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The Applications of GIS on Lithic Raw Material Source Analysis

Sydney James

Senior Thesis
Introduction

Lithic raw material sourcing has long been used to identify patterns of trade and exchange, mobility, behavior, and culture in archaeological research. More recently, geographic information systems (GIS) have provided additional ways for archaeologists to identify these patterns through data visualization and representative visualization. Although the technologies surrounding both lithic raw material sourcing and GIS have increased in availability and usefulness, many studies have been reluctant to utilize them to their full capacity. Additionally, many of these analyses examine relationships in a strictly descriptive way, failing to take into consideration human interaction with the landscape and how it may dictate those relationships.

GIS has become incredibly useful to the field of archaeology for spatial analysis and data visualization (e.g., Kanter 2008; Kintigh and Ammerman 1982; McCoy and Ladefoged 2009). Despite this, archaeology has been slow to take on more quantitative methods of examining spatial datasets (Bevan and Conolly 2009). As a result, spatial analyses have remained descriptive in nature and fail to branch out into conversations of cultural influences on human movement. Research involving raw material sources suffer from the same issue; many are capable of describing where a material came from, but many do not continue to examine the implications on human behavior and movement across the landscape (Dillian 2002).

While lithic raw material sourcing is commonly performed in many geographic regions, the combined use of it with spatial analysis through GIS has potential to more adequately examine spatial datasets and the relationships between raw material sources and archaeological sites. For this reason, it is necessary to utilize both provenance data and spatial analysis of the landscape for more nuanced discussions of raw material procurement and transport.
By applying analytic tools available through GIS software to previously recorded lithic provenance data from northern California (Dillian 2002), this paper will demonstrate the ways in which spatial analysis can provide a preliminary case study with new research questions that consider anthropogenic factors of raw material procurement and transport. Relationships between the archaeological sites and their lithic source, sites and the landscape, and intersite proximity will all be examined. Additionally, a viewshed will determine the areas which can be seen from each site. This project specifically uses characterization and provenance data obtained through x-ray fluorescence as part of Carolyn Dillian’s dissertation (2002) and spatial analysis through GIS run personally in ArcGIS Pro (standard version) by ESRI.

Background

Lithic analysis plays an enormous role in how archaeologists understand human mobility, interaction, behavior, and culture, arguably since the beginnings of archaeology (Odell 2004). A primary way to study some of these concepts is through lithic sourcing. Lithic raw material sourcing in archaeology has its origins in the descriptive work of lithic quarries in the early 1900s. As new methods emerged, studies began to move past description and into analysis of production and exchange (Dillian 2002). The sourcing of lithic materials recovered from archaeological sites has been done in a variety of ways, from surface survey, to visual sourcing, to geochemical analysis. By any method, raw material sourcing has proven useful for many types of landscape analysis in archaeology. Many of these analyses look at ways to characterize the relationship between raw materials and their lithic sources (Bevan and Conolly 2009). Others have gone further and used these relationships to determine procurement strategies (Brantingham
2003). Even still, many of these studies fail to look beyond description into cultural and ideological factors that influence these relationships.

One of the most accurate and efficient methods of lithic sourcing is through geochemistry. Sourcing lithics geochemically is a multi-step process. The first of these steps is characterization, which uses trace element concentrations to determine the chemical composition of the raw material. These characterization data are then used to identify the provenance of the raw material by identifying sources with similar characterization. To source lithics geochemically, one of the more popular methods is neutron activation analysis, or NAA. Another is inductively coupled plasma-mass spectrometry, or ICP-MS.

A third popular method is x-ray fluorescence (XRF), the particular method of characterization referenced for this research. The earliest uses of XRF in archaeology occurred in the 1960s when the University of California Berkeley and others began applying the technology to answer research questions regarding the relationships between site and source (Shackley 2012). For the purposes of studying obsidian in California, XRF is an ideal choice for several reasons. First, only limited preparation is necessary. Second, the technique is nondestructive. Third, samples need only be run for brief periods of time to pull out certain trace element concentrations, and fourth, the data are easily comparable between laboratories (Hughes 1986; Shackley 2012).

The use of GIS in the field of archaeology is a much more recent one, and even more recent when looking at the use of GIS for spatial analysis. Before the introduction of GIS into the field of archaeology, early forms of spatial analysis existed, beginning with the introduction of regional analysis in the 1930s by Julian Steward. By the 1970s and 1980s, regional analysis had
become a staple in archaeological research (Kanter 2008). Initially used to identify possible archaeological sites, the use of spatial technologies for regional analysis eventually began to examine relationships between sites as well. By the late 1980s, archaeologists were beginning to move beyond strictly descriptive methods and into heuristic approaches to research, where there was much more user involvement and consideration of cultural influences (Kanter 2008; Kintigh and Ammerman 1982).

The effectiveness of GIS as a tool for data visualization has served as an important platform for this type of research. The ability for archaeologists to view sites in relationship to each other and to landscape features has provided an unparalleled advantage for studying the relationships that may exist there. An important part of this is that GIS allows for both data visualization and representative visualization; data visualization being the finding of new information and patterns and representative visualization being the ability to predict those patterns (McCoy and Ladefoged 2009). GIS analysis also allows for a human component in the research; that is, human decisions are a crucial part in how an analysis is constructed.

Because of these capabilities, GIS has been used to address a variety of questions in archaeological research. Initially, the technology was used to locate potential sites, particularly prehistoric ones. To do so, archaeologists would look for certain characteristics on the landscape that are typical of those sites. For example, they are frequently found near a freshwater source, such as a lake or stream; a food source, such as a marsh or forest; and possibly near a raw material source. More recently, research has begun utilizing spatial analysis for its ability to examine spatial data sets at a humanistic level. In one case, data visualization was used to understand ecological knowledge throughout time in various indigenous communities.
(Mackenzie et al. 2017). Others have used quantitative spatial analysis to try and identify patterns in the settlement layouts of nomadic groups in Libya (Biagetti et al. 2016). These studies are just some examples of research that incorporated aspects of landscape movement and use approached from humanistic perspectives. These applications of spatial analysis in other areas of archaeological research serve as a framework for the extension of those methods into raw material source analysis.

A 2004 review of the applications of GIS in archaeology indicates three main directions of research: site location models, GIS procedure-related studies, and theoretical issues in landscape archaeology (Ebert). For the purposes of this paper, all directions are taken into consideration. Together, these indicate a shift of the discipline that focuses on research where human thought processes are just as important as the analyses being run. Spatial analyses are only significant if they are guided by human knowledge and backed by a theoretical framework. As Kintigh and Ammerman state, even a small data set can have numerous spatial relationships between points; therefore, the best solution is a more nuanced discussion of spatial relationships guided by observations of human movement on the landscape rather than the strict description of site-to-source relationships. Although descriptive analyses are useful to a certain extent, they do not take into consideration any additional human factors.

The analytic tools available through GIS make the technology extremely useful for combined use with lithic raw material sourcing and heuristic approaches to analysis. While the analytic tools are algorithm based, the thought process that initiates those tools is strictly based on human knowledge. To properly utilize the tools available in a GIS, researchers must first
think spatially about the questions they are trying to answer. This means theoretical perspectives are allowed to dictate how the GIS tools are run, not vice versa.

There are examples of GIS being used to further spatial analysis where lithic raw material sourcing is involved. Many studies have used GIS and raw material source data to examine mobility patterns (i.e. Soto et al. 2017). In some cases, GIS has been applied to look at the relationships between site and source and the influence that has on assemblage variability (Blumenschine et al. 2008). Others still have used geospatial analysis to determine procurement strategies based on stone quality (Rorabaugh and McNabb 2014). Still, these analyses remain descriptive in nature and do not attempt any additional interpretation.

For the purposes of this project, archaeological sites containing Glass Mountain obsidian artifacts will be used. These data come from dissertation work by Carolyn Dillian in 2002. Here, Dillian examined the relationship between the obsidian artifacts recovered from various archaeological sites and their sources. Glass Mountain, located in the Medicine Lake Highland of Siskiyou County in northern California, is a large, tool-quality obsidian source. For quite some time, it was widely accepted that Glass Mountain was the primary source for obsidian tools from prehistoric sites in the area. Geochemical sourcing via XRF of obsidian artifacts recovered from various archaeological sites demonstrates otherwise.

Instead of the majority of obsidian artifacts being sourced to Glass Mountain (as would be expected), the artifacts that could be sourced to Glass Mountain were almost exclusively large ceremonial bifaces. Additionally, the percentages of Glass Mountain obsidian in lithic assemblages nearby were consistently low, with the majority of obsidian artifacts being sourced elsewhere. An abundance of additional obsidian sources in the area also made this claim
questionable. Glass Mountain obsidian was also found in archaeological sites on the northern coast of California, long distances from Glass Mountain. While these bifaces were showing up in coastal sites and in sites near Glass Mountain, however, there was relatively little Glass Mountain obsidian found at sites in between. Continued archaeological work and ethnographic research led to Dillian’s conclusion that Glass Mountain was not the primary obsidian source but, rather, a source used only for tools that had a ceremonial or cultural context rather than a utilitarian one.

Methods

The first step of this process was to identify archaeological sites with previously sourced lithics containing Glass Mountain obsidian. These data came from the dissertation work previously described. Because of time constraints, it was necessary to have a data set with previously sourced data. The sites included are as follows: Ca-Hum-177, Ca-Mod-77, Ca-Mod-2574, Ca-Mod-2825, Ca-Mod-1587/1588 (sites share the same coordinates), Ca-Mod-2566, Ca-Mod-2567, Ca-Mod-1206/1207 (sites share the same coordinates), Ca-Mod-2560, Ca-Mod-27, Ca-Mod-2562, Ca-Mod-1023, Ca-Sha-68, Ca-Tri-1019, Ca-Sis-332, and Ca-Sis-1267. Sites were then plotted into ArcGIS Pro and overlaid onto a topographic basemap. Glass Mountain and the associated obsidian flow were also included. This was done to get an initial visual on the various site locations in relation to Glass Mountain, to the landscape, and to each other.

The second step was a multi-stage process to more closely identify any patterns that appear between the sites and the topography of the region. The first spatial relationship examined
was between Glass Mountain and the various archaeological sites containing Glass Mountain obsidian. This was done to determine if a particular range existed for the travel of Glass Mountain obsidian to the archaeological sites. A multiple ring buffer was run to look at the features within one mile, five miles, ten miles, twenty-five miles, and fifty miles of Glass Mountain to determine the proximity of the sites to the source. Assuming that these would have been trips to and from the site, these distances were chosen to represent reasonable walking distances for one day (one mile, five miles, ten miles), two to three days (twenty-five miles), and four to six days (fifty miles). This was based on the fact that at a 3.5 mile per hour pace, a human can travel twenty-eight miles in an eight hour period. This time estimate is without any stops.

A near analysis was also run to look more precisely at the proximity of the sites to Glass Mountain and to identify any discrepancies in the buffer analysis. The near analysis uses coordinate data to determine distance from the input features to the near features. In this case, the archaeological sites served as the input feature, and the near feature was Glass Mountain and the associated obsidian flow. The analysis provides a relative distance from each site to Glass Mountain. Once this was done, a summary statistics tool was used to identify the maximum distance, minimum distance, and mean distance from Glass Mountain for the given archaeological sites. The analysis gives the distances in meters and have been converted into miles.

The next relationship examined in this step was between hydrology and the archaeological sites. Because the initial topographic basemap has no individual features, it was necessary to include a layer where features were identified and data was available. In this case, two layers were included; one for California rivers and streams, and one for California lakes. The
hydrology was included in these two individual layers simply because of availability; no data was (apparently) available containing all of the above elements.

After layers were added, the next step was to run analytic tools to look more closely at those patterns (or lack thereof). The first tool used was a buffer run on both the California streams and lakes layer and the California lakes layer. This was done to determine a more exact proximity of the archeological sites to water sources. Buffers were run at one mile, five mile, and ten mile intervals to identify any variation or pattern. These buffers were created separately, as opposed to a multiple ring buffer, so that the distances could be looked at individually.

Next, a viewshed analysis was run on the archaeological sites. A viewshed uses elevation of the landscape to determine what can be seen from various points. For this analysis, the input features, which serve as the points of view, were the individual archaeological sites. A viewshed was constructed for up to ten miles away from each individual site. Ten miles was chosen simply as a reasonable distance for human sight. The tool also offers an option to run the viewshed from a certain elevation; in this case, the tool was run from a height on 1.75 meters, which serves as an average human height. This analysis was run to examine exactly where on the landscape people would reasonably be able to see, and if Glass Mountain would be visible or not. The reason for this was to address one of the arguments for Glass Mountain as a utilitarian obsidian source; because the mountain is highly visible and contains large amounts of obsidian (i.e., the “glass” part of Glass Mountain), people would have more likely to use it as a source.
Results

The patterns observed at the initial creation of the map in ArcGIS Pro were not necessarily unexpected. There is a higher clustering of sites around Glass Mountain, which becomes more scarce as the distance increases. Also noted with this first look is that the sites appear to be in close proximity to either rivers or lakes. Again, this is not surprising, as this is a typical pattern for prehistoric archaeological sites (see Figure 1).

The next step looked at the proximity of the archaeological sites to the Glass Mountain itself via a buffer analysis. It was found that of the sixteen sites, all but three fall within a fifty mile radius of Glass Mountain: Ca-Hum-177, Ca-Tri-1019, and Ca-Sis-332. Six sites fall between a greater than twenty-five to fifty mile radius: Ca-Sha-68, Ca-Mod-2825, Ca-Mod-1587/1588, Ca-Mod-1023, Ca-Mod-2574, and Ca-Mod-77. The rest fall within an greater than ten to twenty-five mile radius: Ca-Sis-1267, Ca-Mod-27, Ca-Mod-2566, Ca-Mod-2567, Ca-Mod-1206/1207, Ca-Mod-2560, and Ca-Mod-2562 (see Figure 2).

The summary statistics resulting from the near analysis provide more specific numbers for the proximity of the sites to Glass Mountain. The average distance of the sites from Glass Mountain was 34.4 miles, with a minimum of 8.5 miles (Ca-Mod-2562) and a maximum of 173.7 miles (Ca-Hum-177). There is some discrepancy between this proximity analysis and the buffer analysis, although nothing particularly significant. This may be explained by the way the tools are run. A buffer extends out from the parameter of a given feature - in this case, Glass Mountain and the associated flow are represented by a polygon. The near analysis, on the other hand, can be run in several different ways. Point to line would have created an effect similar to
the buffer. This analysis was run point to point, however, meaning that the distance may have 
been calculated to the center of the feature rather than the parameter.

The individual buffer analysis of the California rivers and streams and California lakes 
gave more detailed results pertaining to the relationship between the sites and their proximity to 
water sources. The sites located farther away from Glass Mountain toward the southwest were all 
within five miles of a stream, river, or lake. Several were closer, falling within the one mile 
buffer. Many of the sites closer to Glass Mountain were not within even 10 miles of a stream, but 
all were within five miles of a lake (see Figure 3).

The viewshed analysis revealed a surprisingly restricted view of Glass Mountain. Many 
of the sites have an unobstructed view, but are too far away to feasibly see the mountain (see 
Figure 4). For all of the sites, the ten mile viewshed ended before Glass Mountain would have 
been in view. There does not appear to be any trend in viewshed direction (i.e. east or west) or 
extent of the viewshed - some sites have an extensive viewshed, while others are relatively 
limited.

**Interpretation**

Many of the initial relationships between the sites and Glass Mountain were not 
surprising. At first glance, we also see that the majority of sites are within fifty miles of Glass 
Mountain itself (see Figure 2). However, this was one of the selection criteria of Dillian’s 
sampling strategy, so that is to be expected (2002). What is interesting are the few sites that are 
relatively far away from Glass Mountain: Ca-Sis-332, which is slightly to the west of Glass 
Mountain and the other sites; Ca-Tri-1019, which is to the southwest; and Ca-Hum-177, which is
southwest and on the Pacific coast. Also, as Dillian points out, Glass Mountain obsidian makes up a large percentage of the large ceremonial bifaces in sites along the northwest coast, but there are very few sites in between (2002). While one would expect to find sites containing Glass Mountain obsidian near the source, the sites that are farther away raise questions about the reason behind the selection of this specific obsidian.

If people were making trips to and from the source, this would indicate that most individuals are traveling for several days at a minimum to obtain the obsidian. While this may not be entirely unusual in places where lithic sources are scarce, that is not the case in northern California (see Figure 5). This raises a question addressed in Dillian’s dissertation of why people would travel so far - from some sites, close to 200 miles - for obsidian when there are much closer sources available. It is also important to note that in each of these sites, no matter what the distance from Glass Mountain, the percentage of Glass Mountain obsidian in the lithic assemblages are astoundingly low. Of the sixteen sites, the highest percentages of Glass Mountain obsidian by far are 40.9% in Ca-Mod-2574 and 32.2% in Ca-Mod-1206/1207, both of which are relatively close to Glass Mountain. The majority of other percentages fall in the single digits (Dillian 2002). This indicates that people know of other obsidian sources, but are choosing to travel to Glass Mountain anyway.

With that in mind, it becomes necessary to look at the reasoning behind this raw material selection. As Dillian argued, Glass Mountain was a source for ceremonial blades almost exclusively. Previously, the claim was that Glass Mountain was the primary obsidian source for all tool types because of its appearance and location. If that were true, one would expect to see the sites clustered only around the Glass Mountain and not elsewhere. The patterning observed in
the GIS does not support that claim. Rather, the range of distance from Glass Mountain coupled with the fact that there are numerous other obsidian sources in the area indicates that a closer look should be taken to understand the relationship between site and source, one that considers human movement and thought.

The relationships between sites and their distance from streams and rivers do not seem indicative of anything either (see Figure 3), as this relationship is typical of prehistoric archaeological sites. Every site within a fifty mile radius of Glass Mountain, with the exception of Ca-Sha-68, is located near an isolated lake, but at least five miles away from the nearest stream or river. Of the thirteen sites within that fifty mile radius, only two are within ten miles of the nearest stream or river - the other eleven are farther away. Outside of the fifty mile radius, however, each of the three outlying sites are within five miles of several streams or rivers. The most likely reason for this is the simple lack of streams and rivers surrounding Glass Mountain. Because it is located on a highland, it is not surprising that the main bodies of water are stationary lakes. Additionally, the area is high desert, and rivers and simply nonexistent. There also appears to be no relationship between the sites and the surrounding environment; sites located directly on the coast, in mountainous areas, and on the highland all contained Glass Mountain obsidian (see Figure 1).

While the relationships between sites and the surrounding environment may not be surprising, it does allow for a preliminary look at how people may have been transporting the material. Rather than looking only at site-environment relationships, this method allows for human movement on the landscape to be considered. While rivers and streams may serve as a freshwater source, they also serve as a mode of transportation across the landscape, and it is
possible that they may have been utilized for transportation to and/or from Glass Mountain. Based on what is shown in the GIS, it may be interesting to look into the use of the streams and rivers for transport of Glass Mountain obsidian.

The viewshed analysis may have provided grounds for continued discussion into the procurement of Glass Mountain obsidian as well (see Figure 4). Glass Mountain is distinctly visible on the landscape due to the copious amounts of obsidian and the extent of the flow (it is highly reflective, thus the name “Glass” Mountain). This was another supporting argument for the claim that Glass Mountain was the primary obsidian source for the region. However, the results of the viewshed indicate that even for the sites closest to Glass Mountain (within a ten mile range), Glass Mountain would still be out of view. Of course, travel around the area could have put Glass Mountain easily in view, at least for sites in the immediate area. For the sites nearer to the coast, however, that argument does not hold. Because there is no apparent pattern in viewshed in this particular case, however, it is probable that there is an explanation for Glass Mountain obsidian use other than visibility and ease of access.

A viewshed analysis also has the potential to identify any possible cultural patterns between sites. For example, it can identify if a site is west or east facing, if a site has an extensive viewshed, or if a site is hidden in a valley with a limited viewshed. Patterns from viewshed results can serve as indicators of several things, from simple geographic site factors such as site orientation and landscape features in view to more detailed analysis of cultural preferences of site location. For the sites within fifty miles of Glass Mountain, the viewshed demonstrates a extensive view (see Figure 4). Because it is a less mountainous area, however, this is not surprising. The three sites farthest away from Glass Mountain (Ca-Sis-332,
Ca-Tri-1019, and Ca-Hum-177) have significantly more restricted viewsheds, but again, the more mountainous terrain means that this is probably typical. The viewshed on Ca-Hum-177 (the coastal site - see Figure 1) is exclusively west facing, although without additional data, this is as likely a circumstance of the landscape as it is an indicator of cultural factors. Although there does not appear to be a pattern in the viewshed of these sites, additional data would allow for a more significant analysis of the viewshed results.

The lack of overall patterning may actually prove useful in this preliminary analysis. While the sample size is small and therefore conclusions on more broad cultural implications cannot be drawn, the lack of patterning in the geographic features of the archaeological sites may indicate that more discussion of intersite relationships need to be considered as a factor in the procurement of Glass Mountain obsidian.

As a conclusion, Dillian also argued that archaeologists need to begin examining the underlying cultural and ideological reasons for procurement strategies, rather than looking strictly at utilitarian function for the sake of description (2002). Here, the lack of patterning indicates that, in fact, raw material selection was occurring for reasons beyond availability, ease of procurement, or quality. With the evidence provided here, exploring a reason behind the selection of Glass Mountain obsidian becomes a necessary step, rather than a second thought. The combined use of GIS analysis with provenance data has provided a useful tool for preliminary explorations of lithic procurement and transport, and may lead to a more nuanced discussion of those methods.
Conclusion

There are, of course, several issues that need to be addressed. The most obvious is the question of why these methods are not sufficient on their own. Lithic raw material source data can provide a wealth of information on its own if analyzed correctly, and there is only so much that GIS can do to aid in those analyses. Though it is true that sourcing alone can provide a lot of information, GIS provides a way for that information to be visualized. Provenance data alone provides information on intersite assemblage relationships, but the visualization of those sites on the landscape is an unparalleled way to examine the relationships between sites and their landscapes on a much larger scale. Even simple analytic tools can provide more exact landscape measurement and detail, and they are relatively easy to work with. Most GIS programs also have advanced analytic tool sets such as interpolation, viewshed, hillshade, and catchment analysis can reveal more nuanced patterns that are difficult to see or understand otherwise.

Another issue is that of cost. Most methods of raw material characterization are not inexpensive, and sourcing required data from both site assemblages and possible raw material sources. For XRF specifically, samples either need to be sent to a specialized lab, where there is a cost per sample, or they need to be run on a personal instrument, which is costly to purchase. While there are methods of sourcing that are more cost efficient, they are not typically as reliable. For sourcing alternatives, some options have been explored. For example, one study found that visually sourcing obsidian in numerous sites across the Maya region was almost as accurate as compositional sourcing (Braswell et al. 2000). Unfortunately, these examples are relatively isolated. While visual sourcing worked in that particular study, Pachuca obsidian in the Maya region is very visually distinct. However, this is not the case for obsidian in most other
regions. Additionally, if the technique were to be applied other lithic types, a visual distinction would be even less present. For this reason, sourcing via geochemical characterization data is currently the best available method.

As far as GIS technology is concerned, the ArcGIS desktop package by ESRI is not low-cost, and although there are open source options such as QGIS, they are not the most popular and do not offer the full range of analytical tools that ESRI programs come equipped with. Admittedly, there is not much that can combat this issue. QGIS has many of the same analytic tools as ArcGIS and is free to download, and for those basic purposes, can prove just as useful. In terms of convenience of data management, storage, and sharing, however, ArcGIS still remains most convenient. Additionally, once GIS software is purchased, most data necessary for spatial analysis can be downloaded and used for free. While the availability of some site data may be limited, geographic data such as hydrology, groundcover, and elevation are readily available.

There are also ways in which this work can be improved. Although this is preliminary, having a larger data set would obviously help validate the patterns being described, and would improve the overall understanding of the relationship between the sites and the surrounding landscape. It should also be noted that limited experience with ArcGIS Pro no doubt slowed this process down, and more may have been accomplished with increased knowledge and time. While these findings are accurate, more experience would have led to more advanced and detailed analyses.

To continue, more work should be done to address those problems. It would be beneficial to run more advanced analytic tools in the ArcGIS Pro in order to identify more discrete patterns.
Continuing to search for more site data with Glass Mountain obsidian in the lithic assemblage would also be beneficial. Including artifact data for each individual site would allow for more quantitative analyses, such as interpolation, to predict patterns on a continuous surface. This would also be useful to identify any core or flake reduction patterns or nuanced relationships between distance from site to source and lithic transport.

Although the analyses used here are relatively basic, they have already proven useful. Most obviously, the GIS allowed for visualization of the data, allowing for a better look at the relationship between the sites and Glass Mountain. While this can be done without a GIS, it is far less nuanced. The GIS also allows for representative visualization, which is much more difficult to do without the geoprocessing tool set available through a GIS. The tools provided by the GIS make more in-depth analyses available, teasing out patterns (or a lack of patterns) that cannot be seen with provenance data alone. For example, while site data alone may have been useful for identifying relationships between the site and the landscape, a viewshed analysis takes this preliminary look a step further by illustrating what people would have been seeing from a given point on the landscape. These capabilities can help archaeologists move past basic interpretations of site-to-landscape relationships and into more nuanced discussion of human interaction on the landscape.

Here, combining spatial analysis of the landscape with provenance data can lead to more nuanced discussions of raw material transport and human movement on the landscape. More data can improve these analyses, but they are observable even with limited information. As a preliminary case study, definitive conclusions cannot be drawn from these spatial analyses. What this research does do, however, is demonstrate how spatial analysis can be used in conjunction
provenance data to look at raw material transport as humans would have been moving on the landscape. While either of these methods alone can be useful for identifying patterns on their own, the methods shown here illustrate how human movement influences interacts with those patterns.

This may make it necessary for archaeologists to move beyond analysis for the sake of description and into a more theoretical framework that takes human condition, culture, movement, and thought into consideration. This concept has the potential to move beyond raw material sourcing focused on lithics and into the procurement and exchange of other materials. Increasingly, studies are being done that attempt to understand the social and cultural aspects of material culture, rather than just the material itself (eg. Overholtzer and Stoner 2011).

Regardless, the overall the effectiveness of spatial analysis combined with raw material provenance data leads to the conclusion that it is a technique that should be more frequently considered for methods of spatial analysis in archaeological research.

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Figures

Figure 1 - Archaeological sites containing Glass Mountain obsidian, Glass Mountain and obsidian flow, and California rivers, streams, and lakes.
Figure 2 - Buffer surrounding Glass Mountain and the associated obsidian flow at one mile, five mile, ten mile, twenty-five mile, and fifty mile intervals.
Figure 3 - Buffers indicating 5 mile parameters around lakes, rivers, and streams.
Figure 4 - Viewshed demonstrating the area visible from the archaeological sites.
Figure 5 - Known obsidian sources in California (California Obsidian Source Index).
Bibliography

Bevan, Andrew, and James Conolly


Biagetti, Stefano, Jonas Alcaina-Mateos, and Enrico R. Crema


Blumenschine, Robert J., Fidelis T. Masao, Joanne C. Tactikos, and James I. Ebert


Brantingham, P. J.


Braswell, Geoffrey E., John E. Clark, Kazuo Aoyama, Heather I. McKillop, and Michael D. Glascock


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