A Predictive Model for Lithic Resources in Iowa

Chad A. Goings

ABSTRACT

Geographic Information Systems (GIS) provide a powerful tool for modeling the natural distribution of Iowa lithic resources now found in archaeological sites. I use two methods to create a predictive GIS model of lithic exposures available for prehistoric use in Iowa: (1) comparing interpolated bedrock surfaces with ground elevations to create outcrop zones, and (2) using four predictors to statistically model the likelihood of rock outcrops within zones. The first method predicted twenty-four of twenty-seven known outcrops (88.8% success rate) in the study area. The second method employs Dempster-Shafer Weight-of-Evidence modeling and logistic regression methods. Kolomogrov-Smirnov tests show the four predictors to be significantly different from background values and model assignments show high probabilities at known outcrops while eliminating vast areas as low probabilities. It is agreed that such models could be used to further study lithic procurement and use. A comparison of predicted outcrops to utilized lithic resources at a multi-component Woodland site demonstrates the use of high quality, non-local material over poor quality local material at this site.

Keywords: chert; Geographic Information Systems (GIS); interpolation; weight-of-evidence; logistic regression

Of the many varieties of Iowa chert, some are more valuable than others for making stone tools. Studies have been conducted in many states to examine lithic resources in an area and commonly involve lengthy reconnaissance surveys (Ballard 1983, 1984; Birmingham and Van Dyke 1981; Kay et al. 1984; Meyers 1970; Morrow 1982, 1983, 1984; Odell 1996; Ray 1983). While these types of investigations are necessary for identifying the variety of chert resources within the bedrock, Geographic Information Systems (GIS) can be used to predict those resources in unexplored areas.

Since the introduction of GIS in archaeology, many successful predictive models for site locations have been created (Allen et al. 1990; Brandt et al. 1992; Judge and Sebastian 1988; Kvamme 1983, 1986, 1990, 1992; Neumann 1992; Phillips and Duncan 1993). There have been few predictive models for lithic resources. Church et al. (2000) give a brief review of geologists and archaeologists that have employed remote sensing techniques to identify exposures of other rock types that were used by prehistoric peoples, such as silcrete (Densen and Peterson 1995), jasperoid (Murphy 1995), porcellanite (Clark 1985), silicates (Hunt and Salisbury 1970; Hunt et al. 1973), and sandstone (Vincent et al. 1972). In 1996, Tim Church created a predictive model for orthoquartzite procurement sites in the Bearlodge Mountains of Wyoming (Church 1996). Church used predictors derived from relief, elevation, geologic, and water body maps in his model. He also emphasized the advantages of predicting lithic resources over site locations (Church 1996:155-157).

The purpose of this paper is to demonstrate how GIS can be employed to map chert exposures and to model where chert varieties exist within the Iowa landscape. Emphasis is placed on the accuracy of using available data to map areas where chert may exist near or at the surface. Southeast Iowa, including Henry, Jefferson, Van Buren, Lee, and Des Moines counties, forms the test area (Figure 1), because chert varieties are well known in this area and because several natural outcrops have been mapped (Glenister et al. 1987:125; Morrow 1984:47-48; Witzke et al. 1990:4).

Chad A. Goings, Iowa Lakes Community College, 300 South 18th Street, Estherville, IA 51334

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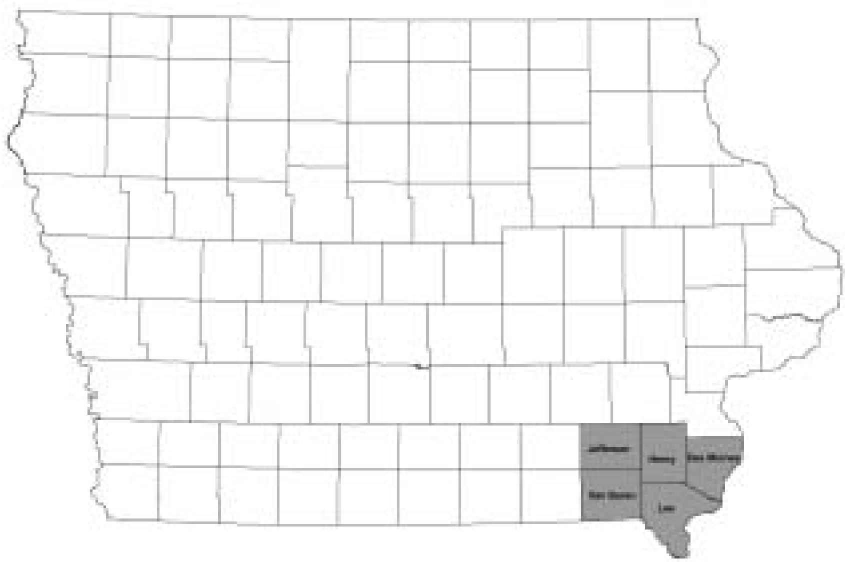

Figure 1. Map showing the location of the five counties used as a study area.

BEDROCK GEOLOGY AND LITHIC RESOURCES

Southeastern Iowa chert varieties occur in bedrock formations, in glacial till, and as stream gravel. The study area lies within two physiographic regions of Iowa: the Southern Iowa Drift Plain and the Mississippi Alluvial Plain (Prior 1991). The Southern Iowa Drift Plain is a dissected landscape composed mostly of loess-covered, Pre-Illinoisan glacial drift. Drainages are fairly well developed and occasionally expose the bedrock of the area. The Mississippi Alluvial Plain consists of the alluvial valley of the Mississippi River. Common landforms in this region are floodplains, terraces, and benches.

Most of the bedrock of southeast Iowa was formed during the Mississippian Period. Vast bodies of water transgressed and regressed over the area during this period. The sedimentary rocks deposited demonstrate a regional dipping trend from the Wisconsin Dome to the Forest City Basin in southwest Iowa and from the Wisconsin Dome to the Illinois Basin in southern Illinois. The Mississippi River trends along a north-northeast structural saddle, which separates these two basins. There are several small northwest trending anticlines crosscutting regional trends (Bill J. Bunker, personal communication 2002). The marine environment predominantly produced limestone, but dolomite and chert are also associated with many of the Mississippian formations (Anderson 1998:180). Some non-chert formations of the Pennsylvanian and Devonian periods are also found in southeast Iowa; however, the chert-bearing formations of interest here are Mississippian in age (Table 1).

The Wassonville Formation consists of cherty dolomite. It is the oldest formation of interest in this study. Two chert varieties are found within this formation: Wassonville fossiliferous and Wassonville mottled chert (Morrow 1984:11). These cherts are thought to have been used prehistorically near outcrop zones, but were not used

Table 1. Chert-bearing formations used in this study (adapted from Anderson 1998).

Formation	Age	Dominant Lithology	Unconformity
"St. Louis"	Middle Mississippian	Dolomite and Limestone	Yes
Salem (formerly Spergen)	Middle Mississippian	Limestone	Yes
Warsaw	Middle Mississippian	Dolomite and Shale	Yes
Keokuk	Middle Mississippian	Limestone	No
Burlington	Middle Mississippian	Limestone	No
Wassonville	Lower Mississippian	Dolomite	No

when more favorable chert was available (Morrow 1994a:123).

The Burlington Formation underlies the Keokuk Formation and is stratigraphically above the Wassonville Formation. It is composed primarily of limestone and ranges from twelve to twenty-four meters in thickness (Morrow 1984:6). The lower portion, which is called the Dolbee Creek Member, exhibits limestone with sporadic nodules of chert. A middle portion termed the Haight Creek Member is mostly dolomite with interbedded limestone and a high occurrence of bedded and nodular chert (Anderson 1998:193). This middle unit is commonly the most massive with a maximum thickness of around twelve meters (Morrow 1984:6). The highest unit, the Cedar Fork Member, is made up of limestone, and does not contain as much chert as the lower portion. All of the units contribute to what are known as Burlington cherts, which are generally regarded as being of high knapping quality. They form many Burlington varieties, commonly termed Burlington mottled white, Burlington mottled gray and tan, and Burlington fossiliferous chert (Morrow 1984:19).

The Keokuk Formation is stratigraphically below the Warsaw Formation and above the Burlington Formation. It consists of limestone beneath dolomites and shale. Chert can be found in the form of beds or nodules throughout this formation, and it can be as thick as twenty-four meters (Morrow 1984:7). The chert found in this formation is called Keokuk chert and is commonly considered to be a fairly good raw material.

The Warsaw Formation consists of lower geode-bearing dolomites and shale and an upper portion of shale (Anderson 1998:198). Chert is found in the form of nodules and has been classified as Warsaw chalcedonic chert. This chert is commonly translucent and waxy in appearance, making it easily recognizable (Morrow 1994b:4). Prehistoric use of Warsaw chalcedonic chert was common.

The Salem and Sonora formations unconformably overlie the Warsaw Formation; together they were once referred to as the Spergen Formation. The Salem Formation consists mostly of dolomite and green shale. The Sonora Formation contains sandstone that commonly grades laterally into the Salem (Morrow 1994b:4). Chert is likely to appear in the Salem Formation and is called Salem chert.

Finally, the “St. Louis” Formation occurs unconformably on top of the Salem, Warsaw, or Keokuk formations. This formation has not been formally correlated with the type St. Louis of Missouri; therefore, the formation is placed in quotation marks (Anderson 1998:199). The “St. Louis” Formation consists of siltstone, sandstone, dolomite and limestone. It contains tabular and bedded chert, which is referred to as Croton tabular chert named for the Croton Member of the “St. Louis” Formation. This chert was once thought to be in the Warsaw Formation, and was known as Warsaw tabular chert or Warsaw banded chert. A chalcedonic chert similar to Warsaw chalcedonic is found in the “St. Louis” Formation in southern Lee County and Missouri, but is more mottled and coarser-grained than Warsaw chalcedonic (Toby Morrow, personal communication 2002). Chert is also found in the form of nodules in this formation and is referred to as Verdi chert. This chert is named for the Verdi Member of the “St. Louis” Formation.

Of all the cherts in the region, Burlington is considered the best for many reasons. One is that it typically has a knapping quality that is equal to or surpasses other cherts in the region. Second, it generally is found as large nodules or in thick nodular beds. Other cherts in the region tend to be in smaller pieces making them more difficult to work with. Finally, there is a much greater volume of Burlington chert near exposures when compared to other cherts of the region. The ratio of chert to limestone is lower in Wassonville, Warsaw and Verdi exposures (Toby Morrow, personal communication 2002).

GIS MODEL 1: A DETERMINISTIC APPROACH BASED ON PROJECTED OUTCROP ELEVATIONS

The 1:24,000 Digital Elevation Models (DEMs) for the study area were obtained from the United States Geological Survey (USGS) via the Internet. A resolution of thirty meters was chosen because not all DEMs are available in ten-meter resolution. Using IDRISI software (Eastman 1999), these DEMs were concatenated into a single DEM (Figure 2). The Iowa Geological Survey Bureau manages a Natural Resources Geographic Infor-

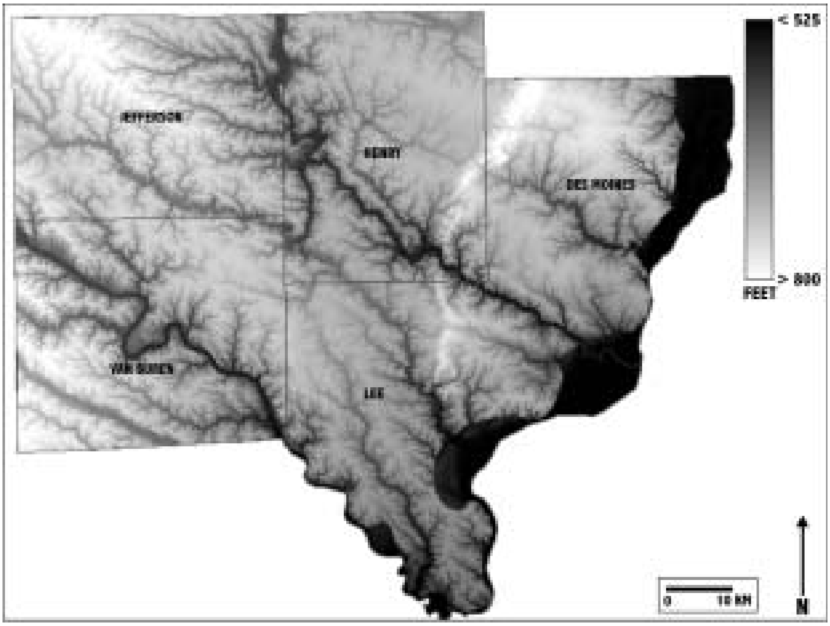

Figure 2. The concatenated USGS Digital Elevation Model (DEM) at a 30-meter resolution covering the study area in southeast Iowa.

mation System (NRGIS) for the Iowa Department of Natural Resources. The NRGIS web site contains many geographic data sets for the state of Iowa that can be downloaded and used in a GIS (http://samuel.igsb.uiowa.edu/nrgis/gishome.htm). The Geological Survey Bureau also has available a Geological Sample (GEOSAM) database that contains stratigraphic information from thousands of sampling points across the state (http://gsbdata.igsb.uiowa.edu/geosam/). The samples were taken primarily from water wells, but also oil test sites, research cores, mines, quarries, and outcrops.

Strip logs contain stratigraphic information recorded at well locations. The strip logs in the study area were examined using a script created in Environmental Systems Research Institute's (ESRI) ArcView GIS. The script was developed by the Iowa Geological Survey Bureau and allows the user to click on a well to produce the associated strip log. However, not all wells have strip logs available or contain legible data. Of the 3,088 wells located in the five counties, 640 have useable strip logs. Absolute elevations were calculated for the upper contact of every chert-bearing formation encountered in each strip log. This was done by subtracting the contact depth from the surface elevation of the well. A spreadsheet was made that contained the calculated elevations and the Universal Transverse Mercator (UTM) coordinates obtained from the GEOSAM well database for each well point.

In ESRI's ArcMap, an extension called Geostatistical Analyst was used to explore the elevation point data. Histograms were examined to determine that the data were normally distributed, because the kriging procedure assumes a normal distribution. Trends in the data were explored and outliers were detected and investigated. Through these methods there was an occasional error detected in calculated elevations and the error was corrected. Upon examining the elevation data for the various formations, a northeast to southwest trend was observed for all six. Therefore, the data were not isotropic (i.e., not having the same variance in all directions). This is to be expected since the regional dipping trend for these formations is generally to the southwest. Using Golden Software's Surfer program, kriging interpolation was then employed to create surfaces for the various formations. This was done using the X, Y coordinates and the elevation data from the spreadsheets. In the interpolation procedures, an anisotropic ellipse was used to give more consideration to points with less variance in the northwest to southeast direction.

A ten percent random sample of points was left out of the interpolation as a test to compare interpolated values to known values. The surfaces were created at the same resolution and covered the same geographic space as the concatenated USGS DEM. Surfaces were created for the following chert-bearing formations: Wassonville, Burlington, Keokuk, Warsaw, Salem, and "St. Louis," and these surfaces were imported into

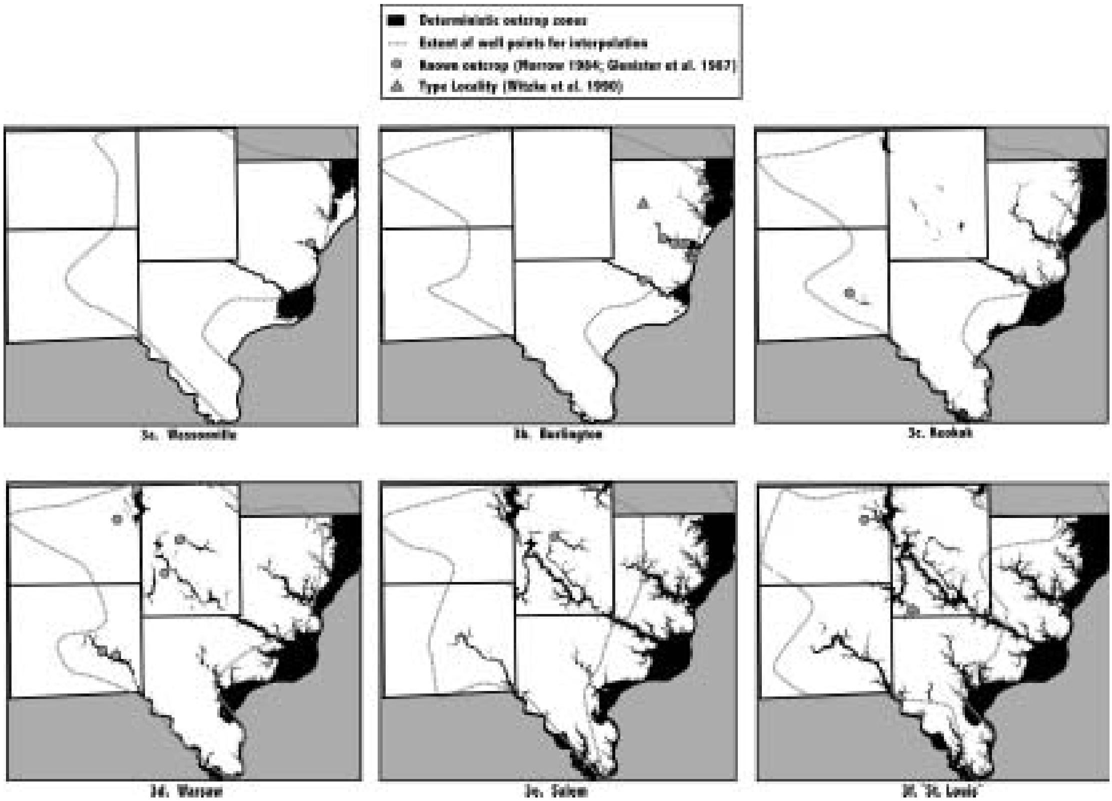

Figure 3. Relationship of the deterministic model outcrop zones to known outcrops.

IDRISI. Each formation surface was compared to the DEM to identify those areas where the interpolated formation elevations were *greater than or equal to* the ground surface elevations. These areas represent predicted outcrop zones and are depicted in Figure 3. Thus, this model is deterministic in the sense that it determines where chert-bearing formations are in relation to ground surface elevations.

TESTING THE DETERMINSITIC MODEL

Table 2 demonstrates the accuracy of the deterministic method based on twenty-seven known outcrops and the random test points. Twenty-four of the twenty-seven were found to be within predicted outcrop zones for an overall success rate of 88.8%. The Cedar Fork Type Locality for the Burlington Formation as well as two known Warsaw chert outcrops were not found to be in the predicted outcrop zone. This is most likely due to errors in the interpolated surface at these locations. A spatial examination of the test point errors revealed that larger errors occurred where there were less surrounding well points from which to interpolate. This is to be expected since there is commonly less variance between points close to each other and more variance between points of a greater distance. For example, there were very few well points to interpolate from in northeastern Lee County. This area is therefore more susceptible to errors than areas with more well point locations.

GIS MODEL 2: PREDICTIONS BASED ON STATISTICAL CORRELATIONS

A second approach to outcrop delineation was attempted based on statistical correlations of common physiographic features of the region. Four predictors, depth to bedrock, slope, distance from streams, and relief were used in this model.

First, it is assumed that as the depth to bedrock increases, the likelihood of a rock outcrop de-

Table 2. Testing the deterministic model.

Formation	Number of Wells Used in Interpolation	Number of Wells Tested in Interpolation	Average Interpolated Error (m)	Interpolation Std. D. (m)	Predicted Outcrop Zone and % correct
Wassonville	207	23	0.71	3.54	Figure 3a (100)
Burlington	403	44	0.33	10.45	Figure 3b (91)
Keokuk	346	38	1.37	6.95	Figure 3c (100)
Warsaw	256	28	1.16	6.4	Figure 3d (66)
Salem	107	11	5.43	6.86	Figure 3e (100)
"St. Louis"	213	23	0.52	5.82	Figure 3f (100)

creases. A depth to bedrock surface was interpolated for the study area using the same method used in GIS Model 1 (Figure 4a). It proved to be easier to interpolate relatively flat bedrock surfaces than the thickness of Quaternary deposits. This is because glacial, wind and fluvial deposits and their subsequent erosion are more complex than solidified marine deposits. The surface was based on 1,922 wells where bedrock depth was recorded.

Second, it is assumed that as slope increases so does the probability of a rock outcrop due to erosion. A slope as percent grade image was cre-

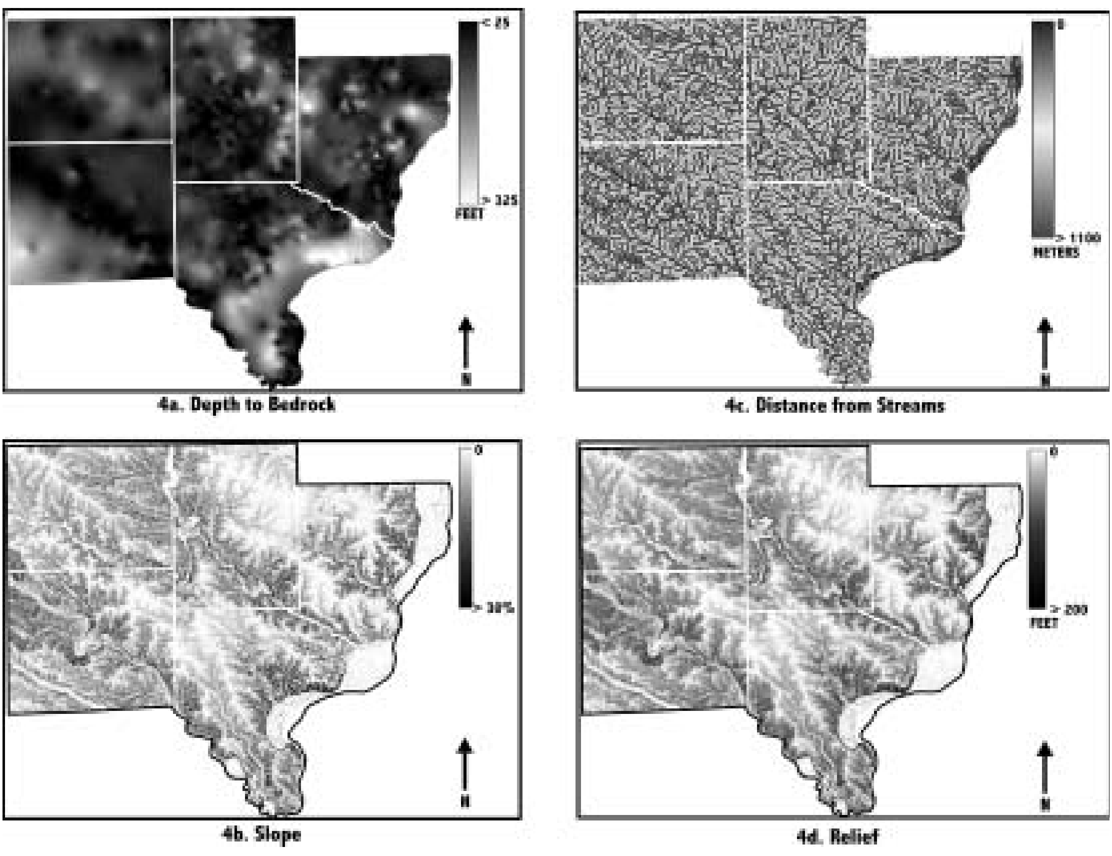

Figure 4. Images of the four predictors used.

ated from the DEM using IDRISI (Figure 4b).

Third, as the distance from streams increase, the chance of a rock outcrop probably decreases. Although slopewash and mass wasting of hill slopes can expose bedrock, it is streams that have dissected that Quaternary mantle that once covered all of Iowa's sedimentary rock. The county stream data from the NRGIS web site and the *Distance* module in IDRISI were used to create an image was that showed distance in meters from streams in the five counties (Figure 4c).

Finally, it is assumed that areas of high relief are more likely to contain rock outcrops than areas of low relief. Two filters were run using a 7x7 kernel that was passed over the entire DEM. One filter extracted the minimum values of the DEM and the other extracted the maximum values within the kernel. The minimum value image is then subtracted from the maximum value image to compute the amount of local relief within ninety meters of each grid location (Figure 4d).

A Two-Sample Kolomogrov-Smirnov test was calculated on each of the four predictor variables between twenty-nine known outcrops and 100 random points. All were significantly different from the background values ($p < .0001$) demonstrating their utility. However, a correlation matrix revealed some redundancy between slope and relief with a Pearson's r of 0.89.

Dempster-Shafer Weight-of-Evidence Model

The first probability image was created using IDRISI's *Belief* module. It is based on Dempster-Shafer Weight-of-Evidence modeling and requires the input of assigned "probability" images, which, in reality, are merely images scaled to range between zero and one, with one being more favorable for the outcome being modeled. In order to convert the four predictor images into "probability" images the Fuzzy module in IDRISI was employed. A linear function was used on each image to create four new images scaled from zero to one. For example, the slope image shows a zero probability where the slope is zero and a probability of one where the slope is 100% or greater. Although most slopes in southeast Iowa are below 30%, it was noted that some reach close to 100% and this is why a value of 100% was chosen as the cutoff.

The *Belief* module was used to create a single image that portrays the probability of a rock outcrop based on the four predictors. This module requires that continuous images be entered that either support that an event will or will not occur. The slope and relief probability images were scaled so that as the numbers increase so does the likelihood of a rock outcrop, and the depth to bedrock and distance from stream images were scaled so that as the numbers increase there is a decreasing likelihood of a rock outcrop. The final *Belief* image is based on all four predictors and is a continuous image ranging from zero to one (Figure 5). In other words, wherever the image shows a value of one, then all four predictors are best met at that locus and a rock outcrop is likely if the predictor variables are accurately mapped and the zero-to-one measurements are scaled appropriately. This result can be regarded as representing "the degree to which evidence provides concrete support for a hypothesis" (Eastman 1999:126).

Logistic Regression Model

In order to utilize a more objective statistical methodology, a logistic regression model was also generated. This model differs from other forms of regression in that the dependent variable is dichotomous (i.e., outcrop present versus outcrop absent). The regression is based on the four predictors used above. Twenty-nine known rock outcrops and a random sample of 100 background points not known as outcrops were generated in IDRISI and used as the dependent variable. Two additional known outcrop sites were added to this model that were not used to test the deterministic model because formation types were not known at these locations. Insightful Corporation's S-PLUS program was employed on the data extracted from IDRISI to perform the various statistical analyses, including the logistic regression and Kolomogrov-Smirnov tests. IDRISI's *Map Calculator* was then used to map the computed function as a probability of outcrop surface (Figure 6).

TESTING THE STATISTICAL MODELS

A layer of known outcrops was created in IDRISI (Figure 7). These areas were digitized as polygons from USGS 7.5-minute topographic maps and consist only of outcrop areas that were visited

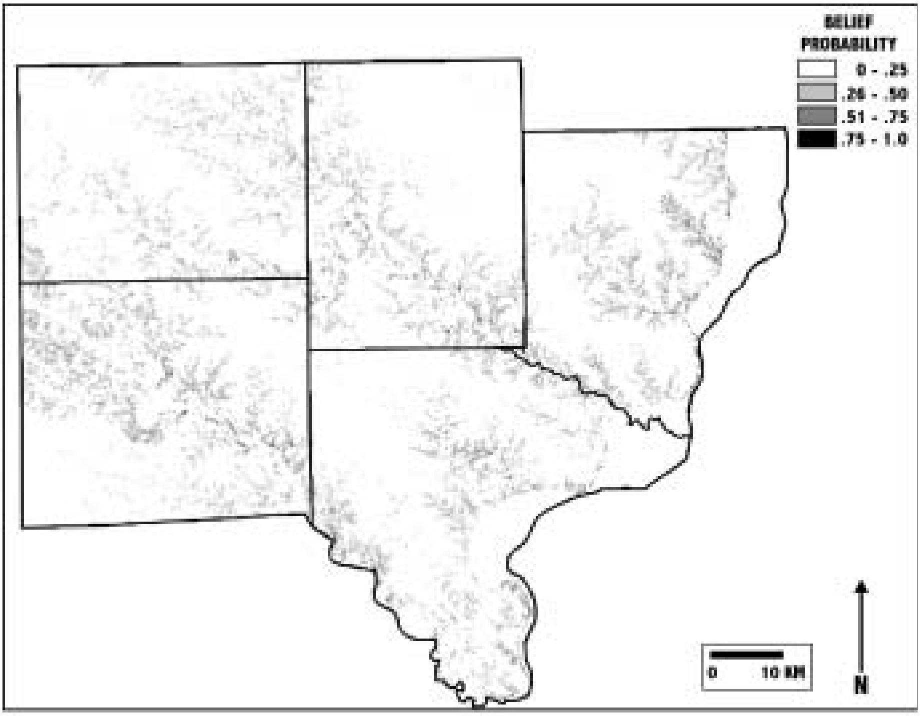

Figure 5. *Belief* probability image based on the four predictors.

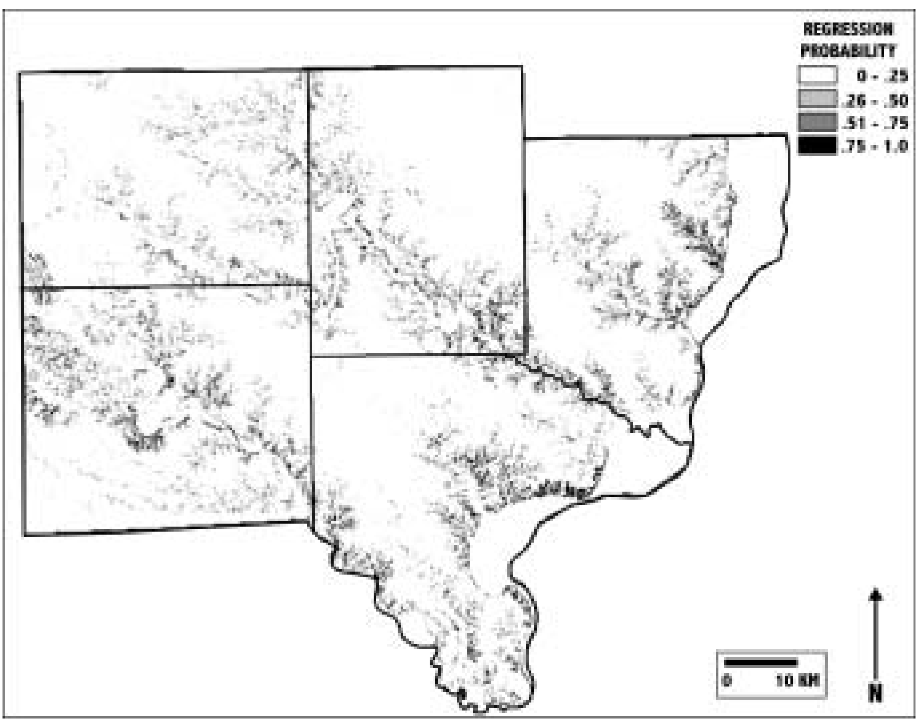

Figure 6. Logistic regression probability image based on the four predictors.

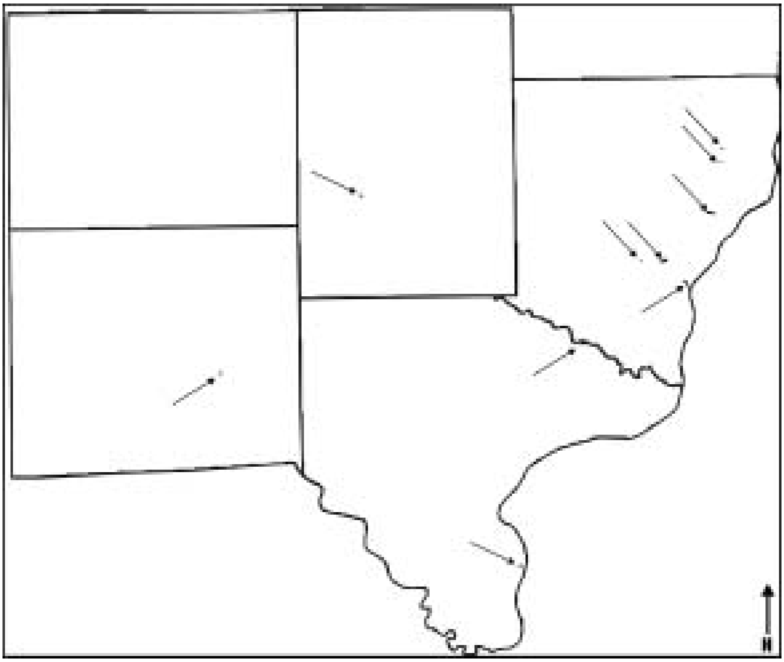

Figure 7. Map of digitized known outcrops.

in the course of this study and where the spatial extent of the outcrop was known. The *Belief* probability image was queried within these digitized outcrop areas to ascertain the nature of the predicted values. The 512 queried locations have a mean value of 0.73 (with a modal value of one), while the entire *Belief* image has a mean value of only 0.07 (and a modal value of zero; Figure 8a).

The logistic regression probability image was also queried using the known outcrops. This resulted in a mean value of 0.91 (modal value of one), while the entire probability image yielded a mean value of only 0.08 (modal value of zero; Figure 8b). These data, coupled with patterns apparent in Figures 5 and 6, suggest that the logistic regression model is much more robust.

13LE357: AN APPLIED EXAMPLE OF MODEL USE

Phase II archaeological test excavations in the Montrose Bottom along the Mississippi River in Lee County by the Iowa Office of the State Archaeologist provided many multi-component sites from which this model could be applied (Artz et al. 1995). 13LE357 is one such site. The site is located on a Holocene-age terrace near the Mississippi River (Figure 9). This is a multi-component site with Early through Late Woodland artifacts recovered.

Arnold (1985), through his ethnographic studies in exploited ceramic resources, found that in order for a resource to be used efficiently it must be accessible within a one-day trip. He states that there are differences in threshold distances between sedentary (five kilometers to seven or eight kilometers) and non-sedentary populations (a maximum of thirty-five kilometers; Arnold 1985:34-35). Rhode (1990) found that for hunter-gathers in the Great Basin food resources no greater than 100 kilometers from an inhabited area would be exploited, and most food resources would have been gathered from within a few kilometers.

A series of ten-kilometer buffer zones were placed around 13LE357 in an attempt to show distance to predicted outcrop zones that intersected high probabilities (>= .95) within the logistic regression image. It should be noted that these buffer zones extend into Illinois and Missouri, and these areas are not in the study area. However, the Mississippi River would have proven to be a major obstacle in lithic procurement and, therefore, Illinois source areas are not likely to have been a major resource for prehistoric people in Iowa. High probabilities for Keokuk, Warsaw, Salem, and “St. Louis” outcrop zones were within a ten-kilometer radius (Figure 9). The Warsaw, Salem, and “St. Louis” can be considered immediately local and the Keokuk is closer to ten kilometers away making it nonlocal. The Wassonville and Burlington predictions were up into Des Moines County designating them as nonlocal resources (Figure 9).

Keokuk, Warsaw, Salem and “St. Louis” chert varieties are of varying knapping quality, and

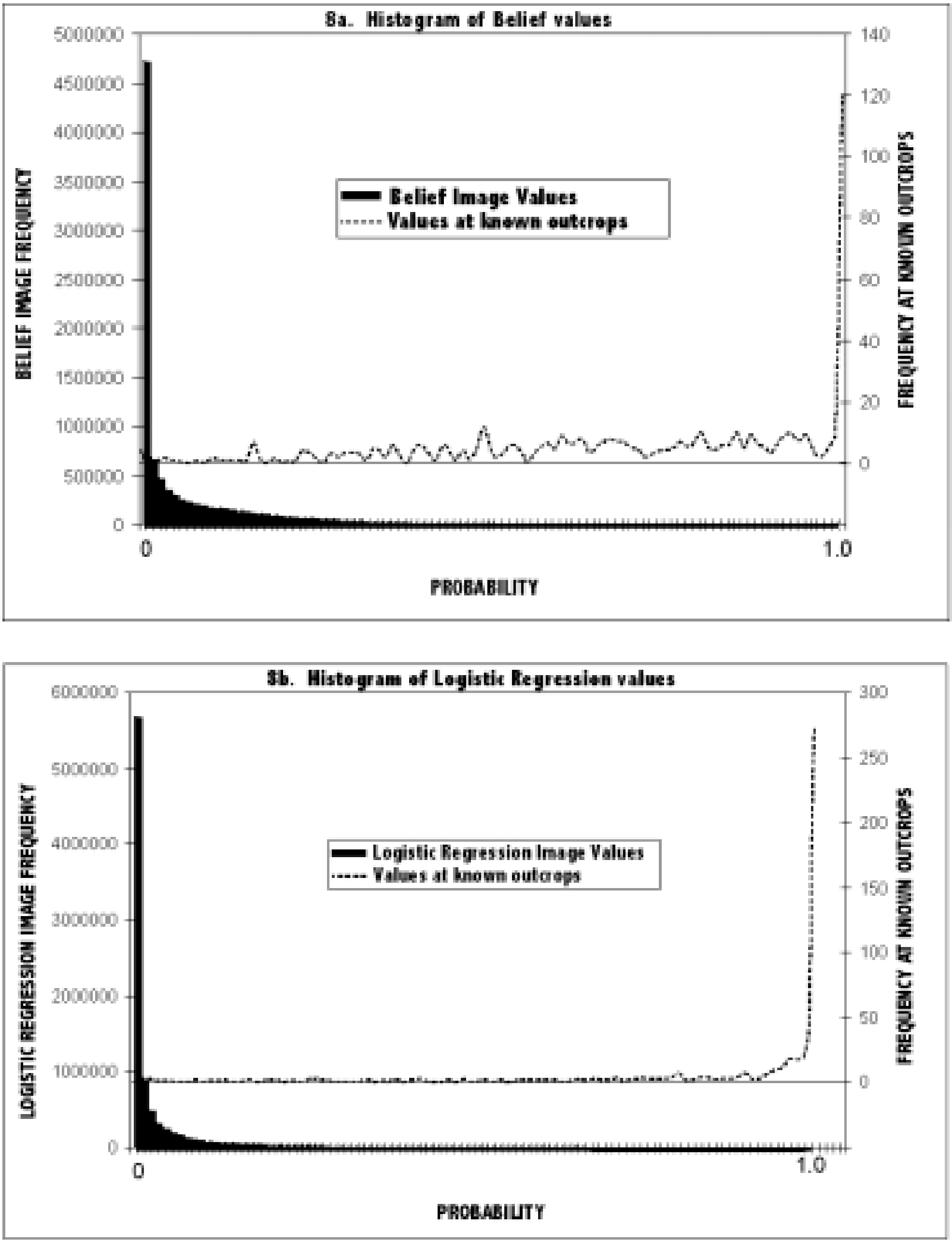

Figure 8. Histograms of the *Belief* and logistic regression probability images and probabilities at known outcrops.

Burlington varieties are considered superior for reasons mentioned previously. According to the predictions, the peoples at this site would have had to travel approximately twenty kilometers to encounter a Burlington bedrock source making it clearly nonlocal. As mentioned earlier, Wassonville cherts are thought to have been used near outcrop zones, but would have not been used when more favorable varieties such as Burlington or Keokuk were available. Even though Maynes Creek cherts are similar to Wassonville cherts, it seems likely that few, if any, Wassonville cherts would be en-

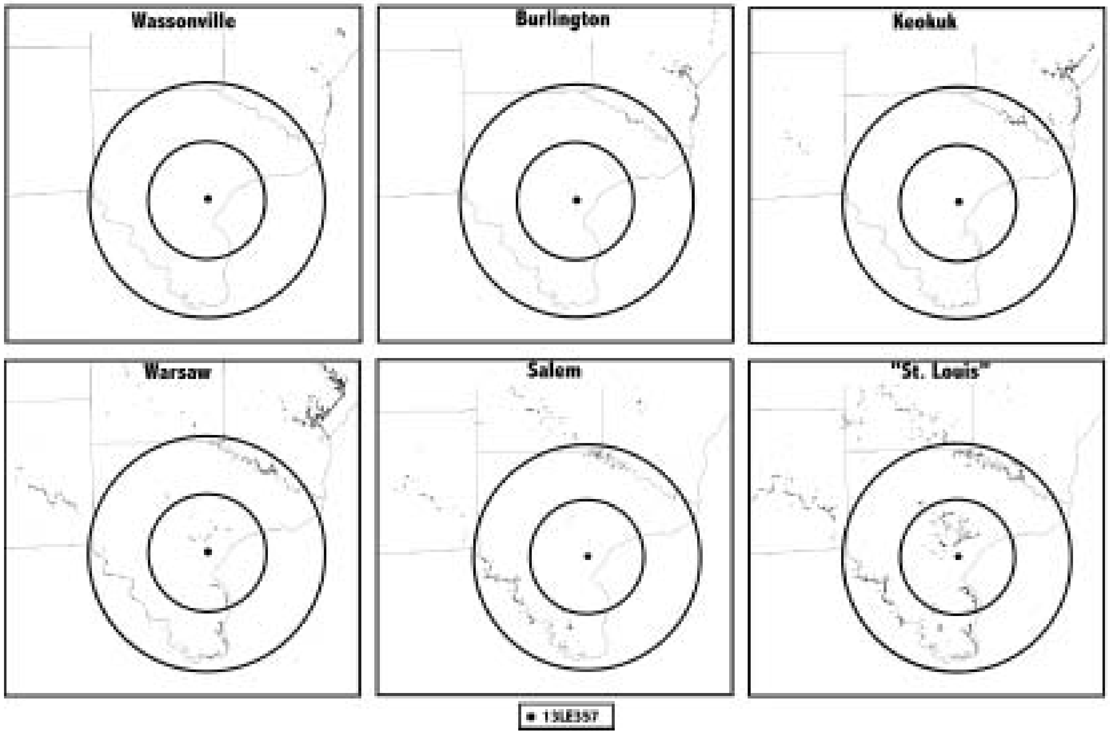

Figure 9. Relationship of 13LE357 to predicted outcrops within ten-kilometer buffer zones.

countered at 13LE357 due to its distance from the site and inferior knapping quality. Source areas for Maynes Creek cream chert are abundant in central Iowa and were used extensively in that region by prehistoric peoples (Morrow 1994a:121). Morrow (1994a:121) states that coarse pieces of this variety were used in southeast Iowa, however, and were obtained from local glacial till deposits in that region. Therefore, this type can also be considered local.

Chipped stone artifacts from 13LE357 were placed into three categories: tools, tested cobbles and cores, and flaking debris based on Artz et al. (1995) identification and categorization. They were grouped by lithic type (Table 3). A majority of these artifacts were of the Keokuk and Burlington types. The predictive model shows the Burlington Formation outcropping at a greater distance than the Keokuk and this suggests trade or travel to obtain this better quality material.

Table 3. Lithic types based on artifact categories from 13LE357.

Lithic Type	Tools	Tested Cobbles and Cores	Flaking Debris
Burlington	8	5	134
Keokuk	7	5	239
Keokuk/Burl	2	0	53
Warsaw Chalcedonic	0	0	4
Cobden/Dongola	2	0	4
Salem (Spergen)	0	0	13
Brown Chalcedony	0	0	1
Shakopee Oolitic	0	0	1
Misc. Chert	2	0	29
Obsidian	0	0	1
Maynes Creek Cream	0	1	3

Table 4. Distributions of local versus non-local materials based on artifact type.

	Local	Nonlocal	Totals
Tools	0	19	19
Tested material/flaking debris	21	442	463
Total	21	461	482

Nonlocal types include Keokuk, Burlington, Cobden/Dongola, Shakopee Oolitic, and obsidian. The Brown Chalcedony and miscellaneous chert types were not identifiable as local or nonlocal. Cobden/Dongola chert types are from the St. Louis Formation, but the only source areas known are in southern Illinois (Morrow 1994a:126). However, Cobden chert is occasionally encountered in archaeological sites in eastern and central Iowa (Morrow 1994a:126). The material is of high knapping quality, and this could suggest the material was traded. Finally, the Shakopee Oolitic type source area is known to be in southeastern Minnesota, northeast Iowa, and southwestern/eastern Wisconsin, and occurs archaeologically mostly in northeast Iowa near its source area (Morrow 1994a:118). There was one flake of Shakopee Oolitic recovered from the site, which may be from the resharpening of a tool not recovered. The obsidian artifacts are clearly nonlocal as there are no known source areas in Iowa.

Table 4 shows the distribution of materials based on artifact types. Due to small cell sizes for some types, statistical analysis was not preformed. The people of 13LE357 had a tendency to use high-quality material that was not immediately available to them. Interestingly, even most of the tested cores and cobbles could not be considered local. This suggests one of three possibilities: (1) special trips were made to collect high-quality lithic resources, (2) the material was traded, or (3) the model did not predict local sources for those varieties.

DISCUSSION

Based on the small number of known natural chert outcrops the method of comparing the ground surface DEM to the interpolated bedrock surface DEM is a valid one. Most chert outcrops occurred within areas of predicted outcrop zones. Many streams showed multiple formations outcropping in the same area. In that case, the stratigraphically lower formations are more likely to be outcropping than higher formations. For example, the "St. Louis" Formation is showing to outcrop in streams in Des Moines County, but few wells in that county encountered that formation. Therefore, this area was extrapolated and not interpolated for the "St. Louis" Formation. The lower formations such as the Wassonville, Burlington, and Keokuk are more likely outcropping.

The *Belief* image was accurate because it showed most of southeast Iowa with low probabilities for rock outcrops, but high probabilities at known rock outcrops (Figure 5). Tests against known outcrops demonstrated that the four predictors were correct in identifying outcrops. The *Belief* image can therefore be compared to the predicted outcrop zones to further narrow down the likelihood of a chert outcrop. The combination of both methods shows where a chert variety is outcropping and probabilities within that area of a greater likelihood.

The logistic regression probability image was also a good outcrop predictor based on the test areas (Figure 6). This image is more conservative than the *Belief* image and has fewer values in the middle probability range. In other words, the image shows vast areas where probabilities are extremely low and fewer areas where probabilities are high. Both the *Belief* and logistic regression images could be useful for narrowing down outcrop areas within the predicted outcrop zones. By reclassifying either the *Belief* image or the logistic regression image to show only areas with high probabilities (e.g., greater than 0.95), a useful tool for identifying rock outcrops would be created. A simple intersection between this image and the various predicted zones obtained by the deterministic methods would show areas of high probabilities for specific chert outcrops (for an illustration of this approach see Figure 9).

Cherts available in the form of stream gravels could also be assigned by these methods. For an outcrop zone within a particular stream, it can be assumed that stream gravels of that chert will be found with larger nodules closer to the source and smaller nodules down stream. The deterministic model includes stream bottoms in its outcrop zones, and in reality, the stream is more likely to be incised below the elevation of the chert-bearing rock indicating a strong likelihood for those cherts in the stream's basal lags.

Many GIS programs offer the ability to create 3-dimensional maps from DEMs. Predicted outcrop zones can easily be draped over DEMs allowing the viewer to visually determine the vertical position of the various chert-bearing formation outcrops. This would help determine the amount of energy prehistoric people would need to expend to obtain that resource from the bedrock. As mentioned earlier, the predicted "St. Louis" outcrop zone was extrapolated in eastern Des Moines County where there were no well points for that formation. A 3-dimensional view would show that the "St. Louis" extrapolated elevations are above the ground surface elevations and is not exposed in the stream valleys of eastern Des Moines County as the stratigraphically lower formations are. In this case, the "St. Louis" cherts would be an excellent candidate for till deposits to the south, as glaciers were a main force in removing this chert-bearing formation.

In a deliberate attempt to only use continuous data, soil maps were not attempted in this predictive model. Soil data does provide further reliability for predicted areas, however. For example, an area shown to be a high probability within the Burlington outcrop zone and also mapped as a Nordness Rock Outcrop soil type gives more evidence for knowing that a Burlington outcrop is likely at that location.

There are some limitations to using these methods. One is that it does not account for chert obtained through glacial till deposits, but glacial transport is hard on fine-grained chert making knappable pieces of sufficient size a rare occurrence (Toby Morrow, personal communication 2002). Also, there are unconformities in some bedrock formations that make it difficult to predict where they will and will not occur. For a particular area of interest this could be overcome by a closer examination of strip logs to see where that formation was encountered. Finally, some areas of the state have more wells than others due to differing populations and qualities of strip logs.

The focus of the paper is to locate bedrock exposures of chert. In reality, chert found in bedrock can present many problems for knappers. First, the exposed chert is commonly too weathered from freeze-thaw action to be of high knapping quality. Second, the extraction of chert from the bedrock is often difficult. Meyers (1970) concluded that secondary stream gravels would have been the best source of chert for prehistoric people in the lower Illinois Valley, but he does list chert found in bluff outcrops as second in importance over alluvial valley floors and talus deposits (Meyers 1970:34). A predictive model such as this should be a good start for chert availability.

If these methods were applied to the entire state of Iowa it could be an important source of information for Cultural Resource Management and research projects. Lithics recovered from site mitigations could be compared to predicted outcrop zones to help in determining the sources of the lithics. Furthermore, such a modeling effort could contribute to the knowledge already gained from previous excavations in the state. An examination, such as that performed on 13LE357, on many sites in one area could start to reveal patterns in procurement and group interactions. As Meyers clearly illustrates in his study of chert resources in the lower Illinois Valley, "chert is in many ways ideal for delineating prehistoric trade routes and networks" (Meyers 1970:5).

CONCLUSIONS

Archaeologists are interested in knowing the distribution and knapping quality of chert within a region to infer behavior about the procurement and use of that resource by prehistoric peoples. There was a reliance on many natural resources for the survival and sustenance of these people. Due to taphonomic processes, evidence of these resources may be lost, and resources must be commonly inferred from secondary evidence. Generally, the most abundant artifacts found at a prehistoric archaeological site are the chipped stone tool and associated debitage. In Iowa, chert was a valuable resource in the making of these tools and could be obtained from glacial or stream gravels or through extraction from bedrock outcrops.

Knowing where chert exists within the environment can help answer many questions about prehistoric behavior. For example, was the chert recovered from an archaeological site local or nonlocal? Was a certain variety of chert used for making a certain type of tool? Was the nonlocal chert traded? Were special trips required to obtain high-quality, nonlocal chert? Was the distribution of chert among groups preferential?

Using GIS can enhance studies that map the distributions of chert varieties within a region. Outcrop zones can be designated and river gravels can be assigned to various components of a watershed. In any region chert recovered from a nearby archaeological site could be classified as local or nonlocal, and distance to outcrop areas calculated with a relatively high degree of accuracy. GIS technology is increasing in efficiency rapidly, and as it does this type of study will only improve. No longer is it necessary to walk a river system to map known chert varieties; GIS applications can do much of that work in a shorter amount of time. Moreover, this model can provide the basis for a systematic evaluation of lithic procurement in the state of Iowa.

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