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Identifying the origins of obsidian artifacts in the Deh Luran Plain (Southwestern Iran) highlights community connections in the Neolithic Zagros

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Exchange networks created by Neolithic pastoral transhumance have been central to explaining the distant transport of obsidian since chemical analysis was first used to attribute Near Eastern artifacts to their volcanic origins in the 1960s. Since then, critical reassessments of floral, faunal, and chronological data have upended long-held interpretations regarding the emergence of food production and have demonstrated that far-traveled, nomadic pastoralists were more myth than reality, at least during the Neolithic. Despite debates regarding their proposed conveyance mechanisms, obsidian artifacts' transport has received relatively little attention compared with zooarchaeological and archaeobotanical lines of investigation. The rise of nondestructive and portable instruments permits entire obsidian assemblages to be traced to their sources, renewing their significance in elucidating connections among early pastoral and agricultural communities. Here we share our findings about the obsidian artifacts excavated from the sites of Ali Kosh and Chagha Sefid in the southern Zagros. In the 1960s and 1970s, 28 obsidian artifacts from the sites were destructively tested, and the remainder were sorted by color. Our results emphasize a dynamic, accelerating connectivity among the Early and Late Neolithic communities. Here we propose and support an alternative model for obsidian distribution among more settled communities. In brief, diversity in the obsidian assemblage accelerated diachronically, an invisible trend in the earlier studies. Our model of increasing population densities is supported by archaeological data and computational simulations, offering insights regarding the Neolithic Demographic Transition in the Zagros, an equivalent of which is commonly thought to have occurred around the world.

Neolithic Revolution | southern Zagros | obsidian sourcing | lithic artifacts | social and technological change

V. Gordon Childe coined the phrase "Neolithic Revolution" in 1936 (1) to describe the emergence of settled, agricultural societies. He specifically chose the word "revolution" to evoke the Industrial Revolution and its rapid effects on economic systems and population sizes. Childe (1), among others, initially favored the "oasis" hypothesis, a model in which human communities, along with future plant and animal domesticates, coalesced within climatic refugia and, subsequently, spread the resulting innovations outward. Such a model eventually conflicted with evidence for a gradual, sporadic process. During the 1940s and 1950s, Robert Braidwood developed the "hilly flanks" hypothesis, which held that the foothills of the Zagros, Taurus, and Levantine mountains were the origins of food production. In 1960, during a survey of Neolithic sites in southwestern Iran to test his idea, Braidwood and collaborators found Neolithic artifacts on the surface of Ali Kosh (AK) in the Deh Luran Plain of Iran. The following year Braidwood sent two students, Frank Hole and Kent Flannery, to conduct a test excavation, and a second excavation followed in 1963 (2). Three occupation phases (two aceramic phases and one ceramic) documented the residents' increasing dependence on food production (2). The Deh Luran sequence later was extended into the Late Neolithic because of Hole's 1968 to 1969 excavations at Chagha Sefid, ~15 km north of AK (3). Together, these two sites have been central to discussions and debates about the emergence, adoption, and sustainability of pastoralism and agriculture throughout the Near East. Given their importance, the data and interpretations for AK and Chagha Sefid have periodically been reconsidered in light of new methods and theories, and these critical reexaminations have often led to considerably different interpretations than those reached several decades ago, sometimes overturning widely held ideas about Neolithic processes.

Consider AK, which is the better known of the two sites because of its aceramic layers—the Bus Mordeh (BM) and AK Phases—and subsequent ceramic Mohammad

Significance

Early scientific investigations of the Neolithic Near East, such as the excavations of Ali Kosh and Chagha Sefid during the 1960s, were pioneering for their time. Modern, critical reexaminations of these (and other) sites have led to substantially different interpretations. New insights with respect to fauna, flora, and chronology have overturned widely held ideas about the emergence of food production. Chemically determining the geological origins of all lithic artifacts made from obsidian has hitherto been overlooked. The observed accelerating diversity in these obsidian assemblages indicates intensifying connections among Neolithic sites, highlighting intercommunity contacts as a mechanism for social change as populations grew during a demographic transition purported to have occurred within food-producing societies worldwide, from western Europe to Mesoamerica.

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Jaffar (MJ) Phase. Early radiocarbon determinations (i.e., beta decay measurements and linear calibration) implied that the site was occupied for about two millennia, circa ∼8200 to 6100 BCE (2). Advances in radiocarbon dating since then have been considerable (e.g., mass spectrometry and calibration curves), so new dates attest that AK was likely occupied for no more than five centuries, circa ∼7500 to 7000 BCE (4). In the 1960s, a pioneering flotation regimen was employed by Hans Halbaek to recover charred botanical remains (2). Seed and stem fragments from cultivated (e.g., emmer wheat, rye, and barley) and morphologically wild species (e.g., legumes) were regarded as evidence for high dietary breadth and as support for Flannery's "broad spectrum" model for diversified subsistence resources (2). Today, however, these remains are thought to reflect animal dung burned as fuel (5). This indicates a greater degree of circumscription than previously expected: herd animals were consuming cultivars and wild legumes in local fields rather than grazing in far-flung grasslands (6). The excavators regarded a decrease in goat size from the aceramic to ceramic layers as an aspect of domestication (2), but later metric studies found that the size reduction is consistent with a contemporaneous change in wild goats (5), perhaps due to a pollen-indicated shift toward drier conditions (7).

Even one cornerstone of the site's interpretation—that it is an early instance of pastoral transhumance—has been convincingly called into question. Drawing heavily upon ethnographic parallels to contemporary pastoralists, it was inferred that the site was occupied only seasonally, serving as a fall and winter encampment, while springs and summers were presumably spent in the highlands (2). Such nomadism was regarded as the most likely mechanism for the transport of obsidian artifacts, a tiny fraction of which (0.8%) had been chemically analyzed for sourcing—that is, matching obsidian artifacts to their geological sources. Renfrew (8) reported two obsidian types among the AK artifacts that he tested: the "Group 4c" source (associated with Nemrut Dağ in Turkey; Fig. 1), which had green-hued peralkaline obsidian, and the unlocated "Group 1g" source, which frequently produced alkaline obsidian with gray tinges (75% of the tested artifacts) but sometimes green hues (25%). Counts of green- versus gray-hued artifacts at AK (and later Chagha Sefid) indicated, it seemed, a diachronic shift toward the preferential utilization of Group 1g obsidian, a trend with ambiguous significance (8, 9). Long-distance transhumance, however, is undermined by the site's faunal evidence, especially the presence of juvenile goats, which would have been harvested in spring or summer, when the community was supposedly in the highlands (2, 10). Isotopic data for caprine birth seasonality at other Neolithic sites reveal that domesticates still had wild, seasonal reproduction schedules (11, 12), unlike contemporary breeds. Additionally, stable isotopes have provided little support for herds grazing in far grasslands [e.g., ʻAin Ghazal (13) and Çatalhöyük (12)]. Consequently, while specialized, long-distance pastoralists existed, to some extent, in the Bronze Age and historical times (operating within a modern economic milieu), there is a notable lack of evidence for their existence during the Neolithic (10).

The geological sources of obsidian artifacts from AK and Chagha Sefid have, until now, not received the same critical reassessment (Fig. 2). This is especially pertinent given that the technique developed by Renfrew et al. (14) traced the movement of obsidian as a means to consider transmission of ideas among Neolithic communities. These early studies, though, were based on small numbers of artifacts since optical emission spectroscopy (OES) was destructive (14). Just 10 obsidian artifacts were analyzed from AK and 18 from Chagha Sefid (9), and the remainder (>2,000) were sorted by color. Crucially, considerably more is known today about Near East obsidian sources. For example, Group 4c of Renfrew et al. (14) included obsidian not only from Nemrut Dağ but also a second source: Bingöl A, ∼120 km west. The origin of Group 1g obsidian, Bingöl B, was identified nearby. Moreover, many obsidian sources across Anatolia and the Armenian Highlands have gray-hued obsidian, further undermining visual attributions. One of the greatest advances in obsidian artifact sourcing since its inception has been the development of portable instruments that can conduct rapid, nondestructive elemental analyses. State-of-the-art portable X-ray fluorescence (pXRF) instruments permit complete obsidian assemblages, not just a handful of artifacts, to be matched to a particular lava flow. Hence, we sourced more than 2,100 Deh Luran Project obsidian artifacts, including 1,945 artifacts from relevant contexts, in the Yale Peabody Museum (YPM). The results of our artifact-by-artifact source identifications reveal previously unobserved trends that revise the original interpretations.

Our findings highlight the dynamic, accelerating connectivity among the Early and Late Neolithic communities in the Zagros. Given the recent arguments (10) that far-traveled, nomadic transhumance in the Neolithic is more of a myth derived from modern history than a past reality, here we propose an alternative model for obsidian distribution among more settled communities. Our sourcing results and reexamination of the entire collection show that diversity in the obsidian assemblage increased over time, a trend that was invisible in the 1960s and 1970s studies. A conceptual model of increasing population densities (Fig. 3) to explain our data (Fig. 4) is supported by agent-based modeling (ABM), which permitted us to computationally test hypotheses involving potential mechanisms. That is, our data and simulations support that diversity in the obsidian assemblage increased as populations grew in the region. We can rule out interpretations based on older data (*SI Appendix*), including the hypothesis (9) that a change in the obsidian sources occurred because of differences in suitability for blade production. When exploring the potential for functional analysis with scanning electron microscopy (SEM), we found support for geophysical and archaeological studies (15–18) that suggest that obsidian use–wear can exhibit inter- and intrasource variation, at least in the Near East. This, in turn, indicates that use–wear research must be supplemented with artifact-by-artifact sourcing of the entire assemblage, the same level of characterization that we argue is required to elucidate how, as settlements grew closer, opportunities for casual intercommunity contact across the landscape rose nearly exponentially. An ability to recognize such trends allows us to test and challenge simplistic but widespread models of Neolithization and, in addition, propose and evaluate hypotheses that center potential mechanisms for social change. In particular, our archaeological data, conceptual model, and computational simulations support the broadly accepted but poorly circumscribed Neolithic Demographic Transition (NDT) (19). It is frequently argued that archaeological data are too imprecise to reveal such population changes, so scholars have previously instead relied on birthrate, mortality, and/or metabolic modeling (20–22). In contrast, our data reveal an intensification in intercommunity connections, consistent with the NDT, that would otherwise have remained archaeologically invisible.

Results

A Diachronic Perspective. Our focus is diachronic, albeit constrained by uncertainties linked to artifact storage and handling

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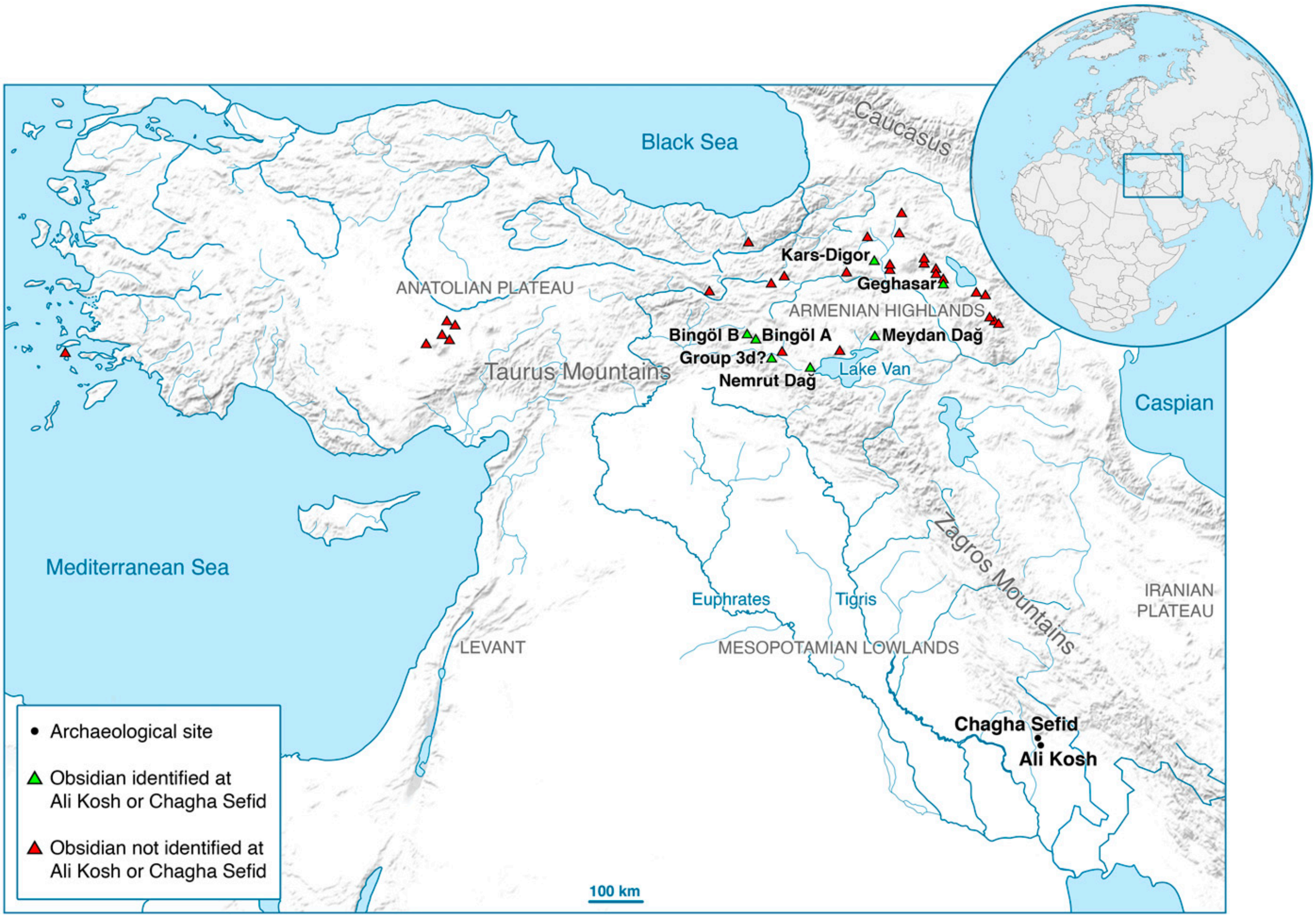

Fig. 1. The locations of Ali Kosh and Chagha Sefid as well as obsidian sources that were and were not identified among the assemblages. Geography based on the National Geophysical Data Center's ETOPO1 Global Relief Model (topographic data), World Data Bank (rivers), and NASA's Shuttle Radar Topography Mission and Natural Earth (coastlines).

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(*SI Appendix*). All artifacts from the aceramic phases (BM and AK at AK; AK at Chagha Sefid) are integrated in our data. These two similar phases reflect diverse subsistence (e.g., agriculture, pastoralism, hunting, and fishing). Soft, friable, chaff-tempered pottery occurs in the MJ Phase and later ones. One of the oldest Near Eastern metallurgical artifacts (a small native copper bead) was also discovered in the MJ layers (2), and other beads, especially turquoise, become common in this phase (2, 3). The Sefid Phase is represented only at Chagha Sefid, as are subsequent phases. The final three phases—Surkh, Choga Mami Transitional, and Sabz, which slowly grade from one into the next without clear, stylistic breaks—reflect a time that Hole (23) collectively labeled the Early Village Period.

Obsidian Reflects Overall Artifact Abundance. With respect to volumetric density (artifact count divided by excavated volume; *SI Appendix*, Table S1), both lithics in general and obsidian in particular exhibit drops of an order of magnitude from the earlier to later phases (e.g., from 248 to 29 n/m^3 for all lithics, an 88% decrease). Most of the decrease occurs after the Sefid Phase, when the overall numbers of recovered artifacts drop markedly (e.g., the number of rim sherds also plummets by 89% from the Sefid to Sabz Phase). Consequently, this seeming decrease in obsidian is likely spurious, reflecting different activity areas in these different phases (3, 9). Additionally, obsidian volumetric density mirrors that for all lithic artifacts, and the obsidian proportions overlap for the BM–AK versus Surkh–Sabz Phases (*SI Appendix*, Table S1). Thus, the relative difference in obsidian abundance is less than the absolute one, and it likely reflects differences in excavated versus site-use areas.

Seven Obsidian Sources. Our elemental analyses reveal, rather than the simple dichotomy of Groups 4c and 1g reported by Renfrew (8, 9, 14), a variety of obsidian sources (Fig. 1 and *SI Appendix*, Table S1). There are seven distinct obsidian sources, albeit four of these sources (Kars-Digor and Meydan Dağ in eastern Turkey, Geghasar in Armenia, and the as-yet-unlocated "Group 3d") contributed only one or two artifacts. Our data confirm that the Group 1g artifacts reported by Renfrew (8, 9) indeed match Bingöl B. Additionally, there is peralkaline obsidian not only from Nemrut Dağ but also Bingöl A, both of which had been combined into Group 4c obsidian.

Distant Sources and Diachronic Shifts. BM and AK Phases have the following: Nemrut Dağ is the predominant source (*SI Appendix*, Table S1), while Bingöl A and B were sources of fewer artifacts. Two artifacts—a blade and a small flake—originated from the Kars-Digor Province of Turkey (~910 km linearly and >1,500 km on foot).

MJ Phase has the following: the amount of Bingöl B obsidian is nearly the same as in the aceramic phases, while the peralkaline obsidian is almost equally derived from Nemrut Dağ and Bingöl A, a hitherto invisible shift. One artifact (the distal end of a blade) originated from Meydan Dağ, north of Lake

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Fig. 2. Composite photograph of 200 obsidian artifacts from the MJ Phase of AK. This set is less than 10% of the Deh Luran Plain obsidian corpus chemically analyzed during the course of this study. These blade, bladelet, and flake artifacts are typical of both sites. (Image credit: Jordan Boggan, Council on Archaeological Studies, Department of Anthropology, Yale University.)

Van. Meydan Dağ obsidian, which Renfrew et al. (14) knew as the unlocated "Group 3a" obsidian from principally post-Neolithic sites, has recently been reported in Neolithic and Upper Paleolithic contexts (24, 25).

Sefid Phase has the following: only the three main sources are represented among the artifacts, and Bingöl B obsidian constitutes the majority only in this one phase.

Surkh–Sabz Phases have the following: Nemrut Dağ obsidian is the most abundant for the first time since the aceramic phases, followed by the Bingöl sources. There are also two rare obsidian sources. One flake originated from the "Group 3d" source that was identified by Renfrew et al. (14) among the artifacts from Choga Mami, the site for which the CMT Phase was named. Its location remains unknown but is likely somewhere between Nemrut Dağ and the Bingöl deposits (26, 27). One small-blade segment also originated from an Armenian source: Geghasar (~860 km linearly and >1,600 km on foot through the Zagros range along the shortest theoretical path).

Artifact Mass as the Metric. Following Wright (28), we contend that, in this context, it is better to use mass, not artifact or blade counts, as a metric. It must be kept in mind that, during the period in question, long prismatic blades and bladelets were often deliberately snapped or accidentally broken into segments and/or microliths (29, 30). Using mass permits us to adjust for the fact that, while a complete prismatic blade would be counted as just one artifact, it would be instead counted as multiple artifacts when segmented, broken, and/or reshaped. *SI Appendix*, Table S1 demonstrates how the source proportions differ by obsidian artifact count and mass.

Shannon–Wiener Diversity Index. Shannon–Wiener Diversity Index (SWDI) (31) is the most common metric in ecology to quantify diversity, and we use it here to measure the diversity of a lithic assemblage rather than a faunal or floral community. A region in which one or two species prevail is less diverse than one in which multiple species exhibit equal abundances. Therefore, SWDI is a metric that accounts for both the number of species present (richness) and their relative abundances (evenness). In this case, rather than individuals belonging to a certain species, the obsidian artifacts originated from a particular source. In a diverse obsidian assemblage, artifacts come from varied sources, each of which is well represented, whereas artifacts largely from a single obsidian source represent a less diverse assemblage (Fig. 3). SWDI has long been applied to lithics to quantify the diversity of types or materials (32–36), so

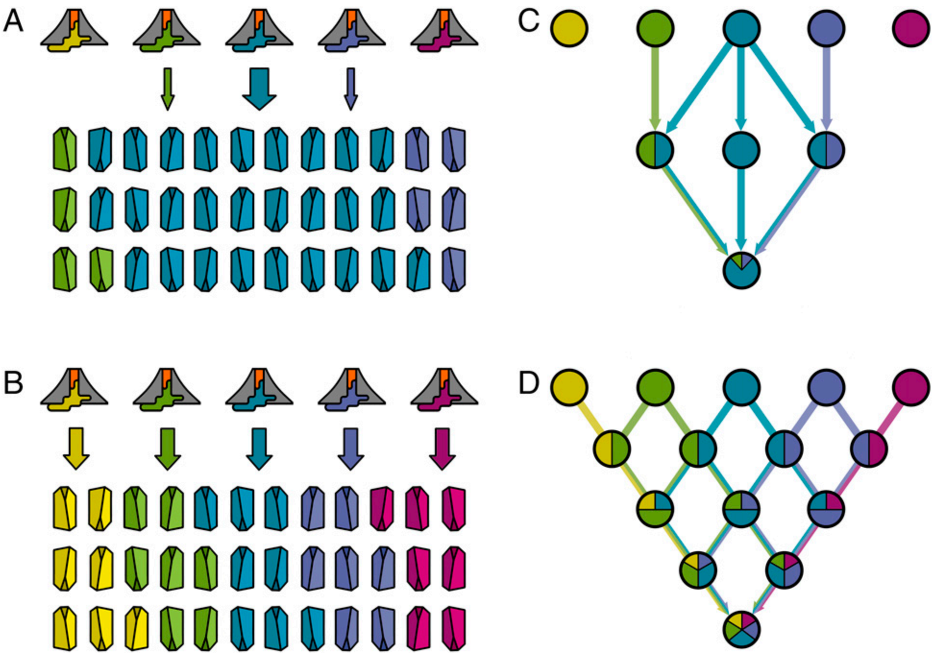

Fig. 3. Conceptual model for obsidian diversity at Neolithic sites such as AK and Chagha Sefid. (*A*) Obsidian that derives from one primary source and two secondary sources leads to an assemblage with low richness (fewer sources), low evenness (one source dominates), and thus low diversity. (*B*) Obsidian that more equally derives from five sources yields high richness, high evenness, and high diversity in the assemblage. (*C*) Interactions between sites with a low density on the landscape lead to an assemblage with low diversity. (*D*) Interactions between sites with a high density on the landscape lead to an assemblage with high diversity.

our approach is well-established. Fig. 4 shows our results based on mass, and it illustrates how values based on artifact or blade counts are misleading.

No Support for Differences in Blade Production. Renfrew (9) determined the mean masses of obsidian blades, bladelets, and their fragments from the Sefid Phase at Chagha Sefid, separated into gray (equated with the Group 1g type) and green (equated with Group 4c) obsidian: 0.53 and 0.65 g/artifact, respectively. He hypothesized that physical properties of Group 4c obsidian may be more favorable to knapping larger blades. We measured the masses of blades and flakes by source and phase (*SI Appendix*). Renfrew's observation that Group 4c blades are, on average, larger than Group 1g blades is a spurious correlation. While the interquartile ranges for obsidian blades from the main sources overlap, Nemrut Dağ blades are, on average, smallest. Bingöl A blades are largest and, when combined in Group 4c, inflate the average. Our data attest that reduction and curation of obsidian from the three primary sources was highly consistent within phases. The discrete increase in blade mass from the MJ to Sefid Phases reflects what Nishiaki (37) considers to be a shift between the Early and Late Mlefaatian lithic industries of the Zagros, when blades increased in size. There is no corresponding, discrete increase in the flake masses.

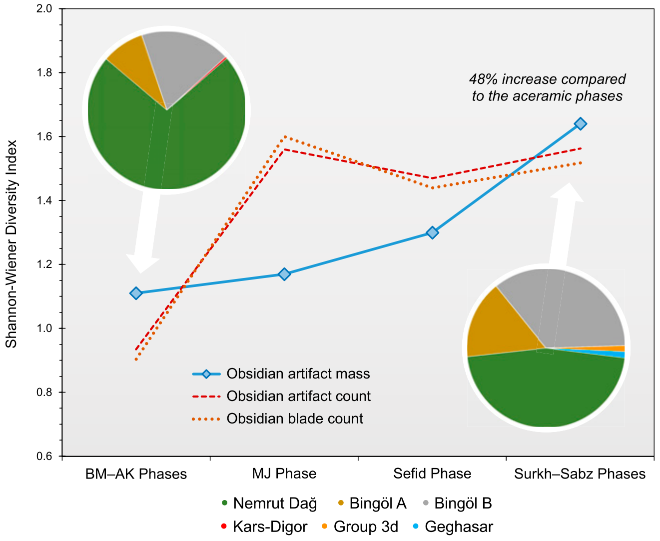

Fig. 4. Accelerating diversity in the obsidian assemblage through time. The simple counts of artifacts obscure the clear pattern in mass, which accounts for phenomena such as deliberate segmentation of blades and bladelets. The pie charts illustrate the starting and ending richness and evenness of the obsidian artifacts, demonstrating why the SWDI value increases.

ABM as Hypothesis Testing. We used ABM (25, 38–40) to model the interactions of pastoralists while moving their herds across short distances through fields and pastures and while collecting toolstone (e.g., cherts from local deposits and the other ∼98% of lithic artifacts) around their central settlements. Specifically, ABM was a tool for hypothesis testing and considering two variables in Neolithic settlement patterns most likely to lead to the observed rise in obsidian diversity: 1) the effect of territory size on the frequency of contacts between neighboring sites and 2) the effect of settlements' separation on the frequency of contacts. The resulting computations suggest that increasing the territory size around a simulated site does not always yield commensurate rises in contacts (*SI Appendix*), and when it does, an increase typically needs to be considerable to yield a notable rise in the contact frequency. In comparison, the sites' spacing has a clear, predictable outcome. Even a small decrease in the separation distance between two sites generates a large increase in simulated intercommunity contacts. Thus, an increase in regional population density, fitting the conceptual model (Fig. 3) for our data (Fig. 4) and the NDT, is a more likely mechanism, based on these simulations, than increases in territory size.

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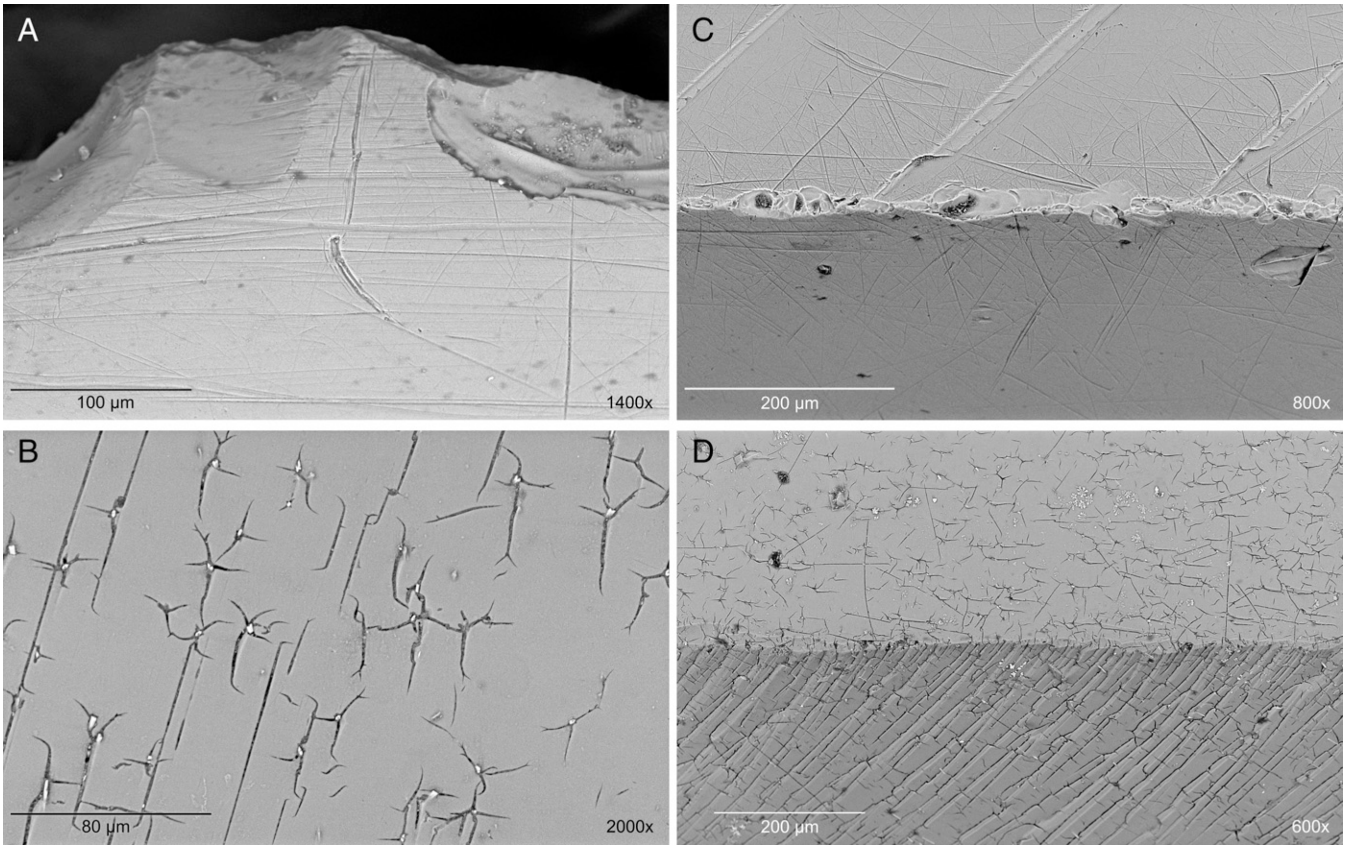

Fig. 5. SEM–backscattered electron images illustrate how magnetite inclusions (brighter dots in *B*) may affect the recording, visibility, and interpretability of obsidian use–wear. (*A*) Inclusion-free obsidian can record microscopic marks so clearly that the layering of scratches can indicate the relative order in which they were made. (*B*) Inclusion-rich obsidian has stress fractures that appear to interact with marks and affect their interpretability. Arrises on obsidian bladelets from Nemrut Dağ (*C*) and Bingöl A (*D*) exhibit this phenomenon. (*C*) Scratches are clear on low-inclusion glass. Note that minuscule flake scars along this arris exhibit few signs of abrasion, suggesting that the scars could be postuse (e.g., postdepositional and postexcavation) damage. (*D*) Inclusion-rich glass demonstrates how stress fissures (*Upper Half*) and ripples (*Lower Half*) can readily influence the potential to record, observe, and/or interpret use- and nonuse–wear traces.

Function, Use–Wear, and Obsidian Sources. It is long known that use–wear can vary by material (41), requiring the same toolstone to be used in the controlled tests and/or actualistic experiments on which interpretation completely depends. Tests using obsidian are rare, while those with more than one source of obsidian are even rarer (16). Recent archaeological and geophysical (15–18) experiments suggest that key variables for the formation of use–wear (15) can differ between and within obsidian sources. Specifically, chemical composition [alkalinity (17)], intrinsic water content (17), and microscopic mineral inclusions (16, 18) can all affect use–wear on obsidian. These three variables were assessed in our obsidian collection, and our data suggest that obsidian use–wear in the Near East will exhibit inter- and intrasource variations (*SI Appendix*). We also examined a sample of the AK artifacts in an SEM equipped with a backscattered electron detector. Our observations show not only that blades may exhibit marks, which, under high magnifications, can exhibit layering which allows their order to be recognized (Fig. 5*A*), but also that differences in obsidian, including the abundance of stress fissures due to magnetite inclusions (Fig. 5 *B*–*D*), may affect the manifestation and/or visibility of use- and nonuse-related marks. An implication is that obsidian use–wear studies must be accompanied by a scientific materials characterization.

Discussion

Obsidian artifacts from AK and Chagha Sefid were studied shortly after their excavation in 1961 to 1963 and 1968 to 1969, respectively, based in large part on appearance, specifically color when viewed in sunlight (8, 9, 18). A subset of 28 obsidian artifacts were tested with OES, which associated most green-hued artifacts with the Group 4c source, thought to exclusively originate from Nemrut Dağ volcano, and gray-hued artifacts with the unknown Group 1g source. Notably, one quarter of the Group 1g artifacts had a greenish tint as well (9), underscoring the potential error rate of visual attributions. Our analyses reveal an unrecognized diversity in the two groups, which reflect broad chemical types rather than actual sources. The greenish obsidian includes artifacts from Nemrut Dağ and Bingöl A, and the gray obsidian derives from Bingöl B as well as four additional sources, including Geghasar in the Armenian Highlands. As larger assemblages are analyzed, more obsidian sources are shown to be relevant (25, 26). Hence, the decades-old scaffolding for our understanding of Neolithic contacts and exchange (*SI Appendix*) is, to some unknown extent, precarious and requires rebuilding. New models, no matter how sophisticated, built primarily on decades-old data (42, 43) will carry forward their flaws. Fortunately, we are not alone in collecting obsidian data for the Neolithic Near East (24, 26, 27, 44).

There is no support for a previously hypothesized reason (9) for the changing obsidian sources. Our data (i.e., masses of blades and flakes by source; *SI Appendix*) indicate no clear differences in the suitability of the three principal obsidian sources for producing blades, nor is there currently compelling evidence that obsidian held a special status at the sites, at least not sufficient to reject a null hypothesis that it was principally utilitarian. The ratios of blade tools to debitage are slightly higher

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for obsidian than chert (0.68 to 1.04 for chert and 1.18 to 1.69 for obsidian), but this is also consistent with reduction and curation of local versus distant lithic resources (45, 46). In addition, exotic materials (e.g., turquoise and native copper) occur as beads in mortuary contexts beginning in the MJ Phase, but obsidian does not occur among them. Following Sheppard (47), though, we note that these are just snapshots in a potentially complex history of obsidian value.

Obsidian artifacts at AK and Chagha Sefid reflect connections among the Neolithic Zagros communities that mediated the movement of such toolstone more than 900 km (and, in three instances among the excavated artifacts, more than 1,500 km). Hole (48) noted these sites "did not exist in a cultural vacuum … the people in Deh Luran shared in technological and social developments that affected the wider area." Our interest in obsidian sourcing lies in elucidating the means by which such innovations were able to spread across the region. Hole (48) regarded transhumance as a probable explanation, but it now seems likely that long-distance pastoralism was much less frequent than has been inferred from ethnohistorical records (10). Our data show that diversity in the obsidian assemblage not only increased over time but also accelerated as it did. We explain the intensifying diversity as a product of increasing population densities. Use of ABM in our hypothesis testing supports this mechanism as a means to account for our sourcing data. That is, our model, data, and simulations each support a scenario in which the diversity of the obsidian assemblage accelerated as populations grew in the region.

Given that the archaeological data and computational simulations support our conceptual model of increasing obsidian diversity as regional population densities rose, these findings have a direct relevance for elucidating the NDT. Paleodemographers such as Bocquet-Appel (21) assert that "archaeological data, such as the increasing density of settlement sites during the transition, are too imprecise to express the demographic shift" at the transition to farming. Hence, their data have been constrained to periods and places where cemetery data can indicate a rise in juvenile skeleton frequency, while mobility reconstructions in these studies are more frequently based on metabolic reconstructions than on archaeological findings (19–22). Typically, the Levant is one of the few areas recognized to have sufficient archaeological data (e.g., structure size estimates) to consider the Near Eastern NDT through its effects on settlement and material culture (19). While the presence of obsidian artifacts has been used as a proxy for regional interconnections during the Neolithic, our artifact-by-artifact sourcing data attest to an acceleration in the intercommunity connections that has previously remained hidden. Reconsidering the entire obsidian assemblage has revealed, we maintain, a diachronic intensification of interactions over the landscape, calling attention to a means by which social and technological innovations may have spread. Such data have the potential to bridge demographic and archaeological research and to form the basis for a middle-range theory that can more directly connect Neolithic population growth and the spread of those innovations widely considered to be part of the Neolithic package.

Abbreviated Materials and Methods

Artifact Assemblage. The YPM has >2,100 obsidian artifacts from the Deh Luran Plain Project. All were analyzed, but artifacts from nearby sites, surface collections, and unclear contexts were removed from the dataset. This left 1,945 artifacts, adding up to ~1.2 kg (*SI Appendix*, Table S1). Each artifact is now individually labeled, but this was not always true. Consequently, researchers' choices and errors in earlier decades compelled us to make conservative choices (*SI Appendix*). For example, artifacts from the AK Phase at AK and at Chagha Sefid were combined at some point, so we combined our data for these sites, which did not affect our diachronic perspective.

Geological Specimens. Elemental signatures of obsidian sources across Southwest Asia were not pulled from the literature, an approach that can lead to ambiguous identifications. Instead, hundreds of geological specimens were reanalyzed for our study using the same instrument as the artifacts. The only artifact compared with literature values was that attributed to the "Group 3d" source, which remains unlocated, and hence, no geological reference specimens are available.

Analytical Methods. The artifacts and geological specimens were analyzed using pXRF in the Yale University Archaeological Laboratories, following established protocols for calibration and evaluation with well-characterized obsidian specimens and standards (49). Variables related to obsidian use–wear were measured via electron microprobe analysis, Fourier transform infrared spectroscopy, and vibrating sample magnetometry.

Source Identifications. The means by which we attributed artifacts to their geological sources differed by the geochemical obsidian variety involved (*SI Appendix*). For alkaline obsidian, which include all but two sources in Southwest Asia (Nemrut Dağ and Bingöl A), "mid-Z" trace elements (Rb–Nb) are both well-measured by pXRF and highly effective for differentiating obsidian sources, revealing clear matches of artifacts to Bingöl B, Meydan Dağ, Kars-Digor, and Geghasar. For the "Group 3d" artifact, its source is unlocated and known entirely from artifacts (27). Its identification is based on the mid-Z trace elements as well as the Mn and Fe contents. Differentiating between Nemrut Dağ and Bingöl A obsidian necessitates precise data for elements that reflect peralkaline geochemical variability (50). We used a multivariate approach based on seven elements and a training set of 92 geological specimens. The resulting function was able to discern them, and it was applied to the peralkaline artifacts, statistically assigning each to their source.

ABM. Using ABM, our focus was varying 1) settlement spacing and 2) territory size under two resource procurement strategies: embedded (i.e., collection in the course of other activities) and direct (i.e., making dedicated forays). To make these two strategies comparable, the number of intersettlement contacts was normalized to 100 (*SI Appendix*).

Simplified Lithic Types. Lithic artifacts at both sites are dominated by blades, bladelets, and blade-based types (e.g., blade segments and microliths). In the entire lithic assemblage of AK, there is a lone bifacially worked projectile point compared with more than 40,000 blades, bladelets, etc. (2, 8). In lithic classifications conducted by the AK excavators, 94% of the obsidian tools are "plain blades," and almost all of the other classes reflect either use or modifications of blades, which led us to employ a simpler classification scheme (e.g., blades, flakes, and cores).

Legacy Obsidian Data. Data regarding these obsidian assemblages were included in the original site reports (8, 9). A few inconsistencies in the legacy data yield interpretive challenges; however, when direct comparisons are possible, there is consistency with our findings, yielding confidence that the YPM collection reasonably reflects the initial assemblages (*SI Appendix*).

Data Availability. All study data are included in the article and/or supporting information.

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