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To cite this article: Setareh Shafizadeh, Mahta Khaki & Ben Marwick (10 Nov 2025): Between Nomads and Settlers: A Quantitative Analysis of Lithic Assemblages from Tula'i (Tuleii), Zagros, Iran, *Lithic Technology*, DOI: [10.1080/01977261.2025.2577033](https://doi.org/10.1080/01977261.2025.2577033)

To link to this article: <https://doi.org/10.1080/01977261.2025.2577033>



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Published online: 10 Nov 2025.



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Between Nomads and Settlers: A Quantitative Analysis of Lithic Assemblages from Tula'i (Tuleii), Zagros, Iran

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ABSTRACT

This study examines the lithic assemblages from Tula'i to investigate the occupation styles and mobility strategies of the inhabitants during the Neolithic. We analyzed the lithic production patterns, focusing on retouch frequencies and lithic densities, to test hypotheses concerning occupation duration: whether Tula'i was a waypoint for village-based herders (short-term occupation) or a seasonal hub for nomads (long-term occupation). We applied Principal Component Analysis (PCA) to identify structure within the assemblages. Our results challenge traditional models by revealing a complex picture of tool production and use that does not conform neatly to the expectations of either highly mobile or sedentary groups. The insights derived from this research refine our understanding of Neolithic settlement practices in the region and reveal the nuanced behaviors of its past communities, suggesting a dynamic interplay between transient and prolonged stays at Tula'i.

ARTICLE HISTORY

Received 21 March 2024
Accepted 6 October 2025

KEYWORDS

Lithic assemblages; Tula'i; Neolithic occupation; lithic production patterns; Principal Component Analysis (PCA); mobility strategies

Introduction

The nomadic pastoral lifestyle is a subject of interest in archaeological studies, as it provides insights into the adaptability and resilience of human societies. Pastoralism is considered a mode of production (Abdi, 2003) and can be defined as the raising of livestock regardless of a migratory or sedentary lifestyle (Hole, 2022), particularly caprines such as sheep and goats in South West Asia (Abdi, 2003). Nomadism is the relocation of whole groups of people based on resource availability (Hole, In press). Nomadic pastoralism is a fully mobile pastoralism and a way of subsistence relying on pastoralism and involving high mobility living in a campsite along vertical or horizontal routes (Abdi, 2003).

The terminology and definition of mobility differ between hunter-gatherers and pastoral nomads. In hunter-gatherer archaeology, logistical mobility refers to the movement of part of a group away from the base camp, either for one day or multiple days (Binford, 1980). Residential mobility is the movement of the entire group and leaving the base camp (Kelly, 1992). In contrast, Pastoral nomadism is the particular mobility for the maintenance of herds, and has several varieties. Semi-nomadic pastoralism occurs when part of or the entire group settles for part of a year. Enclosed nomadism indicates that a nomad group is closely

related to a nearby settled group (Rowton, 1974). Agropastoralism is the combination of pastoral and agricultural activities (Buccellati, 2008). Transhumance is a general term used for seasonal migration. Transhumance is a kind of adaptation to changing weather conditions and resource availability. Vertical transhumance describes the seasonal vertical mobility in mountainous areas (Alizadeh, 2008a; Browman, 2008; Chang, 2008; Frachetti, 2008), where high altitudes are occupied in summer and lowlands in winter. Horizontal transhumance refers to horizontal mobility in search of resources like water without a change in elevation (Milne, 2008).

In Southwestern Asia, particularly in western Iran, pastoralism has been a longstanding tradition. The Zagros mountains have been a focal point of archaeological and anthropological research in search of domestication, agriculture, and sedentism between the 1950s–70s. Research in this region began with Braidwood's team (Braidwood et al., 1961) as he believed the origin of domestication could be traced to the foothills of the Taurus, Zagros, and Levantin Mountains (Braidwood, 1960). Numerous Neolithic sites have been excavated in this region since the mid-twentieth century, including Jarmo (Braidwood & Howe, 1966), Tepe Asiab and Sarab (Braidwood et al., 1961), Karim Shahir (Howe, 1983), and Zawi Chemi Shanidar

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(Solecki, 1963). Explorations have continued into the Neolitization process in the Iranian Zagros region. These studies mostly focused on the central Zagros, at Ganj Dareh (Riel-Salvatore et al., 2021; Smith, 1974, 1978), Guran (Braidwood & University of Chicago, 1983; Mortensen, 1963, 2014), Kelek Asad Morad (Moradi et al., 2016), Abdul Hosein (Pullar, 1990), Sheikh-e Abad and Jani (Matthews & Mohammadifar, 2013), East Chia Sabz (Darabi et al., 2013; Nishiaki & Darabi, 2018), Chogha Golan (Conard et al., 2013), along with the newly excavated site, Qazānchi Tappeh (Mashkour et al., 2023). In the southern part of the Zagros, Neolithic life has been examined through the project at Tappeh Ali Kosh (Hole & Flannery, 1962) and Chogha Sefid (Hole, 1976) in Dehluran and Chogha Bonut (Alizadeh et al., 2003), Chogha Mish (Delougaz et al., 1996), Boneh Fazl Ali (Alizadeh, 2008b; Kantor, 1976), and Tula'i (Hole, 1974) in Khuzistan Plain. Among them, some sites like Ashraf Abad, Tepe Sabz (Hole et al., 1969), Farukhabad (Wright, 1981) at Deh-Luran, and Chogha Bonut and Tula'i at Khuzistan are specifically considered by their excavators to be related to pastoralism (Figure 1).

While we have extensive data on lithic materials from the Neolithic period in the Zagros region (Nishiaki, 2022; Nishiaki et al., 2013; Nishiaki & Darabi, 2018; Riel-Salvatore et al., 2021; Zeidi & Conard, 2013), we have

limited information to associate these characteristics with specific site functions, such as determining whether a site was a village-based settlement or more ephemeral campsite. In many cases, the function of a site can be directly related to its duration of occupation: long-term (as in a sedentary village) or short-term (as in a temporary settlement or campsite). Our question, which we address in this paper, is: how do the lithic assemblages at Tula'i redefine our understanding of mobility patterns and settlement strategies during the Neolithic? In other words, is Tula'i indicative of a duration of occupation: pastoral lifestyle, as a long-term occupation, reflected in lithic production tradition? Specifically, we investigate whether the evidence points to a short-term herder outpost or a long-term nomadic campsite. By analyzing lithic production patterns, we aim to test competing models of occupation duration and resource provisioning strategies. This paper presents a preliminary techno-typological assessment of the lithic assemblage recovered from Teppe Tula'i, Iran, during Hole's, 1974 excavation. Our focus lies in understanding the stone tool production in the context of Tula'i, as a special neolithic settlement, which engages with a debate on its occupational nature— was it a site used seasonally by pastoral nomads, or was it a short-term outpost utilized by a group of herders from a neighboring village.

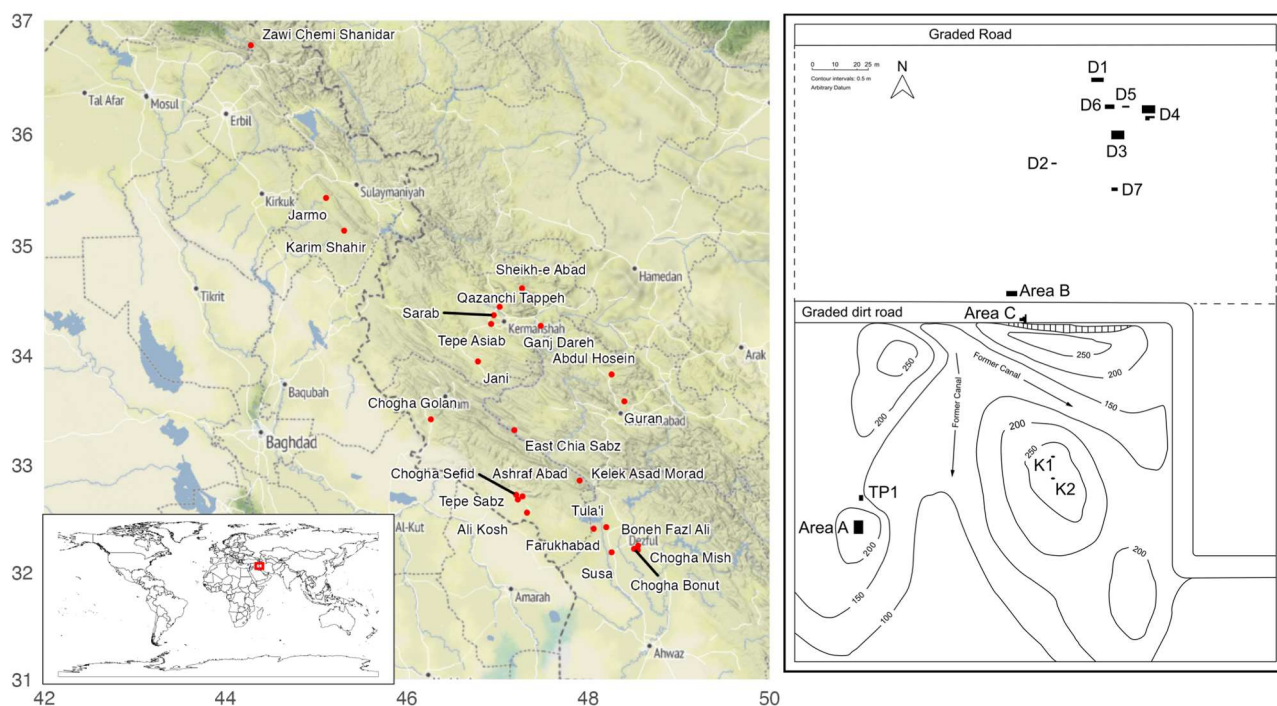


Figure 1. Left: Map of sites mentioned in the text. Right: Location of archaeological excavation areas at Tula'i, adapted from Frank Hole's records.

Background

Tula'i was situated in northwestern Khuzistan, within the lowlands of the Zagros region, Iran, at 32° 25' 25.49" N, 48° 11' 54.62" E, and 110 meters above sea level. This small archaeological mound was located in the middle of a Sasanian canal and an agricultural field and has been destroyed by modern agricultural activities (Hole, 1974). It had a diameter of 60 meters, a height of 1.5 meters, and is located near the Dez and about 4 km east of the Karkheh River. The site was discovered by Henry Wright in 1973 and excavated by Frank Hole in the same year.

Excavation at Tula'i was a salvage project that lasted ten days. Eleven areas were excavated to determine the nature of the site and to gather as much information as possible during the short amount of time (Figure 1). Area A was the main mound, and about 60 m³ was excavated. TP1 (Test Pit 1) was located on the edge of the mound, approximately 10 m north of Area A and on its slope. The TP1 excavation pit measures 5.8 m³. Area D is located 100 m north of the mound with deposits that were interpreted by Hole as tents or temporary shelter areas. In area D1, a 2.1 m³ deposit was excavated.

In the absence of suitable charcoal for radiocarbon dating, Hole used ceramic typology to distinguish chronological changes within the deposits. Based on the ceramics found at other sites in the Deh Luran Plain, Hole dated Tula'i to the late Mohammad Jafar-early Sefid phase (ca. 6200–5900 B.C.) (Hole, 1974). Similarly, Alizadeh (2008b, 2003) aligned Tula'i with the Archaic Susiana 0 Phase (ca. 5900 BCE), which is concurrent with Chogha Bonut– Zone F in the chronological sequence of Susiana Plain.

Floral and faunal remains from Chogha Bonut, located about 35 km distant southeast of Tula'i and in the Dez drainage, are the source of the most important climatic data currently available for Tula'i (Miller, 2003; Redding, 2003). According to the findings from Chogha Bonut, Susiana was primarily a wet grassland in the eighth millennium B.C., potentially interspersed with distinct marshes, each supporting unique flora and fauna. Based on his ethnographic observations, Hole (2009) claimed Tula'i was a winter/spring herders' camp for people who migrated into the mountains to escape the hot summer approximately 8,000 years ago.

Debates on the Nature of Tula'i Occupation: Herder Outpost or Nomadic Campsite?

Hole believed that Tula'i was a campsite used by pastoral nomads. He argued that the site's location at the northern border of the arable section of the Khuzestan plain is

typical of campsite locations away from primary arable locations. Ethnographic observations of recently abandoned camps and testimonies from workers– who are related to nomadic tribes and have worked as laborers at Tula'i– serve as evidence. They suggest that the arrangement of stones at these historical sites like Tula'i was similar to the pattern of modern camps (Hole, 2004; Hole & Amanolahi-Baharvand, 2021).

These elements indicated to Hole that Tula'i distinctly deviates from mounded village sites. Moreover, the presence of stone alignments– deliberately placed stones in a line or pattern indicating tent structures, fire installations, ceramics, stone tools, and faunal remains at Tula'i are characteristics that align with a pastoral camp (Hole, 1974, 1978, 2009). Hole believed that the occupants of Tula'i did not have any relationships with neighboring agricultural communities and, thus, were not an outpost. Instead, Tula'i's inhabitants subsisted on domesticated and wild animal products and other resources obtained from the local environment. He proposed that nuclear families occupied Tula'i over multiple generations, with the whole occupation spanning approximately 50 years (Hole, 2004, 2022).

However, Hole's claim that Tula'i was a mobile herder camp has been rejected by Wheeler Pires-Ferreira (1975), Bernbeck (1992), and Potts (2014). Wheeler Pires-Ferreira's 1975, p. 279) study of the fauna concluded that the site functioned as a village-based fallow herd campsite. Her analysis showed that the site mainly housed domestic goats – primarily older ones – with few young or pregnant females. Her study revealed that 90% of the remains were caprine, and 10% were hunted animals. According to the lack of young or infantile caprines, she inferred that the site was used for pasturing "fallow herds" during winter. Similarly, Bernbeck's (1992) study of the ceramic assemblage supported the "fallow herd camp" idea. He proposed that herders used Tula'i as a winter camp related to nearby village settlements in a system of horizontal transhumance. He rejected Hole's hypothesis of vertical transhumance as he believed that the ceramic parallel clearly showed the link to the lowland settlements at Susiana and Deh Luran. In those interpretations, Tula'i is considered a seasonal outpost camp related to a permanent village occupation.

Alizadeh (2008b, p. 5) further challenges Hole's interpretation, citing the notably sparse population of the plain during that period. Potts (2014) sees Tula'i not as a nomadic campsite but as a place repeatedly used by herders detached from a settlement. He mentions the presence of the midden at Tula'i, and Pires Ferreira's analysis of the age structure of herds as evidence to support his claim. He also acknowledges Cribb's

Table 1. Summary of the debate about occupation at Tula'i and expectations for the lithic assemblage. Based on interpretations by Hole (2004), Wheeler Pires-Ferreira (1975), Bernbeck (1992), Potts (2014), and Kuhn's provisioning models (1994, 2004).

Features/Models	Long-Term Occupation (Seasonal Nomads)	Short-Term Occupation (Village-based Herders)
Duration of Stay	Roughly six months per year	Days to weeks
Occupation Model	Long term	Short term
Provisioning Strategy	Place provisioning (seasonal mobility)	Individual provisioning (Enclosed nomadism)

(2004) assertion that true nomadism requires evidence of the use of horses or other pack animals.

Despite the various interpretations of the specific functions and usage periods of Tula'i's settlement, there's a consensus that the site functioned as a tent campsite. Our aim in this study is to examine how the lithic production patterns at Tula'i can address the ongoing debate on the site's habitation dynamics— a seasonally migrating nomad group or a small group of herders from a permanent settlement. We propose three models to guide our interpretation of the lithic assemblages. The first model posits Tula'i as a "long-term" site, consistent with a seasonally migrating nomad group, a hypothesis supported by Bernbeck and Hole's characterization of the area as a pastoral camp occupied for six months a year (Table 1). If this were the case, we predict the lithic assemblages will be consistent with place provisioning (Kuhn, 2004), which is a strategy where a group equips a location with resources for further use (Table 2). In other words, they would supply a location with more resources, such as lithic materials, than what is immediately needed (Barton & Riel-Salvatore, 2014). We expect lithic assemblages to be dominated by low proportions of cores and retouched flakes, high proportions of local materials, high artifact density, and less formal technologies, as indicated by the presence of ad-hoc tool forms and expedient core reduction techniques (Shipton et al., 2018).

The second model suggests a short-term occupation by herders from a permanent village. If short-term occupation was dominant, we expect the lithic assemblages to indicate individual provisioning (Table 1). This is characterized by supplying individuals rather than a

location. It means the group carries what they need, as indicated by as frequent resharpening of tools via retouching, low artifact density at individual sites due to flaking at multiple locations, and a high proportion of cores relative to flakes (Table 2), a behavior in line with Kuhn's description of provisioning individuals under the constraint of mobility (Kuhn, 1994, 2004). Additionally, there would be an investment in more formal technology to extend the use-life of cores and generate predictable flake products, greater proportions of more distantly sourced materials (Shipton et al., 2018). A third, more flexible model posits that both "short-term" and "long-term" occupations could have occurred at different times as the function of the site shifted over time. Our analysis aims to identify which of these models is best supported by the evidence (Tables 1 and 2).

Materials and Methods

In 2013, the Tula'i assemblage, which is currently housed in the National Museum of Iran, was repackaged and labeled according to excavation records. During this time, we collected data from the stone artifact assemblage. We followed the technotypological analytical conventions of Inizan et al. (1992) and Shea (2013) to define the various forms of debitage and tools for our preliminary study. We categorized lithic artifacts into cores, core fragments, core rejuvenation pieces (including primary pieces, crested pieces, and core tablets), and blanks (flakes, blades, and bladelets). Blades are defined as flakes whose length is at least twice their width and possess straight lateral edges. The same definition applies to bladelets, with the distinction that they have widths narrower than 12 mm. We used chi-square tests

Table 2. Lithic Assemblages Characteristics Based on Occupational Duration and Mobility Patterns Based on Kuhn (1994, 2004), Shipton et al. (2018), and Barton and Riel-Salvatore (2014).

Expected Characteristics of Lithic Assemblage	Long-Term Occupation (Seasonal Nomads)	Short-Term Occupation (Village-based Herders)
Proportion of cores	Low	High
Proportion of retouched flakes	Low	High (due to frequent resharpening)
Proportion of local materials	High	Varies, possibly lower (due to distantly sourced materials)
Artifact Density	High	Low
Blank frequency	High (indicative of surplus production and potential future tool use)	Low (indicative of immediate tool production and use, limited surplus)
Formal Technology	Fewer formal tools	More formal tools
Resharpening and Reshaping of Tools	Prioritized (to extend use and minimize weight)	Frequent, given the mobility and need to maximize utility of carried artifacts

to determine if significant differences exist between the frequencies of artifact types across different excavation areas at the site.

Artifact provenance was originally recorded by area and depth range only. From this information, we have interpolated the chronological units and levels (arbitrary excavation units in Hole's system) for each artifact. Using these details, we examine assemblage variation between chronological units and between excavation areas. To our knowledge, aside from a short report and general classification of lithics at Tula'i (Hole, 1974), this is the first time that a quantitative assessment of the site's lithic assemblages has been conducted.

We examined all lithic artifacts ($n = 3792$) excavated from Area A ($n = 3331$), TP1 ($n = 305$), and D1 ($n = 156$). Hole also excavated additional areas (B, C, D2-7, DH); however, we excluded all 117 artifacts from those areas because of unclear chronological context. Hole also carried out a brief field assessment to explore potential differences in chipped stone traditions between Tula'i and Deh Luran. His investigation focused on sickles, plain blades, and debitage. From this, Hole inferred that the chipped stone practices at Tula'i were closely aligned with those in Deh Luran. He specifically mentioned the low frequency of sickles relative to plain blades (about 1% in level A2) (Hole, 1974).

To explore our aim to understand the inter-assemblage variability of the Tula'i assemblage and its probable relation to the duration of occupation at Tula'i, we use the Whole Assemblage Behavioral Index (WABI) and Principal Component Analysis (PCA). Lithic volumetric density and retouch frequency are the two variables of WABI, jointly used to highlight different aspects of technological organization, individual provisioning and place provisioning in relation to the duration of occupation (Clark & Barton, 2017). WABI can be used to track changes in lithic management systems and land-use strategies because high frequencies of retouch (and correspondingly low artifact density) are often diagnostic of curated assemblages (as a sign of individual provisioning), while low frequencies of retouch (and dense artifact accumulations) tend to represent expedient assemblages (place provisioning). In the case where detailed data about the reduction of individual stone tools is unavailable, WABI analysis can serve as a reliable proxy for assemblage curation to aid in understanding the patterns of technoeconomic decision-making, particularly in the contexts of individual provisioning and place provisioning in past societies (Barton et al., 2011; Barton & Riel-Salvatore, 2012, 2014; Riel-Salvatore et al., 2008; Riel-Salvatore & Barton, 2004, 2007). Studies by Barton et al. (2011), Miller and Barton (2008), Clark et al. (2019), and Riel-Salvatore et

al. (2021) have shown that this method is helpful in analyzing Epipaleolithic, Mesolithic, and early Neolithic assemblages. We expect that this method will be suitable for investigating the nature of site occupation in the Neolithic era using lithic assemblages.

We calculated two values for the WABI: the total number of lithics and the total number of retouched tools in each combination of chronological unit and arbitrary excavation level. By doing so, we can calculate the frequency of retouched pieces as an indicator of lithic curation within assemblages. In addition, using the depth and dimension of each excavated area, we calculated the volume of sediment excavated for each arbitrary excavation level of each chronological unit. Thus, we were able to calculate lithic density per cubic meter of excavated sediment by dividing the total number of lithics by the volume of each analytical unit.

To further investigate structure in the lithic data that might be relevant to understanding the duration and nature of occupation, we used Principal Component Analysis, applying a log transformation to the raw data to better approximate a normal distribution. PCA is a widely used method for extracting information from a dataset with a large number of variables by generating a smaller set of new variables, known as principal components or dimensions, that represent most of the variation in the data. Using PCA can be helpful as we can perceive relationships between and within variables in one analytical process that are difficult to discern from the raw data.

We followed Bicho and Cascalheira's (2020) use of PCA to evaluate differences in the duration of occupation at 17 Upper Palaeolithic sites in Portugal. For application in the Neolithic pastoralism context, we adopted a subset of their variables based on the information available for the Tula'i assemblage. Variables that we used in this study are the Lithic Density (estimated number of artifacts present in 1 m^3 of sediment) (following Clark & Barton, 2017), Core Frequency (relative frequency of cores), Blank Frequency (relative frequency of blanks), Retouch Frequency (relative frequency of retouched artifacts), and Tool Diversity (diversity of tool types within each layer, using Menhennick's index in which the number of tool types is divided by the square root of the total number of retouched tools). We conducted permutation-based statistical tests to evaluate the overall significance of the PCA and the significance of each PCA axis (Camargo, 2022). To evaluate the groupings visible in the PCA space, we used a non-parametric permutation MANOVA (PERMANOVA) to identify if there are significant differences in the lithic assemblages from the three excavation areas.

Reproducibility and Open-source Materials

To enable re-use of our materials and improve reproducibility and transparency according to the principles outlined in Marwick et al. (2017), we include the entire R code used for all the analysis and visualizations contained in this paper in our online materials at <http://doi.org/10.5281/zenodo.10463252>. Also in this version-controlled compendium are the raw data for all the tests reported here. All of the figures, tables, and statistical test results presented here can be independently reproduced with the code and data in this repository. In our online materials, our code is released under the MIT license, our data as CC-0, and our figures as CC-BY, to enable maximum re-use (for more details, see Marwick & Birch, 2018).

Results

Following Inizan (1999) and Shea (2013) as standard conventions to define various forms of debitage and tools, our primary techno-typological observation of the lithic assemblage indicates that while there is a general framework of homogeneity in the technological and typological organization across the three different areas (Tables 3 and 4), chi-square tests reveal statistically significant variations in the distribution of lithic materials (Figures 4). These variations indicate that despite similarities, there are distinctive patterns of tool types and debitage frequencies unique to each area. We categorized the debitage into four key groups: flakes, blades, bladelets, and cores.

The lithic assemblage from Area A, D1, and TP1 at Tula'i is characterized by the systematic production of a large number of bladelets and tools made on bladelets (Table 3). Blades, defined as flakes whose length is at least twice their width, account for 19.8% of total debitage, concentrated mostly in Areas TA and TP1. These blades show high dimensional standardization, indicating a skilled production process. Flakes, on the other hand, are relatively rare, making up only 9.8% of the assemblage, but they exhibit frequent signs of utilization and retouching, particularly in TP1. Bladelets, the dominant blank type (77.4% of all debitage), measure an average of 11 mm in length, 7.8 mm in width, and 1.9 mm in thickness. Their production was highly

Table 4. Tool Types and Quantities at Tula'i, Categorized by Excavation Units D1, TA, TP1.

Tool Type Group	D1	TA	TP1	Total
backed pieces	0	11	2	13
burin	2	8	1	11
denticulate-notch	4	110	7	121
geometric	3	2	0	5
micro burin	0	4	0	4
Perforator	2	50	2	54
retouched piece	5	89	15	109
scraper	4	84	6	94
scraper-notch	0	4	0	4
serrated scraper	0	15	1	16
sickle shine	1	48	6	55
truncated pieces	1	10	0	11
utilized tool	5	282	31	318
Total	27	717	71	815

standardized, likely using pressure flaking, reflecting the expertise of the knappers at Tula'i. The cores are mostly single-platform and unidirectional, with bladelet removals produced through pressure flaking. Unidirectional cores make up 94.1% of the total, while a small minority show multidirectional or bipolar techniques. Core rejuvenation flakes, found alongside cores, suggest that the site saw advanced stages of tool production, with early-stage preparation likely occurring off-site due to the limited presence of cortical pieces.

While we lack information about the raw materials used, we registered a very small number of obsidian pieces, which might suggest that they were imported to the site from a great distance, perhaps northern Turkey, as has been found at other sites in the region (Frahm & Carolus, 2022). The presence of cores, rejuvenation flakes, and a high proportion of debitage show that flint knapping occurred on-site (Table 3). However, there is little evidence for the early stages of knapping – such as the presence of cortical and primary debitage – suggesting that the initial stages of the reduction sequence likely took place off-site. This spatial pattern is supported by the distribution of lithic materials: TA shows the highest density of debitage, indicating intensive tool production. TP1, however, has more diverse tool types and more frequent retouching, reflecting a broader range of activities and potentially longer-term use. In contrast, Area D1 contains fewer utilized pieces but a notable presence of geometric microliths and burins, suggesting different localized activities, possibly related to domestic tasks.

Table 3. Summary of the assemblages at Tula'i, Categorized by Excavation Units D1, TA, TP1.

Area	Cores (n)	Core rejuvenation pieces (n)	Blade (n)	Flake (n)	Bladelet (n)	Retouched Tools (n)	Utilized (n)	Sickle Shine (n)
D1	6	4	33	5	109	21	5	1
TA	142	81	708	151	2245	408	282	48
TP1	2	8	52	29	217	38	31	6
Total	150	93	793	185	2571	467	318	55

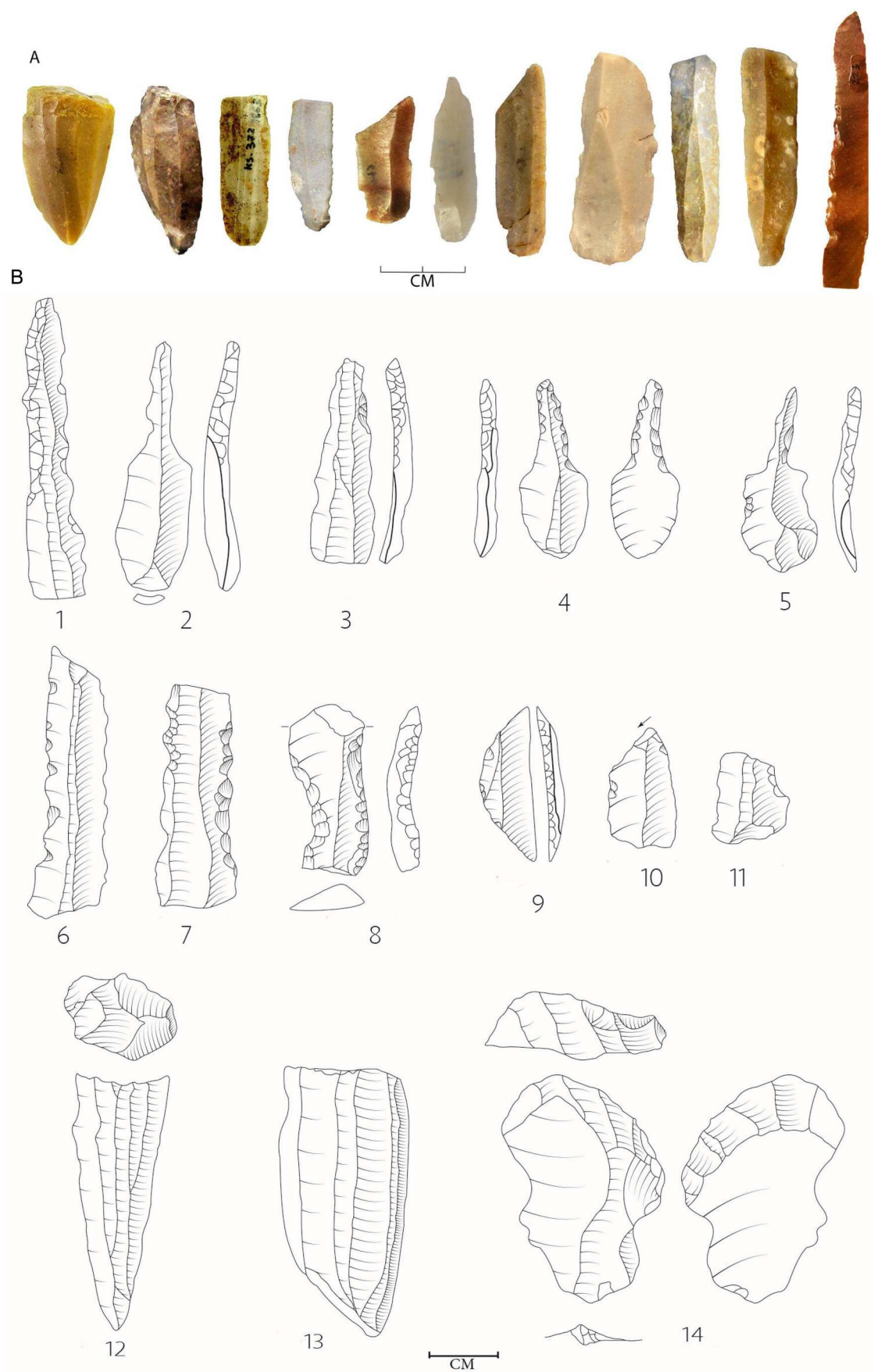


Figure 2. Representative lithic artifacts from Tula'i, illustrating a variety of tools and core fragments from excavation areas TA, TP1, and D1. A. Photographs of selected tools. B. Drawings of artefacts: 1–5: Perforators; 6: Serrated scraper; 7: Scraper; 8: Notched tool; 9: Geometric lunate; 10: Micro-burin; 11: Notched tool; 12: Bullet core bladelet; 13: bladelet Core; 14: Core rejuvenation flake.

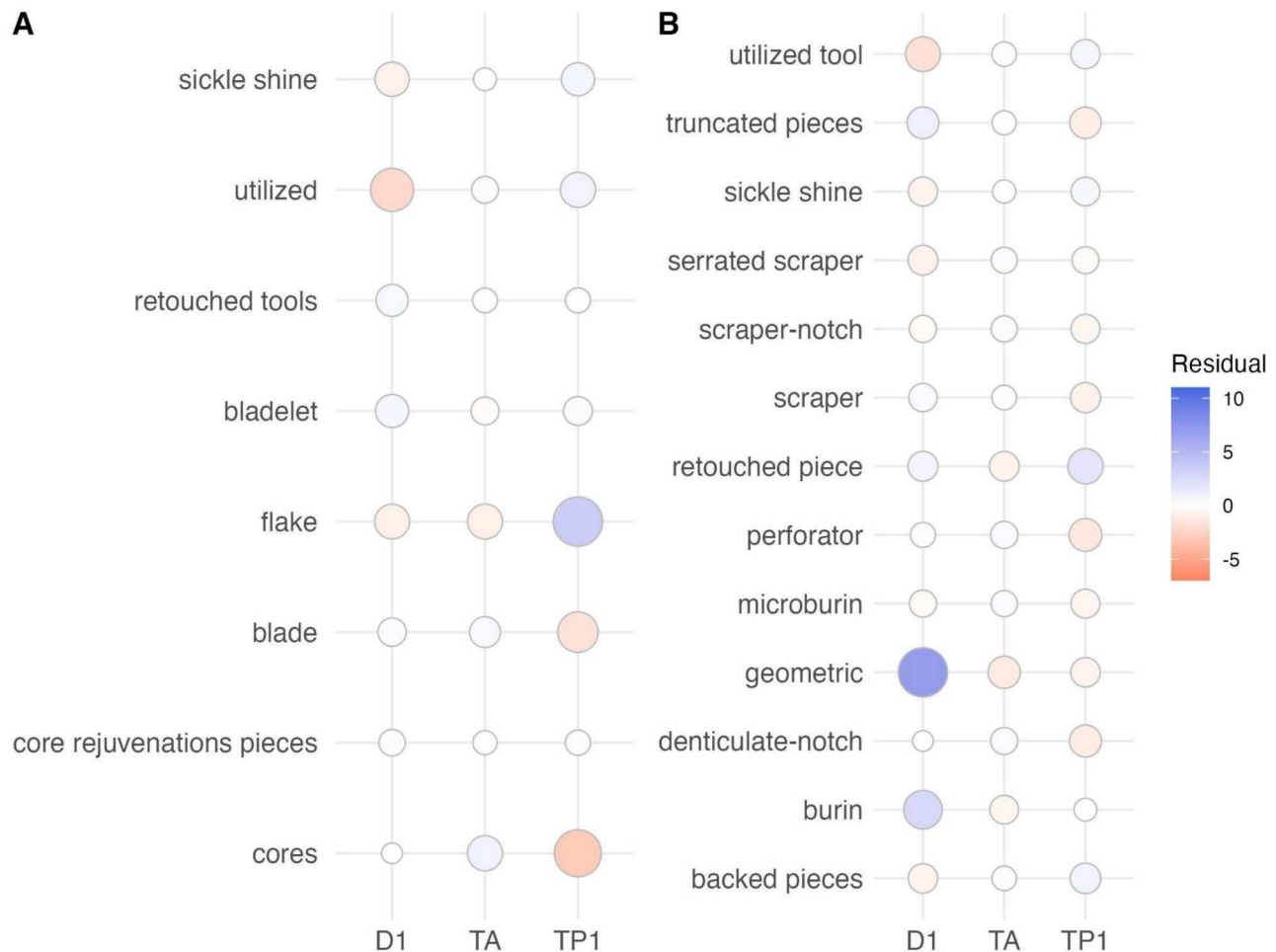


Figure 3. Residual plots from chi-square tests highlighting the distribution of (A) lithic artifact types and (B) tool types across the Tula'i assemblage areas.

Tool types reflect diverse functions, with denticulate-notched tools making up 63.19% of the assemblage, followed by scrapers at 14%. Scrapers exhibit continuous retouching along their edges, often indicating use in a variety of cutting and scraping tasks. A smaller number of specialized tools, such as burins, perforators, and geometric microliths, points to specific functions, possibly related to crafting or food preparation (Figure 2).

A Chi-square test on the frequency of major lithic types by excavation area reveals a significant difference between the areas ($X^2(14, N = 4632) = 34.04, p = .002, V = .06$). Figure 3 shows that there are fewer utilized pieces and flakes in D1 than expected, and more flakes and fewer cores and blades in TP1 than expected assuming a null hypothesis of no difference between the areas. This statistical distinction further highlights the localized nature of tool production and use, with TA showing signs of intensive production and TP1 indicating more diverse and longer-term occupation.

A chi-square test on the frequency of tool type groups by excavation area reveals a significant difference

between the areas ($X^2(24, N = 815) = 74.95, p < .001, V = .21$). Figure 3 shows that there are more geometric pieces and burins in d1 than expected, and more backed and retouched pieces in TP1 than expected assuming a null hypothesis of no difference between the areas. These findings suggest distinct occupational strategies: TP1 appears to have served as a diverse-use area for tasks requiring specialized tools, while D1, with its ash layers, may have been a primary living space used for domestic activities.

Our plot of lithic volumetric density against retouch frequency (Figure 4), using Clark and Barton's (2017) WABl, shows only 1% of the variance in Retouch Frequency can be attributed to Lithic Volumetric Density, with a p -value of 0.572. This suggests that the relationship between the two variables is not statistically significant. However, Principal Component Analysis (PCA) further clarifies the differences between the excavation areas. PCA results reveal that core frequency, blank frequency, and retouch frequency contribute most significantly to the variation between areas. Assemblages

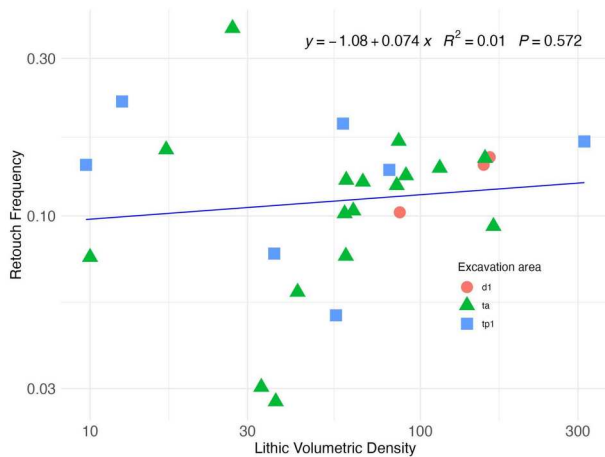


Figure 4. WABI analysis of the relationship between Lithic Volumetric Density and Retouch Frequency.

from TA show higher lithic densities, suggesting more intensive production, while TP1's greater tool diversity and lower core frequency suggest it may have been

used for more specialized or longer-term activities (Figure 6).

To get a broader perspective on the chipped stone artifacts, we ran a PCA on lithic density, core frequency, blank frequency, retouch frequency, and tool diversity. We tested the null hypothesis that the variables used in the PCA are uncorrelated with each other using null distributions of test statistics generated via data permutation. We evaluated the overall significance of PCA with two test statistics that summarize variation in eigenvalues alone (psi) or in combination with the number of variables (phi). Both tests returned a p -value of zero, confirming that the extracted dimensions do synthesize information and that the variation explained by these dimensions was bigger than the variation of a single variable. These two results indicate that the PCA is able to extract a non-random correlation structure from the data. We further used the null distributions to compute a rank-of-roots statistic to select the number of significant PC axes. We found that only dimension

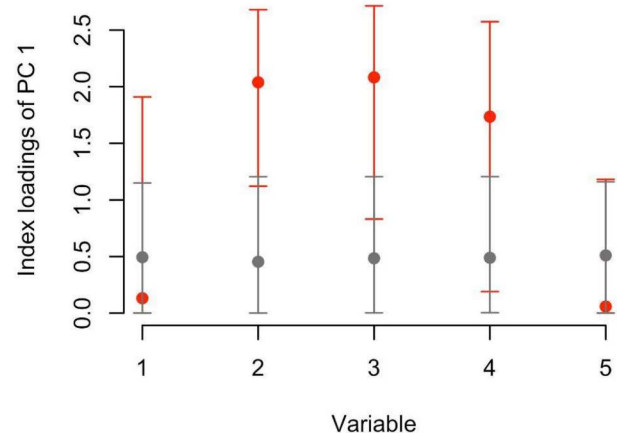
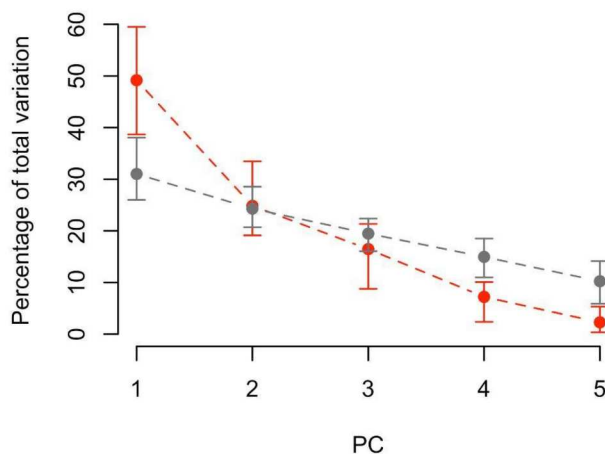
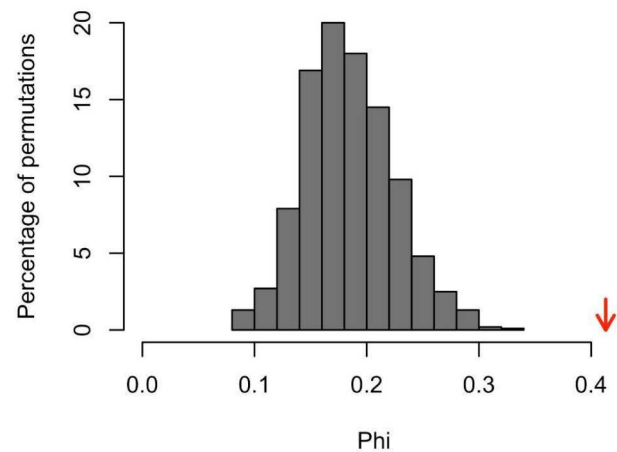
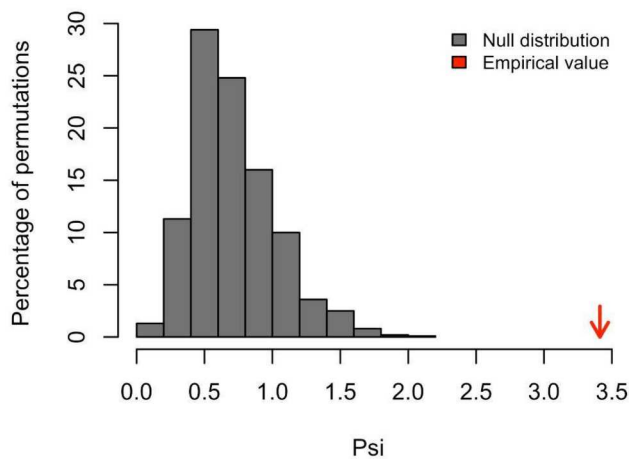


Figure 5. Evaluation of the PCA using null distributions and empirical statistics derived from the lithic data. Lower plots show mean observed values (red dots), 95%-confidence interval (CI) based on 1,000 bootstrap replicates (red bars), mean values, and 95%-CI based on 1,000 random permutations (gray dots and bars, respectively).

Table 5. Summary of the PCA on assemblages at Tula'i.

Dimension	Eigenvalue	Percentage of Variance	Cumulative Percentage of Variance
1	2.46	49.18	49.18
2	1.24	24.85	74.03
3	0.82	16.47	90.5
4	0.36	7.22	97.72
5	0.11	2.28	100

one is significant, so we focus on this in our interpretation of the PCA. The randomization test further shows that of the five input variables, only core frequency, blank frequency, and retouch frequency (variables 2, 3, and 4) significantly contribute to dimension 1 (Figure 5). This suggests that the first dimension reflects a continuum between curated-individual provisioning (higher core and retouch frequencies) and expedient-place provisioning (lower core and higher blank frequencies), revealing the flexible occupational strategies at Tula'i.

The input variables resulted in five dimensions with eigenvalues ranging from 2.46 to 0.11, cumulatively accounting for 100% of the dataset's variability (Table 5). The only statistically significant dimension, Dimension 1, accounts for 49% of the total variance in the dataset, according to Table 4. Dimensions 1 and 2 together account for 74% of the dataset's variability.

Figure 6-A reveals the variables that contribute to each of the dimensions in the PCA. For Dimension 1, three variables exceed the average contribution: blank frequency (34.5%), core frequency (34.8%), and retouch frequency (28.7%). These are the same variables that our permutation analysis identified, confirming their importance in our analysis. Dimension 2 was mostly influenced by lithic density (50.8%) and tool diversity (42%). Dimension 3 was mostly affected by tool diversity (53.9%) and lithic density (32.4%). For Dimension 4, retouch frequency (57.8%) and core frequency (23.8%) are the most important contributors. Finally, Dimension 5 also presents two dominant variables: blank frequency (56.2%) and core frequency (38.1%). However, as Dimensions 1 and 2 are the primary drivers of variance in the data, and Dimension 1 is the only significant one, our focus will be on them.

Figure 6-B shows the biplot of PCA dimensions and the lithic assemblages, representing the association between the assemblage variables and each excavation area at Tula'i. Dimension 1 mainly shows a strong link between core frequency (positive) and blank frequency (negative). Retouch frequency also shows a positive correlation with Dimension 1. Dimension 2 primarily reveals a connection with lithic density (positive) and tool diversity (negative). Within the plot, clusters corresponding to the excavation areas – TA, TP1, and D1 – are discernible.

Most data points from TP1 are in the lower right part of the graph, resulting from lower scores in core frequency, lithic density, and retouch frequency but higher scores in tool diversity and blank frequency. Data points from TA are mostly found in the left part of the plot and generally with higher scores in the second dimension, associated with higher lithic density and lower tool diversity. Data points from area D1 are primarily distributed in the central part of the coordinate plane, indicating that this area has higher lithic density and lower tool diversity, but higher blank frequency.

A permutation MANOVA indicates that there is a significant difference in the lithic assemblage composition across the three excavation areas ($F(2, 26) = 4.001$ $p = 0.038$). We investigated this further using pairwise post-hoc tests and found that this significant difference is between TA and TP1, with the other two areas being statistically indistinguishable (Table 6).

Discussion

Our analysis of the Tula'i collections sheds important new light on some of the lithic assemblage aspects and lifestyles at Tula'i. Our model for interpreting the assemblages proposed that a more mobile lifestyle would present higher retouch frequencies and lower densities (more curated assemblages). Conversely, assemblages belong to a less mobile strategies lifestyle characterized by lower retouch frequencies and higher densities, indicating a more settled lifestyle (a more expedient technological organization).

In the WABI analysis, a low r^2 value of 1% indicates that the Lithic Volumetric Density does not explain much variation in the Retouch Frequency. This aligns with the PCA findings, where lithic density does not significantly contribute to the first principal component, further complicating direct correlations between lithic density and mobility strategies. The absence of a significant relationship in the WABI may indicate that people's mobility and tool use strategies might not align fully with the classical expectations for either nomad or herder groups. This observation directly informs the debate on occupation duration, suggesting that neither short- nor long-term settlement patterns fully align with the expected lithic production and tool maintenance behaviors. This observation challenges the binary classification of the site as a strictly long-term or short-term occupation.

In a comparative context, lithic assemblages from Ganj Dareh exhibit a different pattern, with a distinct negative relationship between retouch frequency and lithic density when examining the range of WABI (Riel-Salvatore et al., 2021). The retouch frequency in Ganj

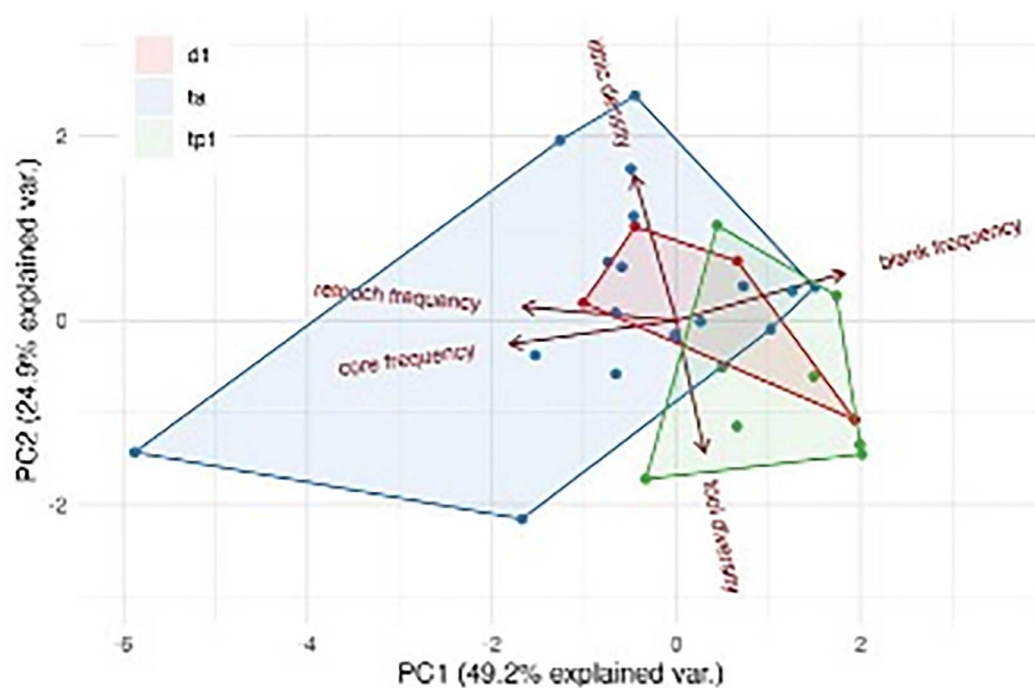
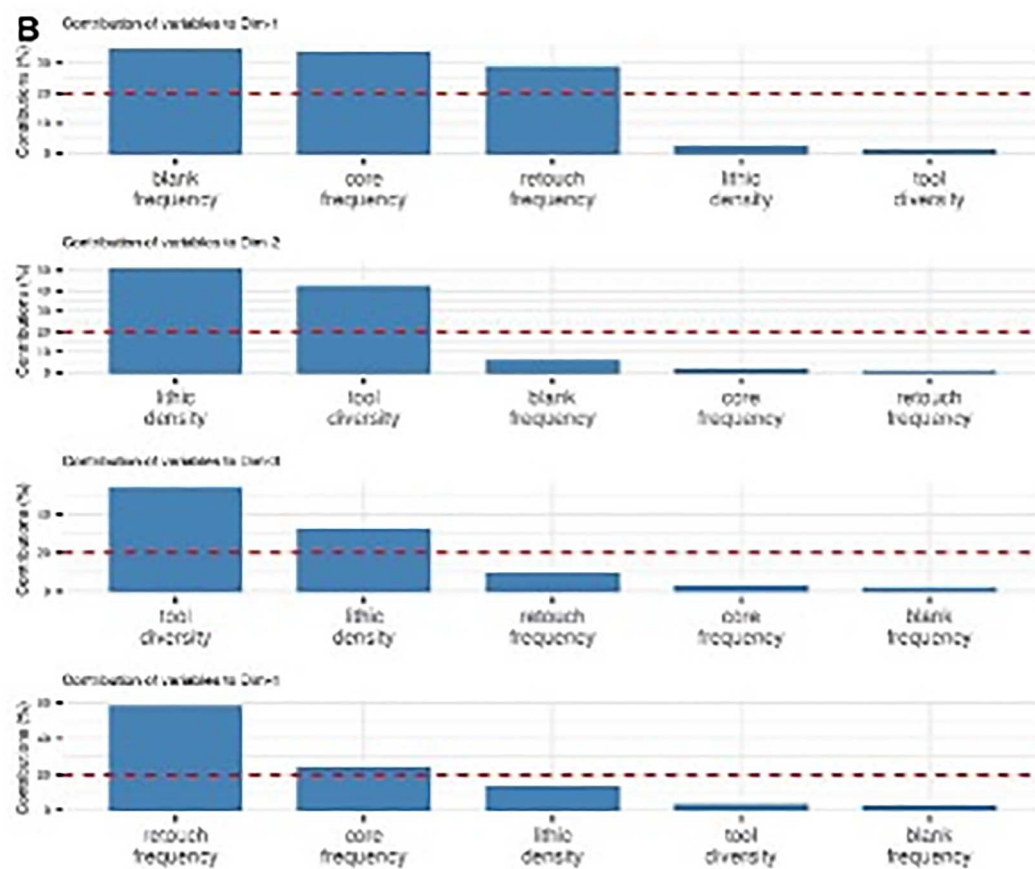
A**B**

Figure 6. (A) PCA Biplot for Dimensions 1 and 2, Showcasing the Correlation of Lithic Assemblage Variables with Excavation Areas (D1, TA, TP1) at Tula'i. (B) Contribution of variables for the first four PCA dimensions.

Table 6. Summary of pairwise post-hoc tests on the excavation areas.

Pair	F	<i>p</i>
D1 vs. TA	1.032	0.316
D1 vs. TP1	2.602	0.092
TA vs. TP1	3.462	0.037

Dareh spans a greater range, extending from about 10 to over 100, while Tula'i's retouch frequency values cluster within a narrower and much lower range, between approximately 0.03 and 0.30. This indicates, firstly, that there were far more retouched pieces and, secondly, that there was a much greater range in the number of tools in the Ganj Dareh assemblage, possibly due to a wider range of activities or a greater emphasis on tool remodification. The broad spectrum of tool frequencies in Ganj Dareh may also imply that individual provisioning of tools was a common practice, as indicated by the high retouch frequencies suggesting repeated use and maintenance of tools. In contrast, Tula'i lithic assemblage shows a more homogenous pattern of very low rates of retouch frequency. This could point to a place provisioning strategy, which results in less variation in retouch frequency.

It shows that the mobility and tool use strategies observed at Tula'i do not conform to those seen at Ganj Dareh, thereby offering a novel insight into Neolithic lifeways. This divergence in patterns is particularly evident in the pronounced variability in Ganj Dareh retouch frequencies as opposed to the small variability in Tula'i's. Such a finding from Tula'i, when juxtaposed with the strong negative correlation at Ganj Dareh, underscores the diversity of Neolithic occupation strategies, with Tula'i's pattern not fitting conventional expectations for either a purely nomadic or herder group. These findings indicate the dynamic and adaptable nature of Neolithic societies, which adjusted their lithic tool use and production strategies to suit their varying needs and environmental contexts.

Beyond the comparison with Ganj Dareh, situating Tula'i within a broader regional framework highlights the diversity of Neolithic settlement strategies and provisioning systems across the Zagros. At Chogha Golan, the emphasis on microlithic bladelet production using pressure flaking and the prevalence of expedient flake tools indicate a place provisioning strategy and long-term seasonal occupation based on localized, on-site manufacture (Zeidi & Conard, 2013; see also Table 1). A similar pattern is observed at Tepe Abdul Hosein, where expedient lithic technologies and the frequent reuse of local raw materials suggest recurrent seasonal visits and embedded tool production (Nishiaki, 2022; Pullar, 1990).

In contrast, sites such as Ali Kosh and Chogha Bonut display assemblages characterized by formalized tool kits, high retouch frequencies, and curated cores – indicative of individual provisioning strategies associated with more mobile, village-based herding populations (Alizadeh et al., 2003; Hole & Flannery, 1962; see Table 2). These assemblages conform more closely to expectations for short-term occupation, where tools are frequently resharpened and curated for transport.

Tula'i, however, presents a more ambiguous profile. The co-occurrence of both expedient bladelet production and formal tools, along with moderate levels of retouch and lithic density, suggests a hybrid provisioning strategy. It does not align neatly with either the long-term seasonal mobility model or fully enclosed nomadic herding (Tables 1 and 2). This intermediate pattern contrasts with Ganj Dareh, where lithic variability – especially in retouch frequency – points more decisively toward individual provisioning and shorter-term use of place (Riel-Salvatore et al., 2021). Direct comparisons between these sites, however, remain challenging due to differences in analytical approaches, as well as the varying scale and size of the sites and their lithic assemblages.

In Tula'i, mobility and tool use strategies offer multifaceted interpretations of lifestyle. These interpretations are integral to addressing the central questions of the paper about the temporal aspects of the site's use. The distinct tool assemblages and retouch patterns in Tula'i support a complex occupational narrative that may include aspects of both short-term and long-term stays, possibly related to seasonal variations in activity and settlement. This evidence does not entirely support Hole's hypothesis of Tula'i as a seasonal campsite characterized by higher retouch frequency and lower lithic density, nor exactly supports the alternative claim of a fallow herd campsite marked by lower retouch frequencies and higher densities.

To further identify structure in the lithic assemblages, we performed a Principal Component Analysis (PCA). The first dimension of the PCA was the only statistically significant dimension and reveals a significant positive correlation with core frequency and retouch frequency and a significant negative correlation with blank frequency. This dimension may be roughly interpreted indicating a curated-expedient or individual-place provisioning spectrum, with positive values for dimension one indicating curated-individual assemblages and negative values indicating expedient-place assemblages. This pattern might indicate a technological strategy at Tula'i wherein the production of cores was prioritized, possibly for specific tool types or functions, while the production of blanks was less emphasized.

The focus on core production could suggest an adaptation to environmental constraints or a response to specific cultural practices. The positive correlation with retouch frequency in Dimension 1 could suggest an emphasis on tool maintenance and reuse, consistent with a mobile lifestyle where efficient use of lithic resources is important. Moreover, the negative correlation with blank frequency could imply a preference for carrying less weight in terms of unworked lithic material. The emphasis on the core frequency and retouch frequency may reflect a strategic approach to lithic technology, showing the importance of the availability and longevity of functional tools. This strategy may also reflect a nuanced approach to site usage, where specific tasks dictated the lithic production patterns observed.

The second dimension, which is not statistically significant, highlights the positive correlation with lithic density and a negative association with tool diversity. Higher lithic density could indicate areas of intensive tool production or use, while lower tool diversity may suggest specialized activities. It is also possible that areas with higher lithic density and lower tool diversity were dedicated work areas where specific tasks were performed, leading to an accumulation of particular tool types and debitage.

Area A, which is the main mound and main activity location of the site, seems to be a zone where a variety of different specialized activities were performed. With many of the TA assemblages having negative values for dimension one, this area may represent more curated individual assemblages, suggesting use by more mobile groups. This is compatible with Hole's assumption that this area is a mound in which most activities were performed, but it also hints at a more complex occupation pattern, resembling more of a village-based fallow herd campsite rather than Hole's proposed pastoral nomad settlement.

Assemblages from TP1 seem to represent a more general-use area, possibly employed for a variety of activities over time. This is supported by TP1's close proximity to the tool diversity vector in the PCA biplot, suggesting that tool diversity is a key feature in this area. With many of the TP1's assemblages having positive values for dimension one, this area may represent more expedient-place assemblages, suggesting long-term use by more sedentary groups. These findings could suggest a dual-use area with overlapping aspects of both herding and nomadic lifestyles. It seems that specialized activities such as processing foods or creating special items such as beads (as these were common activities during the Neolithic in Khuzistan and Dehluran) were happening in TP1, as this

area is mainly influenced by tool diversity. The reduced lithic density and core frequency might be indicative of less intensive lithic production at this part of the site. This may point to a shift in site function over time or to the existence of a specialized activity zone within a larger multi-functional site. Lithic assemblages from TP1 more closely match our expectations for long-term occupation, more consistent with pastoral nomad settlement.

The presence of ashy areas in Area D1, along with the distribution of lithic types, suggests a settlement where domestic and production activities were closely linked, and tools were frequently used for a range of daily tasks, from food processing to crafting, consistent with short-term stays or seasonal activities. Hole's excavation reports describe area D1 as the main location of tents and full of ashy areas. Lithic assemblages from this area show a pattern in the PCA that overlaps with the other two excavation areas. Assemblages from this area are located roughly at zero on dimension one of the PCA, and are mainly distributed in the upper part of the coordinate plane, suggesting lithic density and blank frequency. This positioning in the PCA space may reflect a balance between various activities, indicating a multifunctional space within the campsite. The predominance of geometric microliths in area D1 ([Figure 3](#)) suggests a specialized activity, pointing to a nuanced use of space that may have been seasonally or activity-specific. The presence of ashy areas in Area D1 indicates it as a primary living space. This discovery suggests a dynamic use of space where domestic activities were integrated with lithic tool use and production. We can assume that tools were frequently used, possibly for performing simple daily tasks either of herders on short-term visits or nomads on longer-term visits.

Conclusion

Our study of the Tula'i site gives us new information about how people might have lived there. Despite the low r^2 value from the WABI analysis, which suggests a weak relationship between Lithic Volumetric Density and Retouch Frequency, applying a PCA revealed structure in inter-site activities relating to chipped stone production, use, and discard across the three different excavation areas. Moreover, The observed lithic diversity within areas, particularly in TP1, may suggest a multifaceted use of the area, ranging from special-purpose activities to more general daily tasks.

We suggest that the site experienced diverse occupation types, perhaps a combination of nomadic and fallow herd. The variable and independent nature of retouch frequency and lithic volumetric density at

Tula'i could indicate the site's multifaceted occupational history; that is, different groups utilized the site in diverse ways over time. It is possible that the site was primarily used by pastoral nomadic people, who focussed their stone artifact activities in area TP1. Located on the mound's slope, this area displayed a more diverse range of activities. Despite its lower lithic density and core frequency, its higher tool diversity and blank frequency underscore its role in specialized activities. Various tasks, possibly including food processing and bead creation, might have been performed here. Tula'i was likely also occasionally settled by herders who came to the region with their herds, stayed for a short amount of time, indicated by assemblages in area TA, and then returned to their permanent villages. Area TA was the main location for lithic production, characterized by a higher lithic density and lower tool diversity. This suggests that specific activities in lithic production by short-term herder occupants of the site mostly occurred here. The lithic assemblage from Area D, a primary living space, indicates that the artifacts were frequently used and modified for different daily tasks, either by herders or nomads.

The selective nature of the lithic collection examined here, with the excavator Frank Hole noting that non-diagnostic lithics were excluded from his collection, introduces limitations and potential bias in our analysis. Caution is needed in interpreting site occupation patterns solely based on the available assemblage and comparing them to assemblages excavated by other teams. This caution extends to the understanding of the site's dimensions and the interpretation of its archaeological contexts, acknowledging that our current dataset may not fully represent the range of activities and periods of occupation. Additionally, the hypotheses derived from the analysis, while informed by established models of hunter-gatherer mobility, might not fully account for the specific pastoral nomadic behavior and the complex interactions between different groups and the landscape over time.

For future research, conducting a more detailed analysis of the lithics could provide comprehensive insights into the specific activities at the site. This analysis could include examining tool types, use wear, and raw materials, potentially uncovering details about tool production, their functions, and environmental exploitation. Such an investigation into the assemblages may lead to reconstructing a more precise picture of life, various activities, and occupation durations at Tula'i.

Acknowledgments

We are grateful to the National Museum of Iran for their invaluable cooperation and support in the study of the Tula'i lithic

assemblage. This research, conducted in 2013, benefitted significantly from the resources, expertise, and assistance provided by the museum staff. Special thanks to Frank Hole for his insightful guidance and invaluable suggestions that deeply enriched our work. His expertise and thoughtful engagement with our research have been a beacon of inspiration. We also extend our appreciation to Fereidoun Biglari, head of the Paleolithic Department, for his unwavering support throughout this journey.

Disclosure Statement

No potential conflict of interest was reported by the author(s).

Funding

This research was supported by the Roshan Fellowship, offered by the Department of Middle Eastern Languages and Cultures (MELC) at the University of Washington. The fellowship provided support for laboratory analysis, data interpretation, and manuscript preparation. The authors gratefully acknowledge the pivotal role of this fellowship in facilitating the successful completion of this study; Roshan Cultural Heritage Institute.

Data Availability Statement

The data that support the findings of this study are openly available at the following DOI: <http://doi.org/10.5281/zenodo.10463252>. Additional data related to this paper may be requested from the authors.

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