Masouleh and its cultural landscape: The role of iron mining and iron industries in its socioeconomic development

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ABSTRACT: The historic town of Masouleh in Gilan Province, northern Iran, represents a distinctive cultural landscape shaped by the interaction between human settlement and rich natural resources, especially iron ore. This study investigates the geological, archaeological, and historical evidence for iron mining and metallurgy in the Masouleh region and evaluates their role in the town's socioeconomic development. New fieldwork and laboratory analyses have identified over thirty metallurgical sites within the Masouleh valley and its highland surroundings, yielding slag, tuyères, and fragments of furnace walls that attest to a long tradition of iron smelting. XRF analyses of slag and ores indicate the use of high-grade hematite and magnetite ores, reduced in both bloomery and charcoal-fueled blast furnaces. Comparison with ethnographic and historical records from Qarādāgh and Mazandaran provides insights into the operation of multi-chamber smelting installations at sites such as Kohne Masouleh and Siyapesia. From the Safavid to Qajar periods (16th to early 20th centuries CE), iron extraction, smelting, and blacksmithing underpinned the economy of Masouleh, supplying iron products to regional markets and the royal arsenal. These findings demonstrate that iron metallurgy was central to the technological and economic identity of Masouleh and highlight the need for further interdisciplinary studies combining geology, archaeometallurgy, and landscape archaeology to reconstruct the region's industrial past.

KEYWORDS: Masouleh, iron mining, archaeometallurgy, bloomery furnaces, blast furnaces, tuyères, slag analysis

Introduction

Understanding the environmental potentials of ancient landscapes is crucial for interpretation of the cultural processes of past societies. Archaeologists frequently employ a "landscape archaeology" approach to address a fundamental question: How have human communities interacted with their surrounding geographic space through time? In other words, how did they appropriate this space, and/or transform its appearance through work, and how did they improve its significance through related cultural practices? (Parcero-Oubiña *et al.* 2020, 4379). A comprehensive understanding of archaeological evidence is not possible without recognizing the spatial dimensions of human life and the mutual relationship between humans and their environment. Aspects such as the formation of urban and rural landscapes, identification of ancient agrarian systems, and the reconstruction of social dynamics behind their formation are incomplete without considering this interaction (Parcero-Oubiña *et al.* 2020, 4381).

Masouleh stands out as a distinctive example of human-environment interaction producing a culturally unique landscape (Mozaeni & Bahrampour 2017, 14–18). The district lies in the western part of Gilan Province, northern Iran (Fig. 1). The province of Gilan is situated along the northwestern section of the Alborz Mountain range, on the southwestern edge of the Caspian Sea. The town of Masouleh itself is located at 37°10' N, 48°59' E, at an elevation of 1,050 m, in the upper valley of the *Masouleh Roudkhan* River. It occupies a position within the Talesh

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Figure 1: Map of Gilan Province in northern Iran showing the geographical location of Masouleh (red circle).

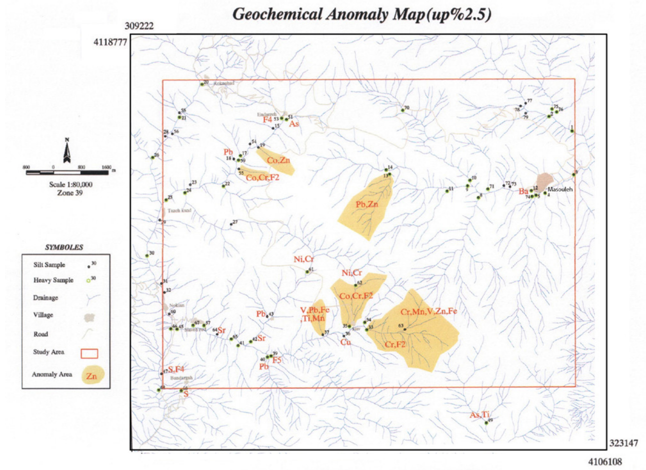

Figure 2: Geochemical Anomaly Map of the Masouleh region showing Fe-Mn-Cu-Zn enrichment zones and the location of main ore indices around the town (after Peyab Consulting Engineers 2002).

Mountains, which separate Gilan from the neighboring province of Azerbaijan (Bazin 1980; 2000). Masouleh is built on a steep mountain slope and is characterized by its distinctive terraced architecture. Owing to its natural and cultural significance, it is one of Iran's most popular tourist destinations, receiving approximately 800,000 national and international visitors annually (Pourali 2016). In recognition of its outstanding cultural value, Masouleh was also inscribed on UNESCO's Tentative List of World Heritage Sites in 2007 (UNESCO 2007). Natural conditions, including the town's location on steep slopes, absence of flat lands for settlement and agriculture, and the presence of lush forests and rich mineral deposits in the surrounding highlands, have shaped a particular lifestyle among its inhabitants over time. This led to a unique architectural and urban planning style, supported by a distinctive social organization. The town's complex real estate management system, the large-scale and structured extraction and processing of local iron ores, the production and export of various iron implements, and its intermediary trade role between the lowland coastal districts and the highland areas of Azerbaijan and Zanjan all testify to this distinctive social organization (*cf.* Beheshti 2017, 9–10).

In Masouleh, the spatial dimensions of human activity are clearly reflected in the material culture – not only in the town's terraced architecture but also in an interconnected network of pathways that integrate the town and its surrounding landscape into a coherent whole (Daneshyar 2017). The town once hosted several caravanserais and bazaar alleys with approximately 400 shops, most of which were specialized in ironworking and remained active until the early 20th century (Rabino 1917, 185; Bazin 1980, II, 162–167). Dozens of archaeological sites, marked by widespread iron slag in the valleys and highlands around Masouleh and seemingly solely focused on smelting, are part of this material culture, reflecting the enduring interplay between human society and the natural environment (Navaiyan 2012, 208–210).

This paper begins with an overview of the environmental potentials of the Masouleh region, particularly its iron ore deposits, based on geological studies. It then reviews historical texts, including accounts by European travelers and reports from Iranian and foreign geographers, historians, and engineers about the landscape of Masouleh and the crafts practiced by its inhabitants, particularly the iron mines and forges. Drawing on ethnographic research regarding traditional mining and smelting practices in nearby regions such as Mazandaran and Azerbaijan from the mid-19th to early 20th century, as well as recent archaeological surveys and excavations of metallurgical sites around Masouleh, this paper ultimately explores the role of iron mining and traditional iron-working crafts in the socioeconomic development of the town.

Iron ore deposits in the Masouleh region

Recent geological and geochemical studies conducted in the Masouleh highlands have confirmed the presence of multiple iron-bearing anomalies distributed within a 10–12 km radius of the town. The Geochemical Anomaly Map (Fig. 2) reveals several Fe-, Mn-, Cu-, and Zn-rich zones, particularly in the Dehrsu, Khale, and Minaru sub-basins, which coincide with known ore indices previously recorded by Peyab Consulting Engineers in 2002 (Mansouri Zaranji 2017). The corresponding analytical data list eight major anomalies identified through remote sensing-based prospectivity analysis (Table 1), with iron grades up to 90 wt% Fe, concentrated mainly in volcanic and tuffaceous formations (listed as Etr, Ev, and g units in Table 1).

The Masouleh region geologically belongs to the northern Alborz volcanic–sedimentary belt, where Eocene andesitic tuffs and basalts host stratiform and vein-type iron mineralizations. The dominant ore minerals are hematite and magnetite, accompanied locally by limonite, pyrite, and manganese oxides. These ore bodies typically occur along fracture zones and at lithological contacts between basic volcanic rocks and intrusive bodies. The highest-grade mineralization is recorded at the Dehrsu index in the upper tributaries of the Chame-Kharim River, where XRF analysis indicates Fe_2O_3 content exceeding 90 wt% (Table 2). Similar high-grade hematite veins occur at Khale in the Viza-bon headwaters and at Minaru, where Fe-Mn-Ba mineralization has been documented.

In addition to these stratiform and vein-type deposits, geological surveys have documented ultramafic–mafic intrusions rich in iron and magnesium near the villages of Chopul, Zudel, and Gilvand Rud, in close proximity to Masouleh (Khal'atbari Jafari *et al.* 2016, 105–106). These intrusive bodies, composed primarily of peridotite and gabbroic rocks, occur as small outcrops along the southern flank of the Masouleh valley and represent an important source of secondary iron enrichment. The contact zones between these mafic intrusions and the surrounding volcanic tuffs exhibit hydrothermal alteration and oxidation, resulting in hematite and magnetite mineralization visible on the surface. According to Peyab Consulting Engineers (2002), the host rock at the Dehrsu deposit consists of volcanic tuff with a 60–120 m wide mineralized zone, while the Khale index exhibits iron mineralization approximately 40 m wide within similar tuffaceous rocks. XRF analyses of representative samples from the Dehrsu deposit yielded Fe_2O_3 values of 90.46 wt% (Table 2). For the Khale index, a Fe_2O_3 content of 97 wt% has been reported (Navaiyan 2012, 214). Additional field observations noted iron-rich conglomerate veins in the upper tributaries of the Seqi-Bon Valley and near the village of Nesrun, as well as thick veins of iron and copper ore in the forests of Kishdarreh, accompanied by traces of ancient surface mining and primitive smelting furnaces (Kolář 2005, 149).

Spatially, these ore sources lie only 3–6 km from the town of Masouleh, forming a semicircular distribution across the surrounding ridges and highland pastures – Goren, Khalil Dasht, and Jalalabad. Their proximity to dense forest cover provided an abundant supply of charcoal fuel, making the region highly suitable for small-scale bloomery and charcoal-fueled blast furnace operations. Historical sources confirm that the Goren and Jalalabad mines remained active until the late Qajar period (1789–1925 CE) (Rabino 1917, 187–188). According to these records, the Goren iron mine, approximately five kilometers southwest of Masouleh, was sealed by a rockfall in the early 20th century. Two ore samples from Goren mine preserved in the Masouleh Museum were subjected to elemental analysis at the Jajarm Alumina Factory Laboratory, revealing Fe_2O_3 contents of 82.38 wt% and 53.56 wt%, respectively (Table 3). The Jalalabad mine, located about 6 km away on the slopes of Shamolum Mount on the west-northwest

Table 1: Identification of proposed anomalies with potential copper, iron, and gold (?) mineralization in the Masouleh area based on remote sensing analysis. Acronyms in the table refer to lithological units on the Geological Survey of Iran maps: Etr = Eocene trachyte–trachyandesite volcanic rocks; Eavb = Eocene andesite and volcanic breccia; Ev = Eocene volcanic units (mainly andesitic–basaltic); g = granitic intrusive body (Source: Mansouri Zaranji 2017, Tables 2–3).

Anomaly ID	Anomaly Center Coordinate (UTM-39S)		Mineralization Evidence			Area (km²)	Prospectivity score (0–9)
	X	Y	Alteration (spectrally detected)	Geology	Geochemical Anomaly		
A1	3269764	433033	Silicic, Argillic, Sericitic/Propylitic	Etr		1.26	8
A2	3269965	430258	Silicic, Argillic, Sericitic	Etr		0.24	7
A3	3272790	430011	Argillic, Sericitic, Propylitic/Iron Oxide	g	Fe	0.49	7.5
	3274173	430022					
	3274913	428994					
A4	3272909	434222	Silicic, Sericitic, Propylitic/Iron Oxide	Eavb	Fe	0.18	6
	3272709	433350					
B1	3271522	425203	Silicic, Sericitic, Propylitic/Iron Oxide	Etr		0.47	7
B2	3281357	434338	Sericitic, Propylitic	g		0.56	6
	3281386	420283					
B3	3278737	419220	Silicic, Sericitic, Iron Oxide	Ev	Fe	0.55	6
	3279292	416691					
B4	3275438	416105	Silicic, Argillic, Sericitic	Etr		0.37	6
	3273757	423598					

of Masouleh, likely supplied ore to nearby smelting workshops throughout the 19th century.

The chemical composition of these ores closely matches the metallurgical residues recovered from the smelting sites in the Masouleh valley. XRF analyses of slag samples indicate deliberate fluxing with silica to enhance reduction efficiency. The high-grade hematite and magnetite ores from Dehrsu and Goren combined with the abundant availability of charcoal, water, and topographic advantages for airflow made the Masouleh highlands particularly favorable for iron smelting. The technological evidence – slag, tuyères, and vitrified furnace fragments – suggests that bloomery and early blast furnace technologies were employed to process these ores (see below).

The spatial correspondence between ore indices identified on the geochemical map and the distribution of metallurgical sites recorded during recent field surveys demonstrates that iron production in Masouleh was a locally integrated system. Most of the 30 smelting sites discovered within the Masouleh valley (see below) fall within a 2–8 km radius of the Dehrsu, Khale, and Minaru ore belts; all accessible through short mule paths descending into the main valley. This proximity strongly implies that smelting installations such as Kohne Masouleh, Ganzara, Kureh-bar, and Siyapesia were supplied directly from these upland ore sources rather than relying on imported materials. Furthermore, the variation observed in slag composition – from silica-rich slags at Siyapesia (Fe_2O_3 ≈ 8 wt%) to the iron-rich residues at Kohne Masouleh (Fe_2O_3 ≈ 73 wt%) likely reflects differences in ore grade and furnace design and/or operating system across the landscape. In combination, the geological, chemical, and archaeological evidence reveals a coherent picture of localized extraction, transport, and smelting, confirming that the Masouleh cultural landscape functioned as a self-sufficient metallurgical province within the Talesh Mountains.

To date, no systematic fieldwork has been undertaken to locate ancient mines or archaeometallurgical evidence in the Masouleh region. Dense forest cover and difficult terrain have impeded fieldwork in specific ore indices and in the wider Masouleh region. Nonetheless, the high potential of iron ore deposits strongly supports the need for targeted archaeological studies to detect ancient mining activities. Presently, aside from the Goren iron mine in the *yaylaq* (summer highland pasture) of the Khalil Dasht and the Jalalabad iron mine, both active until the Qajar era (1789–1925 CE) according to historical sources and oral accounts (*e.g.* Rabino 1917, 187; Sharafi Masouleh 2016), no confirmed earlier iron mines have been documented in the region.

The proximity of high-grade iron ore sources to the town of Masouleh, coupled with abundant charcoal made from local forests, made iron extraction economically feasible in the past. Historical sources frequently reference the use of wood charcoal as fuel in Masouleh forges (*e.g.* Rabino 1917, 188; Kolář 2005, 168). Numerous remnants of charcoal kilns are scattered across the valley and nearby highlands around Chopul, Harzela-Kuh, the *yaylaq* of Kureh-bar, Kohne Masouleh, and elsewhere, attesting to large-scale charcoal production for both domestic and industrial use. Lease agreements show that charcoal kilns were still in operation in the pasturelands of Masouleh until the early 20th century. In 1921, Czechoslovak engineer Jan Kolář, who was working with the Jangal (or Jungle) Movement of Gilan (1915–1921), has noted that the production of charcoal, *Kal Vashunda* in the local Taleshi dialect, formed part of the landlords' economic activities. Some landowners rented parts of their land to tenants (*khoshneshins*) for charcoal production, receiving payment either in cash or through forced labor during the farming seasons. One lease agreement, signed on Wednesday, June 7, 1939, between Ibrahim Amina'taei Asa'di Masuleh (lessor) and Nosratollah Hadisafat Masuleh (tenant), concerns the rental of "a newly built charcoal kiln" in the Tarikesh area of the Masouleh pasturelands, testifying that char-

Table 2: Composition of major oxides in wt% by X-ray fluorescence (XRF) in the mineral samples from the Dehrsu deposit on the tributaries of Chame Kharim (Source: Peyab Consulting Engineers 2002, 69).

Sample Type	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	K_2O	MgO	MnO
M2	66.01	13.67	7.29	1.01	0.14	3.04	0.76	0.215
M3	8.49	0.52	90.46	0.23	0.01	0.01	0.09	0.050

Table 3: Composition of major oxides in wt% by X-ray fluorescence (XRF) in the mineral sample from Goren Khalil Dasht; LOI = Loss of Ignition.

Sample Type	Sample No.	Lab. No.	Al_2O_3	SiO_2	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	SO_3	K_2O	MnO	LOI
ORE	GRN-01	B-7748	1.05	3.03	82.38		0.10	0.25	0.86	8.30	0.05		3.49
ORE	GRN-02	B-7749	11.14	9.52	53.56	1.15	7.03	0.90	0.61			1.56	13.84

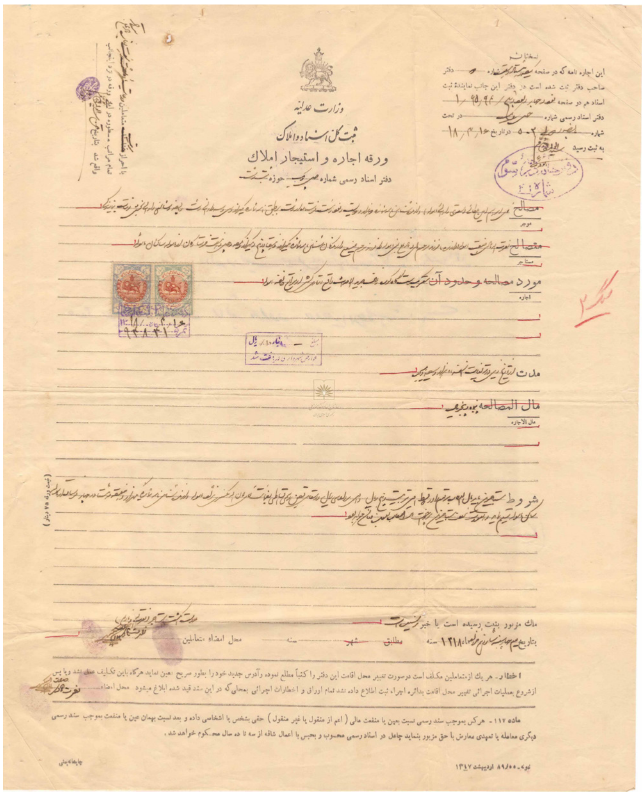
وزارت عدلیه
ثبت کل اسناد و املاک
ورقه اجاره و استیجار املاک

Figure 3: Lease agreement for a "newly built charcoal kiln" in Tarikesh, Masuleh, dated Wednesday, 7 June 1939. Reproduced with permisson from the National Library and Archives of the Islamic Republic of Iran (NLAI), Archive No. 230000360. © NLAI. All rights reserved.

coal production persisted in this region until the early modern period (Fig. 3). Jan Kolář further observed rudimentary furnaces smelting local iron ore with charcoal in the forests of Kishdarreh (Kolář 2005, 168). The Jangal Movement, led by Mirza Kuchek Khan Jangali, was a local rebellion against the Iranian central government that arose in response to the political instability caused by World War I and the occupation of Iran by Anglo-Russian and Ottoman forces.

Altogether, the region surrounding Masouleh presents substantial environmental resources – rich iron ore deposits, quality charcoal, abundant water, and more – that would have sustained metallurgical activity over time. The residents of Masouleh adapted this natural wealth into an advanced system of production that deeply influenced the town's economic and urban evolution. Clearly, iron extraction and tool production played a central role in the historical development of Masouleh and its hinterland; a theme that is further examined in the following sections.

Historical and ethnographic references to the iron mining and smelting at Masouleh

Archaeological discoveries have demonstrated that the Iranian highlands with their rich mineral resources were a major center of metallurgy in the ancient world (Pigott 1999; Helwing 2021). The famous sites of Hasanlu and Marlik in Azerbaijan and Gilan, respectively, are among the earliest places where iron objects were produced during the very late second/early first millennium BC. However, due to the lack of archaeological fieldwork, the precise beginnings of iron metallurgy in the Masouleh region have remained unclear. Furthermore, the history of ironworking as a craft is often associated with tribal organizations that traditionally held monopolies over blacksmithing (Wulff 1966, 49). Undoubtedly, itinerant blacksmiths or 'gypsy' smiths were part of such tribal structures. These mobile groups traveled across different regions of Iran from ancient times to the pre-modern era, fulfilling the ironware needs of local communities.

The natural wealth of the Masouleh landscape, particularly its rich iron ore deposits and abundant charcoal resources, may have encouraged indigenous pastoralist communities with tribal and semi-nomadic lifestyles, such as the ancestors of the present-day Taleshi people, to make limited use of local iron reserves in antiquity. These early social structures may have gradually facilitated the transition from a semi-nomadic way of life to permanent settlement, ultimately laying the foundations for the formation of the town of Masouleh in later periods. Historically, the Taleshi population inhabited Masouleh and the surrounding mountainous areas, organized under tribal leadership that was first titled *ilbegi* and later *Kalāntar* (Bazin 2000).

Regardless of the exact origins of metallurgy at Masouleh, it is certain that organized iron mining, large-scale production of iron tools, and a thriving blacksmithing industry formed an integral part of the town's history from the earliest periods of its settlement; one that has long captured the attention of various observers. Historical sources from the Safavid (16th century) to the Qajar period consistently reference the prosperity of Masouleh's ironworking industry and the significance of its local products. These references include travelogues, administrative records, and geographical surveys.

Accordingly, the iron mines of Masouleh had largely been exploited since at least the Safavid era (16th century) if not earlier, culminating in the Qajar period. For example, part of the iron needed for the royal arsenal in Tehran was supplied from the Masouleh mines at this time. This iron was primarily used in gun factories (*karkhane-ye tuprizi*) to produce firearms and for the casting of cannonballs for the government military. Additionally, horseshoes, nails, and various agricultural and culinary tools were produced from Masouleh's iron which was largely exported to Tabriz, Zanjan, and Tehran through the mountain routes.

One of the earliest references to Masouleh's iron mines occurs in the travel account of Adam Olearius. During his visit to Gilan in 1636, he wrote of Masouleh: "This last is built upon a mountain, by reason of an iron mine, by which the inhabitants, who are mostly smiths, maintain themselves" (Olearius 1669, 148). He further adds, "There are indeed certain forges, at Masula, and Keintze; but the best iron comes from Masula, where it is so soft and tractable, that is malleable, and yields to the hammer without heating" (Olearius 1669, 148).

Samuel Gottlieb Gmelin, a German physician and botanist who traveled under the auspices of the Russian Academy of Sciences to Iran in the 1770s during the late Zand period to study regional flora and fauna, provides noteworthy observations on Masouleh and its ironworking industry. In his book *Travels through Northern Persia, 1770-1774*, Gmelin describes Masouleh as the only place subjected to the Gilani ruler that has the exterior appearance of a town, because others, when they are called so, are nothing but ample villages with dispersed houses; and they are only called 'town' because of their population and their trade (Gmelin 2007, 216). About the Masouleh valley, he writes:

> "There are no villages in it, but only here and there some scattered cattle farms. It is in particular famous for its iron ore. The ore, from which iron is extracted, is red and saffron-yellow ochre, which around Masula lies in large quantities frequently in the mountains in the open air. At Fumen, 3 Persian miles from Masula, situated at the foot of the mountain, it outcrops. The ochre is good and rich; the iron extracted from it is, however, brittle, because they do not know how to handle it. The iron works are private. Everyone has permission to build them and need not pay any special taxes. The inhabitants of Masula pay the Khan an annual tribute of 2,000 rubles; often the latter receives this in the form of shotguns, iron, etc. That part of the population not involved with the iron works and surely the smallest part lives from animal husbandry and tanning oxen, sheep, and goat skins" (Gmelin 2007, 217).

Pierre Amédée Jaubert, Napoleon Bonaparte's ambassador at the court of Fath-Ali Shah Qajar, refers to the inaccessible location of Masouleh in his book *Voyage en Arménie et en Perse* (Journey to Armenia and Persia, 1821), and writes that "the inhabitants are blacksmiths and produce long carbine barrels" (Amédée Jaubert 1821, 430). During this period, Masouleh's iron mines came to the attention of the capital Tehran and experienced great prosperity. By order of Fath-Ali Shah, the head of the royal arsenal (*qurkhaneh*) was appointed governor of Masouleh, rendering the town administratively independent from Fumanat, and the local blacksmiths were tasked with manufacturing cannonballs for the royal army (Bazin 2000).

The Masouleh iron mine maintained its importance under subsequent Qajar rulers and saw further development over time. Mirza Mohammad Saleh Tabrizi, titled *ma'danchi-bashi* (chief mining officer) in the court of Naser al-Din Shah, offers intriguing details about the Masouleh iron mine in his *Ma'dan-nameh* (Book of Mines):

> "The Masouleh iron mine, which I personally inspected with the Russian chief mining officer, is located within mountainous terrain, eight *farsakhs* [ca. 48 km] from Rasht, six from Tarom, and five from the region of Khalkhal. Mining activity has been ongoing for over four hundred years, and the iron produced there is famous for its quality. Before the plague, Masouleh had a larger population, but now the number of working households does not exceed 600 individuals. Due to their lack of expertise, the people of Masouleh laid out the mine poorly from the beginning. They have dug to a total length of approximately ten thousand zarʿ [*sic!*; ca. 10–11 km], with narrow galleries through which a person can hardly pass. Their method is to reinforce the ceiling and walls with timber as they advance the gallery. At present, the mine extends more than ten thousand zarʿ in galleries, all of which are timbered. The livelihood of the people depends entirely on the mine; they engage in no agriculture or other industries. Around ten to twenty workmen extract ore from the tunnels, carrying it on their back, and about thirty to forty proprietors own pack animals and have built multiple furnaces in the surrounding forest. Poor peasants, men and women alike, are hired for wages to transport ore, operate bellows, crush stones, and perform other tasks. The distance from the mine to the furnaces in the forest is approximately one and a half *farsakhs* [9 km]. Ore is purchased for 400 *dinars* per load, transported to the furnaces, and refined into pure iron. Craftsmen

then produce items such as sickles and nails, which are sold in other provinces. Each year, the distance between the mine and the furnaces increases as forest resources are depleted. If a decree is issued by the exalted Royal Court in favor of the Ja'far Qoli Beyk, the brother of the late court *hakimbashi* [physician], the work could be greatly facilitated with the use of water-powered bellows and other means." (Tabrizi 1960, 60–61).

During the same period, economic reforms introduced by the Prime Minister Mirza Taqi Khan Amir Kabir led to significant expansion in Iran's mining sector. In 1267 AH (1850 CE), Amir Kabir issued a decree permitting the free operation of mines, resulting in the revitalization of many old and new mines. Among these were the reopening of copper and iron mines in Qarādāgh, Azerbaijan, by Mir Aghasi Khan, the development and expansion of the Masouleh iron mine by Master Fathollah, chief blacksmith of the royal arsenal, and the exploitation of the Na'ij mine in Mazandaran (E'temad al-Saltaneh 1889, 101; 1989, 1117).

Apparently, the iron extracted from the Na'ij mine was of higher quality than that imported from Astrakhan (Haji-Tarkhān) in Russia, and the iron from Masouleh was likewise of exceptional quality. After a successful trial production of weapons, both sources were used in artillery and munitions factories (E'temad al-Saltaneh 1889, 101; 1989, 1114; Floor 2003, 261). According to E'temad al-Saltaneh, in 1268 AH (1851 CE), 1,000 *tofang-e khandar-e dengi* (flintlock breech-loading rifles) were produced monthly at the *Dar al-Khilafa* arsenal, with part of the iron supply sourced from Masouleh. He reports:

> "Mirza Ali Akbar, a colonel of the arsenal, sent Master Fathollah, the chief blacksmith, to Masouleh to produce iron sheets. He manufactured ten *kharvars* (approximately 3000 kg) of iron and brought it to the arsenal, where it was used to produce gun barrels. The iron was exceptionally soft and of good quality. A decree was issued to continue mining operations." (E'temad al-Saltaneh 1989, 1117).

After the death of Amir Kabir in 1852, his mining policy was reversed, and heavy taxes were imposed on those who wanted to operate mines (Floor 2003, 17). This led to a decline in enthusiasm and the dispersion of skilled workers in the industry. Nevertheless, even during the later years of Naser al-Din Shah's reign occasional attempts were made by local governors to revive mining activities. For instance, *Vaqa'i'-ye Ettefaqiyyeh* newspaper (issue no. 581, Thursday 23 Sha'ban 1282 AH / 1865 CE) reported: "Mirza Mehdi, the *zābet* [local governor] of Masouleh, performed his duties admirably, reassembling the master blacksmiths who had gradually dispersed and reactivating several significant furnaces. The governor [of the province] showed due appreciation for his efforts." In the final years of Mozaffar al-Din Shah's reign (1896–1907), similar revival efforts were again initiated, but these proved short-lived.

Nevertheless, the decline of the Masouleh iron mine and furnaces continued through the late Qajar period. According to existing reports, mining operations came to a halt around 1294 AH (1915 CE), during the reign of Ahmad Shah Qajar, due to the collapse of the mine entrance (Rabino 1917, 188).

H. L. Rabino, who served as the British Consul General in Rasht in 1911, cites in his book *Les provinces caspiennes de la Perse: Le Guîlân* G.-H. Liddell, who visited Masouleh in 1891, about two decades before Rabino's own presence in the region. Liddell noted: "An iron vein lies in a mine located 12 km from Masouleh, which is said to have been exploited since ancient times. Due to its high altitude, mining operations can only take place during the summer months" (Rabino 1917, 188).

James Robertson, a British mining engineer responsible for supplying munitions to the court of Mohammad Shah Qajar, who concurrently worked in the Qarādāgh iron mines of the forested Arasbaran region in Azerbaijan, also reported similar conditions regarding seasonal mining operations (Robertson 1840, 701). His detailed description of the Qarādāgh furnaces provides valuable insights into the operational processes of traditional smelting installations in Azerbaijan and Gilan, which are particularly useful for reconstructing the ancient furnaces excavated at Kohne Masuleh. Likewise, Rabino attributes the reputation of Masouleh among the local Gilanis to the iron mine in the *yaylaq* of Khalil Dasht, citing G.-H. Liddel's 1891 description of the site and its furnaces:

> "About 13 kilometers south of Masouleh there is a vein of iron ore, said to have been worked since time immemorial. It can only be exploited in summer, as it lies at a very high altitude. The workers claim that the deposit is vertical and more than 9 meters deep, but one cannot rely on their statements. The ore is smelted near the mine in six or seven small charcoal furnaces, dome-shaped, which are moved from place to place in order to supply wood for charcoal. One of them,

> 6.5 kilometers east of the town, was in operation and we went to see it. It measured 90 centimeters in diameter and 1.50 meters in internal height, and was built of clay and stone, equipped with a hand bellows. One of the iron blooms taken from the furnace was nearly 30 centimeters in diameter and 15 centimeters thick. When the furnaces are in operation, it is said that they produce nearly 4 quintals [= 400 kilograms] per day." (Rabino 1917, 187–188)

Since the mine's entrance was blocked by a rockfall, iron extraction was ceased by the time of Rabino (Rabino 1917, 188).

It appears that after the collapse and closure of the Khalil Dasht mine, neither the state nor the local governors made efforts to reopen it. From the late Qajar period onwards, iron extraction and blacksmithing in Masouleh gradually declined, never regaining their former prosperity.

Jan Kolář, who was active in 1921 in areas under the control of Mirza Kuchak Khan, including Rasht, Anzali, and the southwestern zones extending to Fuman and Masouleh, and collaborated with the Jangali movement in the manufacture of weapons and ammunition, referred to the weak state of local industry. He reported: "After my arrival, industry in the region began to develop. Old blacksmith workshops near the forest were repaired and a few new ones were built beside them. I began working, manufacturing daggers and bayonets, repairing weapons and ammunition. Often, I would assemble one functional gun from several broken ones." (Kolář 2005, 145).

He also referred to the presence of copper and iron mines and the remains of surface extraction and primitive smelting furnaces in the forests around Kishdarreh (approximately 15 km northeast of Masouleh as the crow flies) (Kolář 2005, 149), which indicates the historic prominence of metalworking industries. However, he did not mention the iron mines or blacksmithing in Masouleh, nor the region's tradition of gunsmithing, which likely suggests that these crafts were already declined during the Constitutional period (1905–1911 CE). A report published in *Kheir al-Kalam*, the first local newspaper of Gilan (Year 1, Issue 41, dated September 17, 1910), further confirms the closure of Masouleh's iron mines and the decline of its smelting furnaces during the Constitutional era: "The region of Masouleh contains an iron mine which, until eleven years ago, was the workplace of numerous blacksmiths. It is unclear what force brought about the suspension of this invaluable mine".

The role of iron mines in the economy and subsistence of Masouleh inhabitants

The presence of iron ore deposits around Masouleh and the exploitation of these mines were fundamental factors in the formation of the town of Masouleh and served as key drivers for its social and economic development. Until the early 20th century, working in the iron mines, charcoal production kilns, iron-smelting furnaces, and smithing workshops for producing various iron tools and, ultimately, trading these items with surrounding areas constituted the backbone of the economy and subsistence of Masouleh's residents. According to available reports, by the early 20th century, the bazaar of Masouleh had 400 shops, most of which remained empty in the winter due to the seasonal nature of work in the iron mines (Rabino 1917, 185). These shops were mostly blacksmith workshops, producing items such as horseshoes, horseshoe nails, knives, scissors, sickles, axes, spears, and even gun barrels. Some of these items were sent in large quantities to Tehran, Tabriz, and other cities in Iran (Floor 2003, 187). Although the social structure of Masouleh has undergone fundamental changes over the past few decades, with traditional crafts giving way to service and tourism-related jobs, people still recognize the "gunmaker's alley" in the Bazaar of Masouleh, where numerous blacksmith shops once operated (Fig. 4).

Many reports from the 17th to 19th centuries written by European and Iranian authors emphasize that residents of Masouleh did not engage in agriculture, and their primary occupation was the extraction and processing of iron (*e.g.* Mirza Ebrahim 1976, 194; Tabrizi 1960, 60; Gemlin 2007, 217; Amédée Jaubert 1821, 430; Fraser 1838, 497).

The actors in the iron industry, who formed the majority of Masouleh's population, were organized in a hierarchical structure and had different roles: landlords who controlled the iron mines or the local forests that provided the charcoal for the furnaces; workers who extracted ore in the mine tunnels; muleteers who transported the ore from the mine to the smelting furnaces; charcoal producers and sellers who provided the fuel for the furnaces by burning wood from the forest; furnace workers who participated in the iron-smelting process, from breaking and crushing the ore to blowing air into the furnace; blacksmiths who worked in smithing workshops to produce various iron tools; and finally, muleteers and petty traders who transported the iron goods to surrounding areas in Azerbaijan, Zanjan, and Tehran (Floor 2003, 187, footnote 6).

Figure 4: Location of gunsmiths and blacksmiths' shops, knife-maker's alley, and caravanserais in the Bazaar of Masouleh. Inset: Sallite image showing location of blacksmith shops still known to Masouleh people as red points (Source: Google Earth; imagery © 2025 Airbus; imagery date: 9 June 2024)

Alongside the actors in the iron industry, a smaller group relied on animal husbandry and related small industries for their livelihoods. These artisans included tanners and shoemakers (*chomushduz*), who produced shoes using leather obtained from local herders. There were also some itinerant traders who, during the grazing seasons, would buy dairy products, especially cheese produced in the highlands, and store them in *khom* (pottery storage jars) to sell at higher prices during peak demand seasons (Bazin 2000).

Given Masouleh's unique location between the low coastal plain and the mountainous heights of Azerbaijan and Zanjan, a network of mule and caravan routes connected the town to the coastal cities on one side and to the highland villages of Talesh and areas outside Gilan, such as Tarom and Khalkhal, on the other (Bazin 2000; Daneshyar 2017). The shortest route from Tabriz to Rasht was through Tarom and Khalkhal, which could be traveled in 15 days, whereas the route through Qazvin and the Sefidrud Valley took 23 days (Bazin 2000). In 1834, James B. Fraser followed this shortcut route from Masouleh during his journey from Rasht to Tabriz, where he recorded valuable observations on the town and its economy in his travelogue.

The specific geographical location on one hand, and the thriving iron industry on the other, turned Masouleh into a commercial hub and an emporium of Azarbaijan and Zanjan in the 18th century. As Fraser reported, many locals turned to mule transport and trade, transporting goods between the low coastal cities and the higher mountain towns (Fraser 1838, 497). Consequently, several caravanserais and a large three-storied bazaar established in Masouleh, leading the town to flourish so much that in 1833, Montieth described it as one of the only towns of Gilan, alongside Rasht, Lahijan, Anzali, and Fuman, with a population of 2,000 people (Monteith 1833, 18).

Archaeological and metallurgical evidence from Masouleh

Over the past four centuries, various writers have referred to the significance of Masouleh's iron mines and smelting furnaces. Yet, no systematic survey has so far been carried out to locate ancient mines or archaeometallurgical sites in the region, and the limited fieldwork has remained scattered and fragmentary.

The first archaeological excavation of a metallurgical site was conducted in 1995 at Kohne Masouleh, following the construction of the Masouleh-Khalkhal road. The excavation campaign uncovered strong evidence of smelting, including furnaces, extensive slag deposits, charcoal heaps, and various iron tools such as nails, horseshoes, knives, scissors, and domestic utensils. Based on the pottery assemblage, these remains were dated to the 10th–14th centuries CE (Moqri 2007, 108–112). More recent excavations revealed remains of additional smelting furnaces (Fig. 5), smithing workshops and iron tools, providing additional chronological data: two fired clay samples from Kohne Masouleh's furnaces, collected during the 2023 campaigns led by M. Charmchian, were thermoluminescence-dated to 1163 ± 55 CE (Seljuk–Khwarezmian period) and 1713 ± 20 CE

Figure 5: Aerial photo from a furnace excavated at Kohne Masouleh in 2023 (Photo: Courtesy of M. Charmchian)

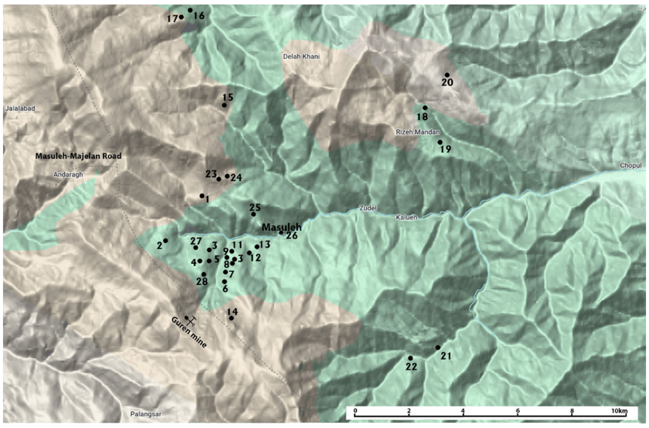

Figure 6: Location of recorded metallurgical sites in the cultural landscape of Masouleh. 1. Kohne Masouleh, 2. Bilga, 3. Kureh-bar, 4. Lase-bon, 5. Tarik-daraa, 6. Serubarun, 7. Ganzara, 8. Khajakhuni, 9. Khajakhuni 2, 10. Khajakhuni 3, 11. Khajakhuni 4, 12. Vizakhuni Sar, 13. Melarzun, 14. Dokhani, 15. Laska, 16. Siakand, 17. Nesrun, 18. Khoma Nesa 1, 19. Khoma Nesa 2, 20. Nesa, 21. Miska, 22. Molemun, 23. Olya-chal, 24. Lashkargah, 25. Khanbaji-sara, 26. Iman, 27. Liz-darra, 28. Siyapesia; coordinates of two sites are not recorded. (Source: Google Maps, Map data © 2025 Google. Scale bar added by author)

(Safavid–Afsharid period). However, most pottery from earlier reports and surface collections observed in 2024 by A. Vahdati, B. Ali Talesh, and A. ʻAali belongs mainly to post-Mongol periods (14th-17th CE).

Despite the importance of these findings, no long-term excavations or systematic field surveys were undertaken to locate other metallurgical sites or ancient mines within the cultural landscape of Masouleh. Only recently, after more than two decades, have excavations at Kohne Masouleh resumed, while limited investigations in 2024 at Siyapesia revealed a furnace provisionally dated to the late medieval (Ilkhanid–Timurid) period.

Scattered reports mention several charcoal-burning kilns and iron-smelting furnaces around Masouleh (Hamrang 2012; Navaiyan 2012). These were identified by local archaeologists through occasional visits and are typically recognized by dense surface scatters of iron slag. Altogether, eight sites were previously reported, but new reconnaissance surveys across the Masouleh valley have now raised the total to 30 (Fig. 6). Most sites are characterized by extensive slag heaps, fragments of tuyères, vitrified wall pieces, and traces of stone structures and charcoal residues (Fig. 7). In the main valley of Masouleh, 24 furnace sites were recorded, namely: Kohne Masouleh, Siakand, Nesrun in the NW heights of Masouleh, the Melarzun site, Vizakhuni Sar, the Khajakhuni Sar 1–4 sites, the Ganzara site, Serubarun, Liz-darra, Tarik-darra, Kureh-bar, Lase-bon, Siyapesia, Bilga, Dokhani, Laska, Nesa, Olya-chal, Lashkargah, Khanbajisara, and Iman. Three industrial sites in the Gilvand Roud Valley include: Dorubarun, Miska, and the Molemun site. Additionally, three sites with iron slag have been identified in the tributaries of the Seqi Bon Valley, located in the Toroshom and Khomanesa heights.

Tuyère fragments – wheel-thrown ceramic tubes – were found at several locations, notably at Kohne Masouleh, Ganzara, Kureh-bar, and Siyapesia. Vitrified tuyères, sometimes with adhering slag droplets (Fig. 8: 2, 3), indicate prolonged exposure to high temperatures. No intact furnace structures were preserved. Their absence is attributable to the use of stone and clay mortar, dismantling of furnace walls to recover metal prills, post-use weathering in the humid mountain environment of Gilan, and the later reuse of furnace stones as building materials. Nonetheless, vitrified wall fragments and tuyères embedded in slag observed at Lase-bon, Kureh-bar, and Siyapesia attest to the former presence of permanent furnace installations.

Although systematic excavation has not yet been undertaken, field observations and surface finds suggest that most sites date to the late medieval and early modern periods (15th–19th centuries CE). XRF analyses of three slag samples from Siyapesia, Ganzara, and Kohne Masouleh reveal significant technological diversity (Table 4). Kohne Masouleh slag is dense and vesicular, with Fe_2O_3 up to 73.2 wt%, indicating high-temperature bloomery or early blast-furnace smelting. Ganzara slag contains 57.6 wt% Fe_2O_3, while those from Siyapesia are highly siliceous (71.3 wt% SiO_2) with low iron (8 wt% Fe_2O_3), reflecting deliberate flux addition and variable reduction efficiency. These variations suggest that the Masouleh ironworkers adapted furnace conditions to ore chemistry and employed skilled techniques for iron extraction.

Figure 7: A set of ore samples, furnace slag, and tuyère pipes from Masouleh cultural landscape. Ore sample from (A) Goren mine (GRN-01) and (B) Khajakhuni; Furnace slag from (C) Siyapesiya with imprint of tong used during smelting; Bloomery tap slag sample from (D) Siyapesiya (SPH-01) and (E) Ganzara; (F) Fragments of vitrified tuyères from Siyapesiya (Photos: A. Vahdati).

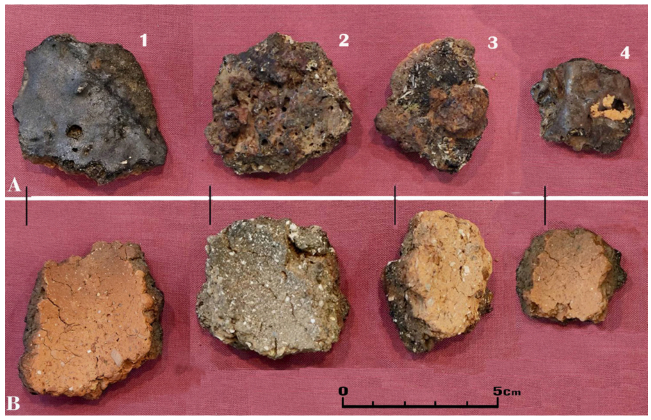

Figure 8: Vitrified tuyères collected at Siyapesiya. The top and bottom rows show opposite sides of the same fragments. At some fragments, slag droplets are still attached, providing evidence for intensive high-temperature iron smelting (Photo: B. Alitalesh).

Altogether, the results of these surveys are consistent with historical accounts describing the widespread presence of furnaces around Masouleh. Given the dense forest cover that hinders visibility of surface remains, a systematic archaeological survey would almost certainly identify many more industrial sites related to iron metallurgy. Overall, the evidence shows that ironworking formed a central component of Masouleh's cultural and economic landscape for several centuries. The ironworkers constructed small bloomery furnaces on hillsides, in forested zones, and near water sources to smelt locally mined hematite and magnetite ores, and may have later employed charcoal-fired blast furnaces. The coexistence of dense magnetite-rich and fluid siliceous slag reflects technological experimentation, while the proximity of slag scatters to water sources and charcoal-rich forests supports the occurrence of on-site smelting followed by blacksmithing workshops for refining and forging the metal.

Structure and operation of traditional iron smelting furnaces based on ethnographic studies (Qarādāgh and Mazandaran)

The structure and operational methods of the iron-smelting furnaces in Masouleh have not yet been fully investigated. It may be assumed that these installations initially functioned as small bloomery furnaces producing spongy iron for local use, later evolving into charcoal-fueled blast furnaces capable of mass-producing pig iron for military and industrial purposes such as cannonballs for the Qajar royal arsenal.

During the 1995 excavations at Kohne Masouleh, remains of three furnaces were discovered in trenches C, E, and F. Each consisted of multiple interconnected sections, including two or more small rectangular chambers linked by narrow channels at the base, and an adjoining circular compartment (Moqri 2007, 102–107). The furnaces were built with flat stone masonry and clay mortar, finished with a mud plaster coating (Fig. 9A). The rectangular chambers contained less slag and showed lower exposure to heat than the circular section,

Table 4: Results of elemental analysis of three slag samples in wt% from the archaeological sites of Siyapesia (SPH-01), Ganzara (GNZ-01), and Kohne Masouleh (KMS-01); LOI = Loss of Ignition (Source: Laboratory of the Jajarm Alumina Factory and the Research Institute for the Conservation and Restoration of Historical and Cultural Heritage).

Sample No.	Lab. No.	Al_2O_3	SiO_2	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	Cl	LOI
SPH-01	B-7746	11.07	71.28	8.00	0.49	0.65	0.60	0.60	3.06				3.69
GNZ-01	B-7747	6.42	24.06	57.57		4.05	1.70	0.60	1.72	3.20			
KMS-01	-	3.10	14.40	73.20	0.10	6.00	1.60	0.14	0.099	0.51	0.46	0.026	

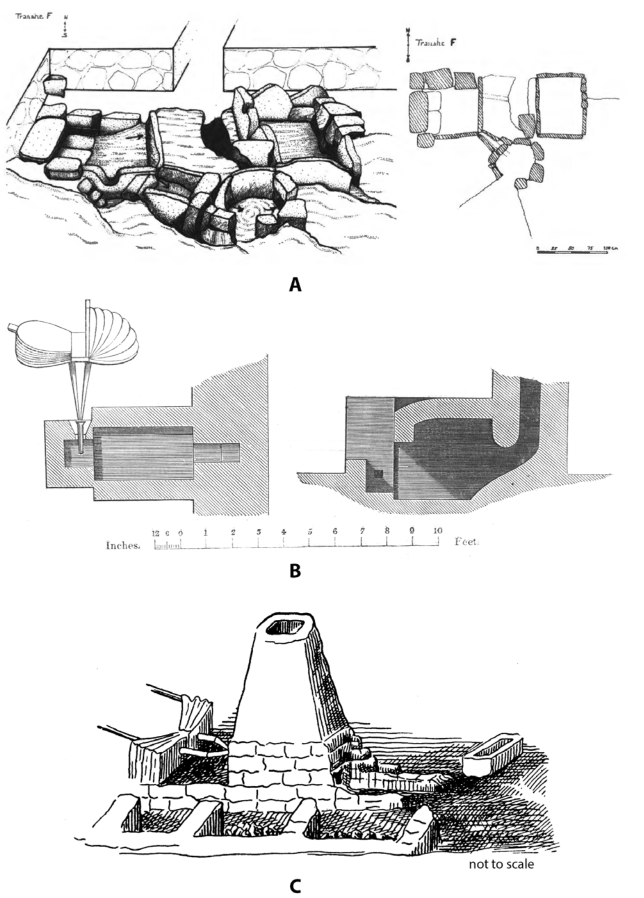

Figure 9: Sketch plans of smelting furnaces in Gilan, Azarbaijan, and Mazandaran: (A) Furnace excavated at Trench F, Kohne Masouleh in 1995 (after Moqri 2007, 106); (B) Furnace at Qarādāgh, Azarbaijan (after Robertson 1843, 703); (C). "Blast" furnace near Amol, Mazandaran (Böhne 1928, 1579)

leading the excavator to suggest that they were used for charcoal storage or for preliminary smelting. The circular chamber, by contrast, appears to have been the main furnace where "iron ore was heated by wood charcoal and hand or water bellows to produce pure iron" (Moqri 2007, 102). According to the excavator's interpretation, crushed ore entered the first chamber for initial heating, then passed through connecting channels to successive chambers for fluxing with limestone and further reduction before final smelting in the circular furnace. Molten material collected at the base was then ladled into molds.

While Moqri's description implies the production of molten cast iron, the archaeological evidence, specifically the furnace layout and abundant slag residues, indicates that the Kohne Masouleh furnaces were more likely bloomery-type installations. These would have produced a spongy bloom of iron subsequently refined by hammering in secondary workshops to yield wrought iron for tools such as horseshoes, nails, and blades.

Additional evidence for iron smelting has been recovered at Siyapesia, a metallurgical site located on a steep slope at 2,100 m above sea level. Its elevated position would have provided a steady natural airflow that functioned as a blowing agent for the furnaces. Archaeological remains include stone-masonry walls with clay plaster, abundant iron slag, vitrified wall fragments, and numerous tuyère pieces, indicating seasonal smelting activities. The vitrified furnace walls and burnt tuyères suggest very high operating temperatures, probably enhanced by natural drafts. This may also explain the extremely low iron content in slag from Siyapesia (SPH-01, Table 3). However, due to the limited excavation area, the overall structure and operational sequence of smelting at Siyapesia remain uncertain.

Although nearly thirty metallurgical sites related to iron smelting have been documented within the Masouleh cultural landscape, only the furnaces at Kohne Masouleh and Siyapesia have been excavated. Consequently, a complete reconstruction of furnace design, spatial arrangement, and operational methods in the region await further fieldwork. Nevertheless, ethnographic and historical evidence from nearby provinces, particularly Qarādāgh (Azerbaijan) and Mazandaran, where traditional smelting persisted into the early 20th century, offers valuable analogies for understanding Masouleh's metallurgical technology. Traditional industries in Iran, characterized by remarkable conservatism, often preserved production methods and product typologies for centuries (Pigott 1984). This technological continuity provides an important basis for archaeological interpretation.

During the Qajar period, state interest in mineral resources led to renewed exploitation of numerous mines across Iran. The lack of domestic technical expertise, however, prompted the employment of foreign engineers, whose detailed reports document the operation of traditional smelting furnaces. Among these, Major James Robertson's 1840 account of iron smelting in the Qarādāgh mountains (Arasbaran, Azerbaijan) and Erich Böhne's 1927 description of blast furnaces near Amol in Mazandaran are particularly relevant.

Qarādāgh

Robertson (1840) observed that iron ore extraction in Qarādāgh, likely of ancient origin, was restricted to the summer months due to snow. Ore was sold to local smiths who produced horseshoes and nails highly valued in Tabriz and neighboring regions. Smelting was fueled by oak charcoal obtained from nearby forests, with each village managing its own woodland resources.

Robertson described the smelting installation as a small hearth (22 x 35 cm^2) dug into the clay floor of the blacksmith's hut, with a slag pit (about 43 cm deep) between the hearth and the rear wall (Fig. 9B). The sides of the pit were lined with heat-resistant stones and plastered with *kahgel*. Ore and charcoal were layered within the hearth, and air was supplied by twin hand bellows protected by a low wall. After several hours of smelting, semi-fluid iron was separated from slag and hammered into compact blooms. Each smelting cycle used roughly 27 kg of ore and 41 kg of charcoal, yielding about 14 kg of iron – an efficiency Robertson praised as superior to contemporary English methods due to the quality of ore and simplicity of single-cycle processing.

Mazandaran

A comparable but more advanced system was documented by Böhne (1928) in Mazandaran. Working under a government commission, he studied traditional blast furnaces operating in mountain valleys near Amol. Unlike the vein ores of Qarādāgh, Mazandaran's iron ore occurred as nodules in riverbeds derived from marl-shale formations. Smelting was mainly a winter occupation lasting four to five months each year. A typical operation involved thirteen workers and two mules: four for ore collection and crushing, five for charcoal production, and four for smelting. Charcoal, mainly from alder wood, was produced in kilns yielding about 320 kg per 48-hour cycle.

The furnace was situated in an open shingle-roofed shed with a central opening for smoke. Along the long side of the shed were three small rectangular chambers, one for keeping charcoal and two for storing crushed ore. The 'blast' furnace in the centre had a conical body made of clay and was approximately 3 m high (Fig. 9C). The furnace had an external diameter of about 120 cm at half-height, and the inner dimensions at the mouth were 50 x 40 cm^2. There was a tap hole at the front of the furnace and at a furnace wall tuyères connected to a twin bellows working with a water-wheel powered mechanism to operate the blast.

The ore was first roasted and calcined in the aforementioned rectangular chambers and then crushed to the size of hazelnuts. Every 24 hours, approximately 440 kg of ore (weighed before roasting) along with 320 kg of charcoal was loaded into the furnace. Every 2.5 hours (when the furnace was in good working order every 1.5 hours), ca 7.5 kg of iron was tapped together with the slag into the forehearth. The iron then was dipped out of the forehearth with ladles and, under agitation, spread out on the damp clay floor, so that it was broken up into shot. These small balls were stored in a wooden trough, sorted, and sold as shotgun pellets. This blast furnace typically produced 60 to 90 kg of iron pellets per day and could produce up to 120 kg when worked efficiently.

Local reports indicated that the iron was used for weapon and tool manufacture and had supplied Tehran's arsenal until the early 20th century (Böhne 1928, 1579). Böhne found extensive slag deposits and remnants of up to 30 furnaces in forested valleys around Amol (Razaka, Angetaroud, and Lavij villages), indicating a long-standing metallurgical tradition (Böhne 1928, 1579).

Discussion

The furnaces described by Robertson and Böhne likely represent technological stages analogous to those once active in Masouleh. Given the conservative nature of traditional Iranian crafts, such practices probably reflect centuries-old metallurgical knowledge. The multi-chambered furnaces excavated at Kohne Masouleh, combining rectangular compartments with a circular smelting core, show strong parallels with the multi-chambered furnaces of Mazandaran described by Böhne. Although Böhne referred to the Mazandaran installations as *Hochofen* (blast furnaces), their limited height, intermittent tapping, and production of malleable rather than pig iron indicate that they were, in fact, high bloomeries or proto-blast furnaces – advanced transitional types that approximated the principles of true blast furnaces without achieving continuous liquid iron smelting. Likewise, the technological evidence from Kohne Masouleh, particularly the dense, vesicular slag and the absence of cast iron or continuous tapping channels, suggests that these furnaces also functioned as high-performance bloomery installations. They may therefore be best described as transitional furnaces representing an advanced stage of bloomery technology that approached but did not fully achieve the operational characteristics of blast furnaces. This interpretation reconciles the structural resemblance between the Masouleh and Mazandaran examples with the archaeometallurgical data recovered from the former. The associated large charcoal residues, surviving charcoal kilns, and early 20th century lease documents referencing kiln rentals further indicate that the furnaces at Masouleh were charcoal-fueled, high-temperature installations capable of efficient bloom production.

Moreover, the placement of some Masouleh furnaces on steep, wind-exposed slopes (*e.g.*, Siyapesia, Lase-bon, Tarik-darra) suggests the use of natural draft airflow in addition to hand-operated bellows. In contrast, furnaces located in valley bottoms near streams (*e.g.*, Molemun and Miska in the Gilvand Roud Valley) were likely equipped with water-powered bellows.

Taken together, these ethnographic analogies and archaeological observations illuminate a coherent technological tradition in northern Iran, in which the Masouleh furnaces represent a regional adaptation of bloomery and early blast-furnace systems optimized for the mountainous environment of Gilan.

Conclusions

The evidence presented in this study underscores the central role that iron mining and smelting played in shaping the historical identity and socioeconomic structure of Masouleh. The integration of natural resources (iron ore, timber for charcoal, water) and a well-designed route network allowed the inhabitants to develop a sustainable and regionally significant ironworking tradition that persisted for centuries.

The combined geological and archaeological data demonstrate that iron production in the Masouleh region was an integrated system of resource exploitation and technological adaptation deeply embedded in its cultural landscape. The high-grade hematite and magnetite ores of Dehrsu, Khale, and Minaru – readily accessible within a few kilometers of the settlement – provided the essential raw materials for smelting, while the dense forest cover of the Talesh Mountains ensured a steady supply of charcoal fuel. The archaeological record, characterized by slag heaps, tuyères, and vitrified furnace debris, confirms that ore extraction, smelting, and forging were conducted within a tightly connected local network. The presence of bloomery-type and early blast-furnace slag indicates a technological continuum, suggesting that Masouleh's ironworkers were capable of adjusting furnace design, flux composition, and air management to the chemical variability of their ores.

From the Timurid-Safavid through the Qajar periods, Masouleh's iron industries supplied tools, weapons, and domestic implements that supported not only local needs but also regional trade networks extending to major urban centers beyond the Caspian region. In this setting, the town of Masouleh functioned not merely as a habitation center but as the industrial hub of a mountain-based economy. Blacksmithing workshops within the urban core reworked bloomery iron into finished products, while smelting installations along the surrounding slopes processed ore directly at the source. This integration of extraction, production, and craftsmanship reflects a sophisticated organization of labor and resources that persisted across several historical phases.

Given the density and distribution of smelting sites across the valley of Masouleh, it is likely that iron production was organized through a decentralized yet collaborative network of seasonal workshops. These supplied raw iron to urban blacksmiths and contributed to regional trade. When viewed in conjunction with historical texts and ethnographic data, this pattern reveals a complex and adaptive system of production that relied on local expertise and environmental knowledge. The seasonal and decentralized nature of smelting activities suggests a high degree of organizational flexibility and integration with other subsistence strategies such as pastoralism and forestry.

Comparisons with Qarādāgh, and Mazandaran demonstrate that Masouleh was part of a broader technological tradition of northern Iran, yet its spatial compactness and adaptation to steep topography gives it unique archaeological significance. The interplay between geology, technology, and settlement thus defines Masouleh as a distinct metallurgical province, where natural and cultural factors jointly shaped the region's socioeconomic development.

Despite these promising findings, many questions remain unanswered. The precise technological processes used in the furnaces, the scale and duration of production, and the socioeconomic organization of mining communities require further investigation. Excavation of key smelting sites, metallurgical analysis of iron slag and furnace remains, and interdisciplinary approaches drawing from historical ecology and ethnoarchaeology are essential for advancing our understanding.

Masouleh offers an exceptional case study in landscape archaeology and historical metallurgy, where environment, economy, and culture intersect in a deeply rooted tradition of resource use. Ongoing research in the region will not only illuminate the local history of industrial activity but also contribute to broader discussions of technological adaptation and cultural resilience in mountainous societies of the Iranian Plateau.

Beyond the regional significance of Masouleh's iron industry, the technological practices documented here also invite future comparative research on long-distance knowledge transfer. As Donald Wagner has noted (Wagner 1993), the Caspian-Central Asian corridor may have played a role in the westward diffusion of advanced smelting technologies. Although such issues lie beyond the scope of this paper, the evidence from Masouleh contributes an important local dataset that can inform broader discussions on the transmission of metallurgical innovations between Asia and Europe.

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