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J. Guilaine, Guirec Querré, S. Cours, J. Coularou, H. Vergely, J. Vaquer, M.
Gandelin

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The variscite « necklace » of the Salpêtre cave, at Pompignan (Gard, France)

A remarkable set of 17 variscite beads was discovered in the 1970s in the Salpêtre cave in Pompignan (Gard, France). Although known and presented to the public in various recent exhibitions, this discovery has never been the subject of a detailed publication. This article aims to fill this gap: it provides the results of the provenance analyses (PIXE). It documents the typology and illustrates the different beads of this original deposit, unique in the south of France. Finally, this discovery is placed in its chronocultural context.

- Blue rock beads called "callaïs" (variscite, turquoise) were socially valued objects during the Neolithic period. They were traded over long distances.
- The necklace from the Salpêtre cave in Pompignan (Gard, France) is the largest known batch of variscite beads in southern France.
- Thanks to the PIXE multi-element analysis, the comparison between rock samples from the main Western European deposits and the archaeological pieces allows to know the origin of the Neolithic blue beads. The 17 beads from Pompignan were analysed.
- The article demonstrates the relationship between a mining deposit (Gavà, Spain) and the destination of the finished products, located several hundred kilometres away (Pompignan, France).
- In general, Neolithic variscite beads are derived from burials and the Pompignan deposit is a unique case for this period. This notion of depositing batches of precious objects will become recurrent in the Chalcolithic and Early Bronze Age.

The variscite « necklace » of the Salpêtre cave, at Pompignan (Gard, France)

Jean Guilaine, Guirec Querré, † Serge Cours, Jacques Coularou, Hélène Vergély, Jean Vaquer, Muriel Gandelin

Abstract :

A 17 variscite beads set, buried in the Salpêtre cave in Pompignan (Gard, France) constitutes a unique Middle Neolithic set of ornaments in the southern France. PIXE (Particle Induced X-ray Emission) chemical analysis of these coins and reference samples from possible sources indicates a mineral origin from the Gava mines, near Barcelona (Spain). This discovery reveals an exchange system of the materials or finished objects on both sides of the Pyrenees mountains during the first half of the 4th millennium BC.

Keywords : Neolithic of western Europe, Middle Neolithic (*Chasséenne* culture), ornaments, variscite, provenance, chemical analysis, PIXE (Particle-Induced X-ray Emission)

Adornments, in prehistoric populations, is not just ornaments but also an « identity language », functioning as a sexual, social, or ethnical marker. In Neolithic times, in the Near East as in Europe, green stones were largely used in jewellery making. As such, in Israel, from the recent Natufian to the pre-pottery Neolithic B (PPNB), between -11000 and -7000 BC, several minerals bearing this hue (apatite, fluorapatite, chrysocolla, malachite, turquoise, amazonite, serpentinite) were used to make beads. The source of the raw materials was often distant from the user location of the productions. And, the choice of a green hue has sometimes been interpreted as a symbol of vegetation, of growing plants, of fertility (Bar Yosef Mayer and Porat 2008). In Cyprus, picrolite, the local green mineral, was largely exploited in jewellery production from the PPNA (pre-pottery Neolithic A) until the Chalcolithic (Guilaine, 2011; Guilaine and Rigaud, 2021; Peltenburg, 1998). During the Neolithic of western Europe, another green rock, the variscite, was used in the fabrication of necklaces during almost the entire period, from the 6th to the 3rd millennium BCE. This mineral is a kind of hydrated aluminium phosphate, also called variscite, the formula for which is $\text{AlPO}_4 \cdot 2 \text{H}_2\text{O}$. Its deposits are essentially located within the Iberian Peninsula, but also in France and Sardinia (Fernandez et al. 2019).

In Brittany, the presence of beads made of variscite is attested in Neolithic contexts – often funerary ones – since the 19th century. Such ornamental objects were discovered in the great Carnacéan tumuli (Tumiac, Saint-Michel, Mané er Hroeck) as well as several Armorican dolmens (Kercado). Right away, the question of the identification and origin of the material was raised. As early as 1864, mineralogist A. Damour studied a few specimens of these light green minerals and identified them as made of a hydrated aluminide phosphate (Damour 1864). Faced with the quality of such productions, A. Damour,

40 followed by A. Lacroix believed in a distant origin of the raw material, and this hypothesis of an exotic,
41 distant rock prevailed for a long time (Veiga Ferreira, 1950).

42 In southern France, E. Cartailhac was one of the first to be interested in these ornaments, some of which
43 came from the dolmens of Aveyron and of Lozère, where he first started working. In 1876, he
44 participated to research on the Castellet hypogeum (Fontvieille, Bouches-du-Rhône), from which an
45 ensemble of 114 beads was extracted. In 1881 he published in the journal he edited, *Matériaux*, E.
46 Piette's article mentioning the « necklace » made of 93 beads issued from one of the compartments of
47 the Halliade monuments at Bartrès (High-Pyreneans; Piette 1881, Mohen 1978). This led him to give an
48 overview of these adornments, the presence of which he identified in Brittany, Spain, Portugal (in the
49 hypogea of Palmela) and in the Midi (Cartailhac 1889). In parallel, research on the north-eastern region
50 of the Iberian Peninsula revealed the existence of numerous beads of the same material within the earth
51 or cists of that region. A. Muñoz, in her thesis on the « Sepulcros de fosa » of Catalonia, provided a
52 synthesis of this issue and brought some doubt to the hypothesis of a distant origin (Muñoz 1965). In
53 the Midi, a few specimens were brought to the attention of two researchers of the mineralogy department
54 of the Commissariat à l'Énergie Atomique (F. Chantret, A. Guillemaut) and revealed that the term callais
55 could regroup variscite, turquoise, or malachite ornaments (Chantret et al. 1970). Variscite ornaments
56 were essentially recognised within the funerary context in individual inhumations (within a dug-out
57 grave or a stone box) or in collective tombs (megalithic structures, hypogea, sepulchral caves).

58 A new and determining impulsion in approaches to the topic came from the recognition, starting from
59 the 70s onwards, of the variscite mines of Gavà, near Barcelona in Spain (Domínguez-Bella 2004, Bosch
60 Argilagos 2019, Molist and Oliva 2019, Moro et al. 1992 and 1995). Following this, renewed attention
61 was given to the geological formations of the Zamora region, where several deposits had been identified
62 (Fabregas Valcarce and Rodriguez-Rellan 2019). Then came the identification of the Pico Centeno
63 deposit (Encinasola, Huelva, Spain) in western Andalusia, (Odrizola et al. 2010, Dominguez-Bella and
64 Ramos-Muñoz 2019). Uncovering the existence of these deposits was combined with diverse analyses
65 programs in order to establish precise baseline referentials characterising each of these three sources:
66 Gavà, the Zamora deposit, and Encinasola. In turn, this meant various scenarios for the circulation of
67 variscite and turquoise during the Neolithic (between 5500 and 2000 BC) at the scale of western Europe
68 could be proposed (Querré et al. 2019).

69 The productions from these various deposits may have similarities and differences. Thus the round or
70 barrel beads are ubiquitous. The large pendants with polar perforation from Breton sites come from
71 Encinasola in the fifth millennium and then, from 4000 BC, from Palazuelo de las Cuevas. The
72 Portuguese cylindrical beads come from deposits in the Zamora region. The large biconical beads with
73 axial perforation come mainly from Gava. The small irregular beads from Final Neolithic collective
74 burials in the south of France do not have, due to lack of analysis, a clear provenance (Querré et al.
75 2019).

76 A remarkable variscite bead ensemble was discovered in the 70s in the Salpêtre cave at Pompignan
77 (Gard, France). Whilst known and presented to the public in various recent exhibits, this discovery had
78 never been published in detail. This article aims to fill this gap in knowledge and communicate the
79 results of the analyses concerning this original ensemble, unique for the south of France.

80

81 **1. The site**

82

83 The Salpêtre cave is located on the commune of Pompignan (Gard, France), 30 km north of the town of
84 Montpellier (fig. 1). It opens on the northern flank of the Hortus cause, at the foot of the Taillade cliff,
85 at an average altitude of 380 m (fig. 2 and 3).

86 This cave was subjected to various investigations over a century. The oldest was by A. Jeanjean who
87 mentioned its interest in a synthesis on the prehistory of the Basses-Cévennes region (Jeanjean 1871).
88 Around 1960, Jacques Audibert, research associate at the CNRS, undertook a little work in the cavity
89 (Audibert 1962). These two operations meant middle Neolithic levels (*Chasséen*) were identified, as
90 well as some final Neolithic (Ferrières and Fontbouïsse cultural groups). In the 70s, S. Cours re-sieved
91 some of the waste heaps and prospected other areas of the cave. This is when the necklace described in
92 this article was discovered. Following this find, S. Cours and J. Coularou dug a deep test pit 10 m from
93 the cave entrance, 3 m deep. At that level, they found hardened sediment. They recognised the reworked
94 aspect of the Neolithic levels but also identified the existence of palaeolithic levels still in place (Azilian,
95 Magdalenian, Mousterian). The Azilian artefacts were described in M. Barbaza's doctoral thesis
96 (Barbaza 1981). It is possible that some Neolithic levels still in place are present in the deepest part of
97 the cavity, under the spoil heaps from older excavations, which would allow ¹⁴C dating, none of which
98 was done at this time.

99 In 1972, M. Escalon de Fonton dug a new test pit, looking for the previously recognised Magdalenian
100 level. The investigation remained fruitless, but a few years later in 1978-1979, L. Meignen pursued this
101 research axis and confirmed the presence of Mousterian occupations.

102 The Salpêtre cave is a long corridor following a north-south cleft; it is 80 m long and 2 m large and
103 reaches a height of 5 m. Towards the deepest end of the cavity, a lateral diverticulum opens into a small
104 room (fig. 4 and 5).

105 The variscite bead cache was found 41.5 m from the cave entrance, where the corridor narrows, and the
106 walls are only 0.5 m apart. This narrowing is even more marked by the fact that a natural step exists
107 there, forming a threshold of sorts (fig. 6).

108 The beads were discovered grouped within a small space. Perhaps they were originally linked by a thread
109 that has now disappeared. In the immediate vicinity, a large ceramic sherd and a pecten shell were found.
110 The sherd (9 x 8 cm) has a curved profile and belongs to a vessel with a thick profile (1 cm). It is
111 identified as a fragment of the ventral part of a spherical container, the diameter of which is estimated
112 to have been around 26 cm. This element bears an engraved decor made of three horizontal strips: a

113 central one with a checkered motif, and two surrounding ones (superior and inferior) presenting a motif
114 made of four lines arranged as rafters. This resembles spherical to cylindrical collared containers typical
115 of the classical *Chasséen*, the widest part of which was often decorated with geometrical patterned strips.
116 The mollusc shell is a scallop (a Saint-Jacques shell: *Pecten jacobaeus*), rather large (width: 13 cm). We
117 cannot exclude that the beads were originally placed within the bivalve.

118

119 **2. Description of the Beads**

120

121 The excavated lot includes 17 elements which could originally constitute a necklace (fig. 9)¹.

122 All the beads, of various sizes, bear witness to a final fabrication state necessitating an important
123 technical investment. Measures were carried out on the bead ensemble: maximum diameter (median
124 point of the maximum width of the transversal section), minimal diameter (median point of the
125 minimum width of the transversal section), diameter of the perforation, maximum and minimum
126 thickness (or length), and maximal and minimum diameter of the bead's extremities. These last
127 measures correspond to the term « méplat » used by F. Herbaut and G. Querré (Herbaut, Querré 2004).
128 The maximum diameter of the beads is between 7.2 and 25.5 mm, for a thickness between 5.9 and
129 40.1 mm. The maximum diameter of the perforations is comprised between 2.1 and 4.3 mm.
130 Dimensions, weights and color are resumed in table 1 and in table 2.

131 Discussing the typological aspect of these beads is difficult, because variscite ornament productions
132 do not correspond to fabrication standards observed on other mineral matter, and we are confronted
133 to a lack of current research (in France) on this aspect of variscite productions (Viel et al. 2019). Looking
134 to the reference work on ornaments of the French Midi region (Barge 1982), the vast majority of the
135 beads of the Salpêtre cave ensemble can be qualified as irregular. It is true that the typological
136 classification of these objects is problematic since they often present asymmetries in their longitudinal
137 and transversal sections. In publications, they are generally described as olive-shaped, or flattened
138 beads...

139 In order to better define the production criteria of the workshops, which seems to evolve over time,
140 typological classification work could help us qualify these productions, such as the one published by H.
141 Beck in 1926 « Classification and Nomenclature of Beads and Pendants » (Beck 2006). This typological
142 example allows for the description and classification of beads whilst considering their shape from the
143 section and the front. Synthetically speaking, the Salpêtre ensemble presents, in most cases, an
144 elliptical transversal section (more or less regular) combined with a convex cylindrical longitudinal
145 section. Several beads present a transversal section associated with a convex, « barrel-shaped » or
146 cylindrical longitudinal section, with both extremities being convex (n°7 and 8). One bead reveals a
147 quadrangular transversal section (n°5) and another can be qualified as a conic trunk (n°17).

148 The polishing of the beads is advanced, giving an intense shine visible on both the bead's extremities
149 and their longitudinal sections. This aspect is also visible on the extremities' surfaces presenting great
150 irregularities such as bead n°13, or on the section of bead n°3. Only one bead (n°2) presents unpolished

¹ These artefacts are kept at the Centre de Documentation Archéologique du Gard (CDAG), 396 avenue Joliot Curie, 30900 Nîmes. Their analysis took place within a PCR (Collective Research Program) titled « Milieu et Peuplement en Languedoc Occidental du Néolithique au Bronze ancien » (dir. M. Gandelin)

151 irregularities that can be interpreted as impacts (3 in total), which must have occurred after the bead's
152 fabrication and bears witness to probable shocks. Besides, traces of red coloured matter (ochres ?; not
153 analysed) are visible inside these asperities. The polishing is so advanced that it is difficult to discern
154 traces of the manufacturing techniques used before that stage of fabrication.

155 Perforations are all cylindrical, and their regularity implies the use of a system to hold the pieces in
156 place, and the use of flint drills mounted on a rotating axis to pierce the beads. A boring step allowed
157 for the regularity of the perforations. These technical observations correspond to the research made
158 on variscite's chaîne opératoire in Catalonia (Molist Montana, Oliva Poveda 2019). The morphology of
159 the beads found in the Salpêtre cave is close to those found in the Gavà workshop and find many
160 comparisons with the beads discovered in grave 83 of the Mine (Beta 155.686 : 5220±110 BP ; 4326 –
161 3793 cal BC (95.4%) ; Bosch Argilagos 2019).

162

163 **3. Chemical and provenance analyses of the callais bead necklace from the Salpêtre cave** 164 **(Pompignan, Gard).**

165

166 The 17 callais beads probably composing a necklace (fig. 10 and 11) found during the Salpêtre cave
167 excavation at Pompignan were subjected to an elemental chemical analysis in order to confirm their
168 mineralogic identity (variscite) and to determine their provenance. This determination was established
169 using the chemometric model elaborated based on the main European sources of variscite (Querré et al,
170 2008; 2012; 2014 ; and forthcoming) as well as PIXE analyses of the Pompignan beads.

171

172 **3.1. Methodology**

173

174 The analyses were carried out using the PIXE method (*Particle-Induced X-ray Emission*) using the
175 AGLAE (Elementary Analysis Accelerator of the *Grand Louvre*) set up from the C2RMF (The research
176 and restoration centre of *Musées de France*) of the Louvre Palace (Paris).

177 The PIXE method was applied to the callais according to a protocol established by one of the authors
178 (G.Q.). This method of elemental analysis is non-destructive and fast. It is based on the fluorescence of
179 X-rays characteristic of the material. The elemental composition of archaeological pieces is compared
180 with a reference sample, representative of the 5 largest European variscite deposits, likely to have been
181 exploited during the Neolithic. The concentrations of major elements allow us to recognize the
182 mineralogical nature of the veins; the spectrum of minor elements and/or traces shows intrinsic
183 variations, specific to each deposit. The contents of iron, vanadium, chromium, arsenic, silicon, calcium,
184 zirconium, uranium, their absolute variations and concentration rates are particularly relevant to
185 discriminate potential geological sources. This model can be used to determine the provenance of
186 archaeological variscite pieces (Querré et al. 2019).

187 Protons of 3MeV were extracted in the shape of a beam a few micrometres in diameter. The bead surface
188 to be analysed was placed a few millimetres from the protons exit window. Four SDD detectors gather

189 the X-Rays created: one for the low energies corresponding to major elements, and three for high
190 energies corresponding to trace elements (fig. 12 a and b). In order to have a mean analysis of the bead's
191 material, the beam scanned the surface over one millimetre square. The acquisition time for the analysis
192 of each bead was six minutes on average. The high and low energy spectrums went through GUPIX and
193 TRAUPIX software analysis, in order to obtain elementary concentrations as well as the detection
194 thresholds for all 24 chemical elements of interest.

195

196 **3.2. Chemical analysis of the beads**

197

198 The concentration of the 24 chemical elements for each of the 17 beads can be found in table 3 and table
199 4. Three chemical elements are present in concentrations higher than 10 % (100.000 ppm): aluminium,
200 silicon and phosphorus. Copper concentrations are low, 65 ppm on average. The beads are therefore
201 indeed variscite, albeit a very impure form considering the high silicon proportions present within. After
202 these three major elements, iron and copper are the most represented, with element concentrations
203 reaching around 2 %. All other elements are found in minor or trace concentrations.

204

205 **3.3. Provenance**

206

207 The chemometric model elaborated to determine the variscite's provenance was applied to the beads
208 found in the Salpêtre cave.

209 The concentrations of the discriminating elements were compared to those of the five western European
210 deposits where the beads might come from : the four Spanish deposits, the Gavà deposit (Barcelona)
211 including the Can Tintorer mines (fig. 13, GA, and table 4), the Encinasola deposit and the mines of
212 Pico Centeno in the Huelva region (fig. 13, EN, and table 4), El Bostal in the Zamora region (fig. 13,
213 EB, and table 4), Palazuelo de las Cuevas (fig. 13, PL, and table 4), and the only known French deposit
214 : Pannecé, in the Loire-Atlantique region (fig. 13, PA, and table 4).

215

216 The relative proportions of the three most discriminating elements (V, Cr and Fe) are, on average, the
217 following: $V^*=7.5$ - $Cr^*=7.8$ - $Fe^*=84.7$. These proportions do not correspond to those of the Pannecé
218 deposits, for which vanadium represents 50 % and within which chrome and iron reach 25% of the total
219 each (see figure 13 as well). The average Cr/V ratio is 1.39 ± 1.05 which is not compatible with the
220 Palazuelo analyses ($Cr/V = 5.08 \pm 6.48$), nor with those of El Bostal ($Cr/V=0.35 \pm 0.04$).

221 The U vs Zr diagram (fig. 13B and table 4) allows us to individualise the variscites from El Bostal,
222 which has strong uranium concentrations ($U = 306 \pm 267$ ppm) and no zirconium ($Zr = 6 \pm 4$ ppm). In
223 the case of the Salpêtre beads, the reverse phenomenon is observed, with low uranium concentration
224 ($U=9 \pm 5$ ppm), often inferior to the detection threshold (LDD = 19 ppm), and average zirconium
225 presence ($Zr = 22 \pm 23$ ppm).

226 Concerning diagram (Cr+V) vs As (fig. 13C), the concentrations observed in the Pompignan variscite
227 beads (Cr+V = 2926 ±1003 ppm ; As = 802 ±418 ppm) are close to those of two deposits : Encinasola
228 (Cr+V=4198 ±1429 ppm ; As = 610 ±802 ppm) and Gavà (Cr+V = 809 ±397 ppm ; As = 302 ±90 ppm)
229 but not those of three other sources : (Cr+V = 2926 ±1003 ppm ; As = 802 ±418 ppm) (Cr+V = 2926
230 ±1003 ppm ; As = 802 ±418 ppm) (Cr+V = 2926 ±1003 ppm ; As = 802 ±418 ppm).

231 Silicon concentrations are extremely high in the Salpêtre beads (Si = 17.6 ±6 %) and can be qualified as
232 elevated as far as calcium is concerned (Ca = 1.8 ±1.2 %). This tends to indicate that the origins of the
233 beads is the Gavà deposit, which is the only one to present elevated concentrations of both silicon and
234 calcium (Si = 11.2 ±7.4 %; Ca = 6.1±8.0 %) (fig. 13 C and table 4).

235 Together, all these geochemical analyses based on the chemometric model bring only one answer to the
236 question of the origins of the Salpêtre cave – the Gavà deposit, in Spain. The high iron concentrations
237 in contrast to the vanadium, the Cr/V ratio, as well as the high proportions of silicon and calcium are the
238 most discriminating factors in this case.

239 This result is coherent with the identification of the site from which the beads originate as *Chasséen*,
240 and thus belonging to the Mediterranean sphere, within which most variscite ornaments come from the
241 Can Tintorer mines (Gavà, Spain). ~~The morphology of the large biconical beads from Pompignan is the
242 same as those deposited in the graves in the Barcelona area.~~

243

244 **4. A cache of ornaments from the southern Pyrenees**

245

246 The analyses of the Salpêtre cave ensemble (Pompignan, Gard, France) bring precious information on
247 the circulation of ornaments outside their fabrication area in a region – southern France – where these
248 analyses are still rare. Indeed, this ensemble is composed of various typological elements, including
249 large, olive-shaped beads perfectly comparable to the productions found on the southern flank of the
250 eastern Pyrenees, and dated to the evolved Neolithic middle. The meridional cultural context is then that
251 of the *Chasséen*. The mineralogical composition of the Pompignan pieces demonstrate it is made of
252 variscite coming from the Gavà deposits. Beyond the synchronism proposed between the *Sepulcros de*
253 *fosa* and the meridional *Chasséen*, which has long been argued for (Guilaine and Muñoz 1964), these
254 interactions are now better understood. As such, polished alpine stone axes and Bedoulian flint a attested
255 within the Catalan funerary artefacts, whilst variscite ornaments are themselves found within *Chasséen*
256 funerary deposits of the Toulouse region (Saint-Michel du Touch, Villeneuve-Tolosane) and as far as
257 the Rhône (Pompignan), or even the Lyon region (Tassin ; Vaquer 2019).

258 The Pompignan ensemble also presents an interest in that it is a deposit of rare pieces placed in a cache,
259 made within a cave, rather far from the cave's entrance. This deposit was hidden, perhaps during a ritual
260 act. We must therefore raise the possibility that as early as the middle Neolithic rare pieces were hidden
261 in such caches. This process continued during the Neolithic through the burial of various productions:
262 flint blades (cf. Sainte-Cécile-les-Vignes deposit, Vaucluse, France), copper ores and flat axes (cf.

263 Centeilles deposit, Siran, Hérault, France), or copper ornaments (cf. Miguro cave, Corconne, Gard,
264 France). This process was particularly developed during the Bronze Age (Gasco, Lachenal, Piningre
265 2018). This hiding of precious objects could signal disparities in the social order and connote the
266 particular status of their owner(s). The example of the Salpêtre cave constitute, in the *Midi de la France*,
267 a unique example. We should also mention the existence of two deposits in western France « au contact
268 des ouvrages symboliques que sont la stèle en grès de la Table des Marchands et l'enceinte de pierres
269 dressées sur l'îlot d'Er Lannic » (“in contact with the symbolic works of the Table des Marchands stelae
270 and the raised stone enclosure of the Er Lannic islet”) (Cassen et al. 2019).

271

272 **5. Chrono-cultural framework: The Early and Middle Neolithic**

273

274 The chrono-cultural insertion of variscite meridional ornaments used to be subject to debate. J. Arnal,
275 taking as basis the closed ensembles represented by the Catalan tombs (*Sepulcros de fosa* culture, Spain),
276 systematically attributed them to the middle Neolithic and made it a cornerstone to date the corridor
277 dolmens of eastern Languedoc (Arnal 1963). In opposition, J. Audibert, witnessing the presence of
278 callais beads within meridional collective tombs, dated them as probably Chalcolithic (Audibert 1962).
279 Progressively, further research meant a long-term chronology could be established for variscite
280 ornaments (Barge 1982, Roscian et al. 1992), now spanning over two millennia (c. 4500-2200 BC). It
281 is however not impossible that this chronology could be stretched further. Indeed, we are not aware of
282 beads pertaining to the *Cardial-Epicardial* cycle in the Midi (\approx 5500-4500 BC) whilst on the southern
283 Pyrenean side such ornaments are attested in a sporadic manner during the *Cardial* (Chaves cave,
284 Aragon), and more often during the *Epicardial* (Cova de les Lladres, in western Vallès, with a deposit
285 of 139 pendants), and also in the Molinot (during the third quarter of the 5th millennium, during which
286 the first exploitations of the Gavà mines are attested: Bosch 2019, Molist and Oliva 2019). To the North
287 of the Pyrenees, the first known manifestations are attested within the Juberrian context (Llo oppidum,
288 Pyrénées-Orientales, France, around 4500 BC) and become more obvious within the *Montbolo-*
289 *Chasséen* context during the last centuries of the 5th millennium (grave 33 of Crès, Hérault; tomb 59 of
290 Caramany, Pyrénées-Orientales ; silo 19 of Cugnaux, Haute-Garonne, France ; Vaquer 2019). If the
291 Pompignan deposit is contemporaneous with the *Chasséen* occupation of the cave, of which a typical
292 decorated sherd was found near the beads, we cannot exclude a date from the end of the 5th millennium.
293 It is during the optimum functioning of the Gavà mines, linked to the peak of the *Sepulcros de fosa*
294 culture (Vallesian/Solsonian, Spain), that the Catalan variscite importations towards the Midi region
295 reach their peak, during the middle - recent *Chasséen*, between 4000 and 3500 BCE.

296 Several sites from the Roussillon, Aude, and Toulouse region, and up to the Rhone corridor (Saint-Paul-
297 Trois-Châteaux, Drôme, France) have yielded beads of various forms, including several « heavy »
298 pieces, olive-shaped, of a kind well-known in Catalonia (tomb 1 of Villeneuve-Tolosane, the “royal”
299 tomb A 185 from Saint-Michel-du-Touch, Toulouse, Haute-Garonne, France) (Méroc and Simonnet

300 1979). Some of the Pompignan pieces show similarities within the same ambiance. Within cave IV from
301 las Claousos at Auriac (Aude, France), used as a collective tomb and for which a ¹⁴C date yielded a
302 recent *Chasséen* attribution, six cylindrical or barrel-shaped variscite beads could come from Encinasola
303 rather than Gavà (Guilaine et al. 2019). Could it be that this reflects a competition between the two
304 deposits (Can Tintorer and Pico Centeno) at a time when Gavà's production was slowing down?
305

306 **6. Continuities in Final Neolithic**

307

308 We are less informed on the origin of the small meridional variscite beads, which remain abundant in
309 the *Midi de la France* during the entire final Neolithic, between 3500 and 2200 BCE. Their typology
310 isolates them from the previously evoked examples. Large, olive-shaped or thick beads have more or
311 less disappeared except in rare cases (Fées de Lunas cave, Hérault, France). The only remaining beads
312 are small discoid models, with irregular outlines, not always well calibrated. The ensemble excavated
313 from the Cabrials collective tombs, near Béziers (Hérault, France), with a flattened shape, is dated to
314 the final Neolithic 1 (Tchéremisinoff 2012). Most of the meridional beads issued from collective tombs
315 (dolmens, natural caves, hypogees) with a long-term use, sometimes over a millennium. They can be
316 numerous: minimum 130 in the Clot-de-l'Oste dolmen at Bouisse (Aude, France; Guilaine et al. 2015).
317 Two beads from the René-Carrié cave at Termes (Aude, France) are composed of materials attributing
318 their origin to Gavà. The exploitation of the Catalan deposits could therefore have been pursued until
319 after 3500 BC, in a less intense manner.

320 The end of the use of variscite stone could be placed towards the end of the Chalcolithic with the
321 diffusion of the Bell Beaker phenomenon. An ensemble of 23 beads accompanied the ancient Bell
322 Beaker deposit found within the ditch surrounding the Mourral site in Trèbes (Aude, France; Vaquer
323 1998). This is a regional association, since the callais is not a general marker of the European Bell
324 Beaker. This example shows that the south of France tradition of using this material could still exist
325 whilst the maritime Bell Beaker phenomenon pursued its supraregional expansion.

326

327 **Conclusion**

328

329 The bead ensemble from the Salpêtre cave of Pompignan originates from the Gavà mines, near
330 Barcelona, some 370 km as the crow flies (this distance being a general indication, since the transfer
331 implied either crossing the eastern Pyrenees, or their circumvolution by navigating the Gulf of Lion).
332 Beyond the burial of this ensemble, which is reminiscent of a cache, perhaps during a ritual act, this
333 discovery confirms the existing relationship between two Neolithic cultures separated by the physical
334 barrier of the Pyrenees. To the south, the *Sepulcros de fosa*, which exploited the mines, fabricated and
335 diffused the ornaments; and to the North, the meridional *Chasséen* who, from the Toulouse region to
336 the Alps, received these jewels which were appreciated for their "exotic" provenance, relative as it was.

337 While slightly offset within the Cevenol mountains, the Pompignan ensemble is located relatively close
338 to a geographic axis – the Bas-Languedoc. Through this axis, Rhone corridor material circulated (blond
339 flint from the Vaucluse, alpine eclogite), which travelled opposite ways to the variscite and crossed the
340 Pyrenees to furnish cores, flint blades, and polished axes for populations of Catalonia. The Pompignan
341 deposit is therefore at the heart of a reciprocity system demonstrating the strong complementarity in
342 exchanges between Neolithic cultures of the first half of the 4th millennium BCE.

343

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464

465 **Auteurs :**

466

467 Jean Guilaine : Collège de France, 11, place Marcelin-Berthelot, 75005 –Paris. jguilaine@wanadoo.fr

468

469 Guirec Querré : UMR 6566 CReAAH, Université Rennes-Sciences, Campus de Beaulieu, 35000-
470 Rennes. guirec.querre@univ-rennes1.fr

471

472 † Serge Cours, 4, Impasse de la Brugue, 33340-Lesparre Médoc

473

474 Jacques Coularou, UMR5608 Traces, Université Jean-Jaurès, 5, allée A. Machado, 31058-Toulouse
475 cedex. j.coularou@gmail.com

476

477 Hélène Vergély, Inrap, UMR5608 Traces, UMR5608 Traces, 561 rue Etienne Lenoir, km Delta, 30900,
478 Nîmes. helene.vergely@inrap.fr

479

480 Jean Vaquer, UMR5608 Traces, Université Jean-Jaurès, 5, allée A. Machado, 31058-Toulouse cedex.
481 jean-sebastien.vaquer@orange.fr

482

483 Muriel Gandelin, UMR5608 Traces, Inrap, Centre de Recherches Archéologiques, Actipolis, rue de
484 l’Acropole, 34500, Villeneuve-lès-Béziers, muriel.gandelin@inrap.fr

485

486 **Illustrations**

487

488 Fig. 1 – Geographic location of the Salpêtre cave (Pompignan, Gard)

489

490 Fig. 2 – Topographic location of the cavity (drawing by J. Coularou)

491

492 Fig. 3 – Cave entrance (photograph by A. Aigoïn)

493

494 Fig. 4 – Plan and stratigraphy of the cave. Localisation of the bead ensemble (drawing by N. Boinet)

495

496 Fig. 5 – Localisation of the discovery near the base of the cave wall (photograph by A. Aigoïn)

497

498 Fig. 6 – Close up: localisation of the beads near a decorated sherd and a pecten shell (drawing by
499 J. Coularou)

500

501 Fig. 7 – Sherd from the ventral part of a decorated Chasséen globular recipient discovered near the
502 variscite beads (drawing by J. Coularou)

503
504 Fig. 8 – Saint-Jacques shell (*Pecten jacobaeus*) discovered near the beads (drawing by J. Coularou)
505
506 Fig. 9 – Necklace restitution picture of the 17 variscite beads deposit (photograph by H. Vergély)
507
508 Fig. 10 – Numbering of the 17 beads analysed according to the PIXE method (photograph by
509 H. Vergély).
510
511 Fig. 11 – Details of the 17 variscite elements composing the ensemble (photograph by H. Vergély).
512
513 Fig. 12 – Variscite beads of the Salpêtre cave in Pompignan being analysed through the PIXE method,
514 in front of the beam extract from the AGLAE particle accelerator (C2RMF, Louvre Palace, Paris)
515 (realisation by G. Querré).
516
517 Fig. 13 – Analyses of the variscite beads of the Salpêtre cave in Pompignan (number of objets analysed:
518 17 ; number of analysis : 17). In the diagrams : V-Cr-Fe ; U-Zr ; (Cr + V) As ; Ca-Si in comparison to
519 the referential for the 5 principal variscite sources in western Europe: Gavà (Barcelona, Spain ; GA),
520 Encinasola (Huelva, Spain ; EN), El Bostal (Zamora, Spain ; EB), Palazuelo (Zamora, Spain ; PL),
521 Pannecé (Loire-Atlantique, France ; PA) (realisation by G. Querré).
522
523 Table 1 – Measures and weights of the 17 variscite éléments of the Salpêtre cave deposits (Pompignan,
524 Gard) (realisation H. Vergély).
525
526 Table 2 – Color of the 17 variscite éléments of the Salpêtre cave deposits (Pompignan, Gard) (realisation
527 H. Vergély).
528
529 Table 3 – Chemical elementary composition obtained through the PIXE method and of each of the
530 Salpêtre cave (Pompignan, Gard). Analyses are expressed as ppm (part per million). In the table, for
531 each element, we also find the average concentrations, their standard deviation, minimum and maximum
532 concentrations as well as the detection limits (LDD) during the bead's analyses in July 2016 (realisation
533 by G. Querré).
534
535 Table 4 – Elemental analysis obtained by PIXE for each of the variscite deposits, in order to develop the
536 chemometric model. Concentrations expressed in parts per million (ppm) and in elemental form. V*,
537 Cr* and Fe* are the relative percentages of vanadium, chromium and iron contents normalized to the
538 sum V+Cr+Fe.
539
540
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542
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The variscite « necklace » of the Salpêtre cave, at Pompignan (Gard, France)

Jean Guilaine, Guirec Querré, † Serge Cours, Jacques Coularou, Hélène Vergély, Jean Vaquer, Muriel Gandelin

Abstract :

A 17 variscite beads set, buried in the Salpêtre cave in Pompignan (Gard, France) constitutes a unique Middle Neolithic set of ornaments in the southern France. PIXE (Particle Induced X-ray Emission) chemical analysis of these coins and reference samples from possible sources indicates a mineral origin from the Gava mines, near Barcelona (Spain). This discovery reveals an exchange system of the materials or finished objects on both sides of the Pyrenees mountains during the first half of the 4th millennium BC.

Keywords : Neolithic of western Europe, Middle Neolithic (*Chasséenne* culture), ornaments, variscite, provenance, chemical analysis, PIXE (Particle-Induced X-ray Emission)

Adornments, in prehistoric populations, is not just ornaments but also an « identity language », functioning as a sexual, social, or ethnical marker. In Neolithic times, in the Near East as in Europe, green stones were largely used in jewellery making. As such, in Israel, from the recent Natufian to the pre-pottery Neolithic B (PPNB), between -11000 and -7000 BC, several minerals bearing this hue (apatite, fluorapatite, chrysocolla, malachite, turquoise, amazonite, serpentinite) were used to make beads. The source of the raw materials was often distant from the user location of the productions. And, the choice of a green hue has sometimes been interpreted as a symbol of vegetation, of growing plants, of fertility (Bar Yosef Mayer and Porat 2008). In Cyprus, picrolite, the local green mineral, was largely exploited in jewellery production from the PPNA (pre-pottery Neolithic A) until the Chalcolithic (Guilaine, 2011; Guilaine and Rigaud, 2021; Peltenburg, 1998). During the Neolithic of western Europe, another green rock, the variscite, was used in the fabrication of necklaces during almost the entire period, from the 6th to the 3rd millennium BCE. This mineral is a kind of hydrated aluminium phosphate, also called variscite, the formula for which is $\text{AlPO}_4 \cdot 2 \text{H}_2\text{O}$. Its deposits are essentially located within the Iberian Peninsula, but also in France and Sardinia (Fernandez et al. 2019).

In Brittany, the presence of beads made of variscite is attested in Neolithic contexts – often funerary ones – since the 19th century. Such ornamental objects were discovered in the great Carnacian tumuli (Tumiac, Saint-Michel, Mané er Hroeck) as well as several Armorican dolmens (Kercado). Right away, the question of the identification and origin of the material was raised. As early as 1864, mineralogist A. Damour studied a few specimens of these light green minerals and identified them as

40 made of a hydrated aluminide phosphate (Damour 1864). Faced with the quality of such productions,
41 A. Damour, followed by A. Lacroix believed in a distant origin of the raw material, and this
42 hypothesis of an exotic, distant rock prevailed for a long time (Veiga Ferreira, 1950).

43 In southern France, E. Cartailhac was one of the first to be interested in these ornaments, some of
44 which came from the dolmens of Aveyron and of Lozère, where he first started working. In 1876, he
45 participated to research on the Castellet hypogeum (Fontvieille, Bouches-du-Rhône), from which an
46 ensemble of 114 beads was extracted. In 1881 he published in the journal he edited, *Matériaux*, E.
47 Piette's article mentioning the « necklace » made of 93 beads issued from one of the compartments of
48 the Halliade monuments at Bartrès (High-Pyreneans; Piette 1881, Mohen 1978). This led him to give
49 an overview of these adornments, the presence of which he identified in Brittany, Spain, Portugal (in
50 the hypogea of Palmela) and in the Midi (Cartailhac 1889). In parallel, research on the north-eastern
51 region of the Iberian Peninsula revealed the existence of numerous beads of the same material within
52 the earth or *cists* of that region. A. Muñoz, in her thesis on the « Sepulcros de fosa » of Catalonia,
53 provided a synthesis of this issue and brought some doubt to the hypothesis of a distant origin (Muñoz
54 1965). In the Midi, a few specimens were brought to the attention of two researchers of the mineralogy
55 department of the Commissariat à l'Énergie Atomique (F. Chantret, A. Guillemaut) and revealed that
56 the term *callais* could regroup variscite, turquoise, or malachite ornaments (Chantret et al. 1970).
57 Variscite ornaments were essentially recognised within the funerary context in individual inhumations
58 (within a dug-out grave or a stone box) or in collective tombs (megalithic structures, hypogea,
59 sepulchral caves).

60 A new and determining impulsion in approaches to the topic came from the recognition, starting from
61 the 70s onwards, of the variscite mines of Gavà, near Barcelona in Spain (Domínguez-Bella 2004,
62 Bosch Argilagos 2019, Molist and Oliva 2019, Moro et al. 1992 and 1995). Following this, renewed
63 attention was given to the geological formations of the Zamora region, where several deposits had
64 been identified (Fabregas Valcarce and Rodriguez-Rellan 2019). Then came the identification of the
65 Pico Centeno deposit (Encinasola, Huelva, Spain) in western Andalusia, (Odrizola et al. 2010,
66 Dominguez-Bella and Ramos-Muñoz 2019). Uncovering the existence of these deposits was combined
67 with diverse analyses programs in order to establish precise baseline referentials characterising each of
68 these three sources: Gavà, the Zamora deposit, and Encinasola. In turn, this meant various scenarios
69 for the circulation of variscite and turquoise during the Neolithic (between 5500 and 2000 BC) at the
70 scale of western Europe could be proposed (Querré et al. 2019).

71 The productions from these various deposits may have similarities and differences. Thus the round or
72 barrel beads are ubiquitous. The large pendants with polar perforation from Breton sites come from
73 Encinasola in the fifth millennium and then, from 4000 BC, from Palazuelo de las Cuevas. The
74 Portuguese cylindrical beads come from deposits in the Zamora region. The large biconical beads with
75 axial perforation come mainly from Gava. The small irregular beads from Final Neolithic collective

76 burials in the south of France do not have, due to lack of analysis, a clear provenance (Querré et al.
77 2019).

78 A remarkable variscite bead ensemble was discovered in the 70s in the Salpêtre cave at Pompignan
79 (Gard, France). Whilst known and presented to the public in various recent exhibits, this discovery had
80 never been published in detail. This article aims to fill this gap in knowledge and communicate the
81 results of the analyses concerning this original ensemble, unique for the south of France.

82

83 **1. The site**

84

85 The Salpêtre cave is located on the commune of Pompignan (Gard, France), 30 km north of the town
86 of Montpellier (fig. 1). It opens on the northern flank of the Hortus cause, at the foot of the Taillade
87 cliff, at an average altitude of 380 m (fig. 2 and 3).

88 This cave was subjected to various investigations over a century. The oldest was by A. Jeanjean who
89 mentioned its interest in a synthesis on the prehistory of the Basses-Cévennes region (Jeanjean 1871).
90 Around 1960, Jacques Audibert, research associate at the CNRS, undertook a little work in the cavity
91 (Audibert 1962). These two operations meant middle Neolithic levels (*Chasséen*) were identified, as
92 well as some final Neolithic (Ferrières and Fontbouisse cultural groups). In the 70s, S. Cours re-sieved
93 some of the waste heaps and prospected other areas of the cave. This is when the necklace described in
94 this article was discovered. Following this find, S. Cours and J. Coularou dug a deep test pit 10 m
95 from the cave entrance, 3 m deep. At that level, they found hardened sediment. They recognised the
96 reworked aspect of the Neolithic levels but also identified the existence of palaeolithic levels still in
97 place (Azilian, Magdalenian, Mousterian). The Azilian **artefacts** were described in M. Barbaza's
98 doctoral thesis (Barbaza 1981). It is possible that some Neolithic levels still in place are present in the
99 deepest part of the cavity, under the spoil heaps from older excavations, which would allow ¹⁴C dating,
100 none of which was done at this time.

101 In 1972, M. Escalon de Fonton dug a new test pit, looking for the previously recognised Magdalenian
102 level. The investigation remained fruitless, but a few years later in 1978-1979, L. Meignen pursued
103 this research axis and confirmed the presence of Mousterian occupations.

104 The Salpêtre cave is a long corridor following a north-south cleft; it is 80 m long and 2 m large and
105 reaches a height of 5 m. Towards the deepest end of the cavity, a lateral diverticulum opens into a
106 small room (fig. 4 and 5).

107 The variscite bead cache was found **41.5** m from the cave entrance, where the corridor narrows, and
108 the walls are only **0.5** m apart. This narrowing is even more marked by the fact that a natural step
109 exists there, forming a threshold of sorts (fig. 6).

110 The beads were discovered grouped within a small space. Perhaps they were originally linked by a
111 thread that has now disappeared. In the immediate vicinity, a large ceramic sherd and a pecten shell
112 were found. The sherd (9 x 8 cm) has a curved profile and belongs to a **vessel** with a thick profile (1

113 cm). It is identified as a fragment of the ventral part of a spherical container, the diameter of which is
114 estimated to have been around 26 cm. This element bears an engraved decor made of three horizontal
115 strips: a central one with a checkered motif, and two surrounding ones (superior and inferior)
116 presenting a motif made of four lines arranged as rafters. This resembles spherical to cylindrical
117 collared containers typical of the classical *Chasséen*, the widest part of which was often decorated
118 with geometrical patterned strips.

119 The mollusc shell is a **scallop** (a Saint-Jacques shell: *Pecten jacobus*), rather large (width: 13 cm).
120 We cannot exclude that the beads were originally placed within the bivalve.

121

122 **2. Description of the Beads**

123

124 The excavated lot includes 17 elements which could originally constitute a necklace (fig. 9)¹.

125 All the beads, of various sizes, bear witness to a final fabrication state necessitating an important
126 technical investment. Measures were carried out on the bead ensemble: maximum diameter
127 (median point of the maximum width of the transversal section), minimal diameter (median point of
128 the minimum width of the transversal section), diameter of the perforation, maximum and minimum
129 thickness (or length), and maximal and minimum diameter of the bead's extremities. These last
130 measures correspond to the term « méplat » used by F. Herbaut and G. Querré (Herbaut, Querré
131 2004). The maximum diameter of the beads is between 7.2 and 25.5 mm, for a thickness between
132 5.9 and 40.1 mm. The maximum diameter of the perforations is comprised between 2.1 and 4.3 mm.
133 Dimensions, weights and color are resumed in table 1 and in table 2.

134 Discussing the typological aspect of these beads is difficult, because variscite ornament productions
135 do not correspond to fabrication standards observed on other mineral matter, and we are
136 confronted to a lack of current research (in France) on this aspect of variscite productions (Viel et al.
137 2019). Looking to the reference work on ornaments of the French Midi region (Barge 1982), the vast
138 majority of the beads of the Salpêtre cave ensemble can be qualified as irregular. It is true that the
139 typological classification of these objects is problematic since they often present asymmetries in their
140 longitudinal and transversal sections. In publications, they are generally described as olive-shaped, or
141 flattened beads...

142 In order to better define the production criteria of the workshops, which seems to evolve over time,
143 typological classification work could help us qualify these productions, such as the one published by
144 H. Beck in 1926 « Classification and Nomenclature of Beads and Pendants » (Beck 2006). This
145 typological example allows for the description and classification of beads whilst considering their
146 shape from the section and the front. Synthetically speaking, the Salpêtre ensemble presents, in
147 most cases, an elliptical transversal section (more or less regular) combined with a convex cylindrical
148 longitudinal section. Several beads present a transversal section associated with a convex, « barrel-
149 shaped » or cylindrical longitudinal section, with both extremities being convex (n°7 and 8). One bead
150 reveals a quadrangular transversal section (n°5) and another can be qualified as a conic trunk (n°17).

¹ These artefacts are kept at the Centre de Documentation Archéologique du Gard (CDAG), 396 avenue Joliot Curie, 30900 Nîmes. Their analysis took place within a PCR (Collective Research Program) titled « Milieu et Peuplement en Languedoc Occidental du Néolithique au Bronze ancien » (dir. M. Gandelin)

151 The polishing of the beads is advanced, giving an intense shine visible on both the bead's extremities
152 and their longitudinal sections. This aspect is also visible on the extremities' surfaces presenting great
153 irregularities such as bead n°13, or on the section of bead n°3. Only one bead (n°2) presents
154 unpolished irregularities that can be interpreted as impacts (3 in total), which must have occurred
155 after the bead's fabrication and bears witness to probable shocks. Besides, traces of red coloured
156 matter (ochres ?; not analysed) are visible inside these asperities. The polishing is so advanced that it
157 is difficult to discern traces of the manufacturing techniques used before that stage of fabrication.

158 Perforations are all cylindrical, and their regularity implies the use of a system to hold the pieces in
159 place, and the use of flint drills mounted on a rotating axis to pierce the beads. A boring step allowed
160 for the regularity of the perforations. These technical observations correspond to the research made
161 on variscite's chaîne opératoire in Catalonia (Molist Montana, Oliva Poveda 2019). The morphology
162 of the beads found in the Salpêtre cave is close to those found in the Gavà workshop and find many
163 comparisons with the beads discovered in grave 83 of the Mine (Beta 155.686 : 5220±110 BP ; 4326 –
164 3793 cal BC (95.4%) ; Bosch Argilagos 2019).

165

166 **3. Chemical and provenance analyses of the callais bead necklace from the Salpêtre cave** 167 **(Pompignan, Gard).**

168

169 The 17 callais beads probably composing a necklace (fig. 10 and 11) found during the Salpêtre cave
170 excavation at Pompignan were subjected to an **elemental** chemical analysis in order to confirm their
171 mineralogic identity (variscite) and to determine their provenance. This determination was established
172 using the chemometric model elaborated based on the main European sources of variscite (Querré et
173 al, 2008; 2012; 2014 ; and forthcoming) as well as PIXE analyses of the Pompignan beads.

174

175 **3.1. Methodology**

176

177 The analyses were carried out using the PIXE method (*Particle-Induced X-ray Emission*) using the
178 AGLAE (*Elementary Analysis Accelerator of the Grand Louvre*) set up from the C2RMF (*The*
179 *research and restoration centre of Musées de France*) of the Louvre Palace (Paris).

180 The PIXE method was applied to the callais according to a protocol established by one of the authors
181 (G.Q.). This method of elemental analysis is non-destructive and fast. It is based on the fluorescence
182 of X-rays characteristic of the material. The elemental composition of archaeological pieces is
183 compared with a reference sample, representative of the 5 largest European variscite deposits, likely to
184 have been exploited during the Neolithic. The concentrations of major elements allow us to recognize
185 the mineralogical nature of the veins; the spectrum of minor elements and/or traces shows intrinsic
186 variations, specific to each deposit. The contents of iron, vanadium, chromium, arsenic, silicon,
187 calcium, zirconium, uranium, their absolute variations and concentration rates are particularly relevant

188 to discriminate potential geological sources. This model can be used to determine the provenance of
189 archaeological variscite pieces (Querré et al. 2019).

190 Protons of 3MeV were extracted in the shape of a beam a few micrometres in diameter. The bead
191 surface to be analysed was placed a few millimetres from the protons exit window. Four SDD
192 detectors gather the X-Rays created: one for the low energies corresponding to major elements, and
193 three for high energies corresponding to trace elements (fig. 12 a and b). In order to have a mean
194 analysis of the bead's material, the beam scanned the surface over one millimetre square. The
195 acquisition time for the analysis of each bead was six minutes on average. The high and low energy
196 spectrums went through GUPIX and TRAUPIX software analysis, in order to obtain elementary
197 concentrations as well as the detection thresholds for all 24 chemical elements of interest.

198

199 3.2. Chemical analysis of the beads

200

201 The concentration of the 24 chemical elements for each of the 17 beads can be found in table 3 and
202 table 4. Three chemical elements are present in concentrations higher than 10 % (100.000 ppm):
203 aluminium, silicon and phosphorus. Copper concentrations are low, 65 ppm on average. The beads are
204 therefore indeed variscite, albeit a very impure form considering the high silicon proportions present
205 within. After these three major elements, iron and copper are the most represented, with element
206 concentrations reaching around 2 %. All other elements are found in minor or trace concentrations.

207

208 3.3. Provenance

209

210 The chemometric model elaborated to determine the variscite's provenance was applied to the beads
211 found in the Salpêtre cave.

212 The concentrations of the discriminating elements were compared to those of the five western
213 European deposits where the beads might come from : the four Spanish deposits, the Gavà deposit
214 (Barcelona) including the Can Tintorer mines (fig. 13, GA, and table 4), the Encinasola deposit and
215 the mines of Pico Centeno in the Huelva region (fig. 13, EN, and table 4), El Bostal in the Zamora
216 region (fig. 13, EB, and table 4), Palazuelo de las Cuevas (fig. 13, PL, and table 4), and the only
217 known French deposit : Pannecé, in the Loire-Atlantique region (fig. 13, PA, and table 4).

218

219 The relative proportions of the three most discriminating elements (V, Cr and Fe) are, on average, the
220 following: $V^*=7.5$ - $Cr^*=7.8$ - $Fe^*=84.7$. These proportions do not correspond to those of the Pannecé
221 deposits, for which vanadium represents 50 % and within which chrome and iron reach 25% of the
222 total each (see figure 13 as well). The average Cr/V ratio is 1.39 ± 1.05 which is not compatible with
223 the Palazuelo analyses ($Cr/V = 5.08 \pm 6.48$), nor with those of El Bostal ($Cr/V=0.35 \pm 0.04$).

224 The U vs Zr diagram (fig. 13B and table 4) allows us to individualise the variscites from El Bostal,
225 which has strong uranium concentrations ($U = 306 \pm 267$ ppm) and no zirconium ($Zr = 6 \pm 4$ ppm). In
226 the case of the Salpêtre beads, the reverse phenomenon is observed, with low uranium concentration
227 ($U = 9 \pm 5$ ppm), often inferior to the detection threshold (LDD = 19 ppm), and average zirconium
228 presence ($Zr = 22 \pm 23$ ppm).

229 Concerning diagram (Cr+V) vs As (fig. 13C), the concentrations observed in the Pompignan variscite
230 beads ($Cr+V = 2926 \pm 1003$ ppm ; $As = 802 \pm 418$ ppm) are close to those of two deposits : Encinasola
231 ($Cr+V = 4198 \pm 1429$ ppm ; $As = 610 \pm 802$ ppm) and Gavà ($Cr+V = 809 \pm 397$ ppm ; $As = 302$
232 ± 90 ppm) but not those of three other sources : ($Cr+V = 2926 \pm 1003$ ppm ; $As = 802 \pm 418$ ppm)
233 ($Cr+V = 2926 \pm 1003$ ppm ; $As = 802 \pm 418$ ppm) ($Cr+V = 2926 \pm 1003$ ppm ; $As = 802 \pm 418$ ppm).

234 Silicon concentrations are extremely high in the Salpêtre beads ($Si = 17.6 \pm 6$ %) and can be qualified
235 as elevated as far as calcium is concerned ($Ca = 1.8 \pm 1.2$ %). This tends to indicate that the origins of
236 the beads is the Gavà deposit, which is the only one to present elevated concentrations of both silicon
237 and calcium ($Si = 11.2 \pm 7.4$ % ; $Ca = 6.1 \pm 8.0$ %) (fig. 13 C and table 4).

238 Together, all these geochemical analyses based on the chemometric model bring only one answer to
239 the question of the origins of the Salpêtre cave – the Gavà deposit, in Spain. The high iron
240 concentrations in contrast to the vanadium, the Cr/V ratio, as well as the high proportions of silicon
241 and calcium are the most discriminating factors in this case.

242 This result is coherent with the identification of the site from which the beads originate as *Chasséen*,
243 and thus belonging to the Mediterranean sphere, within which most variscite ornaments come from the
244 Can Tintorer mines (Gavà, Spain). ~~The morphology of the large biconical beads from Pompignan is
245 the same as those deposited in the graves in the Barcelona area.~~

246

247 **4. A cache of ornaments from the southern Pyrenees**

248

249 The analyses of the Salpêtre cave ensemble (Pompignan, Gard, France) bring precious information on
250 the circulation of ornaments outside their fabrication area in a region – southern France – where these
251 analyses are still rare. Indeed, this ensemble is composed of various typological elements, including
252 large, olive-shaped beads perfectly comparable to the productions found on the southern flank of the
253 eastern Pyrenees, and dated to the evolved Neolithic middle. The meridional cultural context is then
254 that of the *Chasséen*. The mineralogical composition of the Pompignan pieces demonstrate it is made
255 of variscite coming from the Gavà deposits. Beyond the synchronism proposed between the *Sepulcros*
256 *de fosa* and the meridional *Chasséen*, which has long been argued for (Guilaine and Muñoz 1964),
257 these interactions are now better understood. As such, polished alpine stone axes and Bedoulian flint a
258 attested within the Catalan funerary artefacts, whilst variscite ornaments are themselves found within
259 *Chasséen* funerary deposits of the Toulouse region (Saint-Michel du Touch, Villeneuve-Tolosane) and
260 as far as the Rhône (Pompignan), or even the Lyon region (Tassin ; Vaquer 2019).

261 The Pompignan ensemble also presents an interest in that it is a deposit of rare pieces placed in a
262 cache, made within a cave, rather far from the cave's entrance. This deposit was hidden, perhaps
263 during a ritual act. We must therefore raise the possibility that as early as the middle Neolithic rare
264 pieces were hidden in such caches. This process continued during the Neolithic through the burial of
265 various productions: flint blades (cf. Sainte-Cécile-les-Vignes deposit, Vaucluse, France), copper ores
266 and flat axes (cf. Centeilles deposit, Siran, Hérault, France), or copper ornaments (cf. Miguro cave,
267 Corconne, Gard, France). This process was particularly developed during the Bronze Age (Gasco,
268 Lachenal, Piningre 2018). This hiding of precious objects could signal disparities in the social order
269 and connotate the particular status of their owner(s). The example of the Salpêtre cave constitute, in
270 the *Midi de la France*, a unique example. We should also mention the existence of two deposits in
271 western France « au contact des ouvrages symboliques que sont la stèle en grès de la Table des
272 Marchands et l'enceinte de pierres dressées sur l'îlot d'Er Lannic » (“in contact with the symbolic
273 works of the Table des Marchands stelae and the raised stone enclosure of the Er Lannic islet”)
274 (Cassen et al. 2019).

275

276 **5. Chrono-cultural framework: The Early and Middle Neolithic**

277

278 The chrono-cultural insertion of variscite meridional ornaments used to be subject to debate. J. Arnal,
279 taking as basis the closed ensembles represented by the **Catalan** tombs (*Sepulcros de fosa culture,*
280 **Spain**), systematically attributed them to the middle Neolithic and made it a cornerstone to date the
281 corridor dolmens of eastern Languedoc (Arnal 1963). In opposition, J. Audibert, witnessing the
282 presence of callais beads within meridional collective tombs, dated them as probably Chalcolithic
283 (Audibert 1962). Progressively, further research meant a long-term chronology could be established
284 for variscite ornaments (Barge 1982, Roscian et al. 1992), now spanning over two **millennia** (c. 4500-
285 2200 BC). It is however not impossible that this chronology could be stretched further. Indeed, we are
286 not aware of beads pertaining to the *Cardial-Epicardial* cycle in the Midi (\approx 5500-4500 BC) whilst on
287 the southern Pyrenean side such ornaments are attested in a sporadic manner during the Cardial
288 (Chaves cave, Aragon), and more often during the *Epicardial* (Cova de les Lladres, in western Vallès,
289 with a deposit of 139 pendants), and also in the Molinot (during the third quarter of the 5th millennium,
290 during which the first exploitations of the Gavà mines are attested: Bosch 2019, Molist and Oliva
291 2019). To the North of the Pyrenees, the first known manifestations are attested within the Juberrian
292 context (Llo oppidum, Pyrénées-Orientales, France, **around 4500 BC**) and become more obvious
293 within the *Montbolo-Chasséen* context during the last centuries of the 5th millennium (grave 33 of
294 Crès, Hérault; tomb 59 of Caramany, Pyrénées-Orientales ; silo 19 of Cugnaux, Haute-Garonne,
295 France ; Vaquer 2019). If the Pompignan deposit is contemporaneous with the *Chasséen* occupation of
296 the cave, of which a typical decorated sherd was found near the beads, we cannot exclude a **date** from
297 the end of the 5th millennium. It is during the optimum functioning of the Gavà mines, linked to the

298 peak of the *Sepulcros de fosa* culture (Vallesian/Solsonian, Spain), that the Catalan variscite
299 importations towards the Midi region reach their peak, during the middle - recent *Chasséen*, between
300 4000 and 3500 BCE.

301 Several sites from the Roussillon, Aude, and Toulouse region, and up to the Rhone corridor (Saint-
302 Paul-Trois-Châteaux, *Drôme, France*) have yielded beads of various forms, including several
303 « heavy » pieces, olive-shaped, of a kind well-known in Catalonia (tomb 1 of Villeneuve-Tolosane,
304 the “royal” tomb A 185 from Saint-Michel-du-Touch, *Toulouse, Haute-Garonne, France*) (Méroc and
305 Simonnet 1979). Some of the Pompignan pieces *show similarities* within the same ambiance. Within
306 cave IV from las Claousos at Auriac (Aude, France), used as a collective tomb and for which a ¹⁴C
307 date yielded a recent *Chasséen* attribution, six cylindrical or barrel-shaped variscite beads could come
308 from Encinasola rather than Gavà (Guilaine et al. 2019). Could it be that this reflects a competition
309 between the two deposits (Can Tintorer and Pico Centeno) at a time when Gavà’s production was
310 slowing down?

311

312 **6. Continuities in Final Neolithic**

313

314 We are less informed on the origin of the small meridional variscite beads, which remain abundant in
315 the *Midi de la France* during the entire final Neolithic, between 3500 and 2200 BCE. Their typology
316 isolates them from the previously evoked examples. Large, olive-shaped or thick beads have more or
317 less disappeared except in rare cases (Fées de Lunas cave, Hérault, France). The only remaining beads
318 are small discoid models, with irregular outlines, not always well calibrated. The ensemble excavated
319 from the Cabrials collective tombs, near Béziers (Hérault, France), with a flattened shape, is dated to
320 the final Neolithic 1 (Tchéremissov 2012). Most of the meridional beads issued from collective
321 tombs (dolmens, natural caves, hypogees) with a long-term use, sometimes over a millennium. They
322 can be numerous: minimum 130 in the Clot-de-l’Oste dolmen at Bouisse (Aude, *France*; Guilaine et
323 al. 2015). Two beads from the René-Carrié cave at Termes (Aude, *France*) are composed of materials
324 attributing their origin to Gavà. The exploitation of the Catalan deposits could therefore have been
325 pursued until after 3500 BC, in a less intense manner.

326 The end of the use of *variscite* stone could be placed towards the end of the *Chalcolithic* with the
327 diffusion of the Bell Beaker phenomenon. An ensemble of 23 beads accompanied the ancient Bell
328 Beaker deposit found within the ditch surrounding the Mourral site in Trèbes (Aude, *France*; Vaquer
329 1998). This is a regional association, since the *callais* is not a general marker of the European Bell
330 Beaker. This example shows that *the south of France tradition* of using this material could still exist
331 whilst the maritime Bell Beaker phenomenon pursued its supraregional expansion.

332

333 **Conclusion**

334

335 The bead ensemble from the Salpêtre cave of **Pompignan** originates from the Gavà mines, near
336 Barcelona, some 370 km as the crow flies (this distance being a general indication, since the transfer
337 implied either crossing the eastern Pyrenees, or their circumvolution by navigating the Gulf of Lion).
338 Beyond the burial of this ensemble, which is reminiscent of a cache, perhaps during a ritual act, this
339 discovery confirms the existing relationship between two Neolithic cultures separated by the physical
340 barrier of the Pyrenees. To the south, the *Sepulcros de fosa*, which exploited the mines, fabricated and
341 diffused the ornaments; and to the North, the meridional *Chasséen* who, from the Toulouse region to
342 the Alps, received these jewels which were appreciated for their “exotic” provenance, relative as it
343 was. While slightly offset within the Cevenol mountains, the Pompignan ensemble is located relatively
344 close to a geographic axis – the Bas-Languedoc. Through this axis, Rhone corridor material circulated
345 (blond flint from the Vaucluse, alpine eclogite), which travelled opposite ways to the variscite and
346 crossed the Pyrenees to furnish **cores**, flint blades, and polished axes for populations of Catalonia. The
347 Pompignan deposit is therefore at the heart of a reciprocity system demonstrating the strong
348 complementarity in exchanges between Neolithic cultures of the first half of the 4th millennium BCE.

349

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472

473 **Auteurs :**

474

475 Jean Guilaine : Collège de France, 11, place Marcelin-Berthelot, 75005 –Paris. jguilaine@wanadoo.fr

476

477 Guirec Querré : UMR 6566 CReAAH, Université Rennes-Sciences, Campus de Beaulieu, 35000-
 478 Rennes. guirec.querre@univ-rennes1.fr

479

480 † Serge Cours, 4, Impasse de la Brugue, 33340-Lesparre Médoc

481

482 Jacques Coularou, UMR5608 Traces, Université Jean-Jaurès, 5, allée A. Machado, 31058-Toulouse
 483 cedex. j.coularou@gmail.com

484

485 Hélène Vergély, Inrap, UMR5608 Traces, UMR5608 Traces, 561 rue Etienne Lenoir, km Delta,
 486 30900, Nîmes. helene.vergely@inrap.fr

487

488 Jean Vaquer, UMR5608 Traces, Université Jean-Jaurès, 5, allée A. Machado, 31058-Toulouse cedex.
 489 jean-sebastien.vaquer@orange.fr

490

491 Muriel Gandelin, UMR5608 Traces, Inrap, Centre de Recherches Archéologiques, Actipolis, rue de
 492 l'Acropole, 34500, Villeneuve-lès-Béziers, muriel.gandelin@inrap.fr

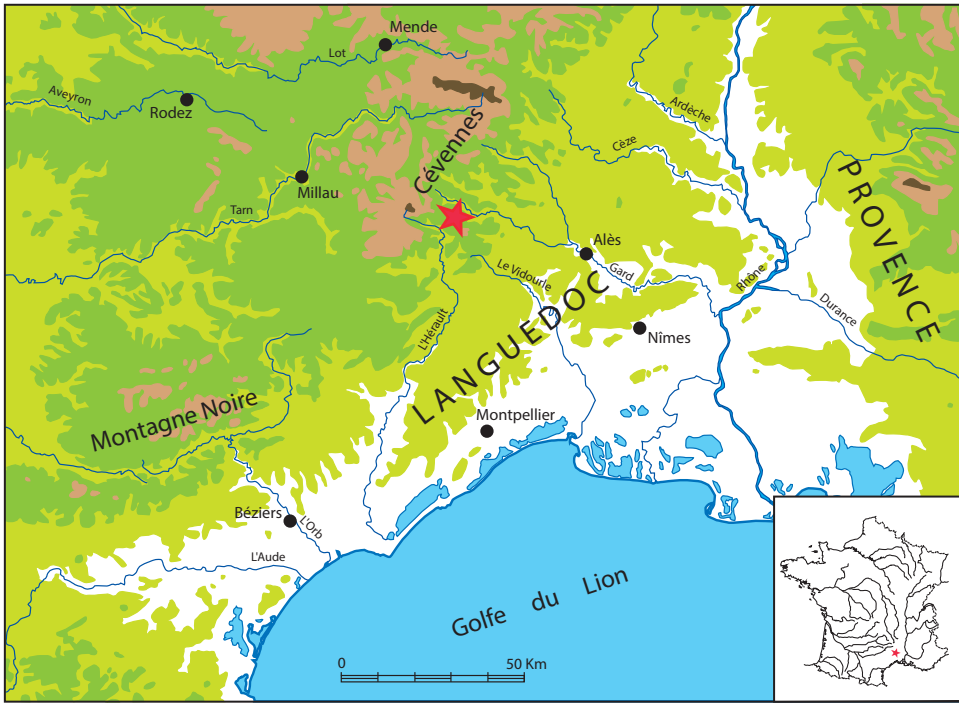
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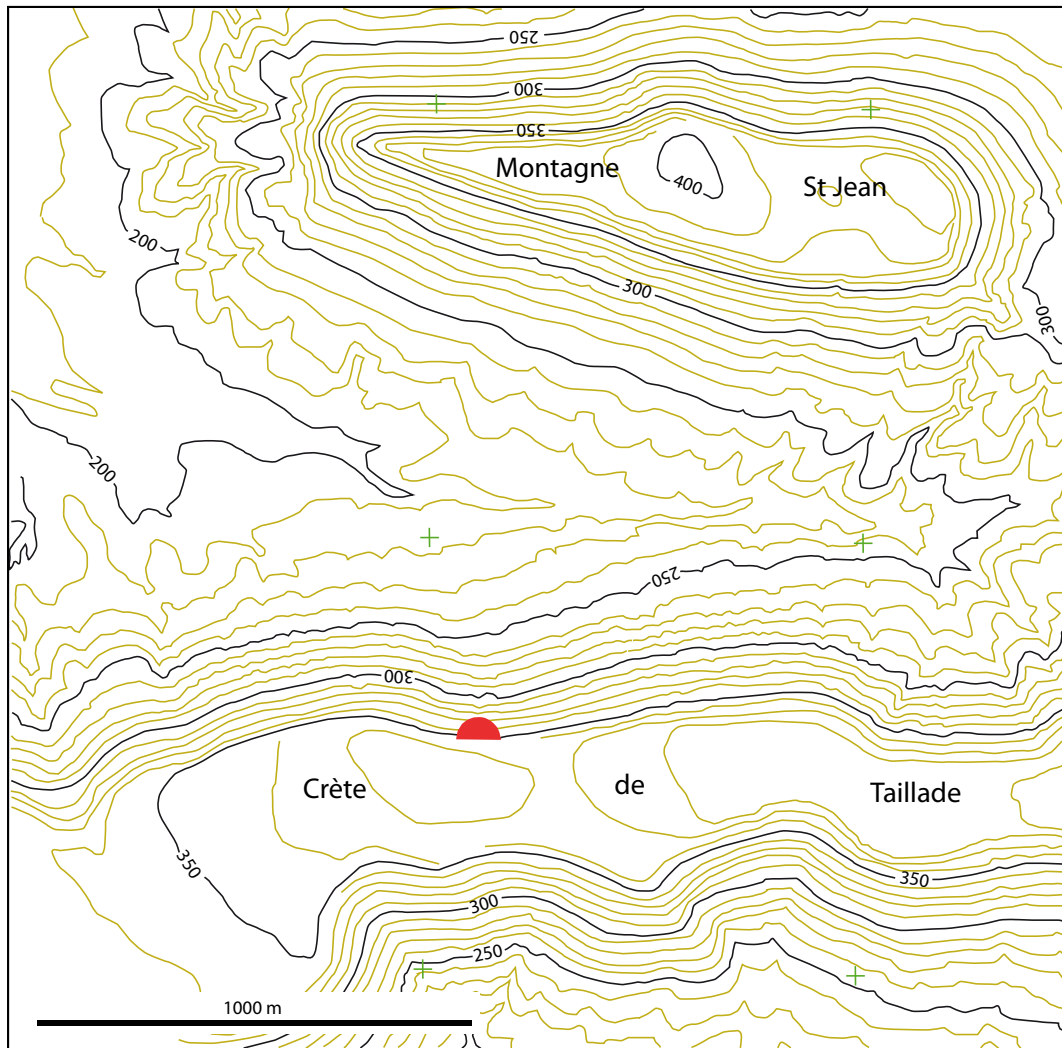
494 **Illustrations**

495

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524
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527 comparison to the referential for the 5 principal variscite sources in western Europe: Gavà (Barcelona,
528 Spain ; GA), Encinasola (Huelva, Spain ; EN), El Bostal (Zamora, Spain ; EB), Palazuelo (Zamora,
529 Spain ; PL), Pannecé (Loire-Atlantique, France ; PA) (realisation by G. Querré).
530
531 Table 1 – Measures and weights of the 17 variscite éléments of the Salpêtre cave deposits
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533
534 Table 2 – Color of the 17 variscite éléments of the Salpêtre cave deposits (Pompignan, Gard)
535 (realisation H. Vergély).
536
537 Table 3 – Chemical elementary composition obtained through the PIXE method and of each of the
538 Salpêtre cave (Pompignan, Gard). Analyses are expressed as ppm (part per million). In the table, for
539 each element, we also find the average concentrations, their standard deviation, minimum and
540 maximum concentrations as well as the detection limits (LDD) during the bead's analyses in July 2016
541 (realisation by G. Querré).
542
543 Table 4 – Elemental analysis obtained by PIXE for each of the variscite deposits, in order to develop
544 the chemometric model. Concentrations expressed in parts per million (ppm) and in elemental form.
545 V*, Cr* and Fe* are the relative percentages of vanadium, chromium and iron contents normalized to
546 the sum V+Cr+Fe.
547
548
549 **Formatting of funding sources**
550

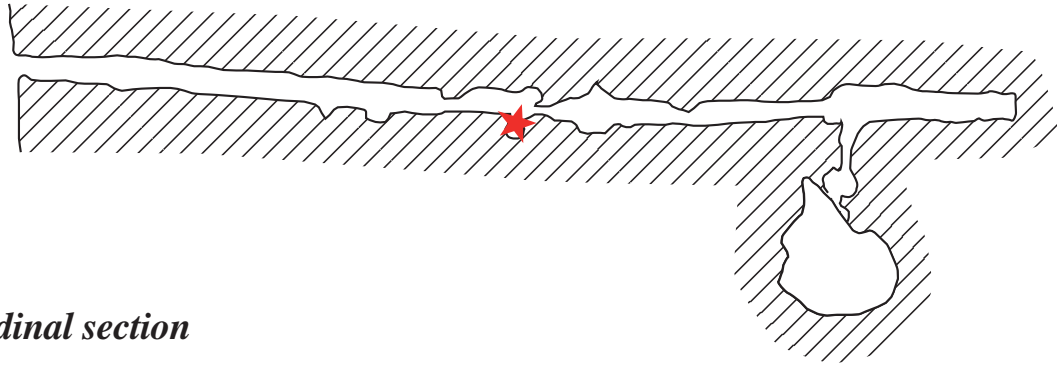
551 Analysis took place within the framework of a PCR (Collective Research Program) titled « Milieu et
552 Peuplement en Languedoc Occidental du Néolithique au Bronze ancien » under the direction of doctor
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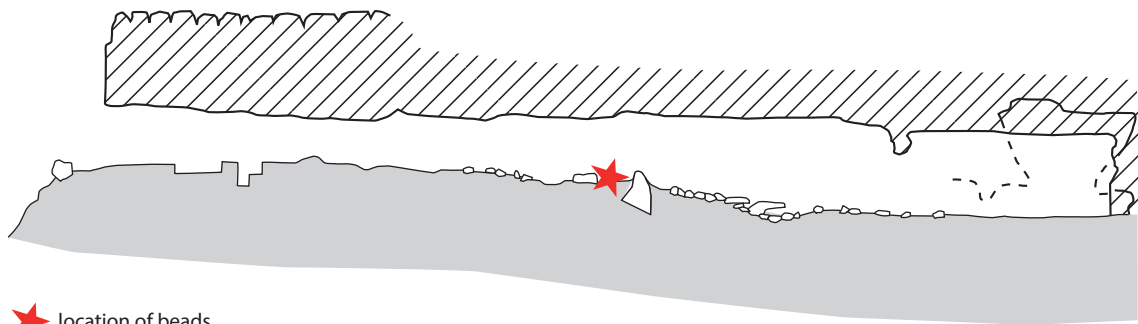




Planimetric view



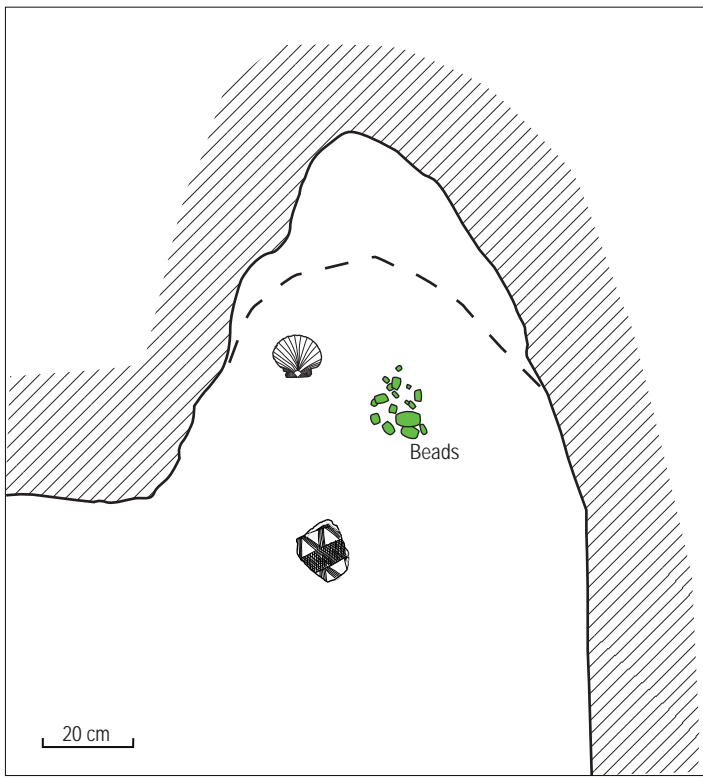
Longitudinal section

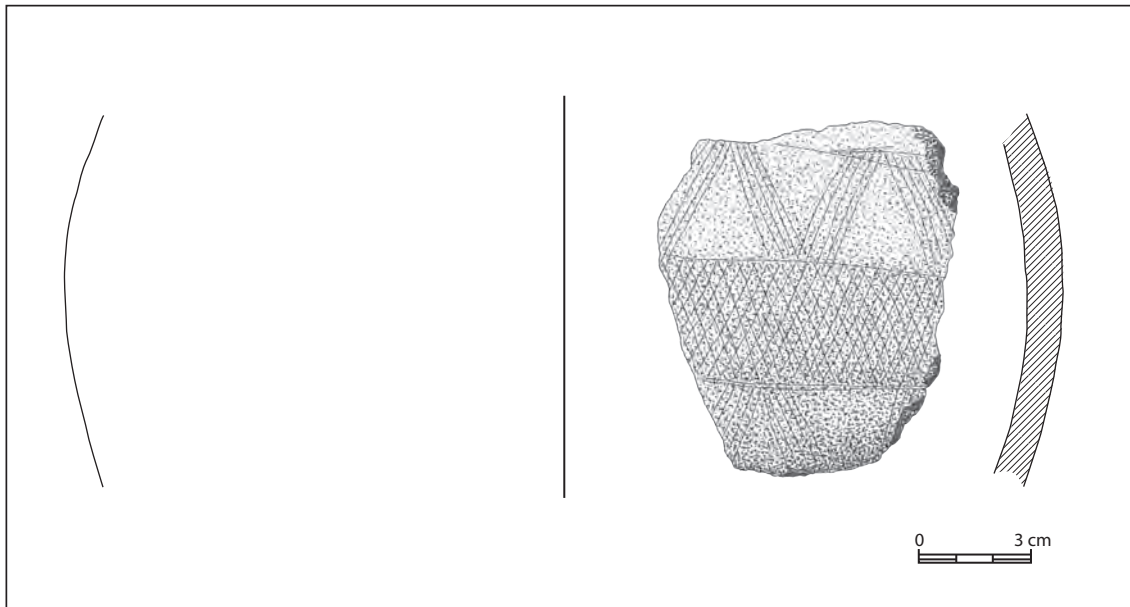


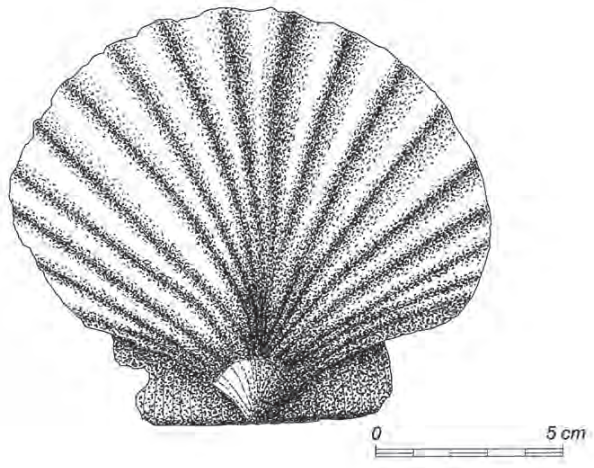
★ location of beads

0 10 20 m

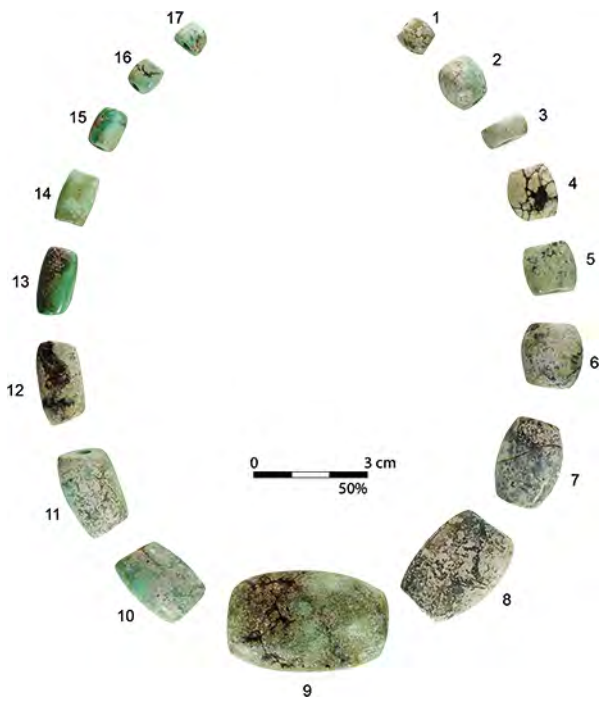




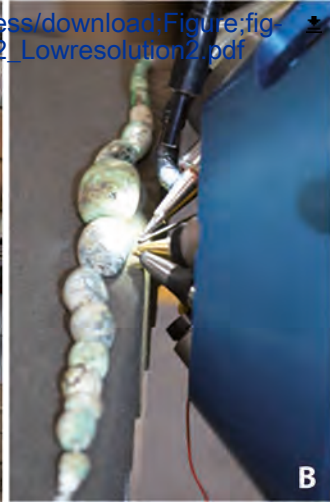
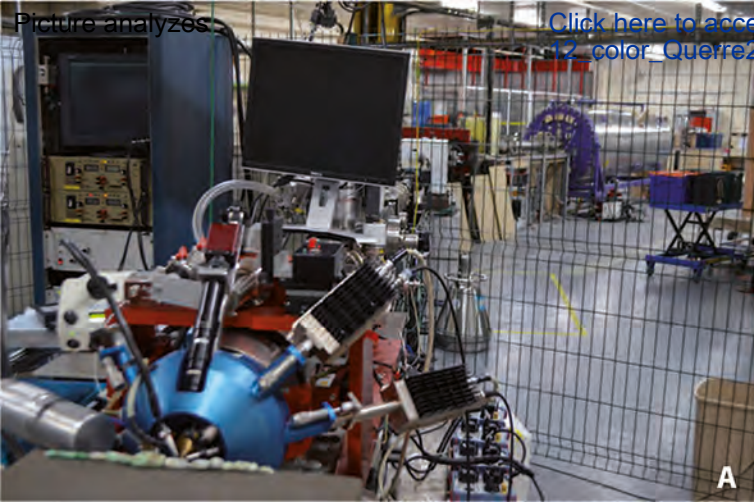


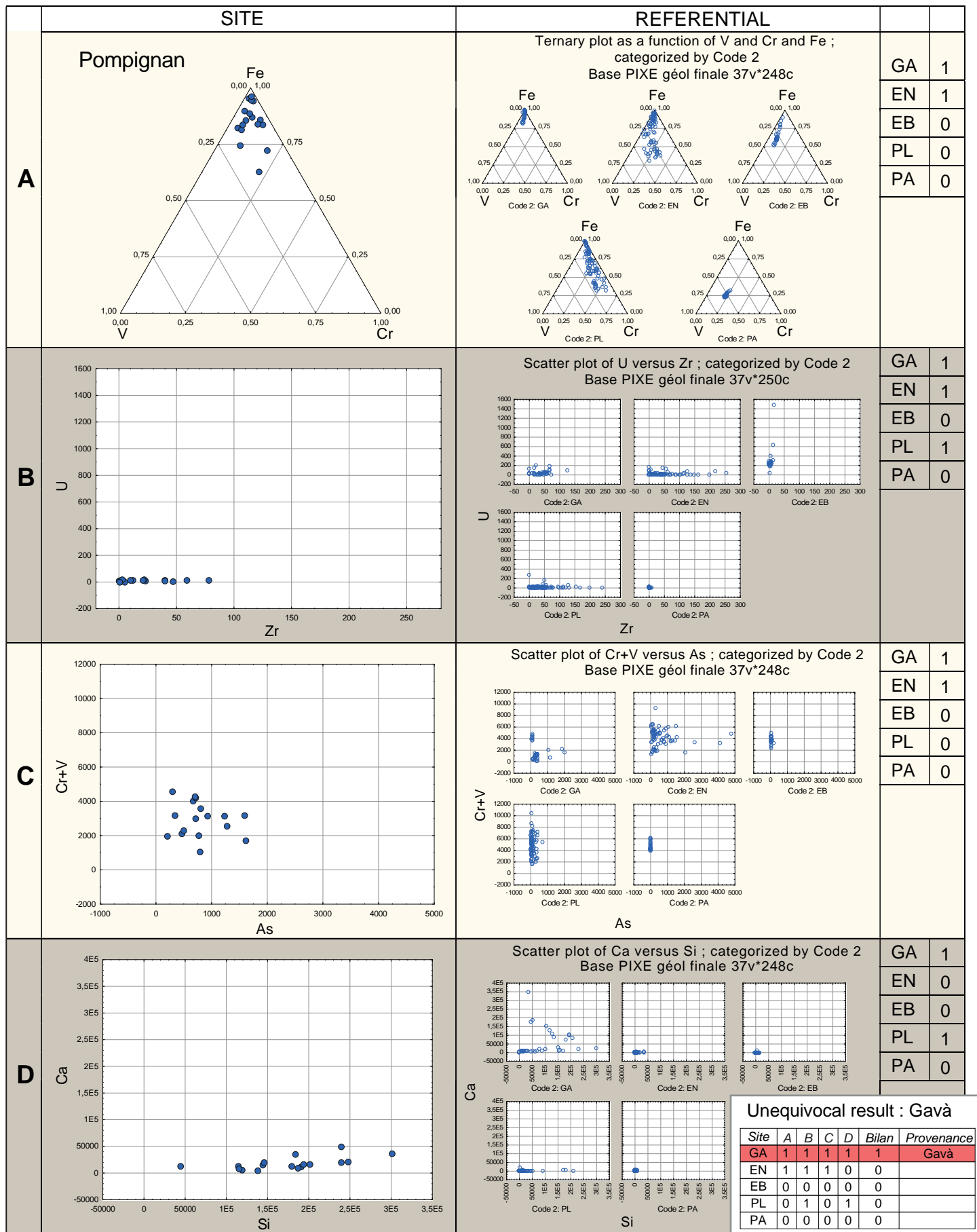












Beads	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
maximum diameter	8.56	11.55	11.74	12.5	13.51	15.41	16.43	20.48	25.15	15.02	14.17	11.48	9.35	13.7	9.14	7.47	7.21
minimum diameter	6.43	10.33	10.4	12.4	7.88	13.17	12.53	11.79	15.88	12.83	11.77	9.7	8.48	12.8	9.12	6.57	6.88
maximum perforation	2.22	2.75	2.72	3.14	3.25	4.01	4.18	3.82	5.01	3.57	3.82	4.35	3.05	2.56	2.89	2.56	2.88
minimum perforation	2.12	2.61	3.17	2.92	2.8	2.95	3.44	3.59	4.34	3.02	3.18	2.92	2.55	2.4	2.39	2.43	2.61
maximum thickness	8.45	12.22	5.95	13.92	13.04	16.64	21.41	28.76	40.1	20.85	22.88	20.94	17.44	8.89	10.43	8.42	6.1
minimum thickness	7.69	11.3	5.12	13.05	12.29	12.95	20.3	27.31	38.1	18.89	18.42	17.7	10.8	7.42	9.45	7.95	5.8
méplat-1 L	6.84	8.27	9.96	9.05	10.22	11.4	10.78	11.45	17.81	11.72	11.44	9.7	7.96	6.95	8.01	5.8	/
méplat-1 l	5.5	7.69	9.22	8.44	7.42	10.92	10.1	9.61	12.75	10.38	8.66	9.64	7.15	5.95	6.1	5.12	/
méplat-2 L	6.57	8.76	10.23	8.44	10.57	11.89	11.39	13.5	16.47	12.97	11.78	11.48	7.54	7.01	7.56	5.56	/
méplat-2 l	5.1	7.93	9.75	7.45	7.72	10.14	9.98	8.85	12.75	11.61	11.26	9.7	/	5.9	6.6	4.78	/
weight in gr.	0.66	2.03	1.16	2.9	2.23	4.99	6.09	9.74	23.81	5.89	5.53	3.36	8.7	1.36	1.02	0.54	0.42
max diameter/méplat 1	1.25	1.40	1.18	1.38	1.32	1.35	1.52	1.79	1.41	1.28	1.24	1.18	1.17	1.97	1.14	1.29	/
max diameter/méplat 2	1.30	1.32	1.15	1.48	1.28	1.30	1.44	1.52	1.53	1.16	1.20	1.00	1.24	1.95	1.21	1.34	/
diam/perf	3.86	4.20	4.32	3.98	4.16	3.84	3.93	5.36	5.02	4.21	3.71	2.64	3.07	5.35	3.16	2.92	2.50
diam/thickness	1.01	0.95	1.97	0.90	1.04	0.93	0.77	0.71	0.63	0.72	0.62	0.55	0.54	1.54	0.88	0.89	1.18

n° beads	color
1	white alteration, green with brownish to black fissures
2	pale green, white alteration
3	white alteration, pale green
4	white alteration, green with black fissures
5	pale green with fine black veinlets
6	white alteration, palegreen with black veinlets
7	white alteration, palegreen with numerous black veinlets
8	white alteration, palegreen with numerous black veinlets
9	pale green, brownish yellow
10	range of pale green with black veinlets, white alteration
11	pale green with numerous black veinlets, white alteration
12	white alteration, green with black fissures
13	blue-green to pale green with broad black vein
14	range of pale green, brownish yellow
15	blue-green to pale green with black veinlets
16	pale green with fine black veinlets
17	pale green with fine black veinlets

Name	Na	Mg	Al	Si	P	K	Ca	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	As	Rb	Sr	Y	Zr	Nb	U	Cr/V	V*	Cr*	Fe*	Cr+V
bead n°1	4907	6833	91650	239585	49442	37622	49058	1237	1002	3552	44	23234	0	49	231	240	50	294	62	508	17	40	5	14	3.54	3.6	12.8	83.6	4554
bead n°2	5529	1784	139117	144166	146878	15942	14868	1075	733	2421	21	18927	0	6	57	53	262	1599	14	133	2	12	0	11	3.3	3.3	11	85.7	3154
bead n°3	6638	3494	67660	301054	11081	36238	36612	1218	928	2208	40	50860	0	32	270	216	124	931	65	372	4	23	0	7	2.38	1.7	4.1	94.2	3136
bead n°4	3797	2029	102817	239669	83357	23965	19200	214	660	366	15	20281	0	2	86	45	34	796	21	163	3	40	0	7	0.55	3.1	1.7	95.2	1026
bead n°5	2540	1280	103287	248037	81168	19603	20377	514	2480	692	19	14683	0	1	26	44	67	348	18	183	2	47	2	4	0.28	13.9	3.9	82.2	3172
bead n°6	4427	2329	155420	44743	210720	7020	12562	653	1363	1763	25	51879	0	6	320	73	202	1228	1	36	2	59	5	13	1.29	2.5	3.2	94.3	3126
bead n°7	1670	2008	155758	114805	172458	9641	12142	598	1211	480	7	14549	0	3	9	25	30	1614	7	66	5	4	0	8	0.4	7.5	3	89.6	1691
bead n°8	3046	1492	141149	146038	115070	28244	20022	481	1207	744	2	11492	1	6	92	33	43	205	8	96	5	2	1	4	0.62	9	5.5	85.5	1951
bead n°9	2311	1486	116936	190784	122418	19780	10862	1506	1582	1977	15	23781	0	0	157	16	291	800	9	102	2	5	1	0	1.25	5.8	7.2	87	3559
bead n°10	4424	1338	126016	186931	130648	17872	9518	115	1660	872	15	7365	5	2	24	23	23	1280	12	99	15	0	0	6	0.53	16.8	8.8	74.4	2532
bead n°11	3753	2007	128787	179294	131446	15068	12858	601	1101	2925	19	10470	3	4	30	32	221	674	13	82	4	10	0	12	2.66	7.6	20.2	72.2	4026
bead n°12	4415	2374	106373	201140	101804	20165	15965	445	800	1178	26	47123	0	4	560	84	64	773	16	111	0	22	0	17	1.47	1.6	2.4	96	1978
bead n°13	2328	1455	142144	138116	162112	14235	3958	516	2901	1296	14	18290	0	5	142	23	52	716	3	12	4	2	2	12	0.45	12.9	5.8	81.3	4197
bead n°14	3224	3024	120878	184156	108418	19563	34597	464	683	1405	17	10759	9	13	61	70	89	464	12	12089	7	3	0	18	2.06	5.3	10.9	83.7	2088
bead n°15	7171	5318	113660	193483	117774	25200	16495	959	1750	2519	42	7159	4	14	66	74	91	703	16	39	8	21	0	13	1.44	15.3	22	62.6	4269
bead n°16	3863	1528	152024	119025	176346	11682	5994	379	1566	739	11	11737	4	1	13	21	50	499	5	116	2	1	0	0	0.47	11.2	5.3	83.6	2305
bead n°17	3562	1903	147390	115079	175144	10273	7639	861	1601	1380	20	23116	0	6	101	25	62	710	6	140	4	78	0	10	0.86	6.1	5.3	88.6	2981
Average	3977	2452	124180	175653	123311	19536	17807	696	1366	1560	21	21512	2	9	132	65	103	802	17	844	5	22	1	9	1.39	7.5	7.8	84.7	2926
standard deviation	1494	1510	24726	62025	49965	8660	11925	386	618	921	12	14585	3	13	144	65	86	418	18	2900	5	23	2	5	1.05	4.9	5.9	8.8	1003
min	1670	1280	67660	44743	11081	7020	3958	115	660	366	2	7159	0	0	9	16	23	205	1	12	0	0	0	0	0.28	1.6	1.7	62.6	1026
max	7171	6833	155758	301054	210720	37622	49058	1506	2901	3552	44	51879	9	49	560	240	291	1614	65	12089	17	78	5	18	3.54	16.8	22	96	4554
LDD	184	127	86	108	88	46	81	23	17	13	12	4	92	1	1	1	1	1	12	4	3	15	4	19					

depo sits	Can Tintorer, Barcelona (Catalonia, Spain)					Ensinasola, Huelva (Andalusia, Spain)					El Bostal, Zamora (Castilla y Leon, Spain)					Palazueto, Zamora (Castilla y Leon, Spain)					Pannecé, Loire-Atlantique (Pays de Loire, France)				
	Min	Max	Mean	standard deviation	σ %	Min	Max	Mean	standard deviation	σ %	Min	Max	Mean	standard deviation	σ %	Min	Max	Mean	standard deviation	σ %	Min	Max	Mean	standard deviation	σ %
Na	315	12680	2835	2591	91	0	4302	867	783	90	0	2336	721	597	83	0	5285	1266	1072	85	65	9503	2771	2207	80
Mg	851	13434	4197	3156	75	0	1811	329	477	145	0	2020	880	597	68	0	2891	604	677	112	0	3485	826	899	109
Al	17713	207192	140062	41732	30	103031	221506	203260	17109	8	179919	215783	201001	7058	4	37377	217013	185243	43748	24	191379	218757	202580	7651	4
Si	14567	300262	112706	74521	66	0	37564	4900	7895	161	0	13361	5885	4421	75	0	211451	163448	37102	227	0	10728	2342	3297	141
P	29621	239250	157836	63047	40	206093	266367	245676	10696	4	242177	261510	254794	6055	2	138422	258780	237810	22335	9	245949	262549	257847	5090	2
K	167	7637	2980	2035	68	0	5388	671	842	125	78	1800	672	432	64	0	81919	1769	9052	512	69	2524	1170	689	59
Ca	4187	345476	61374	80461	131	0	3666	439	515	117	0	6872	641	1343	210	38	19787	846	2183	258	286	4756	1614	1149	71
Ti	0	15127	2699	3571	132	34	3000	573	600	105	0	812	191	175	91	159	2908	1211	628	52	30	334	134	74	55
V	1	888	365	243	67	581	5287	2507	921	37	1729	3594	2763	464	17	35	2773	1106	609	55	2594	4333	3249	565	17
Cr	1	720	443	189	43	125	3860	1691	894	53	550	1281	968	179	18	1207	8980	3734	1527	41	1163	1791	1449	188	13
Mn	0	184	35	49	142	0	44	6	8	132	0	114	16	24	154	0	174	20	26	129	0	19	6	6	100
Fe	7306	24426	13079	4600	35	2274	201149	21386	30558	143	3964	26082	8190	5074	62	1130	298779	35907	71654	200	1185	2090	1586	249	16
Co	0	81	26	22	84	0	55	9	12	130	0	80	23	18	82	0	227	19	41	208	0	18	7	5	78
Ni	0	586	71	122	172	0	189	11	32	279	0	14	4	4	99	0	70	4	9	220	0	11	3	3	92
Cu	11	393	98	108	110	0	3197	416	819	197	64	3510	560	1027	183	8	2768	427	871	204	2	112	27	25	92
Zn	11	163	45	43	96	1	98	21	23	111	217	593	399	88	22	1	138	26	27	107	8	117	22	23	106
Ga	12	259	45	62	138	0	362	71	79	111	9	73	30	20	65	4	420	137	91	66	92	223	163	23	14
As	127	432	302	90	30	45	4783	610	802	131	39	210	62	35	57	26	702	138	126	91	3	16	9	3	31
Rb	0	51	7	11	145	0	201	8	24	299	0	12	4	4	99	0	712	14	80	576	0	4	1	1	126
Sr	96	34525	4847	10011	207	0	322	20	49	245	0	21	4	6	145	0	2590	55	290	531	0	74	19	22	119
Y	0	151	19	35	179	0	128	13	25	200	6	55	23	10	43	0	133	7	18	270	0	7	1	2	256
Zr	0	127	36	26	73	0	256	50	52	104	0	16	6	4	78	0	240	48	46	95	0	10	1	2	235
Nb	0	42	5	9	201	0	14	2	3	179	0	24	3	6	179	0	35	2	6	252	0	6	1	2	174
U	0	205	35	53	153	0	152	17	33	193	37	1468	306	267	87	0	262	13	35	268	0	12	4	3	82
V*	0	7	3	2	70	1	41	18	11	62	8	37	26	8	31	0	21	8	6	75	44	55	52	3	5
Cr*	0	6	3	2	50	0	38	13	11	88	3	12	9	3	29	1	59	25	15	62	22	25	23	1	3
Fe*	88	100	93	4	4	31	98	70	20	29	51	89	65	10	16	31	99	66	20	30	22	31	25	2	10
Cr/V	0.01	126	6.49	24.48	377	0.06	1.77	0.74	0.41	55.37	0.23	0.41	0.35	0.04	11.52	0.94	56.29	5.08	6.48	127.37	0.4	0.57	0.45	0.04	8.66
Cr+V	67	1464	809	397	49	1293	9147	4198	4875	34	2315	4875	3731	618	17	1570	10366	4841	1732	36	3848	6116	4698	736	16