IDENTIFYING SOURCES OF PREHISTORIC TURQUOISE IN NORTH AMERICA: PROBLEMS AND IMPLICATIONS FOR INTERPRETING SOCIAL ORGANIZATION

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Well-made turquoise beads are rare at North American archaeological sites, and the prehistoric sources of turquoise are limited. Mining the turquoise, manufacturing the bead, and using it as part of a bracelet or necklace involve numerous human interactions to transport the raw material from its source to the place where it is finally found in an archaeological context. Accurate identification of turquoise sources affects our interpretation of prehistoric behavior and is the focus of this paper.

THE IMPORTANCE OF TURQUOISE BEADS

Tiny turquoise beads (Pl. IIIC top) found in many archaeological sites provide clues for the reconstruction of human behavior over long time periods and across large geographical spaces. This presentation outlines the use of turquoise by people in Central Mexico and the southwestern United States from the time of Christ to the present in order to determine what trade links may have existed among the various culture groups. The emphasis will be on Chaco Canyon, located in the approximate center of the San Juan Basin of northwestern New Mexico (Fig. 1).

Between 1896 and 1899, the Hyde Exploring Expedition, with George Pepper as the field archaeologist, worked at Pueblo Bonito, the largest site in Chaco Canyon (Fig. 2). Among the rooms he excavated were several in the approximate center of the site which, based on architectural style, were among the oldest. In these rooms were collections of unusual objects; e.g., digging sticks and cylindrical jars which had never before been seen in such numbers. Room 33 contained numerous burials, two of which were beneath wooden boards. These two males were accompanied by thousands of marine shells, turquoise beads, and turquoise pendants; the beads alone numbered around 15,000 (Pepper 1909:222-225). Such remarkable wealth has not been seen again during the nearly 100 years of excavation in Chaco Canyon, and it provides evidence for considering Chaco as an important center between A.D. 950 and 1150.

Knowledge of turquoise sources was limited in the late 1800s. Blake (1858), who was one of the earliest mineralogists to explore the newly acquired territory

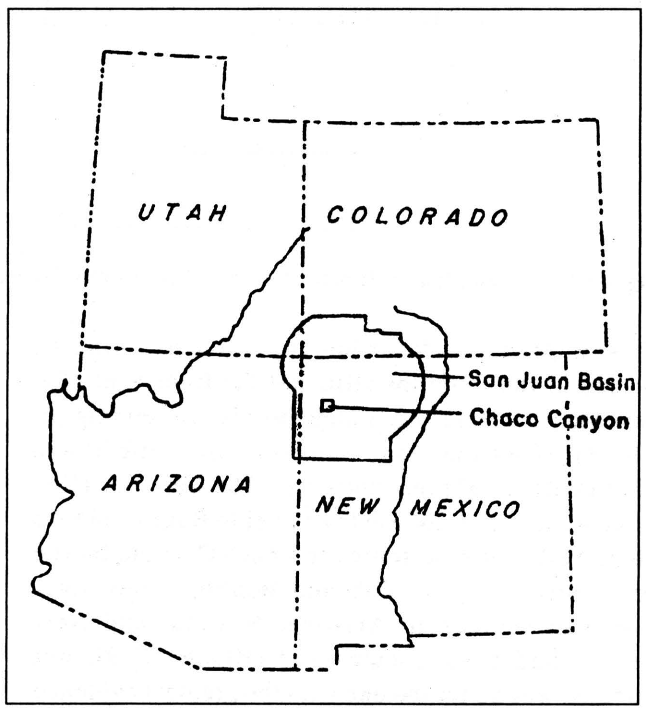

Figure 1. The location of Chaco Canyon and the San Juan Basin in northwestern New Mexico (drawing: Jerry L. Livingston).

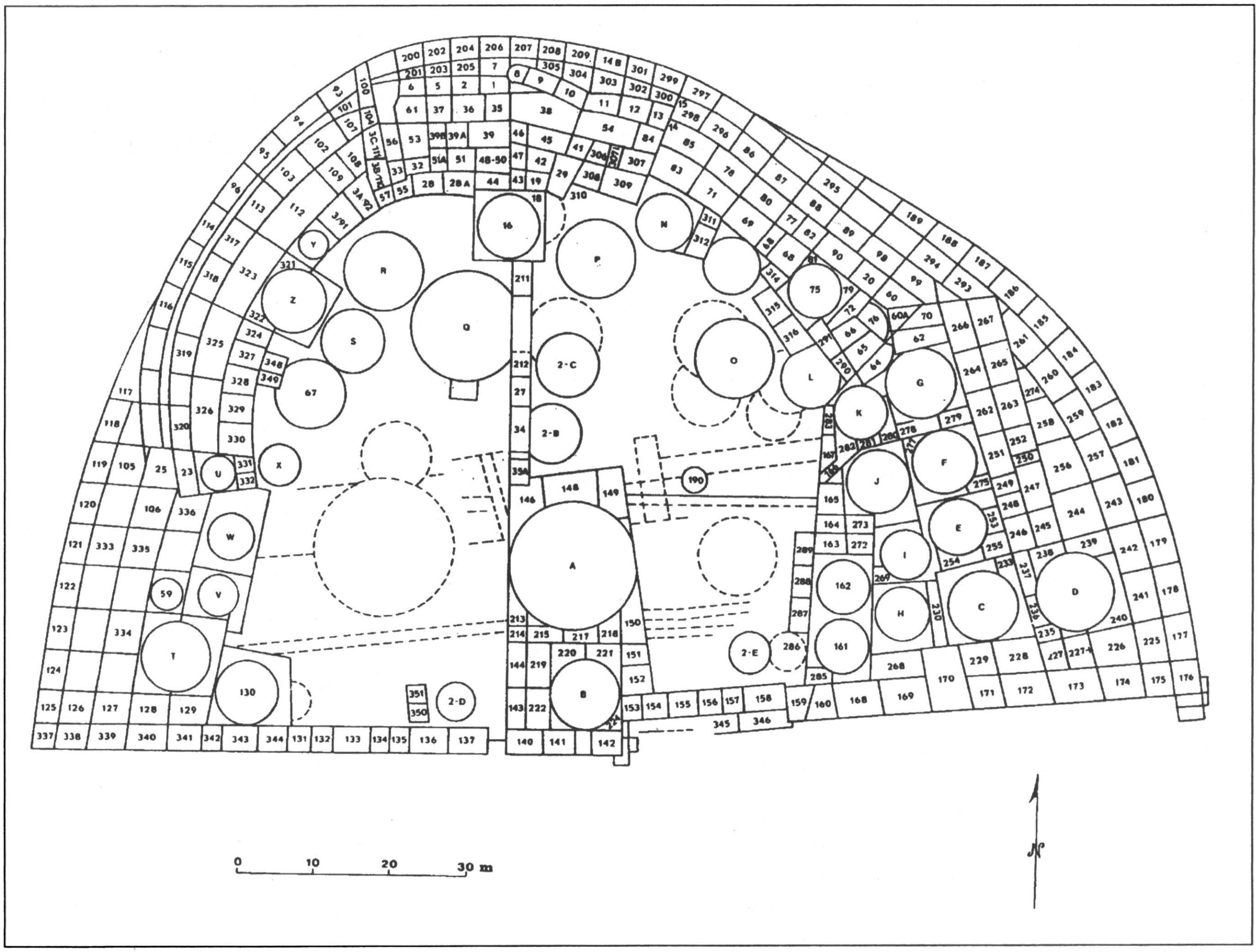

Figure 2. Ground plan of Pueblo Bonito (Lekson 1984:Figure 4.17.)

of New Mexico, described Mount Chalchihuitl, located in the Cerrillos Hills not far from Santa Fe, New Mexico. Here was a huge prehistoric mining pit (Fig. 3), as well as stone tools (Pl. IIIC bottom) and other evidence of prehistoric use. The Cerrillos Hills are approximately 200 km from Pueblo Bonito, and are the nearest turquoise source to Chaco Canyon. By the time Pepper excavated Pueblo Bonito, a few other turquoise sources in Arizona, Nevada, and New Mexico had been documented (Blake 1899), but Cerrillos was by far the one with the greatest evidence of prehistoric use. Because of the similarity in color between the artifacts recovered at Pueblo Bonito (Pl. IIID) and the turquoise samples from the Cerrillos Hills (Pl. IVA), Pepper (1909) suggested that the people at Pueblo Bonito probably obtained their turquoise from that location.

This link between Chaco Canyon and the Cerrillos turquoise mines is still a major topic of discussion. Today, however, there is considerably more information concerning where turquoise artifacts have been recovered. Turquoise has been found at archaeological sites as far south as Guatemala, but it appears in greater quantities in central and northern Mexico and the American Southwest. Because it is a mineral that usually occurs only in arid regions, it has been suggested that major trade networks between central Mexico and Chaco Canyon were established in order to provide turquoise for Mesoamerican consumption. The models provided by Di Peso (1968a, 1968b), Kelley and Kelley (1975), and Weigand (1994; Weigand and Harbottle 1992:84; Weigand, Harbottle, and Sayre 1977) postulate trade networks among various groups. Some archaeologists (e.g.,

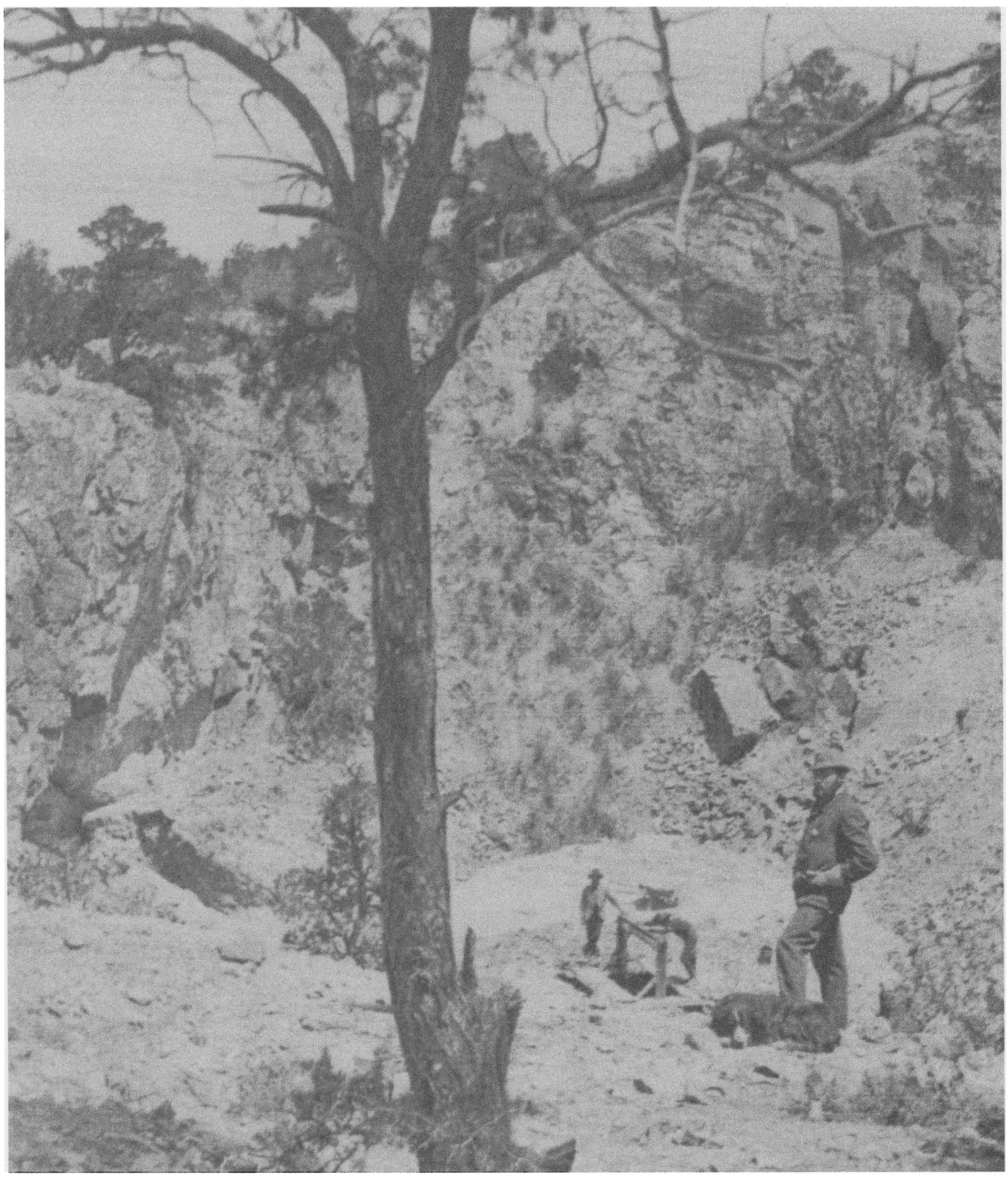

Figure 3. An 1879 photograph of a prehistoric turquoise mining pit at Mount Chalchihuitl in the Cerrillos Mining District, New Mexico. The miners are placing an exploratory shaft in the bottom of the pit (photo: Bennett & Brown; courtesy New Mexico Bureau of Mines, Socorro).

Mathien 1981a, 1986) suggest that the method of transporting turquoise between these two distant areas may have been only loosely structured. It still remains, however, to be determined whether turquoise, or any other material or artifact, reflects actual influences of one group of people in Mesoamerica on others in the Southwest (Lister 1978:240; Mathien and McGuire 1986; McGuire 1980).

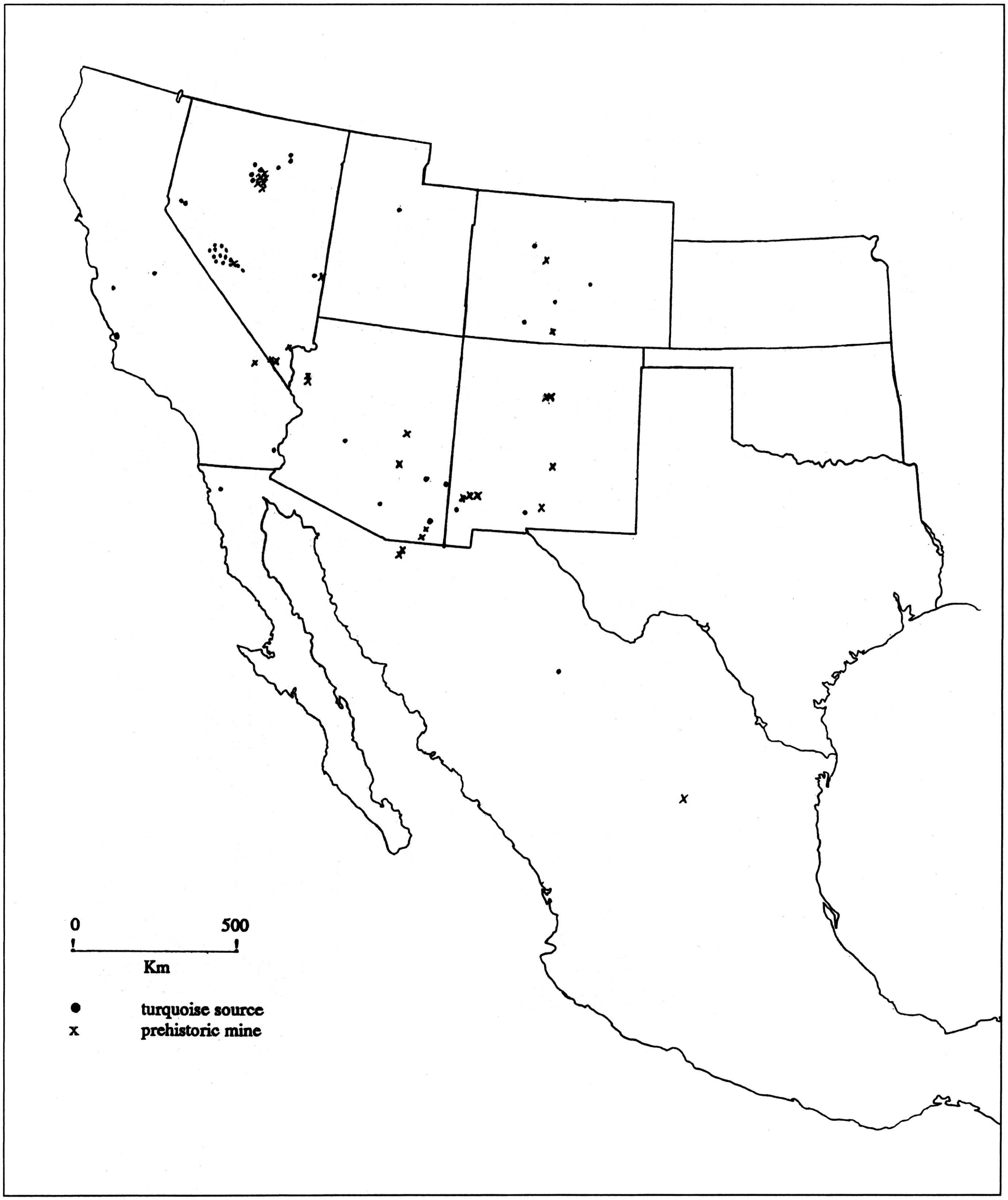

Figure 4. The locations of known turquoise sources in the American Southwest and northern Mexico (all drawings by F.J. Mathien).

TYING TURQUOISE ARTIFACTS TO TURQUOISE SOURCES

To understand turquoise trade networks, characterization of source areas and the comparison of artifacts with source materials is a basic step. Chemical turquoise is found in approximately ten states in the United States and five in Mexico (Fig. 4). The larger turquoise deposits are located in New Mexico, Arizona, California, and Nevada, with lesser deposits in the surrounding states of Colorado, Utah, Texas, Baja California, Sonora, Chihuahua, Coahila, and Zacatecas (Anthony, Williams, and Bideaux 1982; Galbraith and Brennan 1959; Morrissey 1968; Northrop 1959, 1975; Panczner 1987; Pemberton 1983; Pogue 1915; Sigleo 1970; Weigand and Harbottle 1992). Some of the deeper deposits known today were not discovered until copper mines reached some depth. Because prehistoric tools have been recovered from many of these mines, we can conclude that pre-Columbian populations had knowledge of numerous turquoise sources.

Unfortunately, correlating artifacts with specific sources is not a simple matter. Pepper chose to visually assess the color of the stone and its matrix. But appearance is deceiving. Color in a single vein of turquoise will vary. Some colors fade on exposure and use. Leaching and weathering of veins that are closer to the surface versus those lying deeper in the earth also affect color. In addition, we do not know what has happened to artifacts that have lain in the ground for many years. Based on surveys in the Cerrillos Hills, the color of the turquoise from the mines located there is so variable that most specimens from other sources cannot be distinguished from it visually (Pl. IVA).

Such local variability in turquoise is not unexpected. Numerous wet chemical analyses of turquoise from the United States, Mexico, and other countries have resulted in a number of formulae for turquoise (Northrop 1975). Although mineralogists understand the basic chemical elements and the range of variation to be expected in each, they have not fully documented the total composition of turquoise because it picks up numerous chemical elements from the host rock during the formation process (Sigleo 1970).

Recent improvements in analytical technology have provided some information regarding trace element content in turquoise, and larger collections of source material have made it possible to examine artifacts, compare them with the source samples, and suggest possible source areas for them. These studies are not definitive, but preliminary work suggests that they could prove useful. Appendix A reviews the analytical methods used to date and notes problems with each.

A pioneering study by Anne Sigleo (1970) used arc emission spectrography to analyze turquoise from three sites in Chaco Canyon. One artifact from Bc 57 was linked to a mine in Mineral Park, Arizona, while another from the same provenience had some similarity to a mining sample from Cripple Creek, Colorado. An artifact from Chetro Ketl and one from Bc 58 were slightly similar to samples from Crescent Peak, Nevada (Fig. 5). Based on these data, it may be inferred that people living in Chaco Canyon obtained their turquoise from three mines in three different locations. One artifact from Casamero, a Chaco-related community structure, was also similar to source material from Mineral Park. An artifact from another nearby site did not resemble any of the mining specimens. Both Mineral Park and Crescent Peak exhibit considerable evidence of prehistoric use and these areas, as well as Cripple Creek, have been known for many years. They can be considered possible sources of prehistoric turquoise for the Chacoans around A.D. 1000-1150.

Other artifacts that Sigleo analyzed came from slightly later archaeological sites near Zia Pueblo, New Mexico. One may have come from the Cerrillos Hills, another from Mine No. 8 in Nevada (Fig. 6). While the first correlation may be relevant because the dating of the site and the sherds found around the Cerrillos Hills fall within the same time range (A.D. 1200-1600), the latter does not because Mine No. 8 was not opened until the 1900s. Based on this evidence, Sigleo (1970:75) concluded that her results were intriguing but not definitive.

Sigleo also used neutron activation to test turquoise artifacts from two archaeological sites. Thirteen of the objects were prehistoric turquoise beads from Snaketown, Arizona (Sigleo 1975). The beads came from the fill of House 8, which dates from A.D. 500-700. Not only could these beads be linked to the Himalaya group of mines (Fig. 7) near Halloran Springs, California, where there is considerable

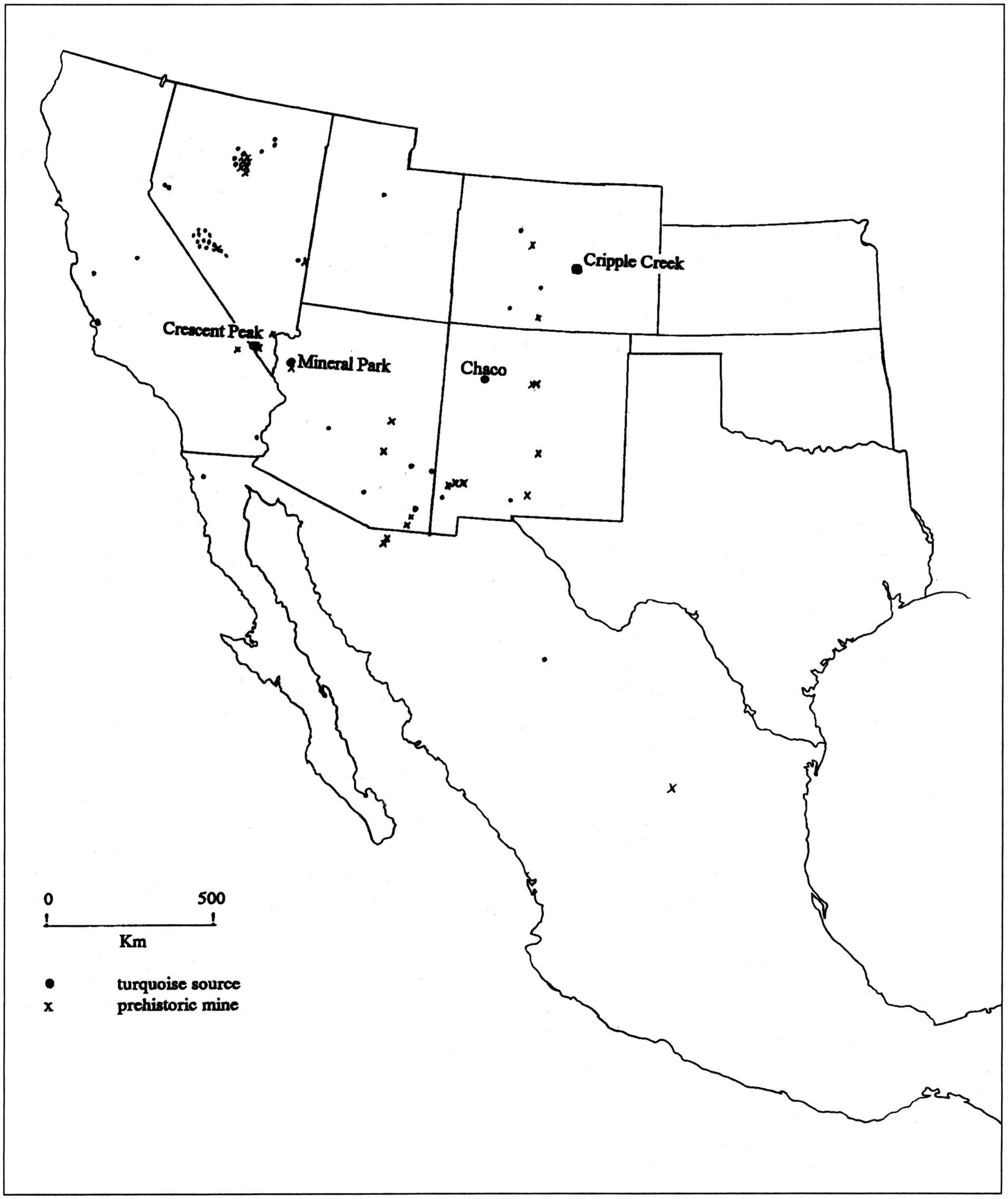

Figure 5. The location of Chaco Canyon in relation to possible sources identified by Sigleo (1970).

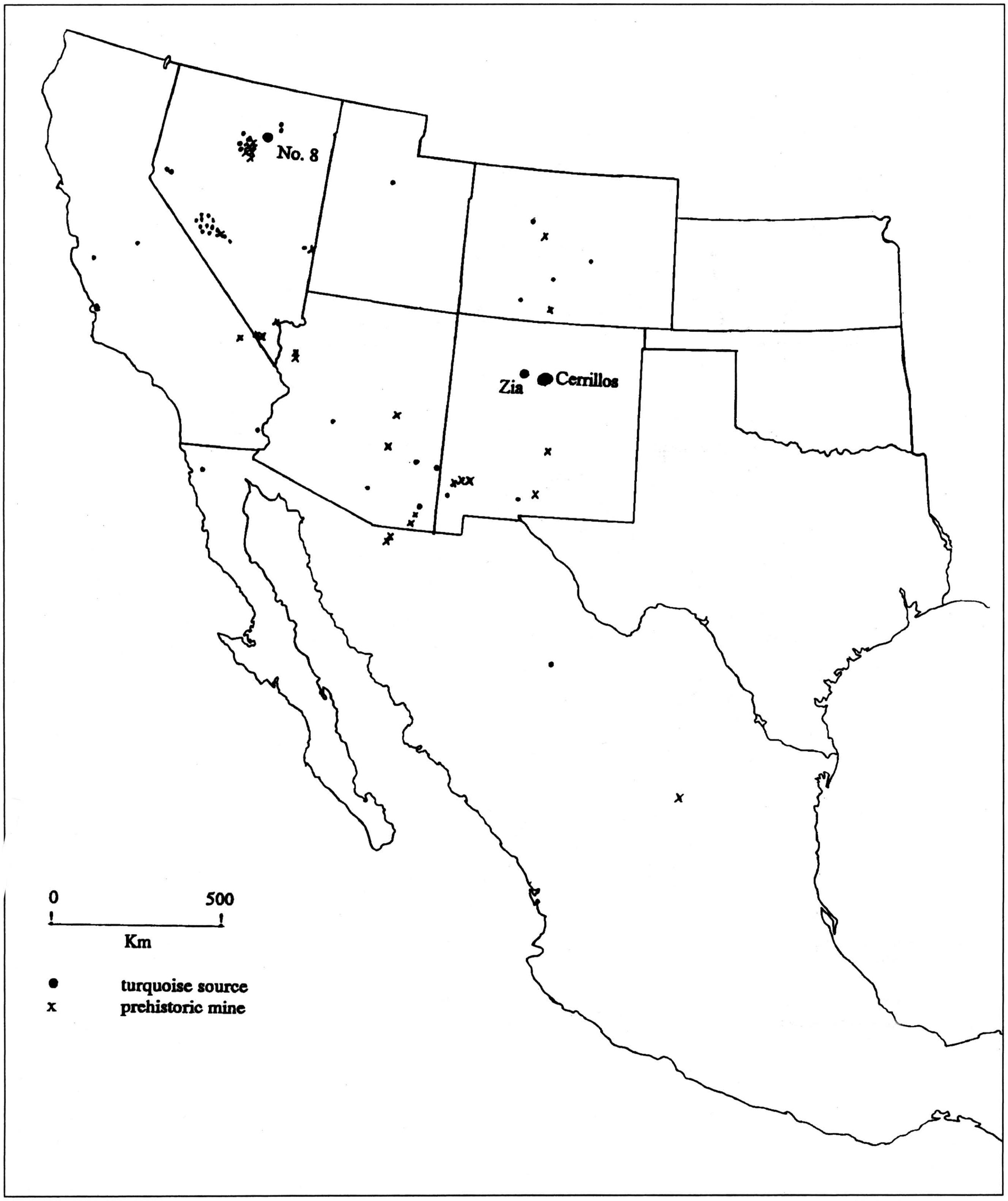

Figure 6. The location of Zia Pueblo, New Mexico, in relation to possible sources of turquoise from nearby small sites as identified by Sigleo (1970).

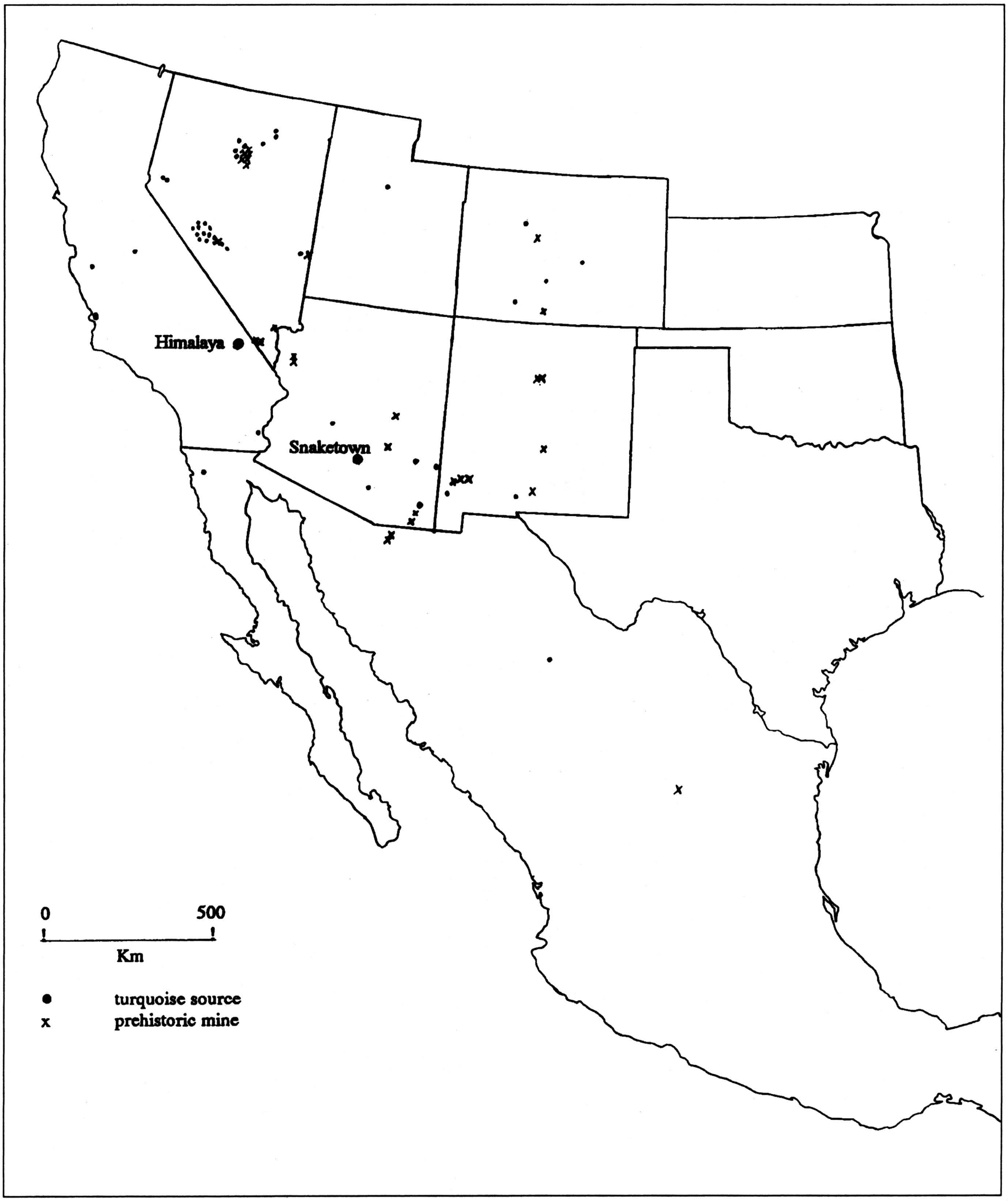

Figure 7. The location of Snaketown, Arizona, in relation to the Himalaya source identified by Sigleo (1975).

evidence for prehistoric mining, but Sigleo was able to separate the beads into two distinct groups that corresponded with two separate mining locations in the Himalaya group.

Di Peso (1974, 2:265, fn. 12, 748-749, fn. 45) reports that Sigleo identified turquoise from a warehouse at Casas Grandes, Chihuahua, as coming from the deposit at White Signal, New Mexico (Fig. 8). The White Signal area is in the Burro Mountains and is one of the closest known prehistoric turquoise sources to Casas Grandes (Sigleo 1970; Weigand and Harbottle 1992). It was within the area attributed to the florescence of the Casas Grandes culture during the period A.D. 1200-1500 (Dean and Ravesloot 1993).

What we learned from Sigleo's analyses is that some prehistoric turquoise beads may have come from sources that show evidence of early mining; the sites and sources that are linked together are sometimes relatively close; and some people (e.g., those living in Chaco Canyon) may have obtained their turquoise from more than one source.

In the early 1980s, Hans Ruppert (1982, 1983) analyzed specimens from mining areas and archaeological sites in both North and South America using an electron microprobe. Not only did he include many more sources and artifacts, but he also identified differences in the chemical element content of turquoise between the two continents. He was confident discussing his South American data. Despite some overlap in the individual chemical elements, source areas could be differentiated based on specific combinations of elements, and many of the artifacts could be assigned to source-sample clusters. He did have some artifacts from South American that did not correspond to any of his source clusters and suggested that they came from sources yet unknown to us.

Ruppert's (1982) results for North America were not as easy to interpret. Altogether he included information on 542 specimens, 462 of which were source samples and 80 were artifacts from numerous sites. He did not discuss specific sources for the artifacts from two Chaco Canyon sites (29SJ629 and 29SJ423), though he did include them in his tables. When I reconstructed the data that included 20 artifacts from these two sites, the specimens grouped in clusters with source material from Cerrillos, New Mexico, Mineral Park and the Courtland-Gleeson area, Arizona, and the King Mine, Colorado (Fig. 9). These results are similar to the evidence provided by Sigleo (1970), and involve some of the same mines. Again, Ruppert had trouble separating those mines and made no inferences because of this problem.

Ruppert suggested a correlation between one artifact from the Mattocks site in the Mimbres area of southwestern New Mexico and some of the artifacts from Chaco Canyon. The Mattocks site specimen differs from turquoise from other Mimbres sites, including one piece from the Galaz site which probably came from the Azure Mine in the Burro Mountains (Fig. 10). Another source area for turquoise found at Mimbres-area sites is the Santa Rita mine in the Little Hachita District of southwestern New Mexico. Ruppert concluded that the data for the Mimbres sites did agree to some extent with an earlier hypothesis of Steve LeBlanc that the Classic Mimbres culture was closely connected with the florescence of the Chaco culture and probably engaged in trade with Mesoamerican groups (Anyon and LeBlanc 1984). He postulated an early trade route through the Mimbres area, which changed during the later Animas Phase when Casas Grandes influenced the people living in the former Mimbres culture area; the supply of turquoise probably changed as well.

A much more extensive and comprehensive neutron activation study of turquoise was undertaken by Phil Weigand and Garman Harbottle using the facilities at Brookhaven National Laboratory. Their work spans several decades and encompasses over 2,000 specimens from about 42 different turquoise sources (28 of which exhibit evidence for prehistoric mining) and numerous sites in Mexico and the United States. The time periods represented include the early use of turquoise, especially in western Mexico where sites with turquoise date from shortly after the time of Christ through the Spanish Conquest. Although a complete report that includes all data on the source specimens and artifacts has not been published, these investigators have provided an early preliminary report, as well as a few site-specific reports and overviews of their project (Bishop 1979; Harbottle and Weigand 1987, 1992; Weigand and Harbottle 1992; Weigand, Harbottle, and Sayre 1977).

The material analyzed from Chaco Canyon included 151 beads, pendants, and raw turquoise from

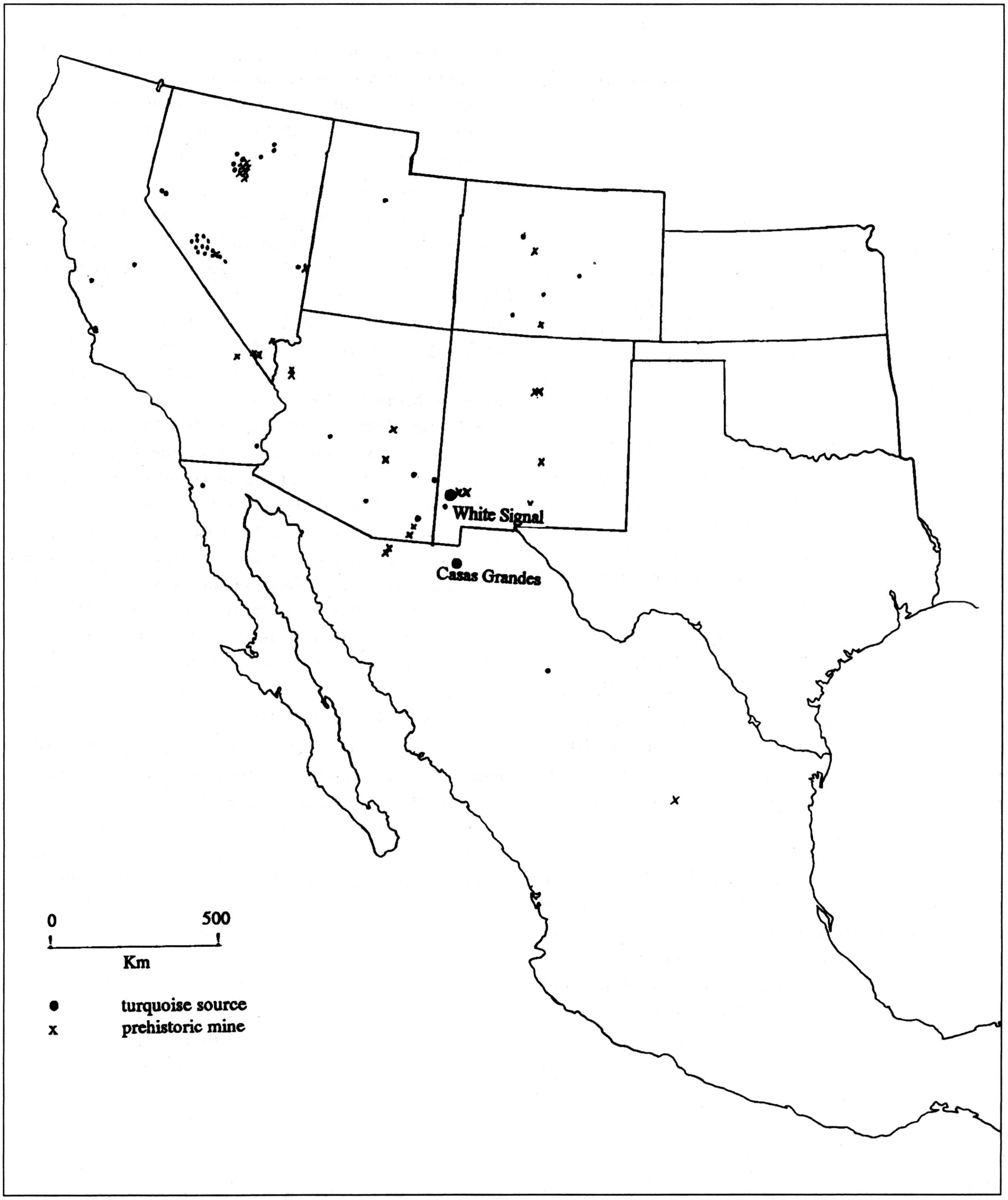

Figure 8. The location of Casas Grandes, Chihuahua, in relation to the White Signal District, a possible source of turquoise (Di Peso 1974).

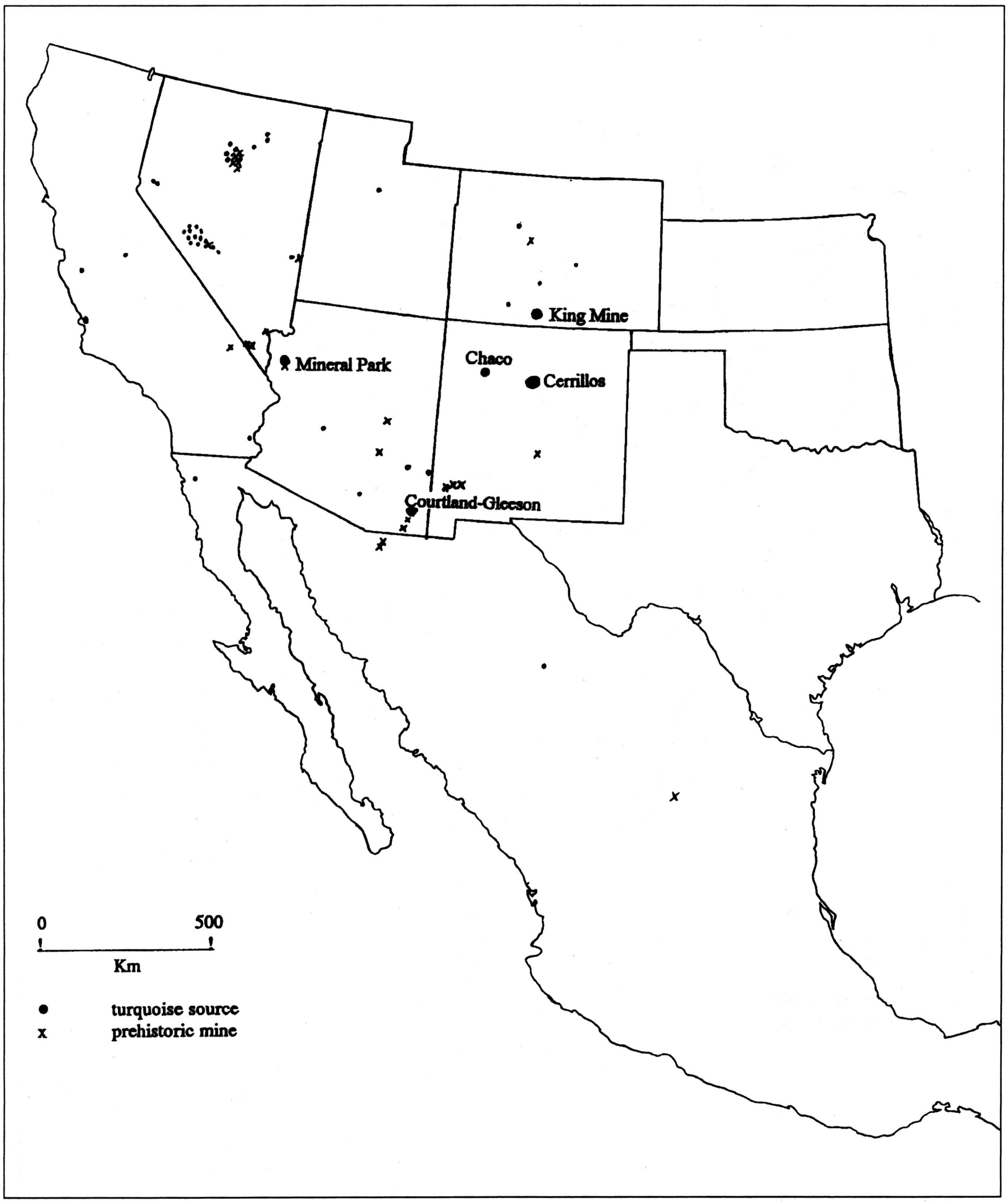

Figure 9. Some mining areas that fell into the same clusters with Chacoan turquoise artifacts (Ruppert 1982:Tables 11 and 12).

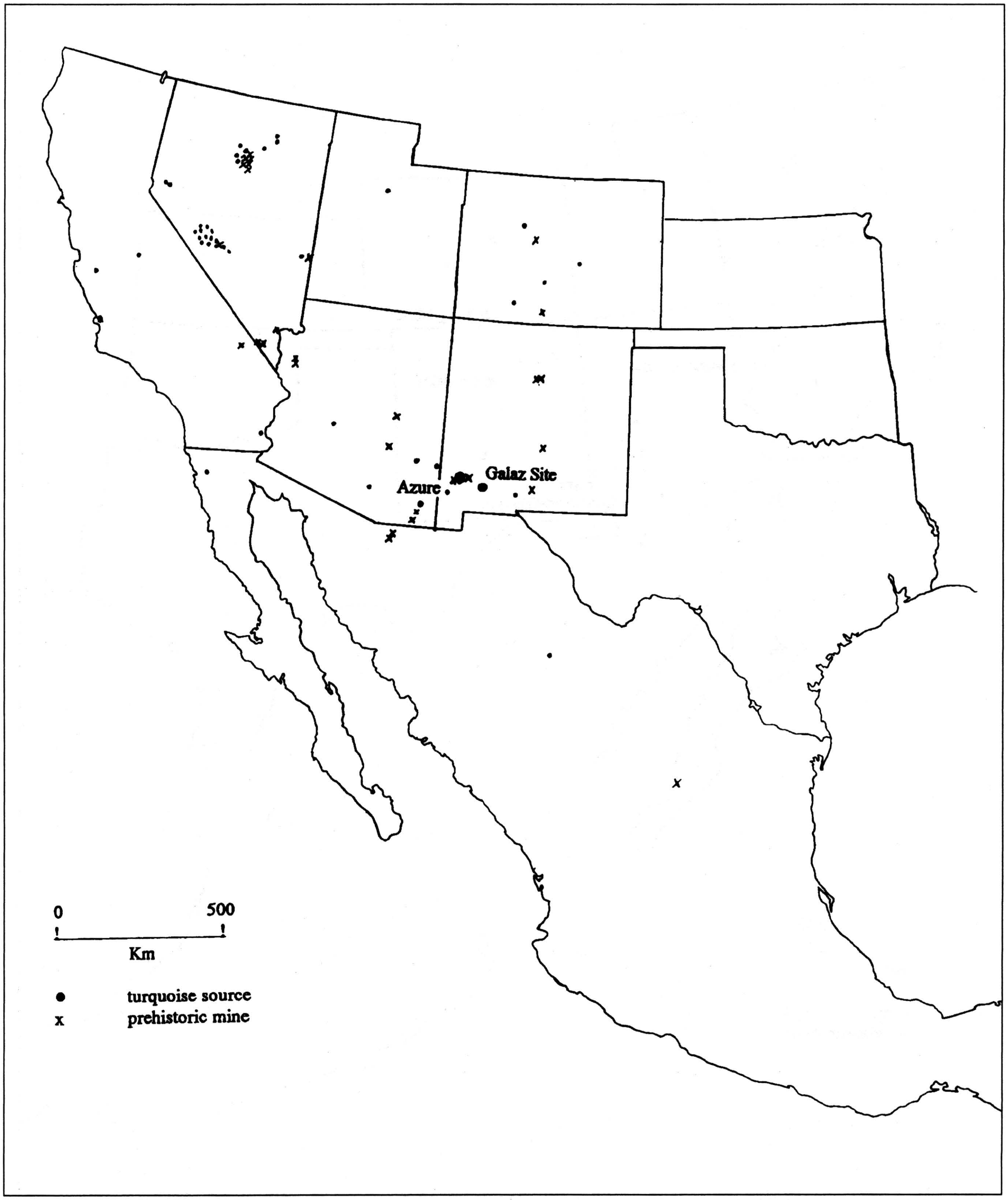

Figure 10. The location of the Galaz Ruin in relation to the Azure mines, a possible source of turquoise identified by Ruppert (1982).

ten archaeological sites dating to ca. A.D. 500-1100. After examining these artifacts, Bishop (1979:4-5; Mathien 1981b) reported that there was relative homogeneity among them with regard to consistent copper values, suggesting a somewhat restricted source area. When compared with other material in their database at the time, some Chaco artifacts could be grouped with artifacts from the site of Guasave in Sinaloa, Mexico (Fig. 11). Some turquoise from site 29SJ629, a known turquoise-jewelry-making site (Windes 1993), showed some similarity to artifacts from Snaketown. Their research was still in its early stages at that time and comparison with source materials was limited, especially for the Cerrillos Hills.

Later, Harbottle and Weigand (1987) had over 1,900 specimens available to them during the analysis of artifacts (including 20 beads) from the San Xavier Bridge site in the Tucson Basin, Arizona. The results linked one series of beads from this site with beads from site 29SJ423 in Chaco Canyon, and other artifacts from San Xavier Bridge were linked with turquoise from several other sites in Chaco Canyon. Harbottle and Weigand (1987:440) also matched one San Xavier Bridge artifact with a bead from Guasave (similar to the data on Chaco), and there were two matches with later sites located along the Rio Grande between Albuquerque and Santa Fe, New Mexico. Only one mine, LA 5028 in the Cerrillos Hills, was considered a reasonable match with one artifact from the San Xavier Bridge site. All these artifacts and the one source sample were assigned to a single cluster in their database.

Other samples from San Xavier Bridge did not fall into such a tight cluster. Some did not match any other sites. Some samples could be matched to turquoise from Snaketown and Chaco, and the source locality of Orogrande in the Jarilla Mountains of New Mexico; or with beads from El Vesuvio in Zacatecas and a source sample from the Azure mine near Tyrone, New Mexico. Other turquoise from San Xavier Bridge linked with one mining sample from Cerrillos and artifacts from several Anasazi sites in Arizona and New Mexico, as well as Casas Grandes; these sites fall into a later period, Pueblo IV (A.D. 1300-1500). Harbottle and Weigand definitely ruled out any matches of San Xavier Bridge artifacts with the Courtland-Gleeson samples they had collected up to that time, but cautioned that additional materials needed to be analyzed.

Although not all their work has been presented in detail, Weigand and Harbottle (1992) indicate specific ties between a number of artifacts from the site of El Vesuvio in the Chalchihuites culture area in northwestern Mexico and the Azure-New Azure mines in New Mexico. An additional number of Pueblo sites from New Mexico hold high potential for having obtained turquoise from the New Azure area. The findings also suggest the Cerrillos Hills as the source for turquoise found at the site of Alta Vista which is part of the Chalchihuites culture.

Weigand and Harbottle (1992) postulate that there were several trade networks operating at different times that involved several turquoise sources in New Mexico, Nevada, and Arizona. They outline three networks that are tied to the Cerrillos Hills:

1. During the Late Classic Period (A.D. 700-900), artifacts link Rio Grande Source Area 1 (source areas 1 and 2 are considered representative of sources in the Cerrillos Mining District) with Snaketown, Arizona, and with El Vesuvio and Cerro de Moctezuma in northern Mexico. Originally assigned to the next period, La Quemada in Zacatecas, Mexico, may now also be added to this group (Nelson 1995).
2. During the Early Post Classic Period (A.D. 900-1200), artifacts link Rio Grande Source Area 1 with Chaco Canyon and Tucson Basin. During this same period, Rio Grande Source Area 2 was linked with Chaco Canyon and the Tucson Basin, as well as Guasave, Sinaloa. Thus, two separate sources in the Rio Grande area provided the turquoise used at sites in both Chaco Canyon and the Tucson Basin.
3. During the Late Post Classic/Pueblo III-IV Period (A.D. 1200-1500), artifacts suggest links among numerous sites along the Rio Grande, including Kuaua, Nambe, Los Aguajes, Cuyumunge, plus Awatovi and Chavez Pass in Arizona; Casas Grandes/Paquime in Chihuahua; Ixtlan del Rio in Nayarit; and Las Cuevas and Zacoalco in Jalisco.

Harbottle and Weigand (1992:84; Weigand 1994:29) also present schematic maps of turquoise trade routes between Mesoamerica and the Southwest in the Formative, Classic, Early Post Classic, Middle

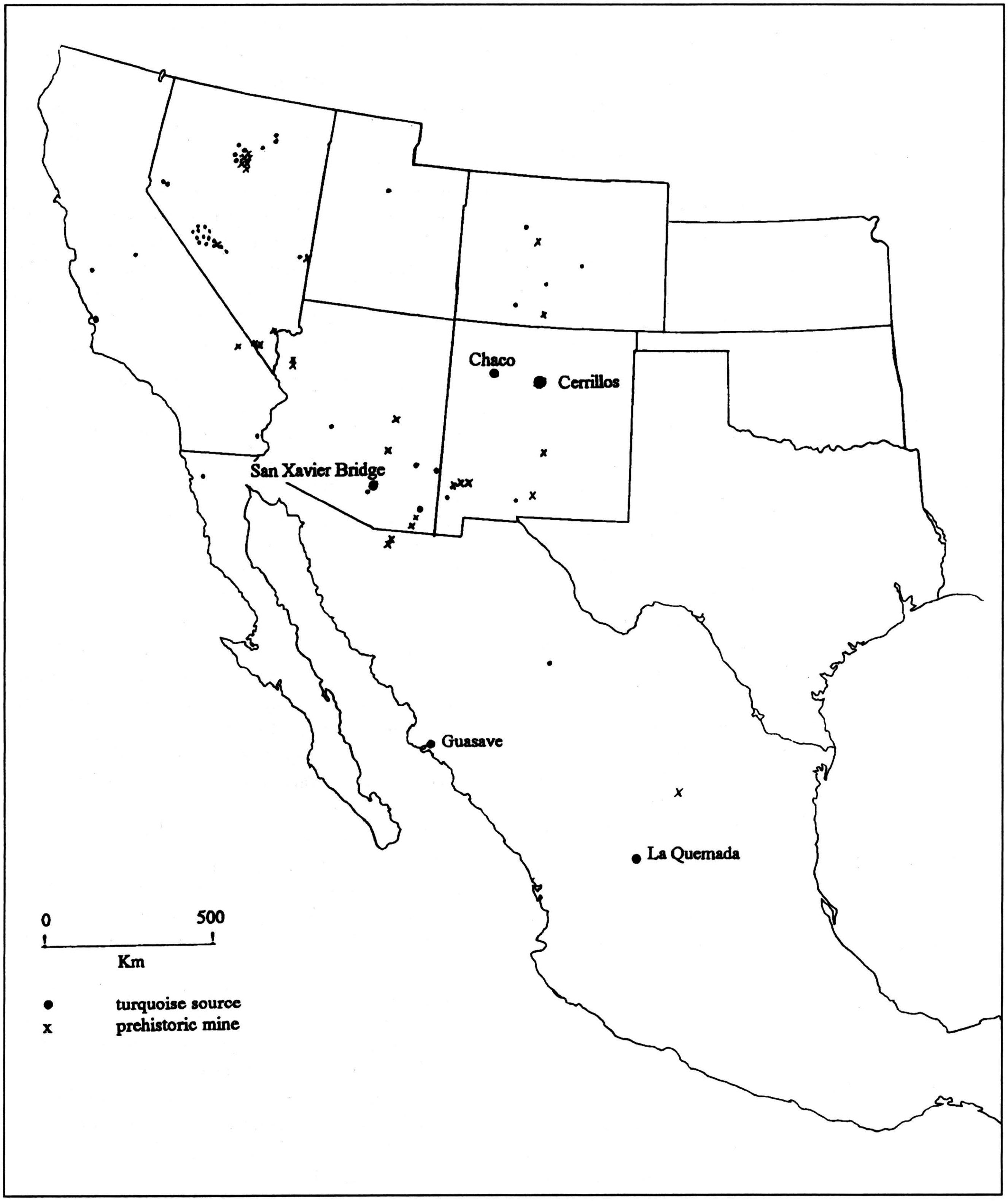

Figure 11. Early Post Classic turquoise trade networks involving Chaco Canyon sites and others in the American Southwest and northwestern Mexico based on Weigand and Harbottle (1992).

Post Classic, and Late Post Classic periods. Links for Chaco Canyon include the Cerrillos Hills, but one possible source in Colorado and one possible source in Nevada are also shown on their maps. These results are not that different from the results obtained by Sigleo (1970) and Ruppert (1982).

X-ray diffraction was used by Welch and Triadan (1991) to compare a turquoise artifact from Grasshopper Pueblo, Arizona, with a turquoise sample from the nearby Canyon Creek mines (Fig. 12). They were able to match these two pieces due to the presence of metatorbenite, a rare mineral found mainly in the area of the Canyon Creek turquoise mine.

IMPLICATIONS OF TURQUOISE STUDIES

Because the amount of information available to archaeologists is constantly increasing, the inferences they make are subject to change. When George Pepper (1909) suggested that turquoise from Pueblo Bonito came from the Cerrillos Mining District, he used only the color of the artifacts and the source specimens, coupled with the distance to turquoise sources, to propose a link between these two areas. At that time, the Cerrillos mines were the best known and also exhibited the most evidence for prehistoric mining. It was a logical conclusion. Because excavated turquoise artifacts had never been found in such great numbers as at Pueblo Bonito and because the Spanish found so much turquoise in use by the Aztec leaders when they arrived in Tenochtitlan (modern Mexico City), another inference about long-distance trade between these areas was made. The known sources of turquoise in Pepper's day were limited to the Southwest and it was only natural that trade networks between these two areas be proposed.

The topic of trade networks between Mesoamerica and the Southwest has been hotly debated for half a century. Based on turquoise and other artifacts, Kelley and Kelley (1975) even proposed that the large ruins in Chaco Canyon are the result of specific interaction between long-distance traders who came up from Central Mexico to obtain turquoise. Chaco was considered the most northerly node on the routes along the Gulf Coast and on the eastern side of the Sierra Madre; the site of Casas Grandes, Chihuahua, was thought to be a major trading center established by members of a trading class who interacted both with the Chacoans and their homelands to the south (Di Peso 1968a, 1968b). More recent evidence indicates that Casas Grandes did not become a key site until the large sites in Chaco Canyon were abandoned (Dean and Ravesloot 1993). Although this evidence negates part of the trade model, we still need to account for the movement of various objects from one area to another.

In his search for answers, Weigand (1994) focuses on mines, miners, and their support systems. He asks numerous questions: Who did the mining at any one mine? How often did they use the mine? How were the miners supported? Did any one group control use of the mine? Was material processed at the mining area? Who used the turquoise once it was mined? Were the turquoise pieces taken back to one area and used there? Were they traded to others? And, if so, before or after being made into beads, pendants, etc.? How much was traded versus kept at the home site? Who did the trading and how often?

The data from the mining areas are still not sufficient enough to indicate specific dates for prehistoric use of all the mines or to identify who mined them, let alone determine if any particular groups controlled them. The Cerrillos Mining District is the best documented, and pottery sherds indicate use by people known as the Anasazi from about A.D. 500 through Spanish conquest. The numbers of sherds dating prior to about A.D. 1275 are few; the majority date to A.D. 1300-1600 (Warren and Mathien 1985). There is some evidence of initial preparation of the turquoise, such as the removal of the matrix, at this source area.

Approximately one kilometer east of the mines is a cluster of six small sites that contain turquoise and mining tools, but very little evidence for agriculture. Wiseman and Darling (1986) propose that these sites were built specifically to house people mining the area and not as permanent self-sufficient habitation sites. The potsherds found at these sites date from A.D. 900-1200 and are typical of those found in Chaco Canyon, in Chaco-related communities to the south in the Mount Taylor area, and at sites to the south of Cerrillos in the Rio Grande drainage. Although these researchers were unable to tie the mines directly to sites in Chaco Canyon, it is not unreasonable to propose at least a link through the Chacoan communities of the Mount Taylor region where two

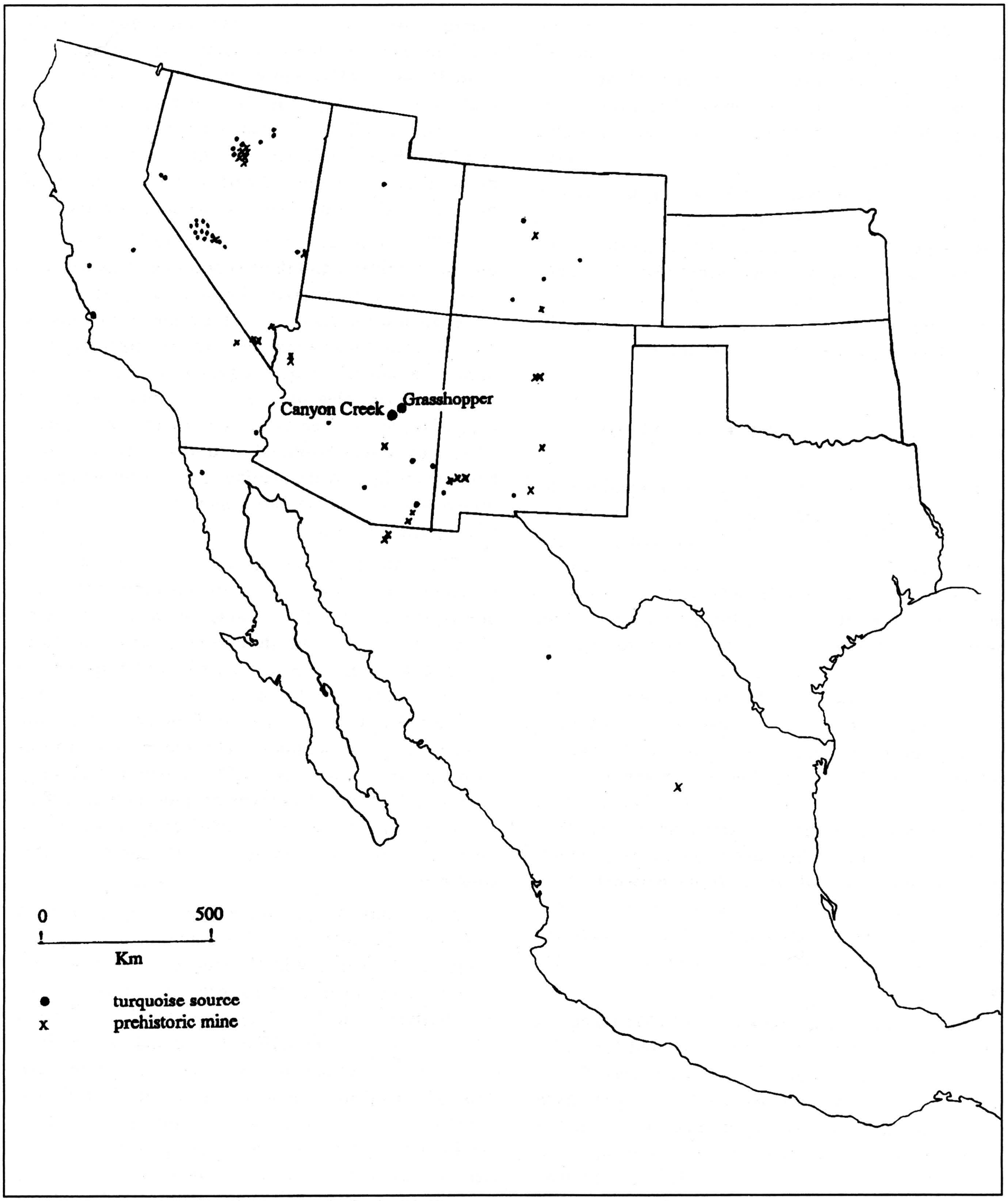

Figure 12. The location of Grasshopper Pueblo and the Canyon Creek turquoise sources identified by Welch and Triadan (1991).

major sites contained evidence of turquoise working, probably jewelry making (Mathien 1981a). Windes (1993) has documented considerable turquoise, including beads, on the surface of small sites in the East Chaco community which date to the A.D. 900s. He proposes that one of the main functions of these sites was the manufacture of turquoise jewelry. Within Chaco Canyon proper, a number of areas where turquoise was worked into jewelry have been identified at large and small sites (Mathien 1984), the majority of them dating ca. A.D. 900-1150.

After A.D. 1300, San Marcos Pueblo was established near the Cerrillos Hills; it may have housed people who mined the area. Unfortunately, the wealth of data for the Cerrillos mines is not available for most other source areas. We still cannot answer many of Weigand's questions–questions that need to be answered if we are to reconstruct a turquoise trade network, especially one extending far south into Mexico.

The studies carried out thus far cannot answer all our questions for several other reasons. First, only a limited number of turquoise artifacts from any one site have been submitted for testing. Given the results for Chaco Canyon alone, where 15,000 pieces were found with just two burials in the same room at one of many sites, how do we know that people in Chaco used only one or a few sources? The studies by Sigleo, Ruppert, and Weigand and Harbottle all indicate that Chacoan turquoise came from several sources that exhibit evidence of prehistoric use.

Second, how do we know who used, let alone controlled, the mining of the various prehistoric sources? Even at the best-documented source area, Cerrillos, New Mexico, the recovered sherd types suggest the prehistoric Puebloans who lived across a broad area of the Southwest, but do not identify which subgroup of people in this large area. For the period prior to about A.D. 1250, the evidence indicates that the miners could have come from the area around Mount Taylor (near Grants, New Mexico), Chaco Canyon, or further south near Socorro, New Mexico. After A.D. 1250, sherds matching those from sites along the northern Rio Grande are more numerous, suggesting more intensive mining efforts during later years.

Third, how do we determine whether the various analytical techniques used are the best ones for the task; e.g., do the various chemical elements that can be discerned by the different tests adequately distinguish the various sources of turquoise? For example, the metatorbenite found at Canyon Creek (Welch and Triadan 1991) has never been reported by other investigators. There are also difficulties in characterizing a source area (e.g., the Cerrillos District [Weigand and Harbottle 1992]), and sometimes researchers inappropriately link an artifact with a source area that was unknown prehistorically (e.g., Mine No. 8 in Nevada [Sigleo 1970]).

CONCLUSIONS

Although the analysis of turquoise beads and other jewelry items provides much needed evidence that can be used to interpret prehistoric lifeways, we have much work left to do. With regard to the identification of turquoise sources, several archaeometric techniques have been tried. Much variation in chemical elements is present in specimens from the same mine and there is a lack of correlation between specimens taken at different depths (Ruppert 1982; Sigleo 1970). Some mines were exhausted prehistorically; others have been destroyed by copper mining. There are limits to the range of chemical elements that can be successfully documented using any one technique (Harbottle 1982). At this time, we cannot be sure that any one procedure will distinguish the various mining districts. As Harbottle (1982) points out, archaeometry is still in its infancy. However, we are now at a point where a critical review of the analytical techniques is needed to determine how best to proceed in our attempts to characterize turquoise sources. A different type of test or a combination of tests may be needed before we can be assured of correct interpretations of the data. It is only when we are certain about our sourcing techniques that we will be able to propose an accurate reconstruction of long-distance turquoise trade networks and the social organizations that sponsored them.

APPENDIX A: TRIALS AND TROUBLES WITH TURQUOISE TESTS

Turquoise is formed as a result of the percolation of copper, aluminum, phosphate, and iron in solution through fissures in bedrock. In its travels, the solution also picks up traces of other elements that become part of the turquoise when the solution mineralizes. Five techniques for detecting these elements have been used with turquoise. Not all of the techniques detect the same trace elements; some are sensitive only to the presence of a few. In addition, one study of lead isotope decay ratios has been carried out.

Spectrometry

An initial spectrometrical test on turquoise beads and pendants from Pueblo Bonito in Chaco Canyon, New Mexico, failed to link artifacts with known sources (Judd 1954:83). Anderson, Stringham, and Whalen (1962:1304-1305), concerned only with turquoise specimens from a copper mine at Bingham, Utah, provide data on nine trace elements and confirmed the usefulness of the method. A third study, using arc emission spectrometry to obtain accurate determinations for eleven elements, revealed definite trends in concentration ratios for the elements barium, cobalt, magnesium, and strontium. Zinc, chromium, nickel, and vanadium were also found to be of interest; the ratio of cobalt to nickel was an excellent indicator of differences among sources (Sigleo 1970).

Sigleo (1970:59-60) examined differences in turquoise specimens from one mine. Her data from Turquoise Hill, Arizona, were so variable that she could not calculate a meaningful mine average for the analyzed elements. Two samples from Battle Mountain, Nevada, taken two inches apart, had nearly identical element concentrations; yet, there was considerable variation in five samples from the same mine, which may represent several sequences of deposition. Samples obtained vertically at 15-m depths at the Santa Rita mine in New Mexico indicated more than one period of turquoise mineralization, but provided no correlation between differences in specimens and vertical depth. Sigleo identified the need for numerous source samples from individual mines to properly determine the characteristics of mineral deposits.

X-Ray Fluorescence

X-ray fluorescence was employed to accurately grade turquoise specimens, especially those that had been dyed or hardened with plastics, as well as to establish that it is a rapid, non-destructive technique that would be useful in determining trace elements (Ronzio and Salmon 1967; Salmon and Ronzio 1962). The analysis of 21 elements in 15 source samples from ten source areas led these researchers to believe that they were able to determine a pattern that was characteristic of the sources of the minerals.

To determine the amount of variability at any one source, 53 specimens from mines in the northern and southern areas of the Cerrillos Mining District were analyzed for 14 elements and the results calibrated as ratios to copper (Mathien and Olinger 1992). No distinction could be made between the northern and southern Cerrillos mines. When the Cerrillos data were compared with specimens from 24 other mining areas, it was not possible to separate these districts. Usually, the counts from Cerrillos encompassed most of those recorded for the other samples.

Electron Microprobe

Ruppert (1982, 1983) analyzed over 1,500 source samples and artifacts from North and South America. Of the 20 calibrated elements, only 12 were selected for inclusion in cluster analyses. Ruppert distinguished deposits on the two continents on the basis of chromium and arsenic content. For South America, the source areas could be characteristically differentiated based on certain element combinations, but for North America the results were less than satisfactory. For example, his 63 source samples from Cerrillos fell into 15 separate clusters, along with samples from other mining areas, including Mineral Park and the Courtland-Gleeson area, Arizona, and the King Mine, Colorado. He was concerned about the reliability of this method to distinguish the various North American sources. Ruppert noted that high cobalt and sulfur, and medium zinc content were more characteristic of the Azure Mine, New Mexico. Four times less zinc was seen in specimens from Orogrande, New Mexico, where some calcium carbonate was also present. No calcium minerals were present in source material from the Little Hachita District or the Courtland-Gleeson area of Arizona. Ruppert's analysis also confirmed Sigleo's observations on the variability in the content of elements at different depths and horizontal loci at a single source.

Neutron Activation

Sigleo (1975) examined her 25 source areas using neutron activation in which 30 elements were investigated. Some elements (gold, barium, lanthanum, lutetium, and iron) varied within mines as much as between them and were not found to be useful.

Ongoing neutron activation studies at Brookhaven National Laboratory (Harbottle and Weigand 1987, 1992; Weigand and Harbottle 1992; Weigand, Harbottle, and Sayre 1977:25-29) analyzed over 2,000 pieces from 28 archaeological sites and more than 40 mining areas in Mexico and the American Southwest. The Azure and New Azure mines, located only 100 m apart, could be easily separated, but at the Cerrillos Mining District, a degree of homogeneity of 10-15% in standard deviation from the mean value could not be obtained. To overcome the latter, artifacts from Pueblo sites in the immediate area of Cerrillos were considered representative of the area (Weigand and Harbottle 1992:168). This *assumption* may not prove true. We await reports of their detailed studies.

X-Ray Diffraction

X-ray diffraction was used to examine a single turquoise sample from the Canyon Creek mines in Arizona and another from the nearby Grasshopper Pueblo. Because the two turquoise samples contained a *rare* copper-uranium phosphate, metatorbernite, known only from this geographical area, Welch and Triadan (1991) concluded that the material from Canyon Creek was probably mined and used by the people from Grasshopper Pueblo.

Lead Isotope Decay

In a preliminary evaluation using stable lead isotope ratios derived from 26 samples from seven mining districts in the southwestern United States and northern Mexico (most from Cerrillos, New Mexico), Suzanne Young was able to separate the Cerrillos mines from all others using a ratio of $^{208}Pb/^{207}Pb$ (Young, Phillips, and Mathien 1994). However, when additional samples from more sources were included, the individual mines no longer clustered tightly (Young 1995:7). Further analysis allowed broad geographical separation, but only areas as large as states could be distinguished (Young, Mathien, and Phillips 1997).

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