

1 **Complexity of Proto-Elamite Administration System: Insights from** 2 **Compositional Data from Sealings and Tablets**

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9 **Abstract**

10 This study investigates administrative practices during the Proto-Elamite period (3100-2900
11 BC) by analysing the compositional data acquired from sealings and clay tablets found in
12 Susa, Malyan, and Tape Yahya using handheld X-ray fluorescence (hXRF). *The relative error*
13 *(RE%) and the expanded uncertainty (U_{Δ}) accounted for the hXRF quantitative data acquired*
14 *from six certified reference materials (CRMs) showed the hXRF data was accurate and the*
15 *standard deviation (σ) of the measurements performed on the CRMs and relative standard*
16 *deviation (RSD) accounted for the measurements performed on the clay materials showed*
17 *that the hXRF data are precise enough to have a clear picture about the compositional*
18 *diversity within the objects under study in terms of major and minor elements. The Proto-*
19 *Elamite writing system and seal imagery, found across various sites in Iran, played a*
20 *significant role in administrative control. This research provides new insights into the*
21 *administrative mechanisms of the Proto-Elamite civilisation and the extent of regional*
22 *interactions. Results suggest that sealings, used to secure storage and portable objects, were*
23 *typically made and used locally, with no evidence of inter-regional transport. The chemical*
24 *analysis of sealings from different trenches within Malyan highlights localised administrative*
25 *practices. In contrast, the Proto-Elamite tablets seem to be transported between sites,*
26 *indicating flow of information or goods.*

27 **Keywords:** Proto-Elamite; handheld X-ray fluorescence; clay sealing; tablet; administrative
28 control; distribution.

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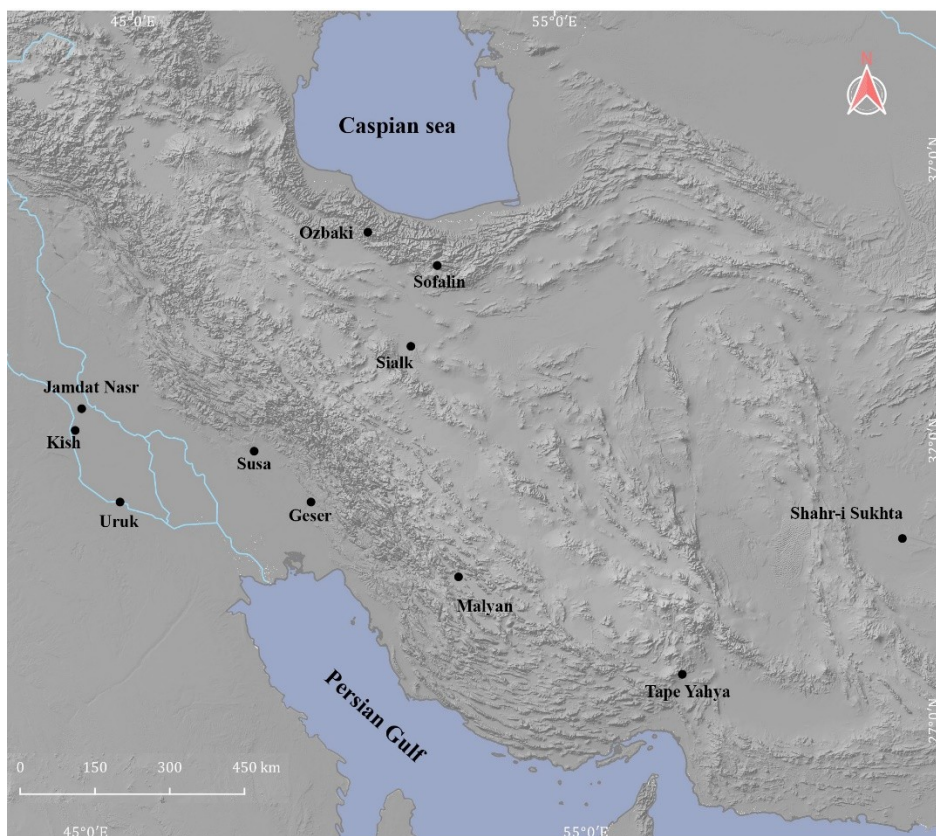
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38 **1 Introduction**

39 This study aims to elucidate the administrative mechanisms and inter-regional interactions of
40 the Proto-Elamite period by analysing the compositional data from sealings and tablets.

41 Through this, we aim to investigate potential administrative interactions between Proto-
42 Elamite sites, which are thought to represent local communities employing similar
43 administrative tools, writing systems, and glyptic art.

44 Proto-Elamite is a term suggested by Scheil (1900) to identify the oldest writing system on
45 clay tablets that were found in Susa. Consequently, this term is used to refer to a specific
46 period dated cautiously between 3100-2900 BC (Dahl et al. 2013). Proto-Elamite tablets have
47 been found in Susa, Malyan, Sialk, Sofalin, Tape Yahya, Shahr-i Sukhta, Geser, and Ozbaki
48 (Dahl 2005, 2018; Dahl et al. 2013) (Figure 1). Another characteristic of the Proto-Elamite
49 period is its seal imagery (Pittman 1994, 2013; Paladre 2022). Tablets and sealings
50 functioned as administrative tools that play a significant role in our understanding of storage
51 and distribution methods in society.



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Given the geographical expansion of the Proto-Elamite writing system, different hypotheses have been proposed regarding the nature of the administrative system in this area. These include early state formation (Wright and Johnson 1975: 274; Lamberg-Karlovsky 1996: 117), nomadic tribes' civilisation (Alden 2013: 224; Sumner 1986: 209, 2003: 2), chiefdom (Yousefi Zoshk 2011: 581-93), and centralisation (Matthews and Fazeli 2022: 230).

The Proto-Elamite period, spanning the late fourth and early third millennia BCE, though precise chronology remains challenging due to limited absolute dating. Relative dating of pottery styles links the Proto-Elamite period to Susa III in Khuzestan (Le Brun 1971), Banesh in Fars (Sumner 1986), Yahya IVC in Kerman (Lamberg-Karlovsky 1971), Shahr-i Sukhta I in the southeast (Amiet and Tosi 1978), and Sialk IV on the central plateau (Ghirshman 1938). Dahl et al. (2013) further refined this chronology through stages of Proto-Elamite writing development at Susa Acropole I, dating from 3100-2900 BCE, where sign forms and tablet shapes evolved from simple to more complex records. By studying relative chronological evidence it has been suggested that the Proto-Elamite period partially overlaps with both the Late Uruk and Jemdet Nasr phases in Mesopotamia (Englund 2004; Petrie 2014; Alden and Petrie 2015).

Research has suggested that there is a direct relation between specialisation and surplus, with increasing exchange and social inequality, and controlling production and distribution (Service 1962; Flannery 1972: 423-424; Blanton & Feinman 1984: 674; Tosi 1984; Brumfiel & Earle 1987: 1-3). The fourth millennium BCE is typically considered a period of increasing exchange between long-distance sites, and Amiet (1986) suggests the term "*age of exchange*" for this period when valuable and semi-precious stones were transferred within a wide area during the fourth and third millennium BCE (Kohl 1978: 475; 1979: 56-58; Johnson 1973; Lamberg-Karlovsky 1971: 94; 1978: 118; Potts 1994; Mutin et al. 2016: 13). However, the texts belonging to this period did not support any transactions related to the commodities that archaeological finds show were transferred between different sites (Englund 2004: 112; Dahl 2018: 386).

In addition, the material culture of the fourth millennium BCE has been the subject of a comprehensive study by Minc and Emberling (2016) to examine the "Uruk expansion" theory that had been suggested by Algaze (1989, 1993). Pittman and Blackman (2016: 881) analysed sealings and argued that the long-distance movement of sealed containers played a limited

86 role in the expansion of Uruk-related material culture. Although special raw materials like
87 bitumen have been transferred during different periods (Schwartz and Hollander 2016),
88 pottery production took place locally (Gopnik et al. 2016), but craftsmen would have
89 circulated over long distances (Alden and Minc 2016).

90 Chemical characteristics of administrative toolkits provide a new line of evidence to indicate
91 whether they were used for local or non-local purposes. Chemical analysis plays a significant
92 role in understanding the details of administrative processes. Does a similar writing system in
93 different sites mean that there was an administrative relationship between them? If the tablets
94 were made locally, what does it mean for the flow of information between sites? Were the
95 sealed portable containers moved over long distances?

96 **2 Materials and methods**

97 In this study, two groups of artifacts have been analysed: sealings and tablets. These clay
98 objects were chosen from Susa, Malyan, and Tape Yahya. These three sites are located in the
99 southern part of modern Iran (Figure 1). Each of these sites demonstrates a different process
100 related to the Proto-Elamite phenomena. In terms of administration, all these sites used
101 almost similar record-keeping methods and seal imagery.

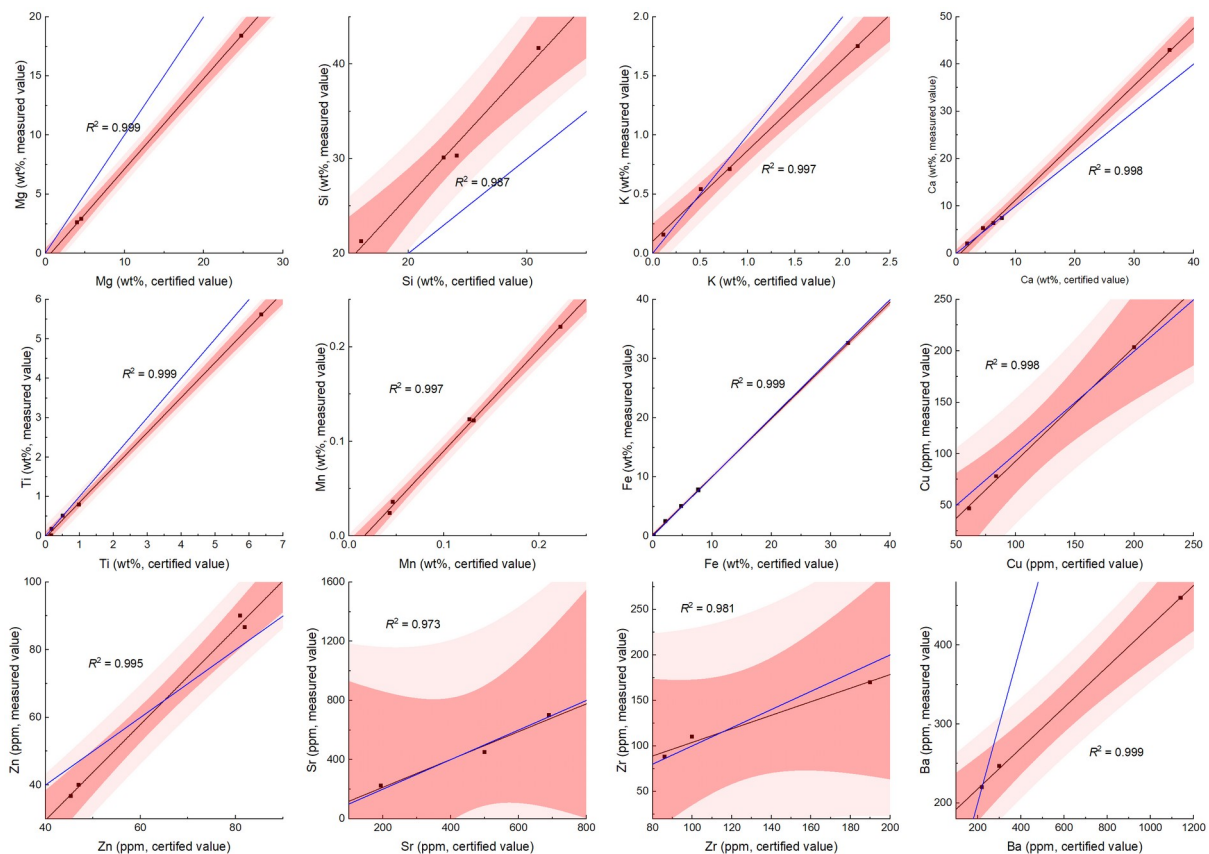
102 Among the collection of Proto-Elamite sealing and tablets kept at the National Museum of
103 Iran, 35 tablets from Susa (labelled with ST-nn), 20 tablets from Malyan (MT-nn), and 15
104 tablets from Tape Yahya (YT-nn) were selected to be investigated. Since museum protocols
105 do not allow to take samples from the sealings and tablets, using a handheld x-ray
106 fluorescence (hXRF) instrument was the most suitable method for acquiring compositional
107 data.

108 **2.1 Handheld x-ray fluorescence (hXRF)**

109 A Niton XL3 handheld device (from Thermo-Fisher) equipped with a Geometrically
110 Optimised Large Drift Detector technology (GOLDD+) and an Ag anode was used to non-
111 invasively acquire quantitative data from the sealings and the tablets which were irradiated
112 while the highest kV and μA used for measuring measurements were 50 kV and 1000 μA
113 with no filters. The hXRF device acquired measurements in three different spectral ranges for
114 light, medium and heavy weight element and quantifies the elements based on the built-in
115 calibration algorithms. In order to ensure accuracy of the quantitative data, a series of
116 certified reference materials (CRMs) including basalt (2116-81), dolerite (SARM 50),
117 granite-gneiss (NCS DC73376), a limestone (NCS DC60107), coulsonite (NCS DC19001)

118 and an ultrabasic rock (NCS DC72301) were used to check the quality of the quantitative
 119 data obtained by the built-in calibration. The selection of the CRMs was based on the
 120 elements present in both the archaeological objects and their range of concentration. As the
 121 calibration curves of the elements shows (Figure 2), the measured values are slightly deviated
 122 from the certified ones.

123 In order to ensure the quality of the quantitative data acquired from the CRMs, standards
 124 deviation (σ) and relative error (RE%), as measures for precision and accuracy of the data,
 125 respectively, were calculated and shown in Table S1. In fact, the low σ and RE% values
 126 accounted for most of elements above their quantification limit ensured that the
 127 measurements are precise and accurate enough to create a picture from the diversity of
 128 chemical composition within the objects under study. In addition, expanded uncertainty (U_{Δ})
 129 (Linsinger, 2010) calculated for the data acquired from the CRMs showed that there is no
 130 significant difference between the measured data and the certified value of the CRMs (Table
 131 S1).



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133 Figure 2 Regression analysis of K, Ca, Ti, Mn, Fe, Cu, Zn, Sr, Ba and Zr for XRF measurements on the CRMs.

134 The black solid line in the regression line, the blue solid line represents a line with slope = 1 and intercept = 0.

135 The pale and dark pink areas show the prediction and the confidence limits at 95% confidence, respectively.

136 The measured values from the sealings and tablets were corrected based on the following
137 linear transformation:

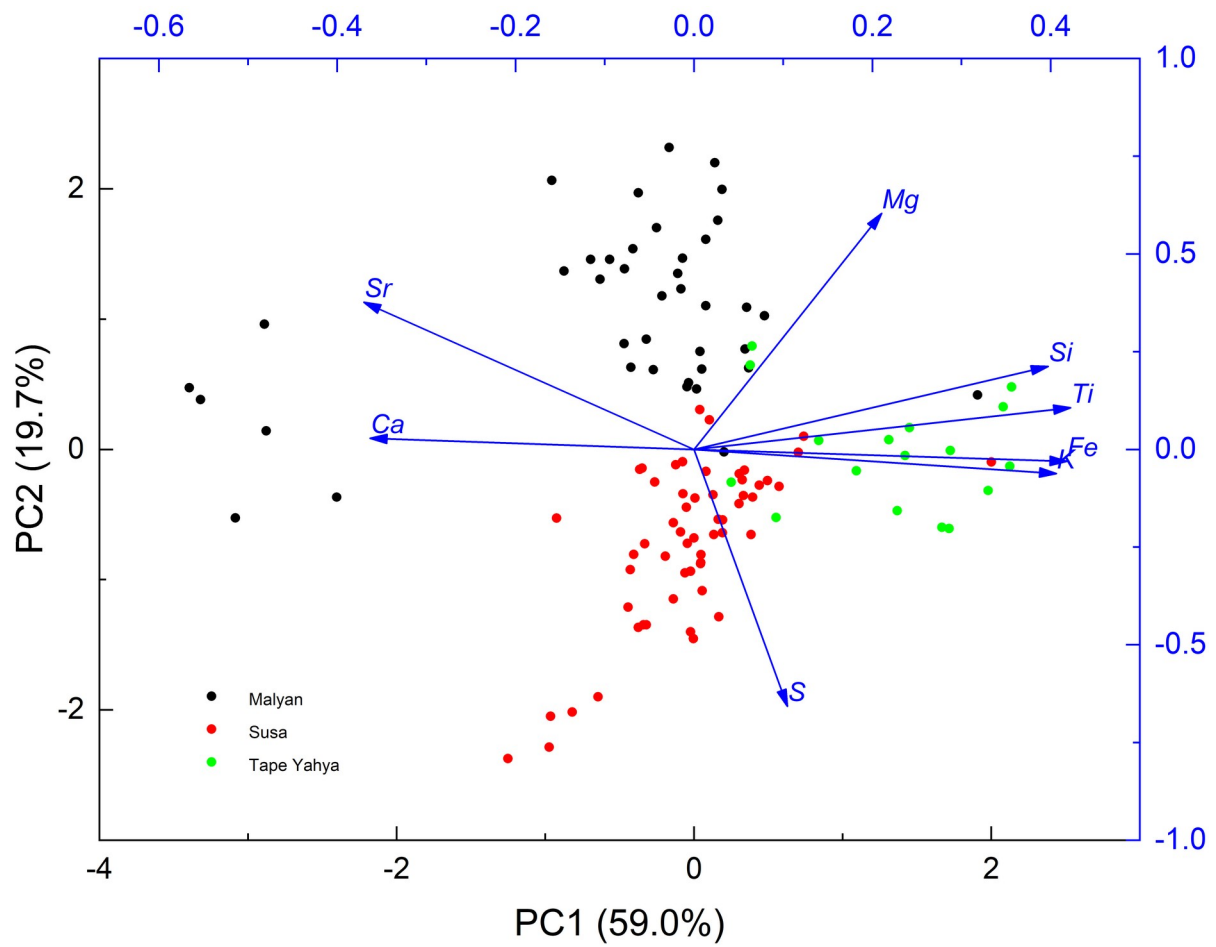
$$138 \quad \text{corrected concentration} = (\text{measured concentration} - b) / a$$

139 where a and b are the slope and the intercept of the regression line obtained for each element
140 in the calibration curves of the CRMs, respectively (Figure 2). The corrected hXRF data from
141 the sealings and the tablets are reported in Table S2. It should be mentioned that elements
142 such as sulphur and chlorine, which did not present in the CRMs above the quantification
143 limit of the hXRF, the measured values for these elements were recorded based on the built-
144 in calibration of the hXRF device (Table S2). As another measure for securing the precision
145 of the measurements performed on the objects under study, the relative standard deviation
146 (RSD%) of the quantitative data was calculated and reported in Table S2. It should be noted
147 that based on the geometry and size of the sealing and tablets two to three spots were
148 analysed from each object.

149 **3 Results**

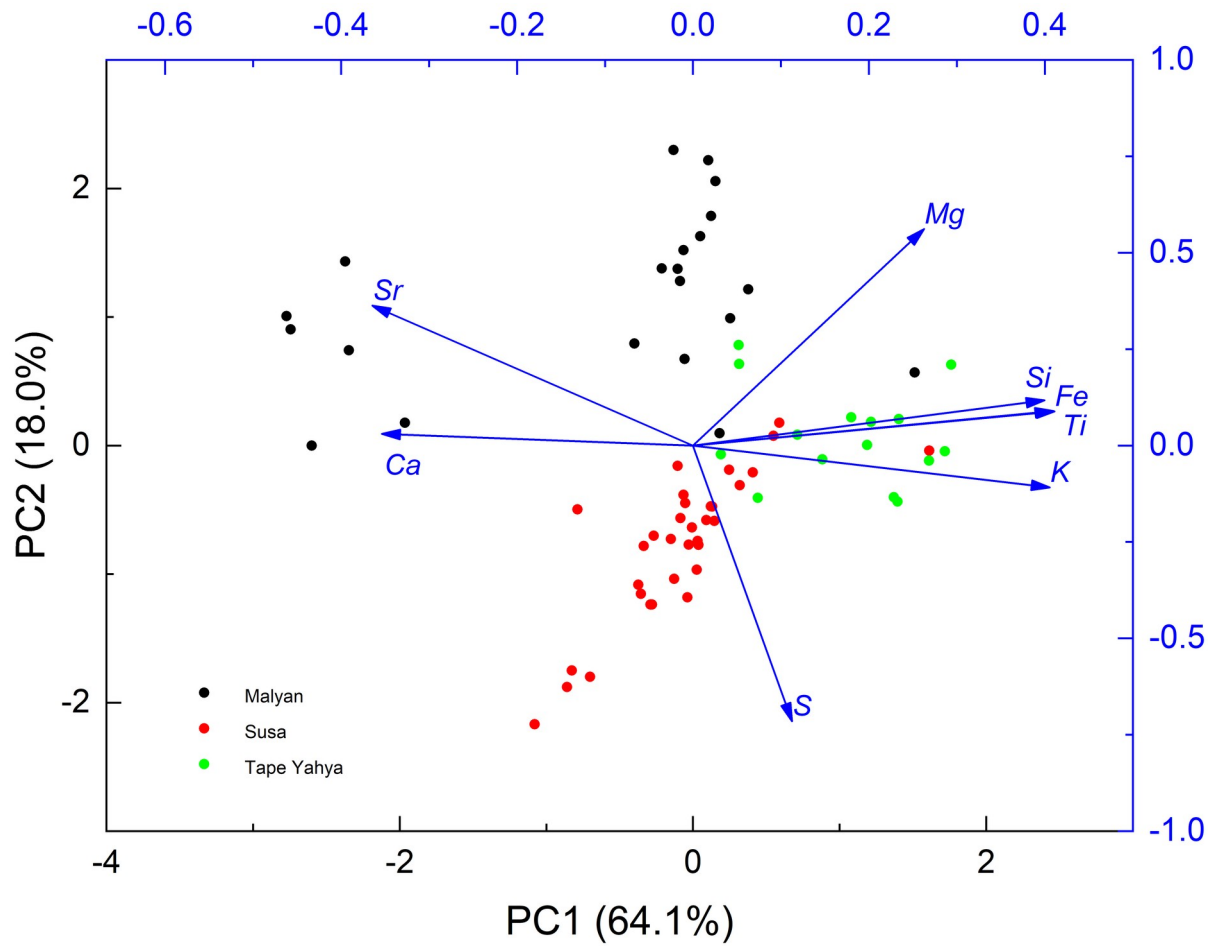
150 Among the elements quantitatively measured by hXRF, those with the highest variance
151 within the whole dataset (Table S1) and the lowest measured relative error (RE%) (based on
152 the data presented in Table S2), i.e., Mg, Si, S, K, Ca, Ti, Mn, Fe and Sr, were selected for
153 further statistical elaboration. In fact, the elements other than these elements either showed
154 low variance in the entire dataset or had low quantity near their detection limit so that large
155 RE% was accounted for them. It must be emphasised that sulphur is rather an unusual
156 element in provenance studies of ceramics objects. However, we included it in the dataset as
157 it showed high variance. Sulphur can be in fact related to gypsiferous soils which the clay
158 objects under study could have been made from.

159 In the first stage of data analysis, elemental concentrations were converted to ppm, then were
160 log-transformed, and subsequently, were standardised in order to uniform the weight to the
161 data. The modified data were then subjected to principal component analysis (PCA) (Figure
162 3). PCA was also performed separately on the clay tablets and sealing in order to observe the
163 chemical variation within each group (Figures 4 and 5). Total variance accounted for these
164 PCA observation of data was above 70%, which was high enough to acquire a general view
165 on the compositional data.



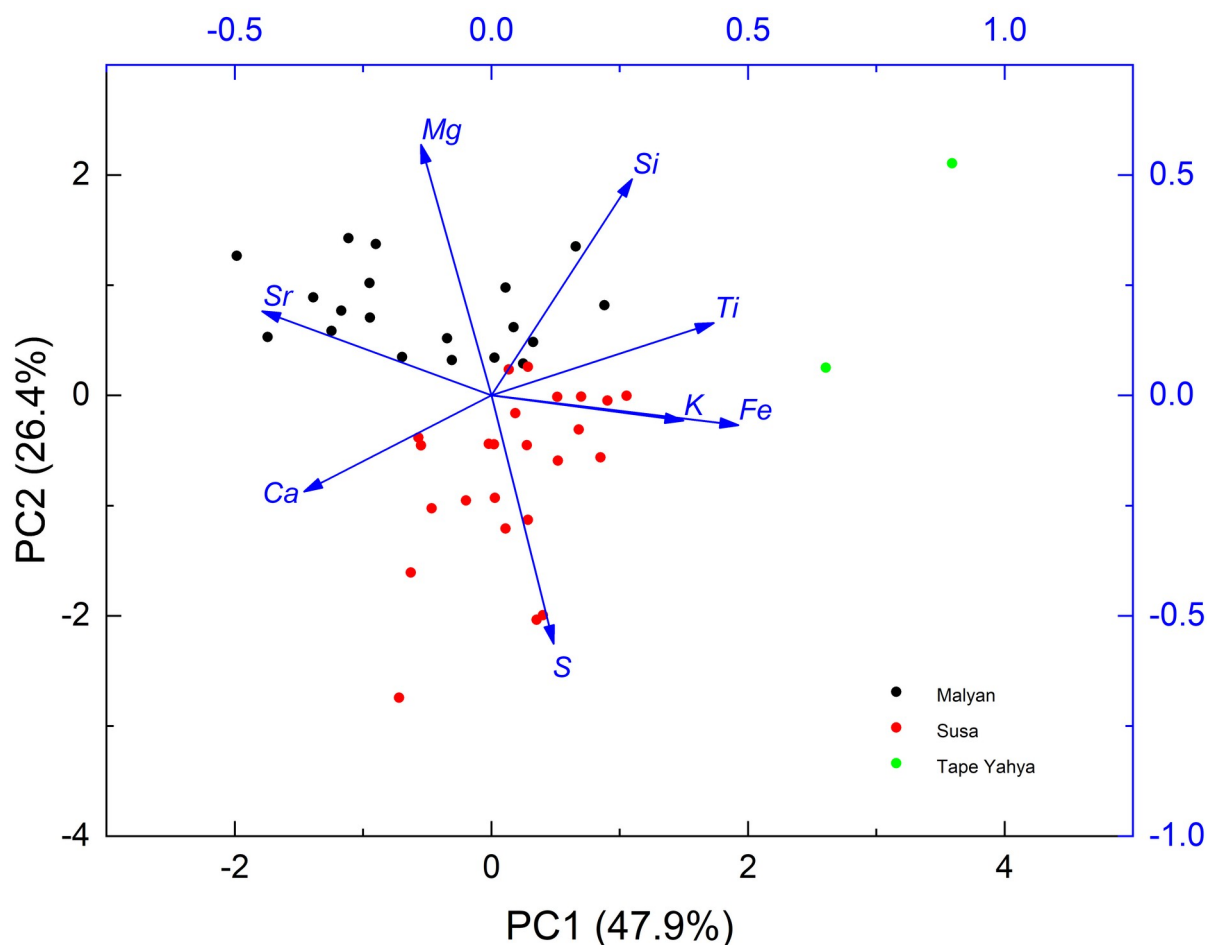
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167 Figure 3 PCA biplot on the compositional data from all sealings and tablets



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169 Figure 4 PCA biplot on the clay tablets



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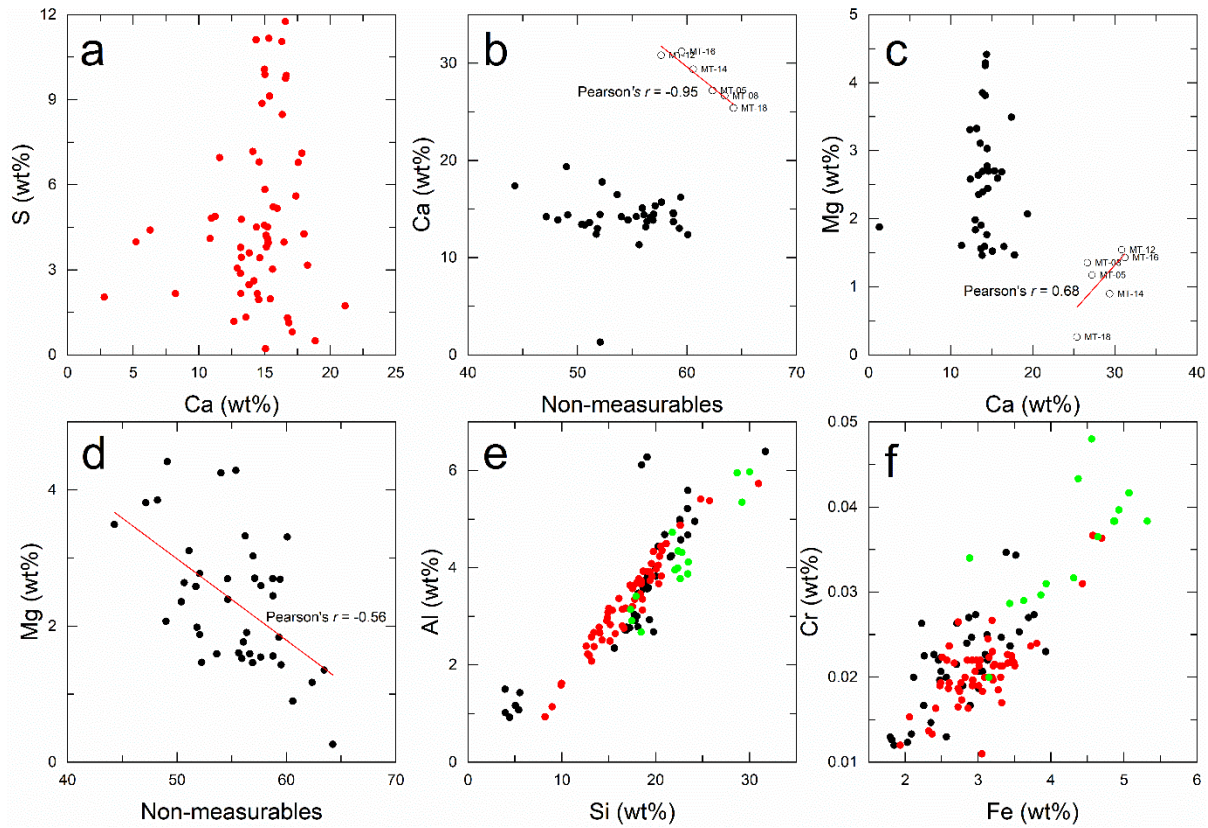
171 Figure 5 PCA biplot on the sealings from all archaeological sites under study

172 As Figure 3 demonstrates, PCA clusters well the artifacts retrieve from each archaeological
 173 site in a district ‘group’ with some exceptions. In other words, the clay artifices found at each
 174 archaeological site has its own unique clay composition. Considering that the door and wall
 175 sealings are most certainly local products (there is no concrete reason to believe that the clay
 176 used for sealings are imported material) the clay objects grouped with the door sealings from
 177 a particular archaeological site is most probably local products. Moreover, PCA biplot in
 178 Figure 3 shows that some tablets from Tape Yahya and Malyan appear to have a different
 179 source than the main group of samples from each site, suggesting they were made in a
 180 different site than where they were found.

181 3.1 Susa

182 As PCA biplot in Figure 2 indicates, the Susa clay artifacts contain high levels of sulphur.
 183 Sulphur is typically present in soils in the form of sulphates, particularly calcium sulphate
 184 (gypsum or $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). Moreover, sulphur can also exist in soils in the form of pyrite or
 185 marcasite (iron sulphides). Therefore, if a significant correlation between iron and sulphur

186 existed, the origin of sulphur could be attributed to iron sulphides present in the soil.
 187 However, the lack of correlation between iron and sulphur negates this possibility.



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189 Figure 6 Bivariate plots on the pair of elements in the clay materials under study (legend as
 190 for the previous figures)

191 The instrumental neutron activation analysis (INAA) compositional data collected from the
 192 clay deposits and ceramics from Susa shows on average ca. 20 and 14 wt% calcium,
 193 respectively (Minc, 2014). This is consistent with our observation from the calcium quantity
 194 in the clay materials from Susa which represent about 14 wt% calcium on average ($\sigma = 3.1$
 195 for 59 objects under study). X-ray diffraction data of the sealings from Susa suggest that
 196 these sealings contain calcite and/or dolomite (Blackman, 1985). Susa is located in an area
 197 with a soil which contains some amounts of sulphate ions. In fact, Susa is covered with non-
 198 saline alluvial soil (Dewan, 1956) where natural sulphur-containing oil-related materials such
 199 as bitumen (O'B Perry and Sotudehnia, 1967; Stern *et al.*, 2008) and sulphur-based inorganic
 200 materials such as gypsum are available. As evidence, qualitative analysis on the soils from
 201 Susa has shown apart from calcite and quartz together with some dolomite and feldspar,
 202 traces of gypsum are present in the soil from Susa (Marschner *et al.*, 1978). In fact, the soils
 203 where Susa is situated on are gypsiferous and belong to large groups of Typic Haplogypsid

204 and Typic Petrogyptsids (Yaghobi et al., 2018). The absence of correlation between sulphur
205 and calcium in the clay materials from Susa (Figure 6a) may be due to the intermixed effect
206 of gypsiferous soil and calcite.

207 It should be mentioned that not all Susa clay artifacts exhibit the same chemical composition.
208 ST-11 resembles the samples from Tape Yahya in terms of silicon, potassium, and iron
209 levels. It is possible that this sample was made in Tape Yahya and then transported to Susa.
210 Moreover, samples SS-16, ST-24, ST-31, ST-32, and ST-33 differ from other Susa samples.
211 This group seems to be made from slightly different soil than the majority of Susa samples
212 (Figure 2).

213 **3.2 Malyan**

214 The PCA analysis of the clay artifacts from Malyan shows that six clay tablets (including
215 MT-05, MT-08, MT-12, MT-14, MT-16, and MT-18) contain significant amounts of calcium
216 and strontium, making them distinctly separable from the other examined artifacts retrieved
217 from this archaeological site. Table S2 reveals that the clay content of these tablets is very
218 low as their SiO₂ and Al₂O₃ contents are significantly low (about 4 and 2 wt%, respectively).
219 These clay tablets, on the other hand, contain about 50 wt% from unmeasurable elements
220 such as carbon and oxygen.

221 The compositional data provided by Zeder and Blackman (2003) shows about 14-15 wt%
222 calcium incorporated in the sealings from Malyan, which is entirely consistent with our data
223 from tablets and sealing from Malyan (ca. 14 wt% on average). The high calcium content of
224 the clay materials from Malyan corroborates also with the high calcium content of sixteen
225 clay-based ceramic bodies from this archaeological site analysed by INAA (Neutron
226 Activation Analysis of Ceramics from Iran (tDAR id: 372489); doi:10.6067/XCV8MG7QZ7)
227 which shows on average ca. 18 wt% from calcium. It is interesting to mention that the
228 calcium content in the clay tablets MT-05, MT-08, MT-12, MT-14, MT-16, and MT-18 with
229 high calcium (ca. 25 wt% on average) is largely correlated with the sum of unmeasured
230 elements (presumably carbon and oxygen) (Figure 6b). This observation shows that these
231 tablets are highly enriched in calcite. Another evidence for such a claim is the high
232 correlation between calcium and strontium in these tablets (Figures 3 and 4). As it is well-
233 known, calcium and strontium are highly associated in calcium carbonate containing rocks
234 and soils. On the other hand, since there is a significant correlation between calcium and
235 magnesium in the high-calcium tablets from Malyan (Figure 6c), the source of magnesium in
236 these tablets is most probably a dolomitic calcite. It is also in line with the phase analysis of

237 the sealings from Malyan performed by Blackman (1985) who reports that the sealings from
238 Malyan contain dolomite/calcite. The negative correlation between magnesium and non-
239 measurable elements (Figure 6d) may be explained by the high calcite content of these
240 objects. The occurrence of magnesium-bearing clay minerals such as palygorskite or sepiolite
241 in these clay artefacts can be ruled out as these artefacts contain low aluminium and silicon
242 content (Table S2; black dots in lower left side of Figure 6e).

243 The PCA biplot in Figure 3 also shows that, except for these six tablets from Malyan, the
244 other examined artifacts from this site contain significant amounts of magnesium, making
245 them distinguishable from the artifacts of other sites. Additionally, one of the tablets from
246 Malyan (MT-03) exhibits considerable similarity to the artifacts from Tape Yahya, containing
247 low amounts of calcium and magnesium but high levels of silicon, potassium, titanium, and
248 iron.

249 There is a clear distinction between sealings from trenches ABC and those from TUV (Figure
250 3). One door lock (MS-13) from trench XX is in the same group as all sealings from ABC.
251 Since this is the only sample from trench XX, no further conclusions can be made. The
252 distinction between ABC and TUV sealings indicates that, in terms of storage and
253 distribution control, there is no clear interaction between these two parts of Malyan.
254 Distribution control was not just local but also showed specialised sections within a site.

255 Tablets from Malyan show different patterns of movement (Figure 2). Four tablets from ABC
256 were analysed, each showing a similar clay source with a distinct group. MT-03 shows
257 similarity with the Tape Yahya collection and seems to have been made in Tape Yahya and
258 moved to Malyan. MT-20 is grouped with the Susa samples too.

259 **3.3 Tape Yahya**

260 The artifacts from Tape Yahya have lower levels of calcium and strontium and higher levels
261 of silicon, iron, and potassium compared to the artifacts from Malyan and Susa. The main
262 group is assumed to be the local samples. However, two samples, YT-02 and YT-06, exhibit
263 significant similarity to the Malyan samples, and tablets YT-01 and YT-07 are grouped with
264 the Susa artifacts. This suggests that these tablets may have been produced in Susa and
265 Malyan and then sent to Tape Yahya.

266 As mentioned earlier, the clay materials from Tape Yahya showed lower calcium content and
267 higher iron concentration unlike the clay tablets and sealings from the other two
268 archaeological sites under study. The low calcium soil used in these materials from Tape

269 Yahya (on average ca. 4.5 wt%) is also consistent with the low calcium ceramic bodies from
270 this archaeological site (one average ca. 3.6) (Minc, 2014). Another fact which corroborates
271 with this hypothesis is that Tape Yahya is situated in a geological setting with serpentinised
272 ultramafic rocks with high chromium and iron content (see Figure 3 in Mutin *et al.*, 2016).
273 The soils around this archaeological site are therefore affected by the rocks in the
274 immediate vicinity of the site. As Figure 6f shows, there is a high correlation between these
275 two elements within the materials from Tape Yahya from one hand and, on the other hand,
276 both chromium and iron content in the clay materials from Tape Yahya is relatively higher
277 than the concentration of these elements in the clay materials from the other archaeological
278 sites under study. In addition, iron and chromium content reported from the ceramic objects
279 of Tape Yahya is about 5 wt% and 340 ppm, respectively (Minc, 2014), which are fairly
280 comparable with the presumably local clay products of this site studied here (*i.e.*, 4.5 wt%
281 and 300 ppm, respectively).

282 **4 An archaeological discussion**

283 **4.1 Tablets**

284 Proto-Elamite tablets are clay objects with inscriptions and sometimes seals. This writing
285 system is the first known in Iran and is slightly younger than proto-Cuneiform in
286 Mesopotamia, making it among the oldest known writing systems in human history. The
287 tablets from Susa make up the majority of the Proto-Elamite tablet corpus, but the
288 archaeological context of almost all of them is unknown because they were found in non-
289 systematic excavations. Fortunately, subsequent systematic excavations revealed a few
290 similar materials (Le Brun 1971: 210). Based on the latest finds and the internal features of
291 the tablets, Dahl and his colleagues (2013) introduced a chronology for the Proto-Elamite
292 period, consisting of different stages of writing development. Four stages have been
293 distinguished in Susa Acropole I based on the chronology of the content and structure of the
294 tablets. These stages range from level 17AX tablets with single sign notations to 14B with
295 complex signs and long entries. The relative chronology suggested for this period is around
296 3100-2900 BC (Dahl et al. 2013: 370).

297 Proto-Elamite tablets were found across the Iranian Plateau at different sites, three of which
298 are the subject of the current study: Susa, Malyan, and Tape Yahya. The absence of
299 stratigraphically recorded excavations in Susa at the time the tablets were found has left the
300 artifacts without context. In Malyan, tablets were found in two trenches, ABC and TUV
301 (Sumner 1974, 2003; Stolper 1985), and in Tape Yahya, they were found in phase IVC

302 (Lamberg-Karlovsky 1971; Damerow and Englund 1989). The content of all Proto-Elamite
303 tablets is administrative (Damerow and Englund 1989), recording the production, storage,
304 and distribution of goods, as well as the management of workers and domesticated animals
305 (Dahl 2005, 2018). The content of these tablets helps us reconstruct some elements of
306 economic interaction in that period. [The Proto-Elamite script remains largely undeciphered,](#)
307 [with only partial understanding achieved, primarily through comparison with Mesopotamian](#)
308 [Proto-Cuneiform. Decipherment efforts focus on numerical systems and recurrent signs \(e.g.,](#)
309 [Damerow and Englund 1989\), which provide insights into administrative records but leave](#)
310 [significant gaps.](#) The decipherment of numerical systems and some signs was achieved by
311 comparing data with Mesopotamian Proto-Cuneiform (Damerow and Englund 1989; Dahl
312 2005; Kelley 2018: 420-30). Administrative practices help us understand social organisation,
313 and regional and inter-regional interactions are key to reconstructing the social complexity of
314 a society (Spencer 1998: 17). [Future advancements in script analysis may offer deeper](#)
315 [insights into Proto-Elamite administrative and social systems \(Dahl 2019; Kelley 2018\).](#)

316 **4.2 Sealings**

317 Sealing involves applying wet clay to a jar or a door over a knot, and while the clay is still
318 soft a seal was impressing on it to secure access to the contents of these containers (Blackman
319 1985: 168; Matthews 1993: 13). While seals are assumed to be the mark of administrative
320 control and ownership (Dittmann 1986: 336; Pittman 1997: 133-136), sealings serve two
321 main functions: securing storage content (door locks and wall locks) and portable objects (jar
322 stoppers, bags, reed mats, etc.) (Matthews 1993; Frangipane 2016). Studies of the reverse
323 side of clay sealings, where negative imprints of the objects they secured are recognizable,
324 revolutionised the study of these sealings' function (Ferioli and Fiandra 1979: 309-312;
325 Ferioli et al. 1979: 20-22; Matthews 1991: 7; Fiandra and Pepe 2000: 467-468; Rigillo 1991:
326 175-222). The process of using sealings can be divided into four phases: when the sealings
327 were attached to the container, the deposit of sealing in the warehouse, keeping the sealings
328 in archive rooms, and finally discarding them (Ferioli and Fiandra 1994: 150). The main
329 concern regarding sealings is whether they were transported with the sealed containers or
330 simply used to keep records locally. Despite the stylistic similarity among Proto-Elamite seal
331 imagery, there is no evidence to confirm that a specific motif has an identical counterpart in a
332 different site.

333 Blackman (1985) conducted a relatively comprehensive study of clay objects from Susa,
334 Sharafabad, Farukhabad, Malyan, and Tape Yahya, aiming to find cultural contact and trade

335 between sites. Although samples show distinct composition clusters according to the sites, in
336 Malyan, two different clusters are evident (distinction of samples from two trenches ABC and
337 TUV) demonstrate that administrative practice is localised in each area (Blackman 1985: 168;
338 Zeder and Blackman 2003: 130-37). He also did INAA analysing on clay objects from
339 Hacinebi Tepe, in which different clusters demonstrate local collection, and a group of
340 objects show close connection with sealing clay from Susa, Khuzestan (Blackman 1999: 55-
341 56).

342 The function of sealing is important to understand the possibility of the portability of the
343 container. Sealings applied on jars or portable objects to secure their content have the
344 potential to be transported with the sealed goods. In contrast, door or wall locks are
345 representative of local storerooms that have been sealed, and the sealings for this purpose
346 seem to be used and disposed of locally.

347 Previous elemental analysis studies (e.g., Blackman 1985; Zeder and Blackman 2003) have
348 demonstrated the presence of local storage facilities and distribution control mechanisms. The
349 sealings examined in this study reveal similar patterns, indicating local practices for
350 managing the storage of goods. In Malyan, distinct clusters of sealings from operations ABC
351 and TUV suggest that storage control was differentiated even within various sectors of the
352 same site.

353 While the sealings are clearly distinguishable between sites and are presumed to reflect the
354 local soil composition, tablets appear to have been transported, suggesting possible inter-
355 regional interactions. Six tablets from Malyan are clearly distinguishable from other artifacts
356 at the site, but their origin remains unclear.

357 Two tablets found in Tape Yahya are clustered with Malyan samples, indicating similar soil
358 composition. This suggests these tablets were made in Malyan and transported to Tape
359 Yahya. These tablets YT-02 (P009545) and YT-06 (P009540) are clustered with sealing
360 samples from the ABC operation. Given the distinct clay compositions of the ABC and TUV
361 sealings, it is likely that these two tablets were transported from the ABC community to Tape
362 Yahya.

363 Two other tablets found in Tape Yahya are clustered with Susa samples, showing similar soil
364 composition. This suggests these tablets were made in Susa and transported to Tape Yahya:
365 YT-01 (P009536) and YT-07 (P009537).

366 One tablet in the Malyan collection is clustered with Yahya samples, indicating it was made
367 in Tape Yahya and sent to Malyan ABC during the BL III level. Although the signs on MT-
368 03 (figure 2; P number not recognized) are not legible, the tablet has an impression of a seal
369 depicting goats.

370 Another tablet in the Malyan collection is likely clustered with Susa samples. MT-20 (figure
371 3; P number not recognized) was found in ABC level II (Stolper 1985: table 1) and records a
372 transaction involving workers and animals. One tablet in the Susa collection is clustered with
373 Yahya samples: ST-11 (P009157) has a seal impression of a seal depicting a bovine.

374 Given that these tablets were found with other tablets of local manufacture, a post-Proto-
375 Elamite trade in curio, or collectibles can all but be ruled out. The tablets shown here to have
376 been transported over longer distances do not appear to detail any trade in goods not readily
377 available at both origin and destination. We are therefore not able to use the texts as evidence
378 for long distant trade.

379 The claim that these artifacts highlight a complex network of local and inter-regional
380 economic and social activities is supported by both geochemical differentiation and broader
381 archaeological frameworks. Anthropologists have shown that specialized production and the
382 division of labour are central to the formation of complex societies, driving surplus,
383 exchange, and social hierarchies (Smith 2008; Tosi 1984; Childe 1950). Proto-Elamite sites
384 like Malyan, Arisman, and Shahr-i Sukhta reflect this specialisation, with evidence of craft
385 production, administrative architecture, and localized resource management (Tosi 1973;
386 Sumner 2003; Helwing 2011; Vidale et al. 2018).

387 Geochemical analysis demonstrates that sealings were locally produced, reflecting localized
388 administrative control. The movement of tablets, on the other hand, suggests inter-regional
389 interactions, aligning with the "age of exchange" hypothesis for the fourth millennium BCE,
390 when goods and administrative tools facilitated long-distance connections (Amiet 1986; Kohl
391 1978). Settlement patterns, such as Malyan's role as a central hub surrounded by specialized
392 satellite sites, further support the idea of structured local and regional exchanges.

393 While the geochemical evidence directly identifies production and movement patterns, it is
394 strengthened by these broader archaeological and theoretical contexts, showing Proto-Elamite
395 society as a network of localized production hubs integrated through strategic exchanges.

396 It is worth mentioning that among the available artifacts, there is no seal impression in Susa,
397 Malyan, and Tape Yahya that has an identical counterpart in the other sites, even though the
398 styles and carving methods appear to be similar. This suggests that goods were not
399 transported between regions with sealings. It is possible that tablets or other methods of
400 record-keeping (if any) were used to show the administrative control over transported goods.

401 In order to interpret the results further, we propose different possibilities. On the one hand,
402 given the unusual layout of some (and perhaps all) Proto-Elamite sites with multiple ‘tape’
403 (sometimes one main and its satellites) within a confined area (this layout is evident in
404 Malyan, Ozbaki, and perhaps Susa if we consider Acropole I, Ville Royal, and Donjon as
405 three different parts in this site), we may speculate that each of these could have distinct and
406 direct social or kinship connections to other ‘tape’ at other sites, without this being evidence
407 of conquest or trade. In fact, it may resemble the ‘city’ transcending a fixed location
408 described by Graeber and Wengrow (2021: 276 ff.).

409 On the other hand, Renfrew (1975) discusses potential interaction processes between
410 archaeological sites, emphasizing the impact of distances between them. In a more recent
411 work, Renfrew and Bahn (2016: 376) propose ten different modes of interaction, including
412 “reciprocity (home base),” which is particularly relevant to this study. This method involves
413 society A visiting society B to exchange goods and services. Evidence suggests that the
414 inhabitants of Tape Yahya engaged in such reciprocal exchanges with those from Malyan or
415 Susa, meeting at their respective settlements. These interactions were documented on tablets,
416 which were then transported back to Tape Yahya. It is also possible that representatives from
417 Susa or Malyan visited Tape Yahya, indicating a bidirectional interaction. The transactions
418 were facilitated either through the direct transport of commodities or by merchants who acted
419 as intermediaries.

420 In addition, contemporary to Proto-Elamite, Mathhews and Richardson (2018) studies on
421 interpretation of city seal impressions from early Mesopotamia, initially seen as records of
422 economic transactions by a league of cities (Jacobsen 1957: 109). However, scholars like
423 Szarzyńska (1993) and Matthews (1993: 49) argued for a symbolic religious role, linking
424 small quantities of commodities listed on tablets to cultic practices involving the goddess

425 Inanna. Archaeological evidence from Uqair revealed seal impressions on tablets in a chapel,
426 depicting cult statues being transported by boat and receiving offerings (Englund 1996: no.
427 37-38). Steinkeller (2002: 255) expanded this interpretation, suggesting the seals were used
428 by collectors of offerings for Inanna, representing a supra city-state institution. Matthews and
429 Richardson (2018: 741) argue that these cultic activities, involving inter-city processions of
430 deities' statues and recorded offerings, were resilience strategies to maintain the dominance of
431 Uruk's cult in times of crisis, reinforcing social and political ties across cities. This practice is
432 compared to similar traditions in later Mesopotamian and Syrian contexts, underscoring the
433 enduring role of religious ceremonies in sustaining urban communities. This cultic relation as
434 'resilience strategy' in Mesopotamia, would be another possibility for interaction between
435 different sites within Iranian Plateau using similar writing systems for communication.

436 **5 Conclusions**

437 The findings of this study shed light on the early processes of urbanisation and administrative
438 organization within Proto-Elamite culture, indicating a system where localized economic
439 control was complemented by selective, strategic regional interactions.

440 The study of Proto-Elamite tablets and sealings from Susa, Malyan, and Tape Yahya offers
441 critical insights into the administrative and socio-economic dynamics of the late fourth
442 millennium BC. Through compositional analysis, the research identifies clear patterns of
443 localized production, as evidenced by the distinct chemical signatures of sealings, and
444 provides compelling evidence for selective inter-regional interactions through the transport of
445 tablets. These findings contribute to our understanding of how early administrative systems
446 operated within a complex network of local and regional exchange.

447 The results highlight the dual nature of Proto-Elamite administration: while most tablets and
448 all sealings were locally produced and used, the transport of a few tablets suggests a
449 mechanism for information flow and perhaps resource coordination between sites. The Proto-
450 Elamite writing system provides evidence of information flow between regions, this study
451 suggests a possible interaction facilitated by the tablets themselves. The shared material
452 culture and administrative practices across the Iranian Plateau, such as the use of similar
453 writing systems and seal imagery, underline a cultural coherence within this region while
454 respecting local autonomy.

455 Future research could deepen these insights by integrating additional compositional analyses
456 of artifacts from other sites and conducting direct sampling of local clay sources. Such
457 studies would further refine our understanding of the extent and nature of inter-site
458 interactions within the Proto-Elamite sphere. Ultimately, this research affirms the importance
459 of multidisciplinary approaches in unravelling the complexities of early civilizations.

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