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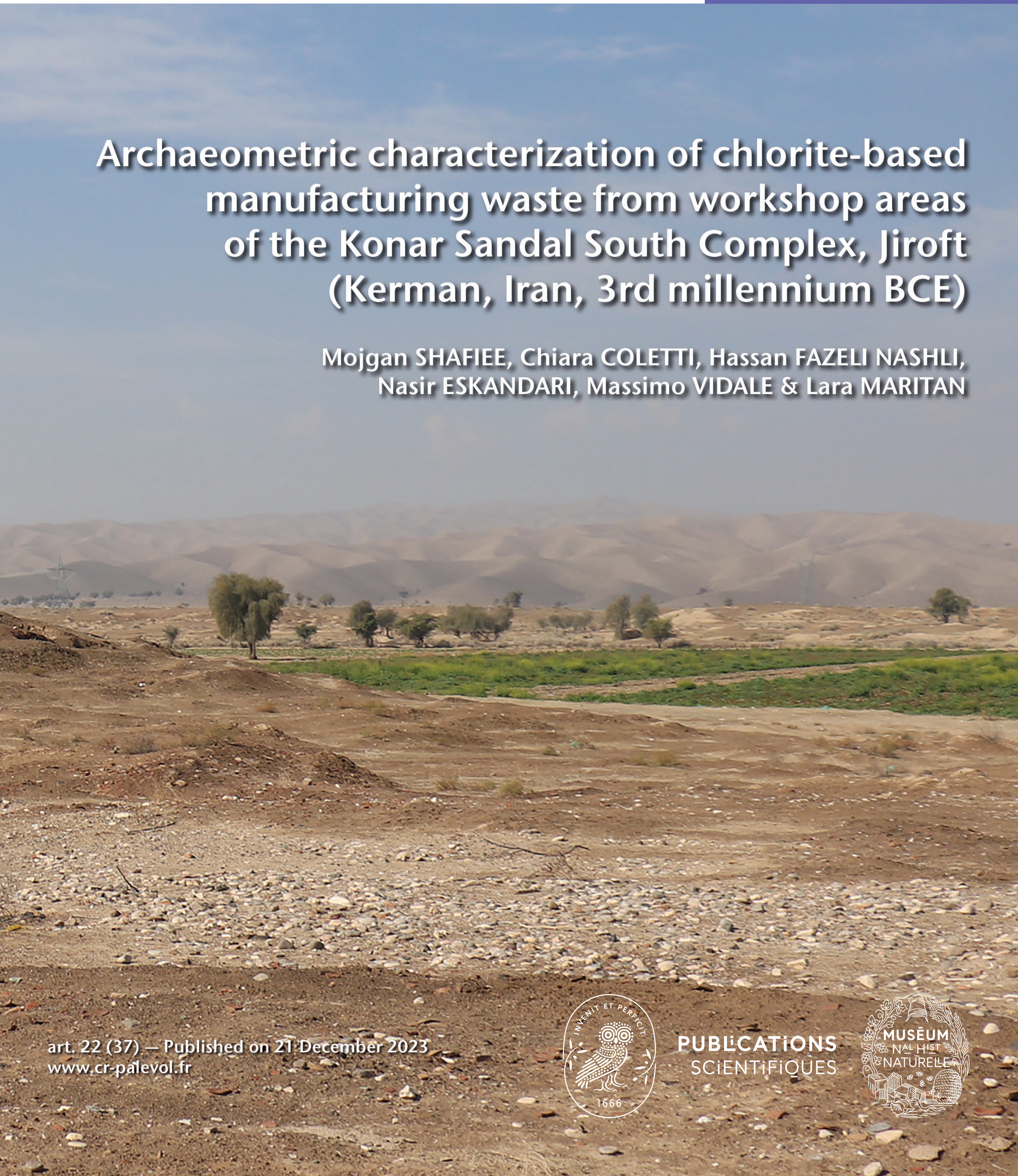

Archaeometric characterization of chlorite-based manufacturing waste from workshop areas of the Konar Sandal South Complex, Jiroft (Kerman, Iran, 3rd millennium BCE)

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ABSTRACT
Sixteen small samples of fragmentary "chlorite" containers, coming from three different workshop sites of the Konar Sandal South network (Iran), were analyzed using a multianalytical approach, consisting in thin-section petrography and mineralogical characterization by X-ray powder diffraction. This preliminary study singled out at least two major different mineralogical groups, suggesting that different craft groups, possibly in different times, exploited different local sources of chloritic rocks. Results also indicates that the surroundings of Konar Sandal South, the main urban hub of the Halil valley, were involved – probably for several centuries – in the production of three major different classes of stone pots (cylindrical vessels with intricate geometric patterns, plain bell-shaped bowls and incised *série récente* vessels).

KEY WORDS
Chlorite,
Konar Sandal south,
petrography,
X-ray powder diffraction,
Jiroft.

RÉSUMÉ
Caractérisation archéométrique de déchets de fabrication à base de chlorite des ateliers du complexe Konar Sandal Sud, Jiroft (Kerman, Iran, 3e millénaire avant Jésus-Christ).
Seize petits échantillons de contenants fragmentaires de « chlorite », provenant de trois sites d'ateliers différents du réseau Konar Sandal Sud (Iran), ont été analysés selon une approche multianalytique, consistant en l'analyse pétrographique en lames minces et en la caractérisation minéralogique par diffraction X sur poudre. Cette étude préliminaire a distingué au moins deux grands groupes minéralogiques différents, suggérant que différents ateliers, éventuellement à des époques diverses, ont exploité différentes sources locales de roches chlorite. Les résultats indiquent également que les environs de Konar Sandal Sud, le principal centre urbain de la vallée de Halil, ont été probablement impliqués – pendant plusieurs siècles – dans la production de trois grandes classes différentes de pots en pierre (vases cylindriques aux motifs géométriques complexes, bol simples en forme de cloche et récipients incisés de la série récente).

MOTS CLÉS
Chlorite,
Konar Sandal sud,
pétrographie,
diffraction X,
Jiroft.

INTRODUCTION

The Halil Rud basin, situated in the southern part of Kerman province, Iran, is renowned for its abundance of ancient sites and significant discoveries. A considerable number of remarkable artifacts from Iran's remote past started surfacing in the antiquities market around 2000. These artifacts apparently originated from several cemeteries plundered in the Jiroft region of south-eastern Iran, exposed after a major flooding incident. Once looting was ceased in 2001, initial surveys conducted in the immediate vicinity of the plundered areas revealed a series of extensive mounds, displaying pottery on the surface that clearly indicated an early Bronze Age dating. In an effort to prevent further looting, the Iranian Cultural Heritage Organization allocated substantial resources and personnel to conduct systematic archaeological investigations with a specific focus on the Bronze Age occupation of the Halil River Basin (Madjidzadeh & Pittman 2008). Up to this point, these investigations have involved preliminary excavations at prominent mounds such as Konar Sandal South, Konar Sandal North, Ghalleh Kouchak, Mahtoutabad cemetery, and Hajjiabad-Varamin, all located within the Jiroft region. One of the most significant cultural characteristics of the newly discovered Halil Rud or "Jiroft" civilization is notoriously the production and distribution, sometimes on long distances, of carved soft stone vessels with a quite distinct iconography, previously labeled "intercultural style". These often beautiful and intriguing objects have been widely discussed (among others, de Miroschedji 1973; Kohl 1976, 1977, 1978, 2001, 2004; Zarins 1978; Amiet 1986; Lamberg-Karlovsky 1988, 1993; Potts 1989, 1994; Lamberg-Karlovsky & Tosi 1973; Muscarella 1993; Hakemi 1997; Aruz 2003; Madjidzadeh 2003a, b; Winkelmann 2005; Perrot & Madjidzadeh 2005, 2006; Piran & Hesari 2005; Hejebri Nobari *et al.* 2012; Piran & Madjidzadeh 2013; Francfort 2021; Vidale 2015; Vidale *et al.* 2021a, b; most recently, Mutin & Eskandari in press).

These artefacts actually appeared, although sometimes in limited amounts, in a very large corridor from Mesopotamia in Iraq via the Iranian plateau into the Indus valley (Potts 1989; Zarins 1992; Pittman 2001, 2003): from Mesopotamia (Mari, Khafajah, Nippur, Ur, Sippar, Uruk, Girsu, Adab, Lagash [Kohl 1975; Potts 1989; Wilson 2012; Butterlin 2014; Pittman 2018]) to the north part of the Arabian Peninsula (Tarut, Failaka, Bahrein, Umm an-Nar [Zarins 1978; Crawford & al-Sindi 1996; Reade & Searight 2001; Pittman 2018]) through south-eastern Iran (Jiroft, Tepe Yahya, Shahdad, Shahr-i Sokhta, Bampur [Pittman 2001, 2018]) (Fig. 1), eastwards to Mohenjo-Daro in Sindh (Pakistan) and Dholavira in Kutch (India [Vidale & Eskandari in press]).

The peculiar label of "intercultural style" was originally meant to qualify the artefacts' production as an ingenious adaptation by supposedly underdeveloped communities of the eastern Iranian Plateau to their presumed economical marginality. Local craft groups embedded in a kind of "meta-cultural zone" (Pittman 2018) would have invented formal and iconographic codes palatable to a wider range of foreign cultures for the purpose of getting profit from long-distance trade links. The paramount case for such model was the evidence of Tepe Yahya, described as a center for the production and trade of decorative chlorite goods during the early Bronze Age by Lamberg-Karlovsky in the 1970s (Lamberg-Karlovsky & Tosi 1973; Lamberg-Karlovsky 1988). Here, the chlorite-processing waste witnessed the production of plain pots and the recycling of broken elaborately carved artefacts into minor recovered objects.

After the disastrous season of lootings of the Halil cemeteries, the amount of the known artifacts of this class dramatically multiplied. Given the irregular provenience of the majority of those available, to a great extent lost to the antiques market, their provenance, absolute chronology and even their authenticity became a source of sometimes harsh, and not always fruitful debate among archaeologists and art historians (e.g. Muscarella 2001). A comprehensive history of research and a refined chrono-typology of the main groups of chlorite artifacts between the 3rd and 2nd millennium BCE may be found in Pittman (2018). At any rate, after the last two decades

Fig. 1. — Map of south-eastern Iran showing the location of the most important early Bronze Age sites of the region. Those of the study area are enclosed within a rectangle. Credits: courtesy of M. Casanova.

of research and publishing, there is a general agreement on a few basic points: 1) these artefacts originated in the Jiroft area of Kerman province in south-eastern Iran (Fig. 1) (as clearly stated already by Amiet 1986 and Hakemi 1997), where a pristine, powerful local polity had independently developed since millennia; 2) the objects' style or styles, with few marginal exceptions, were rooted in a distinctively local heritage of myths, symbols and aesthetic templates (Winkelmann 2005; Vidale 2015, 2017; Marchesi 2016; Pittman 2018; Vidale *et al.* 2021a), production being addressed to the consumption of the local elites; and 3) the chlorite vessels' inventory can be subdivided in two different productions, namely a "*série ancienne*" datable to pre-early Akkadian times (with elaborate figurative patterns), and a later "*série recente*" (distinguished by simpler geometric incised designs, with zig-zag friezes: implications discussed in Mutin & Lamberg-Karlovsky 2020, and Francfort 2021). According to Pittman (2018), the earlier group would be made exclusively with Iranian chloritic rocks, while the later one would have been made in the Arabian peninsula from Omani rocks.

Also, most scholars agree with Steinkeller (1982, 2012, 2013) that the Halil Rud civilization was probably known as the land of Marhaši (in sumerian) or Parahšum (in akkadian), the most important political counterpart of ancient Mesopotamia in the 3rd millennium BCE (contra Francfort & Tremblay 2010; Francfort 2021).

Base material and potential source areas in south-eastern Iran

In the past, archaeologists have constantly and freely used terms such as soapstone, talc, steatite, serpentine, "green stones", "dark stones", "dark soft stones" and chlorite without a sound basis of mineralogical analyses and expertize, and for a long time this caused a certain confusion (original criticism in Lamberg-Karlovsky 1997; see also Jones *et al.* 2007). This is only one of the reasons why scientific characterization of the base materials of the carved chlorite artefacts – very varied in typological terms and produced for several centuries – is still at a preliminary stage. The earliest physical and chemical analyses (Kohl *et al.* 1979), were performed on a consistent group of samples from the Tepe Yahya workshop and from sites in the Persian Gulf and greater Mesopotamia, compared to potential source samples. These latter were first collected from outcrops in the Zagros mountains near the Tepe Yahya site. A set of 375 samples were submitted to X-ray diffraction analysis; then selected ones were analyzed by Mossbauer spectroscopy, X-ray fluorescence and atomic absorption and neutron activation analysis. A number of petrographic thin sections were also realized to distinguish specific mineral associations. Eventually most efforts focused on the attempts at separating groups on the basis of X-ray diffraction analysis.

Unfortunately, Kohl *et al.* (1979), even after the mineral associations, were unable to separate meaningfully a large part

TABLE 1. — All 16 samples selected for this study, with indications on provenience, a brief description.

Sample	Provenience	Description	Photos
Sample 5	Hajjiabad-Varamin HV Craft Area	Cylindrical pot with "scales" within triangles (dark green-grey coloured; thickness = 4.2 mm)	Appendix 1A
Sample 8	Hajjiabad-Varamin HV Craft Area	Rim of a thick, large fine chlorite vessel (dark green-grey coloured; thickness = 6.3 mm)	Appendix 1B
Sample 9	Varamin-Hajjiabad-Varamin HV Craft Area	Wall fragment of a very thick, coarse pot (dark green-grey coloured matrix with black spots; thickness = 9.4 mm)	Appendix 1C
Sample 13	Hajjiabad-Varamin HV Craft Area	Very fine, tiny bell-shaped vessel sherd, undecorated (dark green-grey coloured; thickness = 2.1 mm)	Appendix 1D
Sample 14A	Konar Sandal South Survey KSS2 Trench 9	Very fine, tiny bell-shaped vessel sherd, undecorated (dark green-grey coloured; thickness = 4.2 mm)	Appendix 1E
Sample 15	Konar Sandal South Survey KSS1 surface	Lower part of a sub-cylindrical vessel, incised, *série récente* (dark green coloured; thickness = 5.2 mm)	Appendix 1F
Sample 16	Konar Sandal South Survey KSS1 surface	Wall fragment of an incised vessel, *série récente* (dark green coloured; thickness = 5.2 mm)	Appendix 1G
Sample 17	Konar Sandal South Survey KSS1 surface	Wall fragment of a vessel with two parallel incided horizontal lines (light green-grey coloured; thickness = 4.2 mm)	Appendix 1H
Sample 18	Konar Sandal South Survey KSS1 surface	Wall fragment of a vessel incised with triangles and arches, *série récente* (dark green coloured; thickness = 8.3 mm)	Appendix 1I
Sample 19	Konar Sandal South Survey KSS1 surface	Wall fragment of a vessel with incised triangles, *série récente* (green coloured; thickness = 4.2 mm)	Appendix 1J
Sample 21	Konar Sandal South Survey KSS2 Trench 3-3003	Fragments of a globular vessel (dark green-grey coloured; thickness = 6.3 mm)	Appendix 1K
Sample 22	Konar Sandal South Survey KSS1 surface	Thin, slightly everted bell-shaped vessel rim (dark green coloured; thickness = 8.3 mm)	Appendix 1L
Sample 23	Konar Sandal South Survey KSS1 surface	Thin, slightly everted bell-shaped vessel rim (dark green coloured; thickness = 6.2 mm)	Appendix 1M
Sample 24	Konar Sandal South Survey KSS1 surface	Thin, slightly everted bell-shaped vessel rim (dark green coloured; thickness = 4.2 mm)	Appendix 1N
Sample 25	Konar Sandal South Survey KSS1 surface	Thin, slightly everted bell-shaped vessel rim (dark green-grey coloured; thickness = 7.3 mm)	Appendix 1O
Sample 26	Konar Sandal South Survey KSS2 Trench 9-9004 4-8	Thin, slightly everted bell-shaped vessel rim (dark green-grey coloured; thickness = 4.2 mm)	Appendix 1P

of the samples they analyzed, nor to clearly identify possible sources of the analyzed chloritic base materials. For instance, the variety of chlorites in the mined outcrops near Tepe Yahya, although compatible with the 3rd millennium manufacturing waste, was wide enough to prevent simple segregations. Results have been variously interpreted and reported. A later summary of Kohl & Lyonnet (2008) mentions:

1) a "Sumerian group" from southern Mesopotamia and the Diyala Valley whose chlorites are different from those of Tepe Yahya, while the fragments of Bismaya (ancient Adab) were rather distinctively made of steatite;

2) a Susa-Mari-Yahya group, compatible, in contrast, with the chlorites found in the Tepe Yahya area;

3) a third group with samples dominantly from Susa and Mari (distinctive from Group 2 and presumably not originating at Yahya);

4) a final group gathering samples from Susa, Adab, and the Persian Gulf (including samples from Tarut and Failaka islands).

These preliminary distinctions, however, did not find much space in the following archaeological literature. To complicate matters, a talc-chlorite-dolomite source was recognized for Iranian Khorasan, and a chlorite-quartz deposit was hypothesized for Iranian Seistan; chlorites reportedly coming from the Arabian Peninsula were distinguished in two groups. The Tarut chloritic sherds, moreover, turned out to be mineralogically quite heterogeneous as if locals were getting their stone pots from different source places. The results at the time generated a fuzzy picture, in that the Tepe Yahya workshop(s) clearly were only one of the possible origins of the crafted goods. The evidence was then considered "[…] supportive of a competitive, merchant-driven trading network" extending across large parts of the Iranian Plateau and possibly the Arabian Peninsula (Kohl 2004).

More recently, Emami *et al.* (2017) carried out a new phase of updated archaeometric studies on samples provided by the archaeological expedition by Madjizadeh in 2002, together with others from recent scientific excavations and from the "Jiroft" confiscated artefacts stored in museum collections. Archaeological sites from which the excavated samples were supplied included Konar Sandal North (KSN), Konar Sandal South (KSS), the cemeteries of Ghalleh Kuchak (GHKC), Mahtoutabad and Ghare-Ghato. Archaeological samples were compared with geological ones, taken from contemporary outcrops of the Jiroft region like the Darre Goodmordane Ashin (DGMA) and Sardare Noe Ashin (DSNA). This research revealed that some of the famous stone vessels of the Halil Rud valley are consistent with the mining areas in localised near Esfandaghe (ES, 70 km to the west of Jiroft). Objects from KSN, KSS, the cemeteries of GHKC, Mahtoutabad (MAC) and Ghare-Ghato (GG) turned out similar to samples from the mining zones in Ashin valley in the Esfandaghe (ES) region, sharing the same recurrent crystalline phases (clinochlore, chlorite, tremolite and sapphirine: again, from Emami *et al.* 2017). The archaeological samples from the graves of GHKC,

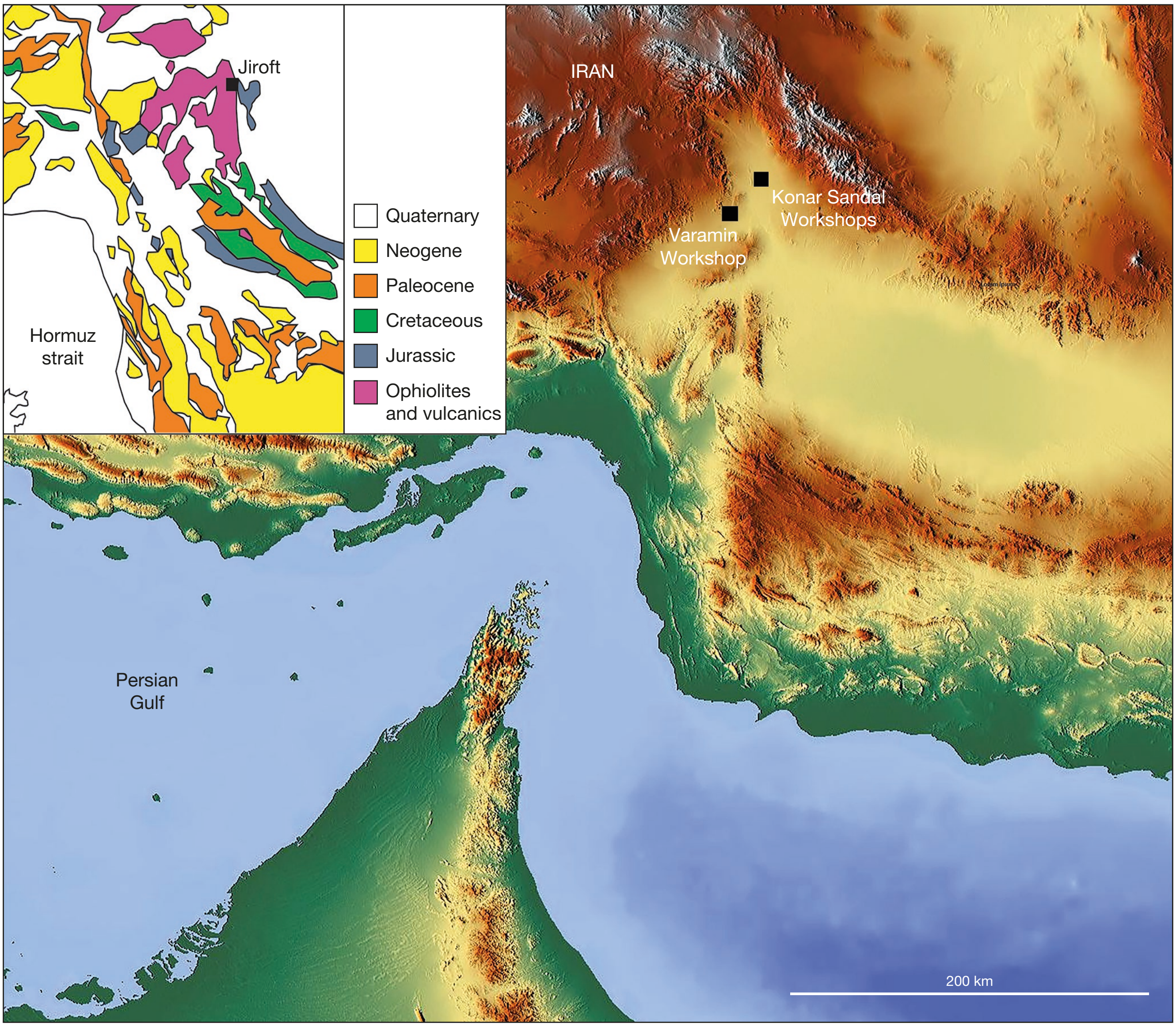

Fig. 2. — Simplified geological map of the study area (in Kerman province, south-eastern Iran) showing the main lithological units (modified after Regard *et al.* 2010), with location of the three workshop areas considered in the text: KSS1 and KSS2 are two stoneworking sites located at the peyphery of Konar Sandal, HV is the other stone processing location found on the surface of Hajiiabad-Varamin.

in particular, have a good correlation to the DGMA host rocks. Thus, both in the cases of the chlorites outcrops near Tepe Yahya and those of ES the most meaningful correlation was between local mining and presumed local processing.

Recent excavations and archaeological surveys in the core of Jiroft plains may help providing further evidence on the origin of these artefacts, even more because it comes from three different manufacturing contexts belonging to the same archaeological complex, respectively one at Hajjiabad-Varamin and two separate spots at the urbanized hub of Konar Sandal South.

Three new stone-working sites

The samples for this study were collected from three stone-working sites (Hajjiabad-Varamin, workshop KSS1 at Konar Sandal South, workshop KSS2 south of Konar Sandal South) in the Kerman province of Jiroft and in other two districts south of the urban center. All sites are located in an area of ophiolitic/volcanic outcrop, as it can be seen from the simplified geological sketch of Figure 2. Details related to samples provenience and sample description are provided in Table 1. The bulk composition of the analyzed samples, of course, exhibited high concentrations of SiO_2, Al_2O_3, MgO, FeO in the crystal structure, reflecting the common chemistry of chloritic rocks. XRF data indicates that the chemical composition of the samples is highly similar to the composition of chlorite with small amount of impurities (Evans & Guggenheim 1988). The samples split in four clusters which exhibit some similarities. Cluster I suggested that the host rocks from ES and SDNA are highly similar to each other, coming from the same geological formation and outcrops, the main constituents being clinochlore and

Fig. 3. — A view of the main craft area of the site of Hajjiabad-Varamin (Eskandari *et al.* 2021).

sapphirine. Cluster II shows a considerable relation between the objects from KSS, KSN, MAC, GMDA and GHCK, which are highly similar to the stones from the DGMA. Cluster II was followed by Cluster III and the similarities between the objects from GHKC and again the host rocks from DGMA. In these cases, the main part of the research objects illustrate suitable segregation and linkage to DGMA. Cluster IV reflects variability between all samples from the metamorphic host rocks in this region. On the whole, these groups were highly similar and comparable to each another on individual axes (Emami *et al.* 2017).

The site of Hajjiabad-Varamin (hereafter HV), near the city of Jiroft in Kerman Province, hosts a large, although deeply eroded settlement with a main mound. It was part of a wide network of coeval sites, including the urban center at Konar Sandal South, 5 km to the north-east (Pfälzner & Soleimani 2017; Eskandari *et al.* 2021). Its occupation ranged from the late 5th to the late 3rd millennium BC, including a number of cemeteries of the late 4th and 3rd millennia BCE (Fig. 3).

To the immediate east of the main mound there is flat dissected area whose surface record indicates an industrial-like scale craft production of the mid-3rd millennium BCE. The production area, in fact, covers 0.5 ha (50 × 100 m) or more, and represents the single largest known industrial site of this period on the Iranian Plateau (Eskandari & Vidale 2022). The surface is formed by the deeply eroded top of a series of dumps rich of broken carinated pots in white banded calcite, together with large amounts of beads of a different, green and brown-banded calcite, split in perforation (Eskandari *et al.* 2021). Heavy drill heads in porphyrite, chert and basalt for drilling vessels are also on record (Vidale & Eskandari 2022). Here, several fragments of undecorated bell-like potsherds, sometimes of exceeding fineness, were found on surface (Fig. 4). Rough abrasion marks on surface demonstrate that these chlorite vessels broke at the last stages of manufacturing (Eskandari *et al.* 2021).

The surface of the production area at Hajjiabad-Varamin, in fact, was littered with thousands of broken stone vessels and other waste. Among this material, nine drill heads were studied and described precisely in Eskandari & Vidale 2022. Comparison of the Hajjiabad-Varamin material with the Shahr-i Sokhta calcite working assemblages led us to recognise evidence of the four manufacturing steps there attested. As at Shahr-i Sokhta (Ciarla 1981: 56, fig. 9), vessel fragments from Hajjiabad-Varamin indicate that a frequent manufacturing mishap was the displacement of the drilling axis from that of the dressed preform. Other evidence for stone-vessel production includes a few banded lumps with multiple, incomplete drillings made from different directions: these could be training or test pieces. The interior of some bases preserve unusual bulbs and evidence for coarse rotatory marks (Eskandari & Vidale 2022).

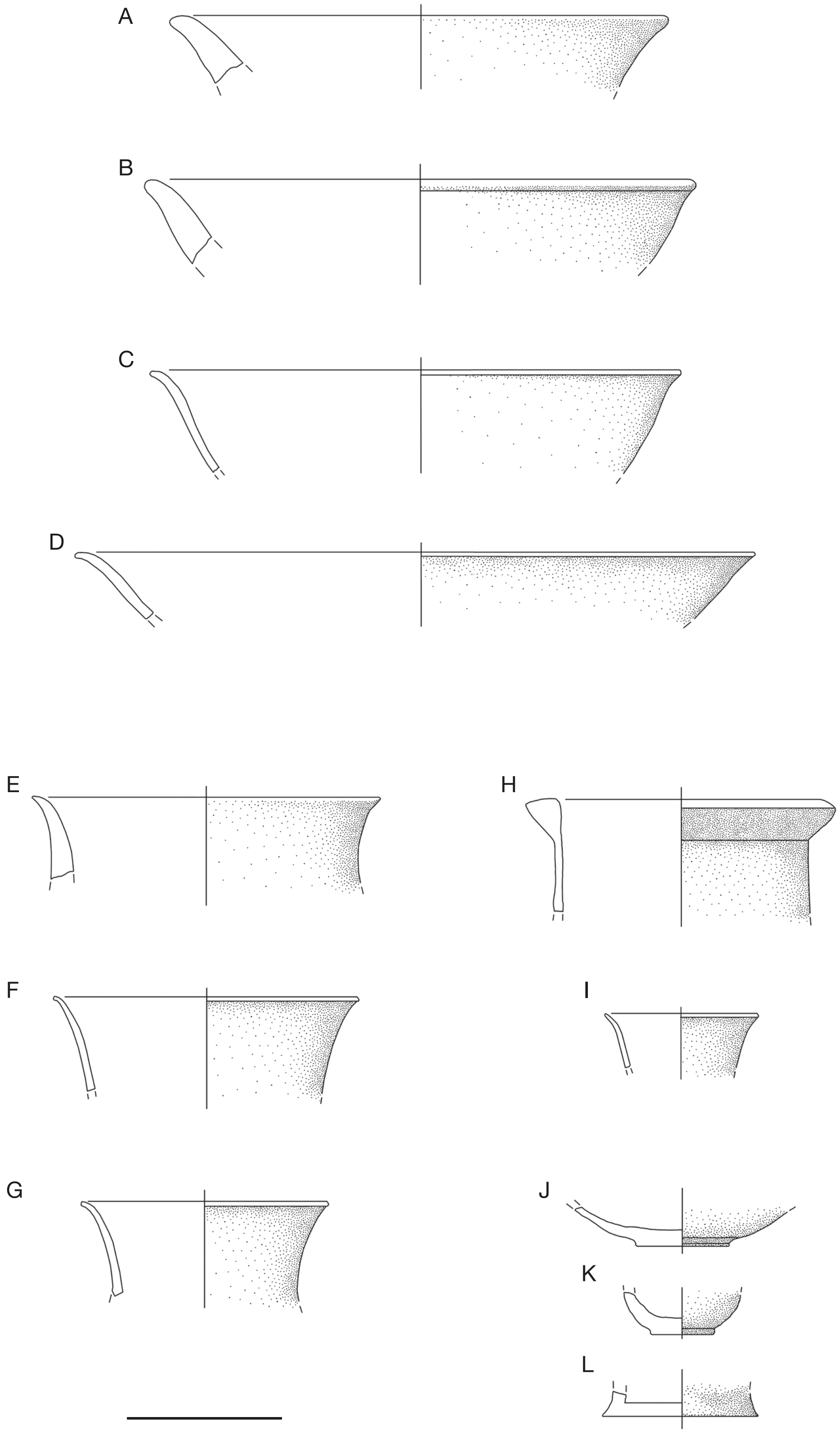

FIG. 4. — Examples of undecorated, bell-shaped chlorite bowls and pots manufactured on the main craft area of the site of Hajjiabad-Varamin (Eskandari *et al.* 2021): **A**-**D**, **F**, **I**, and possibly **J**, belong to bell-shaped undecorated bowls; **G**, **H**, might belong to restricted pots; **K**, might be the base of a small, thick globular vessel; **L**, part of a pot with concave walls. Scale bar: 5 cm.

The site of Konar Sandal South (Madjidzadeh & Pittman 2008) is now considered as the main urban hub of the Halil or Jiroft Civilization. This site was excavated in 2000s for six seasons revealing an early Bronze Age large mud-brick citadel built in at least three phases, surrounded by a massive defensive wall, in the centre of a much larger lower town. In 2020, the site's general area was systematically surveyed by one of the authors (NE) in order to delimit and identify its urban layout and its functional segregation. During the recent survey, two workshops of beads and stone vessels production datable to the 3rd millennium BC were identified. The second workshop considered in this article (hereafter named KSS1) is located 400 meters northwest of Konar Sandal South. The mounded area is about half a hectare. On its surface were found stone drills, broken walls of stone vessels, incomplete and half-finished beads and raw fragments of various stones.

The third workshop (KSS2) is located 700 m southeast of Konar Sandal South. The area measures less than half a hectare. In the center of this manufacturing site a trench of 2 × 2 m for a depth of about 1 m was opened (labeled as Trench No. 9) , unearthing manufacturing waste from the production of beads (banded calcite) and stone vessels (chlorite and limestone) (Fig. 5). The recovered ceramics are comparable to those from excavations of KSS mound (Madjidzadeh & Pittman 2008). The KSS2 workshop area dates back between the end of the first half of the 3rd millennium BCE and the midth of the same millennium, as revealed by a calibrated 14C dating of a charcoal lens stratified among its dumping layers (Fig. 6), an evidence also supported by preliminary ceramic comparisons. In this craft location were also found some fragments of bell-shaped chlorite pots, including tiny sherds of the thin-walled variety, previously discussed in the text. The new date is important because it matches those generally accepted, in the so-called middle chronology, to some rich graves of the Royal Cemetery of Ur, where the same type of plain chlorite bowl is well represented (type 50 in Woolley 1934: 50, pl. 245). Therefore, it provides a link (to be tested, whenever possible, with dedicated archaeometric tests) between the workshop areas of south-eastern Iran and the sumerian end of the distribution chains.

MATERIAL AND METHODS

Material

A set of 16 samples were here analyzed (Table 1). Four of them (5, 8, 9, 13) come from the first workshop, the extensive stone-working area found on surface in the site of Hajjiabad-Varamin or HV (Eskandari *et al.* 2021). Here, samples 8, 9, 13 are fragments of bell-shaped undecorated bowls of the kind discussed at length in Pittman (2018) that she referred to "Group 3". In particular, sample 13 distinguished by a remarkably thin wall. This type is common in the sites of south-eastern Iran and along the coasts of the Persian Gulf, as well as in southern Mesopotamia, for example in Puabi's furnishings in the Royal Cemetery of Ur, for which Pittman (2018) proposed a date included between 2400 and 2200 BCE. Ten artefacts (15, 16, 18, 19, 21, 22, 23, 24, 25, 26) were sampled in the second workshop, KSS1, at the periphery of Konar Sandal South. Samples 15, 16, 18 and 19 doubtless belong to the *série récente* and should represent, as already stated, productions of the late 3rd-early 2nd millennium BCE. Among them, fragments 21 and 26 are characterized by thin walls. Two samples (14a, 26), finally, come from KSS2, the third craft site, always not far from the slopes of the mound of Konar Sandal South. One of them (14a) presents very thin walls.

Note that in among the studied objects only one sample from the first workshop (5) (whose status as manufacturing waste is hypothetical), would belong to the so-called, highly decorated, *série ancienne*. All samples macroscopically display a grey-green color without preferential oriented structure or cleavage.

Methods

All the samples were petrographically characterized in thin sections under a polarized light optical microscope (Olympus DX-50, equipped with a Nikon D7000 digital microphotography system). Thin sections (3.5 × 3.5 cm) were obtained using a dried samples fragment, cut with a diamond saw, saturated under vacuum with a two-component epoxy resin (10:3, Araldite®2020/A:Araldite®2020/B, C.T.S. S.r.l., Italy). After hardening at 40°C, samples were glouted (2:1, Körapox 439/A:Körapox 439/B, Kömmerling, Germany) and mounted on a glass slide and then ground smooth using progressively finer abrasive (silicon carbide and poly crystalline in water diamond suspension with a grain size of 6 µm) until sample was 30 µm thick.

Mineralogical analysis was performed by X-ray powder diffraction (XRPD). A small-volume (*c.* 2 g) of each sample was hand grinded by the use of agate mortars, and the fine powder was inserted on specimen holders for Panalytical diffractometers operating in Bragg-Brentano geometry: 27 mm and 17 mm cavity diameter. Diffraction data were acquired on a PANalytical X'Pert PRO diffractometer, operating in Bragg-Brentano reflection geometry with CoKα radiation, 40 kV of voltage and 40 mA of filament current, equipped with an X'Celerator detector. Qualitative analysis of diffraction data and statistical analysis of diffraction patterns were carried out with X'Pert HighScore Plus® software (PANalytical) and the PDF-2 database. Cluster analysis on raw diffraction data was performed according to Piovesan *et al.* (2013) and Maritan *et al.* (2015), using peaks position and peaks intensity to distinguish the similarity between samples, the Euclidean distance method and a manual cut-off.

Abbreviations

DGMA	Darre Goodmordane Ashin;
DSNA	Sardare Noe Ashin;
ES	Esfandaghe;
GG	Ghare-Ghato;
GHKC	the cemeteries of Ghalleh Kuchak;
KSN	Konar Sandal North;
KSS	Konar Sandal South;
MAC	Mahtoutabad;
PPL	plane-polazied light;
XPL	high interference colours in crossedpolarized light;
XRPD	X-ray powder diffraction.

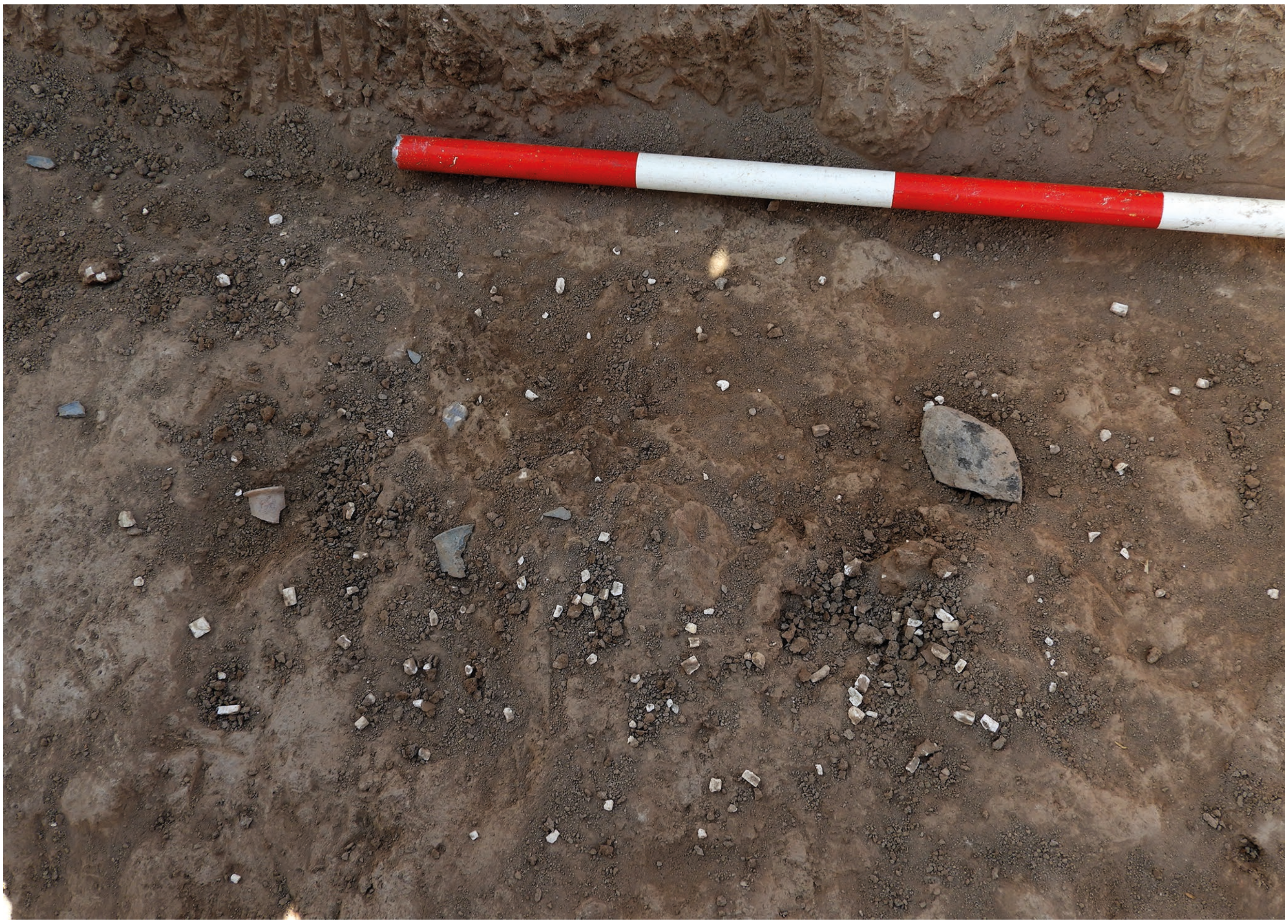

Fig. 5. — A detail of a surface unearthed in Trench 9 of site KSS2. Note the chlorite vessels potsherds and the large number of green-brown banded calcite beads split in perforation.

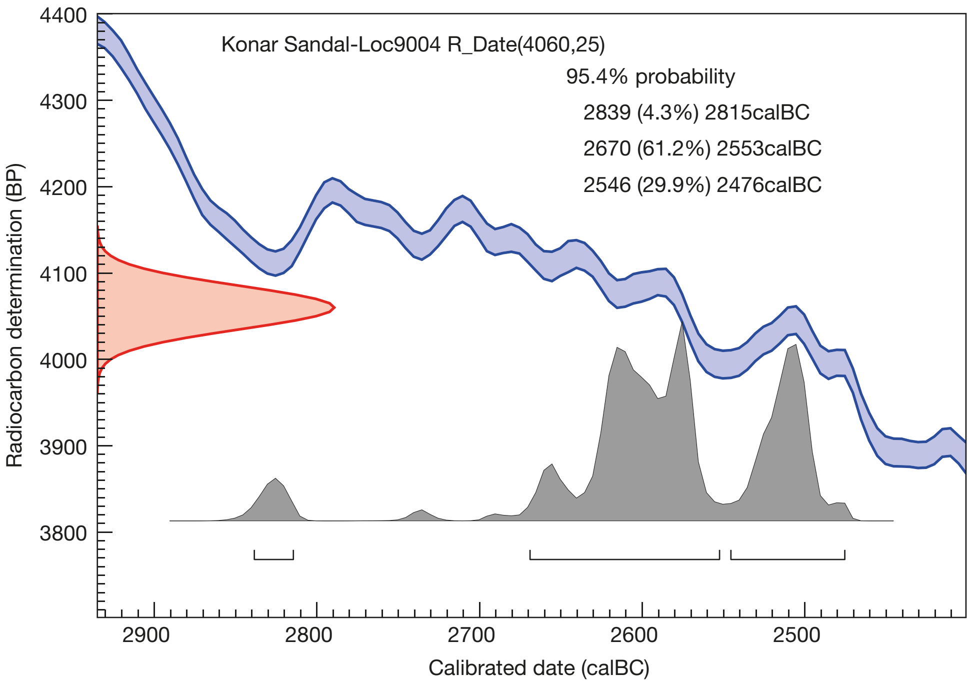

Fig. 6. — C14 date from from a charcoal lens stratified among the dumping layers of workshop area KSS2, Konar Sandal South.

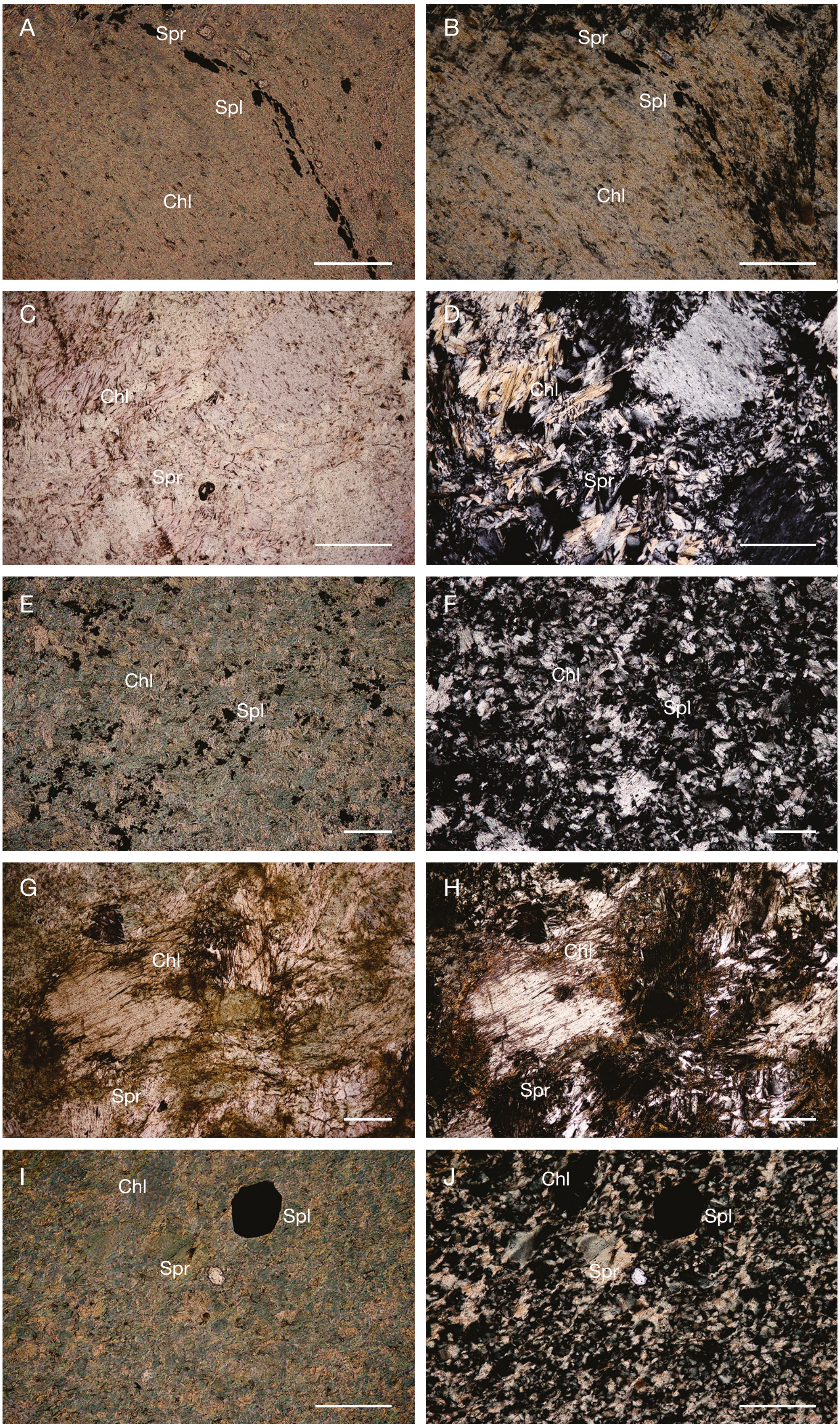

Fig. 7. — Photomicrographs in plane-polarized light (**PPL**) and crossed-polars (**XPL**) of some of the studied samples showing the main features described in the text: **A**, sample 08, PPL; **B**, sample 08, XPL; **C**, sample 17, PPL; **D**, sample 17, XPL; **E**, sample 15, PPL; **F**, sample 15, XPL; **G**, sample 19, PPL; **H**, sample 19, XPL; **I**, sample 09, PPL; **J**, sample 09, XPL. Minerals abbreviation according to Warr (2021): **Chl**, chlorite; **Spl**, spinel; **Spr**, sapphirine. Scale bars: A-D, I, J, 500 µm; E-H, 1 mm.

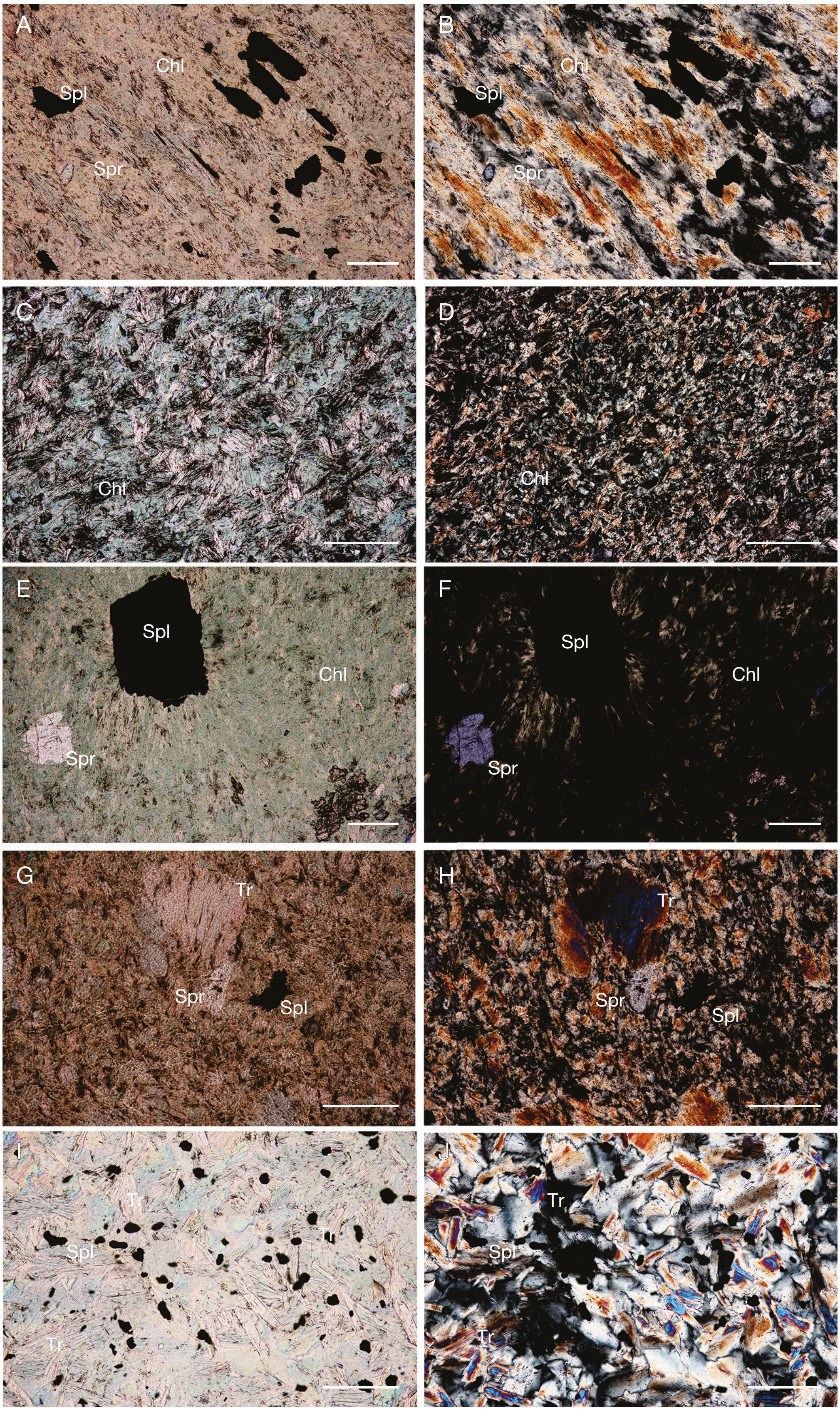

Fig. 8. — Photomicrographs in plane-plarized light (**PPL**) and crossed-polars (**XPL**) of some of the studied samples showing the main features described in the text: **A**, sample 26, PPL; **B**, sample 26, XPL; **C**, sample 23, PPL; **D**, sample 23, XPL; **E**, sample 22, PPL; **F**, sample 22, XPL; **G**, sample 21, PPL; **H**, sample 21, XPL; **I**, sample 24, PPL; **J**, sample 24, XPL. Minerals abbreviation according to Warr (2021): **Chl**, chlorite; **Spl**, spinel; **Spr**, sapphirine; **Tr**, tremolite. Scale bars: A, B, E, F, 1 mm; C, D, G-J, 500 µm.

Table 2. — Mineralogical characterization by XRPD qualitative analysis.

	Chlorite	Sapphirine	Tremolite	Spinel	Opaque Minerals	Halite
Sample 05	×	×	–	–	–	–
Sample 08	×	×	–	×	×	–
Sample 09	×	×	–	×	–	×
Sample 13	×	×	–	×	–	–
Sample 14A	×	×	–	×	–	–
Sample 15	×	×	–	×	–	–
Sample 16	×	×	–	–	–	–
Sample 17	×	×	–	–	–	×
Sample 18	×	×	–	–	–	–
Sample 19	×	×	–	–	–	–
Sample 21	×	×	×	–	×	–
Sample 22	×	×	–	–	–	–
Sample 23	×	×	×	×	–	–
Sample 24	×	×	×	–	–	–
Sample 25	×	×	×	–	×	–
Sample 26	×	×	×	–	–	–

RESULTS

Under the optical microscope, all the samples are mineralogically very similar, generally containing chlorite (more than 90%) as main crystalline phase, and sapphirine and spinels (probably magnetite) as accessory minerals. Main differences among them are related to the mineral fabric and grain-size, features that are dependent also orientation of the cut (thin section) respect to the artifact's morphology. Indeed, although macroscopically all samples do not display evident orientations (also supported by outcrop lithological characterization of similar samples in Emami *et al.* 2017), thin section analysis indicates that they can be divided into coarse-grained and fine-grained ones on a textural base. Relict minerals (such as pyroxenes and amphiboles) are only occasionally (in few samples) present in very low quantity (rare), suggesting they underwent complete breakdown during the metasomatic and hydrothermal alteration of the pre-existing basic and ultrabasic rocks, and the replacement by new secondary phases, mainly chlorite. Chlorite is represented by large pleochroic crystals, randomly oriented, with moderate relief and very low birefringence (Figs 7; 8). In some samples (e.g. 09, 15, 22) a bluish-green variety is found, penninte, or the Fe-rich end member of the chlorite group, chamosite. Few and small crystals of sapphirine, dispersed between chlorite crystals, are also present in all samples. They are easily recognizable by their prismatic habit and the characteristic high relief, low birefringence with indigo-gray interference colors (samples 08, 09, 15, 22, 26, Figs 7; 8). The presence of sapphirine testifies the high-temperature regional metamorphism, characteristic of the granulite-amphibolite facies and Mg-rich rocks. Most of the samples display abundance of opaque minerals, corresponding to spinel and showing a isometric habit, occurring with small (e.g. sample 24, Fig. 8I, J), or large (up to 1-2 mm in size) (e.g. sample 09, Fig. 7I, J; sample 22, Fig. 8E, F) crystals. In crossed-polarized light, they exhibit corona-like textures, as the results of the metamorphic process and fluids circulation during the rock process formation (sample 22, Fig. 8E, F). Few amounts of tremolite is also found (as reported in Emami *et al.* 2017) displaying acicular coloursless crystals in plane-polazied light (PPL) whit high interference colours in crossedpolarized light (XPL) (e.g. samples 21 and 24, Fig. 8G-J).

Because of the nature of the rocks-forming process of these samples, they can present a high variability in a small regional scale, and therefore it is very difficult to trace differences purely on a petrographical characterization. For this purpose, X-ray powder diffraction, already used in the past, is the most effective technique for identifying differences between mineral phases. Mineralogical analysis by X-ray powder diffraction confirmed the mineral assemblages microscopically defined, with a rock composition formed by predominant chlorite (clinochlore/chamosite), small quantities of sapphirine (very low in abundance but present in all samples) and spinels (Table 2).

In spite of the strong similarity among diffraction patterns, statistical analysis allowed to group the studied samples into two clusters, with only two outliers (sample 22 and 24) isolating from them (Fig. 9). Most of the samples gather in Cluster 2 (samples 05, 14a, 15, 16, 17, 19, 21, 23, 25, 26), whereas Cluster 1 groups just three specimens (samples 08, 09 and 13), but similar in terms of shape and all found in the same dumps. The comparison between diffraction patterns of the most characteristic samples of each cluster (as defined by the software) shows differences in some of the peaks of chlorite, at low angle (between 8° and 12° 2θ) and between 20-25° 2θ, 28-30° 2θ, and 40-50° 2θ (Fig. 10). The shift of the diffraction peaks between different samples is related to differences on the chemical composition of chlorite, representing therefore different intermediate terms of the solid solution series between the two end-members clinochlore $(Mg_5Al)(AlSi_3)O_{10}(OH)_8$ - chamosite $(Fe_5Al)(AlSi_3)O_{10}(OH)_8$, each of them having slightly different crystal lattice due to the substitution between Mg^{2+} and Fe^{2+} in the octahedral site. Such differences indicates, according to Emami *et al.* (2017), the exploitation of different varieties of chlorite. On these bases, Cluster 1 is characterized by chlorite richer in Mg, as also attested by its color in plain-polarized light,

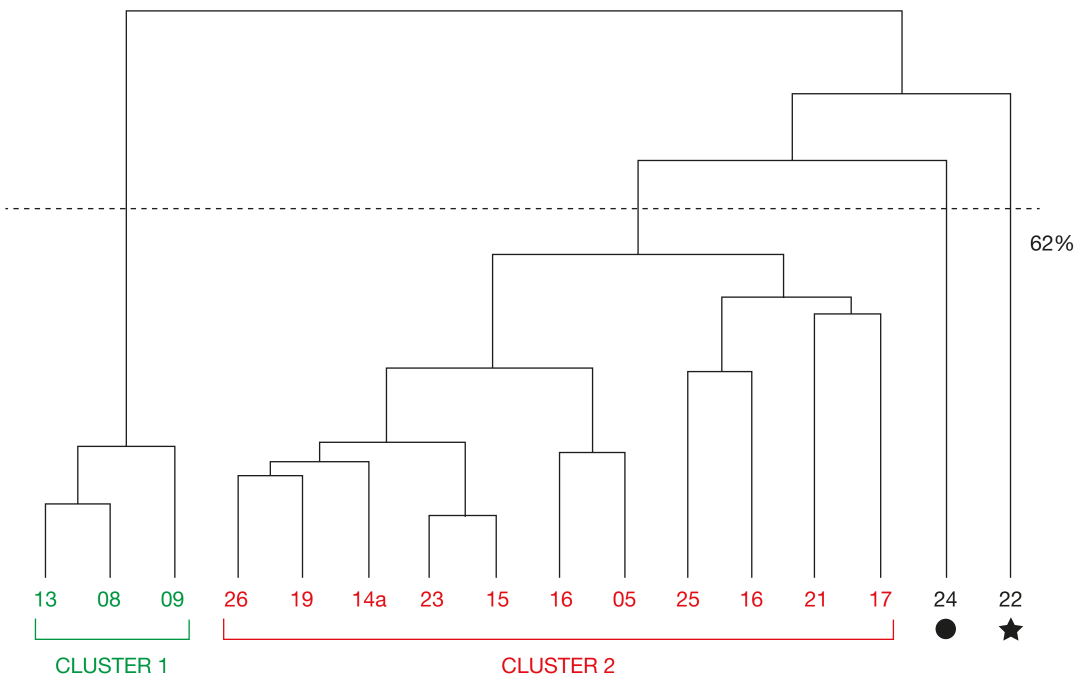

FIG. 9. — Dendrogram obtained by the hierarchical cluster analysis based on peaks position and peak profiles intensity of diffractogram pattern of all the set of samples. Sample 13 and sample 23 are the most representative of Cluster 1 and Cluster 2, respectively. Sample 22 and 24 are identified as outliers.

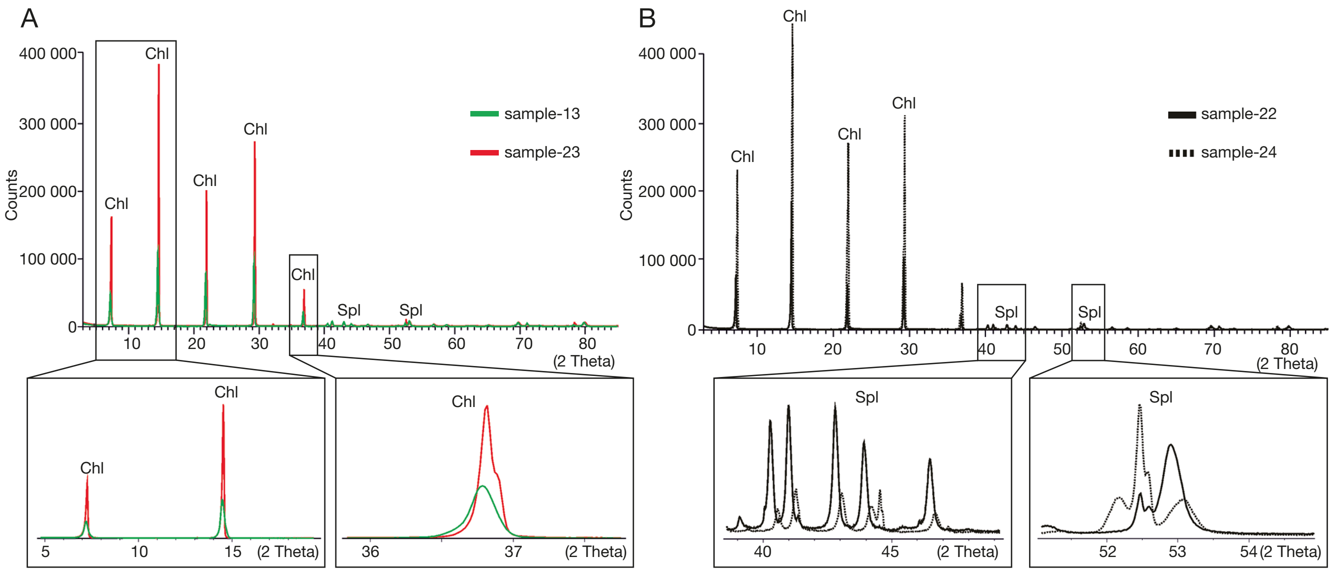

FIG. 10. — Comparison between diffraction patterns of: **A**, the most representative specimens of Cluster 1 (sample 13) and Cluster 2 (sample 23); **B**, the outliers (samples 22 and 24) based on the hierarchical cluster analysis of Figure 9. Specific intervals of the patterns, where the main peaks of the mineral phases fall, are also reported and magnificated to better show the diffrences between samples, whoch are more clear especially at high values of °2Theta (for geometrical reasons).

being almost colorless (Fig. 7C). Iron extensive substitutions may change the colors through golden-brown or dark-greens (Fig. 7E) grading into chamosite. The replacement of Mg by Fe^{2+}, is the responsible of the peak shift that is observed for the samples of Cluster 2 with respect to those of Cluster 1 (Fig. 10). Alteration of clinochlore and chamosite may proceed to vermiculite-like or mixed layered structures, traces of which were detected in all the diffractogram patterns of the studied samples. In few samples also small peaks of tremolite are detected (Table 2), confirming the microscope observations (Fig. 8G-J). Moreover, a phase attributed to the soine group is also present in all the samples, but showing different d-spacing values, related to different term of the spinel solid solutions.

DISCUSSION

In the light of the above, Cluster 1, gathering samples 8, 9 and 13 seems to represent a good proxy for at least a batch of raw material imported and processed in the craft workshop(s) of an industrial site located at some distance from KSS such as that of HV, apparently for making bell-shaped bowls, like those illustrated in Figure 4. The coarsely scraped surface of these pots makes quite probable their local manufacture (Eskandari *et al.* 2021). The rocks used in this context, as already stated, are higher in content of Mg-chlorite components. Of course, the main reason of interest of these and similar undecorated bell-shaped pots, sometimes distinguished by an extreme finesse, is that they were found in presumably coeval royal graves of the Royal Cemetery of Ur in southern Mesopotamia and other foreign locations. Interestingly, however, a member of Cluster 1 (sample 5) belonged to a quite different cylindrical pot, carved with friezes of alternating triangles entirely filled with scales, a common motif in the non-figurative products of the previously called “intercultural style”. This suggests the use of the same extraction area for the (local?) manufacture of at least two different, important classes of products. Sample 5 looks more altered and worn than the fragments of bell-shaped fine pots. This evidence may have its bearing, but cannot be taken *tout court* as the proof of anteriority.

In the chloritic rocks of the more substantial Cluster 2, magnesium (Mg) is partially replaced by Fe^{2+} in the chlorite crystal lattice; they are also distinguished by specific processes of geological formation. The fact that most of the samples of this group were bell-shaped, undecorated pots but only came from the two workshop sites investigated near Konar Sandal (KSS1 and KSS2) suggests that different communities of practices in a wider procurement and processing network may have exploited (possibly in different times) different local sources of chloritic rocks. A significant discovery is that Cluster 2 also contains samples 15, 16, 18, 19, were certainly members of the so-called *série récente*, decorated with more cursive and shallow incisions, presumably produced and traded in the first two-three centuries of the 2nd millennium BCE. Although in this case, at least so far, there is no certain evidence of contextual processing, local manufacture can be taken as very likely.

CONCLUSIONS

The combined approach we applied – petrographic characterization in thin sections joined with mineralogical analysis by X-ray powder diffraction – is confirmed as an efficient methodology to investigate at reasonable costs and investments the mineralogical nature of the 3rd-2nd millennia chlorites industry of the macro-region. Confirming previous partial results by Emami *et al.* (2017), this preliminary study demonstrated that even while serving the same main urban hub of the Halil valley, different workshops might have exploited different local (regional?) chloritic outcrops, probably in multiple production contexts and different times. This happened in the frame of a complex procurement/transformation network which evolved with continuity, possibly without any break, in the course of time. Clusters 1 and 2, in fact, point to two different sources. The isolated samples 22 and 24, typologically not very distinctive, also potentially point to other two individual source areas.

In these conditions, the same KSS network ultimately produced at least three major different classes of stone pots (cylindrical vessels with intricate geometric patterns, plain bell-shaped bowls and incised *série récente* vessels). This is only the beginning of a research that needs to be expanded to a much larger number of archaeological finds and wider collaboration; with a thought to the still elusive sites where the prestigious craft and figurative tradition of the Halil Rud civilization certainly developed for several centuries.

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APPENDIX

Appendix 1. — The 16 samples analysed in this study, see Table 1 for the provenience and descriptions: **A**, sample 5; **B**, sample 8; **C**, sample 9; **D**, sample 13; **E**, sample 14A; **F**, sample 15; **G**, sample 16; **H**, sample 17; **I**, sample 18; **J**, sample 19; **K**, sample 21; **L**, sample 22; **M**, sample 23; **N**, sample 24; **O**, sample25; **P**, sample 26. Scale bars: A, C, 5 mm; B, D-P, 10 mm.