MULTISCALAR PERSPECTIVES ON SOCIAL NETWORKS IN THE LATE PREHISPANIC SOUTHWEST

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Analyzing historical trajectories of social interactions at varying scales can lead to complementary interpretations of relationships among archaeological settlements. We use social network analysis combined with geographic information systems at three spatial scales over time in the western U.S. Southwest to show how the same social processes affected network dynamics at each scale. The period we address, A.D. 1200–1450, was characterized by migration and demographic upheaval. The tumultuous late thirteenth-century interval was followed by population coalescence and the development of widespread religious movements in the fourteenth and fifteenth centuries. In the southern Southwest these processes resulted in a highly connected network that drew in members of different settlements within and between different valleys that had previously been distinct. In the northern Southwest networks were initially highly connected followed by a more fragmented social landscape. We examine how different network textures emerged at each scale through 50-year snapshots. The results demonstrate the usefulness of applying a multiscalar approach to complex historical trajectories and the potential for social network analysis as applied to archaeological data.

El análisis multi-escalar de interacciones sociales y sus trayectorias históricas pueden producir interpretaciones complementarias acerca de las relaciones entre asentamientos arqueológicos. Utilizamos el análisis de redes sociales en combinación con sistemas de información geográfica mediante tres escalas espaciales a través del tiempo en el oeste de la región del Suroeste Norteamericano para demonstrar cómo procesos sociales similares afectaron la dinámica de redes en cada escala. El período de interés, A.D. 1200–1450, se caracterizó por la migración y el desorden demográfico. El tumultuoso siglo trece fue seguido por la coalescencia de poblaciones diversas y por el desarrollo de extensos movimientos religiosos en los siglos catorce y quince. En el Suroeste meridional estos procesos resultaron en una red altamente conectada que atrajo miembros de diferentes asentamientos dentro y entre diferentes valles que habían sido previamente diferenciados. En el Suroeste septentrional las redes inicialmente estuvieron muy conectadas pero fueron sucedidas por un paisaje social fragmentario. Finalmente, examinamos cómo diferentes texturas de redes emergieron en cada escala en períodos de 50 años. Los resultados demuestran la utilidad del análisis multi-escalar para investigar trayectorias históricas complejas y el potencial del análisis de redes sociales para el estudio de datos arqueológicos.

Regional analysis is "ubiquitous" in archaeology today with many strands of research (Kantner 2012). We argue that these analyses are at a threshold of new methods and theoretical insights, offering interpretive possibilities that have not been achievable in the past. In particular, approaches that apply both social network analysis (SNA) and geographic information systems (GIS) to large databases provide new ways for archaeologists to think about and conduct regional analyses. They also provide a way of linking traditional ideas about communi-

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ties defined by spatial analyses with communities defined by shared participation in different kinds of social networks (Yaeger and Canuto 2000). In essence, this shifts the perspective from spatial relations to social relations (Knappett 2011).

An important aspect of regional analyses that carries over to network analyses is the utility of a multiscalar approach. Multiscalar approaches, both temporal and spatial, have been applied by archaeologists in diverse ways. More attention has been paid to varying temporal scales ranging from applications of Braudel's (1972) tripartite divisions of social time into individual events, conjunctures, and the *longue durée* (e.g., Knapp 1992), to the concepts of "time perspectivism" (Bailey 1983, 2007; Holdaway and Wandsnider 2008) and "big histories" (Robb and Pauketat 2013a, 2013b). Varying the spatial scale of analysis has also provided new views of archaeological phenomena (e.g., Bevan and Conolly 2006; Clarke 1977; Fisher and Feinman 2005; Gamble 1999; Knappett 2011; Kowalewski 2003; Muir and Driver 2002; Neitzel 1999; Peterson and Drennan 2005).

A number of important themes come out of this work. The first is how each scale of analysis produces different insights into people's interactions. For example, Kowalewski (2003) demonstrated how different kinds of questions were better suited to short- vs. long-term durations, ranging from local interactions to political economies. A second theme is that no matter what scale is being addressed, archaeologists need to keep sight of the fact that materials were produced and consumed by persons within relational contexts. This point is perhaps the hardest to address over millennia, but is one of the major critiques of processual approaches that ignored the human scale while focusing on regional analyses. Even at large spatial or temporal scales, archaeologically recovered materials are the result of depositional histories or accumulations of things, produced in contexts that range from repetitive daily interactions to marked infrequent performances. Spatial and temporal dimensions are just that—axes along which materials are arrayed through our imposition of analytical scale.

In this paper we primarily use multiscalar analyses in the spatial sense to look at how social networks change depending on the geographic frame. We evaluate three increasingly large scales: an individual valley, the southern Southwest, and a larger area that encompasses the U.S. Southwest lying west of the Continental Divide in Arizona and New Mexico (Figure 1). We refer to these different spatial entities as micro-, meso-, and macroscales respectively. Temporally, we explore the period from A.D. 1200 and 1450 and take a dynamic approach by dividing the 250-year period into 50-year intervals. Finally, we take a relational approach by reconstructing social networks based on shared consumption of decorated ceramics. Each spatial scale results in the identification of different crosscutting structures of interaction and each has different interpretive implications, especially when viewed dynamically. Despite their differences, however, these networks offer complementary ways of viewing the historical processes that characterized the Southwest in the late prehispanic period.

The specific questions that we ask of our multiscalar data revolve around the social consequences of migration and its relationship to the emergence of new religious movements. Migration has been an important underlying theme in the archaeology of the North American Southwest, and the late thirteenth-century migrations in the western Southwest have been the subject of many studies over the last two decades (e.g., Bernardini 2005; Clark and Lyons 2012; Mills 2011). Research has shifted, however, from the identification of where and when migration took place to the impact or social consequences of migration (e.g., Neuzil 2008). Some of the material consequences observed after A.D. 1300 include the diversification of religious architecture, an explosion of innovation in the production of polychrome ceramics, an artistic corpus that includes ideologically charged designs on ceramics and buildings, specialized multicraft production, and increasing social scales of communal feasting (Adams 1991; Crown 1994; Glowacki and Van Keuren 2011; Hays-Gilpin and Schaafsma 2010; Mills 2007a, 2007b; Potter 2000).

Not all of the above changes happened in all areas or at the same time, and the specific role of migrants in these transformations is still being investigated at the local level. Nonetheless, within two or three generations after migration there

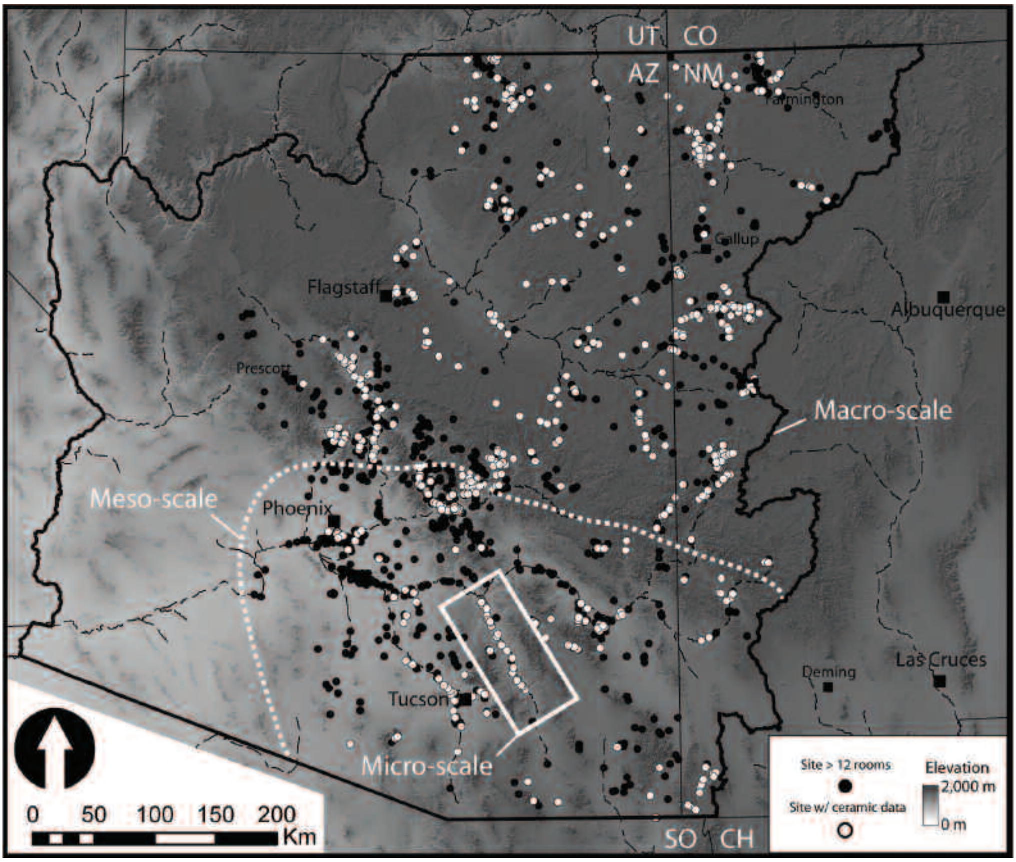

Figure 1. Overall project area with micro- meso- and macroscale areas delineated.

were major transformations in religious organization in the Southwest, including the Katsina religion in the northern part of our study area (Adams 1991) and the Salado ideology or religion in the south (Crown 1994). Our analyses focus on the changing network structures before, during, and after the major period of migration in the late thirteenth century and their relationship to the transformation and spread of new religious organizations of the fourteenth century. We show how a multiscalar network approach provides a new perspective on the impact of migrants on communities at each scale, and especially on the interpretation of the Salado "horizon style," which we interpret as evidence for a socioreligious movement (e.g., Edelman 2001).

A more general goal of exploring our networks at multiple scales is to illustrate the flexibility of network boundaries. The issue of boundary specification has been much discussed by sociologists in the application of social network analysis (e.g., Laumann et al. 1992). While there are often natural boundaries to social groups, networks "have no 'natural' boundaries" (Borgatti and Halgin 2011:2). That is, they are dynamic and situational, and different scales will have different network structures. Thus, understanding how network connectivities may shift at different scales is important for the application and interpretation of network analyses.

In this article we use SNA to investigate the effects of migration on networks at different scales, especially on networks based on decorated ceramics that are ideologically charged and represent the best material markers archaeologists have for tracking the development of new religions. We further seek to better understand the interrelationships of spatial and social scales in archaeological analysis and interpretation more broadly.

Social Network Analysis and Archaeology

Social network analysis focuses on the relations between a set of entities rather than the intrinsic properties of the entities themselves (Carrington et al. 2005; Newman 2010; Newman et al. 2006; Scott 2000; Wasserman and Faust 1994). In SNA, there are two primary data categories: nodes (or vertices), which are the social entities being considered, and edges (or ties), which represent relationships between nodes. Social network analysis approaches use tools first developed in the mathematical field of graph theory to formally explore the structure of relations among social entities. This includes characterizations of the network's structure (e.g., density, diameter, and so forth) as well as the identification of key actors (represented by nodes) using various measures of centrality, which define the relative structural importance of each node in the network (Borgatti 2005). The theoretical underpinnings of SNA rest in a long tradition in sociology and anthropology linking specific kinds of social relationships to general outcomes for individuals and larger groups. In recent decades these approaches have been formally grouped under the general heading of "relational sociology" (Donati 2011; Emirbayer 1997; Mische 2011). A key tenet of relational sociology is that the structure of social relations among individuals or groups is a primary factor driving the distribution of resources (including both materials and influence) among all actors within a network (Borgatti and Haglin 2011; Wellman 1988). Within this theoretical perspective, relations (ties) and the social units of analysis (nodes) are given equal weight, as both are required for a complete characterization of a given social setting (Emirbayer and Goodwin 1994). This model suggests that the structure of relations among actors can fundamentally influence the potential for and trajectory of major social changes at various scales.

A growing body of archaeological applications demonstrates SNA's utility in addressing research questions with broad anthropological relevance, especially when integrated with GIS-based spatial analyses. These include explorations of how social connections diverge from expectations based on distance and geography; the changing network topologies or structures as a result of demographic processes such as migration; how well or poorly connected particular settlements are within the network; and how settlement attributes, such as proximity to roads, the presence and type of public architecture, and other nodal attributes correlate with network position and centrality (Brughmans 2013; Collar 2007; Coward 2010; Golitko et al. 2012; Hart and Engelbrecht 2012; Irwin-Williams 1977; Knappett 2011, 2013; Mills et al. 2013a, 2013b; Peeples 2011; Peeples and Haas 2013; Sindbæk 2007).

Archaeologists working with textual data have the benefit of establishing relations through data from sources such as inscriptions (e.g., Munson and Macri 2009), but many researchers must grapple with other ways of establishing connections through more indirect means such as intervisibility, material culture, or simulations (Brughmans 2013; Knappett 2013). Rather than looking at spatial relations, such as intervisibility, or simulation of networks, the approach taken here focuses on social relations measured by the intensity of social interaction through material culture. It has long been recognized by anthropologists that individual households are distributed across settlements (Netting et al. 1984), socially defined communities are not equivalent to settlements (Canuto and Yaeger 2000), and exchange relationships link physically distant as well as close neighbors (Wiessner 1982). These relationships result in distributions of materials that often do not correlate with spatial variables because the exchange of both goods and information (including technological practices) is heavily influenced by social factors associated with different networks of interaction. Thus, network analyses allow archaeologists to look at similarities that are not constrained by traditional space-based distributional approaches. In fact, the degree to which social relationships, as defined by material culture similarities, do or do not correspond to spatial propinquity is one of the more interesting questions that can be addressed using archaeological data. It is also one that holds broader interest in network science more generally (e.g., Garaganova et al. 2012), and represents an area to which archaeology can contribute.

All network approaches seek to characterize relationships among entities, but formal network analyses take advantage of a suite of quantitative methods for describing social structure (e.g., Wasserman and Faust 1994). Network approaches have a long history in archaeology (Irwin-Williams 1977; Peregrine 1991; Terrell 1977), and the frequency of archaeological applications has increased significantly in the last several years. Recent use of these network analyses in archaeology shows their high research potential in clearly revealing complicated patterns of large-scale interaction in a robust and replicable manner (e.g., Brughmans 2013; Golitko et al. 2012; Knappett 2011, 2013). They also allow archaeologists to examine interaction at different scales to understand how social processes play out among different sets of nodes, whether the nodes are households, settlements, or settlement clusters.

Knappett's (2011) recent work has highlighted how a network approach applied to archaeological material is always multiscalar by virtue of the way that connections are constructed. At the smallest scale, he shows that objects/things and people are connected through the ways in which materials enter into the proximate or face-to-face interactions between people. At the next largest scale he points out that artifacts were made within communities of practice in which learning was an active part of technological reproduction and innovation processes that were repeated and shared by multiple households. These transmission processes produce affiliation networks defined on the basis of "joint participation in daily practices" (Knappett 2011:105). At the largest scale, he advocates looking at the connections among settlements through sets of things and through the cumulative effects of human engagement with things. At this scale, there is more emphasis on consumption—in differences in use and discard of different kinds of goods, especially ceramic vessels, within and between sites. So for example, there may be a "community of practice in feasting" that emphasizes commensalism and results in distinctive assemblages at the regional scale. Knappett's perspective is important in linking the artifact with the assemblage, the local with the regional, and practice with history. Such a perspective provides a theoretical and practice-based link among multiple scales. In our analyses we focus on multiple regional scales, which all would be placed in Knappett's "macroscale"—but in all cases they are created by social practices carried out at each of his smaller scales.

Constructing Network Connections

We use data from the interdisciplinary Southwest Social Networks (SWSN) Project, which added material culture to an existing database of settlements known as the Coalescent Communities Database (CCD) (Hill et al. 2004; Wilcox et al. 2003). The CCD contains information on a large proportion of settlements with more than 12 rooms and dating to A.D. 1200–1550 across the Southwest—including settlement location, number of rooms, and data ranges—and has been instrumental in exploring demographic changes across the region.[1] Data collection included compiling ceramic frequency data from published and unpublished survey and excavation reports; combing through archives to find analysis sheets from unreported excavation projects; amassing electronic and hard copy inventories of ceramics provided by numerous archaeologists; and conducting new analyses of ceramics in museum collections and new fieldwork, including site relocation and infield recording. The database represents the contributions of dozens of archaeologists from many different institutions based on decades of work in the Southwest. A large percentage of the sites we include were excavated as part of cultural resource management projects and account for tens, if not hundreds, of millions of dollars of federal, state, and local funding.

For the 2,784 sites known in the project area (equivalent to our macroscale analyses) we were able to compile ceramic data for 711 of these sites (accounting for approximately 25 percent of sites in the CCD occupied during each 50-year interval). Of these, 590 sites have systematically collected data on decorated ceramics available—i.e. screened excavation contexts or controlled surface counts of all sherds for a specified sample area. In addition to ceramic data, we conducted new analyses and compiled preexisting data on geological sources for over 6,000 pieces of obsidian through X-ray fluorescence (XRF) analyses (Mills et al. 2013a; Shackley 2005) and recorded the presence of public architecture for each settlement. The SWSN ceramic database currently contains over 4.3 million ceramic artifacts, of which we use those that are classified as decorated (slightly less than one-quarter of the total) for this article. In general, non-decorated (non-painted) ceramics such as various red wares, corrugated wares, and plain wares are not as systematically defined and consistently typed as decorated wares throughout the project area and hence are difficult to compare among site assemblages or use to reconstruct networks, especially at the meso- and macrolevels.

Our approach to social network analysis relies on similarities in the consumption of ceramics (i.e., Knappett's [2011] "macroscale"). We use wares rather than the smaller category of ceramic types because wares are less subject to interanalyst variation and can be identified for most sherds.[2] Decorated ceramics for the period of interest (A.D. 1200–1450) include a wide variety of bichromes and polychromes. A combination of attributes defines decorated wares, including tempering material, paste color and texture, surface treatment, and paint type(s). The use of decorated wares to look at interregional social interaction in the Southwest has a long history (Blinman and Wilson 1993). For example, Rautman (1993) used wares to look at directionality of interaction and resource stress. Duff (2002) inferred both intraregional and interregional interaction in the Upper Little Colorado area and between this area and surrounding regions from ware data. Spielmann (2006) also used wares at the regional scale to study Pueblo IV period settlement clusters, distinguishing between emergent and integrated clusters based on ware diversity. Diversity of wares has been used in recent work comparing multiple areas of the Southwest (e.g., Hegmon et al. 2008; Nelson et al. 2011). We differ from the latter studies in our use of SNA techniques, based on the relative frequencies of wares, rather than diversity measures such as richness, but share a focus on decorated wares. In fact, several of these project data sets are now part of the SWSN Database.

Similarities in the wares found in sites' ceramic assemblages are not random but result from two general processes—the flow of goods and the flow of ideas about how to make and use those goods. In the Southwest the former occurred most often through exchange, although migrants may have carried small numbers of goods during resettlement (Zedeño 2002) and some vessels may have been transported by pilgrims (Toll 2001). Processes of transmission responsible for the flow of ideas about how to make and use ceramics include migration, the movement of potters through marriage networks, and participation in shared ideologies or emulation. Although it is difficult to parse out the relative contributions of the flow of goods and the flow of ideas in creating ceramic assemblage similarities, a large body of previous compositional analyses provides information on those wares made in a few locations vs. those made over broad areas. For example, Jeddito Yellow Ware was produced in only a few Hopi villages, and its widespread occurrence outside these areas most likely stemmed from exchange (Bernardini 2007; Bishop et al. 1988), while Salado polychromes were made in most areas within a broad area of the central and southern Southwest (Crown 1994) and their similarities reflect the flow or diffusion of ideas. As this example demonstrates and as we discuss below, some of the strongest similarities in ceramic assemblages are due not to the exchange of goods, but rather the transmission of ideas, resulting in shared communities of practice in the production and consumption of ceramics across a large area of the Southwest.

In addition to the movement of goods and transmission of ideas, similarities in the relative frequencies of wares found in ceramic assemblages are the result of shared consumption and discard patterns. We do not equate shared communities of practice in consumption with direct one-on-one social interaction. While the similarity measure cannot be interpreted as a literal probability of interaction between communities, greater similarities in assemblages instead indicate higher probabilities for shared affiliations in communities of practice. People had choices about the kinds of ceramics to use, and decorated ceramics are especially visible indicators of shared communities of practice in consumption. Decades of archaeological and ethnoarchaeological research has shown that these relationships do not necessarily track linguistic or cultural groups (e.g., Gosselain 2000) and our goal is not to define cultural group boundaries. Instead, we view the similarities as reflecting the likelihood of social interaction between settlements based on cultural, economic, religious, and/or political relations. In the small-scale to middle-range societies of the Southwest during the interval of interest, many of these relations may have been closely intertwined.

To analyze ceramic assemblages through time, sherds in each site assemblage were divided into 50-year intervals using methods developed by Roberts and others (2012). This procedure allows for the comparison of sites with different occupation spans and ceramic production spans. Three different variables underlie the apportionment process: (1) the occupation span of the site; (2) the production span of the ceramic category, in our case the ware; and (3) the demographic curve of the site for those that were occupied for more than 50 years. Site occupation spans and demographic curves follow those created by Hill and his colleagues (2004) for the Coalescent Communities Database, with updates from more recent fieldwork. In general, settlement growth is modeled as a more gradual process than site depopulation. Production spans for each of the 88 ceramic wares (and 591 types within wares) in the SWSN Database were compiled for this project. We represented the popularity of each ware over its production span by normal curves (Roberts et al. 2012; Mills et al. 2013a, 2013b).

For each 50-year interval, we then produced a matrix of similarities between each pair of sites occupied during that interval using the frequencies of different ceramic wares in each apportioned assemblage. The similarity measure is a modified version of the Brainerd-Robinson (B-R) coefficient of similarity (Brainerd 1951; Robinson 1951).[3]

Our similarity index ranges between 0, indicating no similarity, to 1, indicating perfect similarity, and is used to both define and weight ties between settlements, to look at different network properties, and to understand the position of nodes in the network at each scale using different measures, such as centrality. For the purposes of network visualization, for which clarity of graphical displays requires binarization, we defined ties between all sites that shared greater than or equal to 75 percent (B-R score of .75) of their ceramic ware frequencies in common.[4] Importantly, however, we calculated a measure of eigenvector centrality, shown by the relative size of nodes in these figures, based on the original weighted (unbinarized) data (Peeples and Roberts 2013). The resulting ties, based only on the strongest similarities among pairs of sites, may be regarded as those settlements with the highest probabilities of having shared connections. We do not argue that a connection between two settlements implies that each individual in one settlement directly interacted with individuals in the other. Instead, the similarity index highlights pairs of settlements that most likely shared connections, particularly the kind of connections that would result through shared communities of practice in ceramic use and discard. Eigenvector centrality is a frequently used measure of the relative importance of nodes in directing and receiving flows across a given network. This network statistic recursively assigns centrality scores so that a node is central to the extent that it is connected to other highly central nodes (Bonacich 1972). This measure is particularly appealing for archaeological analyses in that it assumes that a given node can influence all other nodes simultaneously, rather than only through first-order ties (Bonacich 1972; Mills et al. 2013b).[5]

Multiscalar Network Analyses

Our multiscalar approach entailed construction of networks at three different spatial scales: (1) the microscale, which we illustrate here with settlements in the northern San Pedro Valley, a linear and geographically circumscribed area in southeastern Arizona; (2) the mesoscale, which is equivalent to the southern Southwest's basin-and-range physiographic province including much of the Hohokam culture area; and (3) the macroscale, which is our entire project area (Arizona and New Mexico west of the Continental Divide) and includes the Hohokam, western Mogollon, and western Ancestral Pueblo areas (Figure 1).[6]

Microscale Analysis: San Pedro Valley

The San Pedro Valley in southeastern Arizona is one area that we have analyzed extensively through network analysis (Mills et al. 2013b). One of the reasons for this focus is that nearly all large, late Prehispanic period archaeological settlements in its northern portion (n = 27) were consistently sampled and analyzed (Clark and Lyons 2012; Figure 2). The northern San Pedro Valley also is the location of well-documented irrigation communities occupied by the "first

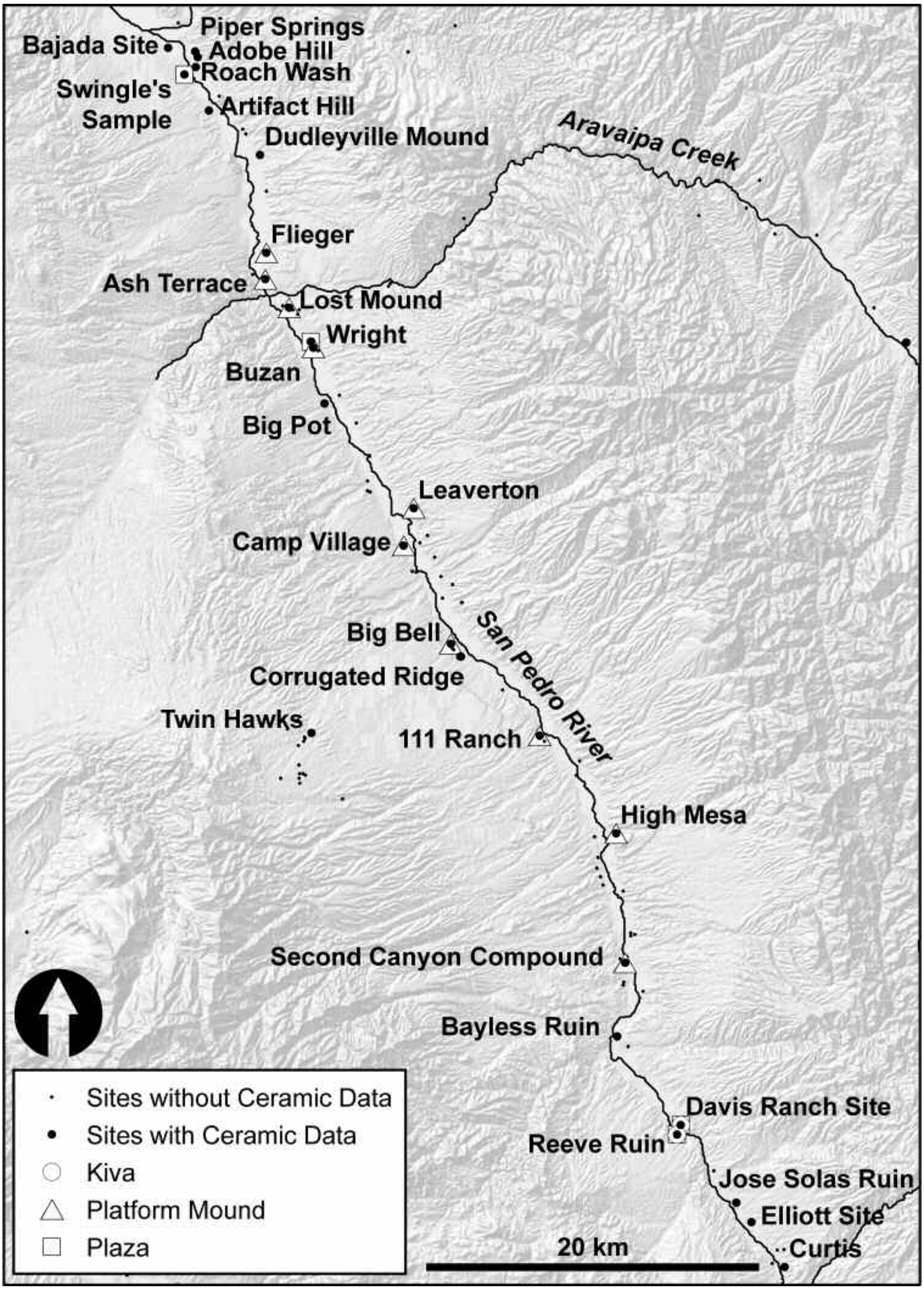

Figure 2: Map showing the location of the settlements in the San Pedro Valley. (Figure: 8.1 from Ch. 8 "The Dynamics of Social Networks in the Late Prehispanic US Southwest" by Barbara J. Mills et al. from *Network Analysis in Archaeology: New Approaches to Regional Interaction*, edited by Carl Knappett [2013], © and by permission of Oxford University Press, USA.)

comers" or hosts, and others that were built somewhat later by Kayenta area migrants who moved from northeastern Arizona in the late thirteenth century (Di Peso 1958; Haury 1958). The non-migrant, "first comers" constructed residential compounds and built ceremonial platform mounds within them (Clark and Lyons 2012). The platform mounds may even be seen as a direct response to the new settlers—a ratcheting up of architecture to mark claims over agricultural territory within a multiethnic context. Local potters in the host settlements, especially those located in the fertile Aravaipa district, where the Aravaipa Creek joins the San Pedro River, produced San Carlos Red-on-brown—the dominant decorated ceramic for the area in the late A.D. 1200s (Lyons 2012).

Migrant villagers lived in pueblos, constructed kivas, and produced most of the Salado polychromes found in the valley, especially in the early 1300s (Clark and Lyons 2012). Based on petrographic analyses, Lyons (2012:306–308) concluded that later Salado polychromes made at migrant settlements circulated to local villages that had formerly made San Carlos Red-on-brown. This would suggest that associated Salado ideology was initiated by the migrants and their descendants, but was ultimately adopted by the host populations. The two groups appeared to have co-resided at several sites that were probably built after A.D. 1350. These late "mixed" settlements are near the Gila confluence in the Dudleyville district at the north end of the valley. Many appear to have been built after San Carlos Red-on-brown was in decline, and at least one of these late settlements (on the west bank) produced Salado polychromes. The evidence for locals is largely based on rock-reinforced adobe walls and perhaps cremation burial. The evidence for migrants is based on room block layout, perforated plates, and possible Salado polychrome production. By this time obvious ceremonial architecture (kivas or platform mounds) is not apparent with the exception of small plazas.

With this history as a backdrop we can look at how decorated ceramic networks correspond to this reconstruction. Figure 3 shows four decorated ceramic networks for the San Pedro valley, corresponding to the A.D. 1200–1250, 1250–1300, 1300–1350, and 1350–1400 periods (the sample of sites after A.D. 1400 is too small for SNA and the valley was largely depopulated by ca. A.D. 1450). The node size reflects eigenvector centrality and node shape indicates the kind of public architecture present: platform mounds, plazas, or kivas. Platform mound sites are the host communities while kivas are present at migrant sites. For these and all network diagrams, nodes are represented in social space, not geographic space.

Several key changes in the San Pedro Valley networks can be identified from these graphs as well as from their associated eigenvector centralities (Mills et al. 2013b:Table 8.1). First, in contrast to the open network of the A.D. 1200–1250 and 1250–1300 periods, the networks of later periods (following the Kayenta migrations of the late A.D. 1200s) are more densely connected. Migrant settlements became increasingly central within the social networks over time; at least in part because they were occupied by potters who produced Salado polychromes, a widely distributed ceramic ware consumed at settlements throughout the valley. By the late 1300s, all settlements had roughly equal percentages of Salado polychromes, whether they made them or not, indicating a shared community of practice in terms of consumption throughout the valley.

Second, neither spatial nor demographic centrality is a reliable predictor of social centrality within the valley. The settlement with the highest eigenvector centrality in the earliest two periods is Ash Terrace, a local platform mound settlement located at the northern edge of the demographic center of the valley during the thirteenth century (Clark et al. 2012:Figures 6.9 and 6.15). Importantly, Ash Terrace is located in the best-watered part of the valley, where the Aravaipa Creek contributes significant moisture to the San Pedro River, and it is within the district where San Carlos Red-on-brown was produced. Another highly central site in this area is Flieger, also the largest settlement in the region for much of the sequence. High agricultural productivity does seem to be closely tied to social centrality in these two cases. But another local site with high centrality, High Mesa, is, as its name indicates, located well above the valley floor and in an area without notably abundant water resources. Its high centrality may be related to the presence of a cluster of rooms inhabited by migrants. Later, migrant sites became

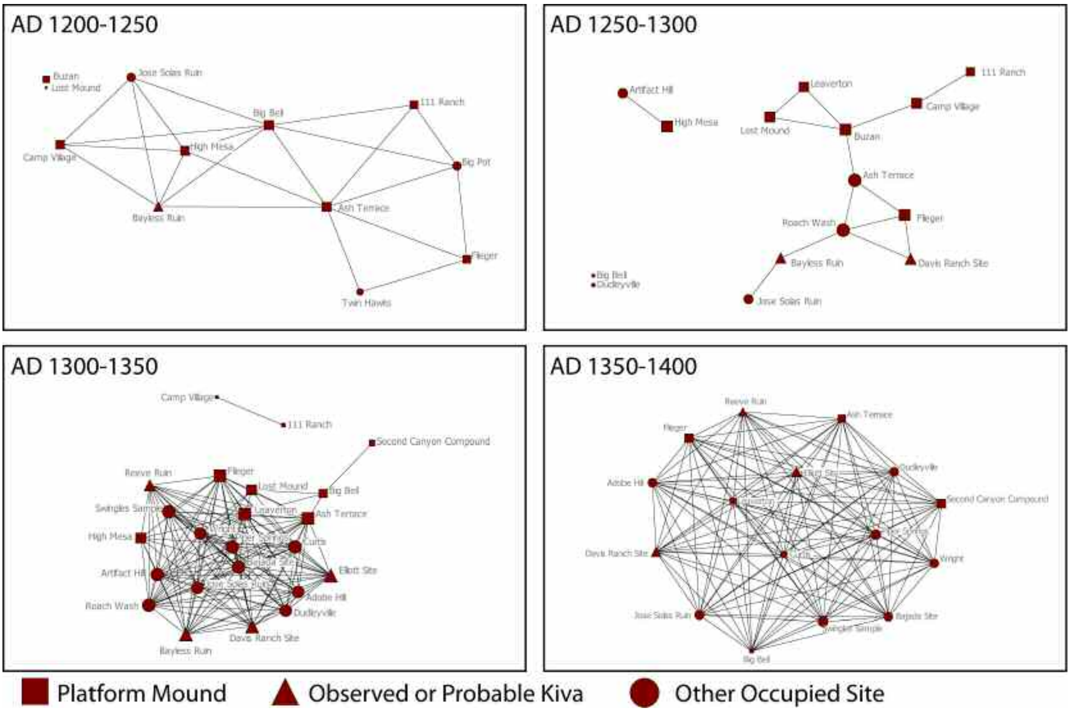

Figure 3. Network plots of San Pedro Valley sites: A.D. 1200–1250 (density = .333), 1250–1300 (density = .133), 1300–1350 (density = .609), and 1350–1400 (density = 1.0). Node size indicates eigenvector centrality and node shape the presence and kind of public architecture.

as central as local sites within the valley, even though the two best known (Davis Ranch and Reeve Ruin) are at the southern edge of the populated zone in the valley. Several sites with probable migrants (e.g., Elliott, Bayless Ranch Ruin, and José Solas Ruin) also have centrality scores that exceed "first comer" sites such as Flieger and Ash Terrace. As with the migrant enclaves at Reeve Ruin and the Davis Site, these sites are all likely producers of Salado polychromes.

Third, many of the sites with early high centrality scores were also those that persisted longest. Again, both Ash Terrace and Fleiger are good examples. Through time, however, migrant settlements became increasingly central within this network, and the relationship between persistence and centrality is weaker in later periods. In fact, some of the most socially central sites in the valley at the end of the sequence were founded later and included residents descended from both migrants and their original hosts (e.g., Adobe Hill, Roach Wash, Swingle's Sample, and the Bajada Site).

Mesoscale Analysis: The Southern Southwest

At the "mesoscale" we consider connections among sites across much of the broader basin and range zone of the southern Southwest (Figure 1). This incorporates the area known as the greater Hohokam region, including the San Pedro Valley discussed above, but also those valleys and basins lying south of the Mogollon Rim (a major physiographic boundary) in southern Arizona and New Mexico.

The mesoscale analyses of the southern Southwest show how changing the spatial scale influences network topology. During the period of migration, from A.D. 1250–1300, each valley system was distinct (Figure 4). Despite this distinctiveness, the sparsely connected network (i.e., fewer ties per settlement) of the San Pedro Valley can be contrasted with the dense and closed networks in the Tucson and Phoenix basins. Outliers, or settlements not strongly connected to any other settlements and shown on the left side of the graphs, are almost all villages without platform

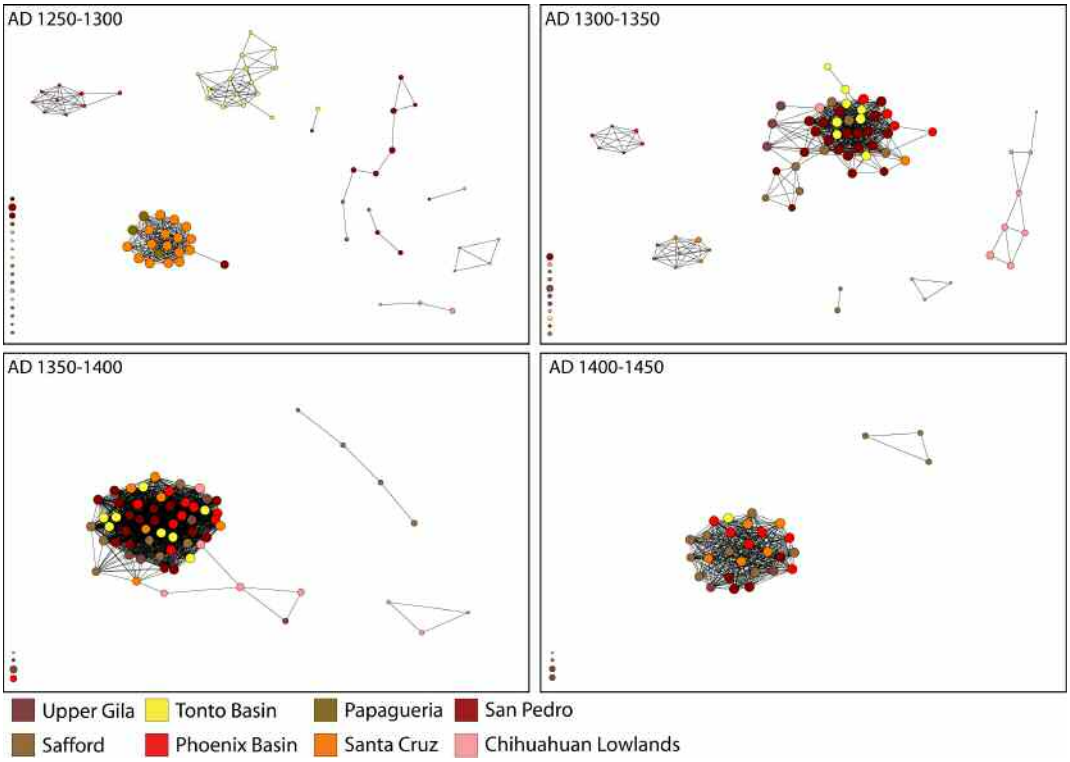

Figure 4. Series of mesoscale (southern Southwest) network analyses. Colors indicate different geographic areas and node size represents eigenvector centrality. Nodes to the left represent outliers to the network.

mounds. At least in terms of relations based on painted ceramics, those villages that did not have public architecture were on the margins of all networks, regardless of valley system. At this scale we can see how each river valley comprised a relatively separate network component during the A.D. 1250–1300 interval.

Over time, closer relations developed among the inhabitants of different subareas of the southern Southwest. During the A.D. 1300–1350 period previously distinct network components in the southern Southwest began to coalesce into a single large component. Phoenix, Tucson, and the Chihuahuan lowlands still stand apart, but other areas show closer relationships with one another based on shared consumption of the same range of decorated ceramics. The trend toward increasing integration in this large area of the southern Southwest is even more pronounced in the A.D. 1350 to 1400 period. The overall diameter of the network, or the longest path to traverse the network, has decreased and most sites are strongly connected to all other sites, reflecting great similarity in assemblages across almost all sites. Moreover, this pattern of increasingly dense ties means that one particular site or region is not markedly more central than others.

The largest network subgroup (also called the largest connected component) in the southern Southwest network after A.D. 1300 is, as with the San Pedro example, driven by shared high frequencies of Salado polychromes. These vessels' painted designs, including feathered serpents (as seen on the bottom of the design field of Figure 5), are believed to have conveyed powerful ideological messages. The large size of late bowl forms of this ware and the presence of decoration on their visible exteriors suggest that these vessels were used in large-scale feasting (Mills 2007b; Lyons and Clark 2012). Their widespread distribution, the social contexts of their use, and their ideological content have been attributed to the growing popularity of the Salado religion (Crown 1994). Crown's instrumental neutron activation

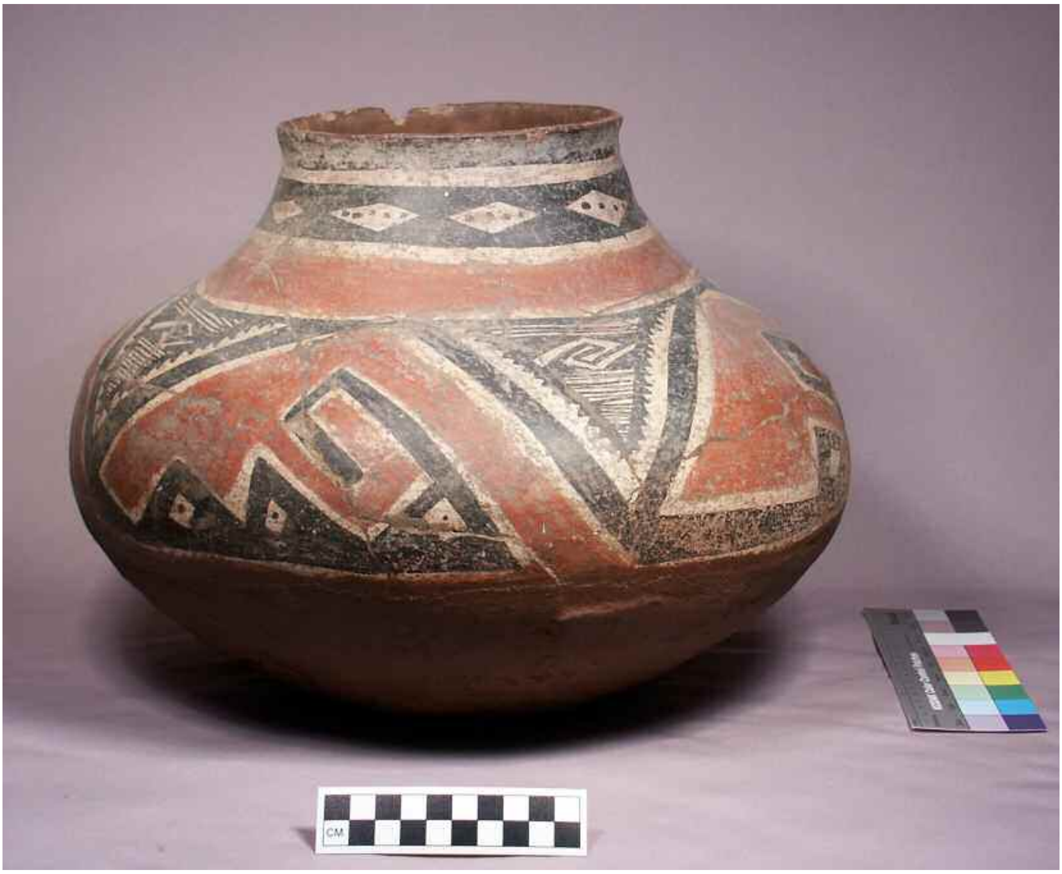

Figure 5. Tonto Polychrome jar. Arizona State Museum #GP-7424 (photo by Mathew Devitt). Note the feathered serpent design on the bottom of the central register.

analysis data established that these vessels were made in most of the areas that they are found, leading her to conclude that they were the result of the spread of an ideology, rather than exchange from a single or limited number of production centers. Social movements can promote the rapid spread of ideologies among people with diverse backgrounds, forming pluralities (Diani 2003, 2011; Edelman 2001). The Salado example fits such a model of a shared ideology integrating a culturally heterogeneous population made up of the descendants of migrants and their hosts.

Thus, at the mesoscale, we are able to see how the increasing connectivity within the San Pedro Valley was actually part of a broader trend toward the creation of strong connections among sites throughout the southern Southwest, driven by the emergence of practices that included the production, use, and consumption of Salado polychromes. The fact that this ware was produced in each valley or basin in which it occurs demonstrates that the flow of information, not exchange, was primarily responsible for the structure of the network. The scale of the interaction and the fact that migrants and hosts were all consumers of the pottery suggests participation in a socioreligious movement, with an overarching network and associated ideology that crosscuts social groups.

Macroscale Analysis: Arizona and Western New Mexico

We refer to the largest scale that we examine here as the "macroscale," which includes all of the sites in the database in Arizona and New Mexico west of the Continental Divide (Figure 6). This scale includes the prominent feature of the Mogollon Rim, a topographic feature that separates the Colorado Plateau from the basin and

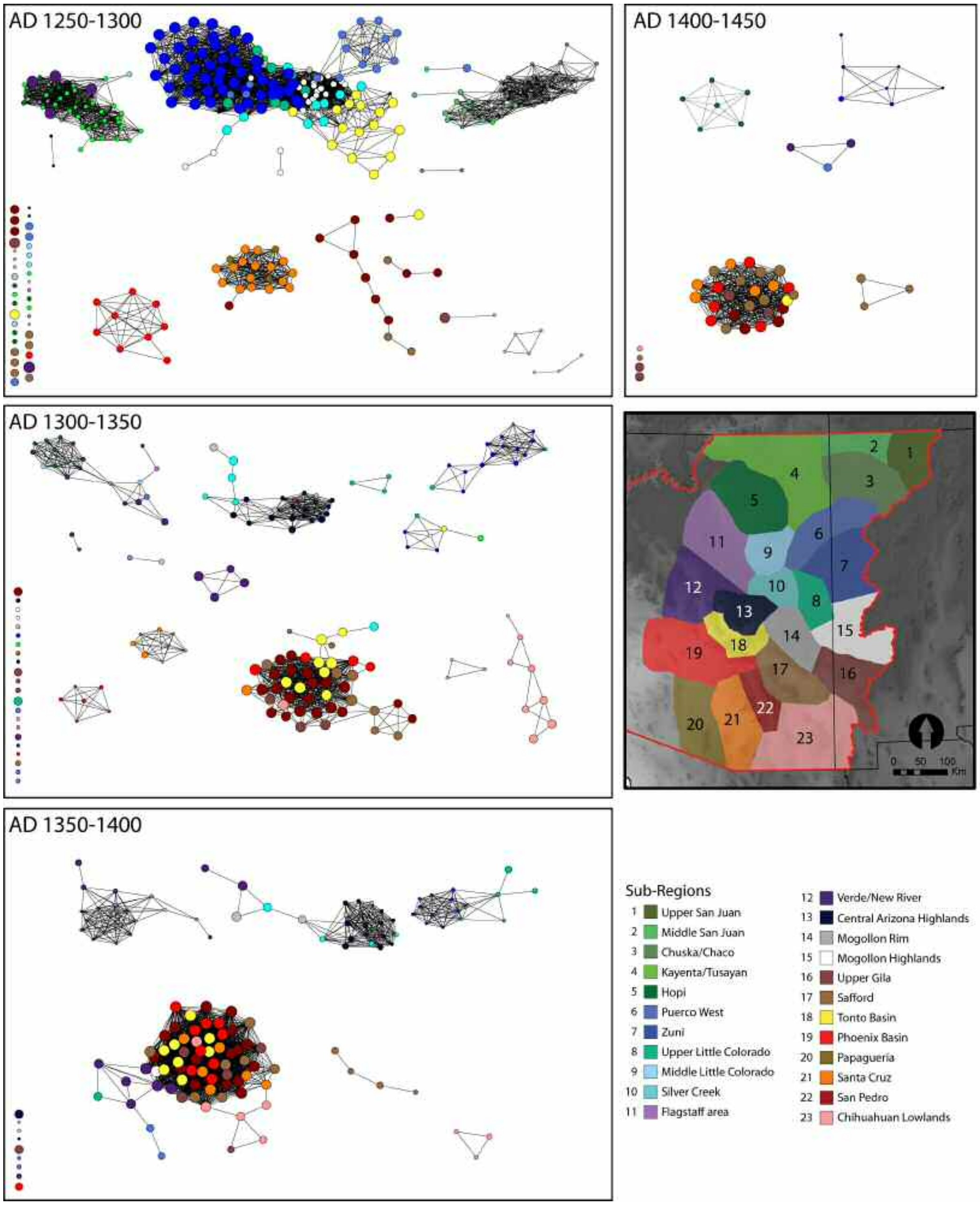

Figure 6. Macroscale networks of the western Southwest by 50-year periods. Geographic regions are color coded and size of node is based on eigenvector centrality.

range province of the southern Southwest. The former is more generally the area occupied by Ancestral Pueblo populations, while the latter is associated with the Hohokam. In between is the aptly named Transition Zone, where the variably defined Mogollon displayed their most distinctive characteristics centuries before A.D. 1000, two centuries before the period analyzed here. Each of these traditional designations contained a diversity of social groups that were enhanced by frequent migrations, especially during the period discussed here.

Network diagrams for A.D. 1200–1250 and 1250–1300 show that parts of the northern Southwest were highly connected, especially Zuni, the Mogollon highlands, the Little Colorado River, Silver Creek, and the Tonto Basin. Other than the Tonto Basin and the Mogollon highlands, south of the Colorado Plateau, non-Plateau settlements were largely disconnected from each other. As at the mesoscale, most thirteenth-century settlements in the southern Southwest had social ties with their spatially close neighbors. The Tonto Basin and Mogollon highlands exceptions are part of the large subgroup dominated by Zuni. At this scale we see not just how northern and southern networks do or do not overlap, but also the relative centrality of nodes in different areas—nodes within the southern networks are much less central in the entire network than those in the north, especially those within the large network subgroup dominated by Zuni. One of the commonalities of these sites is their shared consumption of Cibola White Ware and White Mountain Red Ware ceramics. Some areas within this large subgroup, including the Tonto Basin and Mogollon highlands, did not produce these wares. Rather, both of these areas were consumers of products made on the Colorado Plateau (Wilson 2007; Zedeño 1994). And before ca. A.D. 1275, Silver Creek potters made Cibola White Ware, but not White Mountain Red Ware (Mills et al. 1999). Yet despite these differences in production, all of these areas shared in the consumption (i.e., use and discard) of all of these wares.

Other subgroups or connected components within the thirteenth-century networks include one comprised of settlements in northwest New Mexico, representing post-Chacoan sites sharing Mesa Verde White Ware, Chuska White Ware, and Cibola White Ware. White Mountain Red Ware is present in small amounts at these settlements, but one of the striking differences between these sites and those in the rest of the Southwest is their relatively low frequencies of orange or red-slipped wares. None were made at these sites and the small amounts that are present can be attributed to small-scale exchange. Another discrete group is made up of sites in northeastern Arizona, with assemblages comprised largely of Tsegi Orange Ware and Tusayan White Ware, which dominate sites from the Kayenta, Hopi, and Flagstaff areas. Few of these wares were made in the Flagstaff area, and instead were imported from the Kayenta area (e.g., Geib and Callahan 1987).

A dramatic change in social relations followed the migrations of the late thirteenth century, shown in the network diagrams for the A.D. 1300–1350 period. In the northern Southwest many regions became more disconnected from each other such as Zuni. Silver Creek was more closely tied to the Central Arizona Highlands and Hopi, Flagstaff, and the Verde Valley formed another component. Meanwhile, the Tonto Basin settlements were more similar to those in the Phoenix Basin. Thus, during the period of migration, the northern network began to fragment, while the southern network grew in size and its sites show higher centrality values.

The "hegemony" of the southern Southwest, largely driven by the Salado polychromes that were prominent in building relational networks at the other scales, became even more striking in the next two periods. In the A.D. 1350–1400 period settlements in the Southwest were densely connected, reflecting in part the spatial aggregation of settlements. Yet, the tight cluster in the southern valleys shows that spatial propinquity need not correlate highly with social propinquity. Spatial and social propinquity show their lowest correlation during the late 1300s (Mills et al. 2013a). In the final period addressed here, A.D. 1400–1450, the Southwest became the most fragmented. The overarching homogeneity in the southern (greater Hohokam) area is not apparent in any other area—instead, the other areas became more distinct from each other.

Thus, when we consider the northern and southern Southwest together, differences in the characteristics and trajectories of the networks across the study area are readily apparent. With the exception of a small number of sites in areas lying along the boundary between the north and south, these two areas appear to be characterized by few strong similarities in ceramic assemblages for any interval. The northern Southwest is characterized by the densest connections, the largest connected components, and sites with the highest centrality during the A.D. 1250–1300 interval—the major period of migration. After A.D. 1300, however, a shift occurs as settlements in the south increase in centrality and the number of ties and component sizes increase dramatically, while in the north, dense connections begin to dissolve. Only at this macroscale can we relate dramatic changes in network characteristics to a major period of migration and migrants' source and destination communities.

For social relations as indexed here through decorated ceramics, our micro- and mesoscale analyses show the development of a more homogenous community of practice among all the sites in the post-migration period. In the southern Southwest this pattern is largely driven by Salado polychromes, known for their ideological significance (Crown 1994). Decorated ceramics, which were mostly serving bowls during this period, were one means of bridging different communities—socially and spatially—in the late prehispanic Southwest. Commensal politics and the social diversity created by migration combined to increase relations among villages across this region through shared participation in a social movement indicated by ideologically charged ceramics.

At the largest scale, network analyses illustrate how certain areas may have served to connect the northern and the southern Southwest immediately before and during migration, and how different areas became disconnected through time. For example, the Tonto Basin and the Mogollon highlands were initially more connected to Plateau settlements than to other settlements below the Mogollon Rim. These areas were bridges between the Ancestral Pueblo areas of the Plateau and Hohokam to the south and probable routes of exchange and migration (Clark 2001; Wilson 2007; see also Peeples and Haas 2013 for a similar interpretation based on weak ties or "brokerage" scores). This changed in the post-migration period, with the Salado polychrome network incorporating people living throughout the southern valleys and basins while the networks in the northern Southwest contracted. This scale clearly shows the impact of north-to-south migration on social relations in our study area.

A major contrast between the northern and southern networks is the fragmentation of the northern network after A.D. 1300. Rather than forming a single connected network, as in the south, the northern network broke up into two subnetworks, especially after A.D. 1400. Although the Katsina ideology linked settlements in the north, distinctive identities and expressions of this ideology on ceramics (and other material culture) characterized the two persistently distinctive northern areas of Hopi and Zuni. Ceramic technologies in these different areas diverged, with Jeddito Yellow Ware predominating at Hopi and Matsaki Buff Ware predominating at Zuni.[7] The emerging distinctiveness of Hopi and Zuni networks during the fifteenth century suggests that the competition and conflict between these two groups documented by Europeans in the sixteenth century (e.g., Hammond and Rey 1966) began by the 1400s, if not earlier. Those people living in settlements between these two clusters maintained disparate ties with one or the other. For example, contemporaneous settlements in the Upper Little Colorado had very different network affiliations even though they were close neighbors (Duff 2002). The depopulation of these interstitial communities in the late 1300s and early 1400s meant migration to one side or the other, which must have been a highly political decision for the settlements' inhabitants. The macroregional network snapshots are particularly well suited to showing how these two distinctive Pueblo areas diverged over time and how this divergence became cemented by another migration event during the fifteenth century.

Discussion

The case study presented here shows how the application of SNA to large archaeological databases can reveal different facets of regional social processes when analyzed at different spatial scales. We now discuss the results in terms of three overarching themes: (1) the relationship of material culture to social ties; (2) the substantive contributions of the multiscalar network approach; and (3) general contributions to archaeological theory and methods by using SNA in tandem with GIS.

The Relationship of Material Culture to Social Ties

The substantial amount of previous research in the Southwest provided the opportunity to assemble a database of ceramic frequency data that is unprecedented for the region and perhaps the world. While identification of social ties could be based on the distribution of rare items, such as copper bells or shell trumpets (e.g., Mills and Ferguson 2008), our approach in the present analysis has been to focus on the abundant. Ceramics are ubiquitous for the period and area, and are the result of activities that range from food preparation to storage to serving. We used only the decorated ceramics, which combine more distinctive attributes for consistently defining classes of material and are likely to convey social messages about identity and ideology. Decorated bowls were used for serving and decorated jars were mostly for water collection and storage; both of these functions placed these ceramic vessels in highly social and visible contexts of commensalism, including feasting (Mills 2007b).

Our approach to constructing ties between settlements uses the frequencies of wares recorded at each site, not just their presence/absence. Similarities in decorated ceramic assemblages are ways of constructing social ties based on their shared consumption and discard patterns. Historic archaeologists have noted that differences in the choice and proportions of tablewares are closely tied to differences in social networks (e.g., Pavao-Zuckerman and Loren 2012), even when the same foods are being consumed. Similarly, Knappett (2011) has argued that consumption practices are transmitted horizontally to produce communities of practice (*sensu* Lave and Wenger 1991) within and between settlements and that particularly iconic objects may provide the scaffolding for creating communities at the regional scale. In our case the connections between ceramic assemblages and social networks were produced through shared communities of practices in consumption, and the statistically derived similarity coefficients reflect the likelihood of social ties between the settlements at each period.

The social ties that we constructed through ceramic assemblage similarities are not based on compositional analyses that could be used to infer directionality (e.g., Abbott and Lack 2013; Bernardini 2007). Many of the wares in the Southwest were geographically restricted in their production (e.g., Jeddito Yellow Ware), but others such as Salado polychromes were made over large areas (Crown 2004) or in multiple areas (e.g., White Mountain Red Ware, see Duff 2002). In these latter two examples, the presence of the same wares in different areas indicates that information on how to make those ceramics flowed through migration, marriage, or other social interactions. Recent comparison of networks based on compositional similarities to the methods employed in this article show that networks based on composition are highly correlated with those based on assemblage ware similarity indices, even at the microscale level (Ownby et al. 2014). At the macroregional level these similarities should be even greater because of the production of wares in different geological settings of the Southwest.

Substantive Archaeological Findings from a Multiscalar Network Approach

There are several substantive results from our multiscalar analyses. One major finding is the dramatic restructuring of networks following migration—especially the migrations of the late thirteenth century, but also those of the fifteenth century. This is not surprising, as the demographic changes have been well outlined for over a decade (Hill et al. 2004). What was surprising was how each scale revealed different facets of migration consequences. The microscale analyses of the San Pedro Valley were especially telling with respect to local relations between migrants and their host settlements and the development of centrality within a local network. In particular, first-comer sites in the best-watered areas were the most central before migration. After migration, the immigrants in the San Pedro Valley quickly became as central as first comers in the network. This shift is related to migrants' production of Salado polychromes, as these wares quickly became desirable to their hosts for ideological and economic reasons, most likely in the social contexts of feasting. These feasts were a continuation and elaboration of northern feasting traditions that involved polychrome ceramics (Mills 2007b). Microscale analyses in other areas of the southern Southwest (the Tonto basin) have been conducted with different specific results (Mills et al. 2013b), illustrating how the historical trajectories of each local network were alternatively expressed despite similar regional settings.

The mesoscale allowed us to see how the southern Southwest network grew, drawing people from different but nearby valleys into a vast connected network based on shared participation in the Salado religion. There was an east-to-west edge-to-center expansion of the network, with the populous Tucson and Phoenix basins joining last. The growth and decline (often referred to as "collapse") of this southern network—largely coeval with the greater Hohokam area—is clearly shown at the mesoscale. Network isolates were sites without platform mounds, the major form of public architecture for the Classic period.

Platform mounds were multifunctional buildings that are associated with community inequalities. The fact that they were not built until after migrants moved into the area suggests that their builders were making a statement about their first-comer status. The mounds were often the loci of public feasting events (Elson 1998), supporting the interpretation that feasting was a social conduit for the creation of communities of practice in the consumption of ceramics. The rapidity and near complete adoption of Salado polychrome pottery, along with the strong ideological content of its decoration, reinforces its identification with a socioreligious movement (Crown 1994). The presence of some settlements "outside the network" that lacked public architecture also suggests that intracommunity and intraregional inequalities may have promoted the adoption of Salado polychromes (see also McGuire 2011).

The macroscale helps define the boundaries of the southern network by showing strong disjunctures in practices that relate to the production, consumption, and discard of decorated ceramics. Sites in the transition zone between the Colorado Plateau and basin and range initially bridged the northern and southern Southwest, but were short lived (Peeples and Haas 2013). At the macroscale we can also see how much more central the southern sites were within the regional network than those in the north. Each subregional network, northern and southern, had a different historical trajectory, with distinctive origins and consequences. The participation of most sites within a single connected network speaks to the high degree of connectivity produced by shared consumption of Salado polychromes and, by extension, the Salado religion by the late fourteenth century. When viewed at the macroscale, we were also able to see how the Hopi and Zuni areas contracted and differentiated. The sharp boundaries between these two area documented during the historic period were evident early in the period covered by our analyses and grew more distinct through the late Prehispanic period.

Contributions to Archaeological Network Method and Theory

The multiscalar analyses presented here produced insights useful for future applications of network analyses in archaeology. At the basis of network approaches is that they emphasize the relational connections (in our case between settlements) rather than predetermined categories (Knappett 2011), such as different subareas. A network perspective has also been referred to as the "anticategorical imperative" (Emirbayer and Goodwin 1994:1414). What we have shown is that settlements within different geographic areas, which archaeologists would treat categorically such as the Kayenta or Zuni areas, have varying connectivities to each other at different times. The goal of network approaches is not to recreate culture areas, but to allow the relational qualities of nodes (in our case settlements) define the networks and their change over time. We have chosen to emphasize relations built around decorated ceramics; other materials could be used to construct network relations and then compared to show how particular nodes (in our case settlements) were multirelational as well as multiscalar.

Another contribution of the present study is in showing how mutable network boundaries can be. Network analysts have recently written about the fact that network boundaries are flexible (Borgatti and Halgin 2011:2). Archaeologists should be sensitive to the fact that we may not always be able to control how we define and populate our study areas and it follows that we may only have access to some parts of networks. To understand the maximal size of networks in our analyses (at least given the currently available data) it was necessary for us to significantly increase the spatial scale of analysis from the individual valley or basin level to at least the mesoscale (as used here). In fact, the Salado network was best defined at the macroscale. This suggests that larger datasets will be required for some research questions—a proposition that will require significantly more collaborative work among archaeologists to amass compatible datasets suitable for identifying fluctuating networks over time.

Finally, the analyses conducted here illustrated the dynamic nature of archaeological networks. The time period we investigated was one of the most fluid in terms of population changes and provided a strong backdrop to relational changes. Our analyses were also strengthened by the use of GIS and SNA approaches applied to a large dataset that included settlements before, during, and after significant regional migrations. Analyses of dynamic networks with deep historical roots represent important contributions that archaeology can make to multidisciplinary network science. Because of dendrochronology and the rapid changes in ceramic styles we were able to divide our assemblages into 50-year "snapshots." Other archaeological applications may not have the same degree of temporal control but that does not preclude a relational approach. How this relational approach may be adapted in a particular research context will require careful thinking about how connectivities were constructed in the past, the social networks that materials flowed through, and how objects were actively used. In our analyses we chose to emphasize decorated ceramics because this class of material culture had a strong ideological component during the time period and region we investigated. Material culture has agency within networks and the prospects of future archaeological applications might consider how certain kinds of materials may be better than others for reconstructing relations and revealing the dynamic properties of past interactions.

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Data Availability Statement. The list of types and wares, and the date ranges for the latter, are all posted on the Archaeology Southwest website (http://www.archaeologysouthwest.org/what-we-do/investigations/networks/). Also on the website is information on how to request access to the SWSN Database.

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Notes

1. See Hill et al. (2004) for a full discussion of methods for estimates of date ranges and room size estimates for each 50-year interval.

2. Ceramic types were used for chronological controls following the procedures outlined by Roberts et al. (2012). A listing of all ceramic wares and types can be found on the above Archaeology Southwest website, along with the date ranges assigned to each type and ware.

3. The Brainerd-Robinson coefficient is the most appropriate for comparing frequencies across multiple nominal categories (Cowgill 1990; see also Golitko et al. 2012). The B-R similarity (S) between site a and site b is defined as:

$$S_{ab} = \frac{200 - \sum_k \left| P_{ak} - P_{bk} \right|}{200}$$

k = all ceramic wares
P_{ak} = Percent of ware k at site a
P_{bk} = Percent of ware k at site b

4. Although some information is lost in this binarization process, we have experimented with a broad range of thresholds for defining ties for these graphs that produced comparable results.

5. In previous work we used statistical bootstrapping methods for resampling assemblages during network analyses to identify potential sources of sampling error or other kinds of variation. Random replicates of site ceramic assemblages were created to assess variability in results due to sampling variability in the initial collection of assemblage data. Further, we randomly removed nodes from the database to assess changes in network properties and to determine the potential effects of missing nodes. The results of these analyses suggest that the results described here are robust to both the range of sample sizes available to us as well as the proportion of sites for which we have data. Indeed, our analyses suggest that the patterns documented here were robust when samples were drawn down to as little as 10 percent of the sites for which we have data (Mills et al. 2013a; Peeples et al. 2014).

6. The physiographic feature of the Continental Divide defines the eastern edge of the project area, which therefore excludes the Rio Grande or Eastern Pueblos.

7. Although similar in surface color and with many shared motifs, Jeddito Yellow Ware from the Hopi area and Matsaki Buff Ware from Zuni differ in clays, temper types, fuels used in firing, and the presence/absence of a slip, indicating relatively distinctive communities of practice.

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