Trade Relationships and Gene Flow at Pottery Mound Pueblo, New Mexico

Lexi O'Donnell, Jana Valesca Meyer, and Corey S. Ragsdale

Pottery Mound is a large Ancestral Puebloan site situated within the Middle Rio Grande (MRG) region of New Mexico. This article adds to our understanding of relationships between Pottery Mound, the Western Pueblos, and Mexico through use of biological distance analysis based on dental nonmetric traits. Extensive material and cultural influences, as well as migration events from Western Pueblos to Pottery Mound, have been proposed by several scholars, while others have highlighted parallels to Mexico, especially Paquimé. A total of 1,528 individuals from the U.S. Southwest and Mexico were used to examine relationships between Pottery Mound and these areas. We find no evidence of close biological similarity between Pottery Mound and the Western Pueblos or northern Mexico. Instead, the results indicate biological affinity between Pottery Mound and sites in the MRG region and Mogollon areas. This similarity suggests that although there is evidence for trade between Pottery Mound and other sites in the southwestern United States and Mesoamerica, trade may not have been accompanied by significant gene flow from those areas from which the trade goods originated. It is possible that neighboring regions, such as the Mogollon, served as intermediaries for trade between Pottery Mound and distant regions.

Keywords: biological distance, dental morphology, linear discriminant analysis, migration, trade, Southwest United States, Middle Rio Grande, Northern Rio Grande, Pottery Mound Pueblo

Pottery Mound es un Pueblo Ancestral ubicado en la región del Rio Grande en Nuevo México, Estados Unidos. Usando análisis de distancia biológica basados en datos de morfología dental, intentamos mejorar la comprensión de formas de interacción entre Pottery Mound, los Pueblos Occidentales, y México. Varios investigadores han propuesto influencias notables – incluso eventos migratorios de los Pueblos Occidentales – a las expresiones materiales y culturales de Pottery Mound, mientras otros destacan paralelas con grupos de México, especialmente de Casas Grandes. Aquí examinamos la morfología dental de un total de 1,528 individuos pertenecientes a 68 sitios arqueológicos ubicados en lo que hoy consideramos el suroeste de los Estados Unidos y México para examinar contactos entre Pottery Mound y dichas áreas de interés. Utilisamos análisis de Medida Media de Divergencia, pseudo-distancia de Mahalanobis (D^2) y Análisis Discriminante Lineal para calcular la distancia biológica entre los habitantes de diferentes regiones del suroeste norteamericano y Mesoamérica. Los primeros dos análisis comparan nuestros datos a nivel regional, mientras que el último produce medidas de distancia fenética a nivel individual. Los resultados indican que Pottery Mound no tuvo semejanza fenética significante con nuestra muestra de los Pueblos Occidentales, ni con los de Casas Grandes. Por el contrario: en toda la muestra, Pottery Mound y Casas Grandes fueron entre los sitios más distintos entre sí. Pottery Mound fue lo más similar a individuos de los sitios del Rio Grande Central y de la región Mogollón. Esta semejanza puede indicar que apesar de evidencia arqueológica de intercambio de bienes entre Pottery Mound y otros sitios del suroeste de los Estados Unidos o de Mesoamérica, a lo mejor ésto no ha sido acompañado por un notable intercambio de genes con individuos procedentes de los sitios de orígen de los bienes. No obstante, es posible que regiones vecinas, como la región Mogollón, funcionaron como intermediarios de comercio entre los Pueblos Ancestrales y regiones más lejos. Esa posibilidad está de acuerdo con nuestros datos.

Palabras clave: antropología dental, morfología dental, osteología, filiación biológica, migración, análisis discriminante lineal, suroeste de Los Ustados Unidos, Medio Rio Grande, Norte de Rio Grande, Pueblo del Pottery Mound

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The late thirteenth to fourteenth centuries AD in the U.S. Southwest was a time of demographic turmoil, with several large-scale migration and depopulation events followed by population aggregation in the Northern Rio Grande (NRG) region of New Mexico and southern Arizona (Boyer et al. 2010; Cameron 1995; Crown et al. 1996; Fowles 2004; Kohler et al. 2010; Lipe 1995, 2010; Ortman 2010; Schachner 2015; Varien 2010). The NRG is a roughly rectangular archaeological region restricted by the state line of modern-day Colorado to the north, Isleta Pueblo to the south, the Canadian River (east), and the Rio Puerco and Rio Chama (west; Wendorf 1954:Figure 2). These population movements necessitated renegotiation of social rules and practices while also allowing for formation of new social units (Eckert 2008). Although these migrations likely created new social and demographic conditions, they left varying amounts of archaeological evidence. The Kayenta people of Northern Arizona moved southward to the Point of Pines area, leaving a series of material culture changes in their wake (Haury 1958).

The depopulation of the Mesa Verde region, which occurred around AD 1275, left the area sparsely inhabited, whereas the NRG experienced a population boom but little in the way of material culture changes (Cordell et al. 2007; Glowacki 2015; Kohler et al. 2008, 2010; Ortman 2012; Roney 1995). The Mesa Verde migrations may have altered the demographic composition of the Middle Rio Grande (MRG) region as well. A number of sites emerge in the MRG around this time, including Pottery Mound (Eckert 2008:15–16). The MRG is an area extending from the southern border of the NRG to modern-day Elephant Butte (Jones 2015).

Additionally, there is evidence for extensive interregional connections and trade that likely worked to shape the cultural lives and material expressions of many southwestern peoples (Crown and Hurst 2009; Eckert 2007; Franklin and Schleher 2012; Hibben 1960, 1966, 1967; Schaafsma 2009; Washburn 2019). Evidence for networking with other places throughout the Southwest and Mesoamerica comes from iconography (Hays-Gilpin and Hill 1999; Schaafsma 2009; Washburn 2019), trade goods (Crown and Hurst 2009; Crown et al. 2015; McGuire 2005), and various architectural features (Haury 1945).

Contact between the Hohokam of present-day Arizona and Mesoamerica is well established. Trade goods from northwest Mexico, including copper bells, have been located at Hohokam sites (Haury 1976; McGuire 1980). There is also evidence for trade between Ancestral Puebloans and the Hohokam (McGuire 1980). McGuire (1980) posits that the Hohokam were in a pivotal position for trade and that they may have obtained turquoise in exchange for shells. They were also able to trade turquoise for high-value objects from northwest Mexico, such as pyrite, copper bells, and scarlet macaws. Evidence for exchange between the Pueblos and Mesoamerica exists as well, but this is, perhaps, more tenuous, as discussed below.

Washburn (2019) suggests Mesoamerican influences on iconography in kiva murals. Others have noted parallels between religious symbolism in the Pueblo world and that of Mesoamerica (McGuire 2011:27–28, Table 2.1). Hill (1992:117) suggests that a spiritual system centered upon the Flower World, a complex of metaphoric imagery of flowers referring to "spiritual power" and "life force" (Hays-Gilpin and Hill 1999:1), was practiced by peoples of Mesoamerica and the Southwest. Evidence for this influence comes from depictions of flowers, birds, butterflies, and rainbows on pottery, in rock art, on altar slabs, and in kiva murals throughout the Pueblo world (Hays-Gilpin 2006; Hays-Gilpin and Hill 1999; see also Mathiowetz 2011). Furthermore, depictions of horned serpents indicate Mesoamerican connections in the U.S. Southwest (Phillips et al. 2006; Schaafsma 2007; Taube 1986).

Aside from iconography, evidence for contact with Mesoamerica includes traces of cacao discovered in cylinder jars from Chaco Canyon, whose shapes are reminiscent of those found in Mesoamerica (Crown and Hurst 2009). Macaws—birds native to South and Central America—have been found in a variety of contexts in the U.S. Southwest. They are depicted on pottery and in murals, and their skeletal remains have been found at sites throughout the Southwest (Creel and McKusick 1994; Crown

2016; Hargrave 1970; Minnis et al. 1993). Copper bells have been unearthed at Mogollon sites, and they are interpreted as evidence for trade between the residents of Paquimé and the Mogollon (McGuire 2005).

McGuire (2005; see also Vargas [1995] for a discussion of copper bells) reports that copper bells and macaws were less common at Puebloan sites than sites in other areas with contemporaneous dates. He states that 108 macaw skeletons have been found in the Mogollon, Salado, and Sinagua areas, compared to only nine hailing from Puebloan sites. Bells show a similar distribution pattern. Over 110 have been found in the Mogollon, but few have been found at Puebloan sites (McGuire 2005).

An archaeological site that has purported ties to Mexico and the Western Pueblos is Pottery Mound (LA 416), an eastern Ancestral Puebloan site that was inhabited between about AD 1300 and 1500 (Adams and Duff 2004; Franklin 2018; Ortman 2012). There is also evidence for a later occupation of the site, during Spanish contact (Bletzer 2019; Franklin 2018). This agricultural village is located in the MRG, along the Rio Puerco—a tributary to the Rio Grande (Figure 1; Hibben 1960:267–268). Pottery Mound was a large site, with at least 11 painted kivas (Crotty 2007; Schaafsma, ed. 2007:138; Schaafsma and Schaafsma 1974) and an estimated total of 500 surface rooms (Adler 2007:33). Pottery Mound's "heyday" was likely between AD 1325 and 1475. After AD 1475, it experienced a decline, and the main portion was probably depopulated by 1490 (Franklin 2018:40).

Excavations at Pottery Mound were undertaken through summer field schools conducted by the University of New Mexico between 1954 and 1961 under the directorship of Frank Hibben (1960, 1966, 1967; Vivian 2007:18). Additional salvage excavations took place during the late 1970s and early 1980s (Hibben 1987 cited in Vivian 2007:22). In 1979, Linda Cordell conducted a systematic stratigraphic test excavation (Cordell 1980:3–5; 1989). Petrographic and stylistic analysis of glaze ware sherds from this excavation allowed Eckert (2007:66) to estimate the chronologic sequence of two separate migration events from the Western Pueblos to Pottery Mound.

The people who inhabited this site are thought to have been a diverse group, with connections to other locations throughout the Southwest (Ballagh and Phillips 2015; Crotty 2007; Hibben 1967). Although the people are assumed to have come from varied backgrounds, the site is also reported to be archaeologically "typical" of the Rio Grande tradition (Schaafsma, ed. 2007). Evidence of this conformity includes multiple adobe room blocks with plazas between them and the majority of ceramics found at the site (Adler 2007; Ballagh and Phillips 2015; Hibben 1960, 1966). As the name suggests, Pottery Mound was an important center of pottery production (Eckert 2007, 2008; Franklin and Schleher 2012). Ceramic types from Pottery Mound include three types of Rio Grande Glaze Ware (Rio Grande Glaze-on-red, early Rio Grande Glaze-on-yellow, early Rio Grande Glaze Polychrome), Pottery Mound Polychrome, Hidden Mountain Polychrome, and locally made replicas of Zuni Glaze Ware (indicative of immigrants from Zuni and their descendants; Eckert 2007:62). In addition to pottery, architectural features, including the "ladder type" construction method, are interpreted as suggestive of incoming migrant groups to the site (Adler 2007:37).

The present study evaluates previously published models and hypotheses regarding migrant groups and interregional connections at the Ancestral Puebloan site of Pottery Mound, New Mexico.

Language

Today, Puebloan peoples are linguistically diverse, and it is possible that the patterning of languages spoken now provides some evidence for past population movements. These groupings, however, should not be taken to be correlates of biological relatedness, as discussed in greater detail in the following section. Furthermore, Cordell and McBrinn (2016) posit that due to this diversity, people were likely multilingual. Languages that are spoken today include Hopi, Keresan, Zuni, Towa, Tewa, and Tiwa.

Multiple pueblos today speak Tewa, including Ohkay Owingeh, Santa Clara, San Ildefonso, Nambé, Pojoaque, and Tesuque (Mithun 2001). The origin of the Tewa-language speakers has

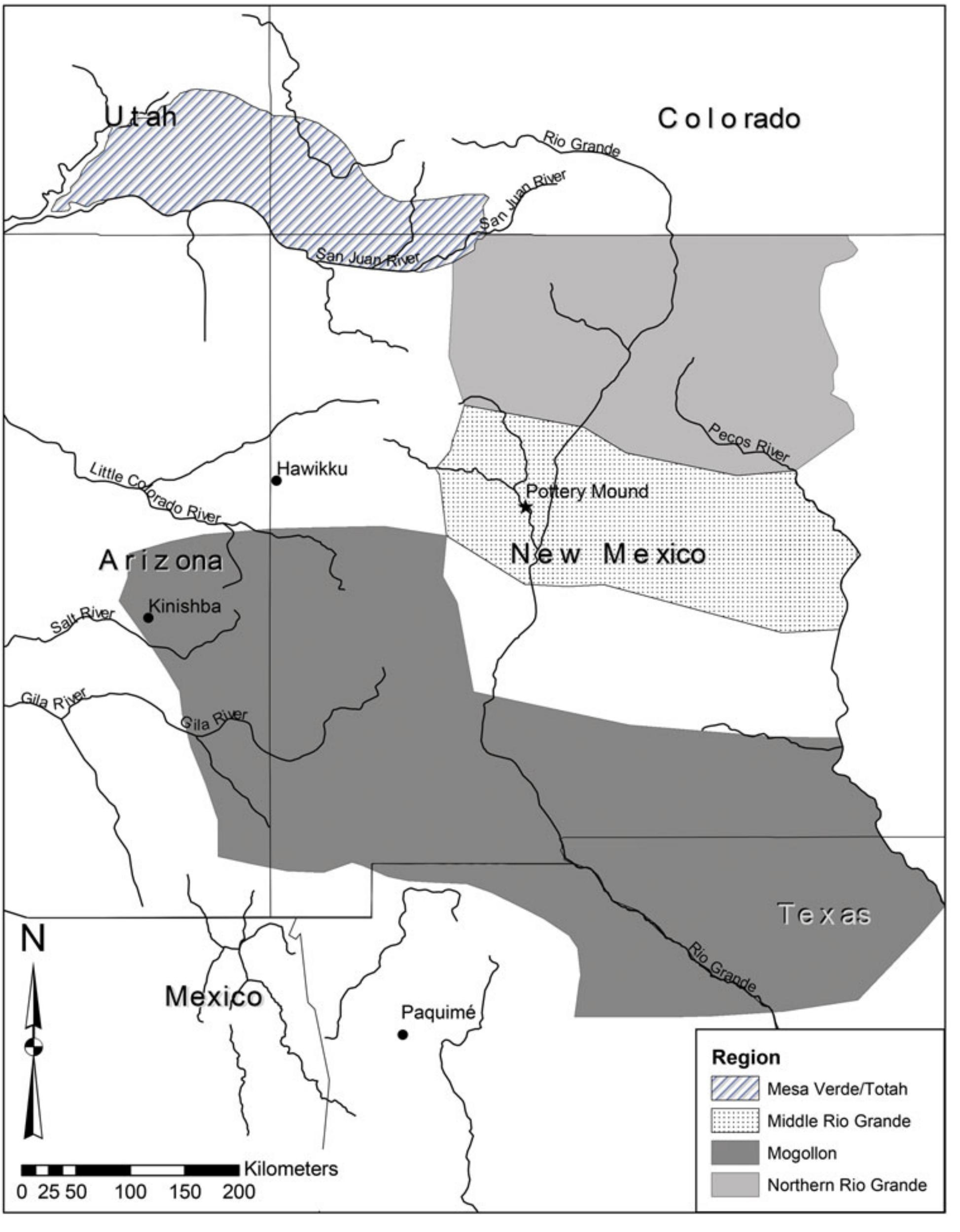

Figure 1. Map of regions and target site (Pottery Mound) included in this study. Map made by William Marquardt.

been contested in the literature (Ford et al. 1972; Ortman 2009, 2010, 2012; Reed 1950). Ortman (2009, 2010, 2012) provides evidence that the Tewa language may have originated in the Mesa Verde region. Other studies, however, suggest that the number of people who would have moved from Mesa Verde to the NRG is too small to have entirely replaced the language that was already spoken in the area (Schillaci and Lakatos 2016).

The Tiwa language can be divided into two groups: North (Taos and Picuris Pueblos) and South (north and south of Albuquerque at Sandia and Isleta Pueblos; Ford et al. 1972; Kroskrity 1993; Wendorf 1954). Ford and colleagues (1972) posited that Tiwa originated in the Rio

Grande Valley, but they could not come to consensus on why the language split into two groups. Although we do not know what language was spoken there, due to its location, it is possible that the people of Pottery Mound belonged to the Southern Tiwa language group (see Ortman 2012:99), or they may derive from a Keres-speaking group.

Biological Distance Studies

Biological distance, herein referred to as biodistance, is a measure of phenetic similarity between or within groups that are separated by space and/or time (Buikstra et al. 1990; Pietrusewsky 2014). An expectation of biodistance analysis is that populations who are more closely related to one another will be more phenetically similar to each other than they are to other groups (Pilloud and Larsen 2011; Stojanowski and Schillaci 2006:50–51). Most previous work on Pottery Mound has focused on the analysis of traditional archaeological materials, such as architecture, ceramics, and iconography (e.g., Crotty 2007; Eckert 2008; Hays-Gilpin 2006; Hibben 1960, 1966, 1967, 1975; Schaafsma, ed. 2007). Other studies have included Pottery Mound in larger-scale biodistance analyses, although the site is often not the sole focus of the works. We provide a brief synthesis (in chronological order) of works that included this site in their analyses either as the sole or secondary focus.

Schorsch (1962) used craniometric data to examine variation among the individuals buried at Pottery Mound. He concluded that males were more variable than females, perhaps indicating that some males at Pottery Mound were "foreign" traders or other visitors to the site, whereas females were local to the area.

In his examination of linguistic and phenetic relationships between Pecos Pueblo and groups of Towa speakers, Mackey (1977) included osteological data from 37 individuals from Pottery Mound as a comparative. They were most similar to individuals from Kuaua and Puaray (Mackey 1977:481, Tables 2 and 3). Mackey (1980) also examined relationships between individuals from Arroyo Hondo and other Southwest groups through use of skeletal nonmetric traits. He found that Tijeras, a site on the margins of the MRG and the Plains, was less similar to Pottery Mound and Kuaua than expected based on geographic proximity.

Although Mackey does not explicitly discuss Pottery Mound's other phenetic relationships, his results (1980:178, Table 37) indicate that there were comparatively smaller biodistances between Pottery Mound, Kuaua, Pecos, and San Cristobal Pueblos. The small biodistances indicate phenetic similarity between Pottery Mound and other MRG sites. Mackey did not find a correlation between the linguistic groupings and phenetic groupings. This result is similar to the findings of Turner (1993), who reported low to no correlation between linguistic groups and biodistance in New Mexico. These studies indicate that language may not have played a role in the structure of biological relationships in this part of the Southwest (see also O'Donnell 2019; Scott et al. 1983; Turner 1993).

Schillaci and colleagues (2001) included 16 individuals from Pottery Mound in their article examining gene flow between Chaco Canyon and other Southwest sites. Pottery Mound appears between Mesa Verde and Pecos Pueblo in their plot (Schillaci et al. 2001:140, Figure 3)—a result indicative of similarity to the NRG/southern Colorado regions.

Finally, O'Donnell and Ragsdale (2017) examined relationships between the Gallina people of the NRG and other groups from the Greater Southwest to determine where the Gallina went after they abandoned their homeland. Their analyses included individuals from Pottery Mound. Results indicate that as a group they were phenetically close to other MRG groups but that as individuals they were diverse. The results of all aforementioned biodistance studies are consistent with archaeological interpretations that the people who inhabited Pottery Mound were a diverse group, with connections to other locations throughout the Southwest (Crotty 2007).

Hypotheses for Interaction

This study evaluates previously published hypotheses regarding trade connections at Pottery Mound. Based on archaeological evidence for associations between Pottery Mound, Mexico, and the Western Pueblos, this article constructs three models that seek to examine gene flow between these places to assist in further establishing what interregional relationships may have looked like at this site in the past.

Model 1: The Western Connection

Kiva iconography and ceramics in Sikyatki style indicate a potential connection between Pottery Mound and Western Pueblo groups in Arizona and New Mexico (Crotty 2007; Schaafsma, ed. 2007). Ceramic wares from Pottery Mound include those from Hopi (Yellow Wares) and locally made Pottery Mound Polychrome with designs imitating Hopi styles (Crotty 2007; Ellis 1967; Schaafsma, ed. 2007). Cordell (1980) reported on a total of 24,321 sherds from Pottery Mound. Roughly 49% were Glaze A wares, 49% were utility wares, and the remainder consisted mainly of Pottery Mound Glaze Polychrome, Jeddito and Sikyatki, Acoma-Zuni wares, and Galisteo black-on-white. Franklin (2018:25) reports an abundance of Acoma-Zuni pottery as indicative of "consistent" trade between Pottery Mound and the Western Pueblos. Eckert (2007) proposes at least two immigration events from the Western Pueblos to Pottery Mound based on ceramic style and manufacturing techniques.

Katsina and Mesoamerican motifs are present on kiva murals, as well as on pottery and in rock art at Kuaua and Pottery Mound (Raat 2012; Schaafsma and Schaafsma 1974). Examples of this iconography include depictions of naturalistic imagery such as flowers, birds, and butterflies, as well as clouds and rain (Hays-Gilpin 2006; Hays-Gilpin and Hill 1999; Mathiowetz 2011). Mythical imagery that includes depictions of horned serpents (Phillips et al. 2006; Schaafsma 2007; Taube 1986) and Katsina deities associated with phenomena such as rain, earth, and maize (Schaafsma 2009) is also present. The Katsina religion is practiced by contemporary Western Pueblos, which include Hopi, Zuni, Acoma, and Laguna (Raat 2012; see Hays-Gilpin et al. [2019] for discussion of Katsina religion at Laguna). It does not appear to have been practiced by Tiwa speaking groups in the MRG (Raat 2012). The presence of these motifs could indicate a religious connection to the Western Pueblos (e.g., Adams 1991).

Crotty (1995) discusses depictions of the War God at Awat'ovi and suggests that they are analogous to a figurine found on modern Hopi altars. Furthermore, she reports a "large, legless figure" in murals from Pottery Mound that may also represent a Katsina deity (Crotty 1995:331). Crotty (1995:336) also discusses the association of the Katsina religion with "masking" and reports that masked figures are not found in most kiva murals at Pottery Mound. Hibben's (1960) early works highlight iconographic similarities between the Pottery Mound and Awat'ovi murals. This, along with the presence of Western Puebloan ceramic types, led him to suggest the possibility of an "intrusion from the west of a large group of Hopi people" (Hibben 1955:179, 1960:268). Others, however, cite arguments for a northern Mexican origin of the Katsina style, so these motifs could also be interpreted as a connection to northern Mexico (Raat 2012).

Based on a model for trade relationships and gene flow to the Western Pueblos, we hypothesize that (Hypothesis 1) the group of people buried at Pottery Mound will show a greater phenetic similarity to people from the Western Pueblos.

Model 2: The Mexican Connection

Hibben's later publications shift focus and emphasize cultural ties to Mexico. These works draw parallels between Pottery Mound and Paquimé in northern Mexico (Hibben 1966; Vivian 2007). Certain iconographic elements of the Pottery Mound murals—macaws and other parrots, a jaguar in association with a bird, and a serpent with feathers and horns—are frequent motifs in Mesoamerica and may indicate a trade connection to Mexico (Hibben 1966, 1967). The jaguar referenced above is depicted in Hibben (1975:Figure 47). The jaguar "was always suspect because it was the only spotted feline represented in the volume except for a blue feline with white and black spots in Figure 77 that Hibben doesn't identify as a jaguar" (Helen Crotty, personal communication 2019). Crotty examined student field notes and found no evidence of a cat in association with a bird reported by Hibben as an eagle. Instead, the notes depict a "plain off-white wash on the wall behind the outline of the seated human figure" (Helen Crotty, personal communication 2019).

Hibben (1966) also reports the presence of a two-tiered "pyramidal structure" and a possible ball court in proximity to the site's main mound. Other researchers have been unable to confirm the presence of either structure (Vivian 2007:16). The material evidence for a Mexican connection is tenuous: a single copper bell found at Pottery Mound is said to be similar to copper bells from Paquimé (Cordell 2015; Vargas 1995). There are also reports of one clay bell that appears to imitate copper precursors (Hibben 1966:525; Lambert 1958).

Hibben claimed to have found the remains of a macaw at Pottery Mound, but thus far, the find has not been confirmed by locating the remains in the collections (David Phillips, personal communication 2019). Macaws are depicted in murals (e.g., Hibben 1967; Schaafsma 2009:668, 675), however. There are also four Ramos Polychrome sherds and one Villa Ahumada Polychrome sherd, which are ceramics of the Casas Grandes tradition (Phillips and Gamboa 2015).

Based on this model for trade relationships and gene flow to groups in Mexico, we hypothesize that (Hypothesis 2) people buried at Pottery Mound will be most similar to people from Mexico, represented by sites in northern or central Mexico.

Model 3: The Rio Grande Connection

Given Pottery Mound's geographic position within the MRG, another possibility is that people from Pottery Mound were exchanging genes rarely (if at all) with people in or from other locations and that they are phenetically most similar to groups within the MRG. A close phenetic relationship to other MRG sites would also be consistent with the majority of Pottery Mound's material culture—such as the architectural layout and the vast majority of ceramics—that is characteristic of typical MRG Pueblos (Schaafsma, ed. 2007).

Based on this model for phenetic similarity to the place in which the site is geographically located, we hypothesize that (Hypothesis 3) the group of people buried at Pottery Mound will be most similar to people from the MRG in New Mexico.

Materials and Methods

Dental Morphological Data

This study incorporates individuals from 68 archaeological sites from New Mexico, Arizona, and Mexico. Due to the number of sites and the question of regional relationships, we collapsed the majority of sites into regional representatives. For example, the MRG includes the sites of Kuaua, Chamisal, Puaray, and Tijeras. As Pottery Mound is our focus, it was entered separately and not included in the combined regional dataset. See Table 1 for descriptions of all sites. This approach (the lumping of sites into regions) is appropriate as demonstrated by many previous biodistance studies (e.g., Hanihara 2010; Hanihara and Ishida 2005; Hanihara et al. 2003; Irish 1998; Willermet and Edgar 2009).

Human skeletal remains and dental casts included in this study are or were housed at the Maxwell Museum of Anthropology's Laboratory of Human Osteology (MMA) in Albuquerque, New Mexico; the Office of Archaeological Studies (OAS) and Center for New Mexico Archaeology (CNMA)/Museum of Indian Arts and Culture (MIAC) in Santa Fe; the Arizona State Museum (ASM) in Tucson; Arizona State University (ASU) in Tempe; the Smithsonian National Museum of Natural History (NMNH) in Washington, DC; and the Instituto Nacional de Antropología e Historia (INAH) in Mexico City. Consultations were done on behalf of the authors by each agency according to its own policies.

Letters written by first author O'Donnell detailing (1) the aims of her research and biodistance analysis in general, (2) the nondestructive nature of the analyses, and (3) the potential for biodistance analyses to aid in cultural affiliation when used in concert with other information (including evidence deriving from geographic location, kinship, archaeology, anthropology, linguistics, folklore, oral tradition, historical information, and expert opinion; as cited in NAGPRA [e-CFR 1990]) were sent on her behalf by MIAC staff to the cultural preservation programs of all included Pueblos or peoples who may have been affiliated. Due to a request not to collect data from individuals buried at some sites, including Nambé, those sites are not included in

Table 1. Descriptions of Collections.

Region/Site	*N*	Dates/Time Period	Current Location[a]	References
Western Pueblo				
Hawikku (Zuni)	20	1400–1680	NMNH	Adams and Duff 2004; Cordell and McBrinn 2016
Middle Rio Grande (MRG)				
Kuaua	50	1350–1700	MMA	Adams and Duff 2004; Cordell and McBrinn 2016
Tijeras	18	1262–1395	MMA	Adams and Duff 2004; Ortman 2012
Puaray	9	1300–1600	MMA, CNMA	Adams and Duff 2004; Cordell and McBrinn 2016
Chamisal	19	1200/1275–1400	MMA	Adams and Duff 2004; Franklin 2017; Sargeant 1985
Pottery Mound	31	1300–1500	MMA	Adams and Duff 2004; Ortman 2012
Mogollon Jornada and Mimbres (MOG)				
Angus Sites (multiple sites)	9	700–1375[b]	MMA	ARMS 2018
Mimbres (multiple sites)	21	1000–1325[b]	MMA	O'Donnell 2019
Adam's Ranch	1	1250–1450	MMA	O'Donnell 2015, 2019
Northern Rio Grande (NRG)				
Sapawe	19	1300–1550	MMA	Adams and Duff 2004; Cordell and McBrinn 2016; Ortman 2012
Yunque	10	1250–1610/ 1275–1600	MMA	Adams and Duff 2004; Adler 1996; Ortman 2012
Tecolote	5	1050/1150– 1300/1325	MMA	Claassen 1994
Pindi	12	1000–1400/ 1275–1400	CNMA /MIAC	Adams and Duff 2004; Adler 1996
Pecos Pueblo	40	1200–1830	repatriated	Adams and Duff 2004; Adler 1996; Ortman 2012
Pajarito Plateau	30	1150–1600	NMNH	Adler 1996
Jemez	137	1300–1600	repatriated	Adler 1996
Gallina (multiple sites)	40	900–1300	MMA	ARMS 2018; Constan 2011
Rio Abajo (RA)				
Gallinas Springs	9	1250–1350/ 1300–1450	MMA	Lekson et al. 2002
Mesa Verde/Totah				
La Plata Highway Sites (multiple sites)	29	1000–1125/1300	OAS	Toll and Akins 2012; Wilshusen and Glowacki 2017
Arizona				
Kinishba	56	1200–1400	ASM	
Turkey Creek Pueblo	22	1240–1300	ASM	
Central Mexico and Oaxaca Valley				
Mexico City—Cuicuilco, Culhuacan, Mizquic, Rescate-Coyoacan, Tlateloco, Xochimilco	243	1200–1520	INAH	Ragsdale and Edgar 2015, 2016
Puebla—Jalapasco, Cholula, Tepepayeca	58	1300–1520	INAH	Ragsdale and Edgar 2015
Tenango Temporada III and V (Teotenango)	27	1250–1450	INAH	Ragsdale and Edgar 2015
Veracruz—El Dorado, Zapotal, Maltrata, Piramide de la Joya, Quautochco	104	300–1200	INAH	
Teotihuacan, Mexico	49	250–600	INAH	
Templo Mayor/Tenochtitlan	47	1400–1519	INAH	Ragsdale et al. 2016
Morelos—Zazacatla, Teopanzolco, Olintepec	89	1200–1550	INAH	Ragsdale and Edgar 2015
Tlatilco	28	1250–800 BC	INAH	
Texcaltitlan	27	1100–1520	INAH	Ragsdale and Edgar 2016

Table 1. Continued.

Region/Site	*N*	Dates/Time Period	Current Location[a]	References
Tlalnepantla-Tenayuca	18	1200–1520	INAH	Ragsdale and Edgar 2016
Northern Mexico				
Chalchiuites, Zacatecas	22	750–900	NMNH/ INAH	
Copper Canyon	32	1300–1700	NMNH/ INAH	Ragsdale and Edgar 2016
Cuatro Cienegeas (near), Coahuila	18	1300–1500	NMNH/ INAH	
Cueva de Candelaria Coahuila	20	1300–1500	NMNH/ INAH	
Guasave	16	900–1400	NMNH/ INAH	Ragsdale and Edgar 2016
Nararachic	24	1200–1700	NMNH/ INAH	Ragsdale and Edgar 2016
Navarachic Burial Cave, Chihuahua	18	1350–1500	NMNH/ INAH	
Paila, Coahuila	12	1300–1500	NMNH/ INAH	Ragsdale and Edgar 2015
Potrero de Cachilar, Durango	14	1300–1500	NMNH/ INAH	
Tayopa, Sonora	15	1400–1600	NMNH/ INAH	
Vista Hermosa, Tamaulipas	25	1200–1550	NMNH/ INAH	
Paquimé	35	1180–1400	ASU	Ragsdale and Edgar 2015
Total number	1,528			

[a]Abbreviations: Arizona State Museum (ASM), Arizona State University (ASU), Instituto Nacional de Antropología e Historia, Mexico City (INAH), New Mexico Office of Archaeological Studies (OAS), Center for New Mexico Archaeology (CNMA), Museum of Indian Arts and Culture (MIAC), Maxwell Museum of Anthropology (MMA).
[b]This comes from information provided by the Archaeological Management Section (or ARMS) in the form of a period name or range of possible periods of occupation. In the linear discriminant analysis (LDA), Northern Mexico and Central Mexico are "Mexican"; Middle Rio Grande, Northern Rio Grande, Rio Abajo, Hawikku, Mogollon, and La Plata Highway sites are "New Mexican"; Pottery Mound is "POT"; Kinishba and Turkey Creek Pueblo are Arizonan. All dates are AD unless otherwise noted.

these analyses and data was not collected. All methods used here are nondestructive.

The first (O'Donnell) and last (Ragsdale) authors made observations on 62 maxillary and mandibular dental traits for all permanent teeth. Traits are not recorded if teeth are broken, if they have large caries (cavities), or when attrition (wear) has obscured visibility. Morphological data was available for 1,528 individuals.

Dental morphological data are produced by examination of standardized traits of the crown and root of the tooth, such as Carabelli's cusp and incisor shoveling, using the Arizona State University Dental Anthropology System. This is a standardized system that utilizes plaques with casts of the dental traits in concert with detailed descriptions from Turner and colleagues (1991) and Edgar (2017). Dental morphological data were collected for each observable tooth, on the right and left sides. The side with the highest score represents the maximum expression of the trait (Turner 1985). Standardized breakpoints from Scott and Irish (2017) were used to dichotomize the data.

Human tooth morphology is under genetic control (Delgado et al. 2018), and dental traits are selectively neutral. Teeth "evolve very slowly" (Scott and Turner 2018:13), experiencing few morphological changes over the course of many generations (Bailey 2002). Several dental morphological studies incorporate groups separated by large time spans, and Hanihara and Ishida (2005) and Hanihara (2010) offer examples of such work. These characteristics of the human dentition render dental morphology useful for tracking population movements because gene frequencies are changing due to population interactions such as migration (gene flow; Irish and Turner 1990; Turner et al. 1991) as opposed to time. Dental morphological traits can be used to compare populations that are separated geographically and temporally. This is challenging to accomplish using aDNA. Due to their highly heritable nature, dental traits can serve as proxies for biological relationships (Irish 2015; Martinón-Torres et al. 2007; Scott and Turner 2018).

O'Donnell (2019:175–177) examined whether trait frequencies of individuals included in this study changed over time or due to regional variation. T-tests were done with weighted traits so as to render traits comparable to one another (on a scale from zero to one) to look for differences in means between time periods. No significant differences were found between trait frequencies over time. Trait frequencies were found to vary by region, however. These results support assertions that traits evolve slowly and that time is not a driving factor in trait variance.

Analytical Methods

Error Tests

Forty-four individuals were examined by O'Donnell with a separation of one week to three months to conduct intra-observer error tests of rater reliability. An additional group of 20 individuals was analyzed by the first and third author to test inter-observer reliability. Cohen's Kappa was estimated for dichotomous data, in addition to the average mean grade difference (AMGD) for nondichotomous data. AMGD is used to examine differences in scoring of categorical data, and it is the absolute value of scoring differences. It does not account for directional differences (whether scores shift up or down the grade scale; Pilloud 2009). AMGD is presented for O'Donnell. Presence-absence variance (PAV) was estimated following Nichol and Turner (1986). PAV is used to assess whether categorical differences in scoring of a trait resulted in it being scored as present in one session and absent in another, or vice versa.

Mean Measure of Divergence and Pseudo-Mahalanobis Distance

For this study, we used the mean measure of divergence (MMD) and the pseudo-Mahalanobis distance (D^2). Due to shortcomings of MMD and D^2, we opted to estimate biodistance using both. MMD is used to estimate biodistance by comparing morphological trait frequencies and a count of the number of individuals with a given trait. MMD can be used to estimate biodistance between groups of small size (as few as 10 individuals; see Irish 2010), as well as for traits with low ($\leq$0.05) or high ($\geq$0.95) frequencies, through the Freeman and Tukey (1950) transformation. Negative MMD values indicate no differences between groups (Harris and Sjøvold 2004; Irish 2010), and they were converted to "0" as suggested by other researchers (Harris and Sjøvold 2004; Relethford et al. 1997). Because MMD assumes no correlations exist between nonmetric traits, correlated traits must be excluded from analyses (Irish 2010). MMD was estimated in RStudio (RStudio Team 2016).

The D^2 statistic was developed for use with dichotomous data. D^2 is estimated through use of *z*-scores and a tetrachoric correlation matrix (Irish 2016; Konigsberg 1990). An issue that arises in D^2 analysis is that it does not correct for small sample sizes (Irish 2016). Unlike MMD, it incorporates adjustments for intercorrelations of nonmetric traits, which aids in the avoidance of erroneous results (Hallgrímsson et al. 2004; Pilloud and Hefner 2016). D^2 was estimated using SAS University edition (SAS Institute 2020).

Prior to estimation of MMD and D^2, we estimated a tetrachoric correlation in SAS University edition for all traits. Tetrachoric correlation is designed for use with binary data. Prior to calculating tetrachoric correlations, we removed dental traits with similar frequencies of expression, as they do not provide information about variation between groups. Clusters based on the three principal components that explained the most variance were calculated using PAST Software (Hammer et al. 2001).

Linear Discriminant Analysis

Individual level analyses were also employed in this study. Linear discriminant analysis (LDA) was calculated in R-Studio using the MASS package. LDA is used to estimate phenetic similarities at the level of the individual (O'Donnell 2019; O'Donnell and Edgar 2015; O'Donnell and Ragsdale 2017). LDA is robust to nonmultivariate normality and skewness of data (Sever et al. 2005). Consequently, it is ideal for use with dental morphological data. LDA was done using the groupings shown in Table 1, but the labels were simplified for ease of reading the plot. MRG, NRG, and the Rio Abajo are labeled as "New Mexican," Pottery Mound is labeled as "POT," Turkey Creek and Kinishba are labeled as "Arizonan," and sites in Mexico and Mesoamerica are labeled as "Mexican." A 2D representation of LDA results was made using RStudio.

Results

Intra- and Inter-Observer Error Tests

Cohen's Kappa results show an intra-observer (O'Donnell) percent agreement between 0.72 and 1, with an average K of 0.74 (see Ragsdale and Edgar [2015] for Ragsdale's error). Inter-observer tests (O'Donnell and Ragsdale 2017) show a percent agreement between 0.7 and 1, with an average K of 0.7. K values between 0.61 and 0.80 are defined as "substantial agreement," and those between 0.81 and 1 are defined as "almost perfect agreement" (McHugh 2012:279).

Traits were scored by O'Donnell as present during one session but absent during another (PAV) between 0 and 23% of the time; O'Donnell and Ragsdale have a PAV between 0 and 31%. These results are comparable to other studies: Nichol and Turner (1986) reported PAV of 0 to 39.6% of the time, and Edgar (2002) reported PAV scores between 0 and 28%.

AMGD for O'Donnell was 30%, comparable to Edgar and Lease (2007), who had AMGD of 35.8%, and to Nichol and Turner (1986), who had AMGD of 33.6% to 37.8%, although slightly higher than Pilloud (2009), who had AMGD of 21%.

Mean Measure of Divergence, Mahalanobis D^2, and Linear Discriminant Analysis

Following the removal of correlated traits, there were 12 morphological traits used in analysis (Table 2). The MMD results (Table 3; Figure 2) explain 86.8% of the variance. These results show that Pottery Mound is most similar to the Mogollon, Rio Abajo, and La Plata Highway groups, all with distances of "0." The MMD (Table 3) shows that the site is moderately similar to Central Mexico and MRG, with distances of 0.14 and 0.17, respectively. Interestingly, the dendrogram (Figure 2) indicates that Pottery Mound is more similar to the MRG—they are on the same branch—than the MMD distances by themselves imply. The site is least similar to Northern Mexico, Kinishba, Hawikku, and Turkey Creek Pueblo. The cluster analysis shows comparable results (Figure 2). Pottery Mound is most similar to the Mogollon, La Plata Highway sites, and MRG. The Arizona sites (Kinishba and Turkey Creek Pueblo) cluster with Northern Mexico.

Table 2. Traits and Breakpoints Used in the Study.

Trait Name	Breakpoint
Interruption Groove, Upper I2	Grade 1+
Tuberculum Dentale, Upper I1	Grade 2+
Tuberculum Dentale, Upper Canine	Grade 2+
Accessory Cusp, Upper P3	Grade 1+
Metacone, Upper M2	Grades 5, 6
Hypocone, Upper M1	Grade 3+
Shoveling, Lower I2	Grade 1+
Distal Accessory Ridge, Lower Canine	Grade 1+
Cusp Complexity, Lower P3	Grade 4+
Trigonid Crest, Lower M2	Grade 1+
Cusp 6, Lower M1	Grade 1–5
Protostylid, Lower M1	Grade 1+

Note: Breakpoints are from Edgar (2017) and Scott and Turner (2018).

D^2 results (Table 3; Figure 3) are similar to those from MMD. The smallest biodistances are between Pottery Mound, the Mogollon, La Plata Highway, and Rio Abajo. The site is plotted at almost the same distance from Central Mexico as it is from the MRG (and moderately phenetically similar). Pottery Mound is least similar to Paquimé, with the largest distance of 34.4. The cluster analysis of the D^2 results is virtually identical to that of the MMD. All results indicate that Pottery Mound is phenetically closest to the Mogollon, MRG, Rio Abajo, and La Plata Highway sites and least similar to Hawikku or Paquimé.

The variance explained by the LDA—68.6% (Figure 4)—is lower than that of the MMD or D^2 because individual level analyses introduce noise and some ability to explain variation is lost. The LDA shows two distinctive clusters. The cluster in the lower left is mainly composed of individuals from Arizona (Figure 4a, 4e) and Mexico (Figure 4b, 4e). The upper-right cluster has two divisions, with individuals from Mexico and Arizona in the upper middle of the plot and Ancestral Puebloans from New Mexico (Figure 4c, 4e) in the lower-right portion of the cluster. Individuals from Pottery Mound (stars, Figure 4d, 4e) demonstrate a pattern of variation indicating

Table 3. Mean Measure of Divergence (MMD) Results (Bottom Diagonal) and Mahalanobis Distance Squared (D^2) Results (Top Diagonal).

	Casas Grandes	Central Mexico	Hawikku	Kinishba	Mogollon	Middle Rio Grande	Northern Mexico	Northern Rio Grande	Pottery Mound	Rio Abajo	La Plata Highway	Turkey Creek Pueblo
Casas Grandes	0.00	27.20	31.90	20.40	29.10	19.80	12.50	23.00	**34.40**	25.40	22.50	9.88
Central Mexico	—	0.00	9.29	4.13	10.40	15.60	5.83	3.49	**10.50**	16.80	15.70	9.65
Hawikku	—	0.22	0.00	15.60	18.90	27.10	17.40	13.20	**19.50**	28.80	24.00	22.78
Kinishba	—	0.14	0.47	0.00	17.70	18.90	4.55	7.73	**15.10**	15.70	19.20	5.57
Mogollon	—	0.23	0.48	0.69	0.00	8.65	12.80	8.87	**3.27**	11.50	6.47	15.52
MRG	—	0.31	0.63	0.55	0.13	0.00	14.90	6.63	**10.10**	3.75	4.33	14.53
North Mexico	—	0.21	0.57	0.13	0.57	0.39	0.00	8.43	**16.50**	17.90	16.10	1.50
NRG	—	0.06	0.19	0.15	0.27	0.20	0.16	0.00	**9.44**	8.26	10.60	9.47
Pottery Mound	—	**0.13**	**0.31**	**0.47**	**0.00**	**0.19**	**0.55**	**0.18**	**0.00**	**8.63**	**5.52**	**19.17**
Rio Abajo	—	0.14	0.37	0.24	0.12	-0.09	0.24	0.01	**0.00**	0.00	8.43	16.04
La Plata	—	0.19	0.51	0.39	0.11	0.11	0.39	0.18	**0.00**	0.05	0.00	17.06
Turkey Creek	—	0.29	0.65	0.04	0.84	0.56	0.01	0.19	**0.72**	0.33	0.49	0.00

Notes: Pottery Mound results in bold. D^2 results include Casas Grandes, but this site was incorporated into Northern Mexico in the MMD, so no distance is available (represented by dashes).

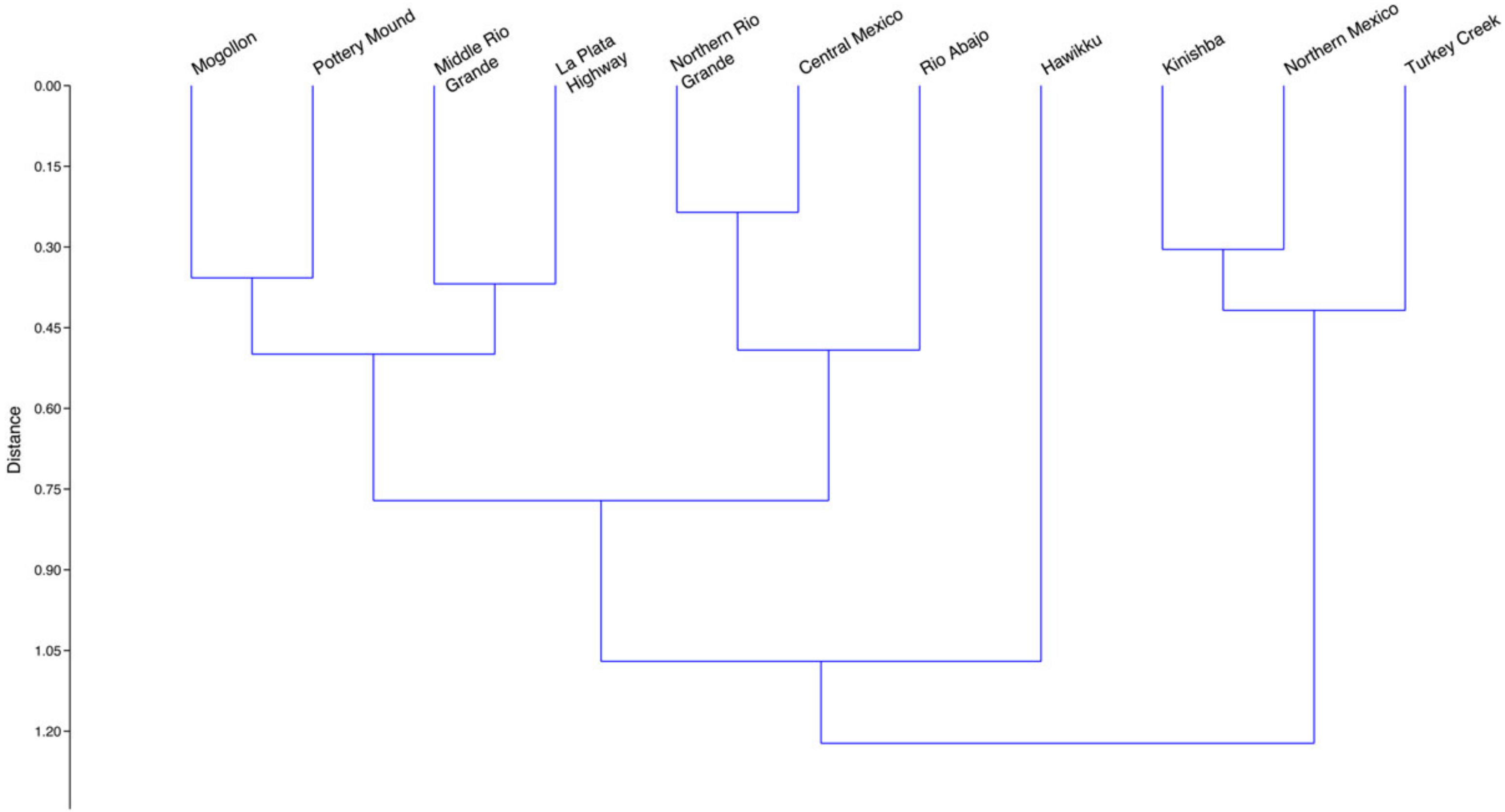

Figure 2. Dendrogram of mean measure of divergence (MMD) results, cophenetic correlation of 0.8502.

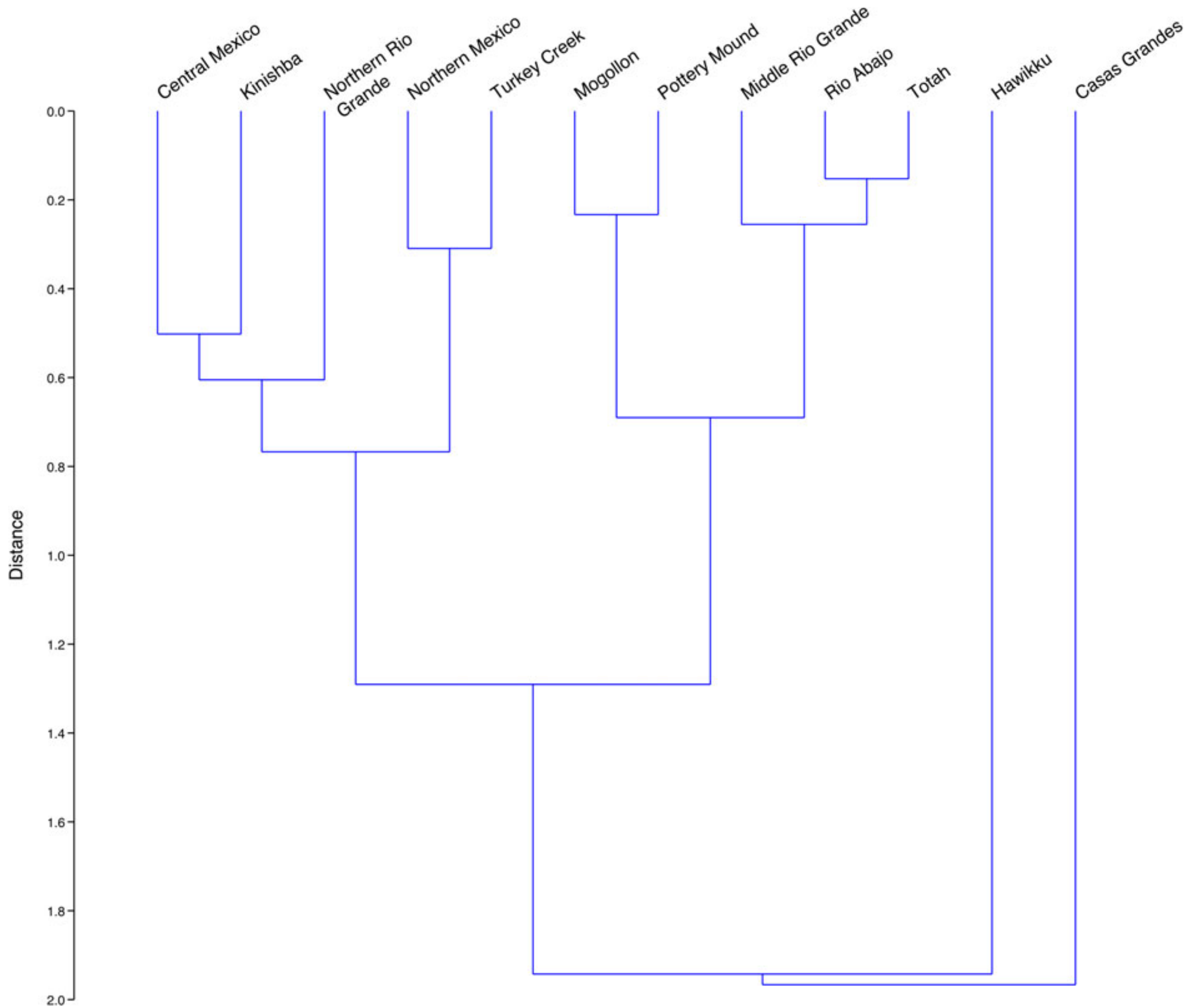

Figure 3. Dendrogram of Mahalanobis distance squared (D^2) results, cophenetic correlation of 0.95.

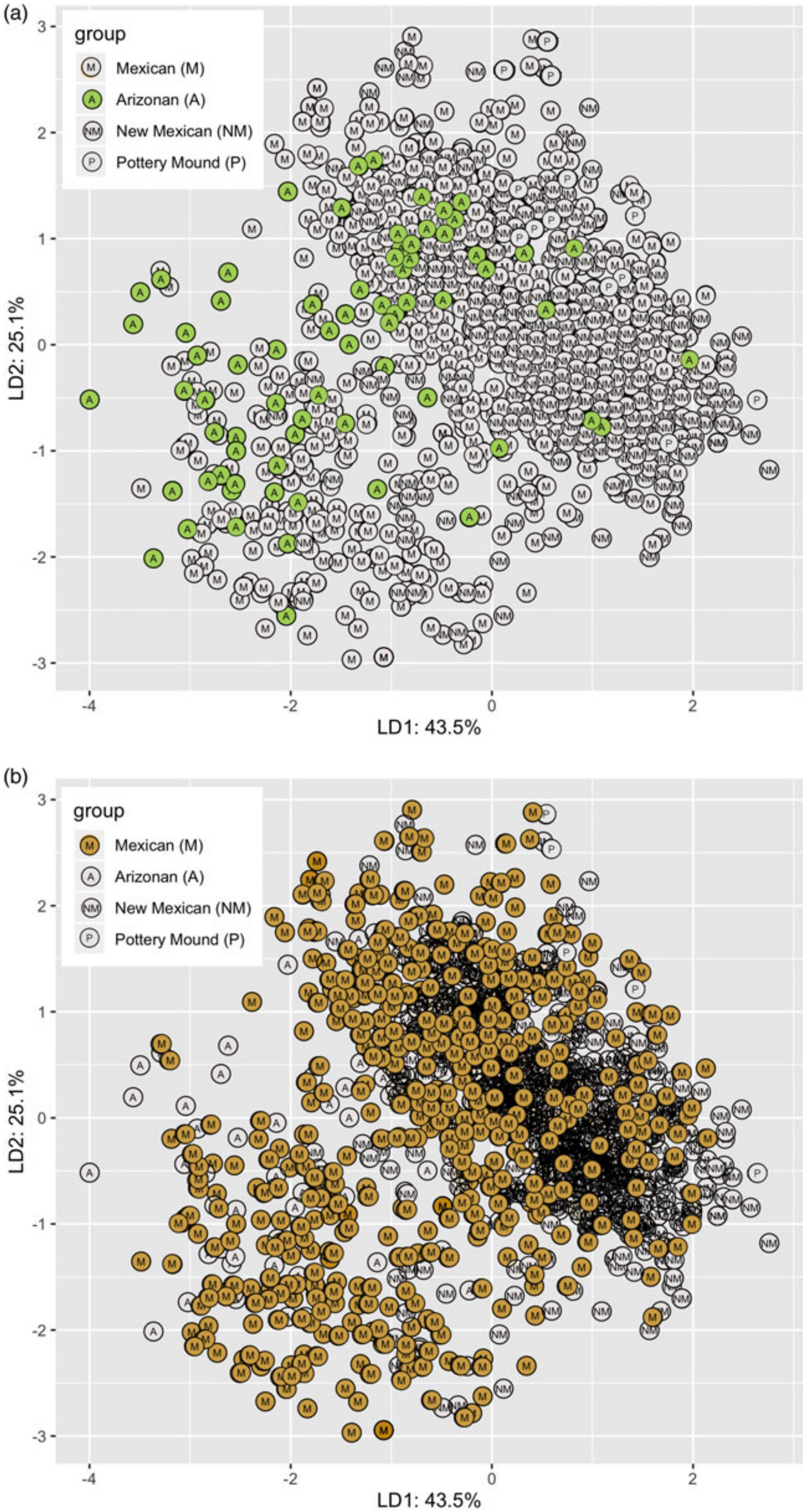

Figure 4. Plot of linear discriminant analysis (LDA) results. The first four plots (a–d) highlight individual groups, whereas e shows all results in a single plot. Figure 4a shows results for Arizonans (A), Figure 4b shows results for Mexico (M), Figure 4c shows results for New Mexicans (NM), and Figure 4d shows results for Pottery Mound (P). Figure 4e shows all results plotted together. (Color online)

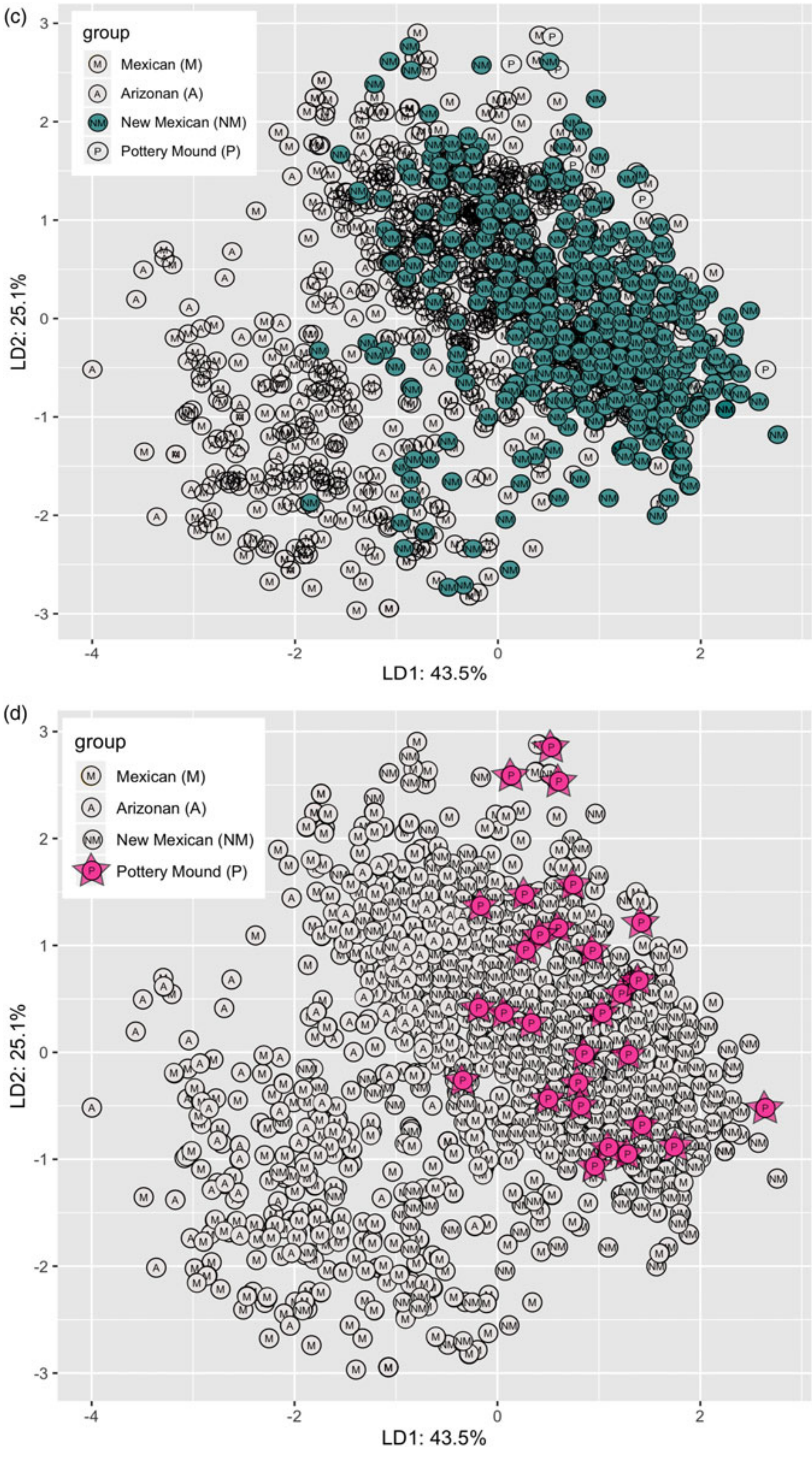

Figure 4. Continued.

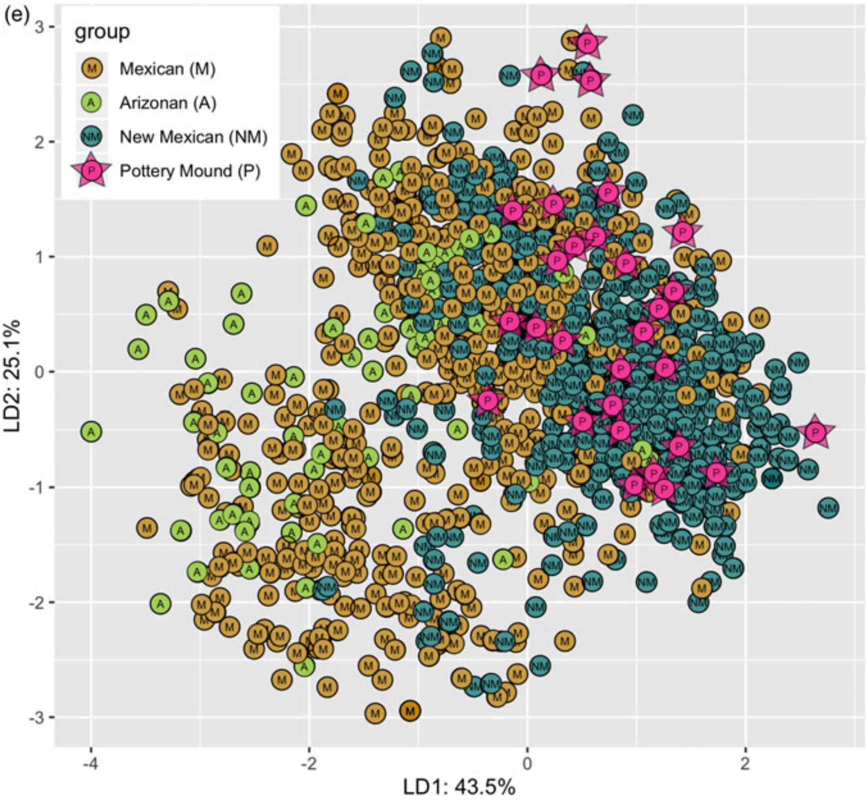

Figure 4. Continued.

that they are New Mexican Ancestral Puebloans, clustering mainly with the New Mexico Puebloan groups. Some individuals cluster more closely with individuals from Mexico and Arizona. This demonstrates the diversity of Pottery Mound inhabitants as individuals.

Discussion

The results of the group-level analyses show that the people of Pottery Mound are phenetically most similar to the MRG, their neighbors to the south—the Mogollon—and to individuals from the La Plata Highway sites. Although individuals (Figure 4) from Pottery Mound exhibit diversity, they are most similar to Puebloans from New Mexico.

Our first model (Model 1/Hypothesis 1)—which examines Pottery Mound's similarity to the Western Pueblos, with Hawikku as a proxy for the Western Pueblos—is not supported by our results. It is conceivable that inclusion of different Western Pueblo groups or a greater number of individuals might change this result. This result does not necessarily mean that trade was not occurring between the two areas, but it does suggest little to no gene flow between them. This appears to be specifically true for the relationship between Pottery Mound and Hawikku, the Western Pueblo representative. Although the number of individuals from Hawikku is small, the MMD statistic employs corrections for this (see Irish 2010).

Hays-Gilpin and LeBlanc propose that Sikyatki style does not necessarily have to be "associated with Hopi or any other extant ethnic or language group" (2007:123). They suggest a possible migration from Pottery Mound toward Hopi Mesas. Although we do not have a Hopi comparative in this article, Hays-Gilpin and LeBlanc's suggestion may explain why we do not see a Western Pueblo connection in the results.

This stands in contrast to Eckert's (2007) ceramic evidence for migratory events toward Pottery Mound bringing Hopi-style ceramic traditions as well as new pottery manufacturing techniques. It is compelling that the appearance of new styles and new tempering methods occurs stratigraphically at the same time (Eckert 2007). Although Pottery Mound is well known for the occurrence of Western Puebloan pottery, the overall percentage of Hopi sherds within the assemblage is small (Schaafsma, ed. 2007), suggesting that possible migrants from the West may have been low in number. The possibility that this study may not have included these individuals or that their small percentage could have been insufficient to affect the biodistance values of Pottery Mound as a group cannot be discounted. Franklin (2018) and colleagues (2014:30) report that imports from Acoma-Zuni are more numerous (926 sherds, 5.1% of the sample) than those from Hopi (160 sherds, 0.1% of the sample) and may indicate "stronger ties" between the two locales. As they currently stand, however, our results imply that these ties may have been through trade alone, with little to no gene flow.

The second hypothesis—that Pottery Mound would be most similar to northern Mexico, due to a purported connection between the Casas Grandes area and Pottery Mound (Model 2/ Hypothesis 2)—cannot be fully refuted. Interestingly, Pottery Mound is least similar to northern Mexico while it is moderately similar to central Mexico. Visual representation of all results suggests that the similarity is likely occurring on only one component or linear discriminant, and for the most part indicates that Pottery Mound is most similar to geographically proximate places. Archaeological evidence for a connection between Pottery Mound and Mexico is tenuous, based on few artifacts and mural motifs.

Neither the architectonic ties nor the asseverated macaw skeleton have been confirmed by later researchers, despite several attempts to do so (David Phillips, 2019 personal communication). Parallels between Mesoamerican and Southwestern iconography and cosmology have been noted throughout the Southwest (Hays-Gilpin and Hill 1999; Schaafsma 2009; Washburn 2019). Similarities between Pottery Mound's murals and those in Mesoamerica could be related to the fact that this site offers a particularly rich iconographic legacy, rather than being a "center of Mexican influences" as reported by Hibben (1967:87).

Model 3/Hypothesis 3—which posited that the people of Pottery Mound, as a group, are most similar to places in close geographic proximity—is best supported by the data. Pottery Mound is phenetically most similar to the Mogollon, MRG, Rio Abajo, and La Plata Highway sites. This result is interesting in light of artifactual evidence for trade and ties to other places in the Greater Southwest, including the Western Pueblos and Mexico, and a lack of phenetic evidence for significant gene flow from these areas. Previous biodistance analyses also indicate phenetic similarity between Pottery Mound and the MRG (e.g., Mackey 1980; O'Donnell and Ragsdale 2017:524; Schillaci et al. 2001; Schorsch 1962; Figure 2). Additionally, Hays-Gilpin and colleagues (2019) propose a model for movement between pueblos not necessarily involving residential migration. Instead, they suggest sodality "diffusion." In this scenario, ritual practitioners were sent to different communities for sodality initiation, and later, they returned home to deliver new rituals to their own community. Our results are not out of keeping with this interpretation, and they are in line with current understandings of Pottery Mound from a purely archaeological perspective (see Schaafsma, ed. 2007).

The Mogollon region lies geographically between the MRG and northern Mexico. Objects from Mexico, including copper bells and macaws, have been excavated in the Mogollon region (McGuire 2005; Vargas 1995). It is possible that the Mogollon region may have served as an intermediary for trade between Mesoamerica and the Puebloan Southwest. If this is the case, the close phenetic similarity between Pottery Mound and the Mogollon could be due to gene flow because of a trade connection.

Conclusions and Future Directions

This study tested three models for gene flow to Pottery Mound based on previously suggested patterning of migration events, trade relationships, and cultural influences (e.g., Eckert

2007; Franklin 2018; Hibben 1960, 1967). Architectural, iconographic, and ceramic evidence suggests a close connection between the site and the Western Pueblos and/or (northern) Mexico, that so far had not been tested using biological data. A connection to the MRG, however, is best supported by our results, which show Pottery Mound to be phenetically most similar to individuals from neighboring areas and the Mogollon to the south. Interestingly, representatives from the Western Pueblos and northern Mexico—areas most often suggested to have had a considerable influence on Pottery Mound—produced some of the highest biodistance values. Consequently, they were least similar to Pottery Mound. It is possible that the result for the Western Pueblo groups is influenced by the small number of individuals from Hawikku, and results could change with an increase in size of the comparative group, or through inclusion of individuals from additional sites in the area.

It is possible that future studies—using an individualized approach and, for instance, combining biodistance analyses with mortuary and spatial data from the site—may shed more light on the questions of gene flow and the biological composition of the community at Pottery Mound.

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Data Availability Statement. Lexi O'Donnell's data is embargoed until 2021 to allow her to publish findings from her dissertation. This data will be available to bona fide researchers upon request after the embargo period lapses. Corey S. Ragsdale's data is available to bona fide researchers upon request.

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