



Lithic networks reveal early regionalization in late Pleistocene North America



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ABSTRACT

North America was colonized by hunter–gatherer populations during the late Pleistocene, and the Clovis culture is the earliest well-documented evidence of this event. Long-standing questions about the colonization process persist, including the extent to which low-density populations maintained contact across the continent and if foraging territories overlapped or were spatially-discrete. Here, we use a network approach to examine the spatial structure of land use associated with the earliest hunter–gatherer populations in North America. In particular, we examine the co-occurrence of raw materials used for stone tool manufacture at archaeological sites across the continent. Using a database of 84 Clovis assemblages we show that there are three large isolated, mostly spatially-discrete, lithic exploitation networks across the continent. These regions closely correspond to previously identified differences in Clovis point form, suggesting that Clovis populations were becoming regionally distinct. This process of cultural diversification that begins in the late Pleistocene, continues to develop into the Holocene.

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1. Introduction

North America was colonized by hunter–gatherer populations sometime during the late Pleistocene (Barton et al., 2004; Bradley et al., 2010; Goebel et al., 2008; Haynes, 2002; Kitchen et al., 2008; Meltzer, 2009; Rasmussen et al., 2014; Reich et al., 2012; Smallwood and Jennings, 2015; Tamm et al., 2007; Waters et al., 2011). The most complete archaeological record associated with the colonization is the well-known Clovis culture found throughout much of North America, dating to between approximately 13,400 to 12,500 calendar years before present (Haynes et al., 1984, 2007; Sanchez et al., 2014; Waters and Stafford, 2007). However, recent evidence suggests that people may have first arrived on the continent as early as 15,000 years ago (Goebel et al., 2008; Waters et al., 2011). Whatever the timing of the initial colonization event,

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the archaeological record and genetic diversity data suggest that densities in these earliest populations were low across the continent compared to population levels of subsequent millennia (Bocquet-Appel, 1985; Goebel et al., 2008; O'Rourke and Raff, 2010; Peros et al., 2010; Surovell, 2000; Tamm et al., 2007). A long-standing question concerning the colonization process is the extent to which the first peoples in North America maintained social interactions over large geographic areas given their low population densities (Anderson, 1990, 1995; Anderson and Gillam, 2000, 2001; Meltzer, 2004), and whether these social interactions resulted in the regionalization and diversification of Clovis subpopulations across the continent.

Here, using network analysis of distinct raw materials in 84 Clovis assemblages we examine the structure of stone tool raw material use across the late Pleistocene landscape. We use shared stone raw material occurrences in artifact assemblages from sites to: 1) show which assemblages have shared raw materials among geographically separated sites; and 2) evaluate the presence or absence of regional boundaries in raw material use and their spatial scale. Our expectation is that if Clovis subpopulations were regionally bounded by knowledge of local environments we would

see spatially-discrete lithic regions across the continent. Archaeologically, these regions would be observed as non-overlapping networks of the shared use of multiple stone raw materials within distinct regional boundaries. On the other hand, if Clovis subpopulations simply used local raw materials available within the radius of their foraging territories, then shared raw material use would overlap continuously at a local scale resulting in a lack of distinct regional boundaries in raw material use at the continental scale. The former finding would be consistent with models suggesting large-scale regional adaptations (Anderson, 1990, 1995; Anderson and Gillam, 2000, 2001; Goebel et al., 2008; Miller et al., 2014; Meltzer, 2004, 2009). The latter finding would be consistent with colonization models suggesting a rapidly moving, wide-ranging population with little or no regional adaptations (Haynes, 1964; Kelly and Todd, 1988).

Network analysis of lithic raw materials has been used successfully by archaeologists in different temporal and geographic settings (e.g., Golitko et al., 2012; Golitko and Feinman, 2015; Mills et al., 2013; Phillips, 2011). This approach offers a set of methods for analyzing and visualizing the interconnection of datasets. Here, we apply similar methods to examine Clovis regionality using stone tools and flaking debris made of distinctive raw materials recovered at Clovis sites. We used the co-occurrence of distinctive stone raw materials in Clovis assemblages to evaluate the structure, properties, and scale of Clovis lithic regionality. In the following network analysis archaeological assemblages are the nodes, and co-occurrences of distinct stone raw materials between assemblages are edges. The networks are binary with symmetric, undirected edges. We employed the spring embedding method using geodesic distances, node repulsion, and equal edge length as the layout criteria to visualize the networks. Our analyses proceeded by first identifying the number of components and isolates in the overall sample of nodes. We then used several measures of network structure to describe the overall network and to compare the structures of the various components within the overall network.

2. Materials and methods

2.1. Materials

We generated data from Clovis lithic assemblages for our analyses. An assemblage had to meet three criteria to be included in the study. First, it had to be reliably dated to the Clovis period, meaning that it either was associated with radiometric dates in the ca. 13,400–12,800 calBP range in the West and ca. 12,800–12,500 calBP range in the East (Gingerich, 2011; Haynes et al., 1984, 2007; Holliday, 2000; Levine, 1990; Miller and Gingerich, 2013; Sanchez et al., 2014; Waters and Stafford, 2007) or contained diagnostic artifacts that are radiometrically dated to these age ranges at another site. We used different age ranges for Clovis in the West and East because Clovis appears to be time-transgressive in that a diffusion process began in the West around 13,400 calBP and ended in the Northeast by 12,500 calBP (Hamilton and Buchanan, 2007). Second, chronologically diagnostic artifacts in an assemblage had to be restricted to those about which there is general agreement that they were produced only during the Clovis period. Third, an assemblage had to be available for study or information concerning raw material sources represented in the assemblage had to be published.

We examined a total of 84 lithic assemblages. The entire list of lithic raw materials for each assemblage can be found in [Supplementary Table 1](#). In terms of regional coverage, our sample spans from Washington State to Nova Scotia and Wisconsin to Texas. We do not have assemblages from large portions of the American Far West (California, Oregon, Nevada, and Utah) or

portions of the Southeast (Florida, Alabama, and Mississippi). Both areas have assemblages that are thought to date to the Early Paleoindian period (e.g., Beck and Jones, 1997, 2010; O'Brien et al., 2001, 2014; Willig, 1991), but at the time the data were collected, neither region had an assemblage that met the criteria for inclusion in the study.

The identification of raw material types and sources of stone artifacts in our sample was based on first-hand visual examinations by the authors or taken from the published literature. Several studies using trace element analysis to verify the source locations of Clovis artifacts have been carried out and we included these results where possible (e.g., Burke, 2006; Hoard et al., 1992; Huckell et al., 2011). Further research will benefit from using quantitative evidence from trace element analysis as it is needed to verify some of the source attributions made solely through visual inspection (e.g., Boulanger et al., 2015). Our sample of lithics from the 84 Clovis assemblages consists primarily of cryptocrystalline sedimentary rocks, including various forms of chert, agate, jasper, flint, and chalcedony. Of the 241 observations of raw material types recorded in the lithic assemblages, cryptocrystalline sedimentary rocks occurred most often (85.2%). The next most common raw material types in the sample are obsidian and rhyolite, both occurring eight times (3.2%). Other raw material types that are represented in low proportions are quartzite (2.8%), quartz (2%), feldspar (0.8%), silicified limestone (0.8%), silicified wood (0.8%), porcellanite (0.4%), argillite (0.4%), and siltstone (0.4%). Cryptocrystalline sedimentary rocks, obsidian, and rhyolite are generally considered high-quality raw materials that are easily worked by flintknappers (Buchanan and Collard, 2010; Eren et al., 2014). The abundance of high-quality raw materials in the Clovis lithic assemblages (91.6%) suggests that the selection of high-quality raw materials extended to all aspects of Clovis lithic tool manufacture. This finding is consistent with the long-held notion that Clovis flintknappers relied on high-quality raw materials to make their stone tools (Goodyear, 1989; Haynes, 1980; Kelly and Todd, 1988).

Many of the raw material types observed in the Clovis assemblages in our sample could be attributed to specific, well-known geological sources. A total of 101 distinct raw material sources are represented in the assemblages. The most commonly observed raw material source was Onondaga chert, which occurred at 15 Clovis sites, followed by Normanskill chert and Vera Cruz area jasper, both occurring at 14 Clovis sites. Edwards and Upper Mercer cherts were also common among sites occurring at 13 and 10 sites, respectively. The remaining raw material sources are represented in less than 10 assemblages each. The five geological sources that occur at 10 or more Clovis sites are spatially extensive and occur mostly in the East (Onondaga, Normanskill, Vera Cruz, and Upper Mercer), but one source occurs in the West (Edwards). A large number ($n = 62$) of raw material sources are represented only in single assemblages and thus do not factor in the network analyses. These unique raw material sources are near evenly distributed between the West ($n = 30$) and the East ($n = 32$) regions of the continent¹. This distribution indicates that the use of unique sources is not biased by region and foragers were using lithic sources in a similar way in the West and East.

2.2. Network methods

We used the identified sources of stone raw materials represented in our sample of 84 Clovis lithic assemblages to construct networks. Assemblages were designated as nodes in our analyses with shared stone raw materials between nodes connected by edges or ties. The Clovis lithic networks are binary with symmetric, undirected ties among nodes having similar stone raw materials. We constructed network graphs using the layout procedure in

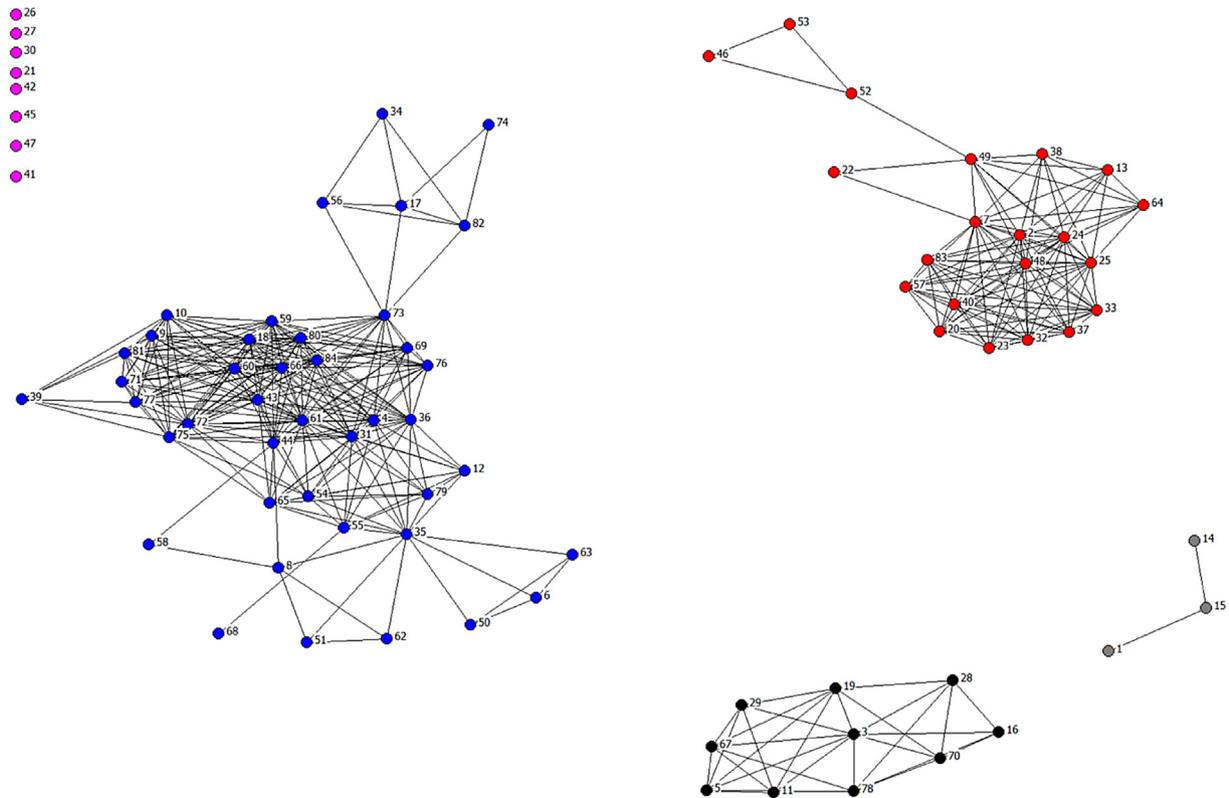


Fig. 1. Spring embedded network map of Clovis lithic assemblages. Assemblages are nodes colored by component. Edges are weighted by component. (key: 1, Adams; 2, Anadarko; 3, Anzick; 4, Arc; 5, Beach; 6, Big Eddy; 7, Blackwater Draw; 8, Bostrom; 9, Bull Brook; 10, Bull Brook II; 11, Busse; 12, Butler; 13, Calvin Graybill #1; 14, Carson-Conn-Short; 15, Coats-Hines; 16, Colby; 17, Conover; 18, Corditaipe; 19, Crook County; 20, de Graffenried; 21, Debert; 22, Demolition Road; 23, Dickenson Cache; 24, Domebo; 25, Drake; 26, East Wenatchee; 27, Eckles; 28, Fenn; 29, Franey; 30, Frazier; 31, Gainey; 32, Gault; 33, Green Cache; 34, Greenville County Site; 35, Hawk's Nest; 36, Hiscock; 37, Hogeys; 38, Jake Bluff; 39, Jefferson II; 40, Keven Davis; 41, Kimmswick; 42, Kincaid Rockshelter; 43, Kings Road; 44, Lamb; 45, Lange-Ferguson; 46, Lehner; 47, Martens; 48, Miami; 49, Mockingbird Gap; 50, Morrow-Hensel; 51, Mueller; 52, Murray Springs; 53, Naco; 54, Nobles Pond; 55, Paleo Crossing; 56, Pasquotank; 57, Pavo Real; 58, Pelland; 59, Poirier; 60, Port Mobil; 61, Potts; 62, Ready/Lincoln Hills; 63, Rummells-Maske; 64, Sailor-Helton; 65, Sandy Springs; 66, Shawnee-Minisink; 67, Sheaman; 68, Sheriden Cave; 69, Shoop; 70, Simon; 71, Sugarloaf/Dedic; 72, Swale; 73, Thunderbird; 74, Topper; 75, Twin Fields; 76, Udora; 77, Vail; 78, Watts; 79, Weed; 80, West Athens; 81, Whipple; 82, Williamson; 83, Yellow Hawk; 84, Zappavigna). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

NetDraw version 2.089 (Borgatti, 2002). We employed the spring embedding method using geodesic distances and 100 iterations using node repulsion and equal edge length as the layout criteria to visualize the networks. We used this method to visualize the overall Clovis lithic network as well as the lithic networks of the three largest components.

We ran several analyses on the overall lithic network using Ucinet version 6.232 (Borgatti et al., 2002). First, we calculated measures of the structure of the overall lithic network including network size and average density. Network size is simply the number of nodes in the network. Network size is an important variable as, in general, smaller networks are easier to connect. The average density of a network is the proportion of all possible ties present in a network. Networks with greater densities are better connected and social and biological information flow more easily within dense networks (Hanneman and Riddle, 2005). Second, we compared the observed average density of the overall network to an expected density of 0 using the Ucinet bootstrapping technique to compare densities against theoretical parameters (Hanneman and Riddle, 2005). Third, we used a matrix correlation to investigate the relationship between the geographical distances among assemblages and the number of shared raw materials among assemblages. Geographical distances were great-circle arcs calculated from the coordinates associated with each site location. Lastly, we determined the presence of components and isolates within the overall lithic network. Components have multiple nodes with

shared raw materials and isolates are nodes that have only stone artifacts made of raw materials originating from unique sources that do not occur in any other assemblages.

In addition to network size and average density we calculated additional measures of network structure for the three largest components. We did this to explore if and how the network components had different structures. The additional measures include degree centrality, closeness, and betweenness. Degree centrality measures the number of nodes adjacent to a given node in a symmetric matrix and therefore gives a measure of local centrality that is not dependent on the location within a network (Scott, 2000). Degree centrality is considered a measure of network activity, with low degree centrality being indicative of low activity levels and high degree centrality being indicative of high activity levels (Freeman, 1979). Closeness is a measure of centrality that is inversely related to minimum path lengths through networks (Wasserman and Faust, 1994). Thus, information moves more quickly through networks with greater closeness. Lastly, betweenness is a measure of the number of times a node occurs on a geodesic, or shortest path among nodes (Freeman, 1979). In social network analysis betweenness measures information control (Scott, 2000), here betweenness can be thought of as a measure of the control of raw material flow. We compared overall measures of degree centrality, closeness, and betweenness for the three largest components. These measures were calculated using Ucinet version 6.232 (Borgatti et al., 2002).

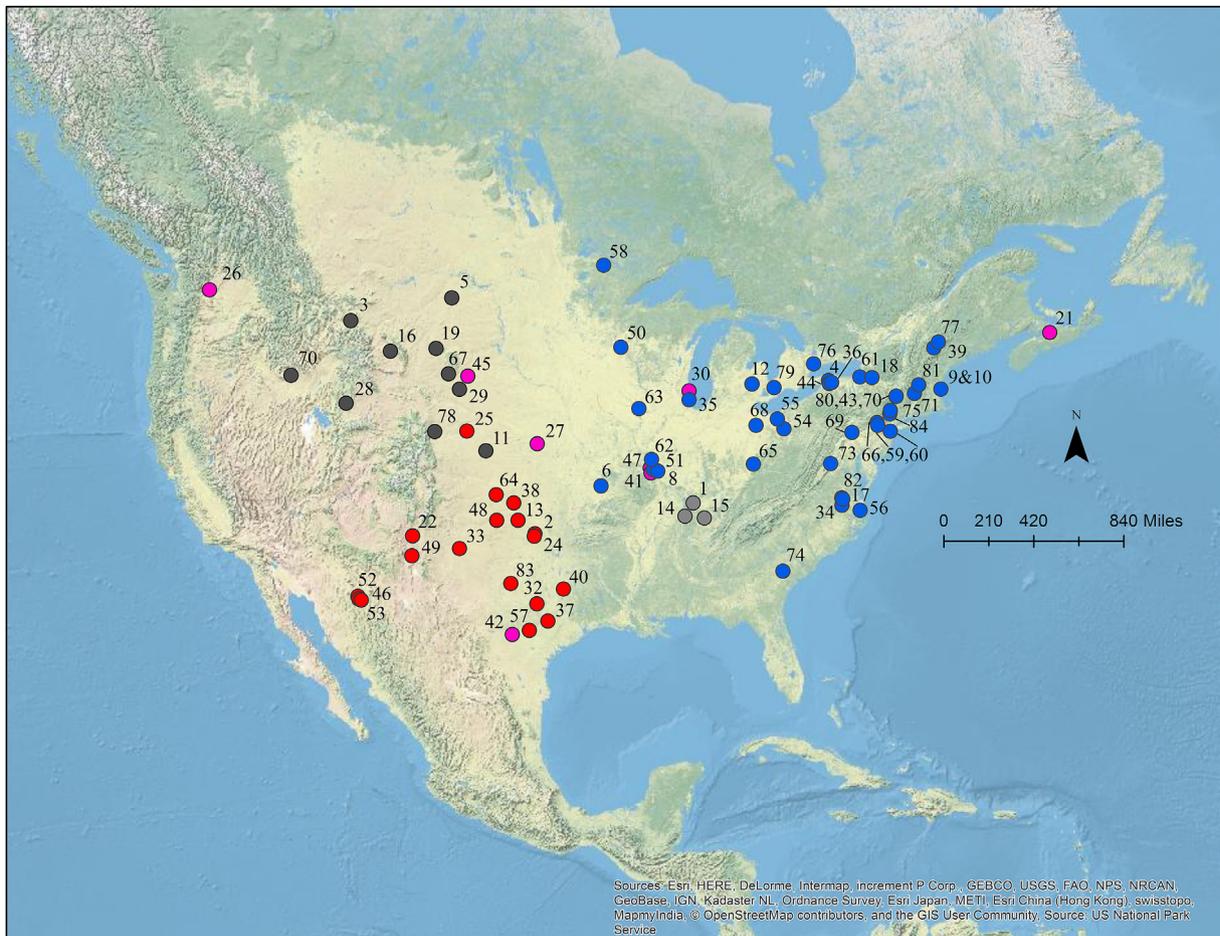


Fig. 2. Locations of Clovis assemblages plotted on a world relief map (ERSI ARCMAP). Numbers are associated with the site names as given in Fig. 1 and assemblages are colored by component (magenta, isolates; black, northwestern; red, southwestern; gray, southeastern; blue, eastern). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

3. Results

The results of the analyses show that the Clovis lithic network has a density of $0.1148 (\pm 0.004 \text{ SD})$; average bootstrap density based on 5000 samples = 0.1252 indicating that 11.48% of all possible ties are present in the dataset (Fig. 1). This density is significantly different from a hypothetical network with an expected density of 0 (Z -score = 4.89 ; $P = 0.0004$), indicating that the number of edges in this network is not simply a product of chance. Neither is the number of edges among the assemblages driven by proximity, as a Mantel matrix correlation demonstrates the lack of a statistically significant relationship between the distance between assemblages and the number of edges among those assemblages ($r = -0.096$; $Z < 0.000$; $P = 0.999$).

Modularity was identified within the network structure using component analysis. In the overall dataset of 84 nodes, 12 distinct components were identified, eight of which are isolated nodes, and four are networks of multiple nodes. The isolates are found across the continent from Washington to Nova Scotia and Wisconsin to Texas (Fig. 2). The four components with multiple nodes vary in the number of assemblages they include; the largest component, the eastern component, has 42 assemblages and spans most of the eastern Seaboard, the Midcontinent, and the Great Lakes; this is followed by a southwestern component with 21 assemblages that encompass the Southern and Rolling Plains of Texas, and the Southwest; a northwestern component with 10 assemblages that

includes the Northwest and Northern Plains regions; and a small component in the Southeast with three assemblages located in the states of Kentucky and Tennessee. Importantly, the four components with multiple nodes do not share any nodes or edges in common, that is, they consist of unique sets of assemblages. In addition, in terms of geographic range, the three largest components—the eastern, southwest, and northwest components—are almost entirely spatially discrete (Fig. 2). The only spatial overlap is a single node; one assemblage from the southwest component (Drake) overlaps with the distribution of assemblages in the northwestern component.

Additional analyses show that the eastern region is the largest component both spatially and in terms of the number of nodes (Fig. 3). The eastern region has the lowest average density, degree centrality, closeness, and betweenness of the three large components (Table 1). This suggests that the eastern region has relatively low amounts of shared raw materials and there are few sites that are central to the network. The relatively low levels of connectivity in the east may simply be a consequence of the large spatial scale of the network and the presence of sparsely connected sub-components within the network. Within the eastern network the densest part of the network is among assemblages located in the Northeast (primarily assemblages in New York, Pennsylvania, Massachusetts, Maine, and New Hampshire) and nodes from the Midcontinent and Great Lakes areas are offshoots from this denser northeastern concentration. These offshoots are connected by

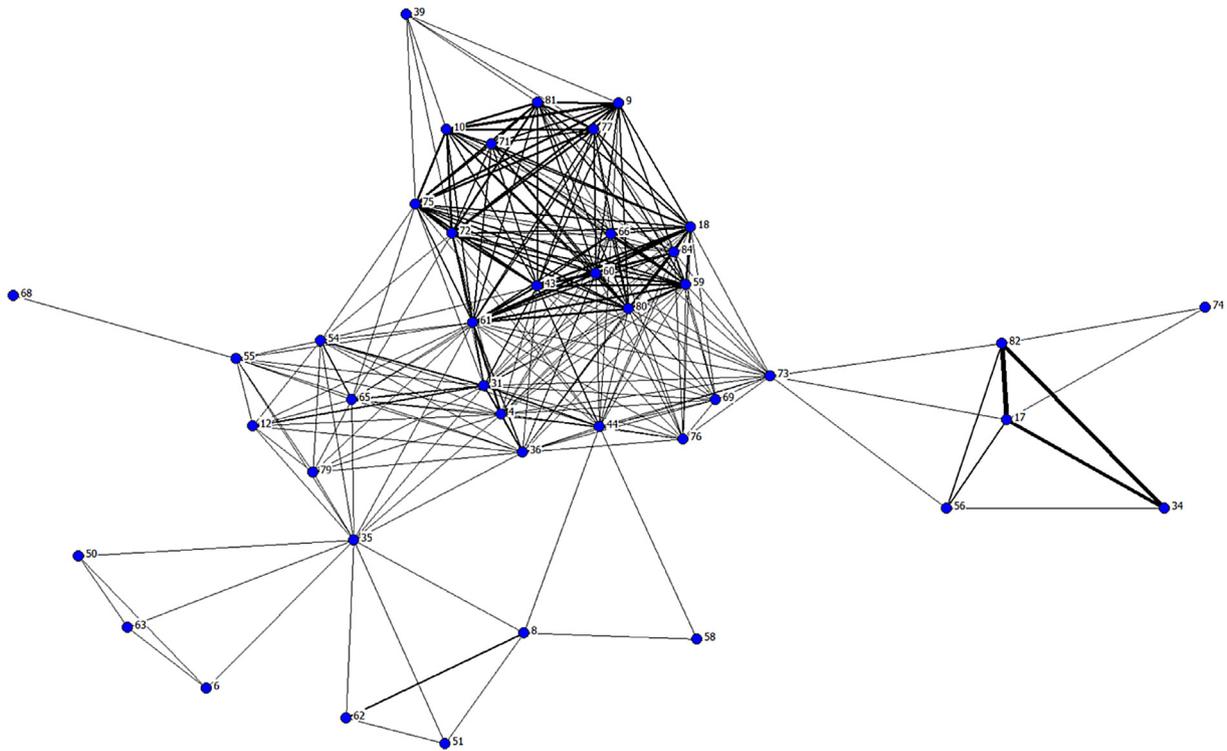


Fig. 3. Spring embedded network map of Clovis lithic assemblages in the eastern network ($n = 42$). Edges are weighted by the number of ties between nodes. Numbers are associated with the site names given in Fig. 1.

Table 1

Measures associated with each of the three largest Clovis network components.

Component	n	Average density	Degree centrality	Closeness	Betweenness
Eastern	42	0.494 ± 0.88	31.01	49.78	2.80
Southwest	21	0.595 ± 0.63	52.38	60.65	3.96
Northwest	10	0.756 ± 0.64	64.44	74.80	4.44

nodes with high betweenness values that act as connectors between the different subregions.

The southwest network ranks second in measures of network structure and connectivity (Table 1). Nodes representing assemblages in the Southwest (Arizona) are connected to the other nodes in the network via the Mockingbird Gap site in New Mexico, the site with the highest measure of degree centrality and betweenness in the dataset (Fig. 4). As such, Clovis sites located on the Southern Plains share similar stone raw materials with Mockingbird Gap in New Mexico and similarly, Clovis sites in Arizona share stone raw materials with Mockingbird Gap.

Lastly, the northwestern network has the least number of nodes, but has the highest density, degree centrality, closeness, and betweenness measures (Table 1). The configuration of the northwestern network is nearly circular with the Anzick and Beach assemblages in the center, both of which are more connected than the other assemblages in the network (Fig. 5). It is noteworthy that the northwest component consists primarily of cache assemblages (80% in the northwest, as opposed to 29% in the southwest and 7–9% in the east).

4. Discussion and conclusions

Our results reveal the presence of discrete raw material regions indicating that Clovis lithic exploitation ranges were not simply an outcome of locally overlapping foraging territories, but the

consequence of local populations having access to a regionally-bounded suite of raw materials, likely accessed via a combination of direct acquisition, trade and exchange. Furthermore, these Clovis lithic regions correspond to major differences in regional environments. Networks in western North America are spatially separated from eastern North America by the Mississippi River Valley. Late Pleistocene eastern North America (east of the Mississippi) includes a number of physiographic regions that were environmentally distinct from western North America (Thompson et al., 1993; Webb et al., 1993). The East comprised primarily temperate mixed woodlands to a tundra landscape that generally graded from north to south in terms of increasing temperature and tree cover (Webb et al., 1993). In contrast, the West includes a wide-range of environments including deserts, plains, pinon-juniper forests, rainforests, and mountains (Thompson et al., 1993). Within the western region, the environments associated with the geographic distribution of the northwest and southwest networks generally reflect a temperature and precipitation difference between the relatively colder and wetter north and the warmer and drier south. The association between the geographic distribution of discrete lithic regions and major environmental differences suggests that Clovis subpopulations had begun to develop distinct regional substructures. Further, the identification of Clovis regionalization suggests an incipient pattern of cultural diversity in the early archaeological record of late Pleistocene North America, a pattern of regional diversity that develops further throughout the Holocene

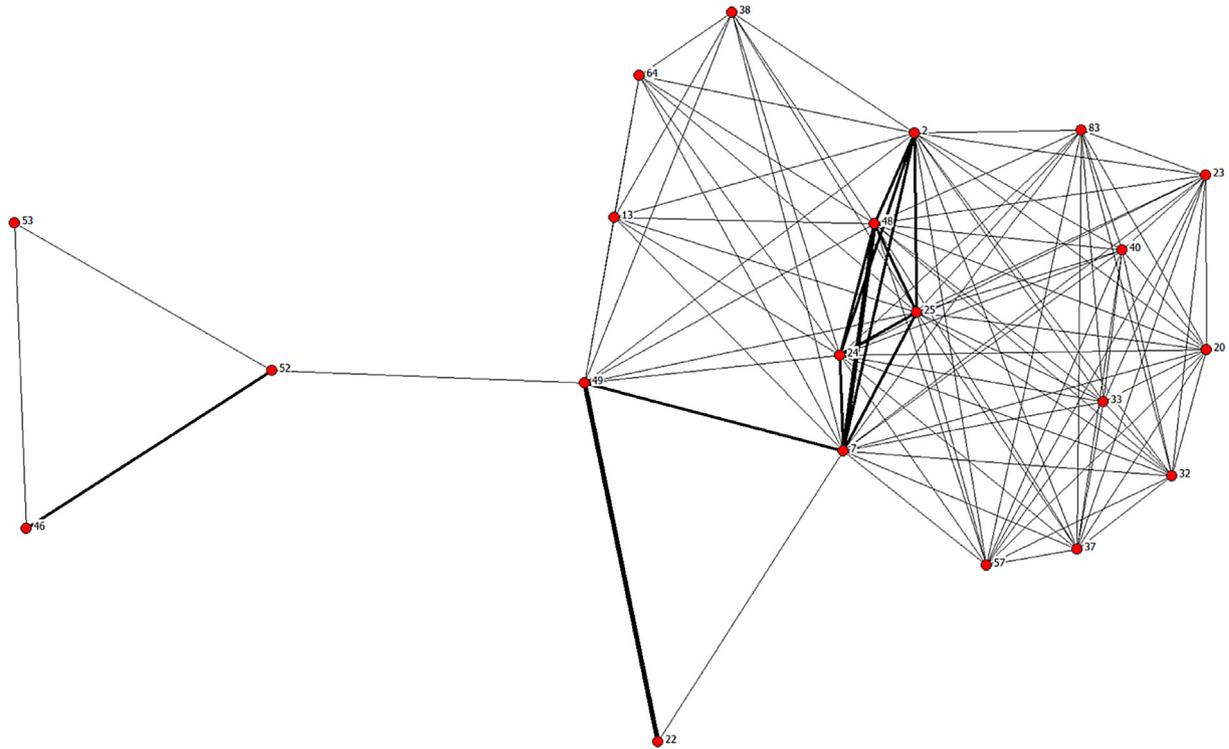


Fig. 4. Spring embedded network map of Clovis lithic assemblages in the southwest network ($n = 21$). Edges are weighted by the number of ties between nodes. Numbers are associated with the site names given in Fig. 1.

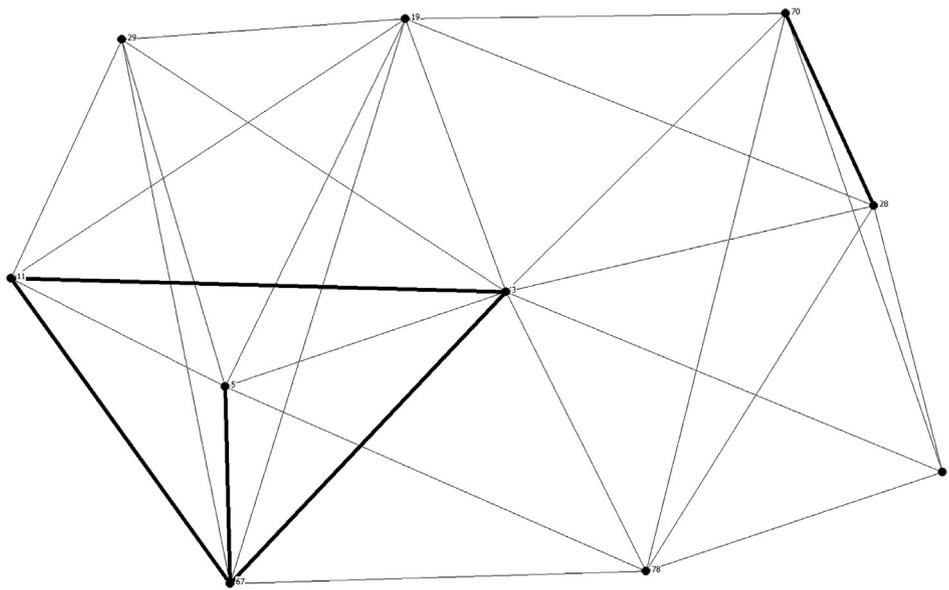


Fig. 5. Spring embedded network map of Clovis lithic assemblages in the northwest network ($n = 10$). Edges are weighted by the number of ties between nodes. Numbers are associated with the site names given in Fig. 1.

(Anderson, 1990, 1995; Anderson and Gillam, 2000, 2001; Meltzer, 2004, 2009; Miller et al., 2014).

An issue that might be raised with regard to our results is that Clovis sites from different regions have different temporal spans and may not be contemporaneous, and therefore the discreteness of the lithic networks could be a result of temporal differences rather than a lack of interaction. Although Clovis sites have been dated to a relatively short span of time (Waters and Stafford, 2007),

there are temporal differences among this small sample of dated Clovis sites across the continent with a gradient of older sites in the west and younger sites in the east (Hamilton and Buchanan, 2007; Steele et al., 1998). This temporal difference would be problematic for the hypothesis that the eastern region operated as a discrete isolated network, if the west had been abandoned during later Paleoindian periods, this would have the effect of making the eastern network artificially appear isolated. However, current

evidence suggests that populations in the west were growing during the late Paleoindian period (Buchanan et al., 2008; Peros et al., 2010). This suggests that eastern Clovis-age populations had the opportunity to interact with and exchange raw materials with groups in the west but did not do so.

Our finding of discrete Clovis lithic regions is consistent with previous studies that have identified regional differences in Clovis as a result of adaptations or isolation (Anderson, 1990, 1995; Anderson and Gillam, 2000, 2001; Buchanan et al., 2014; Eren et al., 2015; Miller et al., 2014; Smith et al., 2015). Interestingly, the regionalization identified in the studies of Clovis points is remarkably similar to the regions we identified in this study. In particular, differences in Clovis point form between eastern and western North America have been identified in two continent-wide studies (Buchanan et al., 2014; Smith et al., 2015). Further comparative analyses of Clovis point shapes within subregions of the east and west showed that differences in point shape correspond closely to the northwest and southwest lithic networks identified in this study, however, both studies found differences within the east that are not found in the raw material networks presented here. The lithic network analysis indicates a connection among all of the assemblages in the Northeast, Great Lakes, and Midcontinent subregions. Our analyses suggest that the groups in the Northeast likely had some connection with populations in the Midcontinent and Great Lakes, however, the density of connections and differences in point shapes suggests some level of local adaptation or isolation among subregions in the east.

The consistency of the results among the present study and those that have identified regional differences in Clovis points (Buchanan et al., 2014; Smith et al., 2015) suggests a level of homophily among foragers expressed in terms of the shared use of raw material sources and point shape. That is, the two lines of evidence suggest that Clovis foragers were more alike to one another within these regions than they were between regions. The identification of spatially-discrete lithic regions across the continent is therefore inconsistent with models of a rapid Clovis migration across the continent that invoke overlapping foraging territories or ranges. Instead our findings are consistent with models of regional Clovis behavior that suggest local populations used and adapted to established territories within defined regions (Anderson, 1990, 1995; Anderson and Gillam, 2000, 2001; Buchanan et al., 2014; Hamilton et al., 2013; Miller et al., 2014; Smith et al., 2015).

With regard to future research, we can think of three steps that will help assess and clarify the preliminary research presented here. The first is to expand the use of quantitative techniques of trace element analysis, such as neutron activation analysis (e.g., Boulanger et al., 2015; Huckell et al., 2011), to source the lithic raw materials present in late Pleistocene assemblages. Currently, only a few studies have used quantitative techniques to source lithic raw materials (<0.06% of assemblages have used quantitative techniques). Most of the identifications in our study are based on macro- and microscopic visualization of artifacts. Many of these identifications need to be verified with quantitative techniques. Second, there are several lithic materials in late Pleistocene assemblages that have unknown source locations. Work done towards locating the geological sources of these raw materials will provide a more comprehensive understanding of how far lithic materials were transported and can provide a baseline to test a gravity distance decay model against (e.g., Mills et al., 2013). Third, finding and excavating appropriate assemblages in regions that are missing from our data set (primarily the Far West and large portions of the Southeast) will provide an interesting expansion of the analyses presented here.

In conclusion, the results of our analyses indicate regional diversity in the earliest period of human occupation in North

America. Based on these findings we can suggest that Clovis populations separated into three regionally distinct variants as they colonized the continent – a process that lasted from a few centuries to a few millennia. This incipient cultural diversification among late Pleistocene hunter–gatherers in North America has been largely unrecognized and untested by archaeologists, but is a pattern that becomes fully established in North America during the Holocene. Our findings also imply that there is a need to re-evaluate the timing and process of cultural diversification in other regions of the globe.

Notes

1. The exact locations of many of the geological outcrops for these raw materials are not known and in at least 17 cases the geological source is completely unknown. Given the limited information on the exact locations of these raw material sources we opted to aggregate these occurrences into western and eastern macro-regions. We followed Buchanan et al. (2014) by using the Mississippi River as the physiographic boundary between western and eastern North America. For cases where the geological source location was completely unknown we used the location of the site as an approximate location of the geologic source. We deemed this approach acceptable for the scale of this comparison.

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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.2015.11.003>.

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