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RESEARCH ARTICLE

# Dating the beginning of the Pottery Neolithic in South Iran: Radiocarbon dates from Tol-e Sangi, the Fars

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## Abstract

The Fertile Crescent of Southwest Asia is considered one of the main centers of the first Neolithization worldwide. However, the dating and processes of its spread to neighboring regions have yet to be studied. This study reports new chronological data from the Fars highlands, southeast of the Fertile Crescent. Although the Pottery Neolithic in Fars has long been believed to have started in the late 7th millennium BC, recent excavations at Tepe Rahmatabad have suggested a date half a millennium earlier, raising controversy. Our data from Tol-e Sangi, a stratified site with Pre-Pottery (PPN) and Pottery Neolithic (PN) cultural deposits, support the advent of the Pottery Neolithic at the beginning of the 7th millennium BC. This suggests that despite the late arrival of the food production economy in the Fars highlands, which is dated from the mid-8th millennium BC, subsequent cultural development followed a path similar to that of the eastern wing of the Fertile Crescent.

## Introduction

The transition from hunting-gathering to agricultural societies is one of the most significant topics in archaeology because of its involvement in a range of significant economic, social, and ideological changes. The Fertile Crescent of Southwest Asia, which encompasses regions with the oldest evidence of a food production economy, is of vital importance to this research (Asouti and Fuller 2013; Bellwood 2023; Zeder 2011, 2024; Zohary et al. 2012). Recent research has revealed that the food production economy emerged in the 12th millennium BC and was fully established by the early 9th millennium BC (Borrel et al. 2016; Ibáñez 2018; Weide et al. 2018). Similarly, investigations of the subsequent dispersals of this novel economy outside the original centers have also developed considerably in the last few decades (Harris 2010; Ibáñez 2018; Nishiaki et al. 2022; Özdoğan 2024). However, because of the vast expanse of the regions that need to be addressed in dispersal research, many blank areas remain.

In the case of the Zagros of Iran, while previous studies have concentrated on Central Zagros, which makes up the eastern part of the Fertile Crescent (Kozlowski 1999), South Zagros has received less attention. Despite the general proximity of the natural environment between the central and southern Zagros, the latter is far from the natural habitat of the main Neolithic cultivars, such as wheat and barley (Zohary and Hopf 2012). Accordingly, this paper provides a new case study of Neolithic dispersal to the southeast. The study area is the Fars Highland Basin (Figure 1), which was subjected to intensive Neolithic studies in the 1950 and the 1960s, which shaped the first chronological framework of Neolithic development in this region (Nishiaki 2018). However, the resumption of fieldwork since the 2000s, equipped with much better research strategies than before, has produced a new picture of the origin and development of the Neolithic economy in Fars (Alizadeh 2021; Azizi Kharanaghi et al. 2014;

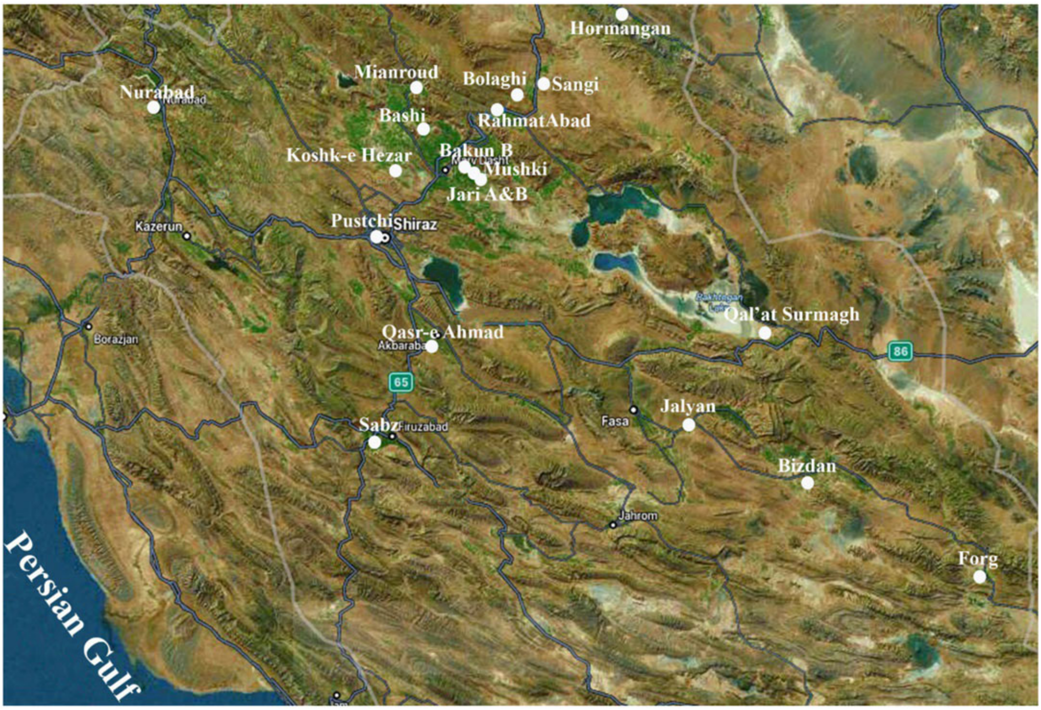


***Figure 1.*** *Map of the South Iran showing the location of Tol-e Sangi and other Neolithic sites.*

Khanipour et al. 2021a; Khanipour and Azizi Kharanaghi 2023; Weeks 2013). One provocative result concerned the beginning of the Pottery Neolithic (PN). For decades, archaeologists believed the first pottery culture in South Iran to be represented by Mushki ware, dating from the late 7th millennium BC (Nishiaki 2010). However, excavations at Tape Rahmatabad in the 2010s produced evidence suggesting the emergence of Neolithic pottery at the beginning of the 7th millennium BC, almost contemporary with the first pottery in the eastern wing of the Fertile Crescent (Azizi Kharanaghi et al. 2012b, 2014). This important result must be validated using data from other regional sites. Thus, the purpose of the present study is to report new chronological evidence from the Tol-e Sangi site, where a neatly stratified sequence from Pre-Pottery Neolithic (PPN) to early PN was discovered (Khanipour and Kharanaghi 2023). This paper also discusses the implications of this new evidence in light of the current interpretive framework for the Neolithization of Southern Iran.

## Regional geomorphology

Tol-e Sangi is located approximately one km south of Morghab City in Safashahr County, west of the Polvar River (Figure 2), Fars. The Morghab Plain is a small plain within the southern Zagros Mountains, covering an area of approximately 9 × 4 km extending from northwest to southeast. Despite its location on a highland plateau (approximately 1800 m asl), the presence of the Polvar River, Bonab Spring, fertile lands, and annual precipitation of ~300–500 mm, provide favorable conditions for agricultural development. Moreover, its plains and foothills are well-suited for animal husbandry. In addition to the structural northwest–southeast-oriented drainage of the Zagros Mountains and the Rud-i Kur, the Rud-i Polvar exhibits a unique transverse drainage pattern. Along its course, the river cuts across two dominant anticlines of Jurassic, Cretaceous, and Miocene ages (Tsuneki and Zeidi 2008). Similar to

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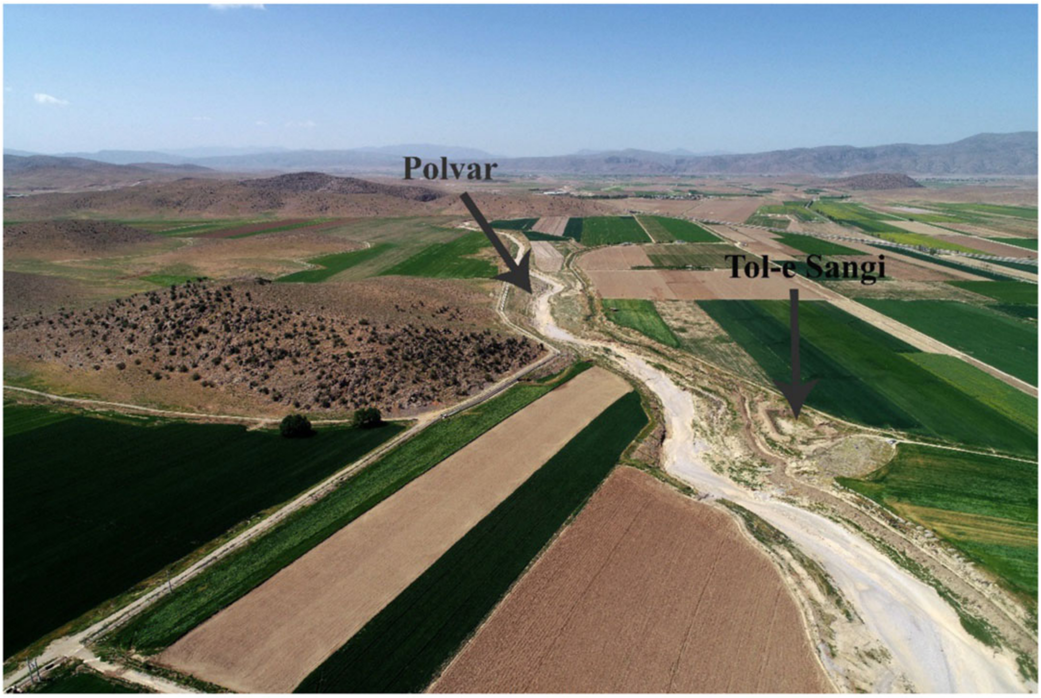


***Figure 2.*** *The Morghab plain and Tol-e Sangi.*

many other canyons in the Zagros, this drainage system originates from a complex interplay of antecedence and superposition (Rigot 2010).

## Excavations at Tol-e Sangi

The Tol-e Sangi site was excavated from May 8 to June 20, 2019, under the direction of one of the authors (M.K.) as a rescue archaeological project against destruction by agricultural activities (Khanipour et al. 2021b). At the time of our first visit, a large pool had been dug into the center of the site for agricultural purposes. As a result, over three meters of the deposit had been dug up and accumulated in the southern part of the site. The surface of the site had also been heavily disturbed by the digging of the pool and other farming activities.

Five trenches were excavated at the site (Figure 3). Trenches 1 and 2 reached virgin soil at depths of less than 2 m, indicating a thinner cultural layer east of the site. Trench 3 was located south of the pool and contained virgin soil at a depth of 516 cm. No architecture was identified in the upper layers, which consisted of soil deposits, ash, or hearths. However, at a depth of approximately 240 cm, a mudbrick wall was found that was approximately 15 cm thick, and its direction was north-south. Excavations revealed numerous hearths and ash deposits at various levels within the trench. The most notable finding from Trench 4, which opened in the northern part of the pool, were the presence of two hearths, painted floors, and walls associated with ashy deposits (Figure 4). The excavations of Trench 5, located in the center of the pool, yielded cultural deposits and stone architecture belonging to the PPN Neolithic period, approximately two meters below the surface.

Overall, the discovery of stone and mudbrick architecture, painted floors, and heating structures indicates permanent settlement at the site. These features make Tol-e Sangi an important site for the late PPN and early PN in southern Iran.

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***Figure 3.*** *Topographic map of Tol-e Sangi and locations of trenches.*

***Figure 4.*** *Architectural remains of Trench 4.*

### *Neolithic pottery of Tol-e Sangi*

A small amount of pottery was recovered during the excavations at Trenches 2, 3, and 4 at Tol-e Sangi. According to the color, the pottery can be divided into two groups: red and buff, although buff pottery rarely appears in the collection. There are different shades of red pottery, ranging from light red to

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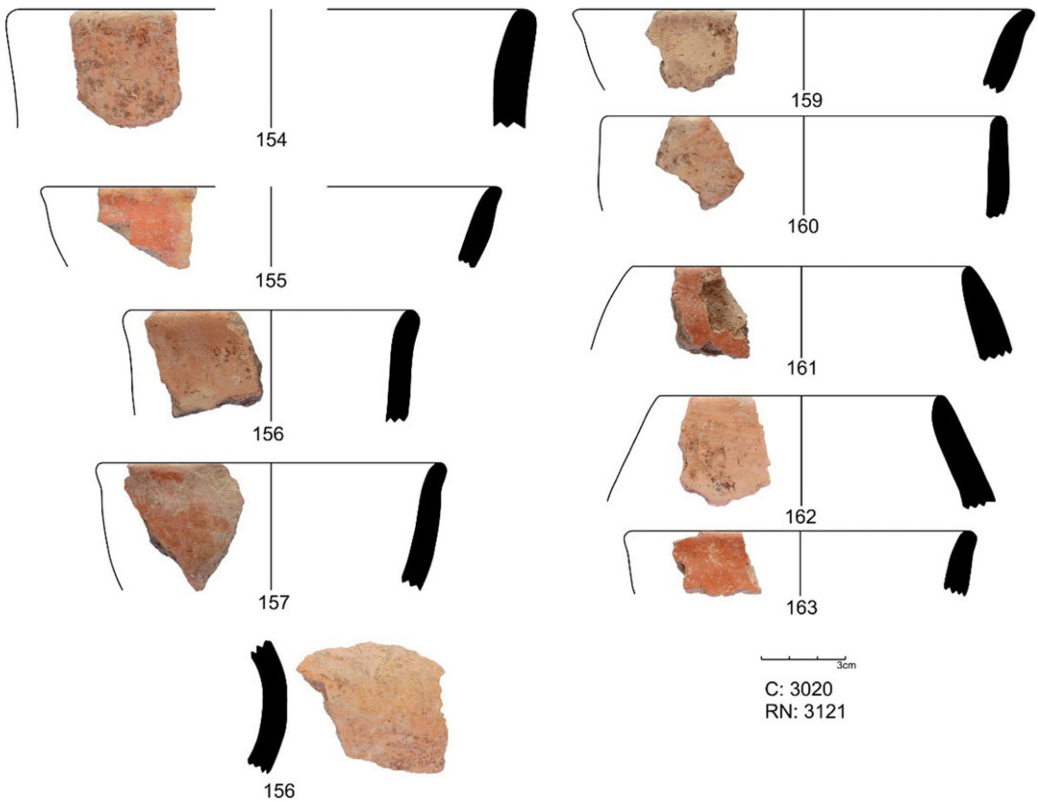


***Figure 5.*** *Pottery from Trench 3, Context 2020.*

brownish red. The surface of the pottery in both groups was smooth, with a red slip on the surface of most of them. Most pottery is plain, but there are a few geometric motifs such as horizontal, vertical, or diagonal bands. The forms of pottery include bowls, beakers, and jars, and bowls are the most abundant in the assemblage (Figure 5). The rims of the vessels include outflaring, upright, and everted rims, and the bases are of two types: flat and concave. These typological features represent a rather homogeneous pottery industry of coarse ware that differs from Mushki ware. Instead, the pottery of Tol-e Sangi is comparable to that of Rahmatabad (Azizi Kharanaghi and Khanipour 2014: Figure 11).

### *Neolithic radiocarbon chronology of Tol-e Sangi*

Excavations of the five trenches did not allow us to correlate each stratigraphy in detail. However, all trenches show upper layers with Neolithic pottery and lower layers without. Given that the use of pottery served as an important chronological division in the Neolithic era of Southwest Asia, the cultural sequence of Tol-e Sangi provides an opportunity to evaluate the timing of the beginning of pottery use in this part of southern Iran. Particularly important was Trench 3, where an uninterrupted sequence of PPN (Phases 14–9) to PN (Phases 8–1) was revealed (Figures 6 and 7).

To determine the date of the PPN-PN transition, a total of 10 charcoal samples were selected for radiocarbon analysis: 1 from Trench 2, 5 from Trench 3, 3 from Trench 4, and 1 from Trench 5. All the samples were analyzed for dating at the Laboratory of Radiocarbon Dating at the University Museum, University of Tokyo (LRD-UMUT), following the standard protocol for charcoal (Omori et al. 2017). That is, pretreatment was made using the acid-alkali-acid (AAA) procedure (de Vries and Barendsen 1954): (1) removing foreign substance from surface of sample and utrasonication in pure water;

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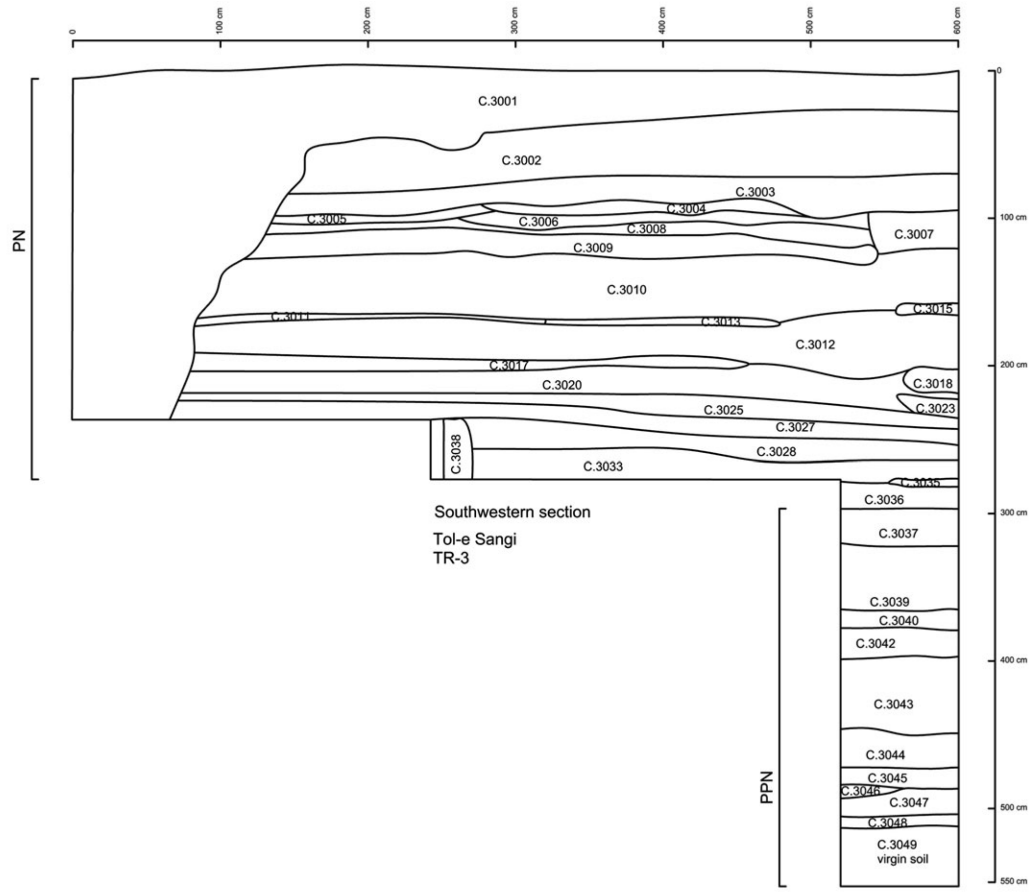


***Figure 6.*** *Southwest stratigraphic section of Trench 3.*

(2) removal of carbonate matters with 1.2M HCl for 16 hr at the temperature of 80ºC; (3) removal of organic acid with NaOH solution (concentration of NaOH and temperature and duration for treatment in Talbe2 alkali treatment); (4) removal of alkali with 1.2M HCl for 17 hr at the temperature of 80ºC (5) neutralization with pure water; and (6) after drying, weighing amount of sample.

For graphitization, a weighed amount of sample in a silver capsule was introduced into an elemental analyzer (EA, Elementar, Vario ISOTOPE SELECT). After quantification of the $CO_2$ separated from resulting components of combusted mixture, purified $CO_2$ was trapped cryogenically in a vacuum line and reacted at the temperature of 650ºC for 6 hr with an excess amount (2.2 times of $CO_2$) of $H_2$ with 2 mg of iron powder catalysis in an isolated grass vessel with a stop cock. The produced graphite was pressed into an Al holder for accelerator mass spectrometry (AMS) at the LRD-UMUT. Some international standards were measured at the same time and $\delta^{13}C$ measured by the AMS was used to calculate the conventional radiocarbon date (Stuiver and Polach 1977).

The results of the AAA pretreatment and graphitization, such as the amount of sample after pretreatment, information on alkali treatment, and graphite weight, are detailed in the archive at LRD-UMUT (Project ID: P-20053). As shown in Table 1, the resultant dates are very similar, covering a period roughly bracketed between 7000 and 6800 BC, within which a PPN-PN transition is placed. The data from Trench 3 were analyzed using a Bayesian method (Table 2; OxCal v4.4.4, https://c14.arch.ox.ac.uk/oxcal/OxCal.html). The results show that the probable median date for the beginning of the PPN is 6956 BC and that of the PPN-PN boundary is 6857 BC, and that of the end of the PN occupation dates to 6750 BC.

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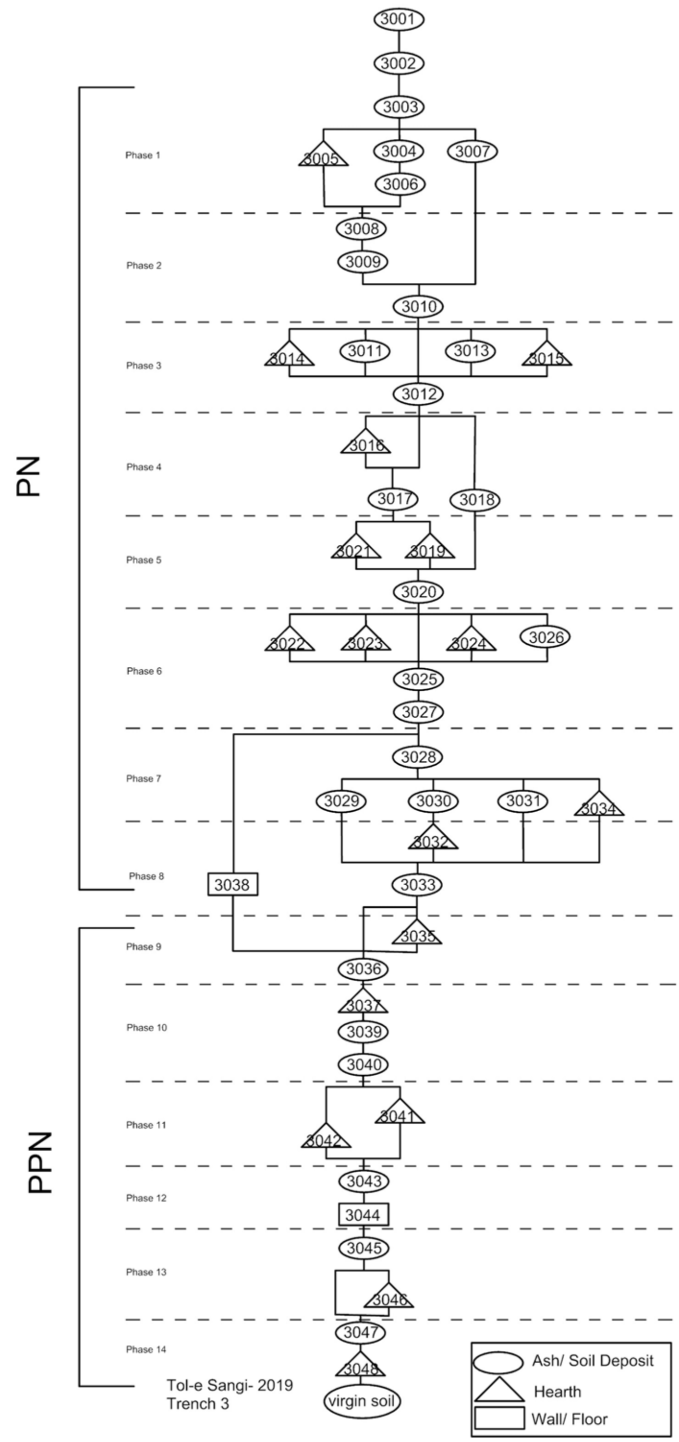


*Figure 7.* *Harris Matrix of Trench 3.*

***Table 1.*** *Radiocarbon dates for the PPN and PN of Tol-e Sangi, the calibration is based on OxCal v4.4.4*

| Trench | Period | Context | Lab code | BP | 1 sigma | 2 sigma | Material | $\delta^{13}C$ |
|---|---|---|---|---|---|---|---|---|
| Trench 2 | PN | C. 2016 | TKA-23164 | 7949 ± 34 BP | 7030BC(20.6%)6966BC<br>6947BC(4.5%)6932BC<br>6915BC(11.7%)6880BC<br>6836BC(22.4%)6767BC<br>6760BC(2.9%)6750BC<br>6722BC(6.2%)6701BC | 7036BC(95.4%)6696BC | Charcoal | –27.9 ± 0.6‰ |
| Trench 3 | PN | C. 3004 | TKA-23156 | 7983 ± 37 BP | 7039BC(46.3%)6906BC<br>6887BC(21.9%)6827BC | 7048BC(90.7%)6767BC<br>6760BC(1.3%)6750BC<br>722BC(3.4%)6701BC | Charcoal | –29.2 ± 0.6‰ |
| Trench 3 | PN | C. 3020 | TKA-23157 | 7914 ± 32 BP | 6906BC(5.9%)6887BC<br>6827BC(61.4%)6687BC<br>6663BC(0.9%)6660BC | 7031BC(12.8%)6965BC<br>6949BC(2.8%)6930BC<br>6917BC(9.3%)6878BC<br>6857BC(0.4%)6853BC<br>6839BC(70.1%)6650BC | Charcoal | –26.3 ± 0.4‰ |
| Trench 3 | PN | C. 3030 | TKA-23158 | 7942 ± 30 BP | 7027BC(17.1%)6969BC<br>6943BC(2.3%)6936BC<br>6912BC(10.4%)6883BC<br>6831BC(30.1%)6747BC<br>6724BC(8.3%)6700BC | 7035BC(43.4%)6874BC<br>6866BC(52.0%)6692BC | Charcoal | –24.4 ± 0.3‰ |
| Trench 3 | PPN | C. 3036 | TKA-23159 | 7930 ± 37 BP | 7025BC(4.8%)7008BC<br>6990BC(5.5%)6970BC<br>6942BC(0.9%)6938BC<br>6911BC(8.7%)6884BC<br>6830BC(48.3%)6693BC | 7035BC(18.7%)6960BC<br>6953BC(18.5%)6875BC<br>6865BC(56.6%)6686BC<br>6667BC(1.5%)6656BC | Charcoal | –26.5 ± 0.3‰ |
| Trench 3 | PPN | C. 3041 | TKA-23160 | 7968 ± 33 BP | 7035BC(53.0%)6874BC<br>6865BC(14.1%)6822BC<br>6784BC(1.2%)6780BC | 7042BC(90.6%)6749BC<br>6723BC(4.8%)6700BC | Charcoal | –25.3 ± 0.5‰ |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Trench 4 | PN | C. 4014 | TKA-23155 | 7892 ± 30 BP | 6806BC(4.7%)6793BC<br>6775BC(63.5%)6652BC | 7026BC(1.9%)7007BC<br>7000BC(3.3%)6969BC<br>6944BC(0.7%)6935BC<br>6913BC(5.0%)6882BC<br>6831BC(84.4%)6644BC | Charcoal | –23.7 ± 0.2‰ |
| Trench 4 | PPN | C. 4023 | TKA-23163 | 7925 ± 34 BP | 7023BC(3.2%)7011BC<br>6985BC(3.9%)6971BC<br>6909BC(7.9%)6885BC<br>6829BC(53.2%)6691BC | 7034BC(16.7%)6962BC<br>6952BC(4.6%)6926BC<br>6921BC(11.5%)6876BC<br>6864BC(60.0%)6683BC<br>6671BC(2.6%)6654BC | Charcoal | –27.4 ± 0.6‰ |
| Trench 4 | PPN | C. 4025 | TKA-23162 | 7994 ± 32 BP | 7043BC(8.2%)7023BC<br>7011BC(9.5%)6986BC<br>6971BC(26.2%)6910BC<br>6884BC(24.3%)6829BC | 7050BC(94.1%)6773BC<br>6716BC(1.3%)6706BC | Charcoal | –27.5 ± 0.5‰ |
| Trench 5 | PPN | C. 5010 | TKA-23161 | 8006 ± 31 BP | 7047BC(10.4%)7026BC<br>7008BC(6.2%)6991BC<br>6970BC(13.7%)6942BC<br>6936BC(11.9%)6912BC<br>6883BC(26.2%)6831BC | 7057BC(93.1%)6811BC<br>6794BC(2.3%)6775BC | Charcoal | –26.8 ± 0.3‰ |

***Table 2.*** *Bayesian analysis of the radiocarbon dates from Trench 3*

| | Unmodeled (BC/AD) | | | | | Modeled (BC/AD) | | | | | Indices Amodel 99.3 Aoverall 101.6 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Name | median | from_68_3 | to_68_3 | from_95_4 | to_95_4 | median | from_68_3 | to_68_3 | from_95_4 | to_95_4 | Acomb | A | L | P | C |
| Boundary End | | | | | | –6759 | –6898 | –6672 | –7021 | –6573 | | | | | 96.2 |
| R_Date TKA-23157 | –6782 | –6906 | –6660 | –7031 | –6650 | –6779 | –6824 | –6696 | –6998 | –6656 | | 109.5 | | | 99.3 |
| R_Date TKA-23158 | –6843 | –7027 | –6700 | –7035 | –6692 | –6804 | –6907 | –6706 | –7000 | –6694 | | 108.2 | | | 99.4 |
| R_Date TKA-23156 | –6909 | –7039 | –6827 | –7048 | –6701 | –6831 | –6916 | –6756 | –7003 | –6703 | | 87.8 | | | 99.4 |
| Sequence PN | | | | | | | | | | | | | | | |
| Boundary Transition PPN/PN | | | | | | –6857 | –6941 | –6771 | –7022 | –6710 | | | | | 99.4 |
| R_Date TKA-23159 | –6817 | –7025 | –6693 | –7035 | –6656 | –6893 | –7020 | –6787 | –7031 | –6758 | | 93.7 | | | 99.4 |
| R_Date TKA-23160 | –6897 | –7035 | –6780 | –7042 | –6700 | –6922 | –7037 | –6819 | –7042 | –6777 | | 106.2 | | | 99 |
| Sequence PPN | | | | | | | | | | | | | | | |
| Boundary Start | | | | | | –6956 | –7054 | –6821 | –7197 | –6710 | | | | | 96.4 |

Notably, the oldest date for Trench 3 was from Phase 11, although the Trench 3 sequence was divided into 14 phases. The first occupation began earlier, most likely during the late 8th millennium BC.

The dates from the other trenches, one PN (C. 2016) for Trench 2, one PN (C. 4014) and two PPN (c. 4023 and 4025) for Trench 4, and one PPN (C. 5010) for Trench 5, also fell within the PPN-PN range of Trench 3 (Table 1). The sum probability of all the Tol-e Sangi dates ranges from the Neolithic occupation to the period between 7050 and 6650 BC. Although the unavailability of charcoal samples from the lowest layers of any trench prevents us from dating the beginning of the occupation, the most important result of radiocarbon dating at this site is the determination of the PPN-PN transition to a period between 6900 and 6800 BC (likely 6859 BC). This strongly supports the recent proposal that the PN began at the beginning of the 7th millennium BC in Tape Rahmatabad (Azizi Kharanaghi and Khanipour 2014; Khanipour and Azizi Kharanaghi 2023). The stratigraphic context is more firmly defined at Tol-e Sangi, particularly for the Pottery Neolithic, which is over 2 m thick, versus a thickness of less than 1 m at Rahmatabad.

### *Tol-e Sangi in the context of the South Zagros Neolithic*

As stated earlier, there is a consensus regarding the appearance of the first Neolithic society in the Fertile Crescent in the 12th millennium BC. However, the archaeological remains of this period do not include morphologically domesticated cultivars, notably cereals, suggesting a preliminary stage of cereal cultivation using wild progenitors (see Borrell et al. 2016). A significant increase in domesticated wheat and barley species occurred at the beginning of the 8th millennium BC, marking the beginning of the Middle PPNB in the West Wing of the Fertile Crescent and the "Neolithic" in the East Wing represented by the Central Zagros (Darabi et al. 2019). In the latter, the earlier period is often termed the "Proto-Neolithic" (cf. Matthews and Fazeli Nashil 2022).

Regardless of the minor differences in timing, evidence from the regions of the Fertile Crescent indicates that Neolithization was a long process lasting several millennia. The 8th millennium BC PPN evidence from Tepe Rahmatabad and now that from Tol-e Sangi allow us to examine whether there was a comparable Neolithization process in the Fars of South Iran. The best-studied "Proto-Neolithic" sites in this region are the two caves TB75 and TB130 in the Sivand Dam reservoir area, excavated as rescue excavations (Tsuneki 2013; Tsuneki and Zeidi 2008). The cultural stratigraphy of these two caves covers the period of 18000–7500 cal BC. Although the poor preservation of plant remains in this cave did not allow excavators to identify plant exploitation, the faunal assemblages provided a basis for evaluating animal exploitation and did not show traces of animal domestication (Hongo and Mashkour 2008).

Accordingly, the oldest evidence thus far of a food production economy in Fars is that from Tepe Rahmatabad. Although the excavations of Rahmatabad in 2005 (Bernbeck et al. 2005) placed the oldest cultural deposits between 7000 and 6700 BC, re-excavations have revealed earlier Neolithic occupations dating as far back as 7450 cal BC (Azizi Kharanaghi and Khanipour 2014). Evidence of food production in the PPN remains of Rahmatabad is attested to by both plant and faunal remains, dominated by domesticated wheat or barley, sheep, and goats, respectively (Davoudi et al. 2017; Tenberg and Azizi Kharanaghi 2016, 144). Thus, Neolithic history in Fars has been pushed back to approximately 7450 BC, 1000 years older than previously thought, based on the data from Tol-e Mushki (Nishiaki 2010).

In addition to the solid evidence of plant and faunal remains, it is important to stress that the Neolithic evidence of Tol-e Sangi is radiocarbon-dated with more samples, 10 compared to only 3 from Tepe Rahmatabad. This suggests that food production in Fars began in the late 8th millennium BC. Considering the absence of evidence of food production in the layer of approximately 7500 BC at TB75, it follows that the Neolithic economy appeared in this region rather suddenly, unlike in Central Zagros, where the evidence appeared in the 12th millennium BC (Riehl et al. 2013). At the same time, the 8th millennium BC is comparable to the oldest date of Neolithic sites in the lowland plains of southern Iran (Alizadeh 2003; Darabi 2018; Darabi et al. 2020; Hole 2000). Evidence from Rahmatabad and now

Tol-e Sangi (Khanipour et al. 2021b), and perhaps Tol-e Qasr Ahmad (Azizi Kharanaghi et al. 2012a) in the Qare Aghaj River Basin in Fars, suggests that the Neolithization of the highland plateau of South Iran started almost simultaneously, as in the lowlands not far from the Central Zagros.

In the current situation, the most significant contribution of the present research is the dating of the PPN-PN transition. As there was no gap in the stratigraphy over the PPN-PN transition at Tol-e Sangi, we were able to determine a more precise date for the emergence of pottery in southern Zagros. A rich series of radiocarbon dates from Tol-e Sangi is a significant addition for evaluating the timing of the PPN-PN transition. Specifically, the period from 6900 to 6800 BC can be considered as seeing the emergence of pottery in southern Iran. Although no architecture was found from the Neolithic period in Rahmatabad, architectural evidence of sedentary settlements, such as painted floors and mudbrick walls, was recovered from Tol-e Sangi. Furthermore, its five-meter-thick cultural deposits provide a reliable chronological basis for understanding how plant and animal exploitation strategies, as well as material cultures, changed during the PPN-PN transition.

## Conclusion

The new radiocarbon dates of Tol-e Sangi place the beginning of the PN in southern Iran during the early 7th millennium BC, as at Tepe Gavkoshi in Kerman (Alidadi Soleimani and Fazeli Nashil 2018) and Ali Kosh in the Dehloran Plain (Darabi 2018). In other words, the communities on the outskirts of the eastern wing of the Fertile Crescent started pottery manufacturing and use at more or less at the same time. This preliminary conclusion is intriguing, particularly as these regions, including Fars, were not the central provinces where the first Neolithization took place. Despite the late arrival of the Neolithic socioeconomy, evidence from the mid-8th millennium BC in Fars suggests that the subsequent cultural development of Neolithic societies followed comparable chronological paths. This finding raises an important issue regarding dispersal processes in the Neolithic economy, suggesting the development of steadier social networks allowing the exchange of cultural knowledge among Neolithic societies, which did not exist among hunter-gatherers. Determining the beginning of the PN in South Iran can thus broaden our research scope to examine socioeconomic changes at the time of Neolithic dispersals.

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