Composition and technology of 18th century high magnesia faïences from Fulda

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In 1996, archaeological excavations close to the ancient Fulda faïence manufacture site unearthed a rich deposit of faïence wastes (biscuits, faïences, technical ceramics). The manufacture was founded in 1741 by Prince Abbot Amand von Buseck and closed down in 1761. This first archaeometric study of a German faïence manufacture included 31 samples produced between 1742 and 1760. Analytical techniques were optical microscopy, X-ray fluorescence, X-ray diffraction and scanning electron microscopy, coupled to an energy-dispersive X-ray spectrometer. Biscuits and faïences are MgO- (5–13 wt.%) and CaO-rich (9–20 wt.%), easily distinguishable from the two French Mg-rich productions of Granges-le-Bourg and Lunéville that we know today. Three samples show high P2O5 (2.6–3.3 wt.%). Such unusual concentrations are not due to the admixing of crushed bones to the clay during processing, or to one of the well-known post-firing secondary contamination processes, but are caused by the presence of sharp edged, rhomboedric grains with sizes around 20–30 μm and an overall chemical composition of apatite. These fragments are interpreted to be remnants of primary phosphoritic elements, present ab initium in the clay, and give some hints as to the origin of the raw materials used. Phosphoritic layers can be found in the German Trias, mostly in dolomitic marls of the Middle Keuper. Such marls form the basement on which Fulda is built and could easily have been extracted by the Fulda manufacture. The high MgO values of the faïences can therefore be linked to the presence of dolomitic grains in the plastic raw material, corroborated by the positive MgO/CaO correlation. Firing temperatures of the faïences were, according to their XRD patterns, mostly between 950 and 1050 °C.

1. Introduction
1.1. German faïence manufactures

Faïence is a tin-glazed pottery, i.e., a type of earthenware covered with a lead–alkali glaze to which tin oxide (cassiterite, SnO2) has been added as an opacifier. According to Rosen (2009, p. 83) the term “faïence” appeared for the first time on May 25, 1601 in archival sources of Nevers as “vessele de fayance” (crockery in fayance). In 1604, the ceramist Jean-Baptiste Conrade was labelled “sculpteur en terre de fayence” (sculptor of fayence earth) (Rosen, 2000). The oldest faïence manufacture in what is presently Germany is Hanau (Fig. 1), founded in 1661 by Dutch protestant fugitives, forced to leave their homeland on the account of their religion (Merk, 1979; Stasch, 2005a, 2005b). Five other manufactures were set up before 1699, and more than 80 new ones in the 18th century (Klein, 1962, 1975; Frégénaec, 1976). The manufacture in Fulda was started in 1741 by Prince Abbot Amand von Buseck who reigned from 1737 to 1756, from 1752 as Prince Bishop (Steen, 1994; Stasch, 2005a, 2005b). The ultimate goal was not to make faïence, but porcelain, as clearly claimed by the Prince Abbot “... habe 1742 eine Porzellanfabrik in der Residenzstadt angefangen und dort die nötigen Öfen installiert” (I founded in 1742 a porcelain manufacture in the town of residence and built there the necessary kilns). Adam Friedrich von Löwenfinck (1714–1754), painter in porcelain in Meissen (1727–1736), became the first director of the Fulda manufacture; he left Meissen in 1736 first for the Bayreuth manufacture and then for Ansbach. This is where, around 1737–1740, he successfully transferred the technique of porcelain overglaze enamel painting, invented in Meissen and applied since 1710, onto faïence objects (Stasch, 2005b). In Fulda, the early ceramic products decorated with the inglaze technique are easy to recognize because of their ink blue colour lined with manganese (Stoehr, 1920, pp. 329, 375) painted by Christian Müller (Stasch, 2005b, p. 25). If Fig. 2a. Certain objects, by the quality of their onglaze polychrome hand decoration, can be attributed to A. F. von Löwenfinck, even though the signature is missing (Wark, 1956; Ducret, 1971, 1983; Rückert, 1990; Surhone et al., 2010), such as the famous vase with lid (Klein, 1993, plate XI) or the table-centre with the “von Fechenbach” coat of arms (Fig. 2c). A. F. von

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Löwenfinck left the manufacture in 1744 to go to Höchst (Ducret, 1971). Fulda kept up its excellent reputation thanks to the commitment of other painters such as Josef Philipp Dannhöffer, Georg Friedrich Hess, and Ignaz Hess. The faïence production came to an end in 1760 because of the Seven Years’ War (Stasch, 2005a). Four years later, in 1764, a porcelain manufacture was set up in the buildings occupied by the former factory by Prince Bishop Heinrich von Bibra (active from 1759 to 1788). It was shut down in 1789 (Ducret, 1971; Fritzsche and Stasch, 1994; Ullrich and Ballmaier, 2002; Stasch, 2005a, 2005b).

1.2. Production technique

There is no archival documentation about Fulda’s faïence production technique or about the site of the extracted clays. The first director of the manufacture (1741–1744), A. F. von Löwenfinck, probably learned the faïence technique during his stay in the manufactures of Ansbach and Bayreuth. Summaries of the faïence technique used in 18th century France and the Netherlands, most probably applied in Germany too, were published by Rosen (1995, 2009), Maggetti (2007, 2012) and Lambooy (2013).

The following short résumé is taken from Heimann and Maggetti (2014, chapter 13): tin-glazed pottery is manufactured from CaO-rich clays in several production steps. After forming and drying, the green ceramic body will be fired in a kiln at maximum temperatures of 900–950 °C (bisque firing). During firing water and other volatile compounds will evaporate. The so-called bisques or biscuits will then be dipped in aqueous glaze slurry. The still porous ceramic body soaks up water from the adhering powdery glaze layer and thus fixes the latter to its surface. If a white product is desired, the ware will be contained, after a short second drying step, in tightly fitting refractory capsules (saggars) and glaze (glost)-fired at approximately 950–1050 °C. For decorated ware, the so-called inglaze colours are painted directly on the dry tin glaze layer prior to glaze firing. This is a rather tricky process as the painted decoration can be corrected only with difficulties since the colour pigments are readily absorbed by the dry, white glaze powder. When corrections are required the faulty part must be carefully scraped off and the glaze including the colour pigments reapplied. The inglaze colour pigments consisting of powdered crystalline matter or frit glass will be ground together with water and a binder, for example starch. During glaze firing the pigment particles are being coated by a thin sheath of molten glaze and subsequently either dissolved in the glaze, remain as insoluble crystallites, or precipitated as colloidal phase. Since only select-ed metal oxides survive the high temperatures of the glaze firing the colour palette are blue, brown, yellow, green, red, black, pink and white.

After glaze firing the white or coloured ceramic can be further decorated with differently coloured overglaze (enamel) pigments, i.e. coloured glassy powders. In this case necessary corrections can easily be accomplished since the enamel colours are suspended in volatile oils such as mixtures of turpentine and linseed oil that are applied with a brush to the smooth glaze surface. Overglaze colours generally possess a lower melting temperature compared to the inglaze colours. The enamel pigments are fixed to the glaze surface by a third firing step, also called as colour firing in a muffle kiln at 600–800 °C whereby the pigment particles sink only slightly into the carrier glaze. Since many more metal oxide pigments will be stable at the low temperature of the third firing the colour palette becomes substantially richer.

1.3. Archaeometric analyses and aim of this study

No archaeometric studies were undertaken on German faïences up to now, with one exception: a single blue, black and white decorated shard from Fulda, studied with scanning electron microscopy, which revealed its richness in silica and calcia (Steen, 1994). The present study was therefore undertaken to: (1) define the chemical characteristics of a corpus which would be representative of the Fulda faïence in order to create the first reference group for German faïence; and (2) define the mineralogical and technological characteristics of this same corpus in order to circumscribe the technique used in Fulda.
map of Fulda and their description (Bücking, 1911, 1912), mostly in the superficial clayey soils of the meadows and fields southeast of Fulda, with only two specimens (FUL 39, 40) from the compact clayey bedrock (Fig. 3).

2.2. Sample preparation

After careful removal of the glaze and the possibly contaminated unglazed other surfaces with a saw, samples of 1.9–13.5 g were obtained from 39 ceramic pieces and ground in a tungsten carbide mill. If available, subsamples from broken objects were used for scanning electron microscopic (SEM) analyses. Only a small chip could be taken from FUL 32, enough to make a SEM tablet. About 1–2 kg per clay was collected at various depths (Table 2), and 50–100 g dry material was used for the analyses.

2.3. Analytical methods

2.3.1. Chemical composition by X-ray fluorescence analysis (XRFA)

Two grams of powdered sample was calcined at 900 °C for 1 h to obtain the loss on ignition (LOI). 0.700 g of calcined powder was carefully mixed with 6.650 g of MERCK spectromelt A10 (Li2B4O7) and 0.350 g of MERCK LiF. This mixture was put into a platinum crucible and melted at 1150 °C for 10 min (Philips® PERL X-2) in order to obtain glassy tablets. These were analysed for major, minor and trace elements using a Philips® PW 2400 wavelength-dispersive spectrometer (Rhodium tube, 60 kV and 30 mA). Calibration was made on 40 international standards (BKR, DTS, PCC, BHVO, QLO, RGM, SCO, BIR, DMC, W-2, SY-2, GA, GH, Mica-Mg, UB-N, DT-N, GS-N, FK-N, AN-G, BE-N, JG-1, JG-1a, JG-2, JG-3, JB-1, JB-1a, JB-2, JB-3, JR-1, JR-2, JA-2, JA-3, JF-1, JF-2, JG-1, JGb-1, NIM-G, NIM-L, NIM-N, NIM-S). Oxides were calculated relative to the standards. Cu- and Pb-concentrations for some clays are low, approaching detection limits. Accuracy and precision were checked using the laboratory reference sample RT. Error has been evaluated by many repetitive measurements of this internal standard to be less than 5% for all elements analysed.

2.3.2. Mineralogical analyses by X-ray diffractionmetry (XRD)

The mineralogical composition was determined on the powdered samples through powder X-ray diffraction using a Philips® PW 1800 diffractometer (CuKα, 40 kV, 40 mA, 0.2–20°, measuring time 1 s/step). The results was proved by measuring well known glass and mineral standards (DLC2, Corning A–D and Plagioclase). The relative mean deviation for major and minor oxide components was 2% for concentrations in the range of 20–100 wt.%, 4% for 5–20 wt.%, 10–20% for 1–5 wt.% and <50% for <1 wt.%.

2.3.3. Scanning electron microscopy (SEM)

Backscattered electron images (BSE) were collected with a scintillator type detector out of polished samples, using a Philips® FEI XL30 Sirion FEI electron scanning microscope. The samples were mounted in an epoxy block, flatly polished with a 0.5 µm diamond paste and then coated with a thin carbon layer. Chemical compositions were determined by energy-dispersive X-ray spectrometry (EDS), operated at a beam acceleration voltage at 20 kV and a beam current of 6.5 nA. Standardless quantification was performed using an EDAX-ZAF correction procedure of the intensities, using spot analyses (2 µm diameter) as well as larger area analyses of homogeneous areas. The detection limits for most elements were about 0.2 wt.%. The reliability of the results was proved by measuring well known glass and mineral standards (DLH2, Corning A–D and Plagioclase). The relative mean deviation for major and minor oxide components was 2% for concentrations in the range of 20–100 wt.%, 4% for 5–20 wt.%, 10–20% for 1–5 wt.% and <50% for <1 wt.%.

2.3.4. Statistics

Factor analysis (principal component analysis PCA, Fig. 6c) was performed with log data of 18 variables (SiO2, TiO2, Al2O3, Fe2O3, MgO, CaO, Na2O, K2O, Ba, Cr, Cu, Nb, Ni, Rh, Sr, Y, Zn, Zr) as determined by
3. Results

3.1. Ceramic bodies

The analysed shards are rich in magnesium (Fig. 4c). FUL 32, analysed by SEM–EDS, has comparable 8 wt.% MgO (Table 3). FUL 2, FUL 4 and FUL 31 are rich in P₂O₅ (Table 3). The faïences can further be separated into two groups, according to their TiO₂, Cr, Ni and Rb contents, as shown in Fig. 4a and e where a small group of four faïences (FUL 1, 5, 7, 9), clustering tightly with the technical ceramics, are well distinguished from a homogeneous group of eight faïences (FUL 30 and FUL 31) show the highest Cr-contents. FUL 18 has the highest Sr-value, and three samples show Zn values ≈ 500 ppm (Table 3). FUL 27 is very rich in CaO, FUL 30 and FUL 31 show the highest Cr-contents, FUL 18 has the highest Sr-value, and three samples show Zn values > 150 ppm (Fig. 4g).

The bodies have a serial distribution (Maggetti, 1994) of their non-plastic inclusions. These pertain to three major kinds, i.e. quartz, orthoclase and coarse clay mineral, embedded in a fine-grained matrix (Fig. 5a, b). Quartz and orthoclase fragments show angular to subangular shapes. Maximum sizes are between 20 and 40 μm. SEM–EDS analyses of the brighter tiny crystals in the matrix (Fig. 5b) are consistent with Ca-silicates such as wollastonite or anorthite crystalized during firing (Maggetti, 1982; Maniatis et al., 1983; Duminuco et al., 1996; Riccardi et al., 1999; Cultrone et al., 2001). Irregularly shaped pores, often with rhomboedric outlines, correspond to primary particles rich in MgO, i.e. dolomite CaMg(CO₃)₂ having reacted with the clay paste during the firing (Fig. 5a, f). Calcium is homogenously distributed throughout the bodies (Fig. 5e). The microstructural aspect of the sample FUL 31, one of the three shards rich in P₂O₅, is heterogeneous. It shows normal-looking areas similar to those in other pieces (Fig. 5a), but also domains with blurred contours and edges, often rich in rhomboedric-shaped crystals (Fig. 5c). Phosphorus is concentrated in these crystals (Table 4).

The studied ceramic samples can be assigned, as shown by their X-ray diffractograms, to two different mineral associations:

(a) Illite (110) + α-Quartz ± plagioclase ± gehlenite ± diopside ± hematite ± calcite (FUL 7, 11, 13, 17, 18, 21, 25, 26).
(b) α-Quartz + plagioclase + diopside + hematite + gehlenite + calcite (FUL 1–6, 8, 9, 10, 12, 14–16, 19, 20, 22–24, 27–31).

Calcite is either a pre-firing phase, in association (a), or a post-firing, secondary phase in association (b) (Maggetti, 1994), as revealed by optical microscopy analysis.

3.2. Clays

The MgO-contents of the eight clays show a wide scatter (Fig. 4c). The superficial clays have, with one exception (FUL 41), low magnesium concentrations (< 5 wt.% MgO), contrasting with the MgO-richer bedrock clays FUL 39, 40.

According to the X-ray diffraction study the eight clay samples can be classified as follows:

(c) Illite + quartz + plagioclase + orthoclase + kaolinite: FUL 37, 42, 43
(d) Illite + quartz + plagioclase + orthoclase + calcite: FUL 38
(e) Kaolinite + illite + plagioclase + orthoclase + calcite: FUL 41, 44
(f) Kaolinite + illite + quartz + dolomite + calcite: FUL 39, 40.
4. Discussion

4.1. Mobility of chemical elements

It is well known that shards can change chemical composition through the migration of chemical elements after firing. This phenomenon could have applied to the shards buried under ground and submitted to the action of pervasive solutions, washing or depositing chemical elements in the ceramic. It is not easy to note such evidence of chemical contamination. Resorting to museum or collectors' objects, such as FUL 32, the only object never to have been buried, cannot be considered since the object was not submitted to XRF analysis. Neither it is possible to resort
to the comparison with local clays, seeing the blend of clays (cf. infra). We must therefore establish the fact that the concentration in oxides and chemical elements generally considered to be mobile (i.e. MnO, Na₂O, Ba etc.) does not seem to be too far dispersed or to reach values much greater than the usual ones. However, special attention deserves the fact that the ceramics are richer in P₂O₅, Pb, Zn, Nb and Sr than the clays.

The great majority of the specimens studied have comparable or slightly higher P₂O₅ concentration than the local clays studied, with three exceptions, FUL 2, FUL 4 and FUL 31. Their phosphorous is significantly higher than the maximum value of 0.35 wt.% P₂O₅ found in the local clays. Admixing of P-rich material (e.g. fired bones) before firing and postfiring contamination (e.g. burial contamination through migrating P-rich solutions) are two processes normally advocated to explain such P-anomalies (Collomb and Maggetti, 1996, and literature therein). However, no such processes took place for these three shards, as shown by SEM images (Fig. 5c), revealing non-porous P-rich crystals (calcined bones have a characteristic porous structure; Maggetti and Ramstein, 2005) with a chemical composition close to the mineral apatite (Fig. 5, Table 4). These crystals are interpreted as primary phases,
present in the clay ab initium. Such P-rich domains can be found as phosphoritic layers of the Lower and Upper gypsiferous marls of the Middle Keuper (Seidel, 2003, pp. 368, 370), but they haven’t been found by the prospection.

Local clays contain less than 35 ppm of Pb, but each of the analysed ceramic objects shows a much higher concentration. This can be due to: (1) an insufficient removal of the lead glaze before milling; (2) an infiltration into the porous body by the lead-rich watery suspension obtained during the removal of the lead glaze; (3) an infiltration of the porous biscuit body by the watery glaze suspension during glazing; (4) an infiltration of the porous biscuit body by the fused glaze during firing; and (5) a contamination of the porous biscuit body by Pb-vapours during firing. We exclude the first hypothesis, as the removal was carefully made. With respect to the other four possibilities, it is impossible to discern which effect(s) is (are) responsible for this contamination.

The positive correlation of zinc and niobium with aluminium (Fig. 4k, l) is evidence that these two trace elements are fixed in the network of clayey minerals present in the raw materials. On the other hand, a fixation of Sr in the calcite/dolomite network cannot be proved through lack of a positive Sr/CaO correlation (Fig. 4m). In this case, post-firing contamination effects could be envisaged, but the copper-rich FUL 32 clay (Fig. 4l) underlines the need for caution against always
explaining such anomalies by a burial contamination — raw materials also can display chemical anomalies. Apart from lead, none of the studied objects seems to have suffered from important contamination effects.

4.2. A new reference group

At first sight, biscuits, faïences and technical ceramics seem to be homogeneous from a chemical point of view. This includes the SEM–EDS analysis of FUL 32. But a more careful analysis brings out a division into two groups, one containing all biscuits, technical ceramics and four faïences (FUL 1, 5, 7, 9) and a second containing the other five faïences (FUL 38, 41) have intermediate MgO and no dolomite either. If the geological history of the Keuper marls was de-carbonated by meteoric waters, as assumed for the Diluvial clay (FUL 44), it is likely that the two clays FUL 42 and 43 are for instance Keuper clays, i.e. Granges-le-Bourg (Maggetti et al., 2009a; Maggetti, 2013) and Lunévile (Maggetti et al., in press), even though the Fulda objects are clearly more homogeneous (Fig. 6). This probably indicates a less thorough attempt at homogeneity than in the two French manufactures.

4.3. Technical aspects

Age related chemical differences of the clays are exemplified in Fig. 4. The Upper Buntsandstein clays FUL 42 and 43 are for instance rich in SiO₂ and Zr, but low in Al₂O₃, Fe₂O₃, Cr and Ni. Both Keuper samples taken at a significant depth (FUL 39, 40) have very high MgO values and contain dolomite, whereas both Upper Buntsandstein clays and one superficial Keuper clay (FUL 37) are MgO-poor without any dolomite (Fig. 4c). The Diluvial clay FUL 44 and two superficial Keuper clays (FUL 38, 41) have intermediate MgO and no dolomite either. If the geological map is correct, one has to consider that superficial strata of the Keuper marls were de-carbonated by meteoric waters, as assumed for the raw materials from Granges-le-Bourg, where the original MgO- (and CaO-) concentrations were found only at a depth of 0.6–0.7 m (Maggetti et al., 2009a; Maggetti et al., 2013). Furthermore, not all MgO is fixed in the dolomite phase, as evidenced by FUL 39, 40, 41 and 44, which is plotted in Fig. 4c higher than the dolomite line, i.e. with not enough CaO to combine all MgO into this mineral. It is therefore likely that the excess MgO is present in another discrete phase (Smeectite or
illite?). The phase association as determined by XRD is in good agreement with the microscopical results.

The prospecting did not succeed in finding adequate clays which could have been used as they were. This is not surprising as 18th century faïence potters worked with a blend of purified clays, as summarized by Maggetti (2012) for the French workshops. Consequently, one can surmise that the Fulda manufacture proceeded in the same manner, mixing one or several clays, one of which would have been MgO rich, much like the dolomitic marls of the Keuper. The generally higher contents in alumina of the ceramics compared to the clays indicate decantation processes which increased the Al₂O₃-rich clay fraction. If one considers the composition of the untreated clays, it is clear that those

Table 4

<table>
<thead>
<tr>
<th>An. Nr.</th>
<th>Area (μm)</th>
<th>Na₂O</th>
<th>MgO</th>
<th>Al₂O₃</th>
<th>SiO₂</th>
<th>P₂O₅</th>
<th>SO₃</th>
<th>K₂O</th>
<th>CaO</th>
<th>TiO₂</th>
<th>Fe₂O₃</th>
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<tbody>
<tr>
<td>Whole body</td>
<td></td>
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<tr>
<td>FUL 31  (4)</td>
<td>2 × 1.5 mm</td>
<td>4.1</td>
<td>18.0</td>
<td>51.6</td>
<td>1.6</td>
<td>0.1</td>
<td>2.6</td>
<td>15.5</td>
<td>1.0</td>
<td>5.6</td>
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<tr>
<td>FUL 31-25</td>
<td>150 × 180 μm</td>
<td>3.6</td>
<td>17.4</td>
<td>56.3</td>
<td>0.3</td>
<td>0.5</td>
<td>3.5</td>
<td>12.0</td>
<td>1.4</td>
<td>5.0</td>
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<tr>
<td>FUL 31-26</td>
<td>400 × 350 μm</td>
<td>4.8</td>
<td>19.1</td>
<td>51.2</td>
<td>0.6</td>
<td>0.6</td>
<td>3.0</td>
<td>13.7</td>
<td>1.4</td>
<td>5.6</td>
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<td>P-rich domain</td>
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<tr>
<td>FUL 31-16</td>
<td>200 × 150 μm</td>
<td>0.1</td>
<td>2.8</td>
<td>16.3</td>
<td>37.4</td>
<td>13.4</td>
<td>2.3</td>
<td>23.1</td>
<td>0.7</td>
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<td>15.4</td>
<td>41.1</td>
<td>12.0</td>
<td>2.7</td>
<td>20.5</td>
<td>0.8</td>
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<tr>
<td>FUL 31-18</td>
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<td>0.1</td>
<td>0.8</td>
<td>0.6</td>
<td>43.3</td>
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<td>FUL 31-19</td>
<td>5 × 5 μm</td>
<td>0.5</td>
<td>2.2</td>
<td>1.4</td>
<td>42.4</td>
<td>0.2</td>
<td>52.4</td>
<td>0.9</td>
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<td>FUL 31-27</td>
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<td>1.2</td>
<td>43.3</td>
<td>0.6</td>
<td>52.6</td>
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<tr>
<td>Apatite (F 3.8/Ca 4)</td>
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<td>45.8</td>
<td>54.2</td>
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Fig. 5. SEM backscattered electron images of: (a) body showing quartz (Q) in a well vitrified matrix. Voids are former dolomitic grains (D) as shown by the magnesium concentrations. Calcium is more evenly distributed throughout the matrix. Faïence FUL 10. Bar 20 μm; (b) orthoclase (O) and quartz crystals. The former doesn’t show any signs of melting. In the matrix tiny newly formed crystals (calcilicates) can be seen. Faïence FUL 10. Bar 10 μm; (c) phosphor-rich rhomboedric shaped crystals in a less porous part of faïence FUL 31. Bar 20 μm; (d) other aspect of FUL 10. Bar 50 μm; (e) Ca map of (d) showing evenly distribution; (f) Mg map of (d) with Mg concentrated in voids = former dolomite grains.
of the Upper Bundstandstein are too rich in SiO₂ and that the decarbonated superficial clays do not have the chemical composition suitable for the mixture. These clays would need to be experimentally treated and then analysed in order to see which could have been used — a project beyond the present study.

As accots were used only once, one understands why the potters made them with the faïence paste at hand and not with a specific refractory mixture. However, saggar pins had to be resistant at high temperatures, go through as many firing cycles as possible, and bear the weight of the ceramic object. Therefore one would expect the use of refractory mixtures with a high mechanical resistance and low CaO + MgO, but this is obviously not the case. High CaO and MgO pastes of saggar pins were also reported from the faïence manufactures of Fribourg (Blanc, 2007) and Granges-le-Bourg (Maggetti et al., 2009b). Such recipes are puzzling and not well understood.

According to their body colours, the studied objects were fire red in dominating oxidizing atmospheres. The ancient firing temperatures can be estimated by comparison of the faïences' phase associations with the phase evolution in experimentally fired dolomitic marls of similar mineralogical and chemical composition (Peters and Jenni, 1973; Maggetti, 1979, 2013; Jornet, 1982; Shoval, 1988; Benghezal, 1989, 1994; Béarat, 1992; Échallier and Méry, 1989, 1992; Mumenthaler et al., 1995; Duminuco et al., 1998; Maggetti et al., 2009a; Trindade et al., 2009). For association (a), inferred temperatures were most probably around 800–900 °C (gehlenite in around 800 °C, illite/muscovite out above 900 °C). They were in the range of 900–1050 °C for association (b), as no illite was detected and as marls will show extensive fusion at 1100 °C (Küpfer and Maggetti, 1978). These temperature estimations are in good agreement with those derived from microstructural observations, as FUL 3, 10, 32 can be classified as "advanced initial vitrification" and LNV 2, 19 and 20 as "advanced extensive vitrification", which develop at firing temperatures of about 900–1000 °C (Maniatis and Tite, 1981; Kilikoglou, 1994; Wolf, 2002). Such temperatures fall in the usual range of the French faïence kilns of the 18th century (Rosen, 1995; Maggetti, 2007, 2012). Association (a) contains biscuits, technical ceramics and one faïence, whereas the remaining samples, i.e. mostly all faïences, pertain to association (b). This result is not surprising, as biscuits were generally fired at lower temperatures than the faïences, the latter being fired twice.

5. Conclusions

The faïences from Fulda are rich in MgO, pointing to the use of Triassic dolomitic marls. It can be deduced that the products from other German manufactures, situated as Fulda on a Triassic subsoil (Fig. 1), should also have a magnesian nature. A peculiarity of Fulda’s faïence bodies is phosphor-rich relics of the original clay. This is the first description of primary P₂O₅ concentrations in ceramics. Fulda’s faïence forms a new chemical reference group, easily distinguishable from the two currently known French MgO-rich groups. These chemical differences can be explained by the use of different MgO-rich clays in each manufacture: Middle Muschelkalk for Granges-le-Bourg, for Fulda and Middle Keuper for Lunéville. Even though the technique used in Fulda is not very different from that of the French manufactures.
(blend of clays, purification process, oxidizing firing in two steps at maximum temperatures of 900–1050 °C), it would seem that the raw materials were not processed as well as in France.

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