Clovis.

2. Materials and methods

2.1. Sample

Eighty-eight stone artifacts from Paleo Crossing visually consistent with Wyandotte chert were selected and sent to the University of Missouri Research Reactor (MURR). These artifacts consisted of small flakes, broken flakes, and block shatter resulting from stone-tool production and tool resharpening, with an average mass of 1.7 g and standard deviation of 2.38 g. Given that NAA is a destructive analysis, we chose chert specimens from Paleo Crossing that were collected by the landowner and were without specific provenience beyond the site itself. Thus, beyond visual criteria, for all intents and purposes the sample was essentially selected at random. Of these, 34 were compositionally analyzed by NAA. The remaining fifty-four archaeological specimens were not necessary for NAA analysis and were saved for future archaeological analysis. An additional 30 modern specimens of Wyandotte chert taken from nodules from Harrison County, Indiana, were also sent to MURR (Figs. 3–4).

2.2. Sample preparation

All specimens were washed in deionized water and scrubbed with a stiff-bristle brush to remove detritus from their surfaces.

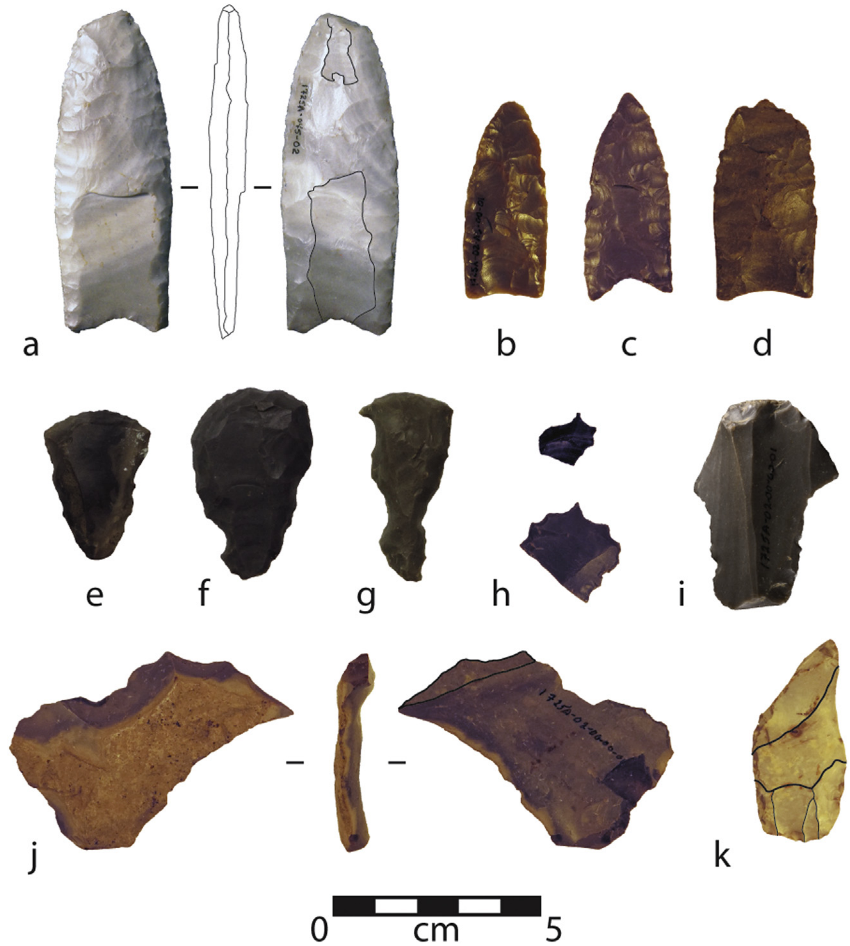

Fig. 2. Characteristic Clovis artifacts from Paleo Crossing, Ohio, include fluted projectile points (a, b, c, d), endscrapers (e, f, g), graver spurs (h), a prismatic blade core remnant (i), overshot flakes (j), and overshot mistakes on fluted bifacial preforms (k). All artifacts are visually consistent with Wyandotte chert, except for (h top), which is visually consistent with Upper Mercer chert, and (k), which is visually consistent with Flint Ridge chalcedony.

Inked catalog numbers were removed from artifacts with ethanol. Small artifact specimens were broken in an agate mortar and pestle, whereas the larger source specimens were placed between two tool-steel plates and crushed with a Carver Press. Small, 50–100 mg fragments were obtained from each crushed specimen, and these were examined under low-power magnification. Fragments with metallic streaks or crush fractures were removed from the sample.

Fig. 3. Wyandotte chert nodules (often referred to as "cannonballs") from Harrison County, Indiana.

Two analytical samples were prepared from each specimen. Portions of approximately 200 mg of rock fragments were weighed into high-density polyethylene vials used for short irradiations at MURR. At the same time, 800 mg aliquots from each specimen were weighed into high-purity quartz vials used for long irradiations. Individual sample weights were recorded to the nearest 0.01 mg using an analytical balance. Along with the unknown samples, standards made from National Institute of Standards and Technology–certified standard reference materials of SRM-1633b (Coal Fly Ash), SRM-278 (Obsidian Rock), and SRM-688 (Basalt Rock) were similarly prepared.

2.3. Irradiation and gamma-ray spectroscopy

NAA at MURR consists of two irradiations and three gamma counts (Glascock, 1992; Glascock and Neff, 2003; Neff, 2000). A short (5 s) irradiation is performed through a pneumatic-tube system. Samples in the polyvials are sequentially irradiated, two at a time, for 5 s by a neutron flux of 8×10^{13} n cm^{-2} s^{-1}. The 720-s count yields gamma spectra containing peaks for Al, Ba, Ca, Dy, K, Mn, Na, Ti, and V. The long-irradiation samples in high-purity quartz vials and are subjected to a 70-h irradiation at a neutron flux of 5×10^{13} n cm^{-2} s^{-1}. Samples decay for seven days after irradiation and are then counted for 1800 s on a high-resolution Ge detector coupled to an automatic sample changer. This count provides determinations of seven elements: As, La, Lu, Nd, Sm, U, and

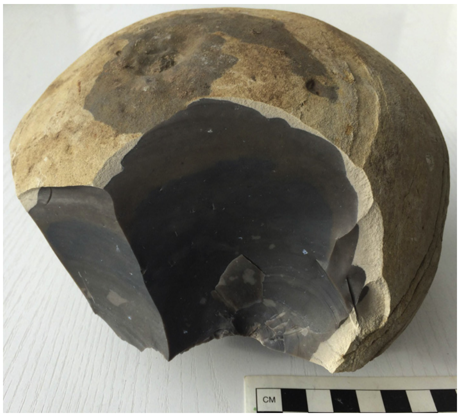

Fig. 4. Wyandotte chert nodule from Harrison County, Indiana, showing a fresh fracture and the tool-stone beneath the outer cortex.

Yb. After an additional three- or four-week decay, a final count of 8500 s is performed on each sample, which provides yield determinations for 17 elements: Ce, Co, Cr, Cs, Eu, Fe, Hf, Ni, Rb, Sb, Sc, Sr, Ta, Tb, Th, Zn, and Zr.

2.4. Data analysis and comparative data

Comparative data used in this study are drawn from previous research at MURR—Wyandotte chert (Harrison Co., IN) and Plummer (aka Lead Creek) chert (Glascock, 2004) and Cobden–Dongola chert from Union Co., IL (Morrow et al., 1992)—and from unpublished data in the MURR database for Flint Ridge (Licking Co., OH), Upper Mercer (Coshocton and Perry Cos., OH), and Brush Creek/ Hughes River (Ritchie Co., WV). Statistical analyses were performed on base-10 logarithms of calculated elemental abundances. Statistical analyses followed standard multivariate methods employed in the use of compositional data to assess provenance (Baxter and Buck, 2000; Bieber et al., 1976; Bishop and Neff, 1989; Harbottle, 1976; Neff, 2002).

3. Results

Nineteen of the 34 (56%) Paleo Crossing debitage specimens exhibit elevated levels of U and Sb, which distinguishes them from all other blue-gray chert specimens in the MURR database except for those obtained from the Ste. Genevieve Formation (see Supplementary Online Materials). Based on concentrations of these two elements alone, all other midwestern sources of blue-gray chert may be eliminated as potential sources of the 34 pieces of Paleo Crossing debitage. Of the two major sources of chert within the Ste. Genevieve Formation, the Paleo Crossing artifacts exhibit concentrations of Al, Ca, Ti, and V that place them only within the range documented for Wyandotte chert from Harrison Co., Indiana (Fig. 5). We note that the Paleo Crossing artifacts plot on the edges of the 90% confidence ellipse for our Wyandotte source sample when projected in canonical discriminant space (e.g., Fig. 5). This suggests to us that the specimens comprising our Wyandotte source sample likely do not fully represent the chemical variability present within chert from the Ste. Genevieve formation. This should come as no surprise given that the Ste. Genevieve Formation is mapped throughout much of western Indiana from the Ohio River northward to Putnam Co., yet all of our source specimens derive from exclusively from Harrison Co.

In most projections of the data, the remaining 15 (44%) specimens show affinity with Vanport Formation chert from the Flint Ridge quarries of Ohio. These archaeological specimens, however, have consistently low to moderate probabilities of belonging to a compositional group matching MURR's Flint Ridge comparative specimens, which exhibit marked compositional heterogeneity. One possibility is that the 15 archaeological specimens derive from Flint Ridge but MURR's current non-artifactual comparative sample does not fully represent the range of chemical variation of the source. The other possibility is that the specimens derive from a source of Vanport Formation chert not represented in the MURR database. In either case, the remaining 15 archaeological specimens derive from the same non-Wyandotte geochemical source that is most chemically similar to Flint Ridge (Fig. 5).

4. Discussion

The results of the first reported geochemical analyses of Clovis artifacts from eastern North America support the hypothesis that the majority of Paleo Crossing artifacts are made from Wyandotte chert (Brose, 1994; Tankersley and Holland, 1994), the primary source of which is 450–510 linear km away from the site. Given that the majority chert toolstone from only one Clovis site in *western* North America—Eckles, Kansas (Hoard et al., 1992, 1993; Holen 2010)—has been geochemically verified to demonstrate long-distance stone acquisition, our results from *eastern* North America more broadly support the long-held but poorly corroborated assumption that Clovis foragers regularly depended on “exotic” stone for tool production. Furthermore, long-distance stone acquisition, either through direct or indirect acquisition of the stone, is also widely acknowledged to be evidence of geographically widespread social contact and territorial permeability (Bamforth, 2009; Ellis, 2011; Goodyear, 1989; Pearce, 2014; Pearce and Moutsiou, 2014; Sholts et al., 2012; Speth et al., 2013). Paleo Crossing thus provides strong inferential material evidence that the fast expansion of the Clovis culture, as already documented by chronometric evidence (Prasciunas and Surovell, in press; Waters and Stafford, 2007), occurred as a result of a geographically widespread hunter–gatherer social network.

Other asserted claims for long-distance Clovis stone acquisition in eastern North America based on macroscopic evaluation of raw material, while not validated, can now at least be considered plausible. Our results thus in part substantiate the recent work of Ellis (2011), who compared Clovis stone-acquisition distance to that of post-Clovis foragers. His meta-analysis, based on visual inspection of materials from 83 Paleoindian sites (including Paleo Crossing) in the Great Lakes, New England, Middle Atlantic, and Canadian Maritimes regions, showed Clovis to possess significantly higher stone-acquisition distances than that of post-Clovis foragers. Given that Clovis represents the earliest significant archaeological signal in northeastern North America, Ellis's (2011) work, especially in light of our results, is consistent with the predictions of forager colonization theory, specifically that Clovis foragers “more closely tied to the colonization process” (2011, p. 387) would have maintained contact among dispersed groups in order to sustain information flow, social relations, and demographic viability on a landscape in which their populations were low and otherwise thinly scattered (Ellis, 2008; Sholts et al., 2012; Brantingham, 2006; Meltzer, 2004; Surovell, 2000). Nevertheless, Ellis's conclusions would be considerably strengthened through geochemical analysis testing of the assemblages he included.

Based on these results we propose that direct human acquisition and group transport of Wyandotte chert is the most parsimonious explanation for its presence at Paleo Crossing (see Ellis, 2011; Meltzer, 1989), although we cannot rule out indirect acquisition through intermediaries or groups or direct acquisition through logistical forays by individuals (e.g., Speth et al., 2013). Given that there are approximately 500 Clovis tools and over 10,000 pieces of debitage from Paleo Crossing (Barrish, 1995; Eren, 2011), and only an estimated 5% of the site was excavated (Brose, 1994), Wyandotte chert is not only the majority raw material in the assemblage but also represents a substantial amount of stone in terms of weight.[3] It seems unlikely that Clovis foragers residing at Paleo Crossing, and who found themselves without their majority raw material, would have acquired it indirectly from a source 450–510 km away while ignoring several sources located less than 100 km away (e.g., Burke, 2006; Ellis, 2011). The same rationale can be applied to the acquisition of Wyandotte chert by means of a logistical foray by a specialized task group. Instead, a more parsimonious explanation is that Clovis foragers "geared up" with Wyandotte chert before entering and exploring the southern Great Lakes region, which was deglaciated after 14,000 B.P. (ca. 17,000 calBP), with ecologically productive environments in place perhaps by 13,000–12,500 B.P. (ca. 15,000 calBP) (Gill et al., 2012; Glover et al., 2011; Herdendorf, 2013; Hill, 2006; Metcalfe et al., 2013; Szabo and Chanda, 2004; Yu, 2000). After which these foragers could have procured stone from outcrops located closer to Paleo Crossing either during their journey to the site or through exchange or logistical forays after establishing a camp at Paleo Crossing. This, of course, is not to say that Clovis colonizing foragers had no knowledge of the area whatsoever. Instead, it is entirely possible that a "working knowledge" of the area had been hitherto achieved through earlier scouting trips aimed to target desirable resource areas (Dincauze, 1993; Ellis, 2011; Eren, 2011; Eren et al., 2012).

If we take the conjecture of direct acquisition (gearing up) a bit further, we note that Sheriden Cave is not far from the least-cost path between the Wyandotte chert source area and Paleo Crossing (Fig. 1). Sheriden Cave, which possessed two bone projectile points, a Clovis fluted point, and a thinned flake-blank large enough to be turned into a fluted point, could conceivably be interpreted as a cache (Redmond and Tankersley, 2005). We find it interesting that not only are the dates of Sheriden Cave (10,915 ± 30 ^{14}C YBP (Waters et al., 2009), calibrated at 2-sigma range to 12,821–12,708 calBP), virtually identical to that of Paleo Crossing (10,980 ± 75 ^{14}C YBP, calibrated at 2-sigma to 13,023–12,717 calBP), the flake blank is made on stone visually consistent with, and asserted to be, Wyandotte chert (Redmond and Tankersley, 2005). We are not suggesting that Sheriden Cave and Paleo Crossing are necessarily connected, but the preponderance of Clovis caches across North America has been linked to the landscape unfamiliarity inherent to the colonization process, meaning that Clovis groups new to the landscape did not know where or when they were next going to find a suitable stone outcrop. By depositing caches or insurance gear, "they created artificial resupply depots, and thus anticipated and compensated for that lack of knowledge" (Meltzer, 2009, p. 252). Thus, if indeed caching, or increased frequency of caching, can be linked to colonization behavior, the presence of caching in eastern North America is consistent with our scenario that the Clovis group or groups that occupied Paleo Crossing geared up with Wyandotte chert prior to heading northeast toward the Great Lakes, into a region where stone sources were initially unknown.

NAA results also tentatively validate the provenance of one of the hypothesized secondary raw materials at Paleo Crossing, Flint Ridge chalcedony (Tankersley and Holland, 1994), located approximately 140 km south of the site. Given that all of the lithic artifacts submitted for geochemical analyses were visually consistent with Wyandotte chert, this unexpected result strongly reaffirms the need for more regular use of geochemical analyses to determine stone provenance and inferences of Clovis long-distance toolstone acquisition. However, this is not to say that Wyandotte chert and Flint Ridge chalcedony are macroscopically similar when examining larger lithic specimens like large flakes, fluted points, and endscrapers. Indeed, on sizable specimens these two raw materials are easy to distinguish visually. However, visual identification becomes commensurately harder as lithic specimens become smaller. Given that our tested artifacts were on average only 1.7 g, perhaps it should come as no surprise that some of the chips submitted for testing were consistent with a non-Wyandotte stone. In other words, if we had submitted tools rather than small flaking debris for NAA testing, our sample percentage may very well have been, or close to, 100% consistent with Wyandotte chert. To reiterate our statement of purpose from the introduction, we were not questioning previous macroscopic analyses suggesting that there is a majority stone raw material at Paleo Crossing visually consistent with Wyandotte chert. Instead, by employing NAA we were testing whether that majority raw material is in fact Wyandotte chert rather than a "look alike."

If Flint Ridge chalcedony was acquired directly by foragers during the journey between the Wyandotte source area and Paleo Crossing, then this scenario would be consistent with the model of foragers "topping-up" their stone supply rather than replacing their supply entirely with a newly encountered stone (Brantingham, 2006). Nevertheless, it is also possible that Flint Ridge stone was procured during a logistical foray after Clovis foragers arrived at Paleo Crossing (Morgan et al., in press) or that the stone arrived at Paleo Crossing through intermediaries (e.g., Speth et al., 2013). Given that only 5% of the visually analyzed Clovis tools were assigned to Flint Ridge chalcedony (Brose, 1994; Tankersley and Holland, 1994), it is surprising that there seems to be disproportionately more flaking debris. Perhaps Clovis foragers "geared up" with tools made of Flint Ridge chalcedony and thus removed them

[3] Researchers have suggested that including both percentages and weights of stone raw material should be standard practice in Paleoindian studies (Bamforth, 2009; Speth et al., 2013). With respect to weight, Speth et al. (2013:121) state, "There clearly is a great need for more data on the actual weight of flint, both local and non-local, that is recovered in Paleoindian sites. Without such data, arguments about the mechanisms by which raw materials moved from quarry to site will remain severely handicapped."

With respect to Paleo Crossing, Brose (1994:66) stated that "initial appraisal of the chipped stone tools' lithology displayed a remarkable predominance of exotic chert" and suggested that "over 65% of the tools are chipped of Wyandotte chert." Tankersley and Holland (1994:61–62) suggested that 158 (79%) of "more than 200 distinctive early Paleoindian chipped-stone artifacts … are manufactured from a Mississippian-age, upper Ste. Genevieve formation chert [and that] Wyandotte is the closest source of this material." Although not stated explicitly, the affinity with Wyandotte chert was likely made by comparisons of color, texture, and fossil inclusions with source specimens under low- and medium-power magnification (e.g., Tankersley, 1984, 1989). Eren's analysis of the entire Paleo Crossing assemblage suggested that 67.6% ($n = 23$) of the fluted points (Eren et al., 2004), 73% ($n = 151$) of unifacially worked scrapers (Eren et al., 2005), and 75.8% ($n = 22$) of non-projectile point bifaces (Eren, 2006) are made on stone that is visually consistent with hand samples of Wyandotte chert curated at the Cleveland Museum of Natural History.

How do these percentages translate into weights? Analyses of the Paleo Crossing stone-tool assemblage are still ongoing, but we can make some estimates. Following Bamforth (2009:142), we focus here on the unifacial stone tools, given that projectile points differ from most other contemporaneous tools in ways that make unreliable sources of information on mobility. The 401 unifacial stone tools at Paleo Crossing collectively weigh 2.54 kg (5.6 lbs). Seventy-three percent of these are made from Wyandotte chert, 1.85 kg (4.08 lbs). This may not seem like a lot of weight, but only 5% or so of Paleo Crossing was excavated (Barrish, 1995). Thus, 1.85 kg/0.05 = 37 kg (81 lbs). This estimation, however, does not consider that (1) most ($n = 239$) of the unifaces included in this calculation are broken, and there are no known refits. Thus, complete uniface specimens would substantially increase this calculation; and (2) the calculation does not include any weights from fluted points, bifaces/preforms, or debitage, of which there are over 10,000 specimens of the latter. Thus, although our simple extrapolation assumes a uniform distribution of Wyandotte unifacial tools across the site as well as a consistent proportion of these items across the site, 37 kg (81 lbs) of Wyandotte toolstone at Paleo Crossing may still very well be a minimum estimate given the two stipulations above.

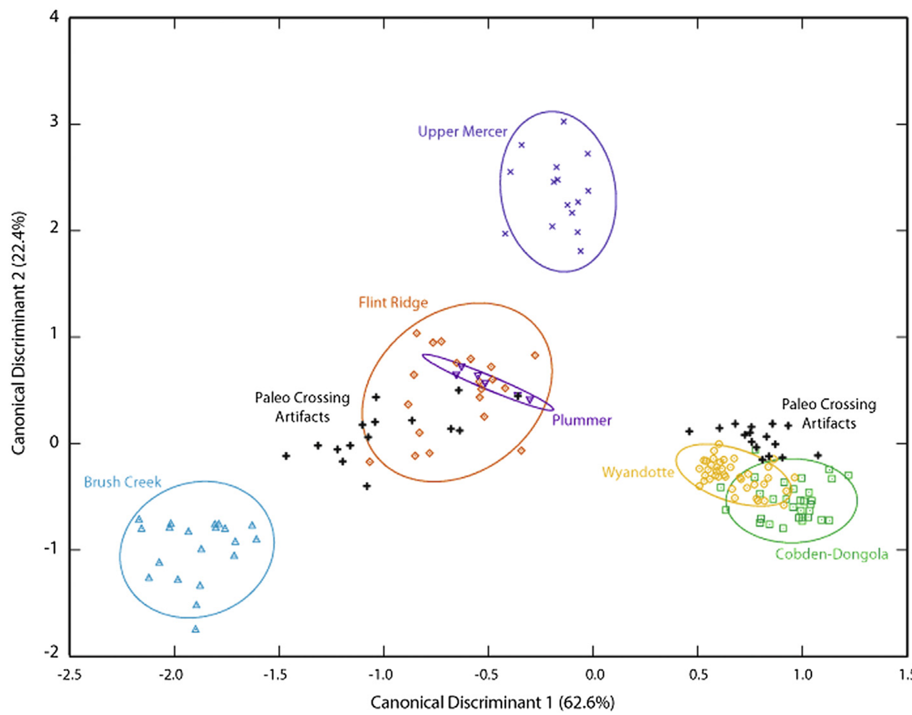

Fig. 5. Plot of the first two canonical discriminant functions showing blue-gray chert source samples and artifacts from Paleo Crossing. Ellipses are drawn at the 90% confidence interval.

from the site, leaving the debris behind (Morgan et al., in press). We find it interesting that the closest Clovis site to Paleo Crossing, and one of the largest Clovis sites in North America, Nobles Pond (Fig. 1), not only exhibits 40–45% stone visually consistent with Flint Ridge chalcedony (Seeman, 1994) but also shows a small amount of stone visually consistent with Wyandotte chert (Seeman et al., 2013). Similar to our discussion of Sheriden Cave, we are not suggesting that Nobles Pond and Paleo Crossing are necessarily connected so directly, only that, if shown to be true, two sites each exhibiting inverse primary and secondary raw materials is consistent with a scenario of stone exchange.

It is important to note, however, that there is evidence for a small Archaic occupation at Paleo Crossing (Brose, 1994; Eren and Kollecker, 2004). While only Clovis artifacts are manufactured on stone visually consistent with Wyandotte chert, both Clovis and Archaic projectile points are manufactured on stone visually consistent with Flint Ridge chalcedony (Brose, 1994; Eren and Kollecker, 2004). Given that small flakes, broken flakes, and block shatter—the artifact types tested here with NAA—are not currently temporally diagnostic, it is impossible for us to know at the present time whether the Flint Ridge flaking debris at Paleo Crossing is predominately Clovis or Archaic or instead a mixture of both. However, the fact that Archaic projectile points are made of Flint Ridge may go a long way toward explaining the discrepancy between the smaller percentage of Clovis tools and the larger percentage of flaking debris made on that stone type.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jas.2014.11.005.

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