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ANTHROPOLOGY

Was Aztec and Mixtec turquoise mined in the American Southwest?

Alyson M. Thibodeau[1]*, Leonardo López Luján[2], David J. Killick[3], Frances F. Berdan[4], Joaquin Ruiz[5]

Archaeologists have long suggested that prehispanic states in Mesoamerica acquired turquoise through long-distance exchange with groups living in what is now the American Southwest and adjacent parts of northern Mexico. To test this hypothesis, we use lead and strontium isotopic ratios to investigate the geologic provenance of 43 Mesoamerican turquoise artifacts, including 38 mosaic tiles from offerings within the Sacred Precinct of Tenochtitlan (the Mexica or Aztec capital) and 5 tiles associated with Mixteca-style mosaics currently held by the Smithsonian's National Museum of the American Indian. Most of these artifacts have isotopic signatures that differ from turquoise deposits in the American Southwest, but closely match copper deposits and crustal rocks in Mesoamerica. We thus conclude that turquoise used by the Aztecs and Mixtecs likely derives from Mesoamerican sources and was not acquired through long-distance exchange with the Southwest.

INTRODUCTION

For more than 150 years, scholars have argued that Mesoamerican societies imported turquoise from the American Southwest or adjacent parts of northwestern Mexico—a region that many archaeologists refer to as the Greater Southwest (*1*–*7*). Turquoise [$CuAl_6(PO_4)_4(OH)_8{\cdot}4H_2O$] was one of several blue-green minerals highly valued by prehispanic societies across both regions, including the Aztec, Toltec, Maya, Mixtec, and Tarascan states in Mesoamerica, and the Hohokam, Mogollon, and Puebloan groups of the Greater Southwest (hereafter "Southwest"). Although turquoise artifacts are found in archaeological sites throughout these regions, major North American turquoise deposits and prehispanic turquoise mines are largely confined to the U.S. states of Arizona, New Mexico, California, Colorado, and Nevada and to parts of northernmost Mexico (Fig. 1) [(*8*) and references therein].

The observation that there are numerous known examples of prehispanic turquoise mines in the Southwest, but not in Mesoamerica, has, in part, formed the basis for claims that Mesoamerican groups imported turquoise from the north (*7*). The long-distance exchange of ideas and other items between Mesoamerican and Southwestern groups is well documented, especially after ~900 CE, when firm evidence for small quantities of Mesoamerican imports (for example, scarlet macaws, cacao, and copper bells) appears in Southwestern archaeological sites (*9*–*11*). Many archaeologists have suggested that turquoise was traded to Mesoamerica in exchange for these exotic goods. In addition, assertions about sources of Mesoamerican turquoise also derive from previous geochemical investigations. From the 1970s through the 1990s, there was a long-term program of chemical analysis by neutron activation of both Mesoamerican and Southwestern turquoise objects (*2*–*5*). These studies interpret the geologic provenance of various turquoise artifacts by comparing their trace and major element signatures with those of turquoise samples from prehispanic mines. Although the resulting publications claim that turquoise artifacts from Mesoamerica derive from Southwestern mines (*2*–*5*), the underlying data were never published. Thus, their assertions that Mesoamerican societies acquired turquoise from the Southwest cannot be evaluated.

Here, we revisit the hypothesis that Mesoamerican turquoise derives from the Southwest by using lead (Pb) and strontium (Sr) isotopes as tools to investigate the geologic origin of turquoise objects associated with the Aztecs and Mixtecs. In the Basin of Mexico, Aztec (Mexica) elites were among the most prolific consumers of turquoise during the Aztec imperial years of the Late Postclassic (ca. 1430 to 1519 CE). Turquoise figures prominently in Aztec poetry, ritual, and cosmology (*12*–*15*) and was used to make a variety of mosaic objects (for example, ceremonial shields, handles on sacrificial knives, mirrors, diadems, pectorals, armbands, necklaces, noseplugs, and earrings) that were worn or wielded by rulers, priests, or other high-status individuals in Aztec society (*16*–*20*) and even decorated wolves and other sacred animals (*21*). Our knowledge of *xihuitl* (or turquoise) in the Aztec empire primarily derives from 16th century documents and codices that contain textual and pictorial representations of the mineral (*17*–*19*, *22*). According to the *Codex Mendoza*, an imperial tribute list, turquoise was sent to the Aztec imperial overlords from two provinces in the southern (Mixteca) area of the empire and from one province in the empire's northeastern corner (Fig. 1) (*22*). Extant examples of Mesoamerican turquoise mosaics include about two dozen Mexica- and Mixteca-style mosaics that reside in European and American museums and have no archaeological provenience (fig. S1) (*16*, *23*–*25*). There are also a number of archaeologically recovered artifacts, including Mixtec turquoise mosaics directly excavated from Monte Albán's Tomb 7 (*26*) and Mexica mosaics from buried offerings within the Sacred Precinct of Tenochtitlan (figs. S2 to S4 and table S1) (*21*, *27*–*29*), which was the political and ceremonial center of the Aztec empire (Fig. 1) (*27*, *30*).

Background

Presently, there are Pb and Sr isotopic measurements of both geological and archaeological samples of turquoise from the Southwest that provide a baseline for evaluating whether Aztec or Mixtec artifacts have a Southwestern origin (*8*, *31*–*33*). These measurements include Pb and Sr isotopic ratios on >150 geological samples of turquoise from 19 different mining districts across Arizona, New Mexico, Colorado, southeastern California, and southern Nevada in the United States, and in northern

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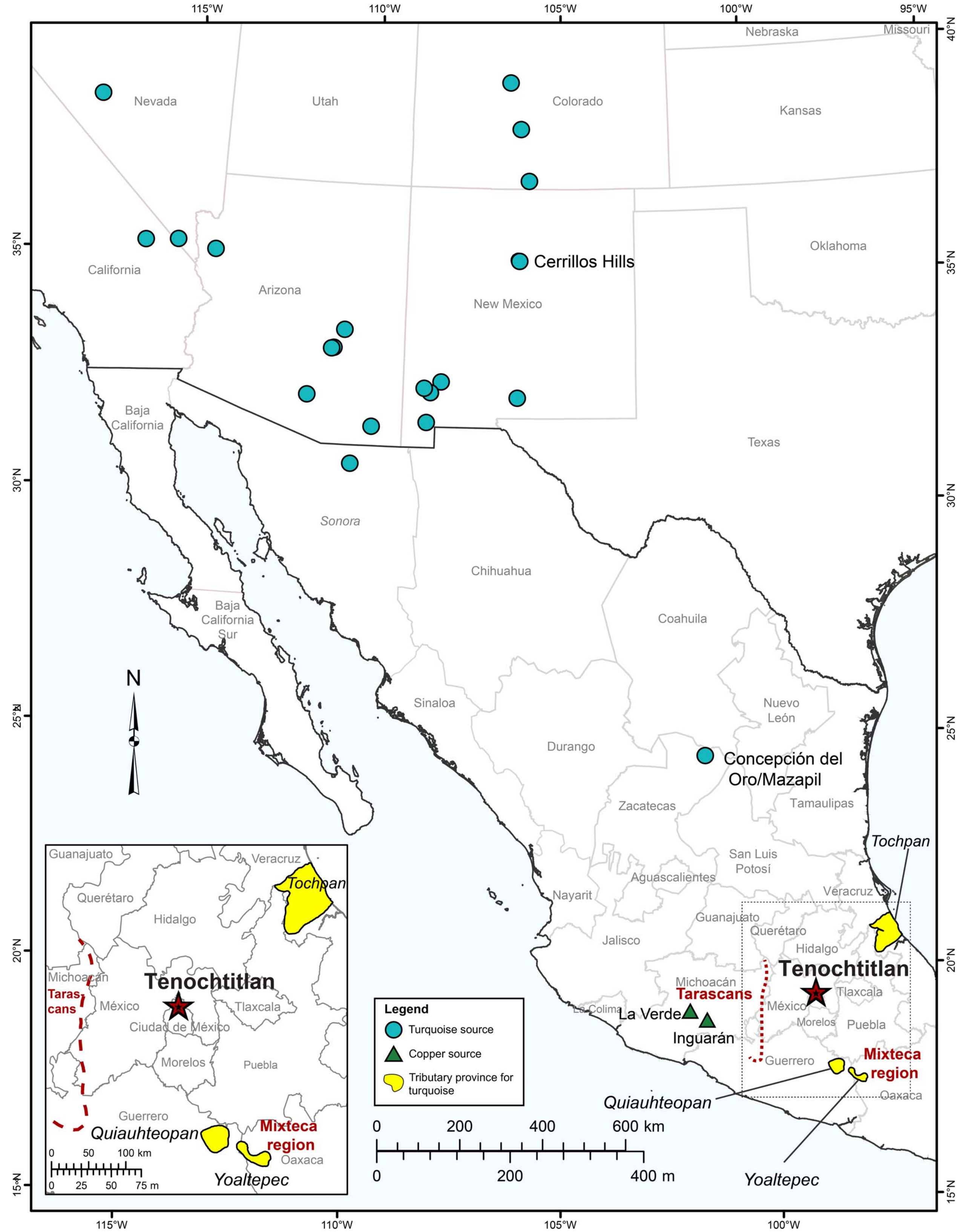

Fig. 1. Map of locations discussed in the text. The Southwestern turquoise deposits shown here are discussed in the study of Thibodeau *et al.* (*8*) and have been previously characterized with Pb and Sr isotopic ratios (*8*, *31*, *33*). No isotopic data are available on turquoise deposits of the Concepción del Oro or Mazapil localities. Aztec tributary provinces are drawn based on the study of Berdan (*18*). Dotted red line indicates approximate boundary between the Aztec and Tarascan empires.

Sonora, Mexico (*8*, *31*). Many of the geological samples derive from mining districts with known prehispanic mining activity.

Unlike the Southwest, where there are many documented prehispanic turquoise mines with associated isotopic data, little is known about possible turquoise deposits within the Aztec empire, including the Mixteca region, or in other bordering areas of Mesoamerica. In Mexico, the southernmost turquoise mines that have been documented in both the geological and archaeological literature are near the municipalities of Concepción del Oro and Mazapil in northern Zacatecas (*2*, *7*, *34*). Some of the older archaeological and ethnohistorical literature preserves secondhand reports of turquoise deposits in Jalisco and Puebla (*18*, *35*, *36*), but, to the best of our knowledge, no scholars have located or verified the existence of turquoise deposits in these areas. However, because turquoise mines are often small and shallow workings occurring near economically significant deposits of copper, they may be easily exhausted, altered, or destroyed by later mining practices. The destruction of ancient turquoise mines is known to have occurred in the American Southwest [for example, see discussion in the study of Thibodeau *et al.* (*33*)] and thus may have also occurred in Mexico as well.

Although we are not aware of any direct evidence for turquoise mineralization in Mesoamerica, Pb and Sr isotopes offer an indirect approach to evaluating the possibility that Mesoamerican turquoise artifacts derive from Mesoamerican sources. To understand how, it is useful to first consider Pb and Sr isotopic variation in Southwestern turquoise deposits. Turquoise is generally formed in the oxide zones of copper deposits and derives its elemental constituents from the weathering of the surrounding geologic formations. In the Southwest, the isotopic characteristics of turquoise deposits vary regionally and reflect broad-scale differences in the age, chemical composition, and sources of the associated rocks (*8*, *37*). For example, in Arizona and New Mexico, many turquoise deposits have Pb isotopic signatures that broadly mirror those of their host copper porphyry deposits and associated felsic igneous complexes. In turn, these porphyry deposits have Pb isotopic characteristics that are consistent with the crustal province in which they are located, which is controlled by the age, initial Pb isotope composition, and U/Pb and U/Th ratios of the Proterozoic crystalline basement rocks that underlie southwestern North America (*38*). Strontium isotopic ratios of turquoise deposits also vary regionally in the Southwest: Deposits that have formed in the weathering zones of Laramide-age copper porphyry deposits or that are hosted by outcropping Precambrian rocks (for example, in central and southern Arizona) tend to have more radiogenic Sr isotopic ratios (^{87}Sr/^{86}Sr range, ~0.709 to 0.845) than deposits that have formed from the weathering of Oligocene copper-gold porphyry deposits in the Rio Grande Rift Valley of New Mexico and Colorado (^{87}Sr/^{86}Sr range, ~0.707 to 0.709) (*8*). Because turquoise deposits with similar isotopic signatures tend to cluster geographically based on the underlying geology, it should be possible to infer the region from which an artifact derives even if it has isotopic signatures that do not match a known deposit. Thus, Pb and Sr isotopes can potentially provide insight into the provenance of turquoise objects even if they derive from deposits that have been destroyed, are not known, or have not been sampled.

As is the case in the Southwest, we assume that any turquoise deposits present in Mesoamerica would form in the oxide zone of copper deposits and inherit their Pb and Sr isotopic signatures from the weathering of surrounding ores and rock units. Thus, existing data on the Sr isotope geochemistry of felsic rocks associated with copper ores in Mexico (*39*–*41*) provide a baseline for predicting whether and how the Sr isotopic compositions of any putative Mesoamerican turquoise deposits would differ from Southwestern ones. Likewise, abundant published data on the Pb isotopic ratios of copper and other mineral deposits in Mexico (*42*–*45*) provide a baseline for predicting the Pb isotopic characteristics of any turquoise deposits that may exist or may have once existed in this region.

Samples

We analyzed a total of 43 turquoise mosaic tiles, 38 of which were excavated from offerings in Tenochtitlan's Sacred Precinct, mainly within the *Templo Mayor* (Table 1) (*21*, *26*–*28*). Offerings containing turquoise artifacts are primarily located in the southern half of the *Templo Mayor* (fig. S3 and table S1) and are related to the cult of the Aztec patron god *Huitzilopochtli*, a war and sun deity. This southern half is also symbolically connected with *Xiuhtecuhtli*, the Turquoise Lord and fire deity. Most of the artifacts analyzed for this study derive from offerings that date to the late 15th century, during Phase VI of the *Templo Mayor*'s construction and the reign of Axayacatl (1469 to 1481 CE). Six of these 38 tesserae came from Offering 125, at the foot of the Great Temple, near the Earth goddess *Tlaltecuhtli* monolith (fig. S3) and which was deposited after Phase VI, during the reign of Ahuitzotl (1486 to 1502 CE) (table S1) (*21*). Although intact mosaics are present in some of these offerings, the tesserae we analyzed were found at the bottom of these ritual deposits, already disarticulated with no wooden supports attached (fig. S4).

We also analyzed five tesserae associated with Mixteca-style turquoise mosaics currently held by the Smithsonian Institution in the collections of the National Museum of the American Indian (NMAI) (fig. S1). These mosaics were described in a 1922 monograph by Saville (*16*) and are believed to have been collected from a cave in the Mixteca region of the state of Puebla, Mexico (*46*). No other information on their provenience is known. The tesserae analyzed were not removed from the objects themselves, but were taken from a small jar of dirt, adhesives, and loose tiles associated with the mosaics (NMAI catalog # 10/8719). Samples from NMAI and Tenochtitlan's Sacred Precinct range in size from about 1 cm (longest edge) to less than 5 mm (fig. S4).

RESULTS AND DISCUSSION

The Pb and Sr isotopic ratios of the tesserae are given in Table 1. Of the 43 tesserae analyzed, we were able to collect both Pb and Sr isotopic data on 31 samples. For the other 12 samples, we obtained either Pb or Sr isotopic ratios. When both Pb and Sr isotopic data are considered, 29 of the 31 tesserae fall outside the distribution of ratios for turquoise deposits in the Southwest (Fig. 2) (*47*). Furthermore, most of the objects form a tight cluster in isotope space, and the tesserae excavated from Tenochtitlan's Sacred Precinct have similar ratios to those associated with the Mixteca-style mosaics from NMAI (Fig. 2). For these reasons, we suggest that most of the turquoise mosaic tiles analyzed for this study derive from the same or geologically similar source(s).

Although the tesserae have signatures that do not match those of any of the known turquoise deposits, their isotopic ratios provide constraints on their provenance. Notably, the ^{87}Sr/^{86}Sr ratios of most tesserae are substantially lower than the ^{87}Sr/^{86}Sr ratios measured in Southwestern turquoise deposits (Figs. 2 and 3). For example, the lowest ^{87}Sr/^{86}Sr ratio measured on a sample of turquoise from the Southwest is 0.70624 (*8*). However, 30 of the 39 Mesoamerican samples for which we have data possess ^{87}Sr/^{86}Sr ratios that are lower (range, 0.70492 to 0.70622). One interpretation of these lower ^{87}Sr/^{86}Sr ratios is that these samples derive from deposits within Mesoamerica and possibly

Table 1. Isotopic ratios of Aztec and Mixtec turquoise artifacts. N.D., not determined.

Sample ID	Offering	$^{87}Sr/^{86}Sr$	% SE	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
Aztec mosaic tiles from the Sacred Precinct of Tenochtitlan								
TM-1	125	0.70580	0.0016	2.0581	0.83373	18.800	15.675	38.694
TM-2	125	0.70576	0.0008	2.0622	0.83560	18.721	15.643	38.605
TM-3	125	0.70554	0.0008	2.0578	0.83210	18.810	15.653	38.707
TM-8	125	0.70565	0.0013	2.0617	0.83537	18.817	15.636	38.589
TM-9	125	0.70627	0.0013	2.0511	0.83155	18.840	15.672	38.645
TM-19	125	0.70615	0.0013	2.0587	0.83153	18.813	15.643	38.734
TM-5	1	0.70618	0.0010	2.0556	0.83257	18.801	15.652	38.646
TM-10	1	0.70861	0.0010	2.0474	0.82817	18.924	15.672	38.745
TM-11	1	0.70579	0.0007	2.0618	0.83543	18.723	15.642	38.603
TM-20	1	0.70609	0.0009	2.0613	0.83522	18.727	15.641	38.603
TM-32	1	0.70598	0.0010	2.0618	0.83546	18.721	15.641	38.600
TM-12	11	0.70561	0.0015	1.9136	0.77403	20.303	15.716	38.854
TM-33	11	N.D.	N.D.	2.0548	0.83342	18.797	15.665	38.622
TM-21	11	0.70492	0.0015	N.D.	N.D.	N.D.	N.D.	N.D.
TM-13	13	0.70513	0.0010	2.0552	0.82892	18.889	15.655	38.814
TM-22	13	0.70557	0.0033	N.D.	N.D.	N.D.	N.D.	N.D.
TM-23	13	N.D.	N.D.	2.0389	0.82542	18.967	15.656	38.672
TM-30	13	0.70545	0.0007	2.0611	0.83536	18.728	15.645	38.600
TM-31	13	0.70525	0.0018	2.0371	0.82083	19.102	15.680	38.912
TM-14	17	0.70532	0.0008	2.0391	0.81894	19.154	15.686	39.056
TM-15	17	0.70547	0.0010	2.0633	0.83534	18.734	15.649	38.654
TM-24	17	0.70958	0.0053	N.D.	N.D.	N.D.	N.D.	N.D.
TM-36	17	0.70560	0.0010	2.0618	0.83431	18.764	15.655	38.687
TM-7	20	0.70579	0.0008	2.0390	0.82169	19.081	15.680	38.906
TM-25	20	0.70655	0.0007	2.0407	0.82427	18.993	15.658	38.763
TM-26	20	0.70564	0.0010	N.D.	N.D.	N.D.	N.D.	N.D.
TM-34	20	0.70520	0.0010	2.0602	0.83383	18.771	15.652	38.673
TM-35	20	0.70554	0.0010	N.D.	N.D.	N.D.	N.D.	N.D.
TM-16	60	0.70507	0.0010	2.0611	0.83550	18.719	15.641	38.583
TM-17	60	0.70529	0.0010	2.0628	0.83601	18.710	15.641	38.595
TM-28	60	0.70559	0.0008	N.D.	N.D.	N.D.	N.D.	N.D.
TM-37	60	0.71480	0.0007	1.9780	0.80346	19.556	15.713	38.683
TM-38	60	N.D.	N.D.	2.037	0.82120	19.096	15.681	38.888
TM-6	60	0.70607	0.0008	1.6922	0.69209	22.866	15.825	38.689
TM-27	60	0.70538	0.0008	2.0591	0.83443	18.746	15.643	38.600

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Sample ID	Offering	$^{87}Sr/^{86}Sr$	% SE	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
TM-29	98	0.70529	0.0008	2.0588	0.83423	18.740	15.633	38.582
TM-18	98	0.70622	0.0021	1.9868	0.80007	19.626	15.702	38.993
TM-41	98	0.70574	0.0029	N.D.	N.D.	N.D.	N.D.	N.D.
Mixtec mosaic tiles from the NMAI (NMAI catalog # 10/8719)								
NMAI-1		0.70637	0.0010	2.0289	0.81575	19.236	15.691	39.026
NMAI-2		0.70659	0.0009	2.0370	0.82416	19.034	15.688	38.773
NMAI-3		N.D.	N.D.	1.8448	0.74256	21.290	15.809	39.273
NMAI-4		0.70730	0.0010	2.0370	0.81831	19.182	15.697	39.073
NMAI-5		0.70737	0.0013	N.D.	N.D.	N.D.	N.D.	N.D.

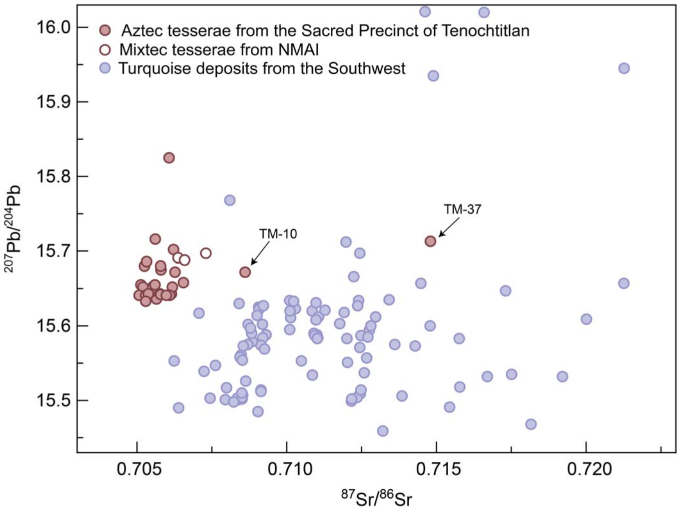

Fig. 2. Pb versus Sr isotope plot comparing Aztec and Mixtec tesserae to geologic samples of turquoise from the Southwest. Note that Aztec and Mixtec tesserae form a relatively tight cluster in isotope space that falls outside the distribution of isotopic ratios measured on Southwestern turquoise. Data on Southwestern turquoise deposits are from Thibodeau *et al.* (*8*), and some data points on geologic samples lie beyond the range of the graph. Symbols are larger than errors.

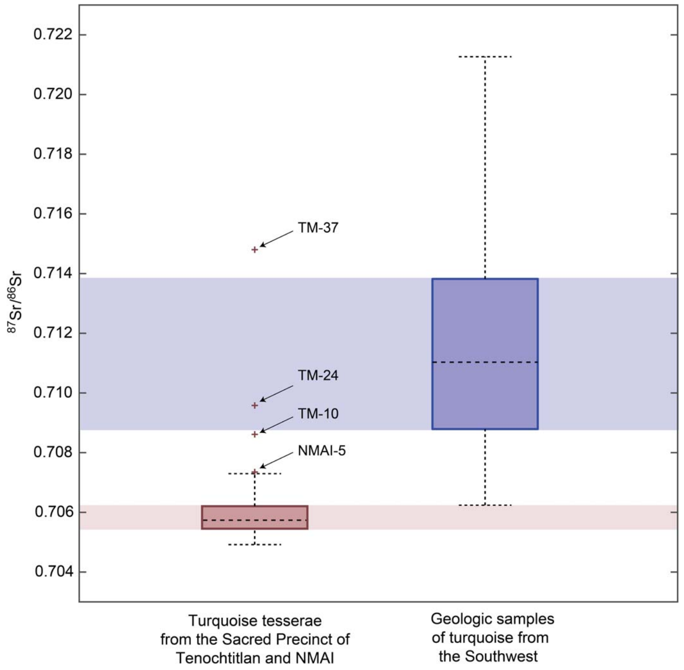

Fig. 3. Box and whisker plot comparing $^{87}Sr/^{86}Sr$ ratios of Aztec and Mixtec tesserae to geologic samples of turquoise from the Southwest. Data on Aztec and Mixtec tesserae are from this study ($n = 39$), and data on Southwestern turquoise deposits are from Thibodeau *et al.* (*8*) ($n = 108$). The tesserae have a median value of $^{87}Sr/^{86}Sr = 0.70574$ and an interquartile range of 0.70545 to 0.70621. Note that all the values within the tesserae's interquartile range are lower than the lowest $^{87}Sr/^{86}Sr$ ratio yet measured on a turquoise sample from the Southwest. The three samples with the highest $^{87}Sr/^{86}Sr$ ratios (TM-10, TM-24, and TM-37) derive from Offerings 1, 17, and 60, respectively, within the *Templo Mayor*, all of which date to the reign of Axayacatl (1469 to 1481 CE).

within western Mexico. In Mexico, the felsic rocks of the Sierra Madre Occidental, Sierra Madre del Sur, and Trans-Mexican Volcanic Belt host a number of copper deposits (*48*). In particular, copper porphyry mineralization extends southward from Arizona along the length of western Mexico to the state of Guerrero (*39*). Prior studies of felsic igneous rocks associated with these porphyry copper deposits have demonstrated that their initial $^{87}Sr/^{86}Sr$ ratios decrease along a north-south trend (*39*, *41*). These different initial ratios account, in part, for regional variations in their present-day $^{87}Sr/^{86}Sr$ ratios. For example, in southeastern Arizona, most felsic rocks associated with copper porphyry deposits have modern $^{87}Sr/^{86}Sr$ ratios greater than ~0.708 (*49*), while similar rocks in western Mexico (for example, Sinaloa, Jalisco, Michoacán, or Guerrero) frequently have values as low as 0.704 or 0.705 (*39*, *40*, *50*, *51*). Because there are regional differences in the Sr isotope geochemistry of felsic magmatic rocks that host copper deposits, we would also expect there to be comparable differences in the Sr isotopic composition of any associated turquoise mineralization. Thus, we suggest that the lower $^{87}Sr/^{86}Sr$ ratios measured on most tesserae (compared to Southwestern turquoise deposits) indicate they derive from Mesoamerican and not Southwestern sources.

Pb isotope ratios provide a second, independent line of evidence that these objects may derive from a source or sources within Mesoamerica. Although the Pb isotopic signatures of the tesserae overlap with Southwestern turquoise deposits (fig. S5A), they cluster in a region of Pb isotope space where they are collectively a poor match for any single deposit or group of deposits (fig. S5B). Notably, there is no overlap between the Pb isotopic composition of the tesserae and the turquoise

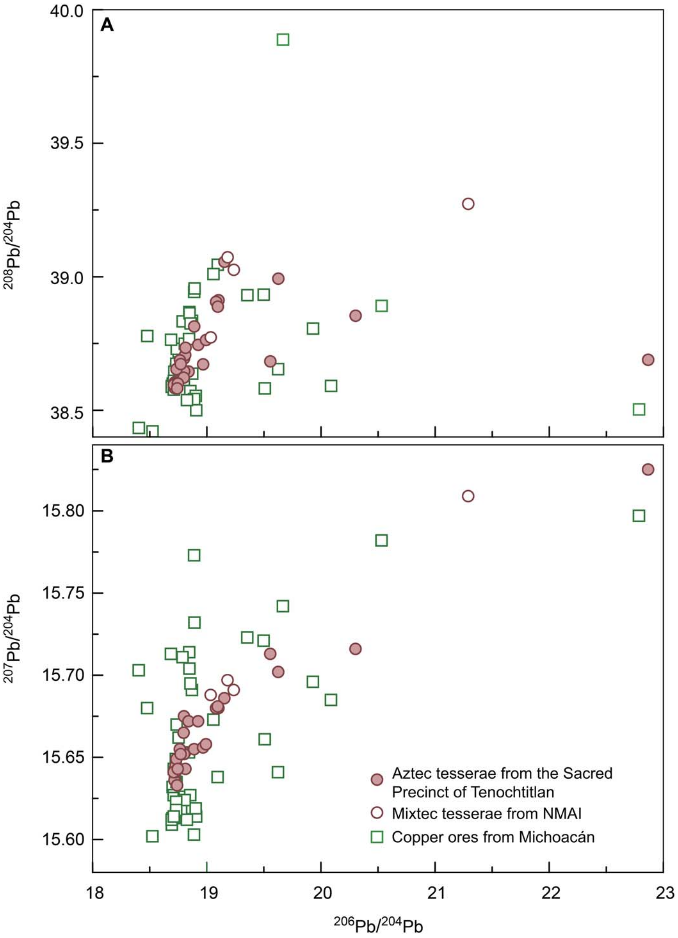

Fig. 4. Pb isotope plot comparing Aztec and Mixtec tesserae to copper ores from Michoacán, Mexico. Copper ores from Michoacán include samples from mines at the Inguarán, El Bastán, La Verde, Esmeralda, and El Zapote deposits. Data on copper ores are taken from Hosler and Macfarlane (*43*). Symbols are larger than errors.

deposits of the Cerrillos Hills, New Mexico (Fig. 1 and fig. S6), which are often considered to be a possible source for Mesoamerican turquoise based on both the size of the mines and the chronology of their exploitation (*52*). In contrast, the tesserae fall well within the range of Pb isotope compositions measured in Mexican mineral deposits (*42*–*45*). Note that samples TM-10 and TM-37, which have $^{87}Sr/^{86}Sr$ ratios that are much higher than those of the other tesserae (see Fig. 2), have Pb isotope ratios that are similar to that of the other samples. Because of this similarity, we suggest that even the few samples with relatively high $^{87}Sr/^{86}Sr$ ratios may derive from the Mesoamerican and not the Southwestern mines.

Although Pb isotopes provide strong evidence that the tesserae derive from Mesoamerican mines, we cannot isolate their exact source(s) because of the substantial overlap among the Pb isotopic signatures of copper deposits throughout western and central Mexico (*42*–*45*, *53*). We do note, however, that the Pb isotopic ratios of the tesserae are an especially good match for copper mineralization from the state Michoacán (Fig. 4), an area to the west of the Aztec capital (Fig. 1) where copper mining and smelting may have begun as early as the 650 CE (*53*) and where at least one Late Postclassic copper-smelting site has been identified (*54*). Although this area was controlled by the Tarascans in the Late Postclassic (Fig. 1), Mesoamerican merchants from virtually all polities operated within and beyond their political boundaries (*19*). Thus, if turquoise was available from mines in the Tarascan region, then it is plausible the material entered the Aztec realm along with other commodities.

It is also possible that the Aztecs and Mixtecs acquired turquoise from other parts of western or central Mexico. The *Codex Mendoza* indicates that the Aztec received turquoise tribute from three provinces (Fig. 1) (*22*). The two southern (Mixteca) tributary provinces were *Quiauhteopan*, which was located in what is today eastern Guerrero and possibly adjoining parts of Puebla, and *Yoaltepec*, which was located in present-day western Oaxaca. The northeastern province *Tochpan* was located in what is today northern Veracruz (Fig. 1). The Pb isotopic compositions of the tesserae partially overlap with the signatures of copper deposits in Veracruz [for example, compare to the study of Hosler and Macfarlane (*43*)], and may also overlap with the signatures of copper mineralization in Guerrero or Jalisco [see Hosler (*53*) and references therein] and with deposits in central Mexico [for example, compare to Potra and Macfarlane (*44*)]. Thus, the isotopic evidence also allows for the possibility that the inhabitants of these tributary provinces (including the Mixtecs) acquired turquoise from local sources or imported it from other parts western or central Mexico.

Unless direct evidence of ancient Mesoamerican turquoise mines comes to light, the specific source(s) of turquoise used by the Aztecs and Mixtecs cannot be identified. This is because neither the Pb nor Sr isotopic data are able to pinpoint the precise origin for these artifacts within Mesoamerica. However, the isotopic data provide strong evidence that none of the Aztecs or Mixtec turquoise artifacts analyzed for this study derive from the Southwest. Our data primarily pertain to turquoise objects associated with the Late Postclassic Aztec Empire and do not provide evidence about the source(s) of Mesoamerican turquoise artifacts from other regions or time periods. However, based on these findings, we suggest that turquoise may not have been an important component of long-distance trade between the Southwest and Mesoamerica.

METHODS AND MATERIALS

To ensure that all tesserae were turquoise (and not other blue-green minerals), we used nondestructive x-ray diffraction and scanning electron microscopy to examine their mineralogical and elemental compositions. Turquoise tesserae were prepared and analyzed for Pb and Sr isotopic ratios in the Department of Geosciences at the University of Arizona according to methods published elsewhere (*8*), but repeated here.

To remove any superficial contaminants or residue of adhesive material, the edges and faces of all tesserae were carefully sanded with a silicon carbide sandpaper and then inspected under a binocular microscope. After sanding, all samples were ultrasonicated in Milli-Q water (18.2 megohm), rinsed four to five times, and set to dry. Once dry, they were crushed with an alumina mortar and pestle. Between each sample, the mortar and pestle set was cleaned by grinding a slurry of silica sand and 200 proof ethanol and rinsing several times with ethanol and Milli-Q water.

All sample preparation procedures were conducted using ultrapure twice-distilled acids. After crushing, samples were weighed into acid-cleaned Savillex vials. Samples were then capped and refluxed in concentrated hydrochloric acid on a hotplate overnight at ~125°C. The next day, solutions were cooled and then, if necessary, centrifuged to remove any undigested material. The supernatant was dried down and redissolved in

8 M nitric acid. Pb and Sr were separated using Sr Spec resin (Eichrom Industries).

Strontium samples were loaded onto degassed tantalum filaments with phosphoric acid and tantalum gel to enhance ionization. Strontium isotope ratios were measured on a VG Sector 54 thermal ionization mass spectrometer in dynamic collection mode at the University of Arizona. Fractionation was corrected using a ^{88}Sr/^{86}Sr ratio of 0.1194. The National Institute of Standards and Technology (NIST)-987 standard was run before, during, and after samples during each analytical session. The average value of the NIST-987 standard over all analytical sessions was 0.710266 ± 0.000014 (2 SD, $n = 19$).

Lead isotope measurements were made on a GV-Instruments Isoprobe multi-collector inductively coupled plasma mass spectrometer. To correct for fractionation, samples were spiked with Tl to achieve a Pb/Tl ratio of approximately 10. Samples were Hg-corrected and empirically normalized to Tl after methods used by (*55*). All samples were then normalized to the values of Galer and Abouchami (*56*) for the NIST-981 standard. The NIST-981 standard was run before, between, and after the samples, and sample and standard concentrations were matched within 20%. The errors on the Pb isotope ratios were calculated from the reproducibility of the NIST-981 standard over the course of each measurement session. Errors associated with each sample are given in table S2.

SUPPLEMENTARY MATERIALS

Supplementary material for this article is available at http://advances.sciencemag.org/cgi/content/full/4/6/eaas9370/DC1

fig. S1. Mixteca-style shield decorated with turquoise mosaic from the collections of the Smithsonian Institution–NMAI.

fig. S2. Reconstructed turquoise mosaic disk from Offering 99 in the *Templo Mayor*.

fig. S3. Location of offerings with turquoise in the Sacred Precinct of Tenochtitlan.

fig. S4. Examples of analyzed mosaic tiles from Offering 60 in the *Templo Mayor*.

fig. S5. Pb isotope plots comparing Aztec and Mixtec tesserae to turquoise deposits from the Southwest.

fig. S6. Pb and Sr isotope plots comparing Aztec and Mixtec tesserae to turquoise deposits of the Cerrillos Hills, New Mexico.

table S1. Offerings with turquoise within the Sacred Precinct of Tenochtitlan.

table S2. Errors on Pb isotope ratios.

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47. Although we only compare the tesserae to geological samples of turquoise from the Southwest in Figs. 2 and 3, the isotopic ratios of the mosaic tiles are also distinct from all turquoise objects that have so far been measured from Late Prehispanic (1300 to 1450 CE) Ancestral Puebloan sites in Arizona and New Mexico (8, 30, 31). They are also distinct from the isotopic signatures of Hohokam artifacts from the Tucson Basin that date between 760 to 820 CE (32).
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51. These variations in Sr isotopic composition are interpreted to reflect variations in the age and type of basement lithologies that underlie these areas (39). In American Southwest and Northern Mexico, igneous complexes associated with copper porphyries intruded through Proterozoic (>1 Ga) crystalline basement rocks with more radiogenic strontium isotopic signatures. South of Sonora, most of Mexico underlain by younger accreted terranes with more primitive Sr isotopic signatures (see Damon *et al.* (39) and references therein).
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