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Tappeh Shoghali; a significant early silver production site in North Central Iran

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ABSTRACT

The fourth season of archaeological excavations at Tappeh Shoghali which is located ca. 40 km southeast of Tehran has revealed numerous metallurgical relics of silver production from Sialk III-IV period (late fourth and early third millennium BCE). The field examination of the objects together with mineralogical and geochemical investigations indicate that the litharge cakes and fragments, a silver-rich lead ingot, and several crucibles and furnaces, as well as miniature dishes are the remaining of a significant silver production activity out of an argentiferous ore in the site during the late fourth millennium/early third millennium BCE. This makes the site one of the earliest silver production workshops and one of the best preserved site hosting ancient silver extraction installations and relics in the Old World. The discovery of this early silver production site in north central Iran alongside the presence of other already known silver (and copper) production sites of early urbanization time in central Iran (e.g. Tappeh Sialk, Arisman, and Hissar) highlighted the relevance of central Iran in the early development of such an ancient technology.

Keywords: Archaeometallurgy; cupellation; mineralogy; geochemistry; Sialk III-IV.

INTRODUCTION

Recent archaeological excavations at Tappeh Shoghali, south of Tehran unearthed numerous metallurgical relics related to silver production activities in the second half of the fourth millennium-early third millennium BCE. The vast and rather well-preserved metallurgical-related installations in the site make it a unique discovery in the field of early silver production in the Old World.Here we report the field observations and preliminary analytical investigations of the metallurgical relics.

From a geological point of view, in Western Asia (as elsewhere in the world) silver is mostly associated with lead (± zinc ± copper) deposits; therefore the majority of the domestic ancient silver objects were produced using cupellation from argentiferous lead-bearing ore (Forbes, 1964; Tylecote, 1992; Craddock,1995; Ramage and Craddock, 2000; Nezafati and Pernicka, 2012). Interestingly, it is now obvious that the ancient miners and metallurgists were aware of the presence of silver in the lead (or polymetallic) ore and could extract it via cupellation technique since at least the fourth millennium BCE (Pernicka, 1987; Tylecote, 1992; Pernicka, 2004). The typical waste material of the cupellation process is litharge (PbO), a mineral that rarely occurs naturally. Therefore, the litharge cakes and fragments are the clear and secure proof of using cupellation technique (Pernicka, 2004). Silver production by cupellation is a two-stage process under controlled thermal conditions. In the first step, the lead-bearing argentiferous ore is smelted at high temperature under reducing conditions to ensure that all silver present is reduced and taken up by the lead. The product of this stage is a silver-rich lead sheet or ingot (Pernicka et al., 2011). The second stage is a selective oxidation of the product of the previous stage (i.e. argentiferous lead) except the noble metals leaving silver and/or gold behind (Craddock, 1995; Nezafati and Pernicka, 2011). Archaeological samples of litharge are usually partly weathered to lead (hydro-) carbonates and contain more than 75 weight percent lead (Pernicka et al., 2011). Hearth linings (cupellae) consist mainly of litharge and the reaction products of litharge with the original hearth material and contain oxides, carbonates, and/or silicates of the lighter elements (Pernicka et al., 2011).

The earliest litharge fragments referred to silver production by cupellation have been unearthed from a few fourth millennium BCE sites of Western Asia. These include Tappeh Sialk (3660-3520 BCE, central Iran; Nokandeh and Nezafati, 2003; Nezafati and Pernicka, 2005, 2012), Habuba Kabira (northern Syria; Pernicka, et al. 1998), Fatmalı-Kalecik (eastern Anatolia; Hess, et al. 1998), Arisman (Sialk III-IV, central Iran; Momenzadeh and Nezafati, 2001), Tappeh Hissar (Hissar II-III, northeast central Iran; Roustaii, 2004), and Ilgynly Depe (Turkmenistan:Helwing, 2014; Hansen and Helwing, 2016). Among the finds from the aforementioned sites, the Sialk fragments seem to be the oldest so far known relics of such process in the Ancient World (Figure 1). It is of interest that, except reacted cupels (and hearths) and litharge fragments, cupellation-related installations have rarely been reported from the abovementioned sites.

Tappeh Shoghali (geographical coordinates: 35°19′38″N and 51°44′29″E), is an area covering about 1x0.5 Km^2 in theVaramin plain, some 40 km southeast of Tehran, north central Iran (Hessari et al., 2007; Figures 1 and 2). The Varamin plain is bounded by the southern foothills of the Alborz Mountains and is drained by the Jajrood River (Figure 2a). Four campaigns of archaeological excavations have been conducted on this site by Tehrani-Moghadam (1991) and Hessari (2006, 2008 and 2015). Results indicate that Tappeh Shoghali has been continuously inhabited from Neolithic to the Iron Age, although the Sialk III (ca. 4100-3400 BCE) and Sialk IV (ca. 3400-3100 BCE, Ghirshman, 1951; Shahmirzadi, 2006) periods have been the most significant periods. Numerous finds including beveled rim bowls and Banesh trays as well as ideo-numerical tablets, cylinder seals, small tokens (figurines), lithic materials, and mud brick covered floor together with many metallurgical-related finds have been unearthed from the site (Figure 3).

RESULTS

In the fourth season of archaeological excavations on Tappeh Shoghali (winter 2015) seven 10x10 m^2 trenches were excavated based on surface and geophysical

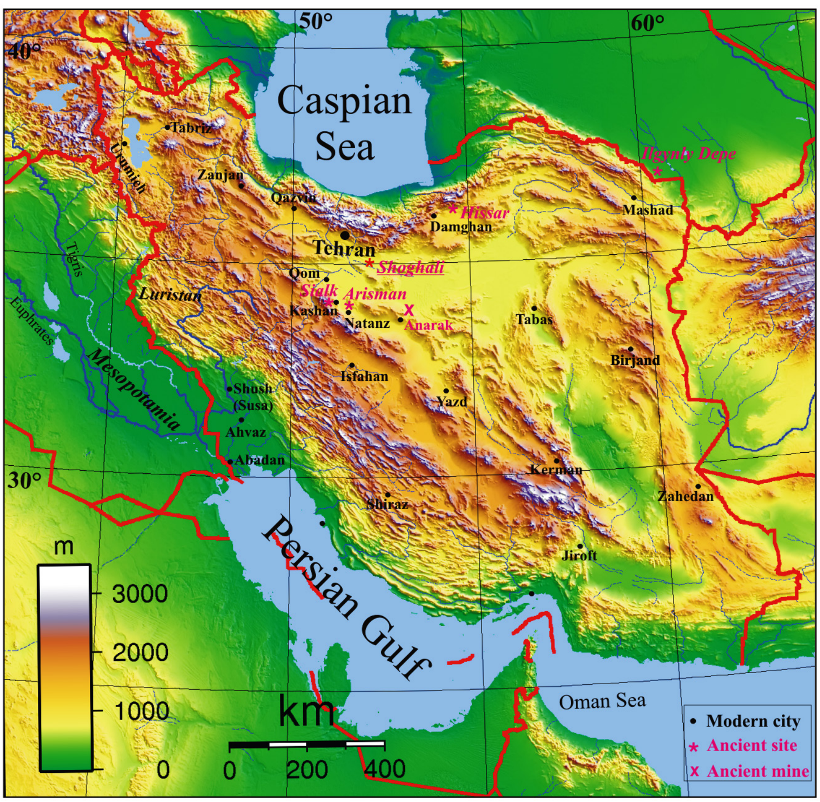

Figure 1. Approximate location of some of the sites and regions mentioned in the text (Background map modified after https://upload.wikimedia.org/wikipedia/commons/b/b5/Iran_Topography.png).

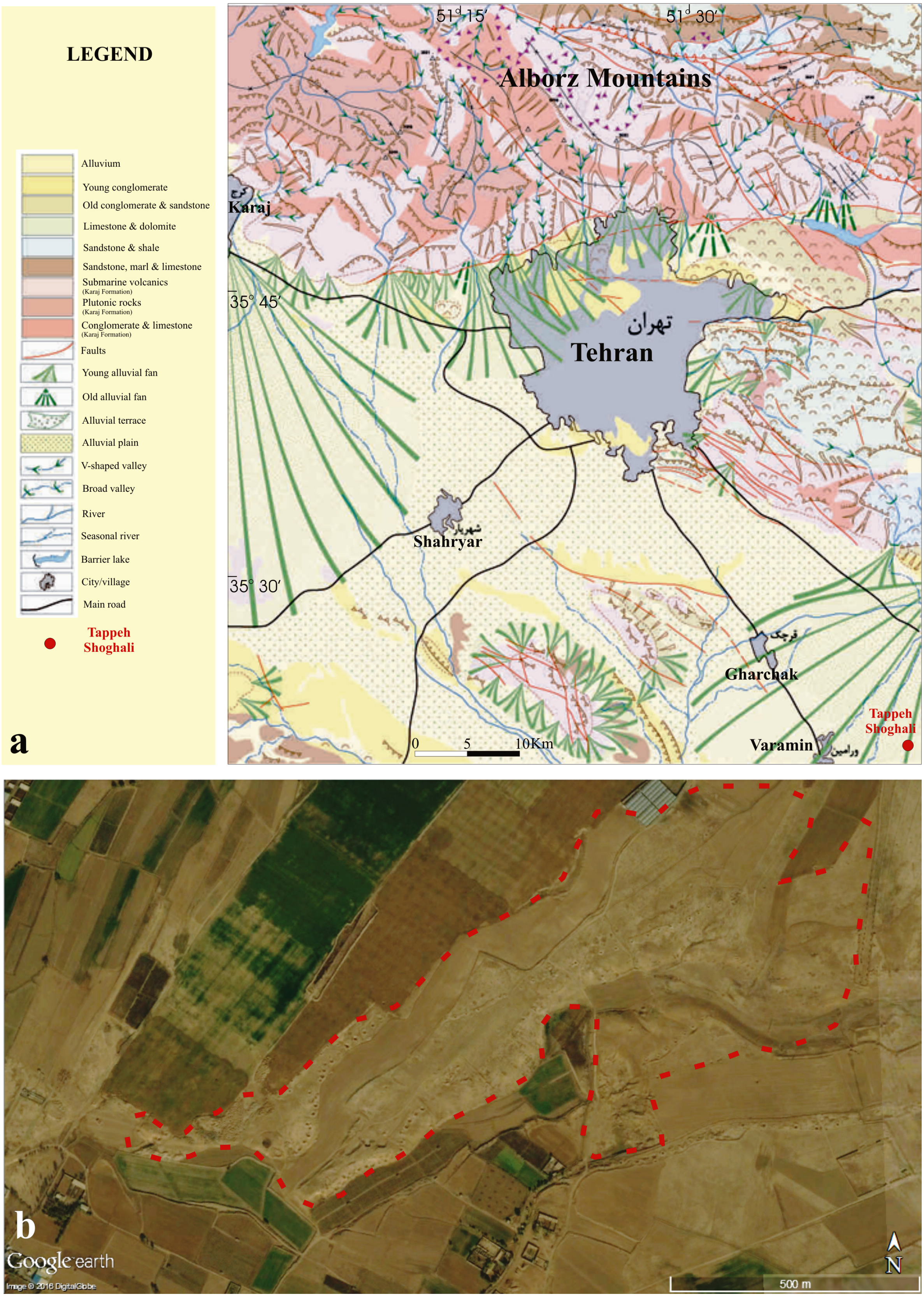

Figure 2. a) location of Tappeh Shoghali on the geomorphological map of Tehran (background modified from http://atlas.tehran.ir/Default.aspx?tabid=167), b) aerial view of Tappeh Shoghali surrounded by agricultural fields (based on Google earth).

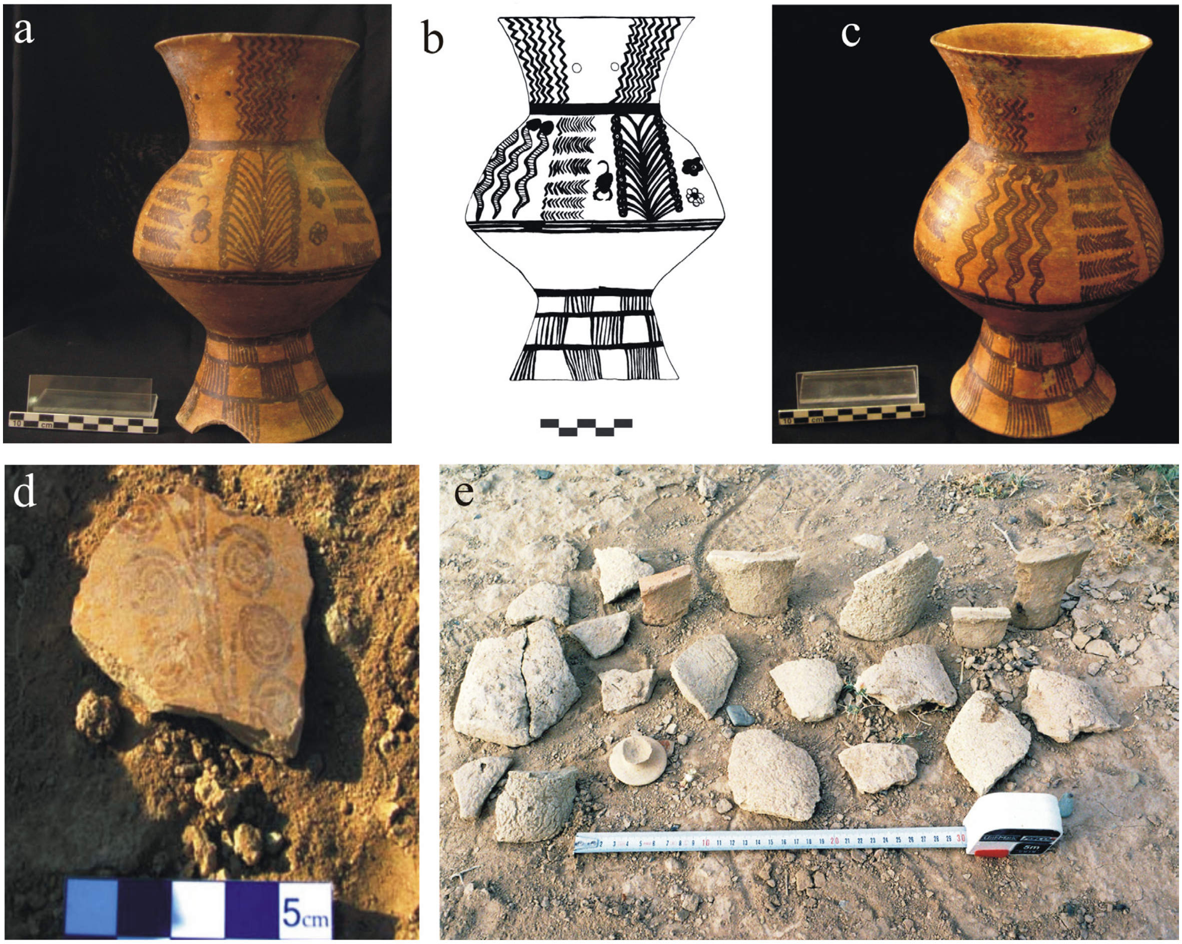

Figure 3. a, b, and c) different views from a Sialk III4-5 jar unearthed from the site (pre-metallurgy period of the site), b and c) Sialk III6-7 pottery shards including beveled rim pottery and Banesh tray pieces (contemporaneous with metallurgical activities on the site).

surveys. In all seven trenches rather well-preserved ancient cupellation-related metallurgical remainings were found which include tempered conduits on the floor, several small furnace-like structures and a probable large (cupelling) furnace, together with a lot of litharge cakes and fragments (more than a hundred pieces), a silver-rich lead sheet (ingot), miniature dishes (possibly evaporating dishes), a few slag pieces, and some mineral beneficiation tools including hammer and anvil stones made of different rocks (Figure 4).

The metallurgical remainings are particularly abundant in the trench No. 3 which was 283 cm deep and consisting of a complex of tempered conduit-like installations dug in the ground which could have been passages for a molten material (possibly molten lead) together with several furnace-like structures aligned in parallel rows (Figure 4 a,c). Moreover, a vase-like vessel (with top diameter about 15 cm) showing some low degree of vitrification and a hole in the bottom was found which fits well into the furnace-like structures (Figure 4c). In this trench, several litharge cakes and fragments (Figure 4b) together with some anvil stones, hammer stones, and few slag pieces were unearthed. An oval dome shaped structure with 2.5x1.5x2 m^3 dimensions in another trench is of interest too. Some holes that seem to be ventilation ducts are observable in the body of this structure. In contrary to contemporaneous silver production sites like Sialk and Arisman, where both copper and silver metallurgy were performed (Momenzadeh and Nezafati, 2000; Nokandeh and Nezafati, 2003; Nezafati and Pernicka, 2005; Nezafati and Pernicka, 2012), no traces of copper metallurgy have yet been found at Tappeh Shoghali.

According to the pottery shards of beveled rim vessels and Banesh tray pieces, the trench No. 3 was attributed to the proto-Elamite time (Sialk III$_{6-7}$; second half of the fourth millennium to the early third millennium BCE). A calibrated radiocarbon dating performed by Hessari and Nishiaki (2016) on a find from trench No. 3 confirms an age of 3350±20 BCE, corresponding to the second half of the fourth millenium BCE.

The litharge cakes are composed of heavy, concave, pale yellow to cream and buff pieces on their external

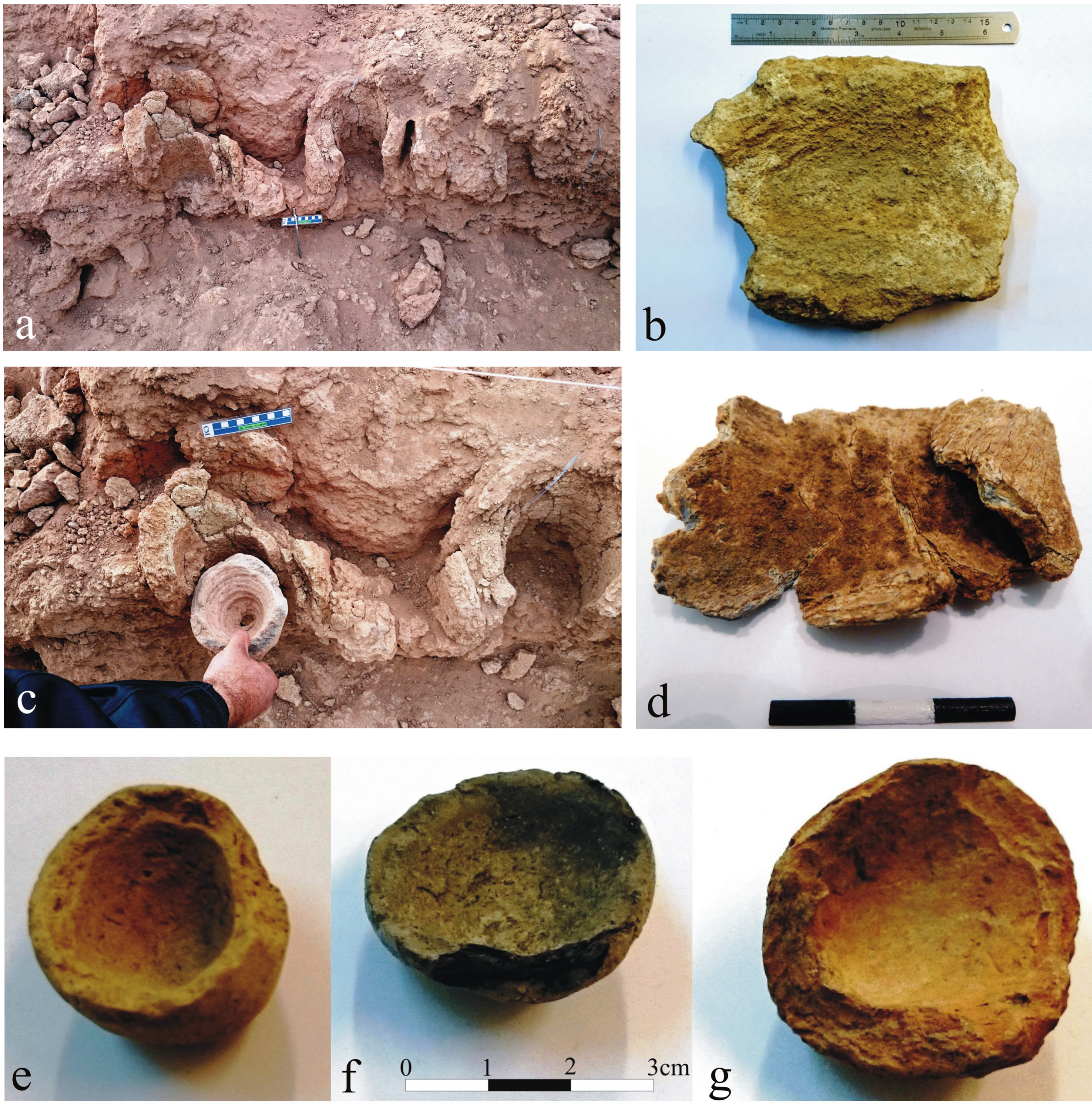

Figure 4. a) a row of furnace-like structures in which the vase-like vessel fits (Sialk III6-7 period); b) a large litharge cake (lump); c) a crucible fitting into a furnace-like structure; d) the argentiferous lead sheet; e, f, g) three partly broken crucibles, all with a 3cm diameter aperture.

appearance whose length in some cases reaches 15 cm. A 7 cm folded sheet of lead was found associated with numerous litharge fragments (Figure 4d). Interestingly, several miniature hemispherical dishes were unearthed together with the other metallurgical remains (Figure 4 e,f,g). These seem to be "partly broken crucibles", perhaps for ore assaying or melting/refinement of silver. Help towards a better interpretation could come from inspection and analysis of (any) remains on the inner surfaces.

In order to examine the exact function of the metallurgical remains, after careful observation and documentation ofthe finds, five samples from litharge cupellae and fragments together with one sample from a lead ingot were taken using scalpel, jigsaw, and diamond drilling. The samples were analyzed using ICP-MS as well as XRD at Zarazma Laboratories, Tehran, Iran. For chemical analysis, the samples were first digested in an HF/multi acid solution and (after dilution) were analyzed using a HP 4500 ICP-MS system manufactured by GMI (detailed procedure of analysis is available under http://http://zarazma.com/UserImage/Zarazma%20Services%20Guide%202016-2.pdf). Two litharge samples were also examined using petrographic investigations.

Mineralogical investigations (Figure S1) show a rather uniform mineralogy for most of the fragments of litharge cupellae including litharge, cerussite, hydrocerussite, massicot, and an amorphous compound (lead glass) as major components and pyroxene (augite), gypsum, lanarkite [$Pb_2(SO_4)O$], laurionite [PbCl(OH)], and in one case tourmaline as minor components.

According to the geochemical results for the major and trace elements, the composition of almost all samples of litharge is rather uniform (Table S2). Based on the analytical results, lead, SiO_2, CaO, and MgO are the major components of most litharge cupellae. Nevertheless, the rather high contents of sulfur, copper, arsenic, and antimony can be an indication of the use of a polymetallic sulfide ore with high amounts of lead and silver. The lead sheet is mainly composed of pure lead (98.1%), sulfur (0.9%) with rather high amount of silver (0.09%), copper, and antimony (Table S2).

DISCUSSION AND CONCLUSIONS

The excavation and chronological results together with the preliminary mineralogical and geochemical investigations, including widespread well-preserved metallurgical-related installations and relics which have rarely been reported from the contemporaneous sites introduce Tappeh Shoghali as a significant early (late 4th-early 3rd millennium BCE) silver production workshop in north central Iran. It seems that the cupel-making materials of Tappeh Shoghali were made of a substance composed of silica (SiO_2) and possibly carbonates (of Ca+Mg) and perhaps some other materials of biological originon which an argentiferous ore (possibly polymetallic) containing lead (as major component) was worked. This ore contained some amounts of copper, arsenic, antimony and sulfur. Due to the low silver contents of litharge fragments, it seems that, the cupellation process was very efficient. In this regard, the silver concentration in the litharge samples of Tappeh Shoghali is similar to the silver contents of litharge fragments reported from contemporaneous ancient sites of Fatmali-Kalecik (Anatolia) and Habuba Kabira (Syria), but lower than the Arisman litharge fragments (Pernicka et al., 2011). Based on the geochemical and mineralogical results, the ore of some argentiferous polymetallic ancient mines of Anarak area (e.g. Baqoroq) would geochemically match the ore used in Tappeh Shoghali and could have provided the ore of the site (Nezafati et al., 2008; Pernicka et al., 2011), nevertheless, more investigations would be needed also on a few nearby ore indications for possible geochemical and mineralogical connections.

The discovery of this early silver production site in north central Iran alongside the presence of other already known silver production sites of early urbanization time in central Iran (e.g. Tappeh Sialk, Arisman, and Hissar) highlighted the relevance of central Iran in the early development of ancient silver production.

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REFERENCES

Craddock P.T., 1995. Early Metal Mining and Production. Smithsonian Institution Press, Washington D.C.

Forbes R.J., 1964. Studies in ancient technology, 193, voI.8, Metallurgy in Antiquity, part 1. Early Metallurgy, the Smith and his Tools, Gold, Silver and Lead, Zinc and Brass, Leiden, Brill.

Ghirshman, R., 1951. L'Iran des origines à l'Islam. Payot, Paris. English translation: Iran From the Earliest Times to the Islamic conquest. Harmondsworth, England, 1954 (reprinted 1961, 1978, Penguin Books, 368 p.). Persian translation by Mohammad Moiin, ElmivaFarhangi Publication, 78, Tehran, 1336/1957.

Hansen S. and Helwing B., 2016. Die Anfänge der Silbermetallurgie in Eurasien, In: Martin Bartelheim, Barbara Horejs, and Raiko Krauss (Hrsg.) Von Baden bis Troia, Ressourcennutzung, Metallurgie und Wissenschaftler; Eine Jubilaeumschrift fuer Ernst Pernicka, Oriental and European Archaeology 3,41-58.

Helwing B., 2014. Silver in the early state societies of Greater Mesopotamia, Metalle der Macht-Frühes Gold und Silber (Metals of power-early gold and silver), 6. Mitteldeutscher Archäologentag, Halle (saale), Tagung des Landesmuseums für Vorgeschichte Halle, Germany, 411-430.

Hess K., Hauptmann A., Wright R., Whallon R., 1998. Evidence of fourth millennium BC silver production at Fatmalı-Kalecik, East Anatolia, in Th. Rehren, A. Hauptmann, D. J. Muhly (eds) Metallurgica Antiqua, Der Anschnitt Beiheft 8, Bochum, 123-134.

Hessari M., Akbari H., Aliari A., 2007. Stratigraphic report of Tappeh Shoghali ancient site, Pishva, Archaeological Reports No.7, Research Institute of Cultural Heritage and Tourism, Tehran, Iran, 165-200 (in Persian).

Hessari M. and Nishiaki Y., 2016. Radiocarbon dating of some samples from different sites of Iran, unpublished report, Art University of Isfahan.

Momenzadeh M. and Nezafati N., 2000. Sources of ores and Minerals used in Arisman: A preliminary study, in N.N. Chegini, M. Momenzadeh, H. Parzinger, E. Pernicka, T. Stöllner, R. Vatandoust, G. Weisgerber, in collaboration with N. Boroffka, A. Chaichi, D. Hasanalian, Z. Hezarkhani, M.M. Eskandari, N.Nezafati, preliminary report on archaeometallurgical investigations around the prehistoric site of Arisman near Kashan, Western central Iran. Archaeologische mitteilungen aus Iran and Turan, Band 32, sonder druck, Dietrich Reimer Verlag GmbH. Berlin.

Nezafati N. and Pernicka E., 2005. The Smelters of Sialk; outcomes of the first stage of archaeometallurgical researches at Tappeh Sialk, in Sadegh Malek Shahmirzadi (ed) Sialk Reconsideration Project Monograph. No.4.

Nezafati N., Momenzadeh M., Pernicka E., 2008. The Iranian ore deposits and their role in the development of the ancient

cultures. Anatolian Metal IV. Der Anschnitt. German Mining Museum (Deutsches Bergbau-Museum), Bochum, Germany, 77-91.
Nezafati N. and Pernicka E., 2012. Early silver production in Iran. Iranian Archaeology 3, 37-45.
Nokandeh J. and Nezafati N., 2003. The Silversmiths of Sialk: evidence of the precious metals metallurgy at the southern mound of Sialk', in S. Malek Shahmirzadi (ed) The Silversmiths of Sialk, Sialk Reconsideration Project Monograph, No. 2 (in Persian with an English abstract).
Pernicka E., 1987. Erzlagerstätten in der Agäis und IhreAusbeutungimAltertum: GeochemischeUntersuchungenzur HerkunftsbestimmungarchaeologischerMetallobjekte, Jahrbuch des Römisch-GermanischenZentralmuseums, 34, 607-714.
Pernicka E., Rehren T., Schmitt-Strecker S., 1998. Late Uruk silver production by cupellation at Habuba Kabira, Syria, in Th. Rehren, A. Hauptmann, D.J. Muhly (eds) Metallurgica Antiqua, Der Anschnitt Beiheft 8, Bochum, 123-134.
Pernicka E., 2004. Silver production by cupellation in the fourth millennium BC at Tepe Sialk. In: Malek Shahmirzadi, S. (ed.) The Potters of Sialk. Sialk Reconsideration Project Monograph, 3, 59-63.
Pernicka E., Adam K., Böhme M., Hezarkhani Z., Nezafati N., Schreiner M., Winterholler B., Momenzadeh M., Vatandoust A.R., 2011. Archaeometallurgical Research on the Western Central Iranian Plateau. In: A. Vatandoust, H. Parzinger, B. Helwing (Eds). Early Mining and Metallurgy on the Western Central Iranian Plateau, Archäologie in Iran und Turan 9,631-688.
Ramage A., and Craddock P., 2000. King Croesus' Gold: Excavations at Sardis and the History of Gold Refining. Archaeological Exploration of Sardis, 11. Cambridge, MA: Harvard University Art Museums, in association with British Museum Press, 2000. pp. 272; ISBN 0-674-50370-8.
Roustaei K., 2004. Tappeh Hesar: A major manufacturing center at the central plateau, in Stöllner T., Slotta R., and Vatandoust A. (eds) Persias Ancient Splendour (PersiensAntikePracht): Mining, Handicraft and Archaeology, Deutsches Bergbau-Museum Bochum, Germany, 222-230.
Shahmirzadi S.M., 2006. Sialk; the Oldest Fortified Village of Iran. Final Report of the Sialk Reconsideration Project. Iranian Center for Archaeological Research, Iranian Cultural, Handicraft, and Tourism Organization (in Persian, with a summary in English), Tehran.
Tylecote R.F., 1992. A History of Metallurgy, Institute of Materials Great Britain (second edition), First published in 1976, First published in paperback in 2002 by Maney publishing for the Institute of Materials. http://zarazma.com/UserImage/Zarazma%20Services%20Guide%202016-2.pdf

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