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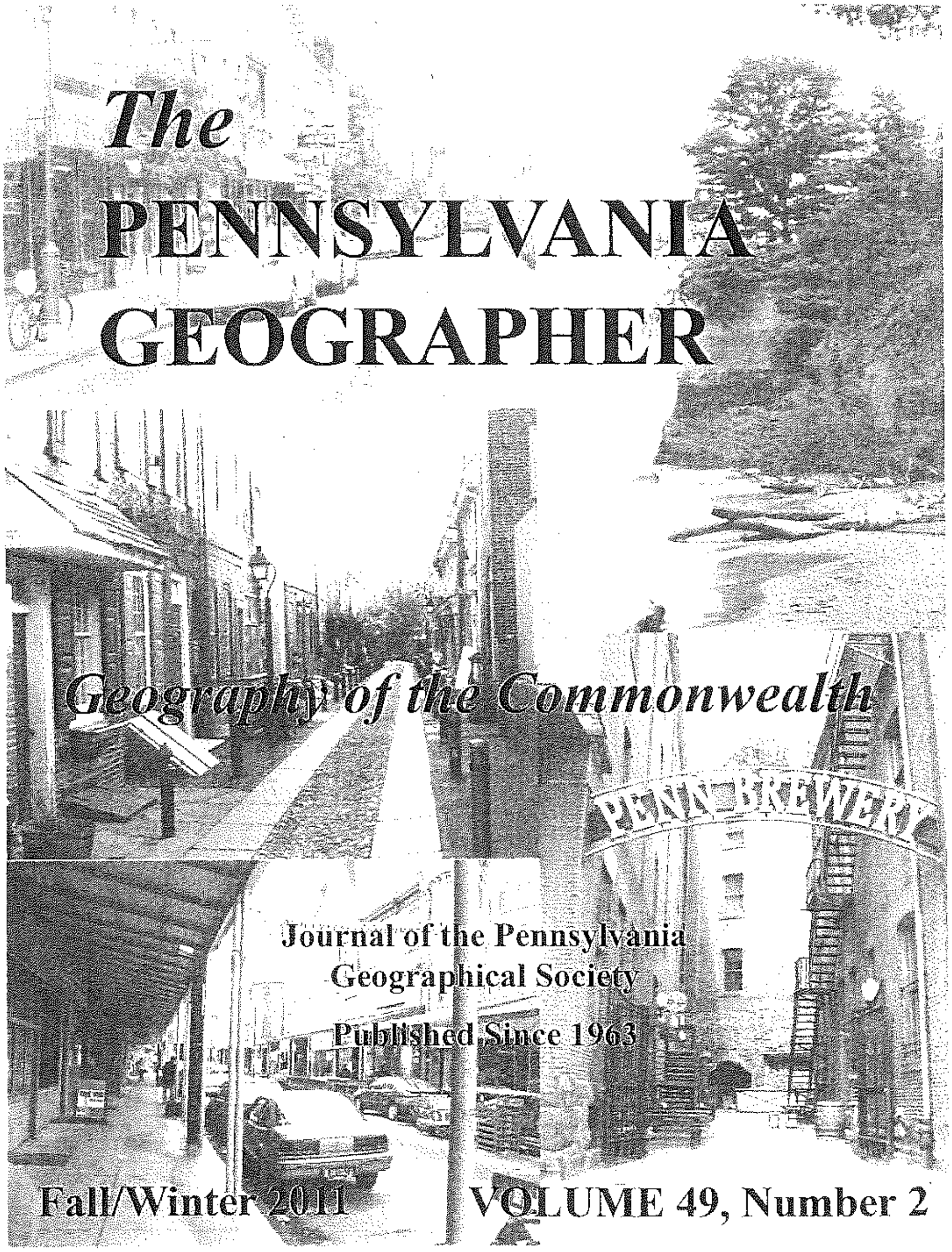

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A GIS ANALYSIS OF THE PRE-COLUMBIAN CHACO LANDSCAPE: APPLYING NEW TOOLS TO OLD PROBLEMS

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Abstract

The civilization that developed at Chaco Canyon in New Mexico between 850-1200 AD constructed what appear to be a series of roads. While the term "Chaco Roads" is generally accepted, the function of these structures is in doubt. Many of the roads seem to be constructed in discontinuous segments, and it is not certain whether these segments are the full extent of the original construction, or merely what remains after hundreds of years of decay. GIS and statistical analysis of the environmental characteristics of road segments assessed the potential for differential erosion. The results of discriminant analysis showed ground-visible prehistoric roads were more reliably predicted by the model suggesting a relationship between environmental setting and ground-visible roads. However, the model did not correctly predict the gaps between ground-visible road segments, suggesting that the roads were fragmentary. More research is needed to improve the predictive capabilities of the model.

Introduction: The Question of Chaco Roads

The cultural tradition known as Anasazi, or Ancestral Puebloan, came to sudden florescence at Chaco Canyon in northern New Mexico between approximately 850 and 1200 AD (Doyel 1992). Among the masonry of the Great Houses and the thousands of artifacts, another intriguing development at and around Chaco has been the discovery of what appears to be a series of roads that lead away from the center of Chaco towards outlying settlements. These Chaco "roads" run in surprisingly straight lines, sometimes for as long as 80 kilometers, seemingly to connect outlying settlements to the core of Chaco (Vivian 2002). The roads ignore topography, going over hills and down canyons instead of around them. Since the roads do not follow the easiest route from their origin to their destination, they do not follow the pattern of road systems in other cultures which tend to follow the easiest path (Kantner 1997). Furthermore, the roads are not continuous, but rather exist as widely separated segments. Much debate has centered on the possibility that the gaps in the Chaco roads were once one interconnected system (e.g. Betancourt 1986 and Roney 1992). These gaps are the source of much uncertainty. Were the roads once constructed across these gaps? Have they since eroded away, or were the roads never built there in the first place? Interpretations of these structures differ.

In the days since the original study of the Chaco Roads, geographic information systems (GIS) have made new analyses possible, allowing for regional investigations that would previously have been much more difficult due to the effort required to bring together and analyze spatial data for a large area. A GIS-based study of soils and climatic factors encompassed by the Chaco Road system might reveal a pattern where roads have remained visible for almost 1000 years, and where they might have eroded away. It is possible that the areas with roads still visible have certain environmental settings that other areas with gaps do not. If a pattern is found that shows that an area between two road segments is potentially more erodible, it might be likely that this road was continuous at one time, but has since weathered away. This might favor the interpretation of the Chaco roads as an interconnected system. If no pattern exists, it might be more likely that those "gaps" never contained a Pre-Columbian road at all. This might support the interpretation of the Chaco roads as being more fragmentary, less for transportation and commerce and more for symbolic or political purposes. A GIS viewshed analysis might reveal additional spatial patterns in the northern New Mexico landscape where the topography allows for visibility over long distances.

Thus, we sought to answer the following questions. Do soil and climatic factors significantly differ between visible road segments and apparent gaps in the road system? Do the road segments and gaps fall within the viewshed of other road segments, gaps, and other Pre-Columbian structures?

GIS-based Studies of Pre-Columbian Landscapes

The use of GIS has greatly enhanced our understanding of many Pre-Columbian landscapes. With it, detailed spatial analysis over both small areas, and more importantly, large regions, is possible. Ebert (2004) offers a framework by which the addition of this technology to the study of Pre-Columbian landscapes can be evaluated. He divides the use of GIS in archaeology into three levels: visualization, management, and analysis. Visualization is simply the making of maps, or turning GIS into a tool for making "pretty pictures." While the utility of an aesthetically pleasing map is not to be underestimated, this is the simplest level of GIS use. Management is that level of GIS which deals with the maintenance and editing of spatial data; Ebert contends that most archaeological GIS projects occur at this level, but management does not involve any theory. Analysis is the highest level of GIS use. At this level, archaeological theory is generated and tested through the capabilities of the software (Ebert 2004).

GIS is frequently employed for predictive uses. That is, determining where archaeological sites will be based on patterns found in data already in hand. Whitley and Hicks (2003) sought to use environmental data, together with the routes of known Pre-Columbian travel routes across northern Georgia, to determine possible locations of other travel corridors. This study employed several levels of GIS analysis, but particularly cost-pathing. A cost-path is the least expensive way across a given landscape, based upon factors given by the user—generally slope or vegetation. Erikstad et al. (2004) were able to use GIS in a similar manner. In order to foster conservation of prehistoric sites in Norway, GIS was employed to combine elevation, soils, and land use data in order to determine the probable location of Bronze and Iron Age grave mounds. This analysis correctly predicted the location of 94% of known grave mounds in the area, and many unknown mounds were discovered in the area predicted by the GIS maps (Erikstad et al. 2004).

Archaeological applications of GIS might also entail reconstructions of ancient or prehistoric landscapes. Contreras (2009) used GIS interpolation tools (from scattered point data) to re-create the landscape surface of pre-Inca settlements in Peru that had undergone significant change in the more than three thousand years between its heyday and modern times. Swanson (2003) used GIS viewshed analysis at Paquimé, a large, complex archaeological site in northern Chihuahua, Mexico. Early studies of the area around Paquimé had discovered cultural traces on surrounding hilltops that were interpreted as fire-signaling stations. Swanson's study determined that these hilltops sites were ideally intervisible and had the potential to form a complex communication network.

Viewshed analysis is a powerful application of GIS in understanding Pre-Columbian landscapes. Williams and Nash (2006) used viewshed analysis in a study regarding Wari settlement in ancient Peru. GIS viewshed analysis showed that a possible strategy for Wari imperialism might have been to occupy important sites from which many sacred mountains, or *apu*, were visible, thereby placing local deities (and thus local societies) under Wari control. By occupying these high places, Williams and Nash theorize that the Wari were able to take local deities "hostage" and ensure locals' cooperation with Wari objectives. Jones (2006) employed viewshed analysis in a study of settlement site choice among the Onondaga Iroquois, in what is now upstate New York. Jones' terrain analysis discovered that most Onondaga settlements stood on hillsides, rather than higher up. This terrain provided the benefit of ideal soils and climate for growing corn, beans, and squash, but sacrificed defensibility. Most of these sites had constructed defensive structures such as palisades to help with this shortcoming. Furthermore, viewshed analysis found that many of the sites in the study area were mutually visible. It is possible that settlements were placed within sight of one another for mutual defense.

The Debate Surrounding the Chaco Roads

The interpretation of both the form and function of Chacoan roads has varied with the times, and with individual scholars' views of the nature and scope of Chacoan society. At issue is the question of what the Chaco "roads" were really for—were they indeed roads, created for an economic purpose, or were they constructed for some other reason? Early on, Earl Morris' (1915) excavation of the Aztec Ruin, a major outlying site 64 km north of the canyon itself, noted without any apparent doubt that the building materials used at the site were brought "over a broad road which is still visible" (Morris 1915: 666). Discoveries at Chaco and other culturally similar sites, known as "outliers," throughout the Four Corners region gave rise to the theory that Chaco Canyon was at the center of a sphere of Anasazi cultural and economic influence encompassing an enormous part of the Southwest (Kantner 2004). In the archaeological wrangling that followed, changing views of the nature of Chacoan roads have played a crucial part in theories of just how complex and wide-reaching Chacoan civilization was.

An "almost innate association of roads with commerce" led most early scholars to economic explanations of the function of Chacoan roads (Vivian 1997b: 37). Ebert and Hitchcock (1980) performed analyses of the road-andoutlier system that placed Chaco society on the low end of the spectrum of economic complexity, based largely on road data. Powers (1984) suggested that "the roads' purpose was to facilitate travel and communication between these sites" (Powers 1984: 53). Betancourt, Dean, and Hull (1986) continued the trend of thinking that the Chaco roads were primarily used for economic purposes. They studied the way in which wooden beams used in construction at Chaco could have gotten there and where they came from. More than 200,000 trees were transported to Chaco from the surrounding mountains at distances of more than 75km. Furthermore, "the absence of transportation scars indicates these logs were carried rather than dragged or rolled" (Betancourt et al. 1986: 370). Betancourt, Dean, and Hull also noted several major roads that travel in the direction of forests in the ranges to the south, west, and north of Chaco. Betancourt, Dean, and Hull suggest that communities in these areas provided timber as their contribution to a redistributive or tributary Chacoan system, and that "the roads, whatever their primary function, would have facilitated the transport of logs to the canyon" (Betancourt et al. 1986: 374).

In 1993, however, David Wilcox noted that many of the Chacoan great houses were too far apart from each other for efficient food transport. Wilcox found that while there is ample evidence for goods coming into Chaco canyon from outlying sites, there is much less evidence for goods going the other way, thereby placing an economic or redistributive explanation for the roads in doubt. He proposed that the roads were crucial transportation systems for an "early state" that levied tribute on its neighbors and kept them in line by military force.

In a piece that marked a major turnabout in thinking regarding the Chaco roads, John Roney (1992) presented a much more conservative view of the whole system. Proposing that "it is far from clear that the pre-Columbian Chacoan roads were built to make economic transport and region-wide communication more efficient," he said simply that the data regarding the roads did not fit those conclusions (Roney 1992: 123). The very linearity of the roads, and an apparent disregard for ease of passage along them, seem to argue against their having been constructed for transportation. Roney also argued that if roads were being used for economic purposes, their courses should in some way contrive to carry the traveler toward the source of the goods allegedly being transported. With very few exceptions, they do not.

Roney's 1992 paper also issued a call for a re-assessment of the extent of the road system. Many arguments for and against certain theories of road use had been built on extrapolations of road courses based upon short segments. However, Roney argued for greater care with these extrapolations. At the last, "the meanings the roads had for their makers, their precise emic function, is probably unknowable. They might have formalized preexisting routes of transportation and communication, but it is equally plausible that they were raceways, avenues for ceremonial processions, or even cosmographic expressions" (Roney 1992: 130). Fowler and Stein (1992) echoed this by grouping roads into an Anasazi "ritual landscape" that was also composed of great houses, great kivas (subterranean ceremonial structures), and earthen mounds, frequently aligned with cardinal directions or culturally important landmarks. Doxtater (2002) discovered a startling series of regional alignments that suggest the Anasazi may have been building just that. Doyel and Lekson (1992) used roads as a unifying cultural influence that brought far-flung settlements together under the banner of Chaco and differentiated them from other contemporary cultures such as the Mimbres, Hohokam, and Mogollon to the south and west.

Kantner (1996, 1997) took up this newer thinking with a series of papers based on the study of the Chacoan roads through GIS. Using GIS, Kantner was able to manipulate large amounts of spatial data to determine idealized "cost-paths," which are the routes that would take the least amount of time and energy to traverse from one site to another. He then compared these idealized "cost-paths" with the actual courses of several Chacoan roads in a limited survey area about 80 km south of Chaco Canyon itself. The results were "fairly unequivocal" (Kantner 1997: 4). Of 17 surveyed roadways, only two fit the criteria for an economic theory of their use. The "roads," then, potentially served some other purpose. Kantner concludes that "all roads appear to fit more closely with explanations that see the roads as having served localized religious or integrative functions" (Kantner 1997: 7).

Whatever the roads may truly have been, the research and understanding of the Chacoan road system has evolved over time. From the early theories of a simply economic interpretation of the network, new ways of researching and understanding have led us to believe that the economic theories do not hold up to criticism, except in certain select instances (such as the roads leading to and from heavily timbered areas outside Chaco). Even if the roads were used for travel and transport, there must have been other functions. Their linearity, their association with ceremonial structures such as great houses and great kivas, and the evidence that goods trafficked into Chaco (but not out again) all argue against a strictly economic theory.

The terrain in which these roads were built is largely flat, open ground. When constructed and well maintained, they would have been visible for miles. Whether people came to Chaco as part of a religious procession, as captives driven before the spears of a victorious Chacoan raiding force, or simply to have a good time in the desert, their approach to the canyon would have been marked by views of these enormous lines, stretching across the horizon. Perhaps these long lines were to Chaco what neon lights are to Las Vegas: they tell you *exactly* where you are. These roads were less useful than unifying; less structural than symbolic. R. Gwinn Vivian, in a recent popular book about the Anasazi, summed up the modern thinking on Chaco roads: "The straightness, or least their directness, was because they needed to be seen from great distances…When you've got one straight damn road you can see for miles and miles, that's a psychological effect" (Childs 2006: 63). Whether for psychological, economic, or spiritual effects, the roads, combined with other unusual alignments, networks of signaling devices, and massive public architecture throughout the Southwest, argue that the Chaco Anasazi probably lived in something like the "ritual landscape" proposed by Fowler and Stein (1992). Whether most of them were aware of it, or whether it was simply for elites, is open for debate.

Study Area

The study area encompasses approximately 12,000 km2 in the Four Corners region of the southwestern United States (Figure 1). This broad area of high desert has an average elevation of approximately 2400 meters (USGS 2001). Chaco Canyon itself is the gorge formed by the passage of the Chaco Wash, an intermittent stream, tributary to the Chaco River. It is completely dependent on rainfall (Vivian 2002). This is a high, relatively flat area surrounded by high peaks. Vegetation is limited and comprises primarily rangeland covered by greasewood, sagebrush, and prickly pear. At higher elevations juniper trees will also appear, though they are generally smaller and limited in number. The relatively mild topography and lack of tall trees make this a landscape where it is

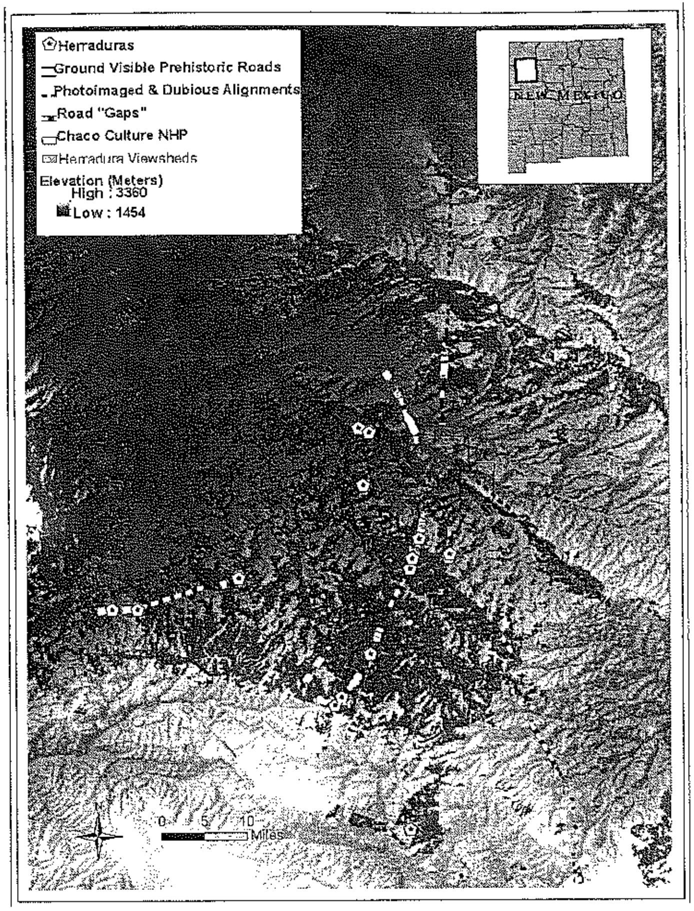

Figure 1. *Chaco Canyon National Historical Park and the surrounding network of prehistoric roads. Three groups of roads were analyzed in this study: (1) Prehistoric roads visible on the ground, (2) roads visible on aerial photographs but not on the ground, or expected to be present based on geographic patterns but not confirmed with field evidence, and (3) gaps between visible roads identified by the authors where no road is known or expected to exist based on previous archaeological investigations (Kincaid 1983, Nials et al. 1987). The location of herraduras and the results of the viewshed analysis are also depicted.*

easy to see for a very long way. The geology of the Chaco Canyon area is primarily sandstone, mudstone, and low-grade coal (Vivian 2002).

The Chaco roads are centered on Chaco Canyon in northwestern New Mexico, in the San Juan Basin, although Pre-Columbian roads of this sort have also been described in southeastern Utah and other places far outside the commonly accepted sphere of Chaco influence (Kantner 1997 and Childs 2006). During the 1000s and 1100s AD, this landscape was at the center of a civilization that extended across approximately 150,000 km2 of the Four Corners region of the U.S. Southwest (Fowler and Stein 1992). Settlements known as "Great Houses" or "outliers," which share many of the same characteristics as those found at Chaco, are found throughout the region—much debate centers on the extent of the Chaco civilization (Lekson 1999).

Chaco roads are ancient, heavily eroded, overgrown, and difficult to see on the ground (Ebert and Hitchcock 1980). They vary in their makeup, width, and manner of construction. In some places earth was merely scraped away to reveal the bedrock below, and sandstone curbs were put in place along the roadsides (Vivian 2002). However, Kincaid (1983) notes that in most places these roads show distinct evidence of large-scale engineering; road cuts, road fill, ramps, and stairways, for example. The roads studied in this paper are those described in the BLM Chaco Roads Project (Kincaid 1983, Nials et al. 1987). Roads appear to run from Chaco in all four cardinal directions, but the two longest and most easily discerned roads are the North Road and the South Road. These run for as long as 100 km in the direction of outlying settlements and they may run longer, particularly in the case of the North Road (Lekson 1999). Roads that run to the east and west of Chaco Canyon are only found in spotty locations along their presumed course (Kantner 2004).

Methods

The BLM Chaco Roads Survey maps were based on USGS 7.5-minute quadrangle maps for the area surrounding Chaco Canyon (Kincaid 1983, Nials et al. 1987). Digital Raster Graphic (DRG) data for the four counties of northwestern New Mexico (San Juan, Sandoval, Rio Arriba, and McKinley) were loaded into ArcGIS 9.2 and used to georeference the scanned BLM maps (USGS 2001; ESRI 2007). DRGs are digitally scanned versions of USGS topographic maps. Since the BLM maps were based on USGS 7.5-minute quadrangle maps and had many of the same features and notations as the DRG maps, georeferencing was relatively straightforward. An important point to note is that the BLM surveys were done at differing levels of detail. BLM Survey Volume 2 (Nials et al. 1987) (southern periphery) goes into much greater detail than Survey Volume 1 (Kincaid 1983). The maps that come with Survey Volume 1, for example, do not have legends and do not cover the roads' entire known length to the same degree of detail. The North Road, which travels for more than 60 km out of Chaco, is only covered in detail for its first 15 km.

The Chaco roads survey data were then classified into the following layers based on the BLM Survey maps and interpretation of orthophotos (USGS 1997-1998):

- Road Group 1: Ground-visible roads that are indubitably of Pre-Columbian origin.
- Road Group 2: "Alignments" that might be roads and are visible in aerial photography, but are either not visible on the ground, of uncertain origin, or both; and "Projected Alignments," roads that should be there if the pattern holds—but evidence of them cannot be found.
- Road Group 3: "Gaps" of varying length were chosen by the authors along road alignments. These are spaces where a known, ground-visible road alignment ends and begins again some distance along the same course. The gaps are the spaces between which no road is known to exist.
- *Herraduras*, which is Spanish for "horseshoe." These U-shaped structures have been found along the roads, frequently at a place where a road's bearing changes. Occasionally a road will pass between two of them. Their function is unknown, but they are almost certainly road-related (Vivian 1997).

To enable statistical analysis of the soil and climatic variables associated with different road types, road attributes were sampled at points separated by 50 m intervals. Environmental data for each sampling point were obtained by intersecting the point with the environmental data layers. Soil variables included potential soil erodibility by water (K factor index, indicates susceptibility of soil to sheet and rill erosion), and potential soil erodibility by wind (wind erodibility index, measured in tons of soil that will erode per year) (NRCS 2005). Climatic variables included minimum and maximum annual temperature and average yearly precipitation for the years 1971-2000 (NRCS 2006). Discriminant analysis was performed in SPSS 15.0 to determine which standardized environmental variables would be good predictors of road group (SPSS 2006).

Viewshed analyses were performed on each of the 18 *herradura* structures noted in the maps. Viewshed analysis, which uses elevation data to determine how much of a given area is visible from a given point, is a time-and-computer intensive process in ArcGIS 9.2, particularly when dealing with large study areas. The *herradura* viewsheds were examined for patterns between road alignments and viewshed extent.

Results

There are 101 segments totaling 33,916 m of ground-visible Pre-Columbian road in the area covered by the BLM survey (Group 1), and 389 segments of road alignments of dubious origin, or visible only in aerial photography, totaling 123,849 m (Group 2). Ten "gaps," areas that sit between two lengths of Pre-Columbian road, for a total of 45,526 m were chosen as part of the study—the "gaps" were broken into 63 different segments (Group 3).

Since the size of the three road groups differed substantially (n = 63, 389, and 101 respectively), groups were treated equally in discriminant analysis to avoid favoring the largest group. This method yielded a lower percentage of correctly predicted cases but provided a better overall model. Group 1 was most accurately predicted by the model, with 68.3% of ground-visible road segments predicted by soil and climatic factors, whereas Groups 2 and 3 were incorrectly predicted most of the time (48.6% and 43.8% respectively) (Table 1).

The first two canonical discriminant functions were moderately correlated with the original variables (0.252, 0.146 respectively) and had relatively low Eigen values (0.068, 0.022), however the functions possessed high chi-squared values (56.881, 14.049) and were statistically significant (0.000, 0.015). Function 1 explained 75% of the variation, and was positively related to Groups 1 and 3, distinguishing them from Group 2. Average minimum temperature and average annual temperature were the strongest predictors and positively correlated, followed by wind erodibility which was negatively correlated with Function 1 (Table 2). These three variables differentiated Group 2 roads from the other groups. Function 2 explained 25% of the variation and distinguished between Groups 1 and 3, with a negative correlation of precipitation, and positive correlations of maximum temperature and water erodibility as the strongest predictors. Thus, Function 1 appears to be a proxy for cooler sites less susceptible to wind erosion, while Function 2 appears to be a proxy for drier sites.

Table 1. Classification results of discriminant analysis show that the model correctly predicted the majority (68%) of ground-visible roads based on soil and climatic factors, but did not correctly predict the majority of dubious road alignments and gaps

Road Group		Predicted Group Membership			
		1	2	3	Total
1:	Ground-visible	68.3	15.8	15.8	100.0
2:	Dubious alignments	31.8	48.6	19.6	100.0
3:	Gaps	34.4	21.9	43.8	100.0

Table 2. Discriminant analysis structure matrix of pooled within-groups correlations between discriminating variables and standardized canonical discriminant functions

Environmental Variables	Function	
	1	2
Average Minimum Temperature	.599	-.040
Average Annual Temperature	.524	.469
Wind Erodibility Index	-.331	.299
Average Precipitation	.147	-.794
Average Maximum Temperature	.305	.701
Water Erodibility (K factor)	-.107	.455

Viewshed analysis of the *herraduras* compared the three road groups (see Figure 1). Sixty-nine percent of Group 1 roads (ground-visible Pre-Columbian roads) were covered by the viewsheds of one or more *herraduras*, while the Group 2 alignments of dubious origin, or those only visible in aerial photographs, were found within 87% of viewsheds.

Discussion

The results of discriminant analysis showed ground-visible prehistoric roads were more reliably predicted by the model, suggesting that there is a relationship between environmental setting and the presence of ground-visible roads. More research is needed to improve the predictive capabilities of the model, including updated archaeological surveys. It is very likely that there are more factors at work on the remaining Chaco roads than climate and soils. Such factors as quality of initial construction, maintenance and use, among many other possible factors, determine whether a road has remained visible, or has been eroded away. Nonetheless, analysis of Chaco roads suggests that climate and soils likely contribute to where Chaco roads remain visible into the present.

The *herradura* viewshed analysis revealed that these structures, which are always found in association with road alignments, cover the majority of the ground-visible Pre-Columbian roads. These viewsheds cover even more of the alignments of dubious origin, or those that are only visible in aerial photographs. This seems to indicate that the *herraduras* were built to keep watch over the roads, whatever their purpose served. There are many more "dubious" alignments than visible roads, and they are spread across a wider area, which may account for the disparity. It is also likely that there are *herradura* structures that were either destroyed or weathered away, or that simply have not been discovered yet. The *herradura* viewsheds that were generated might also provide places in which to search for other Pre-Columbian roads, since they seem to cover most of the known roads.

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